Carbonated Soft Drinks

Formulation and Manufacture

Edited by David P. Steen and Philip R. Ashurst

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Preface

The market for carbonated beverages has grown dramatically in most countries, for example, by 128% in the UK since 1984. This growth has required changes in the way factories are run. Soft drinks are now classified as food products and are produced under stringent hygiene conditions. Twenty years ago this was not always the case – carbonated drinks were often produced in old buildings where cross-contamination could easily occur. Filling technology has progressed rapidly to meet the needs of manufacturers and consumers alike. Whilst the basic counter pressure filler is still the main work horse, new generations of electronically and pneumatically controlled filling machines have been developed that allow production under much more hygienic conditions and to much higher standards of filling accuracy and repeatability.

Primary packaging for carbonated soft drinks in most countries appears to have settled on PET bottles, with 500 ml and 2 l sizes predominating. The returnable glass bottle business is in decline and single-trip glass bottles are now mainly used for specialist products. The growth of can use appears to have stabilised. The 'lightweighting' of PET bottles over the last decade appears to be reaching its limits. Work on this will inevitably continue though at a slower rate as a consequence of the high cost of oil. Developments in barrier technology and new resins mean that shelf life in small PET bottles is not the problem it once was for carbonated products, although the much higher bottle cost restricts the use of such materials to premium product. Closure technology has also improved over the last 10 years with the advent of new neck finishes for PET bottles and improvements in closure design.

After an introduction to carbonated soft drinks, this volume considers the specifications and treatments for water, the main ingredient of any soft drink. A chapter on the other ingredients and formulation of carbonated drinks then follows (Chapter 3). Chapter 4 considers how ingredients are blended together to an agreed specification, and includes sections on sugar dissolving and batch and continuous syrup production. The predominant philosophy now is to manufacture the finished product as ready to drink (RTD), and prove that it is within specification prior to carbonation. In this way losses are minimised, uniformity of product is guaranteed and there is tight cost control of production.

A chapter on carbon dioxide production and the physics of carbonation then follows (Chapter 5). Modern carbonation techniques and feedback control are considered, with a discussion of different carbonation methods. The physics of filling carbonated beverages is included, followed by a consideration of the latest generation of filling machines (Chapter 6).

Chapter 7 deals with primary packaging – the concepts of containing, protecting, identifying and marketing are considered in the light of environmental, legislative and cost factors for the three main containers: glass bottles, PET bottles and cans.

Chapter 8 is on secondary packaging, explaining its importance during the development of a new or existing product. The function of secondary packaging is to ensure that the primary container is delivered to the consumer in prime condition, at the same time as satisfying the ever increasing demands of the trader.

A further chapter deals with production systems, applying the topics of previous chapters to the production line and factory, discussing glass, PET and can lines and describing principles and inspection systems (Chapter 9). This chapter also considers plant breakdown characteristics, line control and management systems. An introduction to the requirements for factory layouts and design is then followed by considerations of performance measurement and benchmarking.

Chapter 10 deals with the increasingly important subject of production planning and distribution. As a consequence of the high weight and comparatively low value of carbonated soft drinks, this topic is receiving much more attention than previously. Supply chain management is discussed in relation to soft drinks, highlighting its importance. It is no longer enough to just produce soft drinks, they must be produced uniformly every day and be distributed to the customer at the lowest possible cost if the producer is to stay in business. Chapter 11 is on quality, environment and food safety; completing the picture by providing the framework within which manufacturing and distribution must now exist.

The aim of this volume is to provide an overview of carbonated soft drinks production in the early part of the twenty-first century, presenting the latest information on carbonation and filling methods. Detailed references provide opportunity for further reading in more specialised areas. Certain topics, such as ingredients and packaging, are not included in great depth here because they are covered in detail elsewhere in the series. The book is aimed at graduates in food science, chemistry, microbiology and engineering who are considering a career in the soft drinks industry, as well as technical staff already employed within the industry and associated suppliers.

The editors are greatly indebted to the contributing authors: without them this book would not exist. All are experienced in their particular fields and, for most of them, the work involved in writing their chapters was a significant extra burden on top of their already heavy workload.

David Steen

Philip Ashurst

1 Introduction

Bob Hargitt

The aim of this introduction is to provide a brief perspective on the historical development of carbonated soft drinks from their first appearance in the late eighteenth century to the present day, and also to consider their future path.

1.1 Early history

The consumption of soft drinks in their various forms has taken place for many centuries in order to meet the body's fundamental requirement for hydration. The most obvious source of hydration is water, but in earlier times the consumption of water was very hazardous as it was frequently contaminated by micro-organisms. Outbreaks of cholera, dysentery and other waterborne illnesses were common in many European cities prior to the twentieth century. The consumption of 'small beers' – drinks which had been boiled, flavoured with, for example common herbs, and slightly fermented – was widespread. Barley waters, flavoured drinks containing pearled barley, were recorded as early as 1320 and the earliest English reference to lemonade was published in 1663. The drink contained lemon juice and was sweetened with sugar or honey and is thought to have originated in Italy. Orangeade was also recorded in the 1660s. All these early drinks were, of course, not carbonated.

Production of effervescent alcoholic beverages, that is, beers and wines where the carbon dioxide was derived directly from fermentation, is recorded as beginning at the latest in 1693, when Dom Perignon is credited with the invention of champagne. However, references to sparkling wines are found in English literature well before this date. Several spas were also known where the water was naturally effervescent and during the seventeenth century scientific interest and study grew in the gas which caused this effect, particularly at Spa in Holland and Pyrmont and Seltzer in Germany. There was considerable scientific investigation across Europe of the gas we now know as carbon dioxide (CO_2) by the middle of the century. In 1741, Brownrigg termed the gas 'mephitic air' and produced effervescent waters from bicarbonate salts. By 1767, Richard Bewley was selling effervescent 'mephitic julep' for its medicinal properties. In 1764, Macbride in Ireland demonstrated the medicinal uses of effervescent waters and their antiseptic properties.

The discovery of the means of artificially carbonating water by dissolution of CO_2 under pressure is attributed to Dr Joseph Priestley in the late 1760s, though there were many other workers active in this field at the same time who probably deserve equal credit. He published his work, *Directions for Impregnating Water with*

Fixed Air in 1772 and Dr John Mervin Nooth developed an apparatus for preparation of effervescent waters, which he reported in the *Philosophical Transactions of the Royal Society* in 1775. Torbern Bergman, Professor of Chemistry at Uppsala University in Sweden, published his work on preparation of artificial mineral waters in 1773. His treatise on Bitter, Seltzer, Spa and Pyrmont Waters has been termed the world's first textbook on the manufacture of mineral waters. In 1780, Duchanoy in France published a treatise on the art of imitating naturally occurring mineral waters. The initial commercial development, deriving from all this scientific work, was that of selling imitation mineral waters, that is, waters to which were added minerals in the proportions found in naturally occurring mineral waters and then artificially carbonated. Hence the term in English of 'aerated mineral waters', which became synonymous with all carbonated drinks. The commercial development of carbonated waters took off very rapidly following the initial scientific and technical discovery.

Thomas Henry, a Manchester apothecary, is generally credited to have been the first commercial manufacturer of artificially carbonated water in the late 1770s. He improved and developed Nooth's design to make an apparatus capable of carbonating batches of up to 12 gal (54 l). The product was sold in tightly corked glass bottles. Henry recommended consumption of lemon juice and soda water for the stomach but did not state whether the two were combined. By the late 1770s he was also selling artificially manufactured Pyrmont and Seltzer waters, that is, imitations of the naturally occurring spa waters. Thomas's son, Dr William Henry, was the inventor of Henry's Law of Gases (1805). The storage of fresh water on board ships during long sea voyages, which could last many months, was a serious problem and the antiseptic effect of carbonation and hence its long 'shelf-life', made an immediate impact upon the British Admiralty. It was also claimed (wrongly) that soda water cured scurvy and one of the first uses of carbonated water was on board a ship. Bottles of soda water have been salvaged from the wreck of the 'Royal George' which sank in 1782. Early effervescent drinks, similar to Bewley's Mephitic Julep, were manufactured by mixing sodium bicarbonate solution with lemon juice or lime juice, which would of course cure scurvy. This was probably the cause of the misconception that CO_2 was a cure for scurvy.

The manufacture of carbonated drinks also rapidly became popular across Europe. Paul, Schweppe & Gosse established a successful business in Geneva, before Jacob Schweppe moved to London in 1792 to set up a factory-scale operation there. The production of mineral waters was well established by 1800, and J. Schweppe & Co opened another factory in Bristol in 1803. His former partner, Nicholas Paul also moved to London in 1802 and set up in competition with Schweppe. Paul is credited with the first commercial use of a high pressure gas pump to aid dissolution and achieve high levels of carbonation, his mineral waters were famous for containing several volumes of CO_2.

Carbonated waters were imported into the USA from the UK prior to 1800. The first commercial production is attributed to Benjamin Silliman, who was professor of chemistry at Yale College. He had seen carbonated waters on his travels to England and had met Joseph Priestley, who had emigrated to the USA. In partnership with a Mr Twining, he began selling carbonated waters in 1807 in Newhaven. Joseph Hawkins established an enterprise in Philadelphia the same year and operations rapidly sprang up in other cities in the north-east, for example, New York, Baltimore and Boston.

An excellent account of the development of the soft drinks industry in the USA was written by John J. Riley.

1.2 The growth of carbonates – production

The carbonated soft drinks industry continued to grow steadily as the nineteenth century progressed. By 1840, there were at least 50 manufacturers in London. At the Great Exhibition, held in London in 1851, J. Schweppe & Co paid £5000 for the concession to sell 'soda and other mineral waters'. They sold in excess of 1 million bottles during the course of the exhibition. Throughout the nineteenth century the popularity of carbonated soft drinks increased steadily and the number of flavours expanded likewise, driven by the popularity of the temperance movement. This growth of carbonates coincided with the industrial revolution through the nineteenth century. Production of soft drinks became more industrialised and a process of continuous improvement soon developed. The *Mineral Water Maker's Manual for 1885* lists over 80 patents, which were registered in the previous year, related to the manufacture and packaging of bottled soft drinks. It also lists approximately 300 trademarks which had been approved between the passing of the Trade Marks Act in 1875 and 1881, including that for the Buxton Mineral Water Co., Fairfield Works, Buxton, in 1876.

Continuous improvement in production and packaging of carbonated soft drinks meant that by the middle of the nineteenth century a manual bottling line was capable of filling 100 dozen bottles per day, but the introduction of steam power increased that to 300 dozen per day. By 1900, it was estimated that 70,000 people were directly employed in the UK soft drinks industry and 22,000 horses were used for product delivery. Total UK production was estimated by Bratby & Hinchcliffe to be almost 300 million dozen half pints (ca. 900 million litres). For comparison, in 1990, government statistics show that almost 18,000 people were employed in the soft drinks industry (manufacturing, distribution, sales and marketing) producing 6717 million litres of drinks. In 1899, there were 2763 soft drink bottling plants in operation in the USA.

The industries of the UK, Europe and USA progressed along slightly different paths owing to the differing circumstances found in those regions, although three types of beverage were found in each region. The industry in the UK, which was becoming more industrialised with large factories supplying products to the masses, progressed along the path of industrial production of soft drinks in returnable bottles sold through shops. In continental Europe the soda siphon type device (i.e. the gasogene or seltzogene) became popular for home use. These were used for the dispensing off of flavoured drinks, not just soda water. The common soda siphon which we would recognise today was patented by Charles Plinth in 1813. However, he used a stop-cock to dispense the contents and the use of a lever-operated device was patented by Deleuze and Dutillet in Paris in 1829. The use of a small metal bulb filled with CO_2 to re-charge a siphon of water was patented by Arthur Marescot in 1874.

In the USA, soda fountain equipment, where drinks were produced in shops for consumption on site, also became very popular. Some carbonates were consumed purely as a source of refreshment but many retained their medicinal pedigree to a greater or lesser extent. The most notable was probably quinine tonic water, which was consumed in tropical regions as a cure for malaria. Dandelion and burdock was obviously of herbal origin, and another popular drink in late nineteenth-century Scotland and in London during the 1890s was Kola Tonic. Kola (or cola) was a nut from West Africa, which was used by Nigerians as a symbol of hospitality. In 1886, Dr John S. Pemberton combined cola with coca (an extract from the S. American coca leaf) to produce his coca-cola 'brain tonic' sold in the soda fountain of his store in Georgia. In 1892, Asa G. Candler took over the business and incorporated the Coca-Cola Company in Atlanta with an aggressive marketing campaign for his 'nutrient beverage and tonic'. The company granted the rights to bottle the product under licence. The first such plant opened in Chattanooga in 1899, followed rapidly by many more. Around the same time Dr Pepper was launched by R.S. Lazenby in Waco, Texas (ca. 1888) and Pepsi-Cola was launched at New Bern, North Carolina by Caleb D. Bradham (ca. 1896, although the name Pepsi-Cola was not coined until 1901).

By the close of the nineteenth century most of the common carbonated soft drinks of today were already on sale, for example, soda water, ginger beer, ginger ale, lemonade, orangeade and other citrus drinks, cherryade, quinine tonic water, bitter lemon, colas, sarsaparilla, root beer, cream soda etc. These would all have been well known to consumers in the late Victorian era.

There is a difference between the American and British definitions of soda water. In the USA, soda water is defined simply as carbonated water, but the UK legislation still requires that soda water must contain a minimum of 550 mg/l sodium bicarbonate. Interestingly the only other legal compositional standard for a soft drink in the UK is for tonic water, which currently must contain a minimum of 57 mg/l quinine (as sulphate).

1.3 Technological development

1.3.1 Carbon dioxide

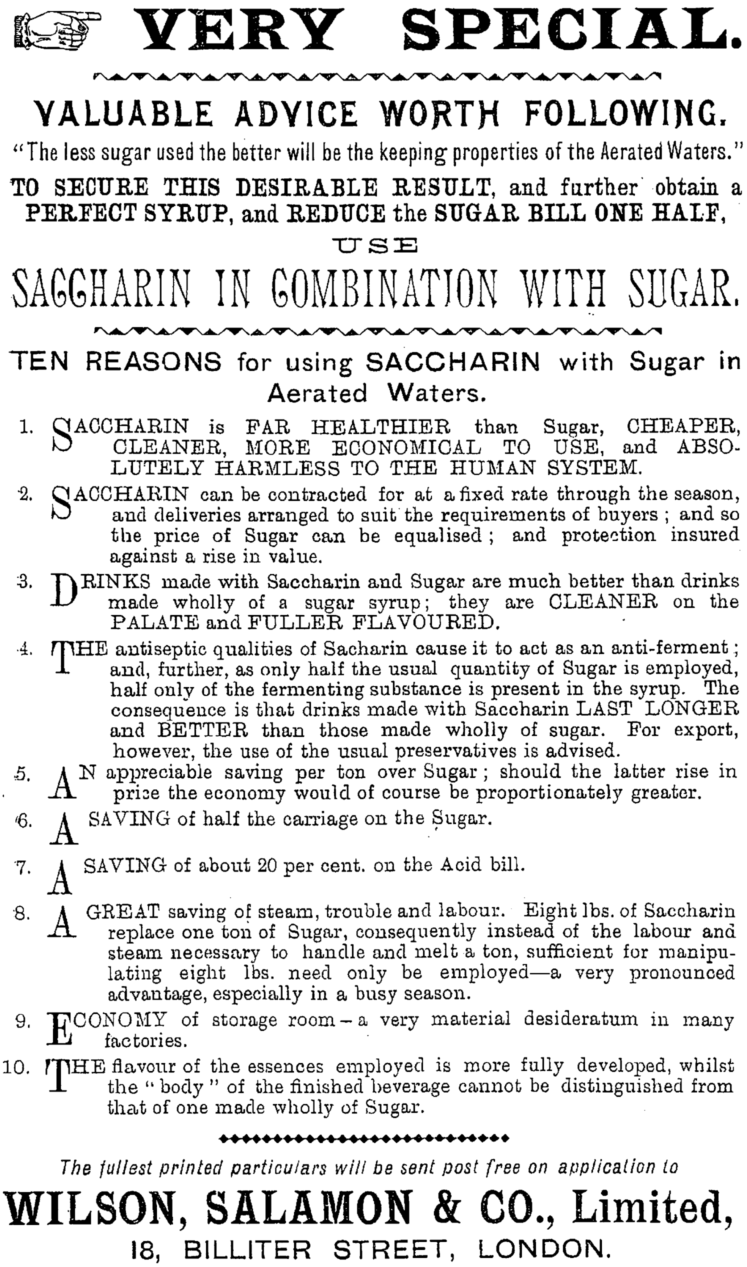
It had been recognised by many scientists in the early 1700s that the gas produced by brewery fermentation, combustion of wood and addition of acids to chalk/marble was one and the same. It was given several names including artificial air (Boyle 1685), mephitic air (Brownrigg 1741), fixed air (Black 1754), gas acide carbonique (Lavoisier 1782) and finally gaz oxide de carbon (Fourcroy 1805).

The most practical/economic means of commercial production was by the action of sulphuric acid on marble chippings (known as whiting) or, at a later date, on sodium bicarbonate. Crushed marble (or chalk or limestone) was cheap and readily available in large quantities. However, the purity of the marble was critical to the quality of the CO_2. Impurities (particularly organic ones) would cause noticeable 'off flavours' in the finished drink. This forced manufacturers to introduce filters and scrubbers to remove taints. Bubbling the CO_2 through olive oil was a commonly used method of removing organic taints. The purification of CO_2 introduced complexity and hence cost to the production process. Although more expensive than marble, sodium bicarbonate could be obtained in commercial quantities at consistently high purity and was preferred by some manufacturers. The product of the action of sulphuric acid on marble is calcium sulphate, which is insoluble in water. Large quantities of the resulting sludge were difficult to dispose of, particularly when the UK municipal authorities introduced controls in the 1890s. Problems of effluent emissions are not new. The liquification of CO_2 by means of high pressure was reported by Michael Faraday in 1823 and the first practical manufacturing equipment was patented by Dr Henryk Beins in Holland in 1877. The commercial manufacture and use of liquid CO_2 for the carbonation of drinks began in Germany and in the USA in the 1880s. The production of solid CO_2 was discovered by Thilorier in 1835, and a patent for the production and use of solid CO_2 was granted to Dr Samuel Elworthy in 1897. The handling and transportation of solid blocks of CO_2 was much easier than for heavy metal cylinders containing liquid CO_2. Though use of liquid or solid CO_2 increased in the late nineteenth and early twentieth century, it was not until the 1950s that transportation of liquid CO_2 by low pressure bulk road tankers became commonplace.

Production of carbonated drinks was traditionally carried out by means of adding concentrated syrup to the bottle and then topping up with carbonated water. A considerable improvement in speed was achieved in 1937, when the Mojonnier Brothers Corporation of Chicago introduced a continuous blending/cooling/carbonating system. Such continuous systems have gradually replaced the syrup dosing systems, though some of the latter remained in operation into the 1980s.

1.3.2 Sweeteners

One of the major drivers of growth in carbonates has been the development of sweeteners and consequent improvement in the quality of low calorie soft drinks, particularly in the USA and UK. Saccharin was invented in about 1874 and very rapidly became popular as a sweetener for soft drinks, usually blended into sugar to reduce cost. Figure 1.1 shows an advertisement for saccharin, which was published in 1890, by which time it was already widely used. A modern supplier may have difficulty substantiating all of the claims made for it. However, it proved to be a popular sweetener in the UK, particularly when sugar was in very short supply during the First World War. A blend of sugar and saccharin (50 : 50 by sweetness) became the standard sweetener system for common soft drinks, for example, lemonade.



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4. THE antiseptic qualities of Sacharin cause it to act as an anti-ferment ; and, further, as only half the usual quantity of Sugar is employed, half only of the fermenting substance is present in the syrup. The consequence is that drinks made with Saccharin LAST LONGER and BETTER than those made wholly of sugar. For export, however, the use of the usual preservatives is advised.
5. AN appreciable saving per ton over Sugar ; should the latter rise in price the economy would of course be proportionately greater.
6. A SAVING of half the carriage on the Sugar.
7. A SAVING of about 20 per cent. on the Acid bill.
8. A GREAT saving of steam, trouble and labour. Eight lbs. of Saccharin replace one ton of Sugar, consequently instead of the labour and steam necessary to handle and melt a ton, sufficient for manipulating eight lbs. need only be employed—a very pronounced advantage, especially in a busy season.
9. ECONOMY of storage room – a very material desideratum in many factories.
10. THE flavour of the essences employed is more fully developed, whilst the " body " of the finished beverage cannot be distinguished from that of one made wholly of Sugar.

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Figure 1.1 Advertisement for saccharin, 1890.

Low calorie soft drinks (containing <10 kcal/100 ml) began to gain popularity in the 1960s and a blend of 1 part saccharin to 10 parts cyclamate produced a good tasting low calorie sweetener system. However, the use of sodium cyclamate came to an abrupt end in 1969 when it was banned in the USA and UK (from 1 January 1970) due to evidence suggesting that it caused bladder cancer. Cyclamate was not banned elsewhere and it remained a very popular sweetener until recent severe restrictions in the EU. The original work was later discredited but it resulted in saccharin being the only permitted sweetener in the UK and this severely limited the growth of low calorie drinks because of the unpleasantly bitter aftertaste of saccharin when used as a sole sweetener. The growth resumed again in the mid-1980s following the approval of aspartame and acesulfame K in the UK in 1983. This growth in popularity of low calorie (or 'light') drinks has been a massive driver of volume growth in the USA and UK, but to a lesser extent in mainland Europe. In the UK, in 1981, only approximately 4% (84 million litres) of the 2040 million litres of carbonates produced was low calorie. By 2003, low calorie represented 32% of the carbonates market of 6500 million litres (see Table 1.1) and a further 25% was reduced sugar (usually for reasons of cost).

1.3.3 Flavours and colours

As previously mentioned the original carbonates were artificial imitations of naturally occurring mineral waters. Manufacturers blended mineral salts in the same proportions as found in the natural spring waters and added carbonated water. A large range of such waters was available during the early 1800s. Early attempts at producing flavoured products were limited by a lack of stable flavourings and spoilage problems. The flavouring materials used consisted mainly of herbal/botanical extracts, for example, ginger, nettle, nutmeg, horehound, lemon oil, vanilla etc., but the technology for manufacture of soluble stable flavouring extracts developed rapidly during the middle of the century with the establishment around this time of many speciality flavour companies (such as W.J. Bush and Stevenson & Howell in London). An early recipe for lemonade consisted of citric acid, essential oil of lemons and sugar syrup, the mixture being topped up with water and impregnated with carbon dioxide – instantly recognisable as the forerunner of today's lemonades. In 1858, Mr Erasmus Bond patented 'an improved aerated

Table 1.1 Growth of low calorie carbonates.

Year	Low calorie carbonates (million litres)	Total carbonates (million litres)	Percentage
1980	84	2040	4
1990	941	4129	23
2003	2099	6560	32

liquid, known as Quinine Tonic Water' and, following the development of a clear soluble ginger extract, ginger ale was first manufactured in Belfast in the 1870s.

By the second half of the century, carbonate manufacturers could buy a very comprehensive range of flavours to use in their products and the science of flavour chemistry was well under way, as demonstrated by the development of artificial vanillin by Tiemann and Wallach in 1872. This reduced the cost of vanilla flavour by a factor of more than ×30 (from $300/lb ($555/kg) to less than $10/lb ($19/kg)). As mentioned above, many of the popular drinks of today were on sale before 1900. The quantity of CO_2 added to a drink has a pronounced effect upon its character and flavour impact. The solubility of CO_2 in water decreases as temperature increases but increases with increasing pressure, that is, a given level of carbonation will generate a higher pressure as the temperature increases. Ice cold water (0°C) will dissolve 1.7 volumes (3.4 g/l) of CO_2 at atmospheric pressure. At CO_2 levels and at temperatures above this, increased pressure must be applied to retain the CO_2 in solution. In some of his early highly carbonated waters Nicholas Paul used carbonations of up to eight volumes of CO_2 (16 g/l); however, the usual carbonation levels now range from about two volumes for a slightly sparkling fruit drink to around five volumes for a mixer drink such as tonic water (see Table 1.2). Mixers require higher levels of carbonation because they are intended to be diluted with spirit before consumption.

In the early 1800s, colours were restricted to mainly variants of brown and red, that is, those which could be produced from caramel or cochineal. This remained the case until the introduction of synthetic aniline dyes around 1880. The *Mineral Water Maker's Manual for 1885* described the manufacture of some colours from vegetable extracts but stated that there was a trend for these to be replaced by the new aniline-based dyes, even though these 'are considered objectionable by many'. It also strongly warned manufacturers not to use colours such as arsenic sulphate, lead chromate, mercury sulphate and copper arsenite, which it claimed were sometimes used to colour confectionery.

1.3.4 Packaging

Waters from natural springs were recognised as being safe (even healthy) to drink from earliest times and were transported by whatever means that were available.

Table 1.2 Typical carbonation levels.

	Volume	(g/l)
Lightly sparkling	2.0	4
Fruit juice carbonate	2.5	5
Lemonade	3.0–3.5	6–7
Cola	4.0	8
Mixer	4.5–5.0	9–10

Naturally carbonated waters were collected into earthenware containers, which were tightly sealed with cork and wax, usually not very successfully. The use of earthenware bottles proved to be unsatisfactory for the more highly carbonated aerated mineral waters and they were soon replaced by glass bottles. Many of the early glass bottles had round bottoms ensuring that they were stored on their side, thereby keeping the corks moist and so preventing leakage from corks drying out. The manufacture of glass bottles was a skilled job as they were hand blown. Although some semi-automation had been introduced earlier, the first patent for an automatic glass bottle blowing machine was granted to Michael J. Owens in the USA in 1904.

High pressure generated inside bottles by the carbonation caused frequent leakage and, although improved by wiring-in-place, corks were generally unsatisfactory. Many alternative forms of seals were patented over the years and these fell broadly into three main categories:

1. Wire and rubber sealing devices were especially popular in the USA until the early 1900s. The wire could be either an internal spring form, which held a seal in place on the inside of the neck, or of the external ‘swing’ type, in which an external wire frame was used to hold a ceramic plug in place against a rubber seal. First patented by Charles de Quillfeldt in 1874, this latter type is still currently in use for some speciality beers.
2. Variations on the theme of using an internal ball made from rubber, ebonite or glass were developed and used with varying degrees of success. The ball was held in place by the internal pressure. The most successful of these was patented by Hiram Codd of London. His bottle was widely used in the UK from the 1870s until the 1930s. A similar bottle, but with a floating rubber ball acting as seal, was patented in the USA by S. Twitchell in 1883.
3. The third popular alternative was the internal screw top bottle. Unlike today’s bottles, the thread was on the inside of the bottle neck and an ebonite or wooden stopper screwed into the neck, with a rubber washer being used to improve the seal. These types of stoppers were in common usage well into the 1950s in the UK. Ebonite, an early type of plastic resin material soon replaced wood, which had a tendency to absorb moisture, causing it to swell and crack the bottle neck.

A major step forward in sealing development was made by William Painter, who in 1892 patented the ‘Crown Cork’, founding the Crown Cork and Seal Company on 1 April 1892. Although initially slow to gain acceptance for two reasons: (a) the existing large capital investment in returnable bottles and bottling plant, and (b) the need for a tool to remove the crown, the crown cork eventually became popular, especially for small single serve and beer bottles. Screw stoppers retained their popularity for the larger bottles where re-sealability was important.

Except for some speciality earthenware ginger beer containers, glass bottles were the only form of packaging for carbonates for over hundred years until the introduction of cans in the 1960s. Then, just as the second half of the nineteenth century had been ‘boom-time’ for product development, the second half of the twentieth century became ‘boom-time’ for packaging and distribution development.

1.4 Recent technological development

Technology certainly played a large part in the growth of soft drinks in the second half of the twentieth century. The development of cans, plastic bottles, high speed packaging lines and improvements to distribution systems have been largely responsible for the increase in availability, the decrease in real-term cost and the resultant increase in consumption.

The advent of railways and large steam ships in the 1800s made transportation feasible and indeed drinks were exported from the UK to the USA as early as 1800. The export trade continued to expand and by the mid-1800s significant trade was being done with the far corners of the Empire. This must have involved considerable cost and on a domestic basis the trade was on a much more local scale. The industry evolved as a multitude of local businesses operating in a small geographical area, though some larger companies operated several production plants in different parts of the country. The UK *Bottler's Year Book 1933* listed more than 2000 soft drink manufacturing companies but by 1983 the list had shrunk to less than 400, and the number is now down to less than 100. Likewise the number of bottling plants in the USA grew to reach a peak of 7920 in 1929, remaining fairly constant until around 1950 and then halved to 3727 by 1965 as improved productivity and distribution started to have a significant effect. This halving of the number of bottling plants took place over a period in which per capita consumption rose by over 60%. More recently, the growth of cans and PET bottles at the expense of returnable glass has played a significant part in this continuing productivity improvement, which has been truly amazing. As recently as 20 years ago a typical returnable glass bottle line producing, say 300 bottles/min, required about 25 operating personnel. Highly automated high speed production lines now fill up to 2000 cans/min using three operators. Likewise, integrated PET bottle blowing and filling operations have also improved production efficiencies significantly. Other factors contributing to improved operational/distribution efficiencies (both in time and cost) include:

- use of shrink wrap in place of crates or boxes
- micro-processor controlled equipment, for example, for palletisation
- automated syrup room operations
- centralised computer-controlled warehousing systems
- automated bar-coding and traceability systems.

1.5 The growth of carbonates – consumption

The growth of carbonates worldwide has been a remarkable phenomenon, not only in the USA and western Europe, but also in Mexico, Brazil, eastern Europe, China and India. In the USA especially, carbonates have dominated the soft drinks market and the carbonates market has been dominated by cola. This worldwide growth in carbonates can be attributed in large part to the two major American cola companies and their aggressive international sales and marketing campaigns. In the UK, Europe and Japan, cola accounts for almost half of the total carbonated soft drinks market and in the USA almost 70%. The scale of carbonates consumption globally is truly impressive, amounting to a total of almost 193,000 million litres in 2004. The Americas (North and South) accounted for more than half of the total (see Table 1.3) but there is little doubt that at their present rates of growth China and India will soon start to make an impact on the global scene. However, in the USA and UK it is clear that carbonates' dominance of the soft drinks market has peaked and begun to wane in the past few years, although exact numbers reported vary because of slight differences in definitions and methodologies between the research companies. In the UK, carbonates volume reached more than half of the total soft drinks market, peaking at around 52% in the mid-1990s. Although the volume of carbonates had been continuing to grow year on year, still drinks have recently been growing more strongly, increasing their market share because of their perceived 'more healthy' image. Carbonate volumes increased from 2.18 billion litres in 1982 to 4.27 billion litres in 1992 and 6.5 billion litres in 2003 (see Table 1.4), however this inexorable climb in volume appears to have stopped. ACNielsen have reported that in 2004 sales value of carbonates fell by 3.3% (4.7% lower by volume) when compared with the previous year. Whilst some of the recent fall in sales can undoubtedly be

Table 1.3 Global consumption of carbonates.

Region	Volume (million litres)	Percentage
North America	63,655	33
Latin America	42,437	22
West Europe	30,863	16
Asia/Australia	28,934	15
Africa	9,645	5
East Europe	9,645	5
Middle East	7,716	4
Total	192,895	

Source: Zenith International.

Table 1.4 Growth of UK carbonates.

Year	Total carbonates (million litres)
1980	2095
1985	2735
1990	4129
1995	5380
2000	5950
2003	6560

attributed to comparison with the record breaking hot summer of 2003, it is clear that carbonates have suffered a slowdown as their market share continues to decline. It has also been reported in trade press that the sales of carbonated drinks in the USA have been virtually static for several years now, and have in fact declined marginally on a per capita basis. Beverage Marketing Corporation (BMC) has recently reported that total US volume sales of carbonates grew by only 0.7% in 2004 to 58.2 billion litres. On a per capita basis that represents a fall of 0.2% to 203.5 l/person, the sixth consecutive year of decline since consumption peaked at 207.7 l/person in 1998. This compares with a western European consumption of around 77 l/person and a UK figure of 111 l/person.

Three factors were largely responsible for the remarkable growth in popularity of carbonates: marketing, lifestyle and technology. ‘Demand creation’ by the major brands using powerful images on a worldwide scale has been a key factor in exciting public interest. This has been coupled with a massive increase in availability. Carbonates are now available at virtually every location; not just in shops and supermarkets, but in cinemas, sports centres, garages and railway stations and are frequently sold from refrigerated vendors for even better refreshment. The trend has also been influenced by changing lifestyles and greater convenience. For example, the ‘easy open end’ on cans had a marked impact on their convenience, and hence popularity, from their introduction in the1970s. The introduction of PET enabled larger sizes of bottles to be manufactured than was possible with glass, that is, 2 and 3 litres, and the introduction of ‘multipacks’ for cans and bottles has encouraged shoppers to purchase larger quantities. This trend has been helped by the move to out-of-town shopping centres easily accessible by car. A frequently ignored supply route for carbonates is that of dispensed drinks, that is, where the drink is supplied to the retail outlet in the form of a concentrated syrup, which is diluted with cold carbonated water at the point of serving to the customer by means of a fixed dispensing system. This type of operation is commonly found in fast food outlets and large bars. Dispensed carbonates account for 11% of the total UK consumption of carbonates (715 million litres) and their growth has been driven by lifestyle changes resulting in a greater proportion of food and drink now being consumed away from home. The move away from returnable glass to PET has also provided for much greater flexibility in the range of available bottle sizes and hence consumer satisfaction. In 1980, glass bottles still accounted for 65% of carbonated soft drinks in the UK. By 1990 this had fallen to 14% and by 2003 to a mere 3%.

The introduction of modern technology has enabled considerable cost savings. This has been achieved by economies of scale, by the ‘light-weighting’ of cans and bottles (thereby saving raw materials), by increased automation, by a reduction in the use of outer packaging and by savings in distribution costs. UK government statistics show that in the 5 years from 1998, the retail price of soft drinks fell by 1% over a period when general inflation was 12%, that is, a real terms price reduction of 13% over 5 years. This is just the continuation of a trend, which has resulted in a very significant long-term fall in the real prices of soft drinks, including carbonates.

1.6 Changing public perception and future challenges

Unfortunately the very success of carbonated soft drinks, and their resulting high profile, has provoked hostility towards them. Initially from the environmentalists, who perceived drinks packaging as a major source of waste and litter, because even though it represents only a relatively small percentage of total packaging waste, it is highly visible. Considerable light-weighting of both cans and bottles and reductions in both the amount and weight of outer packaging has reduced the waste associated from drinks and there is significant recycling of the metal content of cans. However, the introduction of legislation, most notably in Germany, has had a major impact on the industry. Environmental issues will be dealt with in greater detail in Chapter 11.

More recently as the media's attention has focused on obesity, especially where it affects children, the term 'fizzy drinks' has become indelibly linked to 'junk food' to such an extent that it has become a pejorative term. Fizzy drinks are in danger of becoming a hate figure – blamed for the world's ills. There are currently concerted moves in many countries to ban fizzy drinks from schools. Indeed some extremists have gone so far as to propose that they should not be sold within a given fixed radius of any school premises. Some schools already prohibit children from taking carbonated drinks into school, for example in lunch boxes. The promotion of soft drinks to children, particularly by means of television advertising, has come under scrutiny and may well be restricted in the UK, as it already is in some EU countries, for example Sweden. The headlines in the popular press cry out almost daily that fizzy drinks are responsible for not only making schoolchildren obese but also for their bad behaviour and the stunting of their learning abilities. There have also been anecdotal claims that the consumption of carbon dioxide can lead to depletion of calcium from the body with consequent adverse effects on bone density. This remains, however, a theory for which no convincing scientific evidence has been found. Scientific studies, for example, by Heaney and Rafferty in 2001, have found no excretion of calcium from the body associated with elevated consumption of carbonated drinks.

At the time of writing, draft legislation is proceeding through the European Parliament concerning the addition of nutrients (in particular vitamins and minerals) to foodstuffs and any nutritional or health claims which may be made about them. There is a strong campaign supporting the proposal that soft drinks, and particularly 'fizzy drinks', should be prohibited by law from any form of nutritional fortification and from making any nutritional or health claims. It seems that the passage of such draconian restrictions into legislation is unlikely and there is no doubt that the industry has been responding to the consumer's demands for a greater range of products and for products perceived as 'more healthy'. Sales of diet drinks, waters and fruit juices have shown considerable growth. In particular the increase in UK consumption of bottled waters has been phenomenal (see Table 1.5), from a paltry 25 million litres in 1980 to 2070 million litres in 2003, at a retail value of £1.2 billion (€1.8 billion). The bottled water market is however dominated by still waters ($<20\%$ carbonated).

Table 1.5 Growth of UK bottled waters.

Year	UK consumption (million litres)
1980	25
1985	75
1990	400
1997	900
2000	1415
2003	2070

The growth in low calorie carbonates since the mid-1980s has been almost as spectacular as that of bottled waters, from 84 million litres in 1981 to 2200 million litres in 2003. Indeed almost 60% of carbonated drinks now sold in the UK contain sweeteners as a total or partial replacement for sugar. It is generally expected that these trends will continue as the consumer seeks a more healthy lifestyle but it must be remembered that not all consumers seek healthy products and one of the success stories of the past decade has been Red Bull, a so-called energy drink, and its multitude of imitators. Even so, some energy drinks have introduced low calorie versions in recognition of the trend although the author considers the term 'low calorie energy drink' to be an oxymoron.

There is no intrinsic reason why a still drink should be more 'healthy' than a carbonated one. Carbonates can be low sugar, manufactured with 'natural' ingredients, contain fruits, healthy botanical extracts, antioxidants, etc., and be fully compatible with a healthy lifestyle, provided that (like all other foodstuffs) they are consumed in moderation as part of a balanced diet. As part of this trend towards healthy and natural there has been a rapid growth in the number of drinks making use of the healthy heritage of spring or natural mineral waters, in both sweetened and unsweetened products, usually without colour. It is interesting to see carbonates returning full circle towards their late eighteenth-century origins as 'Aerated Mineral Waters'.

Acknowledgements

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2 Water treatment

Walter Tatlock

2.1 Introduction

Water constitutes some 90% of a typical soft drink. The quality of the water used must, by necessity, meet very stringent standards, as each bottle or can of a given drink must be indistinguishable from all others. Statutory requirements as to the quality of a soft drink must be adhered to in each producing country. Any 'off' taste in the water used will be carried over to the soft drink. For these reasons, all the water used in a soft drinks plant must conform to an agreed specification. Each major soft drinks manufacturer has its own standards, developed over the years through trial and error. These standards ensure that wherever a particular drink is produced the taste and quality are the same. In addition, risk to the consumer and to the business must be considered at all times. If the water used is contaminated in any way, the risk to the business increases.

If we consider the water cycle shown as Figure 2.1, it can be seen that the situation is very complex. The figure helps us to understand why water treatment is required and why this treatment must be applied consistently because of where water could come from. The Earth's water is always in movement, and the water cycle, also known as the hydrological cycle, describes the continuous movement of water on, above and below the surface of the Earth. Since the water cycle is truly a 'cycle',

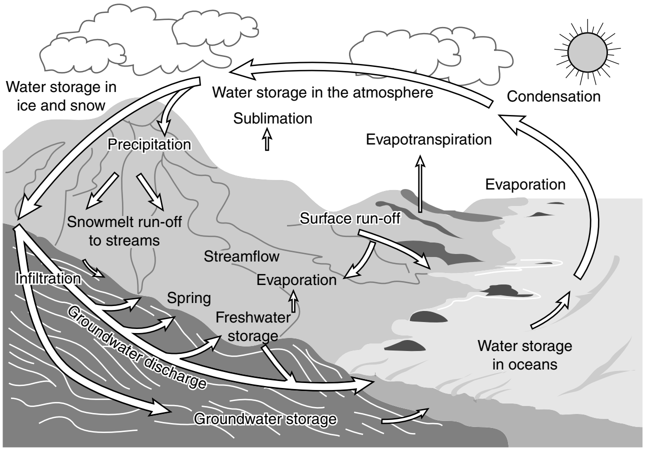


Figure 2.1 The water cycle.

there is no beginning or end. Water can change states among liquid, vapour and ice at various places in the water cycle, with these processes happening anywhere from virtually instantaneously up to millions of years. Although the balance of water on the Earth remains fairly constant over time, individual water molecules can come and go. The water in an orange eaten yesterday may have fallen as rain in some country half way around the world last year or it could have been used 100 million years ago by some dinosaur.

Quite clearly the water cycle has no starting point. However, as most of the Earth's water is contained in the oceans, it seems logical to start here. The sun drives the water cycle and heats the water in the oceans. Some of the water evaporates as vapour into the air, and ice and snow can sublimate directly into water vapour. Rising air currents take the vapour up into the atmosphere along with water from evapotranspiration, which is water that is transpired from plants and evaporated from the soil. The vapour rises into the air, where cooler temperatures cause it to condense into clouds. Air currents move clouds around the globe; cloud particles collide, grow and fall from the sky as precipitation. Some precipitation falls as snow and can accumulate as glaciers and ice caps, which can store frozen water for thousands of years. Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt. Most precipitation falls back as rain into the oceans or on to land, where, owing to gravity, it flows over the ground as surface run-off. A portion of run-off enters rivers in valleys, with streamflow moving water towards the oceans. Run-off and groundwater seepage accumulate and are stored as freshwater in lakes. However, not all run-off flows into rivers. Much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which are saturated subsurface rock that stores huge amounts of freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies, as well as the ocean, as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs.

This cycle repeats itself in many ways all the time. The world's water is distributed and shown in Table 2.1. During this cycle water picks up contaminants: it is said to be the universal solvent. Water has a tendency to dissolve a little of everything it comes into contact with. If, for example, it dissolves sulphur from an industrial chimney, it can form acid rain. As water runs over a particular soil, it dissolves some of the soil's constituents. When the water seeps through the Earth, it dissolves portions of the minerals present. Agricultural by-products, fertilisers, insecticides, bacteria and other contaminants are all present in the hydrological cycle. They can be present in varying amounts in any water source. For this reason, it is important to regularly analyse the water supplied to a soft drinks plant and to install water treatment equipment that will ensure the water is treated to remove all contaminants to achieve the company water standard at all times.

Water is usually supplied from two main sources. A soft drinks bottler either buys the water from a local water company or obtains it from a company borehole. If the water is bought from a local water company, it is normally piped to the bottler to a minimum agreed standard. It is the duty of the bottler to have a written

Table 2.1 Water sources.

Water source	Water volume (km^3)	Freshwater percentage	Total water percentage
Oceans, seas and bays	1,338,002,000	None	96.5
Ice caps, glaciers and permanent snow	24,064,000	68.7	1.74
Groundwater		None	1.7
Fresh	10,530,000	30.1	0.76
Saline	12,870,000	None	0.94
Soil moisture	16,500	0.05	0.001
Ground frost and permafrost	300,000	0.86	0.022
Lakes		None	0.013
Fresh	91,000	0.26	0.007
Saline	85,400	None	0.006
Atmosphere	12,900	0.04	0.001
Swamp water	11,470	0.03	0.0008
Rivers	2,120	0.006	0.0002
Biological water	1,120	0.003	0.0001
Total	1,386,000,000	–	100

Source: Gleick (1996), Encyclopedia of Climate and Weather, vol. 2, pp. 817–23, Oxford University Press, New York.

agreement with the water supplier to the effect that the water should be supplied to this minimum standard. A borehole in the UK is normally licensed by the Environment Agency. To gain a licence stringent testing is required. This testing will categorise the borehole water as natural mineral water, spring water or table water.

Given that water is the main ingredient of a soft drink product, pro rata it attracts the least amount of investment within the industry. This chapter attempts to justify the spending of capital and the allocation of competent personnel resources to manage the water function. If any problem occurs with the water, the reputation of the company concerned is at stake.

2.2 Water quality

Within Europe the minimum requirement is that all water used in a soft drinks factory must comply with the EC Drinking Water Directive 80/778/EEC. All major producers of carbonated soft drinks have their own water standard. This usually requires treatment of all incoming water, except in the case of natural mineral water, where no treatment is allowed. If the water supply is from the local water company, it is imperative that a good working relationship is set up. At certain times, owing either to maintenance or to drought, the source of the water supplied can change. Even though water companies have a statutory obligation to ensure that the water they supply is fit for use, this is to a much lower standard than is required to produce a soft drink, which must taste the same wherever and whenever it is made.

No risk of product taint or colour problems as a result of turbidity issues can be allowed.

I particularly like a statement made by Bill Clinton in 1996, who said, ‘A fundamental promise we must make to our people is that the food they eat and the water they drink are safe’. The UK Water Supply (Water Quality) Regulations 2000 state that:

> *The problems associated with chemical constituents of drinking water arise primarily from their ability to cause adverse health effects after prolonged periods of exposure. There are few chemical constituents of water that can lead to acute health problems, except through massive accidental contamination of a supply. In contrast, contamination of water supplies for a short period with harmful organisms can expose large sections of the population to health risks leading to illness and, in rare cases, to death.*

The messages are clear: we should all be aware of the risks that contaminated water can pose. There is no excuse for not taking the correct actions to ensure that the water we use is of the required quality.

A typical water quality standard for soft drinks is shown in Table 2.2. To ensure that this standard is always met, it is necessary to regularly analyse the water: a full analysis should be carried out monthly, and on a daily basis basic parameters should be checked. There are now available simple testing kits for basic contaminants, often using tablets that can be added to water in a test tube, with the resultant colour of the liquid being compared against a colour chart to determine the concentration of chlorine and so on. Table 2.3 lists the basic tests that are usually carried out. In addition to these simple chemical tests, regular testing for micro-organisms is necessary. The removal of cryptosporidium has become one of the most important procedures.

The first necessity is for a company chemist to agree the water standard with the company’s board. This standard needs to be regularly reviewed against what is actually being achieved. Is the standard too rigid and too problematic to achieve? Have any product problems occurred since the previous review? What technical problems exist in actually achieving this standard with the water treatment plant available? Is further investment in plant required? Do we meet current legislation? What future legislation could affect this standard? Such questions as these will allow the standard to be updated in the commercial world we live in. The key is to provide consistent water quality at all times without going over the top in terms of system sophistication. Risk analysis is a very necessary part of these deliberations. It is important to minimise risk at all times. We do not want to endanger anyone’s health. In the simplest terms, all water used for soft drinks must be free from micro-organisms, taints and odours, clear and colourless and, especially if it is to be carbonated, free from dissolved oxygen.

At each production site the treated water should be tested for conductivity, turbidity, microbiological levels, taste, odour and appearance, alkalinity and free chlorine. In addition, the incoming raw water should be tested daily for turbidity and microbiological levels. Most plants have an in-line turbidity meter that automatically shuts off the supply should the alarm limit be reached. Turbidity is defined as an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through a sample. In simple

Table 2.2 Typical organoleptic, physical, chemical, anionic and cationic standards.

	Maximum level	Comments
Organoleptic		
Odour	Odourless	Taste and odour effects
Taste	Tasteless	Triangular taste test
Physical		
Colour	20 mg/l Pt/Co scale	Drink clarity
Turbidity	1 FTU	Clarity and fobbing
Chemical		
Alkalinity	100 mg/l as $CaCO_3$	Affects product acidity
Benzene	5 μg/l	Can cause anaemia and cancer
Conductivity	500 μS	Action required if >50 μS change
Free chlorine	0.05 mg/l as Cl_2	Off flavours
Organic content	2 mg/l total organic carbon	Taints
Oxygen absorbed from $KMnO_4$	After de-aeration 0.05 ppm	Micro-organism growth and fobbing
pH	6.5–8.5	Acid control
Phenols and chlorophenol	0.5 μg/l	Taste
Polycyclic aromatic hydrocarbons	0.01 μg/l	Reproductive difficulties
Total dissolved solids (TDS)	500 mg/l	Possibly salty, off tastes
Volatile substances extracted by chloroform	0.1 mg/l	Off tastes
Anionic		
Chloride	20 mg/l as chloride	Salty taste and can corrosion
Fluoride	1.5 mg/l as F	Teeth mottling and bone disease
Nitrate	20 mg/l as NO_3	Can corrosion and organic pollution
Nitrite	0.1 mg/l as NO_2	Can corrosion and organic pollution
Phosphate	3 mg/l as P_2O_5	Micro-organism growth
Sulphate	10 mg/l as SO_4	Can corrosion
Sulphite	1 mg/l as SO_3	Possible neurotoxin
Cationic		
Aluminium	0.2 mg/l as Al	Sediment; turbidity
Arsenic	0.05 mg/l as As	Skin damage; circulatory problems
Cadmium	5 μg/l as Cd	Kidney damage
Chromium	0.05 mg/l as Cr	Allergic dermatitis
Copper	3 mg/l as Cu	Liver or kidney problems, stomach distress; toxic
Cyanide	0.05 mg/l as CN	Nerve damage and thyroid problems
Iron	0.2 mg/l as Fe	Taste and appearance
Lead	0.05 mg/l as Pb	Kidney problems; affects mental development in children
Manganese	0.03 mg/l as Mn	Sediment; off flavour
Mercury	1 μg/l as Hg	Kidney damage
Selenium	0.01 mg/l as Se	Hair or fingernail loss; numbness
Sodium	150 mg/l as Na	Salinity when linked to a chloride
Zinc	5 mg/l as Zn	Astringent taste

Table 2.3 Daily water checks.

Test	Incoming water	Treated water
UV efficiency	No	Yes
Taste, odour and appearance	No	Yes
Microbiological levels	Yes[a]	Yes[a]
Alkalinity	No	Yes
Turbidity metre[b]	Yes	Yes
Silt density	Yes	Yes
Free chlorine	No	Yes

Notes:

[a] The tests would usually be TVC <500 per 100 ml sample at 25°C with no coliforms present in the same size sample. Faecal streps should be absent in a 100 ml sample.

[b] This should also have an automatic data logger.

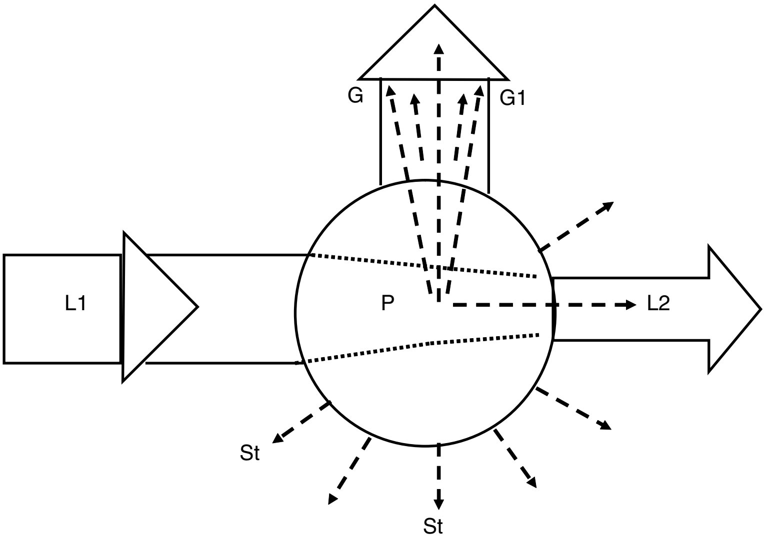
terms, it is a measure of relative sample clarity. The international standard is ISO 7027 (1984 edn). The most widely used unit is the FTU, or formazin turbidity unit, though the United States Environmental Protection Agency uses the NTU, or nephelometric turbidity unit. The NTU is also most widely used in the UK. The World Health Organization (WHO) states that all water turbidity should be below 5 NTU and ideally below 1 NTU. The principle of a turbidity meter is shown in Figure 2.2.

2.3 Town mains water

The town mains is the principal supply of water. Within the UK this supply is warranted to be potable, though not always suitable for the production of soft drinks. Each water supply company has its own water supplies, whether from a lake in Wales or the Lake District, a Scottish loch, a borehole, a river or de-salinated from the sea. UK water companies treat all the incoming water to meet the EU regulations. Some companies have dispensations with time limits imposed on them. They are also responsible for the distribution system from the point of supply to the water treatment works and from these works to each customer.

A factory usually receives its water from a specific water treatment works. However, water can come from a variety of sources according to the level of drought. If there has been no appreciable rainfall for a considerable time, then the risk to a soft drinks company will increase. The water source will probably be more variable and, although potable, will require different water treatment levels from the norm. Such conditions must be catered for within the factory's water treatment system.

Another problem in the UK is the state of many pipelines. Although these are being replaced, some still date back over a century, and such old installations can lead to contamination problems. Even when pipelines are replaced, the act of replacement causes disruption and may result in ingress of excess silt into the system by back-siphoning. The user needs to be vigilant at all times.



L1	Light beam striking the sample
L2	Light beam passing through sample
P	Sample
St	Scattered light
G/G1	Peripheral rays of scattered light beam used for measurement

Figure 2.2 Turbidity metre working principle.

As all water is metered and water is becoming more expensive every day, it should be conserved as far as possible. Most soft drinks factories use over twice as much water as they actually bottle – for example, in cleaning systems. Water usage needs to be monitored, as the cost to purchase water and the effluent costs are very similar, especially if the COD (chemical oxygen demand) and BOD (biological oxygen demand) levels are high. Water conservation needs to be practised at all times, commensurate with ensuring the integrity of the final product. The UK Integrated Pollution Prevention Control (IPPC) legislation requires that waste be minimised by assessing the environmental impact of all materials used and produced on site, water use, and abatement of point-source emissions to surface water and sewers. Assessment includes identifying how much water is taken into and discharged from the site, emissions to groundwater by map location of sewer and drain points, waste handling, basic energy requirements and TOC (total organic carbon) monitoring of water and sewer emission.

By 2007 all industry sectors will have to comply with this legislation. This implies working closely with your water supplier, who will most likely also manage the effluent. The Water Regulations (1999) have replaced local water bylaws with national legislation. In principle, the regulations govern the use of fixtures and fittings across a site and are designed to protect staff, customers and the environment from poor water quality and unnecessary waste.

The Water Framework Directive (WFD) 2000/60/EC is the most significant piece of European water legislation to be produced for over 20 years. The WFD rationalised and updated existing water legislation and introduced an integrated and co-ordinated approach to water management in Europe, based on the concept of river basin planning. The directive takes a holistic approach to water management and will update existing EC water legislation through the introduction of a statutory system of analysis and planning. The major aims of the directive are to prevent further deterioration and to protect and enhance the status of aquatic ecosystems and associated wetlands, to promote the sustainable consumption of water, to reduce pollution of water with priority substances, to prevent deterioration in the status and to progressively reduce pollution of groundwater and to contribute to mitigating the effects of floods and droughts. It is clear that we all need to consider the latest legislation – both water supplier and user – and work together to ensure due diligence.

2.4 Boreholes

Although it is not the intention of this chapter to go into boreholes in any real detail, it is useful to go over the basics. More detail can be found in Senior and Dege's *Technology of Bottled Water* (2004).

A borehole with natural mineral water status and sufficient quantity and quality of water to meet current and future demands is every manufacturer's dream. Often, in fact, the supply has to be treated in some way to ensure that the taste of the soft drinks produced meets customers' requirements at all times. In this case it is often better just to opt for spring water status, where some treatment is allowable. Most boreholes provide very consistent water quality from the aquifer at a constant temperature. In fact, they often supply water at lower than ambient temperature, which is highly conducive to efficient carbonation. Only when the aquifer is near the surface is there usually any risk, because little time is required to replenish from possibly contaminated land. If a borehole supply does not meet the EC water standards it cannot be called natural mineral water or spring water, both of which must meet microbiological standards without treatment. Most waters start off with the categorisation spring water. After two years of testing the local authority may change the category to natural mineral water, which needs, in the UK, to be registered with the Food Standards Agency.

Before a borehole can be drilled in the UK a hydrogeological survey and the agreement of the Environment Agency are required. If this survey shows that a borehole is feasible, then a drilling company must be approached. The hydrogeologist usually manages this on behalf of the client, as full drilling logs are required. Ideally, the borehole should be located at least 50 m from any possible uphill pollution sources. A typical borehole construction is shown in Figure 2.3. Such boreholes are often in excess of 100 m deep. A simple exploratory borehole is often drilled first, and if water in sufficient quantity and quality is found, a full borehole is then constructed. The process of obtaining a certificate to operate is lengthy, and only afterwards can the process of certification to natural mineral water status be commenced.

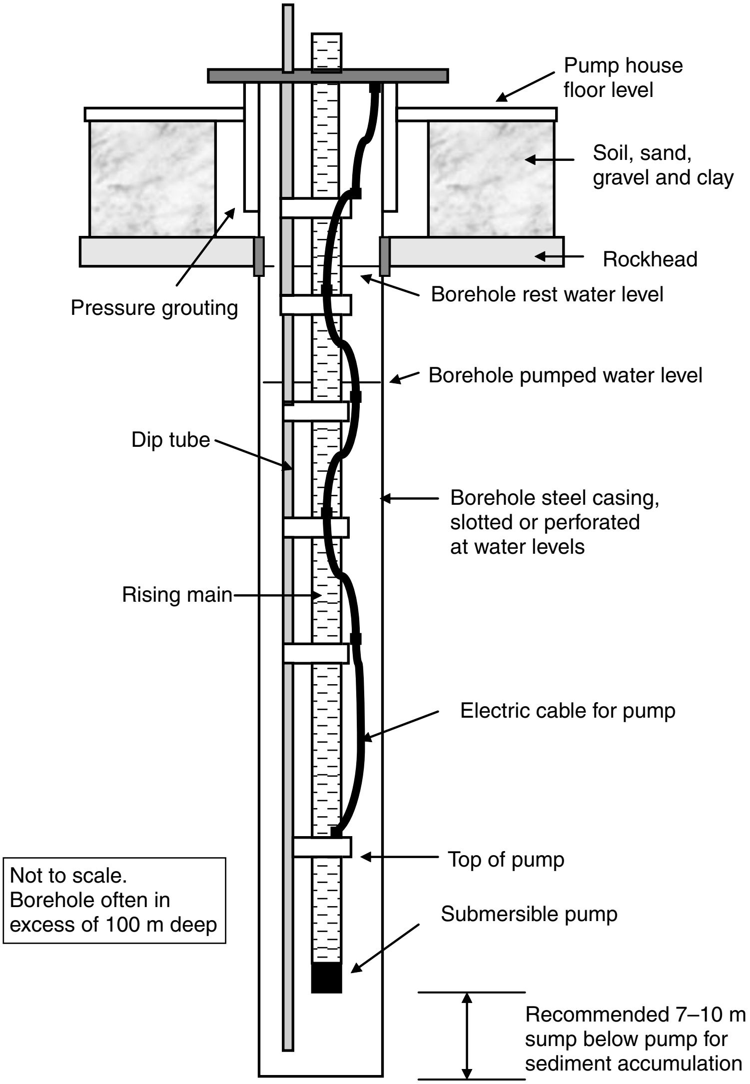


Figure 2.3 Typical borehole construction.

2.5 How to achieve the desired water quality

Whether the water comes from a borehole or from the town mains, it must comply with current national legislation as well as meet the company water standard. This generally implies some form of water treatment. In the simplest form of treatment, the water would just be passed through a sand filter to remove any particulates and a carbon filter to remove any organic material and possible taints and odours. Finally a

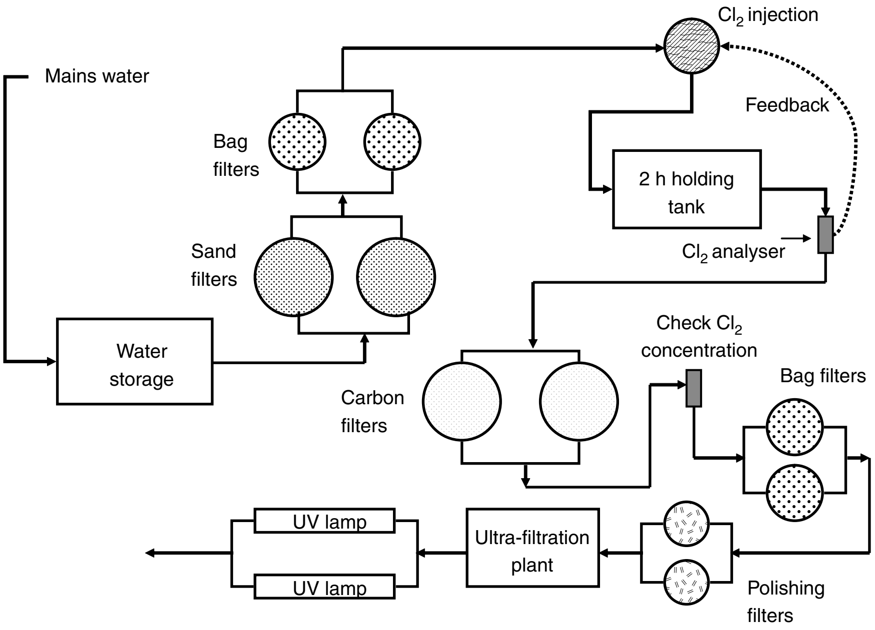


Figure 2.4 Typical water treatment system schematic.

polishing filter down to 2 μm absolute would be used. At this level cryptosporidium is removed. If the water is hard, it is usual to install a coagulation plant, though in modern plants it is preferable to use ion exchange, or even ultrafiltration, owing to the difficulty of controlling the coagulation process. In areas where large amounts of fertilisers have been used, the water is often high in nitrates. These need to be removed by ion exchange. Chlorination of the water is frequently used to ensure it is free from harmful micro-organisms. The carbon filter would then remove any residual chlorine. Finally the water should be passed under an ultraviolet (UV) lamp to ensure final disinfection. Often two sets of lamps are used, one after water treatment and a second at the point of use. In this way any problems caused through poor sanitation in the water pipework are alleviated. A typical system is shown in Figure 2.4.

Ultrafiltration will be dealt with more fully in Section 2.9, together with nanofiltration and reverse osmosis. These three systems operate in different particle size ranges. Typically, reverse osmosis operates in the range 0–1 nm, nano-filtration in the range 0.6–5 nm, ultrafiltration in the range 1–200 nm and micro-filtration above 100 nm. Clearly, the smaller the pore size, the higher the pressure required to achieve separation.

2.6 Sand filtration

A sand filter is usually a carbon steel vessel containing sand on a bed of gravel. It is controlled by five, or sometimes six, valves. Lateral pipes are incorporated just below the level of the gravel. Water is fed into the vessel from the top, often through a single pipe directed at the roof of the vessel to ensure a more even distribution through the sand, thus maximising the effective area for filtration. In other systems a manifold is included at the top of the vessel to direct the water over the full cross-sectional area of the vessel filter media. The water percolates through the sand and is taken out of the vessel through small holes in the lateral arms.

The particulates collect in the sand, and for this reason they must be backwashed regularly. The backwash process is, as its name implies, simply achieved by feeding water in a reverse direction through the filter: through the laterals, up through the sand bed, gently fluidising the bed without actually lifting it significantly, and out through the top pipe of the vessel. Reverse flows, typically in the region of 3–5 psi, must be maintained because of the loss of media from the bed. This backwashing needs to be carried out weekly for several hours until the water is running clean, which is usually tested through a 0.45 μm test filter membrane. If the filter membrane is acceptably clear then the backwash process is considered complete.

A typical charge for a sand filter is shown in Figure 2.5. For a 20 m^3/h vessel it is standard to have 3300 kg of graded sand on top of a bed of 1800 kg of graded gravel. The vessel will be equipped with five valves which can be manually or automatically operated. This allows for normal forward flow and backwashing to drain. It is good practice to check the filter regularly for micro-organisms, and to steam clean the filter if micro-organisms are found. Each filter is equipped with a pressure-relief vent in the top dome and a drain in the base. Backwashing needs to be carried out when the pressure drop across the filter reaches a pre-agreed level, showing that

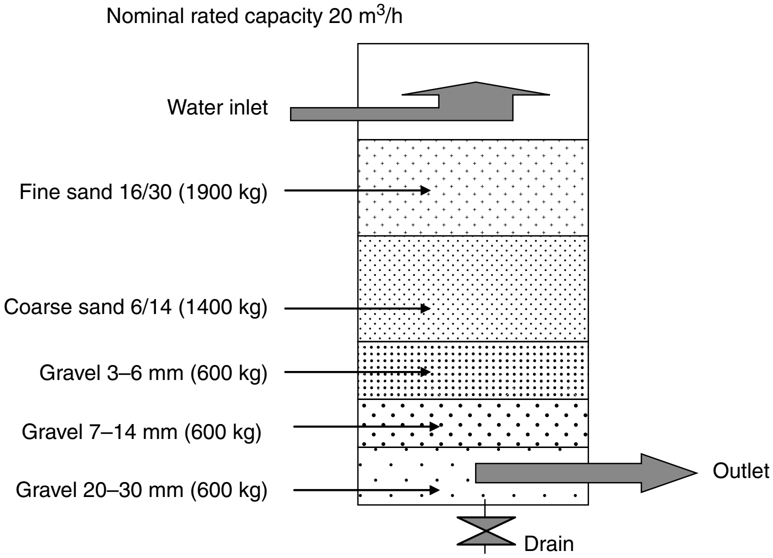


Figure 2.5 Sand filter.

the media is blinding. Automatic valves can be actuated once this pressure drop occurs. For this reason it is necessary to have several vessels in parallel, to allow for backwashing while the other vessels are in use. It is good practice to use 316 stainless steel pipes to ensure minimal contamination through the pipework. The valve matrix allows the pipework to be cleaned without affecting the filter vessel.

2.7 Coagulation

All water contains small particles in suspension. These are known as colloids and have particle diameters <0.01 mm. They include fine silts, bacteria, viruses and colour-causing particles. Owing to their fine nature they can stay in suspension for long periods. They carry the same charges, and repulsion prevents them from combining into larger particulates, which would then settle as a result of gravity. It is necessary to apply some chemical methods to help them settle. This process is known as coagulation. The best-known method is through the addition of an electrolyte: charged particles combine with ions, neutralising the charges. These neutral particles combine to form larger particles which are very damaging to any form of direct interception membrane because of their ability to block the pore structure.

The most common method employs aluminium sulphate, commonly called filter alum, which is added in a controlled amount to the incoming water. Ferric chloride is also often used as an alternative coagulant. It is standard to use an in-line mixer to achieve uniform dispersion of the alum as quickly as possible, the amount of alum added being controlled in relation to the water flow rate. The alum reacts quickly with the water's alkalinity. This reaction produces a gelatinous precipitate of aluminium hydroxide that traps and absorbs impurities. As the alum has a positive charge, this neutralises the negative charge normally associated with colloidal particles, thus allowing them to come together. The initial floc formed is made up of very small particles.

The reaction of alum with alkalinity is given by the equation:

$$\mathrm{Al_2(SO_4)_3 \cdot 14H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 + 3CaSO_4 + 6CO_2 + 14H_2O}$$

The higher the alkalinity of the raw water, the higher the chemical dose required. Care has to be taken over the amount of coagulant added as overdosing can cause a complete charge reversal and restabilisation of the colloid complex, with a resultant increase in turbidity. The water moves from the in-line mixing chamber to a flocculation chamber that is gently stirred. This gentle mixing allows the maximum contact of the floc particles, thereby promoting the formation of larger and heavier floc. After some 30 min it is normal to be able actually to see these floc particles, which look like cotton wool tufts within the clear water. The clear water is allowed to flow over a weir, and the coagulant sinks to the bottom of the vessel. This sludge has then to be removed from the tank. It is a problem actually to get rid of the sludge, and this must be considered when installing such plant. As this process reduces the

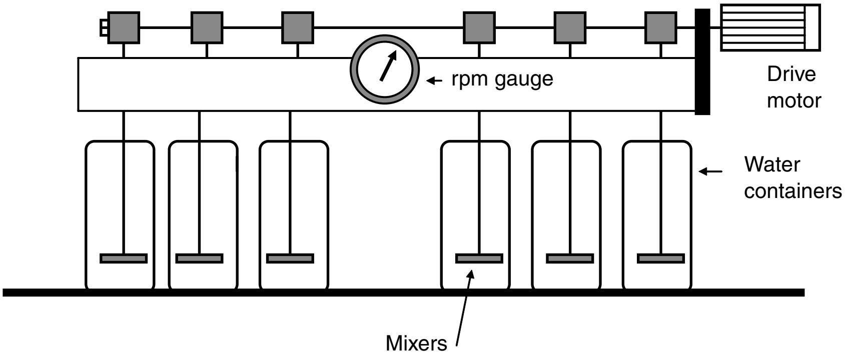


Figure 2.6 Coagulation jar tester.

turbidity of the water, it is usual to measure the turbidity level before and after the process, thereby ensuring process control at all times. At the end of the process, hydrating lime is added to the water to control the pH.

The amount of coagulant required for the process can be determined by a simple beaker test using a laboratory stirrer which is usually set at 100 rpm initially for 1 min and then reduced to approximately 30 rpm for a further 20 min. The liquor is then allowed to settle for 45 min before a sample is taken and the turbidity is measured in NTU or FTU using a nephelometer. These tests mimic the actual process. Often six jars are set up and the tests are carried out with different coagulant additions to determine the optimum result. A typical tester is shown in Figure 2.6.

2.8 Alkalinity reduction

High alkalinity in the product affects the acidity and hence the taste of the soft drink. When dissolved in water, alkalis create a bitter taste. It is necessary to control this to <100 mg/l as calcium carbonate. Alkalinity is often connected to water hardness, hardness being primarily due to calcium and magnesium ions. Alkalinity and pH, though related, should not be used interchangeably. Some forms of alkalinity, such as hydroxides and phosphates, contribute more to pH than others, such as carbonates and silicates. Reduction of alkalinity by ion exchange is the most common route taken. Table 2.4 lists the various systems available. As the chloride anion exchanger, which uses brine as the regenerator, means that no de-carbonator or acid is required, this makes it attractive to many users. The sodium cycle exchange softener uses a strong base anion resin to exchange the alkalinity and sulphates in the effluent for chloride as:

$$\mathrm{ZCl} + \mathrm{NaHCO_3}\ \text{and/or}\ \mathrm{Na_2SO_4} \rightarrow \mathrm{NaCl}\ \text{and/or}\ \mathrm{2NaCl}$$

Table 2.4 Various alkalinity reduction systems.

Process	Acid required	Raw water solids reduced	De-carbonator required
Chloride-cycle anion exchanger	No	No	No
Split-stream hydrogen cycle exchange and raw water	Yes	Yes	Yes
Split-stream sodium and hydrogen cycle exchangers	Yes	Yes	Yes
Sodium-cycle exchanger with acid post-mix	Yes	No	Yes
Mixed-bed or mono-bed hydrogen-sodium-cycle exchanger	Yes	Yes	Yes
Hydrogen-cycle exchanger (strong and weak acid)	Yes	Yes	Yes

Chlorides in the softener pass through the de-alkaliser unchanged. A reduced efficiency comes about owing to the necessary exchange of sulphates for chlorides and alkalinity leakage. With brine-only regeneration the effluent pH will be in the range 5.5–7.5 and the alkalinity will be 5–15% of the incoming raw water alkalinity.

The coagulation process discussed in Section 2.7 often uses hydrating lime, $Ca(OH)_2$, to bring the pH to the required level. The carbonate hardness is precipitated as a sludge. In an upward flow system the clarified water flows up and over a weir and the settled particulates are removed by pumping or filtration.

2.9 Membrane filtration

The concept of reverse osmosis was developed in the late 1950s by the US government as a method of de-salinating sea water. Such systems are now popular as the price and operating costs have made them more attractive. The operating principle of the system is shown in Figure 2.7. The flow containing the components retained by the filter is called the retentate flow; the components passing through the membrane form the permeate flow. Transport through the membrane is achieved by pressure, concentration, chemical or electrical potential difference. The membrane is a semi-permeable barrier through which some particles are transported faster than others, thereby causing separation. Three basic systems exist: reverse osmosis, nano-filtration and ultra-filtration. As noted in Section 2.5, these differ primarily in the size of the particles they separate. Ultra-filtration requires much lower pressures, of the order of 0.5–10 bar, than nano-filtration, which requires 5–20 bar, and reverse osmosis, which requires 8–100 bar. Figure 2.8 illustrates the particle sizes removed by various filtration systems.

Ultra-filtration removes organics over 1000 molecular weight while passing ions and smaller organics. It can successfully be used instead of the coagulation process to remove colloidal particles. The raw water is fed through the semi-permeable

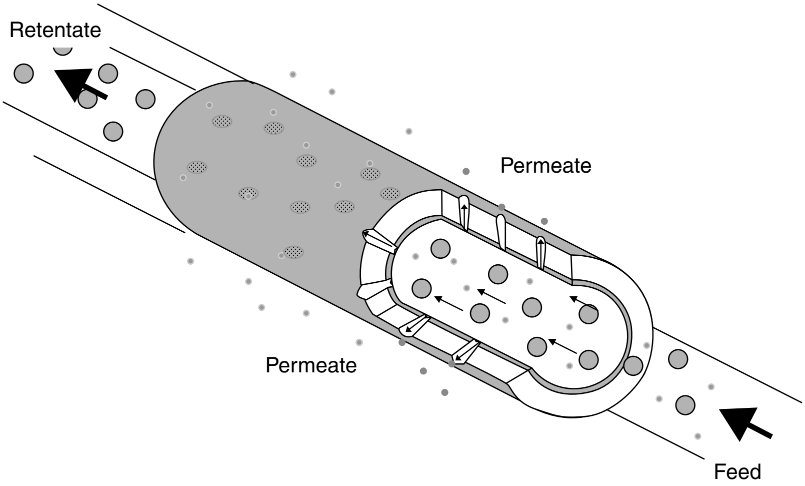


Figure 2.7 Membrane filtration principle (courtesy of Keith Milner).

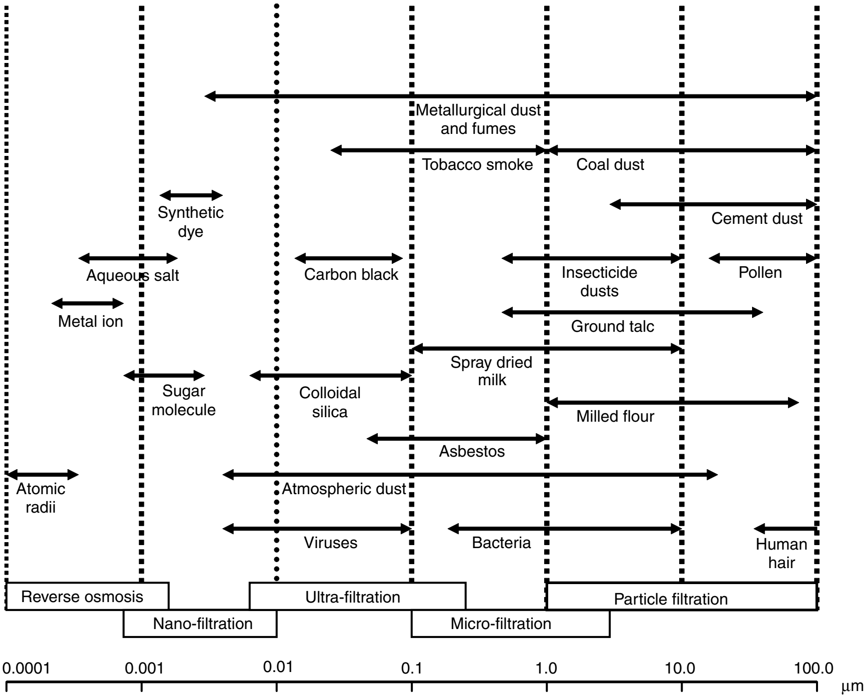


Figure 2.8 Particle size removal by filtration.

membrane. Excess water is used to wash the colloids off the membrane surface to the drain. Unlike in most filtration processes, the membrane, which can be thought of as a sieve, does not bind with trapped material, as the colloids are too large to fit into the opening of the sieve. Because the plant is expensive, it is important to pre-filter so as not to overload the system. Also because of the cost factor it is normal to operate such systems on a constant-flow basis to a storage tank, thus alleviating the problem of peak flow demand. A sand filter is recommended as the initial filter to remove the large particulates, followed by a 5 μm absolute cartridge filter.

A nano-filtration system is a lower power version of reverse osmosis. It is well suited to the treatment of well waters. It is used when the high salt rejection of reverse osmosis is not necessary. It is, however, capable of removing hardness elements such as calcium and magnesium. In addition, it can remove bacteria, viruses, undesirable hydrocarbons and trihalomethanes (THMs), pesticides and other organic contaminants. It is an attractive alternative to lime or salt softening technologies. As it operates at a lower pressure than reverse osmosis, the operating costs are less than those of a comparable reverse osmosis system.

Reverse osmosis removes virtually everything that is presented to it. As its name implies, it works on the principle of osmosis, which is the physical movement of a solvent through a semi-permeable membrane based on a difference in chemical potential between two solutions separated by that semi-permeable membrane. Although reverse osmosis was initially used for most membrane filtration applications, the other, cheaper systems are currently finding more favour. The choice really depends on the final water quality that is required.

Reverse osmosis is really osmosis in reverse. If we had a tank divided into two parts by a semi-permeable membrane and salt were added to one side of this tank, then the osmotic pressure would drive the water from one side to dilute the salt solution on the other side. Eventually, the situation would reach equilibrium, when the two chemical potentials and the hydraulic pressure resulting from the head difference between the two sides equated. This allows a method for measuring osmotic pressure in a given situation.

To reverse this process it is necessary to overcome the osmotic pressure equilibrium across the membrane, as the flow is naturally from dilute to concentrate. This is achieved by increasing the pressure on the raw side of the membrane and forcing the water across. As we force the water through the membrane, so the salt concentration increases, requiring even greater pressure to obtain high-quality water. In all systems the membranes are spiral wound to maximise the surface area available for membrane filtration. They are mounted in high-pressure containers. Usually the membrane stack is two long semi-permeable membranes with a spacer mesh between them that is sealed along the two sides. This is then wound into a spiral tube with another spacer to separate the outside of the stack. Between each membrane layer is a mesh separator that allows the permeate to flow. Water is forced in at one end of the spiral cylinder and out the other. Backpressure forces the water through the membrane, where it collects in the intervening space. The permeate then flows around the spiral and is collected in the centre tube. In an industrial system banks of these membranes are used based on the flow volume required.

Pre-treatment is always recommended for reverse osmosis. The incoming raw water must have a low turbidity to stop the membranes from blinding. As water passes through the membrane, the ionic content of the reject stream increases. This increase in total dissolved solids (TDS) can result in calcium and magnesium precipitating out in the system and plugging the membranes. Calcium and magnesium can be removed prior to the reverse osmosis treatment, or a chemical can be added to the feed water to keep them in solution. Chlorine needs to be removed before using thin-film membranes. This is achieved using carbon filtration prior to water entering the reverse osmosis system. In a typical system the raw water is filtered and softened to remove hardness and carbon is used to remove the chlorination (membranes are sensitive to oxidisers). An alternative is to dose the system with chemicals to remove the chlorine and hold the hardness ions in solution. A typical installation is shown schematically in Figure 2.9.

After the carbon filter, the water is passed through the membranes, where the concentrate is recycled back to the front of the system for another pass and a bleed is taken off this line to drain. This recycling allows very high system efficiencies. The permeate line has a TDS level of approximately 4% or less of that of the incoming water depending on the membrane. The pressure required depends on the concentration of the salt solution of the retentate. For example, a system operating at 1100 ppm on the concentrate side will require some 14 bar pressure to operate.

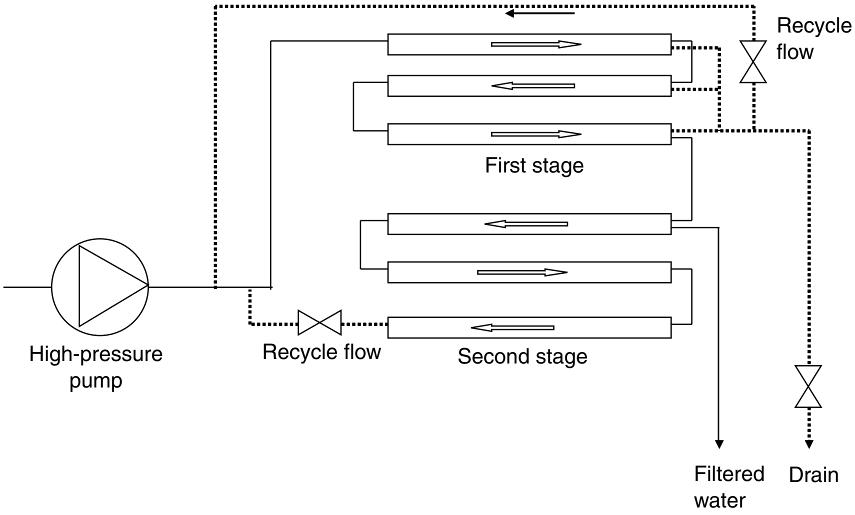


Figure 2.9 Typical membrane filtration system illustrating recycle flow.

The purity of the permeate is determined by the reject ratio of the membrane (92–99.5%) and also by the type of salts in solution. Membranes are very good at rejecting high molecular weight compounds and multivalent ions. Monovalent ions such as sodium and chlorine are not rejected as well and are called the leakage ions. The amount of leakage is determined by the reject ratio. A 95% reject ratio means that 5% of the salt concentration leaks through. On this basis, a 200 ppm input stream would result in a 10 ppm output stream. A membrane rated at 99% would result in a 2 ppm output stream. The reject ratio changes over the life of the membrane, and leakage increases. Each time a membrane is cleaned it will slightly change its properties, so that after many years the ratio may drop to 90% or less.

Cleaning is fairly simple. A volume of water with a cleaning agent (for hardness or organic plugging) is recirculated on the high-pressure side of the system for about 1 h. The membrane is then flushed to drain and returned to service. If properly set up with effective pre-treatment, a system usually has a 1 h cleaning cycle once per month or even less frequently when softening is used as a pre-treatment. Reverse osmosis systems are sterilised periodically during cleaning. The water stored from a reverse osmosis system is optionally passed through a UV sterilisation system, which kills any bacteria in the system.

A softener needs to be checked daily for salt level. Pre-filters need a weekly check. Usually filters are alarmed according to flow rate, so constant monitoring is not necessary. The operating cost depends on three variables: power, chemistry (pre-treatment and pH adjustment) and labour. The power requirement is about 7.5 kW for 7 m^3/h. This is constant while the system is running. Labour costs are usually very low due to the automated nature of the systems. If the proper pre-treatment is used, little or no maintenance is required between cleanings except for chemical maintenance for the pH adjustment system and softener or polymer system. The amount of water rejected will vary with the configuration of the system. Up to six membranes can be connected in series and the theoretical capture rate is approximately 84% (rejecting 16%). By using oversized systems and redirecting the reject to the front of a multiple-pass system, recovery levels can be achieved of approximately 92% (half of the reject to drain, half to the system feed tank). This also requires oversizing the pumps and system to get the required flow rate.

Two types of membrane materials are in widespread use: thin film (TF) and cellulose triacetate (CTA). The TF membrane is chlorine sensitive and requires carbon pre-treatment to remove the chlorine, whereas the CTA membrane is not. TF membranes have a slightly higher reject ratio and operate over a wider pH range than CTA membranes.

Reverse osmosis is sometimes used to reduce the biochemical oxidation demand, which is high when washing down plant owing to the high sugar content. A typical soft drinks factory will have a BOD of the order of 1–2° Brix, which is equivalent to a BOD of some 7000–14,000 mg/l. A membrane system operating at 75% water removal will concentrate the sugar solution to an economic level as the relationship between water removal and sugar concentration is exponential.

2.10 Chlorination and carbon filtration

To prevent bacterial growth, most systems include chlorination. The mains water feed will already have been chlorinated to prevent micro-organism growth through the system. A certain amount of residual chlorine is left in the water to overcome any problems through the pipework system to the customer. If chlorination is included in the factory water treatment system, as required by many major brands, this usually requires an extended contact time to give the chlorine time to effectively kill any bacteria present. Factories often use 8 ppm for 2 h contact time with a requirement that total coliform bacteria and faecal coliform (or *Escherichia coli*) are both totally absent (0 cfu per 100 ml). This requires a water storage tank large enough to take the peak demand flow for the required contact time. Careful dosing of chlorine through a metering system in relation to the water flow rate is required. The outfeed water also has to be monitored to ensure that the concentration levels set in the standard have been achieved. If not, a feedback control system must be incorporated to alter the dosing level to bring the situation back under control. Sometimes chlorine dioxide is used as an alternative to gaseous chlorine. There are some advantages to using chlorine dioxide over chlorine gas, as it is simpler to use and the dosage is more readily controlled.

After chlorination it is necessary to remove the chlorine using carbon filters. These vessels are very similar in construction to sand filters. They use activated carbon, preferably acid cleaned. The activated carbon is specially prepared for this purpose by specialist chemical suppliers. It has been claimed that the Romans used charcoal to purify water and beer. Activated carbon is produced by the controlled burning up to 1000°C of carbon-rich materials such as coal, wood and nut shells. This is then steam or chemically activated to develop the internal pore structure. A typical activated carbon has an internal surface area of the order of 1200 m^2/g. This large surface area is what makes activated carbon such an effective absorbent. Several activated carbon suppliers claim that coconut-shell-based carbons have several advantages over carbons made from other materials in that they have a high density and high purity and are virtually dust-free, since they are harder and more resistant to attrition. Also, the pore structure is very uniform, with the majority of pores falling in the micropore range (5–10 Å), which is particularly effective for water purification applications.

The structure of a carbon filter is shown in Figure 2.10. For a 20 m^3/h vessel it is normal to use some 1500 kg of carbon on top of a bed comprising 500 kg of 1–2 mm sand, 600 kg of 3–6 mm gravel and 600 kg of 7–14 mm coarser gravel. Often the sand is left out, as it tends to get mixed in with the carbon and affect the performance of the system. Like sand filters, carbon filters need to be backwashed regularly. This needs to be done carefully to minimise damage to the activated carbon. It is always a good precaution to use a bag filter after the carbon filter to catch any carry-over of carbon that may occur, which usually happens just after a backwash. Once a month the filters should be steam-cleaned. This will ensure that any micro-organisms that may be in the carbon bed are effectively killed, as

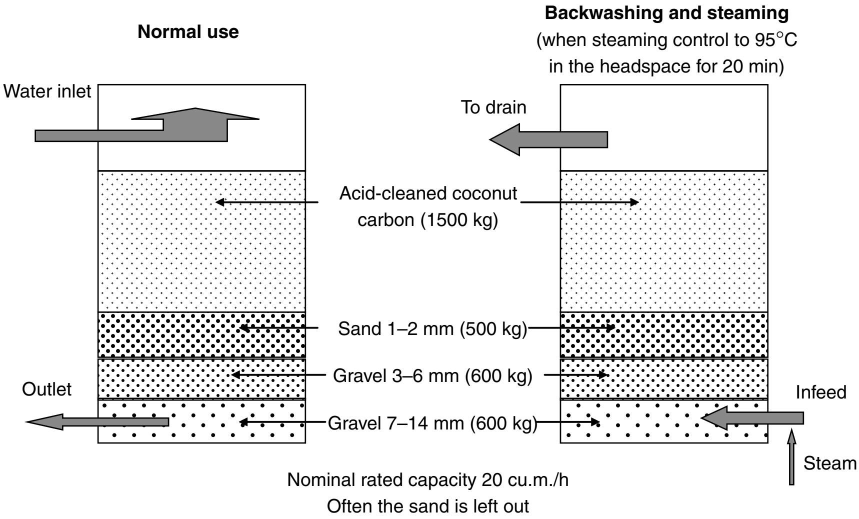


Figure 2.10 Carbon filter.

well as re-activating to some lesser degree the carbon itself. It is usual to replace the carbon bed every few years.

2.11 Iron removal

Iron in sufficient quantity tends to discolour water. Iron is not hazardous to health; in fact it is essential as it transports oxygen in the blood. It is kept at 0.3 ppm or below for taste and appearance purposes as above this level it tends to taint the water red, brown or yellow. A UV lamp that has not been cleaned recently used in a high-iron-content water will be significantly stained by iron contamination.

Iron comes in two forms: soluble and insoluble. The insoluble form appears rusty or yellow. It can cause serious appearance and taste problems. Iron bacteria actually consume iron and leave a yellow or reddish brown slime that can clog systems. Soluble iron is the more common form. It appears as reddish-brown particulates if water is left to stand in a glass for a few minutes.

Once the form of iron that needs to be removed has been determined, several process options are available. There is no single treatment for all types of iron problem. Chemical analysis of the water will tell you what type of problem you have. Soluble iron can be converted to its insoluble form by aeration. Clearly this is a process that is not popular in the carbonated soft drinks business, which wants to eliminate air wherever possible. Filtration media will trap and screen out oxidised iron particulates. This generally requires backwashing to remove the iron from the filter. Soluble iron can also be removed by ion exchange. A suitable material is manganese green sand, which adsorbs dissolved iron. Chemical regeneration is needed. Aerating water with ozone can also convert soluble to insoluble iron.

Chlorination is used to convert soluble to insoluble, filterable iron by sequestration. A catalytic filter medium can be used that enhances the reaction between oxygen and iron and subsequently filters out the insoluble iron.

2.12 Nitrate removal

Nitrate is expressed in reports as either nitrate-N (nitrate as nitrogen) or nitrate as nitrate. The maximum contaminant level (MCL) for nitrate in the USA is 10 ppm (also measured as mg/l). To express nitrate as nitrate, multiply the nitrogen-N figure by 4.43. The MCL for nitrate as nitrate is then 44.3 ppm. The WHO has established a guideline of 50 ppm, whereas the EC has a maximum allowable limit of 50 ppm and a guideline of 25 ppm.

Nitrates, measured as nitrate, can cause corrosion above the 20 mg/l level and for bottled products can cause organic pollution above the 50 mg/l level. Infants below the age of 6 months who drink water containing nitrates as nitrogen in excess of 10 mg/l can become seriously ill and, if untreated, die. Symptoms include shortness of breath and blue-baby syndrome. The higher pH of infants' upper respiratory tract accelerates the conversion of nitrates to nitrites. The nitrite in turn oxidises the infants' haemoglobin to methaemoglobin, which is unable to carry oxygen in the bloodstream. High nitrate levels are usually caused by run-off from fertiliser use, leaching from septic tanks, sewage and erosion of natural deposits. The salts irritate the mucous membranes. The cancer-causing effects of nitrates have not been fully researched. However, nitrosamines and nitrosamides, nitrate reaction products, are felt to be potential human carcinogens.

Nitrites, also measured as nitrogen, are caused by the same factors as nitrates and give rise to the same problems. They can cause methaemoglobinaemia (blue-baby syndrome) and they have a direct-acting toxic effect on the nervous system and blood vessels. It is interesting to note that nitrates are converted into nitrites in the gastrointestinal tract, whereas nitrites are converted to nitrates in the blood.

Nitrates are highly soluble in water and for this reason can soak into the ground easily. Often nitrate levels fluctuate seasonally, seemingly based on rainfall. Shallow wells are more quickly and adversely affected than deep, well-constructed ones. If your area or well is prone to nitrate contamination, regular water analysis is recommended.

Nitrate removal systems include ion exchange, reverse osmosis, distillation, bio-de-nitrification and electro-dialysis. The most commonly used treatment approach is ion exchange, the same technology water softeners employ. With this type of system, chlorides are exchanged for the nitrate, and the high-nitrate waste is flushed into a holding tank or drain. Depending on the application, it is often more desirable to drill a deeper well or tie in to an alternative water source than to treat the water for nitrate because of the high levels of brine discharge from such systems.

Biological de-nitrification is a respiration process whereby bacteria break apart the nitrate (NO_3) molecule. The primary by-products of this respiration are harmless nitrogen gas (N_2) and carbon dioxide (CO_2). Water enters a series of reactor towers which contain naturally occurring, non-pathogenic bacteria. These bacteria are stimulated by the automatic addition of a small amount of organic carbon (acetic acid), which the bacteria use to break down the nitrate molecule. The gases produced are vented harmlessly into the air.

Electrodialysis was introduced commercially in the early 1960s, about 10 years before reverse osmosis. The development provided a cost-effective way to desalt brackish water and spurred considerable interest in this area. It depends on the following general principles: most salts dissolved in water are ionic, being positively (cationic) or negatively (anionic) charged. These ions are attracted to electrodes with the opposite electric charge. Membranes can be constructed to permit selective passage of either anions or cations. The dissolved ionic constituents in a saline solution, such as Na^+, Ca^{2+} and CO_3^{2-}, are dispersed in water, effectively neutralising their individual charges. When electrodes connected to an outside source of direct current, such as a battery, are placed in a container of saline water, electrical current is carried through the solution, with the ions tending to migrate to the electrode with the opposite charge.

To desalinate water, membranes that will allow either cations or anions (but not both) to pass are placed between a pair of electrodes. These membranes are arranged alternately, with an anion-selective membrane followed by a cation-selective membrane. A spacer sheet that permits water to flow along the face of the membrane is placed between each pair of membranes. One spacer provides a channel that carries feed (and product) water and the next carries brine. As the electrodes are charged and saline feed water flows along the product water spacer at right angles to the electrodes, the anions in the water are attracted and diverted towards the positive electrode. This reduces the salt concentration of the water in the product water channel. The anions pass through the anion-selective membrane but can pass no further than the cation-selective membrane, which blocks their path and traps the anions in the brine. Similarly, under the influence of the negative electrode cations move in the opposite direction through the cation-selective membrane to the concentrate channel on the other side. Here, the cations are trapped because the next membrane is anion selective and prevents further movement towards the electrode. Using this arrangement, concentrated and diluted solutions are created in the spaces between the alternating membranes. These spaces, bounded by two membranes (one anionic and the other cationic), are called cells. A cell pair consists of two cells, one from which the ions migrated (the dilute cell for the product water) and the other, in which the ions concentrate (the concentrate cell for the brine stream).

A basic electrodialysis unit consists of several hundred cell pairs bound together with electrodes on the outside and is referred to as a membrane stack. Feed water passes simultaneously in parallel paths through all of the cells to provide a continuous flow of desalted water and brine from the stack. Depending on the design of the system, chemicals may be added to the streams in the stack to reduce the potential for scaling. Recent advances in membrane technology and the development of electrodialysis reversal make this a direct competitor to reverse osmosis. These advances have reduced the cost of membranes and have lowered membrane resistivity to create membranes that are more nitrate selective.

As for reverse osmosis, the raw feed water must be pre-treated to prevent materials that could harm the membranes or clog the narrow channels in the cells from entering the membrane stack. The feed water is circulated through the stack using a low-pressure pump with enough power to overcome the resistance of the water as it passes through the narrow passages.

2.13 Polishing filters

In general, a sand filter followed by a carbon filter removes the trace chemicals found in most surface waters. Filtration is then used to polish the water to the required standard. As with most processes, the quality standard keeps being improved, mainly as a result of consumer demands and the changing needs of industry.

Over the past few years the need has emerged to provide certified media with the ability to remove the cryptosporidium organism. Pall Filtration has been at the forefront of this media development. It has produced high surface area membranes which have the ability to withstand high flow rates, but it is only just able to validate cartridges for this application. The use of low/medium-UV treatment has a place in the changing water demands as it has been well demonstrated that this process eliminates the cryptosporidium oocyst. The use of reverse osmosis water is now an alternative, but it is still a very expensive way to meet the soft drinks companies' requirements.

To polish the water following sand and carbon filtration, it is standard to use polypropylene depth filters initially. These are often followed by finer filters with a pleated high surface area construction, often made of glass fibre. These impart a positive zeta potential to enhance particle removal. Final filters are used to control the microbial content of the water. These can go as low as 0.45 μm absolute. However, the cost of running such filters is high. A 2 μm absolute filter has been claimed to remove both the cryptosporidium oocyst and *Giardia lamblia*, which together are present in over 67% of all surface water and in the USA have been detected in 39% of drinking water supplies (Clancy *et al.*, 1998). Filters down to 1 μm absolute have been developed specifically for the purpose of removing these two oocysts.

Filter bags are being increasingly used as an alternative to cartridge filters. Bag filters have come a long way since they were invented. Initially they were considered as good coarse filters to remove particles in the visible clarity range of 40 μm. In the past 15 years, bag filter technology has improved along with improved manufacturing techniques from sewing to welding and media technologies from needle felt to melt-blown materials. Efficiencies of 99.9% and above at 1 μm absolute are clearly achievable using filter bags.

GAF Filter Systems Ltd. has played a major role in bringing this innovation to the marketplace. It led the way with all-welded felt bags in the late 1980s; it then invented a ‘pressure-reactive’ sealing ring (Sentinel) which eliminated the bypass around the top of the filter bag. These two developments significantly improved the efficiency of the filter bag as we understood it.

This was followed by the move to melt-blown media. GAF again led the way with its ABP range of filter bags, rated 99% efficient. It revised the design with some further improvements in the welding technology and re-named these AGF bags. In 1997 GAF developed an absolute filter bag (PROGAF); this was the first bag on the market to offer all of the efficiencies of an absolute cartridge, with additional pre-filters incorporated in to the upstream layers of the same element. This meant that several stages of cartridges could be replaced with one stage of filter bags. The major advantage was the reduction in operating costs and operator time during filter change-outs.

In several successful applications the introduction of filter bags has reduced the operating cost below that of the traditional cartridges. This has afforded the changes in bag technology a very central role in helping to provide the technology changes we have seen in the marketplace. As an example consider flow rates of 80 m^3/h of town mains water being processed through a traditional sand filter followed directly by a carbon filter. Trials have been carried out using established cartridge filters in high surface area configuration with differing pore grade structures, starting with 20 μm, followed by 6 μm and then by 2 μm. All the cartridges tested had a tightness rated (Tr) value of 99.98%; in other words, they were wound very tightly. This system was used in conjunction with new UV tubes capable of offering an alternative way to ‘sterilise’ the water.

The problems seen were the differing qualities of town potable water being provided by the local utility services; although they complied with EU standards, not all had the same filterability. The measure of this is the silt density index (SDI). This index quantifies the amount of particulate contamination in a water source. SDI is widely accepted for estimating the rate at which colloidal and particulate fouling will occur in water purification systems. As the quality of water sources often changes, this test needs to be performed weekly. ASTM D-4189-95 defines this test. The 0.45 μm filter was chosen because it is more likely to clog from colloidal matter than from hard particles such as sand or scale. SDI is based on the decay in flow rate during a 15 min period across a new 0.45 μm filter installed in a built-in holding fixture. Flow rate measurement accuracy is ensured by automatically maintaining a constant 30 psi (2.07 bar) across the membrane. Samples of 500 ml are taken at the start of the test and after 15 min. The time to take each of these samples is measured. SDI is then defined as:

$$\mathrm{SDI} = \frac{(1 - (t_\mathrm{i}/t_\mathrm{f})) \times 100}{15},$$

where t_i is the original time and t_f is the final time to collect a 500 ml sample.

SDI tests were carried out at different stages of the filtration system; this allowed the monitoring of how the medium was performing. In this particular study, the potable water after sand and carbon filtration still had a high SDI of between 12 and 14. This was necessitating frequent changes of the cartridges, thereby making the cartridge system prohibitively expensive to run. The water test results indicated the need to reduce the SDI readings. It was realised very early that what was required was to present consistent water SDIs of five or lower. The new generation of polypropylene and polyester melt-blown bags was introduced. Evaluation took place over a number of months, during which time a pattern began to emerge for the bag types. In order to capitalise on the success of the media, changes had to be made in the choice of commercially available assemblies, and with the introduction of the pressure equipment regulations (2005) it was a genuine case of manufacturers re-designing the next generation of filter assemblies to take the high-flow-capable bags. A typical filter is shown in Figure 2.11. This type of system has been found to satisfy the requirements regarding oocyst removal, with the added benefit that reducing the silt levels has enabled an increase in carbonation performance, and hence line efficiency.

Another type of system is the Kalsep Fibrotex unit. This is a fibrous self-cleaning depth filter that reduces particulates in feed streams. The elements comprise thousands of synthetic fibres arranged in a bundle around a central core. During filtration the bundle is twisted and compressed, forming a tight helical matrix. The flow

Figure 2.11 Bag filter.

passes radially from the outside to the inside of the element. Particles are caught up in the fibrous matrix. Automatic backwashing untwists and stretches these fibres when a small backwash flow is in operation. Such units are claimed to be suitable for reverse osmosis pre-filtration. Banks of these bundles are used to provide the necessary filtration.

2.14 Ultraviolet systems

Strong sunlight disinfects water by permanently de-activating bacteria, spores, moulds and viruses. Scientists a century ago identified the part of the electromagnetic spectrum responsible for this well-known effect, defining the wavelengths as between 200 and 300 nm, often called UV-C. Ultraviolet sterilisation works by dissociating the DNA structure of living cells, thus preventing their multiplication. A UV disinfection unit comprises an enclosed chamber with an inner sleeve of high-purity quartz which contains one or more shortwave ultraviolet lamps. Water passes through the chamber and is subjected to the UV-C which shines through the quartz sleeve. As the genetic structure of bacteria or viruses in the water is exposed to the UV-C it will be destroyed. As UV-C cannot pass through particulates, it is important to pre-filter to as low a level as is commercially viable to enable the UV system to work optimally. UV has been shown by Clancy *et al.* (1998) to kill protozoan (such as cryptosporidium) oocysts.

UV can operate at various pressures. Low-pressure lamps are the oldest source of UV light and the most common type of lamp, being efficient at converting electrical energy into disinfection wavelengths as the output is centred around 253.7 nm, which the manufacturers of these systems state to be the optimal wavelength for disinfection. They also offer the longest lamp life (stated as a minimum of 8000 h). These lamps operate at lower temperatures than other UV lamps and they do not accelerate internal fouling of optical surfaces. The spectral output is monochromatic. One of the problems with this type of lamp is the time needed to fire up, which can be of the order of several minutes. Hence care has to be taken to use delay switches in any system using low-pressure UV systems, such that the process can operate only when the light is actually on.

Medium-pressure systems tend to use a wavelength of 265 nm, though recent research in the USA has shown that 271 and 261 nm wavelength light are the most effective for the deactivation of particular target organisms. These lamp types are polychromatic, with a continuous output from 200 to 300 nm. Typically, the lamp surface will reach 800°C, which is why a protective sleeve is incorporated into such systems. Should the water flow stop for any reason it is necessary to power the lamp down to prevent over-temperature problems.

All these lamps come in a variety of sizes, and many are multi-tubed. In general the medium-pressure systems are smaller than their low-pressure equivalents. All systems need to have wipers fitted to the tube where the iron and manganese levels are high, as the iron and manganese tend to bake on to the surface of the tube.

2.15 Ozone technology

Ozone is a gas comprising three oxygen atoms. It can be created naturally, as in a lightning strike, or synthetically using an ozone generator. Ozone is the result of a high electric current being passed through oxygen (O_2) molecules. Introducing high levels of electricity into oxygen breaks the molecular bond of the O_2, creating two single oxygen atoms. These single oxygen atoms then adhere to remaining O_2, creating ozone (O_3).

It is this third atom being only loosely bonded that makes ozone such a powerful cleaning agent. With an oxidising power 3000 times greater than that of bleach, ozone is the second most powerful oxidant in existence. When ozone gas is introduced into an environment with bacteria, mould or any other organic material, it readily donates one of the oxygen atoms in its chemical make-up to destroy that material. Ozone can also destroy some inorganic materials, such as calcium and arsenic, and a number of trace metals, such as iron. Once the third oxygen atom has been donated to oxidise the organic component, there are only oxygen (O_2) molecules left. This is one reason ozone is a preferred oxidant, as opposed to various chemicals, because it does not leave any type of chemical residue on materials, only pure oxygen.

An ozone generator is utilised to create ozone by using either ambient air or an oxygen concentrator, which is usually incorporated into the generator, and a series of plates that produce high electric charges. By using an oxygen concentrator instead of ambient air, the generator can produce higher concentrations of ozone with lower quantities of power, resulting in a reduction in the size of generator needed for a particular application, thereby lowering equipment and operating costs. The generator takes the ambient air or oxygen and passes it across the series of high-electric-current plates. Ozone molecules are formed through the separation and recombination of oxygen atoms, and the resultant ozone gas is discharged through an exit port.

The concentration of ozone in water is usually measured in one of two ways: with an oxidation reduction potential metre or with a direct-read measurement in ppm. The former method utilises a scale of measuring the free available electrons and it is difficult to take a true reading from. For this reason the direct-read method is preferred. This measures the actual dissolved concentration of a gas, in this case ozone, in solution.

It is claimed that ozone is capable of the destruction of bacteria and viruses, the oxidation of iron and manganese, heavy metal precipitation, colour destruction, taste improvement, algae and protozoa destruction, hardness reduction and hydrogen sulphide and mercaptans elimination. A UV lamp generates 0.1% ozone by weight. UV and ozone react rather violently and in a sense destroy each other, which can result in this combination being used when neither works on its own but together they achieve the required result. If this is the case, the reaction takes place in a few seconds. For water treatment it is usual to have 1–2 ppm ozone in contact for 5–10 min, depending on the water quality. After treatment the minimum requirement is to pass the water through a carbon filter to absorb the excess unreacted ozone, allowing it to convert back to oxygen. Such a filter will also collect any precipitations following ozone treatment.

2.16 De-aeration

As discussed in Chapter 5 on carbonation, it is ideal to de-aerate water to <0.5 ppm dissolved oxygen to prevent nucleation problems. In addition, the lower the oxygen level in the water, the less risk of product deterioration there is. For these reasons the inclusion of de-aeration plant is of the utmost importance to the producer of carbonated soft drinks. Although aeration systems are sometimes used to treat water and remove iron and manganese, this is clearly not a process that can be used in our industry. The last thing we want to do is introduce air into the product.

Two main methods of de-aeration exist: vacuum and reflux, or a combination of both. It is normal to de-aerate the water alone, as dealing with the final product will entail regular cleaning due to contamination from flavour to flavour. If sugar dissolving is carried out on site, the water for this is also de-aerated, as is the water used in syrup make-up. Although with boiler feed-water systems it is normal to use steam to de-aerate the water, this is not possible here, as the last thing that is required is warm water.

The most common type of de-aerator sprays water into a tank under vacuum. This is then pumped into a second tank, where a small amount of carbon dioxide is present as a stripping gas, a process known as reflux. Levels as low as 0.05 ppm residual oxygen are quite common for such a unit. Early systems utilised one or the other of these processes, but by combining them we get the best of both worlds. Such a system is shown in Figure 2.12.

Systems are normally skid mounted, one horizontal tank being placed on top of another utilising a liquid-ring vacuum pump. The carbon dioxide is injected into the water stream, and the resultant water still has up to 0.5 volumes of residual CO_2 left after the process, depending on the amount used in the original feed. The contact is usually through a vertical static mixer.

Another system uses hydrogen, which is fed in a controlled manner into the water feed, the pipework incorporating a mixing section to ensure the hydrogen is dissoluted in the water. This then passes to a catalytic reduction tank, where the hydrogen and oxygen are split into ions, forming water. Very low dissolved oxygen levels are reported for such systems, which use much less energy than the vacuum systems.

Dissolved oxygen is usually measured using an oxygen electrode, as invented by Leland C. Clark in 1962. This has a thin organic membrane covering a layer of electrolyte and two metallic electrodes. Oxygen diffuses through the membrane and is electrochemically reduced at the cathode. There is a carefully fixed voltage between the cathode and anode so that only oxygen is reduced. The greater the oxygen partial pressure, the more oxygen that will diffuse through the membrane per unit time. The result is a current that is proportional to the oxygen in the sample. Temperature sensors are built into the unit. The meter uses cathode current, membrane temperature and pressure information to calculate the dissolved

Figure 2.12 De-aerator (courtesy Diessel GmbH).

oxygen content. Several commercially available instruments are available for both laboratory and in-line use.

2.17 Factory water distribution systems

It is important, whether the factory is fed from a borehole or from the local mains supply, to have a buffer storage of water prior to the water treatment system. Many mains suppliers like a factory have up to 24 h supply of water stored, so that if any supply problems occur the factory has a reserve as well as the possibility at peak demand of siphoning the factory water back into the mains system. The water should be fed into at least two storage tanks. Nowadays the preference is to have 316 stainless steel vessels, though fibreglass and even glass-lined vessels are sometimes used. For a borehole supply the tremendous advantage of having sufficient water storage is the ability to pump water from the borehole consistently, thus alleviating any problems of erratic demands causing silt to be drawn from the aquifer. Often a factory will have a maximum allowable draw-off from the borehole in terms of both hourly and daily demands as part of the licence agreement. If the factory demand exceeds the hourly demand but is within the daily allowance, then water storage solves the problem. Each tank needs to be fitted with a low- and high-level probe, with the control system switching the valves from each tank as required. This

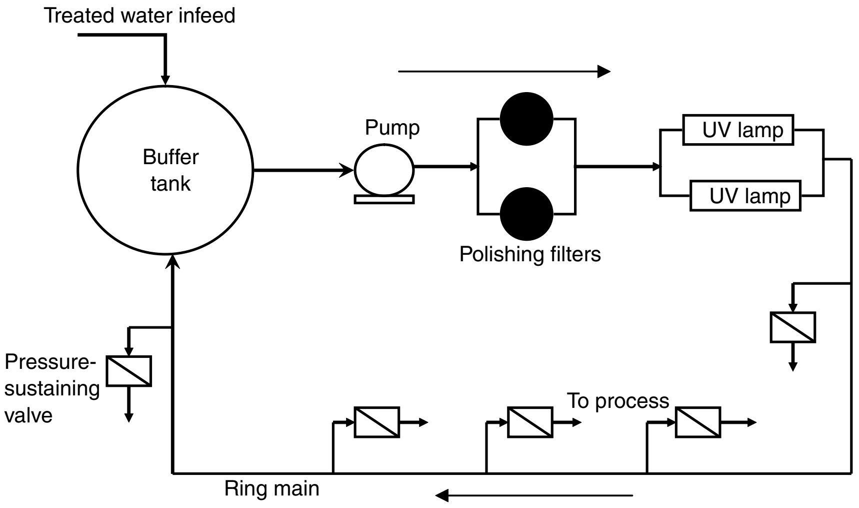


Figure 2.13 Factory water ring main.

applies to the input as well as the output from each tank. The tanks need to have inspection hatches and a sampling method to take water samples, so as to ensure that no problems with microbial growth are occurring. If all tanks become full, a gradual turn-off system for the water supply is required.

The water is then sent on demand to the water treatment plant. It is important that the flow rate through this plant is kept as constant as possible so that each item of the plant operates at its design capacity. Besides the increase in capital costs associated with larger plant to cope with peak flow demand, such plant will take up more space and cost more to run and maintain. This means that another storage vessel is required after the treatment plant to act as a buffer. Storage vessels are relatively cheap compared with filtration plant. If a factory water ring main is installed, they are necessary to receive the flow back at the end of the ring main. A typical ring main is shown in Figure 2.13.

It is important to fit pressure-sustaining valves throughout the ring, especially at points of take-off to production lines and the syrup room. Take-off demands can be instantaneous, causing a drop in pressure, and hence flow rate, through the line. Once a request for water is made by any item of plant it must be satisfied without any undue problems. Often a pressure relief valve is incorporated. Pressure is admitted at the valve inlet and acts on the lid area. The valve is regulated by adjusting the spring pressure. In this way the valve lid is kept on its seat. As the pressure increases above this setting, the extra load acting on the lid compresses the spring further. This allows it to leave its seat, and excess pressure is discharged.

In addition, pipeline sizes must be in relation to the required flow rate. The normal clean-in-place (CIP) agreed flow rate is 1.5 m/s, and this is recommended for use in any design. On this basis if the average throughput of a plant is 100 m^3/h, then the main ring main will be 150 mm internal diameter. At each off-take the pipe diameter will reduce. Say, for instance, a filling line uses 20 m^3/h, then it would be 100 mm internal diameter. In this way the system is balanced. At each take-off point a pressure-sustaining valve needs to be installed. Any water not used is fed back to a small holding vessel, usually for a plant of such size of the order of 20 m^3. CIP cleaning needs to be incorporated into the ring main design. At each point of use, a UV lamp should be sited to minimise any risk due to microbial infection within the system.

2.18 Factory water systems

This chapter has discussed how a modern factory can be set up to provide the water quality necessary at point of use. Plants need to be designed to satisfy the company water standard at all times, as well as providing sufficient water quantity as required at point of use now and in the foreseeable future. It is no good designing a plant for the present if this large capital expense cannot satisfy future demands. Although nobody has a crystal ball, sales growth rates for the next 5–10 years can be agreed with the board of a company, and it is then necessary only that any plant item should satisfy this plan.

The plant needs to be automatically controlled. The first step is to ensure that any change in the quality and/or quantity of the incoming water is sensed immediately as this will affect the overall plant performance. With mains supply this could be caused by a burst pipe upstream allowing ingress of Earth into the system or it could be that a problem has arisen with the water supplier's main reservoir, requiring a switch to an alternative supply with different characteristics. For this, automatic sensors are required which will shut off the supply to the storage tanks until such time as a solution to the problem can be found.

All the processes need to be PLC (programmable logic controller), or PC controlled, with sensitive in-line instrumentation to allow feedback control systems to operate effectively. They must be capable of meeting demand day in and day out. Maintenance will be required, depending on the plant type, taking that item of plant out of use for a certain period. This factor must be allowed for in the design of the complete system in that more than one of a particular unit needs to be installed. This requirement also applies to the need for regular cleaning through backwashing, etc. As standards are continually being reviewed so must the design of the water treatment system. New technologies and improved instrumentation are always being developed. These have to be followed up, and if they are found to be applicable and to reduce the risks to the product from poor water quality, they should be installed provided they are also commercially justifiable.

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3 Ingredients and formulation of carbonated soft drinks

Barry Taylor

3.1 Introduction

Present-day standards in most countries demand that food and drink, in general, must be of a defined quality and present no health risk to the consumer. It is therefore essential that at every stage of production correct procedures are adopted and ingredients are selected to meet legal requirements of purity and to conform to the legislative controls that apply.

This chapter will look towards those ingredients whose individual contributions serve both to stabilise the soft drink during its shelf life as well as ensuring that it may exhibit a characteristic identity in its organoleptic performance throughout. Typical levels of use in both formulation and application will be indicated.

The wide variety of products encountered in today's beverage market reflects a background of intense creativity in terms of the characterisation of drink types. The area of carbonated soft drinks is no exception. The art of producing carbonated beverages has developed over more than two hundred years, and the resulting history makes interesting reading. It will be useful to consider the background to the development of the soft drinks industry and how the word 'additive' found its way into the vernacular.

3.2 Factors influencing development of the industry

Soft drinks, or to quote their early designation 'mineral waters' or 'table waters', emerged as a commercial prospect in the mid-eighteenth century, their development towards full-scale production followed hot on the heels of the industrial revolution taking place at that time throughout Europe and the western world. Before this, although freshly pressed, or squeezed, juices were available for direct consumption – fitting the description 'soft drink' – these were inherently unstable if stored, quickly succumbing to yeast attack and the resulting fermentation. It is not surprising therefore that in the Middle Ages (and before) brewing was the only reliable method of producing a stable beverage, as the alcoholic content produced by the fermentation of natural sugars inhibits further yeast or microbial activity.

Brewing became an art, and most country estates of any substance held their own supplies of alcoholic beverages. In Northern Europe these tended to be fruit wines, mainly produced from hedgerow stock or, in the case of Mediterranean countries, from the ubiquitous grape. Beers, ciders, perrys and the like were also widespread according to the locality.

It was the discovery of carbon dioxide that made the stabilisation of a non-alcoholic drink attainable. During the eighteenth century there was great progress in the discovery of gases and the composition of the air we breathe. Effervescing spa waters and natural mineral waters, which carried with them a decided health benefit connotation, had been known and consumed for some time, and great scientific interest was expressed in the constitution of such waters. However, although spa waters were sometimes effervescent, their consumption often fell well short of anything that could be considered enjoyable. The thought of actually drinking effervescent mineral waters did not arise until the eighteenth century. Before this the health spas were used primarily for bathing and relaxation. In addition to the presence of carbon dioxide, the foul sulphurous taste of some spa waters, covering trace mineral elements, nonetheless convinced consumers they were being put back on the road to recovery from their ailments.

The identity of carbonic acid gas (otherwise known as fixed air, *gas sylvestre*, or carbon dioxide) in naturally occurring waters was demonstrated in 1741 by Dr Brownrigg, who is also credited as being the first to accomplish the artificial aeration of mineral water (Stevenson & Howell Ltd, 1926).

Later in the century Dr Joseph Priestley, FRS, was able to claim the discovery – and demonstrate the practical implications – of the principle of charging, or saturating, water with carbon dioxide by methods similar to those we are familiar with today. In 1772 Priestley invented ‘an apparatus for making aerated water’, which he exhibited to the Royal College of Physicians, and upon which the college reported favourably.

In 1794 Priestley and his wife moved to Northumberland, Pennsylvania. Although Priestley was acquainted with John Adams and Thomas Jefferson, it seems he did not take up American citizenship, and certainly he kept well away from the political affairs of the nation. He may well, however, have retained his interest in aerated waters, for it was at about this time that seltzer fountains caught on in the USA and a new industry emerged. Fuelled mainly by the temperance movement, the healthy image of seltzer waters soon grew, and the waters came to include varieties flavoured with botanical extracts, fruit juices and the like. Soda fountains remained in vogue in America well into the nineteenth century. Each used a stream of carbonated water to dilute flavoured syrups; the more sophisticated designs supplied a choice of flavours, with the drinks dispensed for direct consumption.

Among the earliest soda water manufacturers in Europe were Jacob Schweppe and Nicholas Paul, who were business partners in Geneva before going their separate ways and moving to England. Schweppe set up in London in 1792 to make his artificial carbonated waters on what was effectively a factory scale. Paul was operating commercially in London by 1800, and it is to this period that we can effectively date the origins of ‘soda water’ as an accepted term for a product.

Meanwhile, attention was turning to the problem of keeping the gas in the bottle, for it was well known that corks, unless wet and in contact with the liquid contents, fell well short of requirements. As a result, there followed different designs of bottle and bottle closure intended to retain the essential preserving capability of carbon dioxide (Figure 3.1).

The Victorian era was one of invention, and the new aerated waters industry was a demanding field. Because corks were porous, they had to be kept moist to prevent gas loss. One solution was to construct a bottle that could not stand vertically: the

Barnett & Foster, Proprietors of Galloway Bros. 103

Bottles and Jars of every Description

Full particulars and current prices on application.

Fig. U174. Fig. U175. Fig. U176. Fig. U177. Fig. U178. Fig. U179. Fig. U180. Fig. U181. Fig. U182. Fig. U183.

Screw and Swing Stoppers

Per gross
Vulcanite. Domed (*Hacyo*); Flat (*Filgi*); Chisel-headed (*Filju*) 5/6
Lignum Vitæ. .. (*Haczu*); ,, (*Filho*); ,, (*Folka*) 5/3

Swings from 4/9 per gross.

Full particulars on application.

Niagara Works, London, N.; and Bolton, Lancs.

Classified Index, page 120. Instructions for telegraphing in code, page 123. Terms of sale, page 119. Telegrams: "Drinks, London." Codes: ABC (4th and 5th editions), Western Union, Premier and Private. Copyright 1916. See special note re prices, page 119.

Figure 3.1 The quest to retain carbon dioxide in a bottle took many forms, a few of which are shown here (from an early trade catalogue).

egg-shaped ‘side-lying’ Hamilton bottle (ca. 1809) kept its cork permanently in contact with the liquid and was used successfully for a time, but it had disadvantages in terms of filling and of quantity storage. Glass and earthenware stoppers, and then screw stoppers made of earthenware, were tried (ca. 1843) with varying degrees of success. In 1870 Hiram Codd, a Londoner, introduced his patented globe-stoppered bottle. This was so constructed that the pressure of carbon dioxide gas from the charged liquid forced a glass ball against a rubber ring inserted in a groove in the bottle’s neck. This formed a secure closure but needed only a slight downward force on the ball to release the pressure and allow the bottle to be emptied. A ridge of glass at the base of the neck prevented the ball from falling back into the liquid contents.

About this time the screw (vulcanite)-stoppered bottle and the ‘swing’ (ceramic) stopper, operated by a wire spring, were also in widespread use. Then towards the end of the nineteenth century there appeared an entirely new closure concept, the ‘crown cork’. This was devised in Baltimore, Maryland, in 1889, and a patent was later awarded in the UK during April 1892. The crown cork consisted of a thin metal disc crimped at the edges and originally lined with cork which was clamped around the bottle opening using external mechanical force. Such closures are still in use today, although the cork liner has now been replaced with a soft plastic coating. When introduced, the crown cork had the advantages of both lower cost and, because of its one-time use, greater hygiene than other types of closure.

The interest in aerated waters was, of course, due to the stabilising effect of the dissolved carbon dioxide gas, the first additive of major importance. As part of the developments around the filling and containerising of the new drinks there were other changes in formulation that fall under the term ‘additive’.

3.3 The move towards standardisation

Flavourings, colourings, acidulants and new preservatives were tried, at times with disastrous results. There is ample evidence that with the lack of early statutory controls, the contents of some bottled products would have been lethal to the consumer. An early edition of *Skuse’s Complete Confectioner*, published ca. 1890, contained information on cordials and other beverages and, in a section on flavours and colours, seriously admonished against the use of chrome yellow (lead chromate) as it had been known for certain confectioners to use a little chrome yellow for stripes in sweets. Heaven forbid it should also be used in beverages! Much of the hazard was created by the presence of impurities in some of the materials used in the manufacture of certain additives. Frequently, the sulphuric acid or vitriol used in the generation of carbon dioxide from whiting, or more effectively from bicarbonate of soda, was contaminated with metallic impurities, including arsenic and nitrous compounds, and care had to be exercised to select the best grades. A recurring problem, again centred on impurities, was the risk of contamination owing to contact of the materials used in the preparation of soft drinks with lead and copper.

The *Mineral Waters Trade Review and Guardian*, January issue, 1875, dwells on the subject at some length and a particular case is cited where lemon oils imported from Messina, Italy, were found to be heavily contaminated with lead following a period of storage in copper cans. The contact surfaces had been ‘tinned’, and it was established that the solder used for the purpose contained relatively high levels of lead in its blend. Today the limits of impurities are well defined in legislation. Under European regulations non-alcoholic beverages for consumption without dilution are given maximum limits for lead (0.2 mg/kg), arsenic (0.1 mg/kg), copper (2 mg/kg) and zinc (5 mg/kg).

In terms of food and drink additives, custom and use eventually indicated what dosage levels were acceptable, but there was no rigid system of assessment for these. In England, the Mineral Water and Food and Drugs acts were placed on the statute books in 1875. These instruments informed very clearly, but nevertheless with some generality, what the industry should not do but omitted to indicate what might be done without fear of the consequences. For instance, Section 3 of the Act of 1875 stated, ‘No person shall mix colour, stain, or powder . . . any article of food, with any ingredient or material *so as to render the article injurious to health* with the intent that the same may be sold in that state’. There was no restriction on colouring material of any kind other than that nothing ‘*injurious to health*’ could be used.

The absence of standards of quality or composition, apart from those relating to pharmaceutical products (the reference here was the British Pharmacopoeia), caused confusion in the early years. Toxicology was in its infancy as a science and many of the ingredients used in the manufacture of beverages to stabilise and standardise the drink in apparent safety have subsequently been determined to be injurious to health at the levels used. It has been said that in the area of food and drink ‘Everything is a poison: it just depends on the dosage or intake’. Assessment and control have developed to the point where, by and large, all food ingredients are now controlled by legislation. When and where appropriate, certain ingredients are removed from the permitted list or limited to an acceptable daily intake (ADI).

Different countries employ their own legislative controls for food ingredients, but two main areas exert great influence upon world opinion: the European system controlled by the EU parliamentary council using designated E-number listing for permitted food additives and the system used in the USA, where at federal level the Federal Food, Drug, and Cosmetic Act (FFDCA) lays down the framework for food safety.

3.4 The constituents of a soft drink

The term ‘soft drink’ applies to beverages containing flavourings and/or fruit juices together with other constituents of technological or nutritional value designed to enhance the appearance and stability of the product and to ensure its organoleptic properties are maintained for a reasonable shelf life. In order to meet current stringent quality and legislative controls a new beverage is subjected to extensive trials to assess the suitability and performance of all its components, and it is essential to arrive at the correct formulation to achieve a reproducible product. Table 3.1

Table 3.1 Soft drink components: general usage and contribution.

Component	Typical use level
Water (quality must meet rigid requirements) Bland carrier for other ingredients; provides essential hydration effects to enable body metabolism	Up to 98% v/v when high-intensity sweeteners are used
Sugars Contribute sweetness, body, to drink; acts as synergists and give balance to flavour	7–12% m/v when sole source of sweetener
Fruit juice Provides fruit source identity, flavour, mouthfeel effects; contributes to sweetness and acidity	Widely variable usage; usually up to 10% as natural strength, although some specialised lines in excess of this
High-intensity sweeteners Provide sweetness, calorific reduction; synergist action; often used in combination, e.g. aspartame with acesulfame K	Use based upon sucrose equivalence (e.g. aspartame might be employed at 0.4–0.6% m/v as sole sweetener)
Carbon dioxide Provides mouthfeel and sparkle to drink (carbonates only)	0.3–0.6% m/v
Acids (e.g. citric) Contribute sharpness, sourness and background to flavour; increases thirst-quenching effects	0.05–0.03% m/v
Flavours Provide flavour, character and identity to the drink	Nature identical and artificial: 0.1–0.28% m/m Natural: up to 0.5% m/m
Emulsion (flavour, colour, cloud etc.) Carrier for oil-based flavours or colours; gives cloudy effect in drink to replace or enhance cloud from natural juices	0.1% m/v
Colours (natural or synthetic) Standardise and identify colour tone of drink	0–70 ppm
Preservatives Restrict microbial attack and prevent destabilisation of the drink	Statutory limits apply (e.g. sorbic acid up to 250 ppm in EU)
Antioxidants (e.g. BHA, ascorbic acid) Prevent oxidation; limit flavour and colour deterioration	Less than 100 ppm subject to user country legislation
Quillaia extract (saponins) Acts to provide heading foam; mainly of use in carbonates	Up to 200 mg/l (EU); up to 95 mg/l (USA)
Hydrocolloids (mucilaginous gums) Carageenans, alginates, polysaccharides, carboxy methyl cellulose etc.; provide mouthfeel, shelf-life stability, viscosity	0.1–0.2% per GMP (good manufacturing practice), minimum amount required to create desired effect
Vitamins/minerals Use in 'healthy-living' drinks to provide nutritional requirements	ADI applies

lists the functional constituents of soft drinks and their typical usage levels. More detailed discussion follows.

3.5 Water

Water, as the main component of a soft drink, usually accounts for between 85 and 95% of the product and acts as a carrier for the other ingredients. It must conform to rigid quality requirements and not interfere with the taste, appearance, carbonation or other properties of the drink. Depending on the location of the bottling plant, the source of water and the product specifications, it may be necessary to treat the water used in the manufacture of soft drinks. In most urbanised areas of the world, public water supplies can meet consumer potability requirements, but for the soft drinks manufacturer this is not always a suitable qualification to use the water as a raw material, and most soft drinks factories carry out their own treatments to counteract possible changes in quality. This is most important in areas where changes result from the use of a national grid system for water supply.

Public water supplies in developed countries are continually monitored to ensure compliance with national water supply regulations and to minimise the risk of contamination. In the UK, in accordance with the Water Supply (Water Quality) Regulations 1989 and 2000, water companies are required to make public a register containing information about water supply zones. The register includes information on undertakings, relaxations, departures and sample analysis results for each water supply zone.

In less developed countries, water treatment becomes even more essential wherever microbial loading could provide cause for concern and it is necessary for a full water treatment to effectively ensure the wholesomeness of water supplies for boiling.

3.5.1 Requirements

Water should be free from

- high levels of elements and mineral salts
- objectionable tastes and odours
- organic material.

It should also be

- clear and colourless
- free from dissolved oxygen
- sterile, that is, free from micro-organisms.

Ideally, a non-variable supply of water should be available at all times of the year to allow a standard manufacturing process to be established.

3.5.2 *Quality of fresh water*

The quality of fresh water supplies depends on the geology of the catchment area. All fresh water is derived from rainfall, which filters through the upper layers of soil, extracting minerals and organic material en route. For example, rainfall on chalk areas will result in a supply of water with a high dissolved solids content, high alkalinity and total hardness, whereas the opposite is the case when rain falls on granite.

In marshlands and peaty areas water may well be pale yellow and contains appreciable amounts of dissolved organic matter. Such waters are sometimes termed 'humic' (because the yellow colour derives from the humic and fulvic acids present) and are likely to possess an unpleasant odour and bitter taste.

3.5.3 *Water hardness*

The term 'hardness' refers to the presence of calcium and magnesium salts. 'Temporary hardness' is due to the presence of the bicarbonates of calcium and magnesium, and 'permanent hardness' to calcium and magnesium chlorides, sulphates and nitrates. 'Total hardness' is the sum of temporary and permanent hardness. Measurement is expressed as the equivalent concentration of calcium carbonate in milligrams per litre or parts per million metre per volume and is also termed 'degree of hardness'. Approximate classifications are

Soft: <50 mg/l as $CaCO_3$
Medium-soft: 50–100 mg/l as $CaCO_3$
Hard: 100–200 mg/l as $CaCO_3$
Very hard: 200–300 mg/l as $CaCO_3$.

Water for use in soft drinks should ideally be soft or medium-soft.

3.5.4 *Water treatment*

The tried and tested form of water purification involves continuous treatment with a coagulant (e.g. $Al_2(SO_4)_3$, $Fe_2(SO_4)_3$) and chlorine, together with lime to reduce the alkalinity as necessary (Figure 3.2). A gelatinous precipitate, or 'floc', forms (hydroxides of aluminium or iron) which absorbs foreign organic matter. The chlorine sterilises the water by virtue of its microbiocidal and oxidising properties.

After treatment, the water is passed through a sand filter and then an activated carbon filter to remove traces of chlorine. It is then passed through a polishing filter (usually a cartridge filter of pore size <10 μm).

3.5.5 *Water impurities and their effect*

3.5.5.1 *Suspended particles*

Suspended particles may consist of complex inorganic hydroxides and silicates or, sometimes, organic debris. Particles too small to be easily distinguished can cause

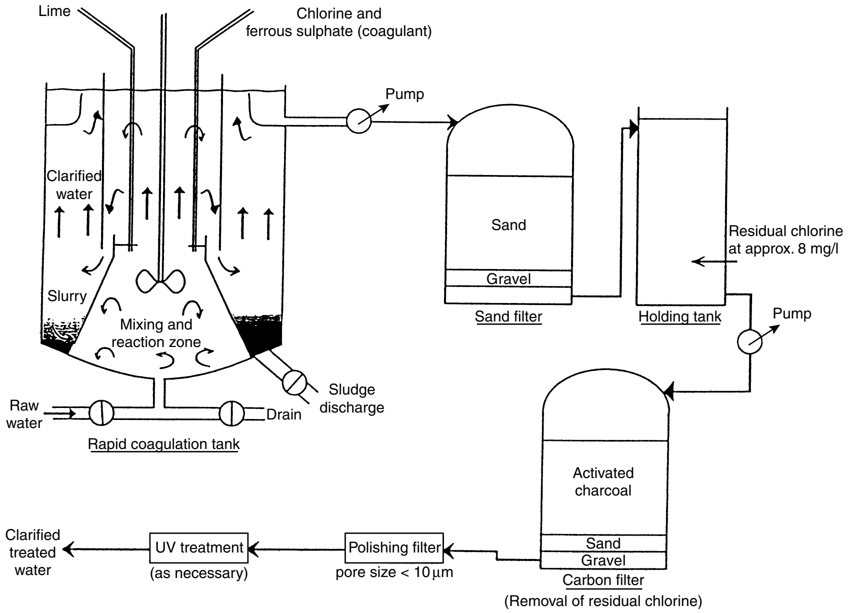

Figure 3.2 Diagram of a water treatment process using rapid coagulation.

difficulties when the drink is carbonated, acting as minute centres of instability and resulting in a loss of carbonation and foaming (gushing) at the filler-head and variable fill volumes.

In non-carbonated drinks there may be visible deposits and sometimes a 'neck-ring' in the finished product, caused by agglomeration of smaller particles. Filtration of the incoming water stream is therefore essential.

3.5.5.2 Organic matter

Organic matter is most likely to be present in water from soft regions and from surface water reservoirs. The organic material may include humic acid, algal polysaccharides and polypeptides, protozoa and microbial contaminants. The result is unsightly porous crystalline precipitation during storage as the organic species, notably algal polysaccharides, respond to the lower pH conditions of the soft drink or react with other components in it.

3.5.5.3 High alkalinity

High alkalinity is due to the presence of bicarbonates, carbonates and hydroxides of the alkaline earth and alkali metals, principally calcium, magnesium, sodium and potassium. The effect of high alkalinity is to buffer acidity in a soft drink, creating a bland taste. It is essential, therefore, to maintain a consistent alkalinity level, and the majority of manufacturers aim for <50 mg/l as $CaCO_3$. Alkalinity can be reduced by coagulation treatment or by ion exchange.

3.5.5.4 Nitrates

Modern methods of intensive farming using nitrate-based fertilisers have led to a noticeable increase in nitrate levels from aquifers lying beneath agricultural land. The recommended limit for nitrates has been given as 50 mg/l by the World Health Organization (WHO). The health risk of nitrates is a condition known as methaemoglobinaemia seen in infants. This condition signifies that blood contains excessive methaemoglobin, an abnormal substance formed by the oxidation of the iron in haemoglobin (the pigment in red blood cells).

3.6 Saccharides and high-intensity sweeteners

In the early years of the soft drinks industry, what else would be required to provide the element of sweetness but sugar? 'Sugar' is the disaccharide sucrose, which is the benchmark for other sweetener types. In acid solutions sucrose can undergo a process known as inversion, breaking down into its constituent monosaccharides, glucose (or dextrose) and fructose (or laevulose). Glucose is less sweet than sucrose (relative sweetness = 0.6) and fructose is sweeter (relative sweetness = 1.5). Consequently, a desired sweetness profile can be achieved by selective combination of these different carbohydrate types.

3.6.1 Bulk sweeteners

The term 'bulk sweeteners' is used for sugars whose normal usage level in beverages places them as the second ingredient, behind carbonated water, in the product declaration. This level is typically at 7–12%, depending upon product type and market preference. Both dry and liquid forms are available. Granulated sugar (sucrose) is the dry, crystallised, highly purified form produced via extraction of sugar cane and sugar beet. Liquid sugar, which is widely used, is the standard product, an aqueous solution of sucrose at 67% m/m (67° Brix) at 20°C. Other bulk sweeteners, often referred to as 'corn syrups', are glucose syrup and high fructose glucose syrup (HFGS). Both are formed by the controlled hydrolysis of starch. In the preparation of HFGS, an enzyme system is used whereby a proportion of the glucose present is isomerised to fructose, giving a similar composition to invert sugar: for example, glucose 42%, fructose 42%, other sugars (maltose, maltotriose, higher dextrins etc.) 16%. These syrup types are used extensively in the soft drinks industry.

Fructose in its pure form has also attracted interest in recent years. It is commercially available as an anhydrous crystalline powder or in its aqueous solution and has been successfully used as a replacement for sucrose as its increased sweetness enables use at lower levels. Fructose is very soluble and relatively more hygroscopic than sucrose (Danisco Sweeteners 2003, Tech. bulletin). It has a distinctive clean taste and may be used in synergy with other bulk sweeteners, and also some high-intensity sweeteners, to improve overall taste profiles. When fructose is ingested, its metabolism is not dependent upon insulin, and for this reason it can provide an important element in the diet of people suffering from diabetes.

3.6.2 Intense sweeteners

The use of intense sweeteners has increased significantly over the past 20 years owing to the appearance, and acceptance, of new types in the market. Saccharin, the first intense sweetener to be used on a commercial scale, has a difficult taste profile that can seldom be masked with any success in application. During its long history (initially being employed as a substitute for sugar in the case of diabetic patients around 1890), consumers have had to accept its often bitter/metallic aftertaste.

In 1983 aspartame and acesulfame K were approved for use under the European Sweeteners Directive/Amendment 96/83/EC and immediately found favour in the soft drinks industry (aspartame in particular) as a replacement for saccharin. Although aspartame provides a clean, lasting sweetness, it has the disadvantage of undergoing hydrolysis and loss of potency during storage. Below pH 3 and above pH 5, hydrolysis will occur relatively swiftly; hence conditions in the range pH 4.2–4.3 are required, where maximum stability is achieved. Aspartame and saccharin have been successfully used in combination, and also with acesulfame K, where a more sugar-like taste may be achieved. Because of the phenylalanine content in aspartame, a warning statement is required on the label of products containing the sweetener. In the UK the words ‘contains a source of phenylalanine’ must appear on the label to enable those who suffer from phenylketonuria (an inherited disorder in which the enzyme that converts phenylalanine into another amino acid, tyrosine, is defective) to factor the consumption of aspartame into their daily intake calculations.

3.7 Carbon dioxide

Before turning our attention to the acidulants used in soft drinks, it is worth noting that in carbonated beverages there is an additional effect of dissolved carbon dioxide gas. Although it is not officially recognised as an acidulant, its inclusion provides extra sparkle, mouthfeel, flavour and sharpness to the drink. Carbon dioxide is a colourless gas; it is a product of animal respiration and is also formed during the combustion of carbon. As of 2006, the earth’s atmosphere was about 0.038% by volume (380 μl/l) CO_2. The unit of measurement of dissolved carbon dioxide is volumes of the gas corrected to normal temperature and pressure (i.e. NTP = 0°C and 760 mmHg), per volume of the liquid. More recently, it has been expressed as grams per litre. (Note: 1 l CO_2 at NTP weighs 1.97 g.)

The solubility of CO_2 in water varies according to the temperature of the water and the pressure of the gas. It decreases with increased temperature and increases with increased pressure. At 15.5°C and a pressure of 1 atm (15 psi), water will absorb its own volume of carbon dioxide. Raising the pressure to 10 atm (150 psi) will bring about an increase in the gas solubility to around 9.5 volumes. Carbonated beverages are typically formulated to be in the range of 2–3 volumes dissolved gas. The effect of dissolution is to form carbonic acid (H_2CO_3), and this in turn dissociates partly to form bicarbonate and carbonate ions.

3.8 Acidulants

Acidulants are an essential part of beverage formulation, with the acid component usually third in order of concentration. Acidity has a variety of functions in addition to its primary thirst-quenching properties, which are the result of stimulation of saliva flow in the mouth. Because of the consequent reduction in pH, an acidulant can act as a mild preservative and in some respects as a flavour enhancer, depending on the other components present. In addition, by functioning as a synergist to antioxidants such as BHA (butylated hydroxyanisole), BHT (butylated hydroxytoluene) and ascorbic acid, acidulants can indirectly prevent discolouration and rancidity. Table 3.2 lists the most commonly encountered acidulants.

Table 3.2 Acidulants used in beverage formulations.

Acidulant	Molecular weight	Melting point (°C)
Citric acid, 2-hydroxy-1,2,3-propane tricarboxylic acid $HOOCCH_2C(OH)(COOH)CH_2COOH$	192.1	152–154
Tartaric acid (D-tartaric) 2,3-dihydroxy butanedioic acid HOOCCH(OH)CH(OH)COOH	150.1	171–174
Phosphoric acid orthophosphoric acid H_3PO_4	98	42.35
Lactic acid (DL-lactic) 2-hydroxy propanoic acid $CH_3CH(OH)COOH$	90.1	18
Malic acid (D-malic) 2-hydroxy butanedioic acid $HOOCCH(OH)CH_2COOH$	134.1	98–102
Fumaric acid *trans*-butenedioic acid HOOCCH=CHCOOH	116.1	299–300
Acetic acid ethanoic acid CH_3COOH	60	16–18

3.8.1 Citric acid

Citric acid is the most widely used acid in fruit-flavoured beverages. It has a light fruity character that blends well with most fruit flavours, which is to be expected as it occurs naturally in many fruit types. Unripe lemons contain 5–8% citric acid. It is also the principal acidic constituent of currants and cranberries and is associated with malic acid in apples, apricots, blueberries, cherries, gooseberries, loganberries, peaches, plums, pears, strawberries and raspberries. It is associated with isocitric acid in blackberries and tartaric acid in grapes.

Citric acid was originally produced commercially from lemons, limes or bergamots by pressing the fruit, concentrating the pressed juice and precipitating citric acid as its calcium salt, from which it was subsequently purified. It is now produced by the action of enzymes on glucose and other sugars.

Citric acid is a white crystalline solid; it can be purchased as a granular powder in its anhydrous state or as the monohydrate. Present-day soft drinks formulations usually employ the anhydrous form, which has cost-in-use advantages over the more traditionally used monohydrate.

3.8.2 Tartaric acid

Tartaric acid occurs naturally in grapes as the acid potassium salt. During the fermentation of grapes, tartaric acid precipitates out from solution as crystals as its solubility decreases with the increasing alcoholic concentration of the wine. Tartaric acid is also a natural component of numerous other fruits such as currants, blackberries and cranberries.

Tartaric acid can be obtained in four forms: dextro, laevo, meso and the mixed-isomer equilibrium, or racemic, form. Commercially, it is usually available as dextro-tartaric acid. It has a sharper flavour than citric acid and may therefore be used at a slightly lower level to give equivalent palate acidity. (Note: palate acidity is a purely subjective measurement and it is generally agreed that a number of acids can be used at concentrations different from those indicated by their chemical acid equivalent; see Table 3.3.)

Tartaric acid can be isolated from the crude deposit of tartrates obtained during wine fermentation, in a similar manner to the process for citric acid, that is, by leaching the deposit with boiling HCl solution, filtering it and re-precipitating the tartrates as the calcium salt. The free acid is obtained by treating the calcium tartrate with sulphuric acid and further purification by crystallisation.

Tartaric acid (dextro-form) is a white crystalline solid with melting point (m.p.) 171–174°C. Tartaric acid has a strong, tart taste and it complements natural and synthetic fruit flavours, especially grape and cranberry. For use in beverages, tartaric acid must be perfectly pure and guaranteed for food use. One problem that may need to be addressed is that tartaric acid salts, particularly the calcium and magnesium tartrates, have lower solubility than citric acid. There is consequently a tendency

Table 3.3 Palate acidity equivalents.

Acid	Concentration (g/l)
Acetic	1.00
Ascorbic	3.00
Citric	1.22
Fumaric	1.08
Lactic	1.36
Malic	1.12
Phosphoric	0.85
Tartaric	1.00

Note: These concentrations, in water, were considered to be equivalent (tartness, sourness) in taste trials carried out in the laboratories of Borthwicks Flavours (now Danisco (UK) Ltd), Wellingborough (1990). Although subjective they give an approximate comparison of the pure acid effect in solution.

for unsightly precipitates of insoluble tartrates to form in hard water, and in such conditions it is preferable to use citric acid.

3.8.3 Phosphoric acid

Phosphoric acid is the only inorganic acid to be widely used in food preparations as an acidulant. It does, however, occur naturally in the form of phosphates in some fruits, for example, limes and grapes. In the soft drinks industry its use is confined almost entirely to cola-flavoured carbonated beverages, where its special type of ‘astringent’ acidity complements the dry, sometimes balsamic, character of cola drinks. Phosphoric acid has a drier, and perhaps sharper, flavour than either citric or tartaric acid, tasting rather of flat sourness than the sharp fruitiness of citric acid, and it therefore appears to blend better with most non-fruit drinks.

Pure phosphoric acid is a colourless crystalline solid (m.p. 42.35°C) and it is usually employed in solution as a strong syrupy liquid, miscible in all proportions with water. It is commercially available in solution concentrations of 75, 80 and 90%. The syrupy nature of the solution occurs at concentrations greater than 50% and is the result of hydrogen bonding between the phosphoric acid molecules. Phosphoric acid is corrosive to most construction materials, and rubber-lined steel or food-grade stainless steel holding vessels are generally recommended.

3.8.4 Lactic acid

Lactic acid is one of the most widely distributed acids in nature and it is used to a great extent by the food industry. Its use in beverages, however, is limited. It has a mild taste relative to the other acids and is used in soft drinks as a flavour modifier or enhancer rather than as an acidulant.

Lactic acid is supplied commercially as an odourless and colourless viscous liquid. It is produced via the fermentation, using lactic acid bacteria, of carbohydrates such as corn, potato or rice starch, cane or beet sugar or beet molasses.

3.8.5 Acetic acid

Acetic acid has a very limited use in beverages, only finding use where its vinegary character can contribute to a suitable flavour balance in the product. It is seldom used in fruit beverages. Pure glacial acetic acid is a colourless crystalline solid (m.p. 16°C) with a suffocating, pungent aroma. It is one of the strongest of the organic acids, and as such can displace carbonic acid from carbonates.

3.8.6 Malic acid

Malic acid, which occurs widely in nature, is closely associated with apples. It is the second major acid, after citric, found in citrus fruits and it is present in most berry fruits. Malic acid is slightly stronger than citric in perceived acidity, imparting a fuller, smoother fruity flavour.

Malic acid is a crystalline white solid (m.p. 100°C) and is highly soluble in water. As it is less hygroscopic than citric acid it provides good storage properties and shelf life. Unlike tartaric acid, its calcium and magnesium salts are highly soluble and it therefore presents no problem in hard-water areas.

Malic acid finds use in a variety of products, mostly in fruit-flavoured carbonates. It is the preferred acidulant in low-calorie drinks and in cider and apple drinks, enhancing flavour and stabilising colour in carbonated and non-carbonated fruit-flavoured drinks. Malic acid can also be used to mask the off-taste of some sugar substitutes. Blends of malic and citric acids are said to exhibit better taste characteristics than either acidulant individually.

3.8.7 Fumaric acid

Fumaric acid is not permitted under UK or European legislation for direct use in soft drinks, although it is permitted, under Annex IV of Directive 95/2/EC (modified by Directive 98/72/EC), within strict limits, in instant powders for fruit-, tea- or herbal-based drinks. Fumaric acid finds wide use as an acidulant in other countries, notably in the US market, where it has GRAS (‘Generally Recognised As Safe’) status. Fumaric acid is currently manufactured in the USA via the acid-catalysed isomerisation of maleic acid. In terms of equivalent palate acidity it can be used at lower levels than citric acid, and typical replacement is suggested at two parts fumaric per three parts citric acid in water, sugar water and carbonated sugar water.

The main drawback to the use of fumaric acid is its slow solubility rate in comparison with citric acid and the need for special methods in its dissolution.

3.8.8 Ascorbic acid

Ascorbic acid, better known as vitamin C, is used not only as a contributory acidulant but also as a stabiliser within the soft drinks system, and its antioxidant properties serve to improve the shelf-life stability of flavour components. Many of the ingredients used in flavourings are susceptible to oxidation, particularly aldehydes, ketones and ketoesters. Ascorbic acid shields these from attack by becoming preferentially oxidised and lost, leaving the flavour component unaffected.

It should be noted that although ascorbic acid acts well as a browning inhibitor in unprocessed fruit juices, its effect can be destroyed if the juice is subsequently pasteurised or heat-treated. In such cases ascorbic acid can initiate its own chemical browning reaction.

Another disadvantage of ascorbic acid is its effect on some colours in the presence of light. In the case of azo colours, such as carmoisine, a light-catalysed reaction occurs, resulting in cleavage of the –N=N– linkage and consequent destruction of the chromophore. The bleaching will be specific to light of a certain wavelength and, where the phenomenon occurs, will account for the sudden loss of colour occuring in perhaps only part of a consignment of bottled product, containing, say, ascorbic acid, and colourings, carmoisine and sunset yellow, in its formulation, positioned in direct sunlight, whereas the remainder having been left in conditions of north facing light, or partial shade, will remain unchanged.

3.9 Flavourings

It is the flavour of a drink that provides not only a generic identity but also its unique character. This part of the sensory profile is responsible for pleasing and attracting the consumer. For example, having decided on a cola drink, the consumer will be able to differentiate between colas by virtue of the background flavouring components, which collectively provide a reference point to which the consumer can return, consciously or not, on future occasions whenever a particular brand of drink is tried.

A flavouring consists of a mixture of aromatic substances carefully balanced to convey the right message to the sensory receptors of the consumer. The preparation of such a mixture is a serious matter: the flavourist, like the perfumer, must be well versed in the technique, creative and able to translate ideas into a practical product. Although it is often difficult for the consumer to describe taste, the flavourist has no such limitations. The professional flavourist is seldom at a loss to describe organoleptic attributes, calling on a personal library of stored knowledge relating to flavouring substances and types. For example, some descriptors that might be applied to a peach-flavoured drink are

sweet
acidic
ripe
juicy
skinny
fresh
fruity
floral
stewed
lactonic
estery
jammy
astringent
aldehydic
perfumed

Depending on the desired profile, the flavourist may add to, or subtract from, a central theme until an acceptable blend is reached. Where work on a new product is to be collaborative, it is often necessary for the technical teams concerned to agree upon a suitable vocabulary of flavour terms.

Although the art of the flavourist depends largely on individual sensory abilities, it is frequently necessary in present-day flavour work to enlist analytical aid at an early stage of the project. Modern instrumental analytical techniques are capable of detection to extremely low limits, but it is still usually necessary to prepare an extract, or concentrated version, of the target flavour before carrying out the analysis. This can be achieved by such methods as solvent extraction, distillation, adsorption chromatography, dialysis, headspace concentration and cryogenic or adsorbent trapping.

A good gas chromatographic/mass spectometric (GC/MS) system can be used to identify profiles of compounds and individual flavouring substances up to, say, 98% of the target flavour, thus bypassing much of the time-consuming preliminary work associated with organoleptic flavour matching. GC/MS can provide an extremely rapid and reliable assessment so that a tolerable flavour match requires only slight ‘tuning’ adjustments for completion of the work.

A technique more recently employed to provide additional information on the mechanisms involved in the sensorial aspects of eating and drinking, and the in situ production/release of flavour molecules, is proton transfer reaction mass spectroscopy (PTR/MS). Whereas standard GC/MS involves the formation and consequential fragmentation of molecular ions, forming a characteristic profile of the resulting ions sorted by their mass/charge ratio, PTR/MS employs a less drastic, soft ionisation approach whereby there is noticeably less fragmentation and a simpler profile to assess. The procedure provides a powerful tool in understanding how the flavouring is perceived by the consumer. It is an extremely sensitive method of analysis that has been applied to flavour volatiles released to the oral and nasal cavities during eating or drinking. The performance of a flavouring will frequently be influenced by its mode of application, synergistic effects between individual components and, not least, changes in the substrate during consumption of the food itself. PTR/MS analysis can provide useful and accurate information on this latter aspect.

In the creation of a flavouring there is inevitably a component of comparison against what is already accepted as the generic base. Thus a strawberry flavour is at once typical, to a marked degree, of the fruit itself; however, on a commercial level the characterisation of this base flavour into something new will set the product apart from the competition and may lead to success in the market. Descriptors such as fresh, cooked, jammy, green, wild, ripe, full-bodied, creamy, estery, sweet, artificial and natural may be applied in the assessment as the taster searches for an adjective to best describe what is being conveyed via neurological pathways from taste sensors to brain. At best, the subjective nature of such an assessment will find some commonality across several tasters. It is at this point that the flavour may be identified as a winner, although even now success will depend upon application type, marketing strategies and so on.

Gas chromatography has enabled remarkable progress in the identification of volatile flavouring constituents occurring naturally in fruits and botanicals, for example, and also in food and drink products. From approximately 500 in 1955, it has grown to some 7000. Many ingredients are available to choose from, although in practical terms there is little need to select outside a group of 2000 when creating that extra modification that will distinguish the new flavouring. The majority of flavourings on the market are derived from fewer than 800 or so of these ingredients. A typical commercial flavouring will contain between 15 and 60 components, although among these there may be natural extracts carrying a composite blend of constituents in their own right.

3.9.1 Flavourings and legislation

Most food ingredients have been well investigated in terms of use and effect, categorised and registered on permitted lists as appropriate to local legislation. Flavourings, however, by virtue of their complexity have always existed as a separate group. Distinction is made under various systems as to whether flavourings are of natural origin. This follows adoption by the UN Food and Agriculture Organization (FAO)/WHO Food Standard Programme, the Codex Alimentarius Commission, of a proposal put forward by the International Organization of the Flavour Industry (IOFI) (ca. 1975) to divide flavouring substances into three categories:

- *Natural flavours and natural flavouring substances* are preparations and single substances, acceptable for human consumption, obtained exclusively by physical processes from vegetable, and sometimes animal, raw materials either in their natural state or processed for human consumption.
- *Nature-identical flavouring substances* are substances chemically isolated from aromatic raw materials or obtained synthetically. They are chemically identical to substances present in natural products intended for human consumption, whether processed or not.
- *Artificial flavouring substances* are, for the purpose of the Codex Alimentarius, those substances which have not yet been identified in natural products intended for human consumption, whether processed or not. They are hence only made available via synthesis.

Perhaps the most frequently cited register of flavouring substances appears in the GRAS listings compiled by the ‘Flavor and Extract Manufacturers’ Association (FEMA) of the USA. They comprise those substances ‘Generally Recommended As

Safe' when used in the minimum quantities required to produce the intended physical (i.e. sensory) effect and in accordance with the principle of good manufacturing practice. Each substance is allocated a FEMA number to enable cross-referencing with other listings, for example, those of the Council of Europe (CoE), US Food and Drug Administration (FDA) and Chemical Abstracts Service (CAS).

In Europe, flavourings have generally been considered to be compound ingredients, and concern has been expressed about the safety of their 'undeclared' components. Following extended interaction with representatives of the European flavour industry, trade associations and other bodies, a new list has been drawn up of all chemical substances currently in use, for flavourings, in the member countries. This was published in the *Official Journal* of the EC on 27 March 1999. The register currently has in the region of 3000 entries for flavouring substances used in or on foodstuffs. Work continues in assessing the level of health risk that may be associated with these ingredients, with a view to limiting their use as necessary.

Food safety within the European Community is now the responsibility of the 'European Food Safety Authority' (EFSA) which was established by the European Parliament in 2002 to replace the 'Scientific Committee for Food' of the EU and other technical bodies such as the Committee of Toxicology (COT) in the UK. EFSA became fully operational by June 2003, its two main areas of work are Risk Assessment and Risk Communication. Existing as a separate legal entity its role is to provide the European Commission with independent scientific advice.

3.9.2 Flavourings in application

Flavourings for soft drinks are of two main types: water miscible and water dispersible. Water-miscible flavourings are formulated to dissolve easily in water, forming a clear bright solution at dosages usually in the region of 0.1%. They typically contain mainly oxygenated, highly polar compounds. Water-dispersible flavourings are, strictly speaking, 'insoluble', including in their make-up a relatively non-polar oil phase, usually citrus, which conveys the characteristic zest-like contribution from the peel. This type of flavouring is introduced in the form of an emulsion, enabling oil-based flavouring substances to be incorporated in a soluble form.

3.9.3 Water-miscible flavourings

3.9.3.1 Flavouring mixtures

Relatively simple mixtures of flavouring substances, carefully dispensed, are dispersed/dissolved in a suitable carrier solvent system such as ethyl alcohol or propylene glycol. Such mixtures tend to exhibit variation in sensory profile following the immediate blending operation, and a short period of maturation is necessary to allow the flavouring to settle as the components may interact and stabilise. These inner workings reflect the reactive nature of the oxygenates responsible for the perception of flavour. Aldehydes, alcohols, esters, ketones, lactones, phenols, terpene derivatives and so on may interact to form a kind of equilibrium mixture containing, for example, acetals, ketals and additional ester types from interactions between alcohols and acids present in the original mix and also from transesterification reactions. Once it has settled, the new flavouring remains in a relatively stable condition throughout its allocated shelf life under recommended storage conditions.

3.9.3.2 Flavouring essence

An essence is a traditional flavouring product prepared by washing a selected oil blend (predominately citrus oils) with an aqueous alcoholic solvent mixture (e.g. 60% ethanol/40% water). The process is carried out under cool temperatures, for example, 5–10°C, either batch-wise or by counter-current extraction. It is an extraction process in which the aqueous extract phase becomes the flavouring. The soluble oxygenated flavouring constituents present in the essential oil blend (e.g. citral in lemon oil) are effectively partitioned between the two phases of the mixture. The low temperatures employed ensure that the transfer of any oil into the hydro-alcoholic phase is minimised, as a poorly processed essence will tend to cloud when used in the drink formulation.

Table 3.4 lists the components of a sample water-miscible flavouring. Initial mixing should be vigorous and thorough to establish a homogeneous state that on settling and separating out will again form two layers, the lower of which is the essence. The separation stage is critical in the traditional mix-and-settle batch method and may take several days to achieve. Counter-current processes involving,

Table 3.4 Example of a water-miscible flavouring – peach flavouring.

Vanillin	50.000
SVR (ethyl alcohol 95%)	95.000
Cinnamic aldehyde	0.225
Terpinyl acetate	0.720
Methyl anthranilate	0.720
Linalyl acetate	0.940
Benzaldehyde	1.200
Oil of neroli bigarade	1.440
Geraniol	2.820
Oil of petitgrain, terpeneless	3.925
Oil of petitgrain	4.000
Amyl butyrate	4.800
Amyl acetate	4.800
Amyl valerate	9.000
Amyl formate	10.800
Ethyl hexanoate	10.800
Ethyl valerate	26.400
Aldehyde C14	75.000
Propylene glycol (solvent)	600.000
Water (solvent)	100.000

Note: Prepare mixture (in order shown), mixing well at each stage. Leave to stand for 24 h. Separate from an upper oil phase. Filter to produce a clear, bright product.

for example, the use of spinning disc or pulse column techniques do not involve the same degree of pre-mixing and achieve separation in a shorter period of time. However, as they are continuous processes, it is essential to correctly size the plant required in order to maintain an adequate stock. Unlike the batch process, counter-current techniques cannot always easily accommodate a sudden escalation in product order.

3.9.3.3 Flavouring extract

The term 'flavouring extract' is usually applied to liquid extracts prepared by solvent extraction of botanical materials, for example, vanilla pods and ginger root. Traditionally, the process has been one of maceration, whereby the chopped, kibbled or ground botanical is loaded into a percolator column together with the chosen solvent system (usually ethyl alcohol/water combinations). The components are allowed to steep in the cold.

Periodically (e.g. daily) liquid is run off from the bottom of the percolator and returned to the top. After a prescribed time, equilibrium is considered to have been reached and the extract is drained off and replaced as necessary, with fresh solvent to provide a combined extract to meet specifications. This may be used as it is or in combination with other flavours. This basic procedure of liquid/solid extraction has been improved upon by a number of ingenious systems whereby, in most cases, the solvent is pumped through the botanical mass, using different techniques. If the solvent is warmed, extraction time can be reduced considerably.

3.9.4 Water-dispersible flavourings

The important water-dispersible type of flavouring is more commonly referred to as an 'emulsion' and is designed to introduce oil-soluble flavouring substances into a beverage system. Emulsions can provide both flavour and cloud effects and are produced by the mechanical dispersion of an oil phase carrying the flavouring components into an aqueous phase containing selected hydrocolloid materials.

A typical sequence used in emulsion manufacture is shown in Figure 3.3. In order to achieve optimum product performance, great care is required at the mechanical stage of emulsion manufacture, and the uniformity and size of droplets in the dispersed oil phase are critical. If the emulsion is to be used to promote a stable cloud in the beverage and to maximise optical density then the ideal is a droplet of approximately 1–2 μm in diameter. Above this limit, and if the particle distribution curve is not strictly Gaussian, instability will occur as a result of the oil droplets coalescing, and effects such as 'clearing-up', 'clearing-down', 'ringing' and 'creaming' will be observed, sometimes within a few days and certainly on storage. If particle or droplet size remains uniform, stable emulsions can be produced with a particle size average well below 1 μm (say, between 0.3 and 0.5 μm), but there will be a reduced cloud effect (see Figure 3.4). This is not a problem when the dispersion is intended primarily for flavouring.

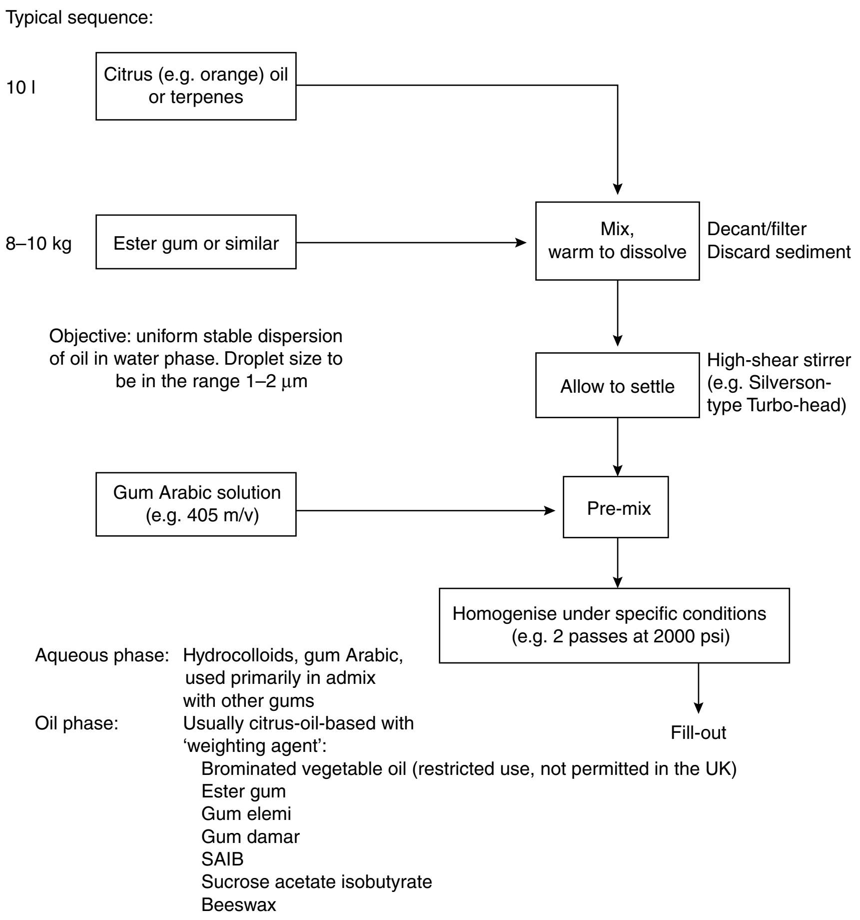

Figure 3.3 Cloud and flavour emulsions.

Mechanical parameters are important, but they are not the only area of control. Selecting the correct mix of stabiliser components is also critical. Beverage emulsions are essentially different from food emulsions. Their application in a mobile, liquid phase at concentrations in the region of 0.1% results in the formation of a uniform dispersion of the component droplets. In order to be stable and to avoid the effects mentioned in the previous paragraph, these must remain separate from each other and must not interact with other components of the beverage formulation. For example, should another emulsion be present (say, a β-carotene colour emulsion), the likely differences in particle size will result in a tendency for mutual attraction, with resulting instability.

Oil phase: Oil-phase components comprise the base oil (usually citrus as orange/lemon oils or terpenes) and a suitable dissolved cloudifying/stabiliser agent such as ester gum or the glyceryl ester of wood rosin (E445), gum damar, gum

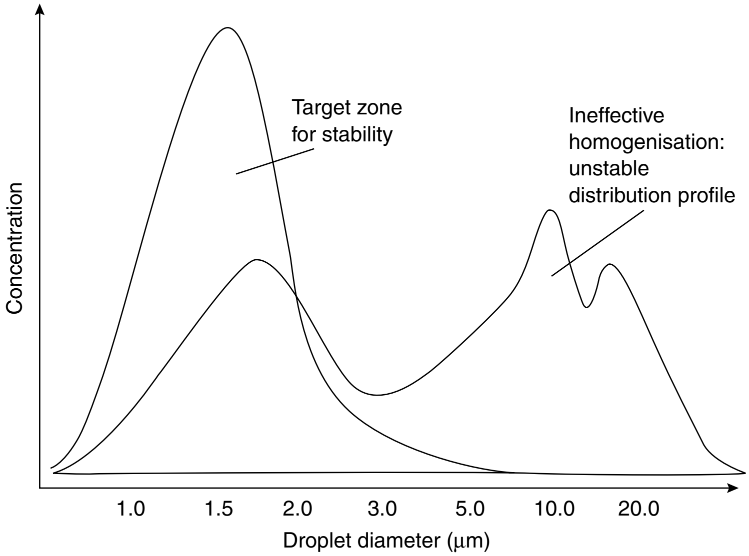

Figure 3.4 Particle distribution in emulsions.

elemi, sucrose acetate isobutyrate (SAIB) (E444) or beeswax (propolis) (E901). Legislation governing the use of cloudifying agents varies throughout the world, with the most regulated areas being the USA and the EU. Currently, ester gum and SAIB are permitted for use in non-alcoholic cloudy drinks under European law, whereas beeswax is limited to use as a glazing agent for confectionery or in certain colouring materials. Ester gum is permitted in the USA, whereas SAIB is not. The gum exudates, damar and elemi, are effective cloudifiers, but their use is subject to national interpretation and practice. Of the two, gum damar is the more interesting as it is the only truly naturally sourced cloudifying/stabilising agent of any consequence. Propolis is also used successfully in certain applications, although like damar it is not officially recognised in Europe or America.

Ester gum is produced by the action of glycerol on pinewood rosin to produce its esterified form, a mixture of di- and tri-glycerides, then purified by a process of steam-stripping in order to de-aromatise it, providing an odourless, tasteless, gum of m.p. 80–90°C. SAIB is produced by controlled esterification of sucrose using acetic and isobutyric acid anhydrides, and its composition consequently depends on reaction conditions.

Water phase: The water phase is, of course, complementary to the oil phase in that its hydrocolloidal components tend to provide a protective buffer zone around each oil droplet. One theory is that the polymeric molecules of the hydrocolloid are drawn to the oil–water interface by charge effects promoted by the oil-soluble cloudifier components referred to above. These micelles exhibit a composite charge, repelling neighbouring micelles of similar charge to prevent coalescence and maintain a stable system.

Of the many water-soluble polymers that can act in this manner as emulsifying agents, the most regularly used are gum acacia (also referred to as gum Arabic) and the modified starches. Gum acacia has been employed for many years as an emulsifier in beverage emulsions. Unlike other vegetable gums (e.g. tragacanth, guar) it has the advantage that it can remain relatively mobile in aqueous solution at concentrations of 30% m/m and above. The gum is obtained as the exudation from selected species of acacia. Upwards of 500 species of acacia are to be found over Africa, Asia, Australia and Central America, but only the varieties grown in Africa are of commercial interest. Of these, *Acacia senegal* and *A. seyal* are the most important. It is *A. senegal* that is the accepted standard for beverages. The two species are grown widely in a broad band of countries across west Africa through to Sudan and Ethiopia. The gum tears are hand picked and sorted by local people and transferred to central agencies for grading and distribution on the world markets. Apart from raw form and physical quality, the main feature differentiating the two species is the optical rotation. *A. senegal* is laevo-rotatory, with a specific optical rotation of −25 to −35° whereas *A. seyal* is dextro-rotatory, with a specific optical rotation of +30 to +45°. Gum acacia is a complex polysaccharide with protein groupings. The level of protein present is thought to be a major factor in its favourable performance as a beverage emulsifier. It has not been unusual for blends of the two types to be offered to the beverage industry as gum Arabic arranged so that the optical rotation would be always laevo-rotatory but falling short of the optimum required purity. The purity specification issued by JECFA (the Joint FAO/WHO Expert Committee on Food Additives, 1995) refers to gum Arabic as the ‘dried exudation from stems and branches of *Acacia Senegal* (L.) Willdenow or closely related species of *Acacia* (fam. Leguminosae)’. An earlier reference (JECFA, 1990) to the use of specific rotation and nitrogen content as purity criteria has been dropped, which facilitates the use of mixtures of different acacia gums under the description ‘gum Arabic’.

As with all natural products, the quality and harvest yields of gum Arabic are subject to climatic conditions. In addition, in Sudan and Ethiopia availability has also been affected by political factors. Since 1984 prices have shown major fluctuation and, at times, have been far higher than those of other polysaccharides. Because of this, the starch industry has made great efforts to develop replacements. Perhaps the most successful, to date, have been the starch sodium octenylsuccinates, where native starches have been modified by substitution with 1-octasuccinic anhydride (OSA). The introduction of a hydrophobic grouping onto the starch polymer results in highly effective emulsion-stabilising properties. The conditions during manufacture can be controlled to give some variety in performance to the range of modified starches available, but in general a key attribute is the low viscosity of their aqueous solutions, which can enhance the formation of uniform droplets during the homogenisation stage of emulsion manufacture. Typical concentrations of the OSA starches used for beverage emulsions are approximately 10–12%. Starch octenylsuccinates are registered as E1450 under European legislation and are generally permitted additives under Annex 1 of Directive 95/2/EC.

3.9.4.1 Brominated vegetable oil (BVO) emulsions

This section is included more for academic than practical interest as the use of brominated oils has been severely restricted under European legislation over the past twenty years, although until comparatively recently brominated oils were in use in India and parts of Asia. The term 'weighted' is frequently used when describing the oil phase, alluding to the early use of BVO to adjust the density of the oil phase in order to stabilise the dispersion in ready-to-drink (RTD) beverages.

The reaction of bromine with vegetable oils, such as peanut or maize oil, involves the addition of bromine atoms at the unsaturated double-bond sites of the oil to produce a progressive increase in the molecular weight and hence the density, which may thereby be easily adjusted to a predetermined value. Densities in the range of 1.24–1.4 are usually achieved. For example, the density of an oil phase comprising 'folded' orange oil can be adjusted from 0.875 up to, say, 1.03 by the addition of brominated oil, placing it in the density region of the target beverage and hence ensuring a stable system. The amount of weighting oil required can be calculated following the method devised by Pearson:

1. Write the target gravity of the finished beverage in the centre of a square.
2. Enter the specific gravities of the essential oil and weighting oil in the upper and lower left-hand corners, respectively.
3. Subtract the larger from the smaller number on each diagonal and place the resulting difference (omitting the decimal point) in the empty right-hand corner, giving the volume ratio required.

In Figure 3.5, for example, 475 parts by volume of the oil mix will comprise 320 parts citrus oil plus 155 parts of the weighting oil, giving a gravity of 1.030, identical to that of the finished beverage.

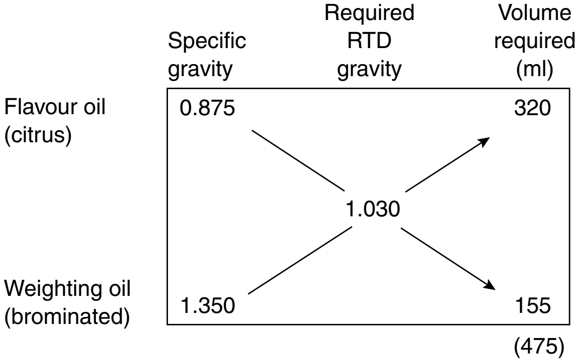

Figure 3.5 Example of the use of weighting oil.

3.10 Colours

Those of us fortunate enough to be able to distinguish a variety of colours will appreciate the influence that this sensory dimension exercises on our judgement in matters important to our well-being, such as food and drink. The perception of colour influences the taster's reception of a drink, and thus colouring is inevitably controversial. One point of view states that colours, which possess no measurable nutritional value, can have no role in food or drink other than that of deceiving the consumer. To a certain extent this is true, but to appreciate the full value of colour as a food additive, or more specifically as a soft drink additive, it is necessary to appreciate the synergy between the sensory responses of sight and taste.

Colour provides a means of correctly presenting a beverage to the consumer so that the perceived organoleptic attributes are correctly ordered in a sequence of appreciation. Both quality and quantity of colour are of importance, and certain colours will evoke, or perhaps complement, a particular taste. Reds will favour the fruitiness of soft drinks, for example, blackcurrant, raspberry and strawberry. Orange and yellow tend towards the citrus flavours. Greens and blues reflect the character of peppermints, spearmint and cool flavours, sometimes herb-like and balsamic, and the browns align with the heavier flavours, for example, colas, shandies and dandelion and burdock. Therefore, the deceit, if it can be so termed, is aimed at ensuring the consumer is able to maximise the enjoyment of the beverage concerned.

When a soft drink is based in part on fruit juices, it may be necessary to restore the appearance of the juice if its natural colours have been destroyed by heat processing or to intensify the colour when the contribution from the juice is weaker than that normally associated with the effect the compounded drink is intended to convey. Colour adjustment may also be necessary to ensure uniformity of product and to offset natural variations in colour tone and intensity associated with the juice type employed in the beverage formulation.

Above all, colour is a major parameter in the assessment of quality, serving at the time of production to standardise the product. It can also provide useful information about quality changes during storage, such as colour deterioration resulting from temperature fluctuations or microbial spoilage effects.

The use of food colours is carefully controlled under various pieces of legislation. There is at present no universal listing of colours for soft drinks, and it is necessary to investigate the permitted list to ensure compliance for goods to be manufactured in, or exported to, a specific country.

Both the EU and the FDA have published lists that are regularly reviewed. Most concern has been expressed over the use of azo colours, to which some people have an allergic reaction – most frequently to sunset yellow (E110, FD&C yellow no. 6) and tartrazine (E102, FD&C yellow no. 5).

Although a number of food colours are suitable for use in soft drinks, it should be appreciated that the contribution of any one of these cannot be entirely predictable. In any soft drink formulation the colour component, as with all other ingredients, has to be carefully selected for its performance in the presence of certain acids, flavourings, antioxidants and even preservatives. It is essential, therefore, at all stages of development that meaningful storage trials are completed to ascertain the real contribution from colour in the newly finished beverage.

Food colours are broadly divided into two classes: natural (Table 3.5) and artificial. In the USA these are listed as either 'exempt from certification' or 'certified colourants'. The natural colours are botanical extracts, with the exception of carmine (a red colour), which should perhaps be termed an entomological extract as it is obtained from the insect *Dactilopius coccus*, or cochineal beetle, which breeds and feeds on particular cacti indigenous to Central America (Table 3.6).

Table 3.5 Permitted food colourings derived from natural sources (EU Directive 94/36/EC).

Colour	Sources	Shade	E-no.	Stability	
				Light	Heat
Anthocyanins	Grape skins, elderberry, red cabbage, hibiscus	Red–purple–blue, pH dependent	E163	Good	Good
Water soluble; natural indicators; red in acidic solutions (most stable) and bluer as pH increases					
Beetroot Red	Red beetroot (*Beta vulgaris*)	Pink to red	E162	Poor	Poor
Water soluble; limited stability to heat, light and oxidation; most stable between pH 3.5 and 5					
Carmine	Cochineal insect (*Dactilopius coccus*)	Strawberry red, orange/red hues	E120	Excellent	Excellent
Soluble in alkaline waters, solubility decreasing with lowering of pH; will precipitate below pH 3					
Annatto	Seeds of annatto shrub (*Bixa orellana*)	Orange	E160(b)	Fair	Good
Bixin is oil soluble and frequently used for beverages in the form of an emulsion; norbixin is water soluble in alkaline conditions and will precipitate in acid pH; versions stabilised to about pH 3 are available					
Beta-carotene	Carrots, algae, palm, synthesised	Yellow to orange	E160(a)	Fair	Good
Oil soluble; colour sensitive to oxidation; shade varies with concentration; water-dispersible versions available					
Paprika	Red pepper (*Capsicum annum*)	Orange to red	E160(c)	Fair	Good
Oil soluble; sensitive to oxidation; water-dispersible versions available					
Lutein	Aztec marigold (*Tagetes erecta*)	Yellow	E161(b)	Good	Good
Oil soluble; egg-yellow colour; good stability; the xanthophyll lutein is a carotenoid colour which occurs in green leaves, vegetables, eggs and some flowers					
Curcumin	Turmeric (rhizomes of *Curcuma longa*)	Yellow	E100	Poor	Good
The purified colour, curcumin, is not water soluble, but water-dispersible systems are available					
Chlorophylls	Green-leafed plants	Green	E140; E141	Poor; Good	Poor; Good
Natural chlorophyll (E140) is oil soluble, but water-dispersible forms are available; copper chlorophylls (E141), effectively chemical modified natural extracts, are water soluble					

Table 3.6 Artificial (synthetic) colours permitted in soft drinks to a maximum level of 100 mg/l.

Colour	E-no.	Colour stability			Colour contribution
		Light	Heat	Acids	
Quinoline yellow	E104	Good	Good	Very good	Greenish yellow
Tartrazine (FD&C yellow no. 5)	E102	Good	Good	Very good	Lemon yellow
Sunset yellow (FD&C yellow no. 6)	E110	Good	Good	Very good	Orange shade; similar to orange peel
Carmoisine (azorubine)	E122	Good	Good	Good	Bluish red
Ponceau 4R	E124	Good	Good	Good	Bright red
Patent blue FCF	E131	Good	Good	Poor	Bright blue
Indigotine (FD&C blue no. 2)	E132	Fair	Poor	Fair	Dark bluish red
Brilliant blue FCF (FD&C blue no. 1)	E133	Good	Good	Good	Greenish blue
Green S	E142	Fair	Good	Good	Greenish blue

Note: With the proviso that individual levels of E110, E122 and E124 may not exceed 50 mg/l (EU Colour Directive).

3.11 Preservatives

A preservative can be defined as any substance that is capable of inhibiting, retarding or arresting the growth of micro-organisms or any deterioration of food due to micro-organisms or of masking the evidence of any such deterioration. In Europe defined maximum levels of permitted preservatives are given according to the food substrate concerned. For soft drinks consumable without dilution, the relevant directive is European Directive No. 95/2/EC (Table 3.7). The *p*-hydroxy benzoates previously cited in the legislation are no longer permitted for use in soft drinks, although they are still allowed for certain food uses.

As mentioned in Section 3.7, carbon dioxide, though not added specifically as a preservative, contributes to the inhibition of micro-organism growth and, coupled with other factors (e.g. pH), to the stability of the drink. It is deemed to be effective at concentrations over 2.5–3.0 volumes, and for this reason the incidence of spoilage in carbonated beverages is less than that in non-carbonated versions.

Although preservatives can be used to good effect in beverage formulations, they should never be considered infallible and there is no substitute for stringent quality and hygiene controls at every stage of manufacture. Raw materials should be assigned, within their own product specification, workable limits for microbial activity so that there is little chance of excessive contamination in the finished beverage product. Equally, all processing plant, machinery and containers likely to come into contact with the product during manufacture should undergo a thorough cleaning (sanitisation) before use.

Certain strains of yeast, moulds and bacteria can survive in relatively low pH conditions, and some of these can exist and grow in the presence of certain

Table 3.7 European Directive 95/2/EC.

Preservative	mg/l	E-no.
Sulphur dioxide (carry-over from fruit concentrates only)	20	E220
Benzoic acid	150	E210
Sorbic acid	300	E200
Benzoic/sorbic acids (in combination)	150/250	E210/E200

preservatives, so it is important that everything is done to prevent escalation of their numbers. Under favourable conditions a typical rapidly growing yeast strain can double its population every 30 min; at this rate in 12 h one yeast could become 16.7×10^6, provided no inhibitory factor is present.

3.11.1 Micro-organisms and beverages

Although there is little evidence of the formation of toxic fermentation products in beverages, the problem of spoilage frequently arises. Because of their utilisation of sugars, yeasts are of most immediate concern.

Yeasts are classified with the fungi and are unicellular for most of their life cycle. Together with moulds and bacteria they can bring about a deterioration in flavour, producing taints, off-notes and differences in mouthfeel. Most yeasts can grow with or without oxygen, whereas most bacteria cannot survive in oxygen. The majority of yeasts thrive at temperatures between 25 and 27°C; some can survive at temperatures over 70°C and others can exist, apparently quite comfortably, at 0–10°C. Bacteria exhibit certain deviations in characteristics, with an optimum growth temperature at around 37°C.

Soft drinks provide an ideal growth substrate for many micro-organisms, given adequate supplies of the required nutrients. Apart from water, the environmental necessity, typical requirements are sources of carbon (carbohydrates), nitrogen (amino acids), phosphorus (phosphates), potassium, calcium (mineral salts) and traces of other minerals, for example, sulphur, iron, cobalt and even vitamins. Because of the obvious link with protein formation during cell growth, the presence of combined nitrogen is of particular importance. Also, where they are introduced to beverages via fruit pulp or caramel (colouring), there will be a greater susceptibility to spoilage by certain micro-organisms.

Perhaps the most difficult aspect of dealing with microbial contamination in soft drinks relates to the delay factor when an apparently good quality product leaves the bottling line for storage and distribution only to be returned later, maybe after several weeks, when severe deterioration in performance has taken place. Fortunately, such occurrences are rare in the modern soft drinks industry, but to any manufacturer this is a nightmare scenario that must be avoided at all costs. A bottled drink constitutes a unique system, which can inhibit or enhance the growth of micro-organisms. Micro-flora, if present, will enter a dormant stage during which their chances of survival are assessed in relation to the immediate surroundings. Following this 'lag' stage, during which specific micro-flora may adapt to their new environment and start to grow, there is a burst of species-dependent activity, during which the population doubles repeatedly at a steady rate. As a bottled drink is a 'closed' system, waste products and diminishing nutrients will serve to slow down the growth and eventually bring it to a standstill, at which point the death rate increases and all activity stops. Although the product is perhaps not a health hazard, it has been spoiled and can no longer satisfy its intended function.

3.11.2 Sulphur dioxide

Because of its ease of production, gaseous SO_2 was one of the first chemical compounds manufactured and used by human beings. In early times it was used as a preservative by burning sulphur prior to sealing wine into barrels or storage jars. It is one of the most versatile agents used in food preservation and is well known for its microbiocidal effect on bacteria, moulds and yeasts. Nowadays it is generally employed in the form of a sulphur-dioxide-generating salt (Table 3.8). For example, sodium metabisulphite is converted in acid medium:

$$\underset{(190)}{Na_2S_2O_5} + H_2O \rightarrow 2NaHSO_3$$

$$2NaHSO_3 + 2H^+ \rightarrow 2Na^+ + 2H_2O + \underset{2 \times (64)}{2SO_2}$$

that is, 190 parts of the metabisulphite produce 128 parts SO_2.

Table 3.8 Preservatives and their salts.

Preservative	E-no.	Alternative form used at equivalent level	E-no.
Benzoic acid (m.p. 122°C)	E210	Sodium benzoate	E211
C_6H_5COOH		Potassium benzoate	E212
Benzene carboxylic acid		Calcium benzoate	E213
Sorbic acid (m.p. 133°C)	E200	Sodium sorbate	E201
$CH_3CH{=}CH_2{–}CH_2{=}CHCOOH$		Potassium sorbate	E202
2,4-hexadienoic acid		Calcium sorbate	E203
Sulphur dioxide (gas)	E220	Sodium sulphite	E221
SO_2		Sodium hydrogen sulphite, sodium bisulphite	E222
Sulphurous anhydride			
		Sodium metabisulphite	E223
		Potassium metabisulphite	E224
		Calcium sulphite	E226
		Calcium hydrogen sulphite, calcium bisulphite	E227
		Potassium bisulphite	E228

The microbiocidal effect increases as the pH falls below 4.0 and, because of this, SO_2 is ideally suited for most soft drinks formulations. However, its preserving action is impaired by a tendency to react with many fruit components of soft drinks to form organic sulphites, in which state the SO_2 is said to be ‘bound’. Although the preservative properties are mainly due to free SO_2, it is necessary to analyse for total SO_2 (i.e. free plus bound) as legislation for safe working requirements refers only to maximum total concentrations.

Although SO_2 is used to good effect in the preservation of concentrated citrus juices, with typical concentrations of 1000–2000 ppm m/v, it is now limited under European legislation to no more than 20 ppm in non-alcoholic flavoured drinks containing fruit juice, and only as carry-over from concentrates (95/2/EC; see Table 3.7). A number of specific drink products under the same legislation are permitted to have higher levels (e.g. concentrates/dilutables based on fruit juice and containing not less than 2.5% barley [barley water]), but for the majority this much-reduced limit (previously set at 70 ppm) clearly emphasises the importance of improved manufacturing practices in terms of plant hygiene. JECFA has recommended an acceptable daily intake of not more than 0.7 mg/kg body weight for SO_2.

Disadvantages associated with SO_2 are that some people can detect it as an unpleasant backnote or taint and that it can provoke allergic reactions. Asthma sufferers tend to be susceptible to the effect of gaseous SO_2, small traces of which can promote an asthmatic attack, and foods containing sulphites can have an associated risk of gas liberation when they are swallowed.

3.11.3 Benzoic acid and benzoates

Benzoic acid occurs naturally in some fruits and vegetables – notably in cranberries, where it occurs in amounts of the order of 0.08% m/m (Fellers and Esselen, 1955). It is also found in some resins, chiefly in gum benzoin (from *Styrax benzoia*) and in coal tar. Commercially available benzoic acid is produced by chemical synthesis.

Pure benzoic acid is a white powdery crystalline solid (m.p. 122°C) only sparingly soluble in water at normal temperatures. Because of this it is added to the drink in the soluble form of its sodium or potassium salts. It is normal practice to completely disperse the benzoate during batch make-up before the acid component is added (resulting in pH reduction) to avoid localised precipitation of the free benzoic acid owing to its solubility having been exceeded (the solubility of benzoic acid = 0.35% m/v at 20°C). It is the free or undissociated form of benzoic acid that exhibits preservative action and hence its use is only effective at low pH values, ideally below pH 3, where the degree of dissociation reduces to below 10%.

Benzoic acid is generally considered to exhibit an inhibitory effect on microbial growth. Improved synergistic results are obtained when it is used in conjunction with other preservatives, for example, SO_2 or sorbic acid. It is interesting to note that the current European directive, which expresses individual limits of 300 mg/l for sorbic and 150 mg/l for benzoic acids in non-alcoholic flavoured drinks, nevertheless permits a joint preservative use of up to 250 mg/l sorbic acid with 150 mg/l benzoic acid.

Allergic reactions to benzoic acid have been reported, particularly among children known to be hyperactive in response to other agents, for example, tartrazine. The maximum ADI for benzoic acid, recommended by JECFA, is 5 mg/kg body weight.

3.11.4 Sorbic acid and sorbates

Sorbic acid is found naturally in a number of fruits and vegetables – notably in the juice of unripe mountain ash berries (from *Sorbus aucuparia*), where it occurs together with malic acid. Sorbic acid and its salts are among the most widely used preservatives in the world. In soft drinks the most commonly used form is potassium sorbate because, as with benzoic acid, there are problems in preparing its solution (the solubility of sorbic acid = 0.16% m/v at 20°C). In common with benzoic acid, as a microbial inhibitor, sorbic acid and its sorbates show reduced effectiveness with increased pH. Although activity is greatest at low pH values, sorbates have the advantage of being effective at pH values as high as 6.0–6.5, in contrast to benzoic acid, for which the comparative range is pH 4.0–4.5. The undissociated form, as with benzoic acid, is primarily responsible for its preservative action.

In the USA sorbates are classified as GRAS and have maximum permissible levels in various foods of 0.05–0.3%. The EU permits levels within the range 0.015–0.2%, although in soft drinks the limit is 0.03% (300 ppm m/v). In addition to being less toxic than benzoates, sorbates seem to be less obtrusive in terms of taste detection by certain individuals and allergenic reactions. Overall, sorbates are considered to be among the safest food preservatives in use and WHO has set the ADI for sorbate at 25 mg/kg body weight.

3.12 More functional ingredients

The functionality of the ingredients already discussed tends to contribute self-evidently to the main identity of the drink. Apart from the preservatives, these ingredients are used primarily for taste and colour. Other ingredients also serve to improve performance and further characterise the drink.

3.12.1 Stabilisers

Stabilisers have been mentioned in the context of the production of water-dispersible flavourings and emulsion-based cloudifying systems. In addition to contributing to overall stability, such additives are also used, where appropriate, in soft drink formulations to impart stability to natural clouds, for example, dispersions of fruit solids, and to improve mouthfeel characteristics by increasing the viscosity of the drink.

Under European legislation there are more than 50 E-coded materials with stabilising properties for food use, although perhaps no more than 10 are used on a regular basis in soft drinks formulations. These include the alginates, carrageens, vegetable gums, pectin, acacia, guar, tragacanth, xanthan and carboxy methyl cellulose. Also included, under number E999, is extract of quillaia, which is specifically permitted in soft drinks and, apart from its use as an emulsifier, is valued for its heading properties.

3.12.2 Saponins

The saponins occur in the roots of many plants, notably the genus *Saponaria*. The name derives from the Latin *sapo*, meaning soap, because of the lather-like reaction that occurs when parts of these plants are soaked in warm water. This ability to generate foams is useful in beverages such as ginger beer, shandy, cream soda and cola formulations to improve and standardise heading foam characteristics.

Saponins for beverage use are sourced from quillaia bark (*Quillaia saponaria* Molina) and the yuccas. Of the latter species, two main varieties are used in the USA for production of the water extract: the Mohave yucca (*Yucca mohavensis*) and the Joshua tree (*Y. brevifolia*).

The effect of saponins in beverages is to create a very stable foam, and at the levels used they are colourless and tasteless. The dried extract, however, possesses an acrid, astringent taste. Permitted limits are quoted in terms of the dry weight of the extract. In Europe, subject to Directive 95/2/EC, quillaia is permitted only in non-alcoholic drinks, to a maximum level of 200 mg/l.

3.12.3 Antioxidants

Perhaps the most common problems encountered during storage are the oxidation effects involving certain ingredients of a drink. Both flavour and colour components can be subject to deterioration in the presence of dissolved oxygen to the detriment of the product. Antioxidants are therefore included in those formulations containing ingredients most vulnerable to oxidation. Oxidation can frequently be attributed to the oxygen permeability of the plastic materials used in container manufacture, but it is essential that the oxidation process should not start at the production stage of the drink or with any of its ingredients. Citrus-flavoured drinks, notably lemon drinks, are frequently susceptible to oxidation, and so antioxidants may feature in their formulation.

Oil-based, water-dispersible flavours (emulsions) are protected by the addition of oil-soluble antioxidants such as BHA and BHT to the oil phase before the emulsification process. The typical usage level in essential oils is 1000 mg/l, and as the flavour emulsion will be used at the rate of approximately 0.1%, the level of antioxidant in the finished beverage will be of the order of 1 mg/l, which will safely comply with an ADI of 5 mg/kg body weight for either additive.

Increasingly, greater use is being made of natural and nature-identical antioxidants as in many countries use of BHA and BHT continues to be restricted on health grounds. Ascorbyl palmitate (6-O-palmitoyl-L-ascorbic acid) and its sodium and calcium salts, natural extracts rich in tocopherols (vacuum-distilled from soya bean oil, wheat germ, rice germ, cottonseed oil, etc.) and synthetic alpha-, gamma- and delta-tocopherols are used to good effect in preventing oxidative deterioration in oil-based systems. In combination, ascorbyl palmitate and alpha-tocopherol (vitamin E) synergise to exhibit enhanced antioxidant properties.

3.12.4 Calcium disodium EDTA

Calcium disodium EDTA, a mixed salt of ethylene diamine tetraacetic acid, is prepared by reacting the acid with a mixture of calcium and sodium hydroxides. It acts as a sequestrant by a binding action that removes traces of metal ions from raw materials or process water. These metals (e.g. iron) can destabilise the beverage by their tendency to catalyse degradation of flavouring components, causing oxidation and off-notes. Their removal serves to maintain stability of the products during storage and to increase shelf life.

Under European Directive 95/2/EC, calcium disodium EDTA is permitted only in a limited number of foods, including some canned and bottled products, with maximum levels specified in each case. In the USA (Code of Federal Regulations), it is permitted to a level of 33 ppm in canned carbonated soft drinks, to promote flavour retention.

3.13 Retrospective investigation of a soft drink

Having considered many of the ingredients used in the preparation of a soft drink, it is now appropriate to look behind the label of a product that contains at least some of the materials reviewed. This will demonstrate how the various parts complement each other. The product to be considered is a notional low-calorie pineapple and grapefruit crush. The term ‘crush’, although no longer falling under any legal definition (the 1964 UK Soft Drinks Regulations required a minimum of 5% v/v as single-strength juice), is generally accepted to refer to a carbonated drink containing natural fruit juice. The label on this product might carry the following description:

> Sparkling low-calorie pineapple and grapefruit crush

and its ingredients panel would be presented in one of the following ways, or possibly as a combination of both:

> *Ingredients*: Carbonated water. Concentrated fruit juices (pineapple, grapefruit) (5% when reconstituted). Citric acid. Acidity regulator (sodium citrate). Artificial sweeteners (aspartame, saccharin). Flavourings. Preservative (sodium benzoate). Antioxidants (ascorbic acid, ascorbyl palmitate). Colour (lutein).

> *Ingredients*: Carbonated water. Concentrated fruit juices (pineapple, grapefruit) (5% when reconstituted). Citric acid (E330). Acidity regulator (E331). Artificial sweeteners (aspartame, saccharin) (E951, E954). Flavourings. Preservative (E211). Antioxidants (E300, E304). Colour (E161b).

The ingredients are presented in descending order of concentration and listed under their respective categories. They may be named individually or by reference to their E number, if applicable. Flavourings are, at present, listed as a category, and there is no need to name their individual components, but this could change under future European legislation.

In order to manufacture this beverage the bottler will require a recipe, such as

Low calorie pineapple and grapefruit crush made from 8-fold pineapple and grapefruit compound.

Aspartame	137.0 g
Sodium saccharin	90.7 g
20% sodium benzoate solution	206.0 ml
8-fold pineapple and grapefruit compound	12.5 l
Lutein colour liquid	50.0 g
Water to make	100.0 l

This recipe produces 100 l of low-calorie pineapple and grapefruit bottling syrup intended for dilution in the ratio of 1 part syrup to 5.66 parts carbonated water. It would be recommended that this product be pasteurised before carbonation to 3 volumes CO_2.

Made to the above recipe, the syrup and beverage will conform to the following specification:

	Syrup	Beverage
Aspartame (mg/l)	1372	206
Acid (% m/v as citric acid anhydrous)	3.53	0.53
Saccharin (mg/l)	693	104
Benzoic acid (mg/l)	600	90

The compound/concentrate used in the recipe is described as eight-fold, which relates to the bottling syrup, not the finished drink:

8-fold pineapple and grapefruit compound

20% sodium benzoate solution	1.18 l
6-1 concentrated pineapple juice	40.00 l
6-1 concentrated grapefruit juice	4.44 l
Citric acid anhydrous	27.90 kg
Tri-sodium citrate	1.34 kg
Ascorbic acid	0.54 kg
Ascorbyl palmitate	0.16 kg
Pineapple flavouring	2.13 l
Grapefruit flavouring	4.26 l
Pineapple flavouring	0.27 l
Water (to 100 l)	

This compound exists as a vehicle to introduce the characterising components into the beverage: thirst-quenching properties from the acid, flavour and body from the juice (also contributing to mouthfeel). A major part of the identity of the final drink is provided by the flavouring ingredients. In order to stabilise and protect these, oil- and water-soluble antioxidants are included.

The exact quantities of flavouring materials can be determined from the following ingredient formulae:

Flavourings		Active flavour components (l)
Pineapple flavouring (2.13 l)		
Ingredients:		
Pineapple esters 200-fold comprising approximately 90% water		0.21
Pineapple flavouring (0.27 l)		
Ingredients:		
Lemon oil, terpeneless	1	
Sweet orange oil 12-1	2	
Ethyl caproate	10	
Isoamyl butyrate	14	
Allyl caproate	18	
Ethyl butyrate	59	
Ethyl propionate	53	
Glycerol	48	
Water	232	
Ethanol (SVR)	563	
	1000	0.04
Grapefruit flavouring (4.26 l)		
Ingredients:		
Cedarwood oil (10% in isopropyl alcohol)	2	
12/1 concentrated grapefruit oil	4	
4/1 concentrated grape oil	5	
Lemon essence oil	8	
5/1 concentrated grapefruit	15	
Grape oil Israeli	20	
Grapefruit essence oil	48	
Isopropanol (food grade)	898	
	1000	0.43
Active flavouring components:		
Total		0.68

Thus 100 l of the eight-fold pineapple and grapefruit compound contains no more than 0.68 l of flavouring materials. This is used in the bottling syrup at 12.5% v/v, which is diluted 1 part syrup to 5.66 parts carbonated water to provide the finished drink. The effective flavour dosage rate is given by the product of the two dilution factors, that is, $8 \times 6.66 = 53.28$ times, and the real concentration of flavouring materials at RTD beverage strength is therefore $0.68 \div 53.28 = 0.0128\%$ v/v or, as it is more frequently expressed in the flavouring industry, 128 ppm. This is quite a modest input for the level of flavour impact it is able to generate.

3.14 Food safety

Food has always been of major interest to human beings. Although its primary function is survival, it now has additional connotations of health, enjoyment and acceptability. Today's consumer looks to suppliers and manufacturers for a product with no associated consumption risk that is marketed in accordance with strict observance of the laws governing food safety.

Although microbial contamination is always a concern with respect to food alone, it is much less of a potential hazard for beverages, where the lower pH conditions make the survival of pathogenic species virtually impossible and the likelihood of food poisoning equally remote. In addition, any attack from, say, yeasts and moulds would manifest itself as spoilage and be easily detectable either visually or organoleptically well before any lasting danger could be done. However, to be assured of complete safety it is necessary to look further, below the superficial and into the actual ingredient make-up of the drink itself.

The safety of food additives and other ingredients is monitored according to guidelines issued by the joint committee of JECFA, WHO and the FAO. Knowledge of health safety is gained primarily as a result of animal feeding trials coupled with relevant short- or long-term toxicological investigations. In later stages of testing humans may also be included in the studies to ascertain that their physiological reactions are similar to those found in animals.

Because of food's potentially longer-term ingestion, the standards applied to food additives in feed trials are significantly more stringent than those applied to, say, pharmaceuticals, where, in order to treat some illness successfully, certain side-effects of the treatment can be tolerated. The ADI is an estimate of the amount of a food additive, expressed in milligrams per kilogram of body weight per day, that can be consumed safely over an entire lifetime. ADI levels are set by JECFA based on the result of various feeding trials. As a general rule, the ADI value is set at one-hundredth of the intake that produces virtually no toxicological effects in long-term animal feeding trials.

The registration of a 'new' ingredient, or perhaps the retention of an existing one, under the European Miscellaneous Additives Directive is a complicated and long-drawn-out procedure, not just because of the strict protocols employed in the assessment itself but also because of the accompanying exchanges between all interested parties representing the member states in setting up the application. The opinions of agricultural and trade associations, consultancies, research establishments and other organisations may be called upon in the preparation of a suitable dossier laying out the justification for inclusion of an additive. The associated costs are enormous. Currently, starting from scratch, the costs involved in preparing a monograph on the constituent and physical properties of a proposed additive, together with a full toxicological study, will be of the order of

£230,000 ($425,000) – so it is little wonder that new additions to the list are few in number.

An ongoing issue periodically generating media coverage is the intolerance of members of the population to certain food ingredients. This is most concerning when serious allergenic reactions occur. The apparent growth in the prevalence of severe allergic reaction to peanuts during the 1990s was a case in point. It initiated, throughout the manufacturing industries, a series of controls on the raw material supply line to ensure products are, where appropriate, free from nut components and labelled accordingly. In 1996 the European Scientific Committee for Food (SCF) issued a report on *Adverse Reactions to Food and Food Ingredients*. The level of intolerance to food additives was indicated in the report to be 0.026%, equivalent to just under 3 people per 10,000 of the population.

3.15 Future trends

In a world undergoing continual change, with a population well above six billion, the challenge facing the soft drinks industry is perhaps increasingly complex. To provide products that are wholesome, durable, acceptable in character and interesting to an ever-growing market has been the objective for many years, but with the increasing realisation that almost anything we consume can have detrimental as well as beneficial effects, the focus today is very much on additives, processing aids and functional ingredients. The term ‘functional drinks’ is now part of our vocabulary, and this is an area with great scope for future development. The general aim of a functional drink is not just to alleviate thirst but also to contribute to a sense of well-being in the consumer by assisting with diet, metabolism and improved lifestyle.

Healthy lifestyle drinks, drinks with added vitamins, drinks with pro-biotic properties and isotonic drinks are already available and provide a base for further innovation. Claims such as ‘rich in fibre’, ‘fat free’, ‘sugar reduced’, ‘beneficial in calcium adsorption by the body’, ‘improving intestinal flora’, ‘pro-biotic’, ‘with ascorbic acid’ and ‘energy reduced’ will doubtless continue to be seen and will have to be supported by sound evidence to comply with labelling regulations.

Although PET (polyethylene terephthalate) bottles and ring-pull aluminium cans have proved extremely suitable for carbonates, it is likely that there will be fresh progress in the area of drinks packaging – particularly so as environmental concerns and the recycling of packaging materials have become an issue.

During the past decade, legislative controls have become more stringent, with the gradual phasing-out or reduction in use of many additives previously considered an essential part of the production formula, and this trend is bound to continue. In conjunction with this, improved packaging, aseptic processing techniques and the selection of top-quality raw material ingredients will become prestigious, creating a highly specialised system of presentation designed at all times to satisfy the consumer. In the final analysis, it is the customer upon whom the continued success of a beverage product depends. Image is important, but behind the image there must be substance and quality; performance must satisfy, and this is what the successful marketing of soft drinks relies upon.

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4 Syrup preparation and syrup room operations

John Horman

4.1 Introduction

The modern syrup room bears no relation whatsoever to the syrup room of a century ago or even, for that matter, twenty years ago. The advent of modern flow metering systems and PLC (programmable logic controller) control has made drastic changes to the way we operate. As will be discussed in Chapter 11, legislation, driven by concerns over product quality, has meant major improvements to the way we run and operate our plants. Nowadays plants are situated in hygienically designed rooms, with all pipework in 316 stainless steel and hardly a person in sight. Raw materials are kept in a separate room to minimise any risk of contamination from packaging, etc., which might have originated in some far off third world country. This major change in the way our factories are designed and run is part of a gradual ongoing change in the twenty-first century. Nobody knows what is round the corner except that change and improvements are an ongoing process. Time does not stand still. One possible problem with future development could be the lack of UK trained scientists and engineers, in what is seen as an unglamorous, poorly paid profession. Government and industry both need to address this issue to ensure that the profile and standing of technologically motivated individuals increases. It is no good having all these marvellous factories and systems in place without the skilled professionals to staff them with the necessary experience and qualifications.

The syrup room of old would have operated with small mixing tanks using a wooden paddle. Very likely the vessel would originally have been made of wood as well. The very thought of how they cleaned these vessels, and the microbial problems that must have occurred, does not bear consideration. Raw materials would be placed in sacks around the room and weighed out to a given recipe using simple weighing equipment and measuring jugs. The level of accuracy of these measured quantities and the subsequent drink reproducibility must have been a major problem. Often without accurate metering sugar and water would be added to the vessel to a given tank level, measured either by a mark on the side of the tank or by a dip stick. Some of these methods existed up to the late twentieth century in some smaller soft drinks plants. During the second half of the twentieth century metering systems for sugar and water were incorporated. Often these were of unhygienic design and construction, and somewhat dubious accuracy. Pipework was usually in unplasticised polyvinyl chloride (UPVC) with poorly made pipe joints and cast iron or plastic valves that gave rise to high micro-biological counts. Such a problem can be seen in Figure 4.1, where a poor pipe joint is shown. It was only due to the preservative nature of carbon dioxide and the use of returnable glass

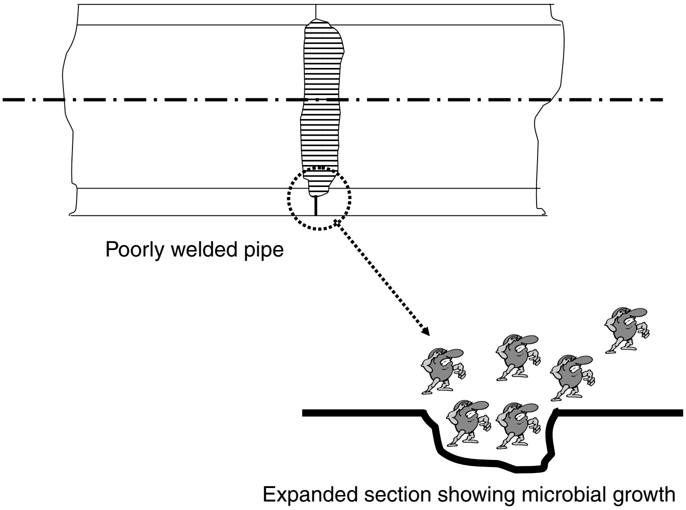

Figure 4.1 Poor pipe joint.

bottles which gave rise to a quick turnaround that serious problems rarely arose. It was only with the advent of the can, and later PET bottles, that the industry had to live with long shelf lives and products distributed nationally and internationally. This meant initially increasing preservative levels and then when legislation was introduced minimising their use in the development of hygienic processing.

4.2 Syrup composition

This chapter will only consider the basics as whole books have been devoted to this subject and the previous chapter has dealt with it in some depth. The main ingredients of a carbonated drink product are water, sugar or other sweetener, acid, sometimes fruit juice, flavours and emulsions, colours, preservatives, antioxidants and of course carbon dioxide.

Acids give the tart taste to a soft drink and are usually the third main ingredient. The three principal acids used are citric, phosphoric and malic acid, though other acids such as tartaric, lactic, acetic, fumaric and ascorbic are occasionally considered. These can be delivered either in powder form or as a liquid in bulk. With modern metering systems the use of bulk liquid acid is now becoming the norm. Citric acid is the most commonly used acid for carbonates. It is very soluble in water in that 10 g will dissolve in 100 ml of water at 22°C. Carl Wilhelm Scheele, a Swedish chemist first isolated citric acid from a lemon in 1784. Some 200,000 tonnes of it is used in the USA alone for food and carbonated drinks purposes. It is commercially produced by fermenting cane sugar, molasses, and dextrose by use of the fungus *Aspergillus niger*. The original process of extraction was from fruit juice by adding lime to form a calcium citrate (an insoluble precipitate) that is then exposed to sulphuric acid, thereby recovering the citric acid. Phosphoric acid is used primarily for cola-based drinks. It is available in liquid concentrations between 75 and 90%. Above 50% concentration it is rather syrupy. Unfortunately it is highly corrosive so it is important when handling to use rubber gloves and to process it through 316 stainless steel pipes and plant. Malic acid is allied to apples and, after citric acid, is the most commonly used in the drinks industry. It is highly soluble in water. The quantity used in a soft drink is dependant on the recipe. Acids prevent the growth of pathogenic organisms within the drink and pH levels below 4.5 are normally considered free of pathogens. The acid level for a typical carbonate is 0.2–0.5% with a pH between 2.6 and 3.0, whereas a cola drink, using phosphoric acid, will have 0.06% acid with a pH of 2.4–2.8.

Besides water, as discussed in Chapter 2, sugar in all sugar drinks represents the second major ingredient. This is sucrose extracted from either beet or cane. It is obtained by liquid extraction from crushing followed by recrystallisation. Whether a company takes the sugar in a granular form for dissolving on site, or as a liquid is usually dependent on the price. A typical soft drink will have some 10% sugar, normally defined as the °Brix level which is the percentage weight for weight of sucrose present. This may sound excessive until you think that a glass of fruit juice contains some 10% of natural sugars. Sugar is normally added to enhance taste. It is a carbohydrate that breaks down in the body to form the energy source, glucose.

For low-calorie drinks sweeteners are used instead of sugar. They have a very high sweetener level so that only small quantities are required in the drink. The main sweeteners in use are acesulfame-K, aspartame, cyclamates and saccharin. The choice of which sweetener to use in any specific drink depends on the type of product, the taste, the availability and the price. These sweeteners can also be blended together including sometimes with sugar. They are normally delivered in bag form on pallets.

Preservatives inhibit the growth of micro-organisms thereby allowing the product to be kept for a considerable time before it deteriorates. They are present in bread and all major foods, as otherwise spoilage rates would be very high and the risk of illness through eating or drinking manufactured items very likely. However, carbon dioxide itself prevents mould growth and high levels of acidity, and carbonation also assists in inhibiting the growth of yeasts and bacteria. The most commonly used preservatives are benzoic acid and sorbic acid, which are effective against most yeasts and moulds.

Flavourings, which may be natural or artificial in nature, allow a wide variety of drinks to be produced. Most of those used in the soft drinks industry tend to be natural in origin. A large industry exists just to satisfy the demand for these. They can be water miscible or water dispersible, the former as the name implies being easily dissolved in water though often they are dissolved in a suitable carrier such as ethyl alcohol or propylene glycol. Some are used in the form of an emulsion, thereby allowing oil-based flavourings to be supplied in a soluble form.

Colours provide a drink with a perception of what it will likely taste like. In addition to a given brand the colour is part of the image, and needs to be reproduced accurately for each serving. They are normally provided in powder form. Other possible ingredients include anti-oxidants, saponins and stabilisers.

The chemist from his or her brief from marketing must develop a recipe to meet this requirement. From experience and a degree of trial-and-error a recipe is presented and accepted by marketing. This will be after stringent tests on the product lifecycle, where any deterioration of taste with time or colour degradation will be noted. With any brand, any change in any ingredient supply must involve careful testing to ensure the product profile is unchanged. Above all due diligence is required to ensure that at all times the product as specified is safe for the consumer.

4.3 Syrup rooms and proportioning systems

In these systems the syrup is usually prepared in the syrup room in a concentrated form, typically in the ratio 3 parts syrup to 17 parts water. For juice products this is much less down to the order of 1 part syrup to 3 parts water. This includes all the ingredients with just a small amount of water to ensure that the viscosity was low enough to promote reasonable flow conditions. The syrup is prepared normally in batch vessels using water and liquid sugar feed through volumetric flow meters. Often these are not of very hygienic design, having been installed over 25 years ago. The feed is through a pipe in the top of the vessel often leading down the side of the vessel to the bottom. This was to try and minimise aeration due to feeding liquid into the air rather than under liquid at all times. The ingredients would be pre-mixed in a stainless steel bucket and added to the syrup vessel. High preservative levels were required in the product to ensure product security. Whilst the bucket might have disappeared some time ago, the old-fashioned syrup room still exists in many factories. Often a pre-mix is made up and metered to the syrup tank, using water as the wash through at a metered level. However, the vessels are often open to atmosphere and have rather crude blending arrangement, rather than the more sophisticated mixers used in modern vessels. The state of the syrup room often needs attention, in that risks from overhead beams that are difficult to clean, and similar problems associated with older sites, make product quality an ongoing issue. It is only by very stringent cleaning regimes, including operator hygiene, that these systems are still in use today.

It is at the proportioner just before the filler that the final product is produced just prior to carbonation. In fact, most such units incorporate the carbonator. In the Mojonnier system a fixed orifice is used to meter the syrup component whilst the water is fed through a variable orifice. They both operate under a constant head of pressure as shown in Figure 4.2. A float valve in the product tank ensures a fixed head feed to the carbonator as well as controlling the water and syrup feeds. The set-up of such a system always meant that the initial product was out of specification, though once set up it remained accurate. Also the last part of the batch would be out of specification which will cause some loss of product. This is due to the fact that the emptying of the syrup tank gives rise to a lower syrup head pressure than that of the water. Another such system used dosing pumps one for water and another for

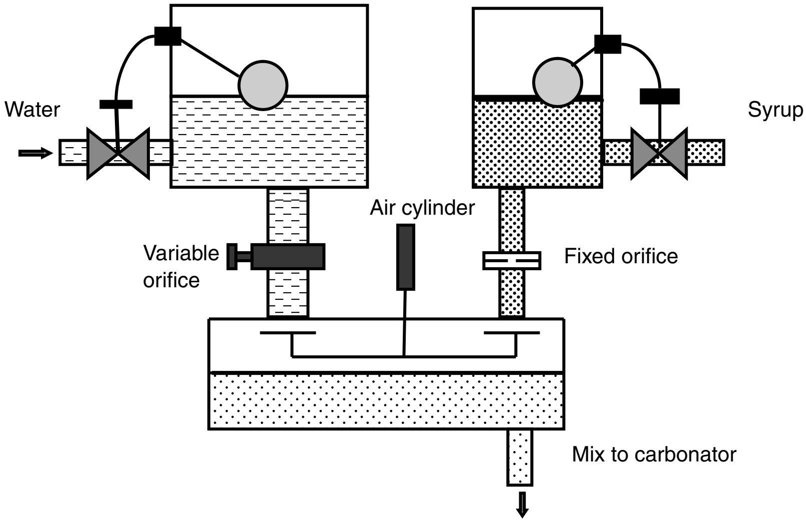

Figure 4.2 Mojonnier system.

syrup. These systems usually included a water de-aeration as well as a subsequent carbonator. Typical pumps used were Bran and Luebbe. Once set up they were reliable and repeatable. The problem was the same as for the Mojonnier of initial start up and the end of each batch where out-of-specification product was produced with subsequent losses. Neither system is as accurate as modern metering systems. At the time they were introduced consumers did not have the high standards that they do today and the modern requirement of perfection each time was not so prevalent. Of course, nowadays, metering pumps can be used in a series to produce the same effect as the mass flow meters. This is further discussed below. Even today many systems incorporating the carbonator are sold, but they now use mass flow meters to blend the syrup and water, as illustrated in Plate 4.1. This system also includes de-aeration. These have the same degree of accuracy as the systems discussed in Section 4.4, including feedback control on syrup density to ensure better uniformity of the final product. Owing to the nature of having to feed from a syrup tank, often in an old syrup room, these systems are best suited to older factories with lower throughputs.

4.4 The modern syrup room

Nowadays these are situated in an air-conditioned specially designed area set to a high standard commensurate with the production of food stuffs. The plant is PLC controlled with in-line clean-in-place (CIP) systems. Banks of valves with a lot of pipelines and stainless steel tanks are in evidence, a far cry from twenty years ago. Meters have now progressed from volumetric to mass flow, where density

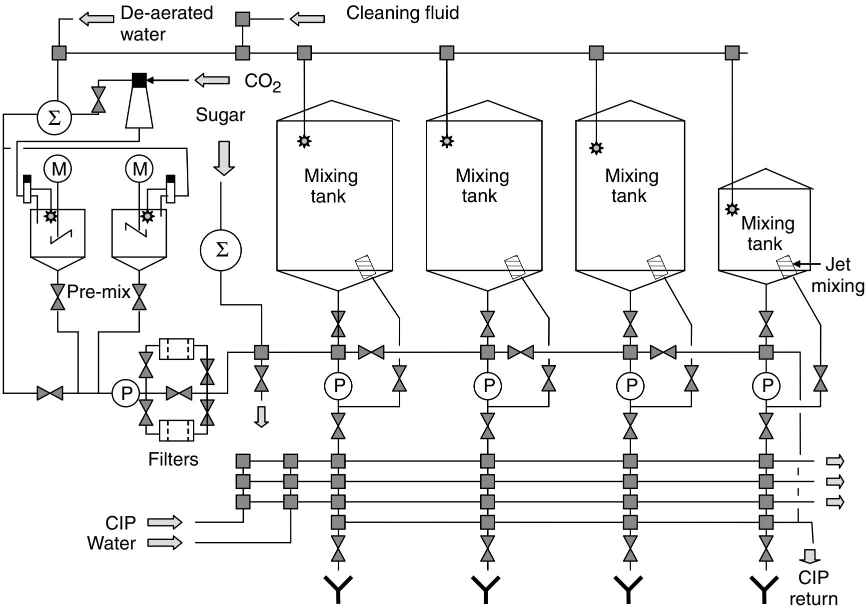

Figure 4.3 Volumetric flow meter system.

correction of key ingredients can be incorporated. The key to these systems is that they produce the final beverage on the premise of getting the product right first before carbonating.

The early automated syrup rooms used volumetric flow meters. These were extremely accurate in terms of the volume of liquid metered through. A typical system is shown in Figure 4.3. A pre-mix of the main ingredients besides water, sugar and acid would be made up. Once the pre-mix had been made up and checked, it was possible to start the syrup batch. The skid unit normally comprised two meters, one for water and one for all the other ingredients. The recipe would have been set in the computer, which interfaced with the PLC control system. The route would be selected on the PC, including which mixing vessel the batch was to be sent to. All pipelines were left with water in them after the previous batch. The amount in this pipeline to any particular tank is known. The sugar is then metered into the tank. Following this a known amount of water is metered through to wash the line out. This is then repeated for each ingredient, whether this be citric acid, malic acid, pre-mix or juice. At the end of the batch a further known quantity of water is added. Early users of these systems used to add less water than the recipe stated so that they could err on the side of caution and add more water when the batch had been mixed and the Brix measured. Due to the accuracy of such a system this was rarely required. If it was required it was usually due to the sugar being slightly out of specification. The system would allow for this if required through an on-line density meter. The final syrup would be produced to a much higher accuracy than the recipe specification, which has led to cost savings as well as better uniformity of product as delivered to the consumer. To minimise the risk of aeration of the product all dosed infeeds go through the base of the mixing vessel. Ideally this should be a flush-mounted valve to the base of the tank so as not to have any dead areas in the vessel where the product cannot be circulated. Clearly the outfeed to the filling lines also uses this same valve being routed through the valve matrix. The mixing vessels are normally issued with a sight glass and accompanying light as well as a hygienic sampling tube.

More modern systems use mass flow meters. These meters can also measure density, though to an order of magnitude less than for an actual density meter. They can feed to a batch vessel, say of 30,000 l capacity, or direct to the carbonator. The accuracy of the mass flow meters is such that they can produce product to within ±0.01 °Brix, which has been proven on many occasions. A typical skid is shown in Figure 4.4. Any deviation in the liquid sugar brix can be compensated immediately by the addition of more or less water. It is even possible to add major flavours through the mass flow metering skid. Clearly this is only of interest on production lines where major brands are produced. The flavours for these are normally delivered in special intermediate bulk containers (IBCs), which can be simply coupled up to the infeed pipework of the skid. Such systems require a sophisticated control system and can be readily interfaced with the site MRP system. Batch vessels often use

Figure 4.4 Mass flow meter skid (courtesy of Diessel GmbH).

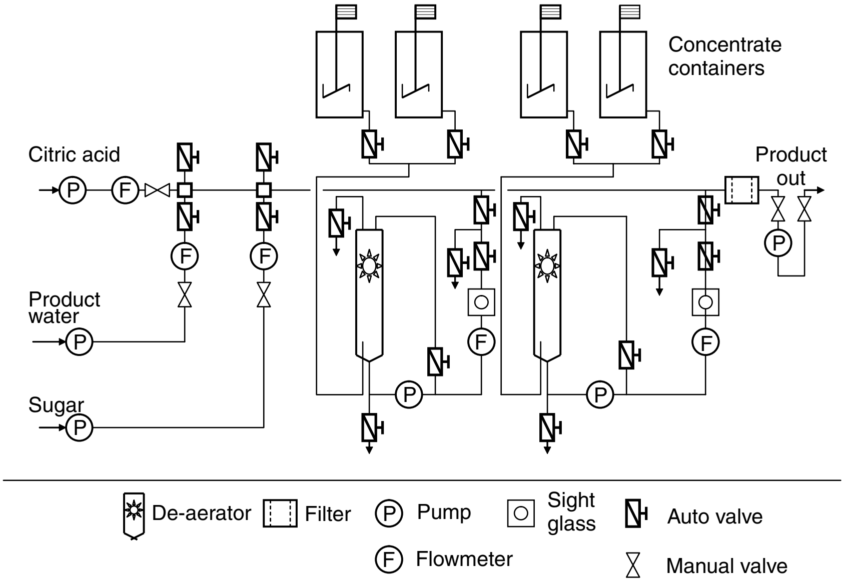

Figure 4.5 Continuous blending system (courtesy of Diessel GmbH).

re-circulatory pumps to ensure the product stays well mixed. A densitometer can be installed in this line if required as a cross check on the system. Similarly, such an instrument can be installed on the feed line to the carbonator for in line blending operations. A continuous blending system using volumetric flow meters is shown in Figure 4.5.

A typical valve matrix is shown in Figure 4.6. It is not uncommon to have over 500 such valves within a system. Whilst this may seem to be a heyday for the valve manufacturers, it is important to ensure that several lines run at once and also whilst one or more is being cleaned. These use block and bleed valves.

For the beverage feed to the filling line two systems are in common use. One method is to pump the product over, then using water to push the last vestiges to the point of use. As a flow meter accurately measures the quantity of liquid passing through it, it is known when the product flow is completed out of a tank and thus when the water is to be added. As the flow rate, pipe diameter and distance to the point of use is known, it is possible to achieve a reasonably good cut off, taking into account the fact that a certain degree of diffusion of product and water will have occurred. A conductivity probe sited at the point of use can act as a safety valve to help minimise product loss during transfer.

Another method is to use a pig. This is an object made from food grade silicon or similar materials that are tough and flexible that pushes liquid through a pipe. They are normally propelled by air or water using special valves at each end of the pipe. The pig is normally returned to its original position after use ready for the next run. A schematic to illustrate the principle is shown in Figure 4.7. As the transfer time is small, this time lost is of little importance. The pigs can travel round bends and have the advantage over the water flush method of further minimising product losses.

Figure 4.6 Valve matrix (courtesy of Diessel GmbH).

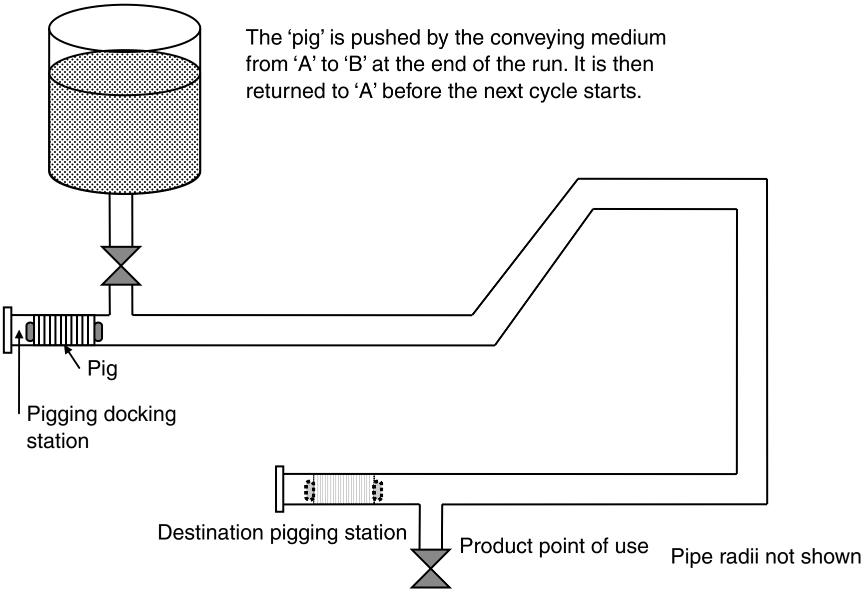

Figure 4.7 Pigging system schematic.

In fact, the use of pigs enables faster product changeovers than using water as the product chaser, as there is no mixing of product and water at the interface. Many different pig designs exist in order to make them cater for more complex pipework situations. Pigs have even been developed that will pass through complex pipework of differing diameters. One such is the pig developed at Bristol University, which is called the ‘clean ice pig’. This is made of a so-called smart material, showing non-Newtonian characteristics, that acts like a fluid that can squeeze through complex pipework ‘scraping’ the surfaces clean.

4.5 Instrumentation

The main in-line instrumentation is some form of Brix meter. Off line these are normally refractometers, whilst on-line they can be either density meters or refractometers. The author’s preference is for density meters, as they are, by experience, more reliable, easier to keep in calibration, accurate and simple to clean by a normal CIP. This view has been formed due to the possibility of build up on the prism of a refractometer, although modern designs are now much improved and regular cleaning will largely alleviate this query. A refractometer measures the refractive index: the speed at which light passes through a liquid. The denser the liquid the slower the light will travel through it, and the higher its reading will be on the instrument. As Brix is temperature dependent, any measuring unit must incorporate temperature compensation. °Brix is the refractometric solids content of a liquid and is the percentage of w/w sucrose. This is directly related to density.

The use of modern densitometers is based on the Coriolis principle, named after G.G. de Coriolis (1792–1843), which is an effect whereby a mass moving relative to a rotating frame of reference is accelerated in a direction perpendicular both to its direction of motion and the axis of rotation of the frame. They are based on the use of an oscillating U-tube, and offer high accuracy density measurement, having an accuracy of the order of 1×10^{-4} g/cm^3 and repeatability of 1×10^{-5} g/cm^3. An in-line unit is installed as a spur feeding back into the main line, as the flow rate and pipe diameter for a densitometer are much less than the 100 mm or so of the process pipeline. An in-line refractometer can be mounted in the main line. It is also important that the quality control staff take samples and measure Brix off line using a high quality, temperature compensated, refractometer interfaced to the MRP system. All such instruments must be regularly re-calibrated. However, a recent article by Masselli shows that for diet products the influence of carbonation will produce an error per 0.1 g/l of 3.5% of the Coca Cola standard of 3.5% for a densitometer and less than 0.02% for a refractometer. This problem is obviated when first making the syrup and then carbonating, as the Brix measurement could be taken on uncarbonated product.

Conductivity probes are often used to indicate whether diet products are to specification, whilst for the actual product an HPLC is normally part of the everyday syrup-room-quality-control equipment in order to ensure that the final beverage is to specification. However, due to the high accuracy of modern densitometers it is possible to measure the density of most diet products in line and thereby control the process.

4.6 Sugar

Sugar can be delivered either as liquid sugar, normally at 67 °Brix, or in granulated form. The type of delivery used is dependent on the usage, cost and availability of the sugar. In some places it is cheaper to dissolve the sugar on site, whilst in others it is cheaper and simpler to buy as liquid sugar. Whatever the requirement, they both have to be stored in bulk storage tanks of 30,000 l, or even more for large factories. The size of the vessel is dependent on throughput, sugar deliveries and space considerations. The vessels must incorporate a CIP system.

4.6.1 Sugar dissolving

Two types of system are used. These are the batch dissolving vessels of 20,000 l capacity, dependent on actual throughput requirements, and the semi-continuous sugar dissolving system. Within the UK, it is normal to use 67 °Brix final sugar solution. It is important that the sugar following dissolving is kept at 18°C, as lower than this viscosity problems arise in processing, whilst at higher values carbonation issues occur. The connection of any liquid sugar line to the factory must be CIP cleanable. Good communication systems must exist between the delivery driver and the syrup room receiving staff. Glucose can be delivered in a similar way, except here the storage vessels should ideally be heated.

For small batch dissolving systems the sugar is delivered in bags whilst for larger installations it is delivered by road tanker, either direct to the mixing vessel or to storage silos. In the smaller systems, the bags are opened and emptied into an elevator, which feeds the vessel. Heated water at some 60°C is fed to the vessel in a predetermined quantity dependent on the amount of granulated sugar added and the required final Brix. The vessel is normally horizontal and fitted with three vertical stirrers. A viewing screen is included in the end of the tank, as well as a sampling point. Regular samples are taken for Brix. This shows a gradual increase in Brix level that levels off. The final amount of water is then added to give the correct brix level. More sophisticated versions of this system use metered amounts of water and sugar, with feedback control of the Brix to give liquid sugar to tighter tolerances. This would use either a density meter or an in-line refractometer. CIP nozzles are incorporated into the top of the vessel to ensure that thorough cleaning takes place. Care has to be taken in the control of the effluent to ensure that this goes to the effluent drain and that the sugar concentration is low, otherwise the effluent cost will be high. For this reason many users feed the waste water to a storage tank and dilute it before discharging to drain, or even solidify it and take to a special waste disposal area. For any tanker delivery it is normal to weigh the vehicle before and after to ensure that the delivered weight corresponds to the ordered and billed

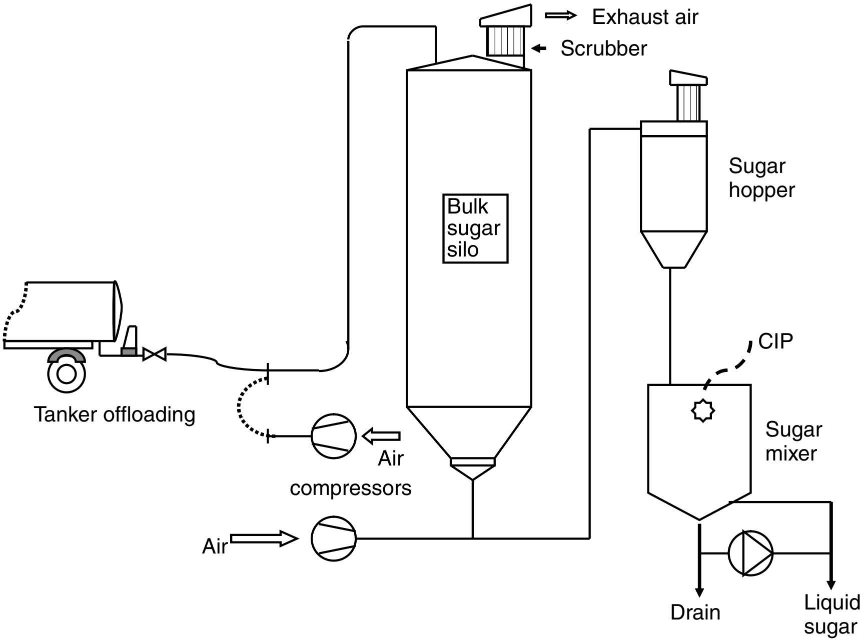

Figure 4.8 Tanker unloading bulk sugar.

quantity. Alternatively, the site can have its own weighbridge. Care must be taken in the delivery area in case of any accidental droppage of sugar. The area must have adequate drainage to an effluent drain and be easily washable.

Continuous sugar dissolving is becoming more popular. A typical unloading facility is shown in Figure 4.8. The sugar is pneumatically conveyed, using either the tanker's own blower or a purpose-built unit on the user's premises to a storage tank. These blowers have air driers to ensure that the air will not introduce moisture that could give rise to problems with the granulated sugar within the silo. It is not usually feasible to have a storage silo for each delivery to ensure full traceability, as silos tend to contain several such delivery loads. However, isolation to one of a few delivery batches is possible. A de-aerating filter is fitted to each silo to extract the sugar dust from the air being expelled. This filter is automatically de-dusted by food quality compressed air, being filtered to 0.01 μm, at regular predetermined intervals. The sugar fines then drop back into the silo. Most silos incorporate a bridge breaking facility, usually a vibrating bottom. On demand the sugar can be either screw or pneumatically conveyed to the dissolving plant. This is usually via a small balance tank that will accurately dose the required quantity of crystal sugar. A silo air drier is sometimes incorporated into the system, especially in regions of high humidity, due to the hygroscopic nature of the granules.

The granulated sugar and water are dosed into a small dissolving vessel, as shown in Figure 4.9, the setting of which exceeds the desired final Brix value.

Figure 4.9 Sugar dissolving system.

Most of the sugar is dissolved by the strong circulation in this tank. The sugar is then passed through a plate heat exchanger thereby allowing quick dissolution of the sugar and also pasteurisation of the final solution. The minimum holding time is normally 40 s. The hot sugar solution is then passed through a de-aerating vessel, filtered and an in-line density meter, via a water meter, ensures the final Brix to a very high accuracy of ±0.1. The sugar solution is then returned to the flash pasteuriser and cooled. A high level of regeneration is incorporated into the flash pasteuriser system. The complete operation is PLC controlled with total logging of all information. The solution is then passed to one of a series of storage vessels.

4.6.2 Liquid sugar storage

These vessels are normally of 30,000 l capacity or more. They are made in type 316 stainless steel to food quality standards. All entries are via the base of the tank to minimise any air entrainment. They are normally sited in a tank farm, where four or more such vessels can be sited. They have high overfill and low and near-empty-level probes that are normally fitted as pressure pads to give a weight estimate of the contents. The two high level probes are installed to ensure no overfilling is possible, whilst the near-empty probe ensures that the system does not pull air and implode the vessel. To this end a hygienic air breather is also fitted to the vessel, often incorporating a UV lamp to ensure that only sterile air is fed to the vessel as it empties. Spray ball systems are installed, as effective cleaning is critical if microbial problems are to be minimised. These sprays need to ensure good coverage of the vessel walls providing sufficient mechanical energy to remove any loose soil. Non-invasive-level measurements can be taken using two ultrasonic transducers clamped to the outside walls of the vessel, one being bottom mounted and the other mounted on the side wall. In this way variations in temperature and density can be compensated for. These transducers transmit a high frequency ultrasonic pulse and receive echoes from the liquid surface or the opposite wall of the vessel.

Accuracies of ±0.2% are claimed. Another method is to use a pressure pad on the base of the vessel. However, such a system is never fully accurate owing to the pipework connected to the vessel and the pumping of product in and out.

4.7 Pre-mixes

A pre-mix is where all the minor ingredients are produced prior to the main batch of syrup. Some of these may require dissolution in warm water, whilst others may have to be dissolved in a weak acid solution, prior to adding to this pre-mix. In some instances where citric acid is delivered in bags this can also form part of the pre-mix ingredients. This leaves only the addition of the pre-mix with liquid sugar, water, possibly juice and another acid such as malic in the main syrup mixing vessel.

'The traceability of food, feed, food-producing animals and any other substance intended to be, or expected to be, incorporated into a food or feed shall be established at all stages of production, processing and distribution.' So states article 18 of EU Directive 178/2002. The implications of this are that systems must be in place so that all ingredients used in the manufacture of carbonated soft drinks are traceable. Most major manufacturers were already satisfying this directive well before its introduction, and several commercially available systems are available on the market. They can be integrated with MRP systems, thereby forming part of the main factory control system.

Minor ingredients are normally delivered in drums, whether as a liquid or powder. Each drum has a specific barcode identification. For ingredients delivered in bags these should be dumped into plastic or stainless steel drums, to which the product barcode can be added thereby ensuring traceability. The bags are normally opened and dumped via a bag dump station incorporating its own dust extractor. This minor ingredients system integrates with the main syrup room system. Major ingredients are delivered in bulk and separately metered and recorded on the main syrup room system. These systems improve batch accuracy and repeatability whilst maintaining batch traceability. It does increase the 'right first time' batches by a significant amount over traditional paper-based systems as well as increasing productivity.

The scheduled work plan is fed into the system, which already has all the recipes loaded. For a given batch size the necessary weighings are calculated and the order of addition listed on the screen. The operator is then prompted for the first ingredient, which they confirm by barcode scanning using RF wireless technology. This gives the ingredient and the lot details which are then recorded. The screens are usually digital with an indicator showing when the weighing is nearing completion. In this way the operator is prompted to slow down the addition thereby increasing the weighing accuracy, as well as the speed at which it is done. If too much of a particular ingredient is added erroneously, the system locks out and can only be restarted by management intervention. This involves re-sizing the batch which, once agreed, is done automatically by the programme. The other advantage of such systems is the updating of stock records for each ingredient. Several work stations can be used. In terms of health and safety it is good practice to install dust extraction at the pre-mix station. These often use a centralised dust extraction system.

For large batches, applicable to long-run lengths on major brands, multi-ingredient weighing systems can be used. These often employ mobile weighing carriages running on a mono-rail track. These carriages are loaded with a weighing bin. The recipe is fed into the main control system, which then sets in motion the automated dosing of each ingredient. The carriage moves around the track to each individual feed station, where material is dispensed in accordance with the recipe. On completion of the batch the carriage can then be fed to the main syrup blending tank. Such systems can easily cater for expansion, provided the site area is large enough.

The actual pre-mix is normally prepared in a small vessel to which the pre-weighed ingredients are added. Often this vessel is equipped with a high shear mixer to ensure complete mixing of difficult-to-dissolve ingredients. This mixer is often fitted in-line and also acts as the transfer pump to the main syrup vessel. The pre-mix would circulate through the mixer back into the pre-mix tank until required for use, when a valve would open allowing the transfer across.

4.8 Pasteurisation

Louis Pasteur demonstrated that it was the multiplication of bacteria that caused wine, beer and milk to go sour and that, by heating the liquid, the bacteria would be destroyed. In 1862, in conjunction with Claude Bernard, he developed the first milk pasteurisation process. It has been found by experimentation that the number of pasteurising unit (PU) can be given by the formula:

$$\text{PU/min} = 1.389^{(T-60)}$$

where T is the temperature in degrees centigrade. Each product will have a required number of PUs which it needs in order to be treated dependent on the risks inherent in the materials used and its shelf life. Two types of pasteuriser are in common use in the soft drinks industry. These are the tunnel and flash pasteuriser.

4.8.1 Tunnel pasteurisation

This is a sophistication of the old retort system, though operating at lower temperatures, where the product is fed into a special vessel which is sealed and heated to a specified temperature, held at this temperature for a set period and then cooled. Except for very small batches this system is rarely used.

This is the least risk scenario. These are only for can and glass bottles with metal caps, although PET bottles can if suitably manufactured be pasteurised, this is not the case for plastic closures. Only low carbonated products are considered, as the pressure built up during pasteurisation would otherwise exceed the internal pressure resistance of the container. A typical tunnel pasteuriser is shown in

Figure 4.10 Tunnel pasteuriser (courtesy of Krones UK Ltd).

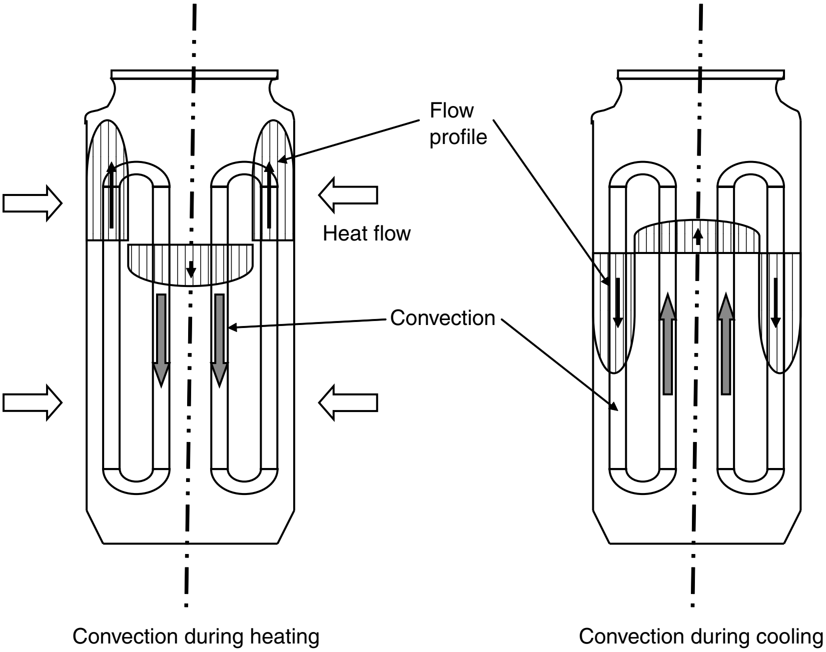

Figure 4.11 Convection flow in a can during tunnel pasteurisation.

Figure 4.10. These machines are relatively sophisticated. They heat and cool the container by the use of water jets whilst passing below these on either a conveyor bed or walking beam. Often they are double-deck machines to accommodate the required throughput in the minimum space. The heating and cooling of a beverage in a container is by convection set up by the external temperature changes along the tunnel bed as illustrated in Figure 4.11.

If we just consider the heating cycle initially, as the water jets contact the container surface they heat this surface up. Through the container wall a temperature gradient exists due to the conduction of heat through the wall. The temperature within the product adjacent to the wall will depend on the wall thickness at that point. This increase in temperature near the container wall will set up convection currents within the bottle. Clearly all pasteurisers and containers are different, thus implying that separate tests for each new container, pasteuriser and product are required. In modern pasteurisers continuous control of the pasteuriser can be provided by logging the temperature of the water jets both along and transversely through the tunnel. One problem that has always been a dilemma is the transverse variability due to blocked jets, etc. This system of monitoring would give an immediate alarm and allow remedial action to be taken. Clearly regular maintenance of the jets would help reduce this risk as would regular checks on the instrumentation including re-calibration.

Using modern control techniques with good instrumentation feedback, control can be achieved at all times to ensure that pasteurisation is occurring within tight limits on a time–temperature basis. These can be recorded on a PC for record purposes which, as discussed in Chapter 11 of this book, is extremely important. It is quite usual to also have a multi-pen chart recorder fitted that will give a manual record of the process, though at one transverse position through the tunnel only. Use of a Redpost at regular intervals actually measures the pasteurisation within the container as it passes through the tunnel. It acts as a check on the pasteuriser performance, as it allows a full print out of the pasteurisation performance at the time it was passed through the system. However, as it only passes through at one position at a time it is a good idea to do three passes using the middle and two sides to ensure uniformity. The time–temperature profile gives the number of PUs the product has been treated to. Typically, the maximum temperature is up to 70°C for 20 min.

A problem that regularly occurs during tunnel pasteuriser is downstream stoppages. This causes the pasteuriser to slow down or worse to actually stop. The problem is preventing the product from over cooking whilst still ensuring that it receives the correct number of PUs. Product spoilage is prevented by rapidly reducing temperatures below 60°C. When the process starts again, the reverse procedure is applied. Control of the conveying speed can also be used to ensure that the correct pasteurisation levels are achieved. A typical tunnel pasteuriser time–temperature chart for water and product is shown in Figure 4.12. A typical pasteuriser has two heating zones: an over temperature zone and a holding zone. Also it has two, sometimes three, cooling zones. The temperature gradient must be gradual at all times to minimise thermal stress and possible container bursting. Most modern pasteurisers recycle the water between chambers to minimise the heating up costs of the water as well as being environmentally friendly. It is normally only the final cooling section water that is sent to drain. This must be very clean as any residues could lead to can corrosion problems. Anti-fouling agents are used within the water system to minimise any jet problems.

These machines can also be used as can warmers. A can warmer is useful in periods of high humidity when the risk of can corrosion is high. This warms the cans

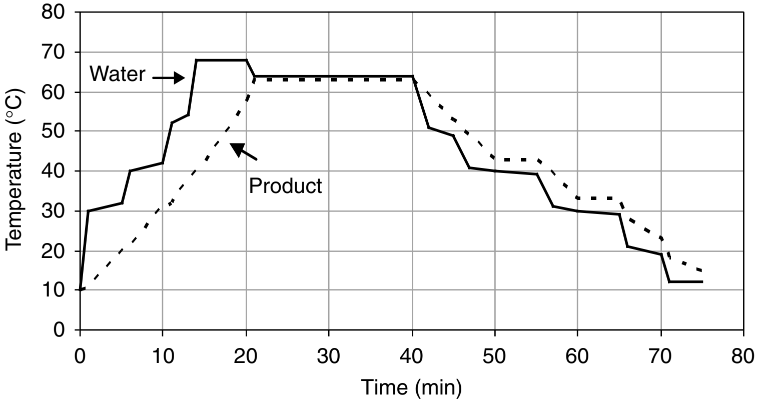

Figure 4.12 Time–temperature graph for a tunnel pasteuriser.

above the dew point and reduces the risk of condensation occurring within the secondary packaging. This can give rise to corrosion within the scoring on the ring pull.

4.8.2 Flash pasteurisation

A flash pasteuriser is basically a hygienically designed heat exchanger. They are normally of plate design but can be tubular if dealing with large fruit cells. A typical system is shown in Plate 4.2. The product is heated and then held at a set temperature in a holding tube. For a known flow rate the residence time can be determined in this fixed diameter tube. After this the product is cooled to the required temperature for filling. During the heating and cooling process regeneration is used to minimise energy costs. Carbonated products can be flash pasteurised within such systems if required, though clearly parts of the system need to be able to withstand the pressures generated. However, it is normal practice to post carbonate. An argument exists that once a product has been flash pasteurised then it should be filled as quickly as possible through the minimum number of processes to prevent re-contamination occurring. With flash pasteurising, it has always been a problem to keep the product free from contamination before it is filled. The use of microbial sprays and good CIP systems on the filler can allay some of these fears, as the product is never exposed to atmosphere once pastereurised. It is also possible to just flash pasteurise only the sensitive components of a beverage and then mix these with the non-sensitive parts: usually water. If this water is treated and then made microbiologically safe by UV treatment this will produce a similar result to treating the whole product but at a lower cost, both capital and operating, with no real extra risk involved. Clearly this would have to be used in conjunction with a modern metering system straight through to the filler, so that no contact with possible contamination could occur. The normal limits for a flash pasteuriser are 30–60 s at 85–93°C. This would give, at the top end, PUs of 51,188 according to the formula above. Control within

±1 PU is possible, which when one considers that this represents a deviation of 0.1°C shows how well these systems have been developed.

The plates are designed to distribute the liquid, whether product or process, uniformly across the width of the plate. The main plate area is designed to promote turbulent flow, which in turn implies improved heat transfer, taking into account the need for minimal pressure drop across the plates. A flash pasteuriser is normally constructed of plates which alternatively carry product and heating or cooling medium. To give maximum regeneration, the product being heated is placed next to the product being cooled. It is only at the end of the heating cycle that hot water is needed and at the exit of the unit that low outlet temperatures are needed. Here it is common to use food quality propylene glycol as the cooling medium. The plates can be welded or gasketed together, it also being possible to glue these gaskets in position if required. These plates are then held together in a frame. The gap between these frames allows for fruit cell products to be treated as gaps of up to 12 mm are available. It is normal to have a pre- and a post-tank. These are used if a problem occurs during processing and it is necessary to re-circulate the product through the flash pasteuriser again. This implies that great care is required in the design and specification for such systems. They need to be fully instrumented with an efficient plc control system. A flash pasteuriser is installed to minimise the risk against product spoilage. The system design must ensure that this occurs.

4.9 Clean-in-place systems

Sanitation is principally undertaken to remove all undesirable matter from any surface in contact with the product to a level at which the residues remaining present minimal risk to the product during its shelf life. By shelf life we imply the stated shelf life plus a reasonable period afterwards, such that due diligence can be seen to apply. Undesirable matter includes micro-organisms, ingredient residues, foreign bodies and cleaning materials. The last one is often forgotten about, and it is critically important to ensure that any chemicals used for sanitation are effectively removed prior to the plant re-commencing production. If we are to ensure any sterility within the filling process it is necessary to ensure that adequate cleaning regimes are in place. It is normal to have a series of tanks to hold the various CIP chemicals, including water, such that several plant items can be cleaned at once. The main aim of a CIP system is to provide sufficient contact time for the chemicals, at the required temperature, whilst at the same time allowing sufficient mechanical 'scouring' of plant and pipelines, at a velocity in the turbulent regime in excess of 1.5 m/s. Hence a CIP system needs to use the four energy factors of mechanical or scouring energy, chemical energy, thermal energy and time. A typical system is shown schematically in Figure 4.13. These systems normally operate on the following basis:

1. Rinse the system out for a predetermined time using water to drain.
2. Circulate 1.5% hot caustic at 80°C for about 15 min. To ensure that the required temperature of the caustic has been reached it is measured at the

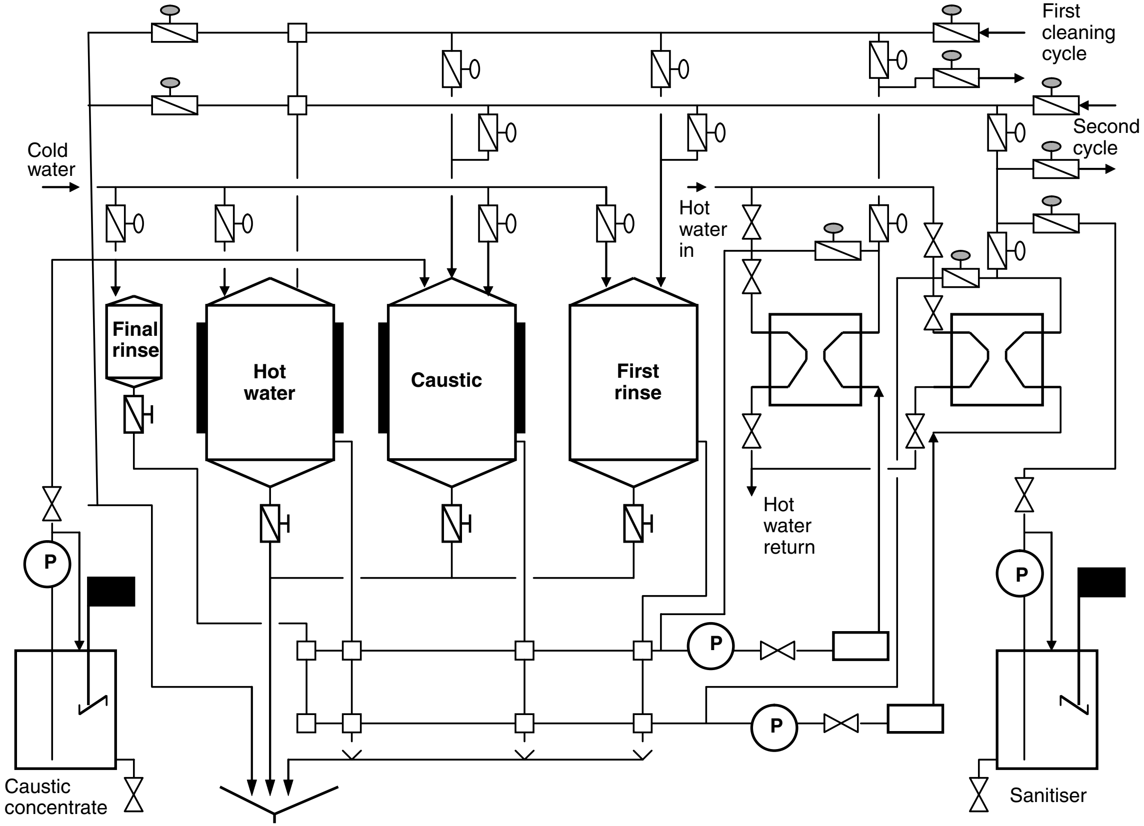

Figure 4.13 CIP system schematic.

exit from the system being cleaned: this ensures that all parts to be cleaned have been subjected to a minimum caustic temperature. The clean cycle time is only taken when the temperature is equal to or greater than the set temperature. The caustic lye is returned to the hot caustic tank through filters. It is usual to use an in-line heat exchanger to heat the lye.

3. Hot water is then circulated at 75°C for 15 min, allowing the interface with the caustic to go to drain. This is done by time, as the flow rate and pipe diameter are known. For safety reasons a conductivity probe is often used as a secondary device to ensure no lye is left within the system. The main hot water is returned to the lagged hot water tank via a filter.
4. A cold water rinse back to the main system water tank is then used. The water, filtered to the order of 2 μm absolute just prior to the tank inlet, within this tank is then used for the next CIP as the initial rinse to drain. Sometimes a sanitiser is added to the final cold water rinse. This needs to be dosed in accurately, and is kept in the cleaned system until just prior to use, where it is cleaned with clean rinse water.

For certain products an acid also has to be used to ensure full cleaning. This is often the case when dealing with fruit pulp, which tends to stick to pipe surfaces.

The use of such a system is mandatory if product spoilage is to be minimised. Clearly for each product a different set of parameters may have to be used if certain product residues are to be completely removed. Some soils may have dried onto surfaces and be very difficult to remove. Each plant area to be cleaned will be different and a separate programme will be required for each. In any system design separate circuits for different process areas are required, such that efficient cleaning can take place whilst other plant items are operating normally. Gone are the days when cleaning was only done at weekends. Now it quite often needs to be done several times a day especially when dealing with sensitive products and processes. If a CIP is not done regularly any soils will be that much harder to remove. It is imperative that a regular cleaning routine is set in place. Full records must be kept of each cleaning operation; this includes records of all return temperatures, flow rates, times and chemical concentrations by interfacing with a simple spreadsheet computer programme.

The CIP chemicals normally come in IBCs, which can be stored in an isolated area away from all ingredients prior to use. They are normally then lifted onto a small platform and connected to the CIP system. For large installations, the chemicals can be bulk delivered to storage vessels on site. Safety to operatives and spillage risks need to be considered in this part of the design.

It is important to ensure that the final rinse water is filtered to at least 2 μm absolute to minimise any risks. All temperature, dosing meters and concentration probes must be regularly re-calibrated to ensure that the system will effectively clean at all times. For tanks spray balls are used. It is important that the cleaning fluids do not settle in vessels, as this can lead to scum lines which are difficult to remove. Full contact for a given period is required with continuously moving liquid to achieve optimum cleaning conditions.

4.10 Process plant hygiene requirements

Poorly installed plant and pipework will give rise to microbial problems. As discussed in the previous section, CIP will ensure that all these can be kept clean. It can only do this if the plant itself has been well designed and installed. Problems occur where there are deadlegs in pipe systems, at pipe joints and where valves are installed. Only accredited stainless steel welders, working to agreed specifications, should be employed.

Micro-organisms can attach to surfaces and ultimately form layers of biofilms or can be incorporated in the soil. The numbers of microbes will multiply dependent on time, temperature, available water, nutrient supply and microbial agents. Often this rate of increase can be exponential. It is important in any design that no area is designed in to allow these microbes to grow. In the literature many instances of poor design giving rise to expensive costs due to product recalls, and worse illness and even death, are given. It is worth spending a bit more on plant items and attention to detail to minimise such risks. This begins at the system specification stage, and includes not only major plant items but the valve choices and the pipework layout. Clearly for all these systems sanitation needs to be addressed. It is no use having a well-designed plant if no CIP plant is included. For this reason all plants must be capable of withstanding the chemical and temperature treatments that they are going to be subject to during their lifetime. Most major plant items are depreciated over ten years and have up to twenty years of life. This factor has also to be taken into account. Unfortunately there are few international hygiene standards, and those that do exist are mainly associated with the dairy industry. The EC Directive 98/37/EC does have a short relevant section which states that plants intended for the preparation and processing of foods must be designed and constructed so as to avoid health risks. It has seven hygiene rules that must be observed: the suitability and cleanability of materials in contact with food, surface finish and design features such as joints, absence of ridges and crevices, avoidance of the use of fasteners such as screws and rivets (as these can come loose and fall in the product), the design of internal angles and corners, drainage of residues from plant surfaces, dead spaces and voids and finally shaft seals and bearings. Compliance to this directive is shown in the CE mark. This directive also includes a section that states that plant suppliers must indicate the recommended cleaning chemicals and cleaning methods for both open items such as conveyors and closed items such as pipelines where CIP systems will be used.

Materials in contact with the product must be resistant to chipping, cracking, flaking, corrosion and abrasion as well as preventing the penetration of unwanted material. They must have adequate strength over the expected temperature range, be non-toxic, non-absorbent and non-tainting. Whilst various grades of stainless steel exist, the use of type 316 seems to satisfy all these requirements. The surface finish is equally important, as soiling can be difficult to remove if the surface roughness is high. For a process plant where the product is in contact with the surface, and CIP systems need to be employed, a surface finish of 0.8 μm Ra should be used.

Due to wear and tear with age any surface will deteriorate. Inspections of pipe surfaces needs to be carried out periodically to ensure that if this is the case, then that section of pipe can be replaced. Welds and joints on vessels, such as syrup mixing tanks, need to be smooth and continuous. Flanged joints must be carefully sealed with a gasket to prevent any possible micro-organism ingress. This applies in flash pasteurisers, for instance. All fasteners should be very carefully considered. Besides the fact that they can come loose and fall into the product, they do present a microbial risk in themselves. They need to form a bacterial tight seal at all times. Self-drainage from any plant item must not be impaired. It must be designed into any process system. Like the problem of dust in the corners of a room, it is important to ensure that no internal angles or corners exist where microbial growth could occur. They must be well radiused.

Probably the most important criteria in any pipeline is to ensure no deadlegs. Whilst the design of the system may well not include any, it is not unknown for them to be introduced during installation for expediency. If they are unavoidable then they must be readily accessible for cleaning. Where a bearing or shaft seal is in the product area they must use edible lubricant that will not taint the product. How they can be cleaned as part of the CIP system needs to be carefully considered. Doors, dust covers and panels must be designed and maintained to prevent the ingress of contaminants. Ideally they should be sloped to allow drainage when cleaning. Instrumentation must be constructed of acceptable materials for food use and must not contain any liquid that could taint the product; such items include pressure gauges. The design of sampling devices must be carefully considered, as they can lead to possible contamination.

4.11 Syrup room building design

Similar arguments apply to the design of the building such as the ones that apply to process plant, and the hygienic design of a building is as important as the hygienic design of the plant within it. It needs to be designed to minimise ingress of vermin including birds. All surfaces must be readily cleanable and the drainage system must withstand corrosive chemical attack from cleaning agents. Liquid sugar and concrete do not go well together. Old syrup rooms used to be potholed due to the aggressive nature of sugar. The buildings need to be split into several parts, so that hazards can be controlled. In the author's experience the best compromise, as all designs are compromises due to the large number of factors that must be satisfied, not least being commercial ones. Raw materials coming in bags and sacks on pallets can well be contaminated. They need to be isolated from the actual process area. These should be so designed that operatives should weigh out the ingredients from these bags and feed them into a hygienic container, using a sieve to collect any possible unwanted bag or other contaminant. These should then be stored in a separate ingredients room. This ingredients room can then contain the minor ingredients weighing station and the pre-mix vessels. As this is this area where the ingredients are exposed, it is classified as high risk area. Special attention to its design is required. It should be a separate hygienically designed room with security doors. The standard of floor and wall finish must be of a high hygienic order. This is normally a food grade floor, such as epoxy or tiled, with a food quality wall covered to the floor. This will normally have a suspended ceiling. The light fittings must have diffusers fitted, and care must be taken to prevent any vermin, insect or bird ingress. All holes for pipework through the walls need to be carefully considered to ensure that they are well sealed.

An area primarily for liquid sugar and citric acid, which can be delivered in bulk, needs to be provided. If juice products are being used then juice tanks need to be provided. As these vessels will be constructed of 316 stainless steel with suitable valves and pipework that can be located in the main syrup room. The main syrup room with the metering plant and final product batch tanks, if used, can be installed in the same area as the storage vessels. In all cases the product is fully enclosed and the risk of airborne contamination is low. Often this area is sited in the main factory area for ease of access by staff.

The main ingredient store should be sited with an external door. No especial care should be taken with the construction of this room except that the floor needs to be constructed so as to prevent possible deterioration due to chemical attack. The CIP system should ideally be installed in a separate room, as the chemicals for cleaning can be aggressive. However, owing to space and cost constraints they are often installed in the main factory, in a side area that is well bunded. For safety reasons it is normal to ensure that safety showers are installed in this area. It is normal to rack the palletised ingredients. These should allow all pallets to be stored off the floor so that the area can be effectively cleaned.

The area should include a specially designed cleaning system specifically for walls and floors. These normally have a ring main from which cleaning lances can be connected. They can wash down with rinse water, hot water or chemicals to a predetermined programme.

It is important to have a hand wash bay on entering the pre-mix area, such that it is mandatory that all staff to wash their hands on passing through it. The best design for these is a corridor with wash basins sited such that they present a barrier that has to be gone round purposefully to avoid using them. Hygienic air hand driers are normally used in conjunction with these hand wash facilities, though the preference these days seems to be for disposable paper towels. Ideally all employees working in these sensitive areas should be encouraged to take national hygiene courses and obtain the necessary qualifications.

4.12 Future developments

For large plants the trend will continue for in-line blending and carbonation. This is ideal for major brand production. For smaller batches batch-continuous production to large (ca. 30,000) vessels will be usual. It is far better to ensure that you have the Brix correct before carbonating. In this way the process is fully in control and product loss is minimised. Such systems allow the plant to operate at the lower end of any specification and thus generating money with minimum risk to the product. The increasing cost of transport could well see the return of smaller factories feeding specific areas of a country. In this case it is likely that one mass flow metering skid could feed direct on-line to the carbonator for the long-run length products, whilst a second mass flow skid would feed syrup vessels of 10,000 l capacity for the short-run length products. As these short-run length products are more and more likely to become specialised products of high value the accuracy of metering and getting it right first time is of paramount importance. This can only be achieved using highly accurate and highly reproducible measuring equipment that also allows full traceability of product ingredients.

5 Carbon dioxide, carbonation and the principles of filling technology

David P. Steen

5.1 Introduction

Carbonated water is water containing carbon dioxide and is produced by passing carbon dioxide under pressure through water. To produce a ready to drink (RTD) carbonated soft drink, carbonated water is combined with a syrup.

Naturally occurring carbonated mineral waters have been around for a long time. These effervescent waters exist due to excess carbon dioxide in an aquifer having dissolved under pressure. Whilst claims for the medicinal properties of these mineral waters have been grossly exaggerated, the presence of carbon dioxide does make aerated waters and soft drinks both more palatable and visually attractive. The final product sparkles and foams. It gives the 'fizz' to carbonated drinks, the cork pop and bubbles in champagne and the head to beer.

The first non-carbonated soft drinks appeared during the seventeenth century. Joseph Priestley produced the first man-made palatable, carbonated water in 1767, whilst three years later a Swedish chemist Torbern Bergman invented the process that produced carbonated water from the reaction between chalk and sulphuric acid thus allowing the commercial production of aerated mineral water. A few years later in 1783 Jacob Schweppe, a young watchmaker and amateur scientist, perfected an efficient system for manufacturing carbonated mineral water and founded the Schweppes Company in Geneva. He relocated to Drury Lane, London, England in 1790. These machines were mass manufactured for sale to others. Since then the addition of flavourings to aerated waters has seen the development of major soft drinks brands throughout the world. To meet the need for carbonated soft drinks the soda fountain was developed by Samuel Fahnestock in the USA in 1819. The first US patent was issued for the 'means of manufacture of imitation mineral waters' in 1810 to Simons and Rundall. However, it was not until 1832 that carbonated beverages became popular, when John Mathews developed his machine for carbonating water. The notable achievements of patenting the crown cork by William Painter in 1892 and the automatic production of glass bottles using a glass blowing machine in 1899 by Michael J. Owens, at last allowed carbonated soft drinks to be successfully bottled without significant loss of carbonation. Since then developments in closure technology, glass and PET bottle production, can design and manufacture, syrup making methods, carbonation technology and filling machine developments as well as secondary packaging developments have led to the worldwide beverage industry as we know it today.

In this chapter, we will explore the basic chemistry of carbon dioxide, how it is produced, the required specification, delivery to the customer and storage on site. We will then look at methods of vaporising the gas and how this gas can be effectively used to carbonate soft drinks. An introduction to carbonated soft drinks filling is then considered, forming the basics for a more detailed discussion of modern filling techniques in Chapter 6.

5.2 Carbon dioxide

Carbon dioxide was one of the first gases to be described as a substance distinct from air. The Flemish chemist Jan Baptist van Helmont in the early seventeenth century noted that when he burned charcoal in a closed vessel, the mass of the resulting ash was much less than that of the original charcoal. He interpreted that the rest of the charcoal must have been transmuted into an invisible substance he termed a '*gas silvestre*', which we now know as carbon dioxide. Carbon dioxide was studied more thoroughly by a Scottish professor of medicine, Joseph Black. He found that limestone (calcium carbonate) could be heated or treated with acids to yield a gas that he called 'fixed air'. He observed that this fixed air was denser than air and did not support either flame or animal life. He also found that this gas would, when bubbled through an aqueous solution of lime (calcium hydroxide), precipitate calcium carbonate. He used this phenomenon to demonstrate that carbon dioxide is produced by animal respiration and microbial fermentation.

Carbon dioxide is a colourless, non-toxic, inert gas that is virtually tasteless and is readily available at a reasonable cost. It is soluble in liquids, the degree of solubility increasing as the liquid temperature decreases, and can exist as a gas, liquid or a solid. When dissolved in water it forms carbonic acid. It is carbonic acid that produces the acidic and biting taste found in carbonated waters and soft drinks. Above a certain level of carbonation carbon dioxide has a preserving property, having an effective antimicrobial effect against moulds and yeasts. It achieves this with moulds by depriving the moulds of oxygen required for growth whilst with yeasts it tends to stop the production of more carbon dioxide as a by-product of the fermentation of sucrose to ethanol.

Carbon dioxide gas is heavier than air, having a density of 1.98 kg/m^3 at 298 K, some 1.5 times that of air. It has a molecular weight of 44.01 and does not burn, though it will support the combustion of magnesium. As it is fully oxidised, it is not very reactive. It is a fairly stable compound that only decomposes at very high temperatures into carbon and oxygen. It can cause death by suffocation if inhaled in large amounts. The gas is easily liquefied by compression and cooling. When liquid carbon dioxide is quickly decompressed it rapidly expands and some of it evaporates, removing sufficient heat so that the rest of it cools into solid carbon dioxide.

Carbon dioxide is a waste product in organisms that obtain energy from breaking down sugars or fats with oxygen as part of their metabolism. This process is known as cellular respiration. This includes all animals, plants, many fungi and some bacteria. Plants utilise carbon dioxide during photosynthesis thereby constructing carbohydrates. In higher animals carbon dioxide is primarily held in solution in the blood which transports it from the body's tissues to the lungs to be exhaled. It makes up some 0.038% by volume of the earth's atmosphere. In various parts of the world it is formed underground and issues from fissures within the earth. This happens notably in Italy, Java and Yellowstone National Park in the USA. Carbon dioxide is a known contributor to the greenhouse effect, the balance in the atmosphere increasing each year thus disrupting the natural carbon dioxide cycle. The initial carbon dioxide in the earth's atmosphere was produced by volcanic activity. This was essential for a warm and stable climate conducive to life. Current volcanic releases are some 1% of that released by human activities. The earth's oceans contain a large amount of carbon dioxide in the form of bicarbonate and carbonate ions and much more than that found in the atmosphere. The carbon dioxide is in the form of bicarbonate and carbonate ions, the bicarbonate being produced in reactions between rock, water and carbon dioxide. An example is the dissolution of calcium carbonate:

$$\mathrm{CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-}$$

Such reactions tend to buffer atmospheric changes. Reactions between carbon dioxide and non-carbonate rocks also add bicarbonate to the oceans. These reactions can later be reversed to form carbonate rocks thereby releasing half of the bicarbonate as carbon dioxide. This has produced large quantities of carbonate rocks over the last few million years. So much now exists that if all these carbonate rocks were converted back to carbon dioxide, the resulting level of carbon dioxide would weigh 40 times as much as the rest of the atmosphere. Eventually most of the carbon dioxide added to the atmosphere will be absorbed by the sea and become bicarbonate ions, the process taking about one hundred years to achieve.

Carbon dioxide can exist as a solid, a liquid or a gas. The effect of temperature and pressure on the state of carbon dioxide can be seen from the phase diagram as shown in Figure 5.1. At the triple point carbon dioxide can exist simultaneously in the three states as a solid, a liquid or a gas by just a small perturbation. All phases are in a state of equilibrium at the triple point. This exists at 5.11 bar and −56.4°C. Above 31°C it is impossible to liquefy the gas by increased pressure. This is termed the critical point. At normal temperatures and pressures carbon dioxide is a colourless gas. At high concentrations it has a slightly pungent odour. Carbon dioxide cannot exist as a liquid at atmospheric pressure. Liquefying occurs by compression and cooling between the pressure and temperature limits at the triple point and the critical point. Above the critical point of 31°C it is impossible to liquefy the gas by increasing the pressure above the corresponding critical pressure of 73 bar. When liquid under pressure is released to the atmosphere it is released as a gas and a solid only. This appears as a dense white cloud because of the solid content

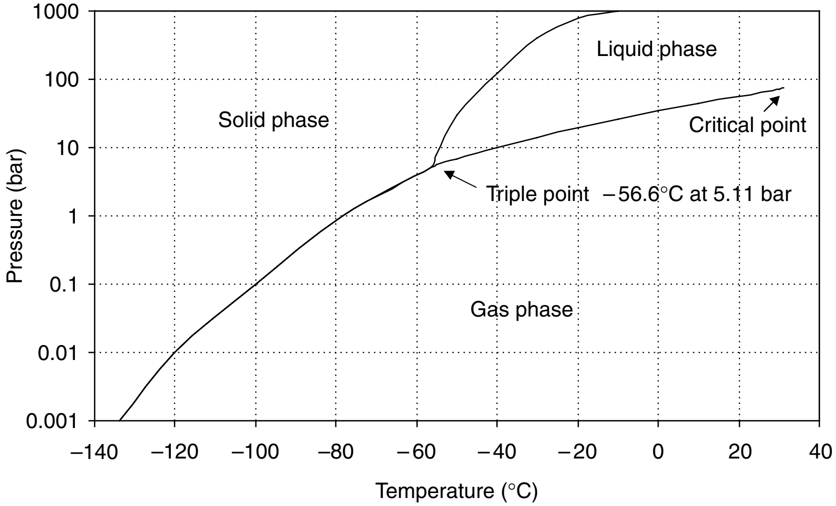

Figure 5.1 Carbon dioxide phase diagram.

and the condensation of atmospheric moisture at the low temperatures obtained. The solid falls to the ground as snow. The compression of this snow forms a translucent white solid known as dry ice.

As carbon dioxide regulates the breathing function, an increase in concentration causes an increased breathing rate. The Occupational Exposure Standard (OES), from EH40, which is updated annually, is 0.5%. However, changes in the breathing rate may not be noticed until the concentration reaches 2%. At this concentration the breathing rate increases to about 50% above the normal level. Prolonged exposure at this level for several hours may cause a feeling of exhaustion and a headache. At higher concentrations carbon dioxide may cause asphyxiation and can temporarily paralyse the respiratory system. Breathing in a rich carbon dioxide atmosphere can cause immediate rapid breath and loss of consciousness. Symptoms of asphyxiation can include rapid and gasping respiration, nausea, vomiting, cyanosis and rapid fatigue. This may lead to loss of consciousness or death from anoxia. Hence the hazards associated with the use of carbon dioxide need to be explained to any personnel who may be exposed to it.

5.3 Production of carbon dioxide

Carbon dioxide is produced commercially by several different processes. These include the combustion of fuel oil, the reaction between sulphuric acid and sodium bicarbonate, the extraction of carbon dioxide from the flue gas of a boiler or similar heating facility, the distillation of alcohol and the fermentation of beer. It can also be extracted from waste gas streams. Table 5.1 shows the various possible processes used to produce carbon dioxide. Following this extraction the gas must then be

Table 5.1 Various carbon dioxide production systems

Feedstock	By-product from	Throughput tonne/h
CO_2 from fermentation	Brewing fuel ethanol distilleries	≤8
CO_2 from solvent-based acid gas removal systems	Hydrogen Ammonia Methanol Other syngas Processing Natural gas Sweetening	1–20
CO_2 rich off-gas	PSA hydrogen Mineral processing	0.1–20
CO_2 lean gas	PSA hydrogen purification Direct iron ore reduction	0.1–20
Flue gas	Process steam boilers Power plants Gas engines	0.1–20
Oil or natural gas	N/A	0.1–1
Landfill gas processing	N/A	

cleaned to ensure it is free from any impurities and is fit for the purpose. The most economical sources of carbon dioxide are carbon dioxide wells and natural gas sweetening or synthetic gas purification by-products.

5.3.1 Fermentation

When a sucrose-based solution is mixed with yeast and oxygen in a fermenter, carbon dioxide vapour and alcohol are produced. The carbon dioxide can then be passed through a separator to remove trace carryover of foam. Once the foam has been removed the carbon dioxide is compressed. It is then scrubbed by water in a packed tower, removing water-soluble impurities such as alcohol and ketones. A typical process flowchart is shown in Figure 5.2. The system can operate with inlet purity as low as 80% recovering up to 99.9% CO_2. Such a plant can yield up to 99.998% pure carbon dioxide. Such plants operate in both breweries and distilleries. This process normally provides the cheapest source of carbon dioxide when it is available in sufficient quantity.

5.3.2 Flue gas recovery

These systems can be directly fired from a self-contained system designed specifically to produce a flue gas for carbon dioxide recovery or be a recovery system

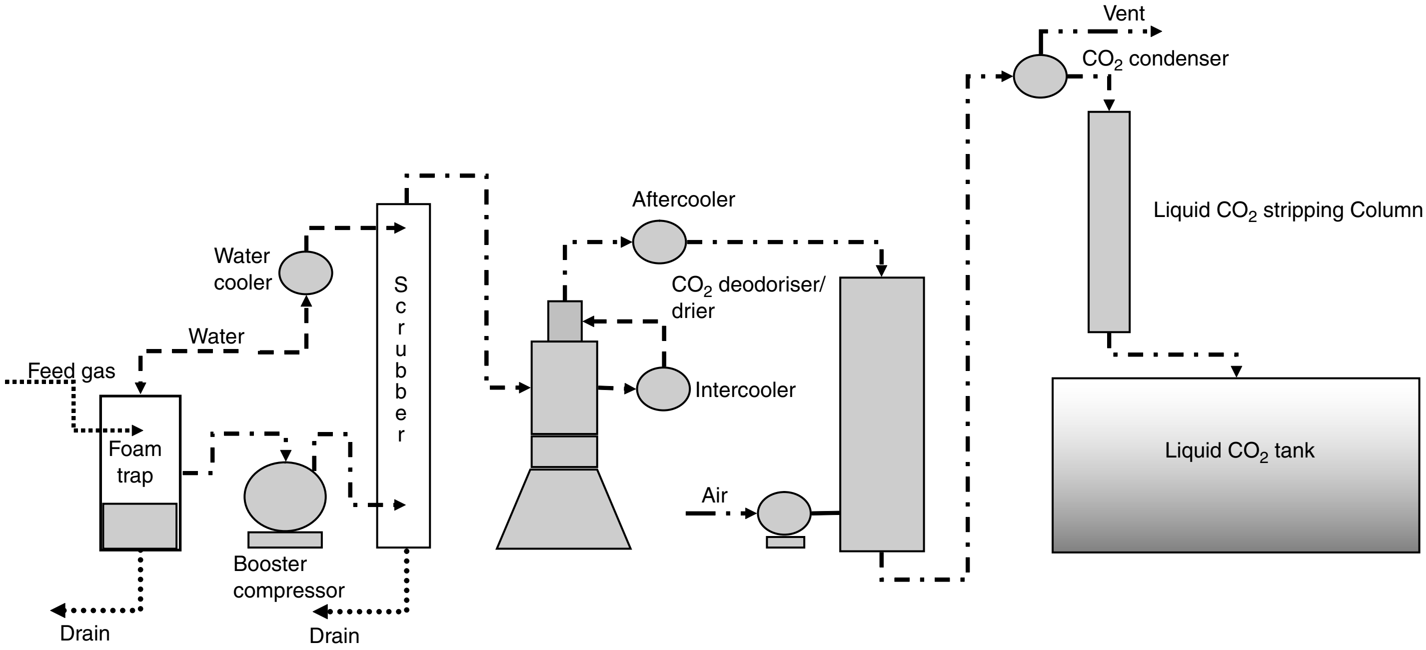

Figure 5.2 Typical carbon dioxide fermentation recovery system.

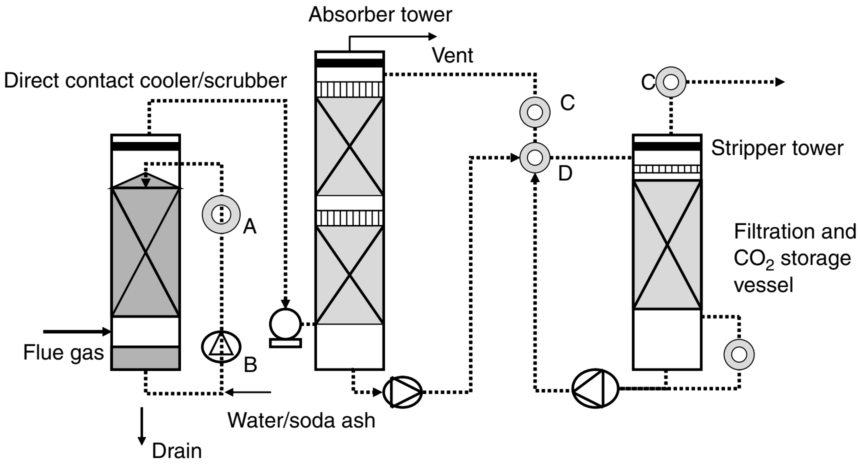

Figure 5.3 Carbon dioxide production by flue gas recovery. (A) Recirculation cooler, (B) recirculation pump, (C) cooler, (D) lean/rich exchanger.

from existing steam boilers. They are normally gas oil or natural gas fired. This is based on burning a hydrocarbon fuel such as light oil or natural gas specifically to produce carbon dioxide. The flue gas from this process, which contains less than half a percent of oxygen by volume, is cooled and scrubbed to remove any impurities that may be present. The resultant flue gas is then passed through an absorbent tower where it is contacted with a carbon dioxide absorbing solution. The resultant absorbing solution, rich in carbon dioxide, is pumped to the stripper tower. The heat from combustion of the fuel is used to release the carbon dioxide in vapour form from the absorbing solution. The absorbing solution is then recycled and reused. The resultant carbon dioxide vapour is then cooled and further treated to meet the requirements for use within a beverage. Recovery levels in excess of 95% are possible. A typical system is shown in Figure 5.3. The consumption of steam is the single most important cost item. Gas turbines can be used but normally give rise to high energy costs and are normally discounted. Large manufacturers of aerated waters and carbonated soft drinks manufacture their own carbon dioxide on site. They purchase packaged systems thereby reducing their operating costs.

5.3.3 Membrane separation systems

These have been around for some time, but until recently the membranes were not reliable enough in operation to be commercially viable. They purify CO_2 from waste gas streams with low CO_2 concentrations. They can recover CO_2 down to a level of 8%, though commercially greater than 20% is thought viable. The process operates at pressures less than 10 bar. The membranes use the fact that CO_2 and

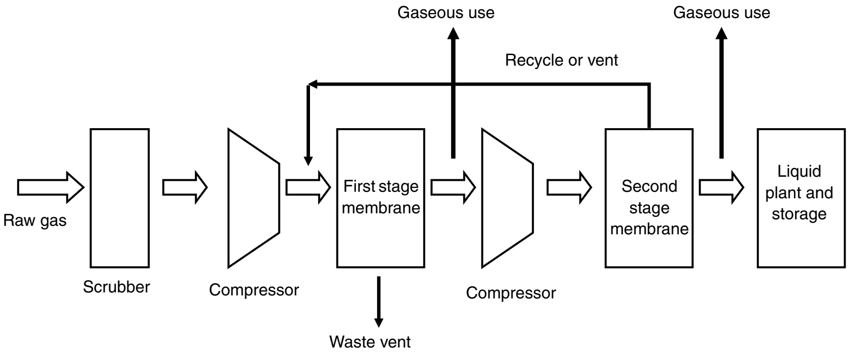

Figure 5.4 Membrane CO_2 recovery system.

water vapour are fast gases that quickly permeate the membrane allowing nitrogen to flow through the fibre bores as the waste stream. Fast gases are hydrogen, helium and water vapour, whilst the moderately fast gases are carbon dioxide and hydrogen sulphide. The slow gases that will not permeate the membrane include the aliphatic hydrocarbons, nitrogen and argon. It is very efficient to separate CO_2 from nitrogen and methane, but it is difficult to separate gases with similar permeation rates like CO_2 from oxygen and CO_2 from hydrogen. It will give purity levels up to 95%. The process is illustrated in Figure 5.4. As soft drinks require much higher levels of purity it can be considered as the first process only to be followed by traditional MEA systems that use wet chemical processes as described in Sections 5.3.1 and 5.3.2.

5.4 Specification of carbon dioxide

The European Industrial Gases Association working with the Compressed Gases Association of America and the International Association of Beverage Technologists has prepared a specification for liquid carbon dioxide for use in foods and beverages. This is shown in Table 5.2. It is to this minimum standard that all carbon dioxide need be delivered to soft drinks and aerated mineral water manufacturers. The user must take great care when using carbon dioxide to ensure that it is fit for the purpose. Actual scares such as the benzene incidents and the risk of contamination from nuclear plants have to be considered. None of us know what the next possible incident might be. It is our duty to ensure that any possible risk is minimised. All supplies must have a certificate of conformance for that particular batch. The supply chain must be regularly audited, including the actual carbon dioxide manufacturing plant, storage and distribution to site. A full HACCP of the site installed system is required to ensure that any inherent risks are minimised. A list of possible impurities is given in Table 5.3. Dependent on the method of carbon dioxide production then the certificate of conformation must include analytical checks for each batch on the relevant listed compounds. These analytical checks

Table 5.2 Commodity specification for carbon dioxide (CGA/EIGA limiting characteristics).

Component	Concentration
Assay	99.9% v/v min
Moisture	50 ppm v/v max (20 ppm w/w max)
Acidity	To pass JECFA test
Ammonia	2.5 ppm v/v max
Oxygen	30 ppm v/v max
Oxides of nitrogen (NO/NO_2)	2.5 ppm v/v max each
Non-volatile residue (particulates)	10 ppm w/w max
Non-volatile organic residue (oil and grease)	5 ppm w/w max
Phosphene[a]	$\leq$0.3 ppm v/v
Total volatile hydrocarbons (calculated as methane)	50 ppm v/v max of which 20 ppm v/v max non-methane hydrocarbons
Acetaldehyde	0.2 ppm v/v max
Benzene	0.02 ppm v/v max
Carbon monoxide	10 ppm v/v max
Methanol	10 ppm v/v max
Hydrogen cyanide[b]	$<$0.5 ppm v/v
Total sulphur (as sulphur)[c]	0.1 ppm v/v max
Taste and odour in water	No foreign taste or odour

[a] Analysis necessary only for carbon dioxide from phosphate rock sources.

[b] Analysis necessary only for carbon dioxide from coal gassification sources.

[c] If the total sulphur content exceeds 0.1 ppm v/v as sulphur then the species must be determined separately and the following limits applied:

Carbonyl sulphide: 0.1 ppm v/v max
Hydrogen sulphide: 0.1 ppm v/v max
Sulphur dioxide: 1.0 ppm v/v max

need to be carried out to the ISBT agreed standards. The risk of contamination is very real. If too much gas is withdrawn off the top of the tank then contaminants can build up due to distillation of the liquid carbon dioxide within the tank. Other possible risks are oil contamination from the transfer pump between the delivery tanker and the user's tank, degradation of the delivery hose, contaminated hose connections by particulates, water, oil or mud or contamination by the backflow of cleaning fluids from the user's process. Dedicated tankers are required, which are not used on nuclear plants or such, where a risk of cross contamination exists. As the supplier guarantees the quality of the carbon dioxide with a certificate of analysis for each batch delivered, the need to analyse the carbon dioxide is not felt to be necessary for the users.

5.5 Delivery to the customer

Carbon dioxide is delivered as a liquid, most frequently by road tanker. It is then transferred to pressurised vessels of 5–50 tonne capacity and held at a pressure

Table 5.3 Possible trace impurities by source type (excluding air, gases and water).

Component	Combustion	Wells/geothermal	Fermentation	Hydrogen or ammonia	Phosphate rock	Coal gasification	Ethylene oxide	Acid neutralisation
Aldehydes	✓	✓	✓	✓		✓	✓	
Amines	✓			✓				
Benzene	✓	✓	✓	✓		✓	✓	✓
Carbon monoxide	✓	✓	✓	✓	✓	✓	✓	✓
Carbonyl sulphide	✓	✓	✓	✓	✓	✓	✓	✓
Cyclic aliphatic hydrocarbons	✓	✓		✓		✓	✓	
Dimethyl sulphide		✓	✓		✓	✓		✓
Ethanol	✓	✓	✓	✓		✓	✓	
Ethers		✓	✓	✓		✓	✓	
Ethyl acetate		✓	✓	✓		✓	✓	
Ethyl benzene		✓		✓		✓	✓	
Ethylene oxide						✓	✓	
Halocarbons	✓					✓	✓	
Hydrogen cyanide	✓					✓		
Hydrogen sulphide	✓	✓	✓	✓	✓	✓	✓	✓
Ketones	✓	✓	✓	✓		✓	✓	
Mercaptans	✓	✓	✓	✓	✓	✓	✓	
Mercury	✓					✓		
Methanol	✓	✓	✓	✓		✓	✓	
Nitrogen oxides	✓		✓	✓		✓	✓	✓
Phosphine					✓			
Radon					✓			✓
Sulphur dioxide	✓	✓	✓	✓	✓	✓		✓
Toluene		✓	✓	✓		✓	✓	
Vinyl chloride	✓					✓	✓	
Volatile hydrocarbons	✓	✓	✓	✓		✓	✓	
Xylene		✓	✓	✓		✓	✓	

Examples of specific analytical methods are given in the ISBT document '*Analytical Methods for CO_2 analysis*' as prepared by an adhoc working group of the European Industrial Gases Association working in conjunction with the Compressed Gases Association of America and the International Society of Beverage Technologists (ISBT).

in the region of 20.5 bar at −17°C, the temperature being maintained by the use of a small refrigeration unit. This is shown schematically in Figure 5.5. From the phase diagram all we require to do to change from the liquid to the gas phase is to vaporise the liquid using either steam, water or electricity. This is normally done in tubular heat exchangers. Electric vaporisers are normally only used on very small plants or as standby equipment because of the high energy cost of operating them. The most common system is to use steam, which has traditionally always been available on soft drinks plants for bottle washing, pasteurisation and factory heating. With the continued demise of the returnable glass bottle, the amount of

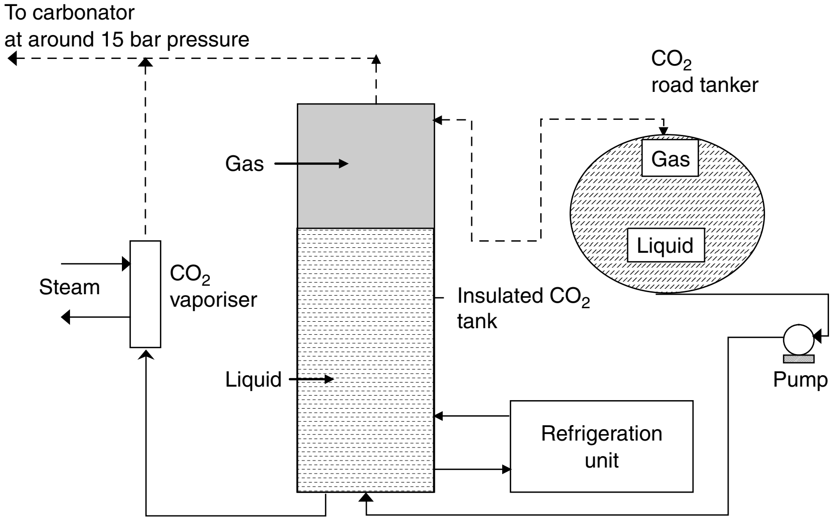

Figure 5.5 Carbon dioxide delivery schematic.

steam consumed and therefore the amount of steam required to be generated is reducing. This is only partly made up by the increasing requirement to pasteurise products. The use of water is becoming more attractive as it is cheaper to use and the process actually reduces the temperature of the water, though not by a significant amount. This saves subsequent product cooling costs as well as the cost of steam generation. A typical 2 tonne/h carbon dioxide vaporisation system requires a constant flow rate of 50 m^3/h of water at ambient temperature to be effective. Yet another method is the use of ambient air blown across evaporator coils. This is stated to achieve significant energy savings over conventional steam vaporisation.

It is important to ensure that both the gas phase and the liquid phase in the tanker and the receiving tank are connected. This allows the gas, displaced by the liquid, to be delivered to the storage tank, to flow into the tanker and balance the pressure between the two vessels. Non-return check valves must be incorporated to ensure that no backflow occurs. The system needs to be installed in accordance with the recommendations of the gas supplier, whilst regular planned maintenance on the system is necessary to ensure that risks are minimised.

Carbon dioxide fed to the production line should be filtered to remove any possible contaminants. Whilst each batch has a certificate of conformance it is always better to be safe than sorry. Risks exist from contamination by sulphur compounds, aromatic hydrocarbons, aldehydes and potentially harmful submicron particulates and bacteria. Such contaminants can cause off flavours and product spoilage. Modern multi-stage filters can remove water, ethylene glycol, hydrocarbons, ammonia, olefinic hydrocarbons, benzene, volatile oxygenated hydrocarbons, volatile sulphur compounds, carbonyl sulphide, sulphur dioxide, hydrogen sulphide and other trace impurities. The gas is filtered down to 0.01 μm. Again 'out of sight out of mind' has to be taken into consideration. It is critical that if such filters are installed then these are regularly changed. This is to prevent situations that if a problem has occurred the filters become saturated and allow the contaminant to leach back into the system. Pressure reducing valves are fitted in the supply line to the carbonator after the vaporiser.

5.6 Carbon dioxide storage

The tanks are either sited vertically or horizontally, with the current preference being for vertical tanks due to space constraints. They are normally sited outside with suitable weather protection for the associated electrical equipment. If it is necessary to situate the vessel inside a building then adequate ventilation and two separate exits must be provided. The basic requirement of any tank is to maintain a constant tank temperature independent of the environment and the withdrawal rate of the gas. For low and medium pressure tanks it is necessary to use refrigeration units to cool the gas space in the storage tank so as to maintain the gas temperature within pre-described limits. An electric heater is often incorporated within the tank to ensure that if the gas withdrawal rate is too high then the significant temperature drops, and hence pressure drops, within the tank do not occur. If this was to happen then a temporary disruption to the gas supply would occur. The tank is normally insulated with at least 10 cm thick urethane. This is normally covered with a pre-painted aluminium jacket. The actual tank is usually constructed in fine-grain carbon steel. It is normal practice for a bulk vessel to have at least two suitably sized relief valves, connected to the vessel via a changeover valve. This allows one valve to be maintained whilst the other is in operation. The outlets from these valves must be piped to a suitable safe point, where any carbon dioxide discharge will not represent a hazard. These relief valves are fitted to prevent over pressurisation which could give rise to tank rupture. For a small cost the company logo or brand is often applied to the tank. Tank instrumentation will include the tank operating pressure, capacity gauge and a high and low audible alarm. The location of the vessel needs to take into consideration access for the delivery unit. An unobstructed access route is required such that in the case of an emergency in the vicinity of the storage vessel the delivery vehicle can be disconnected and moved to a safe place with the minimum of delay. Care needs to be taken to also ensure the security of the vessel, which is normally contained in a locked, fenced-in area. It is important to regularly survey the vessels to ensure that they conform to the Pressure Systems Regulations, that they satisfy insurance requirements, that the lagging is in good condition so as to keep the gas temperature within the required limits, and that the heating and refrigeration systems are operating satisfactorily. The normal storage pressure is in the region of 20.5 bar at −17°C. This has been found to be the most practical operating level and has been adopted as the worldwide standard by most carbon dioxide suppliers. Your carbon dioxide supplier must always confirm his agreement in writing that your storage system is fit for the purpose. Self-contained breathing apparatus should be made available if the storage vessel is situated inside.

5.7 Carbonation

5.7.1 Basic considerations

Plate 5.1 shows bubbles of carbon dioxide in carbonated water floating to the surface. This occurs when the carbon dioxide bubbles out when carbonated water is depressurised. If we consider a liquid–gas mixture in a sealed container, the state of equilibrium is said to exist when the rate of gas leaving the liquid solution equals that entering it. If you take any PET bottle of carbonated soft drink and shake it, the liquid gas interface will initially fob. However, after a short while, the equilibrium condition will have been reached and the liquid will be quiescent. If the cap is then opened and some of the contents poured out, the cap replaced and the procedure repeated again, it will be noted that before shaking the bottle is limp but after shaking it becomes hard. In this process gas has come out of the solution to attain the equilibrium condition. This state is just stable. Any decrease in pressure, or increase in temperature, will render the mixture metastable, that is, supersaturated, such that the temperature/pressure combination is insufficient to keep the carbon dioxide in solution. If this occurs then the gas is spontaneously released giving rise to fobbing. If the mixtures were agitated or some irritant, such as small particulates added to the mix, then the rate of gas release will be even more pronounced. This is due to nucleation sites being generated by the presence of these particulates or other gases, such as air.

Any carbonated product that is held in a container that is open to the atmosphere will gradually lose carbonation. This is due to the gas being liberated to the atmosphere as the liquid/gas interface continually strives to achieve the equilibrium condition. In a closed container the gas fills the container headspace, thus increasing the headspace pressure. This happens quickly at first and then slowly as equilibrium is approached. The rate of transfer of gas from the product to the headspace depends on the proximity of the headspace pressure to the equilibrium pressure, the temperature of the liquid, the nature of the beverage, the extent of any agitation and the presence of any irritants. A quiescent, stable product will take many hours to reach equilibrium when not subjected to any external forces such as agitation, movement, temperature or pressure change. However, the same product roughly shaken will only take seconds to achieve the equilibrium condition. The faster the rate of change towards the equilibrium condition the sooner this condition will be reached.

For a given volume, the amount of carbon dioxide which a solution can maintain depends on the temperature and pressure. The higher the temperature the greater the pressure required to maintain the carbon dioxide in solution. Conversely, the lower the temperature the greater the amount of carbon dioxide that is retained in solution. Henry's law was postulated by William Henry (1774–1836) and states,

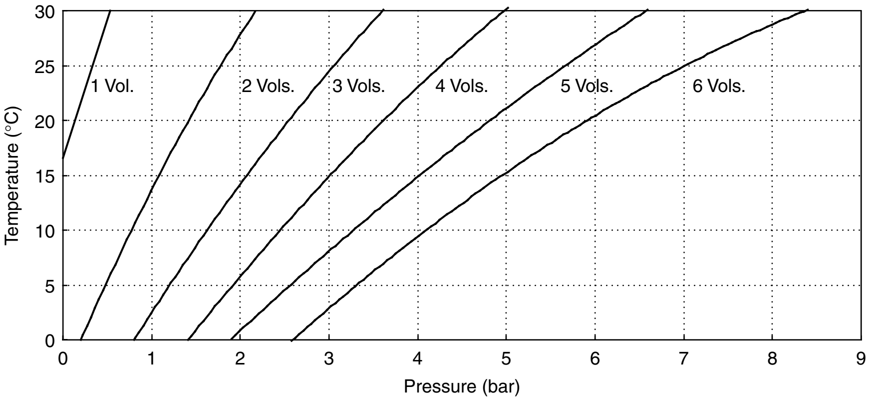

Figure 5.6 Carbonation chart.

'The amount of gas dissolved in a given volume of solvent is proportional to the pressure of the gas with which the solvent is in equilibrium', whilst Charles' law (1746–1823) states, 'The volume of an ideal gas at constant pressure is directly proportional to the absolute temperature'. These two laws can be combined to form the universal ideal gas law:

$$p \cdot V = m \cdot R \cdot T$$

where p is the absolute pressure, V is the volume, m is the number of moles of gas, R is the gas constant (for that particular ideal gas) and T is absolute temperature. A mole is that quantity of a substance which has a mass numerically equal to the molecular weight of the substance. For carbon dioxide the molecular weight is 44.01 and R is 0.18892 J/mol K. From this relationship the carbonation chart shown in Figure 5.6 can be deduced. Here the concept of carbonation volumes is introduced. Volumes 'Bunsen' is where the gas volume is measured at atmospheric pressure (760 mmHg) and the freezing point of water (0°C). It is defined as the number of times the total volume of dissolved gas can be divided by the volume of liquid in the container. As an example, a product with four volumes carbonation will contain carbon dioxide to the extent of four times the volume of the beverage. A 1 l container carbonated to 2.5 volumes would contain 2.5 l of carbon dioxide, and likewise a 3 l container carbonated to 4 volumes carbonation would contain 12 l of carbon dioxide. One volume 'Bunsen' is equivalent to 1.96 g carbon dioxide per litre. This is often simplified to 2 g/l. For PET bottles normally, the smaller the container the higher the carbonation volumes. As will be discussed in more detail in Chapter 7, the rate of loss of carbon dioxide by permeation due to a high surface to volume ratio is large. Shelf life is normally defined as 15% carbonation loss in 12 weeks, which a 2 l bottle can easily meet. This will reduce to ca. 9 weeks for a 500 ml bottle and some 7 weeks for a 250 ml bottle. The light weighting of PET bottles gives rise to thinner wall thicknesses and hence greater permeation

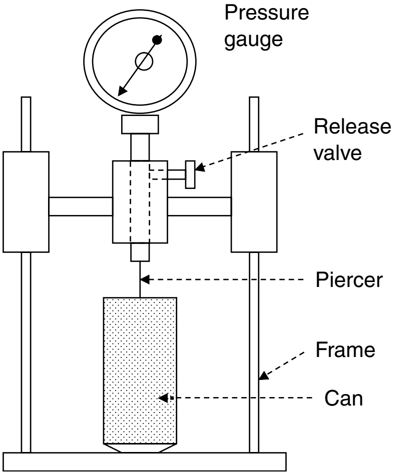

Figure 5.7 Measurement of carbonation.

and a shorter product shelf life. Cans have carbonation levels up to 3.5 volumes. Any higher internal pressures that can be generated during expected use would cause can rupture to occur. Glass bottles can be designed to accommodate higher pressures, such as tonic water which is traditionally a high volume carbonation product, dependent on design and wall thickness.

5.7.2 Carbonation measurement

This is measured using a device similar to that shown in Figure 5.7. It consists of a jig in which the container can be restrained and a piercer which, when used to pierce the container, allows the gas pressure to be read. The container is placed in the jig and is first of all pierced, then shaken, before the pressure is measured. The release valve is then opened until the pressure gauge reads zero and all the gas has been exhausted from the container headspace. The release valve is then closed and the container shaken again. The pressure is retaken. The container is released from the jig and the temperature of the contents taken. The carbonation chart is then used to determine the volumes of carbonation. Why do we need to go to the extent of releasing the pressure from the container before we take the pressure reading? The problem is air inclusion in the beverage. This gives a twin-gas system of air and carbon dioxide. It is necessary to first release the air to determine how much carbon dioxide is present. Air is approximately one-fiftieth the solubility of carbon dioxide in a liquid. Hence any air contained within the beverage will exclude some 50 times its own volume of carbon dioxide. The Law of Partial Pressures was postulated by Jon Dalton (1766–1844) as ‘the pressure *P* of a mixture of gases that do not chemically react is equal to the sum of the pressures of the individual constituents when each occupies a volume equal to that of the mixture at the temperature of the mixture'. This can be written for a mixture of N number of gases as

$$P_{\text{total}} = P_A + P_B + \cdots + P_N$$

The partial pressure of a constituent gas in a mixture is equal to the product of the total pressure and the mole fraction (X) of that gas in the mixture, that is,

$$P_i = X_i P_{\text{total}}, \text{ where } i \text{ corresponds to an individual component.}$$

the mole fraction X being a method of expressing the composition of a mixture

$$X_i = m_i/\Sigma m \quad \text{and} \quad X_A + X_B + \cdots + X_N = 1$$

Air is primarily made up of 79% nitrogen and 21% oxygen, ignoring for simplicity the presence of the inert gases. In any carbonated mixture we will have carbon dioxide, nitrogen and oxygen present. Due to the differing solubility and proportions of oxygen and nitrogen, the dissolved air actually contains 35% oxygen and 65% nitrogen as the solubility of nitrogen is low. It is this enrichment of oxygen that can give rise to spoilage problems with the product if care is not taken to minimise the amount present. The presence of air will also give rise to a higher pressure and hence a false reading of the volumes carbonation from the carbonation chart. The amount of air present clearly has to be minimised when taking carbonation measurements. If we consider a bottle with a gas headspace of 5% of the bottle volume, on the first snift the gas loss would be 5% of the bottle volume. On the second snift we would lose a further 5%. If only carbon dioxide were present in the headspace we would expect to lose 5% pressure on the first shake and some 7% by the second shake. If other gases were present we would lose more pressure. Thus the amount of air present in the product can also be estimated during carbonation measurement. If excess air is found then actions need to be taken to minimise its presence. The problem is often caused by air entrainment or poor sealing with the filler bowl. This can be seen from an example where by volumetric analysis it has been found that the headspace of a carbonated drink container contains 90% carbon dioxide, 3.5% oxygen and 6.5% nitrogen.

For our example if the mixture pressure is taken as 4 bar, then we can develop the table below where M is the molecular weight of the particular gas:

	M_i	V_i/V	$(V_i/V)M_i$	m_i/m	P_i
Oxygen	32	0.035	1.12	0.026	0.14
Nitrogen	28	0.065	1.82	0.043	0.17
Carbon dioxide	44	0.90	39.60	0.931	3.60
Total		1.00	42.54	1.000	4.00

The carbon dioxide pressure is then only 3.6 bar. From the carbonation chart, assuming a temperature of 20°C, the volumes carbonation at 4 bar would be 4.3 but only 4.1 at 3.6 bar. Hence with the presence of air we have lost 0.2 volumes carbonation. This is the maximum tolerance normally given for volumes carbonation during the manufacture of soft drinks. A typical off-line carbonation check unit will automatically rotate the container at a given speed for a given number of revolutions, automatically snift, measure the pressure and temperature and give the actual volumes carbonation. The principle of the unit is that it does everything that a manual unit does but does it repeatedly. Anything done by a human must be prone to change. Each individual will do things slightly differently. What is needed for process control is total repeatability. Automation of quality control will give this. It does not matter whether the actual value that the unit gives is 100% correct. What matters is that it is repeatable and that similar instruments will give the same reading. The human variable has been eliminated.

5.7.3 De-aeration

As discussed earlier the presence of air in the product causes product deterioration, as well as giving a false reading of the level of carbon dioxide present due to the partial pressures involved. Hence we should minimise the amount of air present during carbonation. Experience has shown that the aim should be to reduce the level of air within the product to below 0.5 ppm wherever possible. In this way the product will be at minimum risk from deterioration due to the presence of oxygen, and hence will have an improved shelf life, whilst at the same time this ensures minimal filling problems. The presence of air and carbon dioxide gives rise to the phenomenon known as fobbing, due to nucleation sites being generated by the presence of air within the product. The higher the air content the more difficult it is to hold carbon dioxide in solution. Two main methods of de-aeration exist, vacuum or reflux, both of which are normally applied to water rather than the final product. This is due to the fact that if we only de-aerate the water then no product contamination of the equipment occurs and consequently less product risk is involved. Also the frequency of cleaning is increased. In modern plants it is normal to de-aerate all the water used in the product. This also includes the water used to make up the syrup content, in this way minimising the amount of air that is present in the final product. The average throw water to syrup is normally in the range of 5 or 6 to 1. As syrup also contains water it is usual for added water to amount to some 85% of the volume of the product. During processing simple methods such as introducing all liquids into mixing vessels through the base of the vessel will minimise the entrainment of air, as will careful mixing of the product. It is important after de-aeration not to re-introduce air again because of poor practices.

Chapter 2 has considered the de-aeration process in more detail. Here we will only go through the basic operations. The most effective method of de-aeration is to atomise water into a vessel held under a vacuum. In this way air is stripped out as the atomised water is exposed to the vacuum. Water is sprayed into a horizontal tank under vacuum. This is then transferred into a second horizontal tank where a small amount of stripping gas, normally CO_2 or N_2, is added. This can reduce the residual oxygen level down to 0.05 mg/l. It normally leaves some 0.5 mg/l residual carbonation, which when the product has to be carbonated anyway is no real problem. Alternatively, by applying a positive carbon dioxide pressure in a sealed vessel the air attaches to the carbon dioxide, in a process known as nucleation, and is then driven off through a vent. Often these two processes are combined, such that the effective use of vacuum de-aeration followed by reflux de-aeration will give an air content of well less than 0.5 ppm in the water and 0.5 ppm in the final product, as the syrup will also have been produced from de-aerated water. GEA Tuchenagen have developed a system based on the catalytic removal of the oxygen. The rate of water flow and the oxygen concentration in the water are measured accurately. From the values obtained the required amount of hydrogen to be added is calculated and metered into the system. The hydrogen is then dissolved in a static mixer. The water with the dissolved oxygen is then fed through a catalyst bed. Levels as low as 0.01 mg/l residual oxygen are claimed as is very low energy usage compared to vacuum de-aeration.

5.8 Carbonation systems

5.8.1 Carbonators

The physics of carbonation show that it is simpler to carbonate if the product temperature is low. Hence early carbonators used refrigeration to carbonate at ca. 4°C. A typical system is shown sketched as Figure 5.8. The water only is often carbonated to ensure minimum contamination of the system by syrup. The product is spread over chilled plates, such that the product runs down the plates as a thin film. This is carried out in a constant pressure carbon dioxide atmosphere, the lighter air that is displaced being bled off. The product being chilled as a film maximises the surface area available to the carbon dioxide thus promoting effective carbonation. This also has the added benefit that at a lower temperature the carbon dioxide stays in solution easier, thus minimising future filling problems. However, the energy usage is high and packaging problems are created due to condensation within shrink-wrapped packs as the temperature reaches ambient conditions. This is especially a problem for steel cans where corrosion can easily occur. To overcome this problem the packaged product requires to be warmed to ambient conditions thereby further increasing the energy load.

In general, carbonators take the form shown schematically in Figure 5.9. Two basic methods are possible. These are the injection and dispersion of carbon dioxide into the liquid to be carbonated, and the fine spraying of the product into a carbon dioxide atmosphere. For batch production it has been found by experience that the most effective method is to spray the water into a carbon dioxide atmosphere within a pressurised vessel. Using nozzles to achieve this will give an efficiency of the order of 75% as will spraying the water over cascade plates. Higher efficiencies up to 95% can be achieved by using packings within the pressure vessel column. Owing to the difficulty of effectively cleaning these systems, water rather than product is

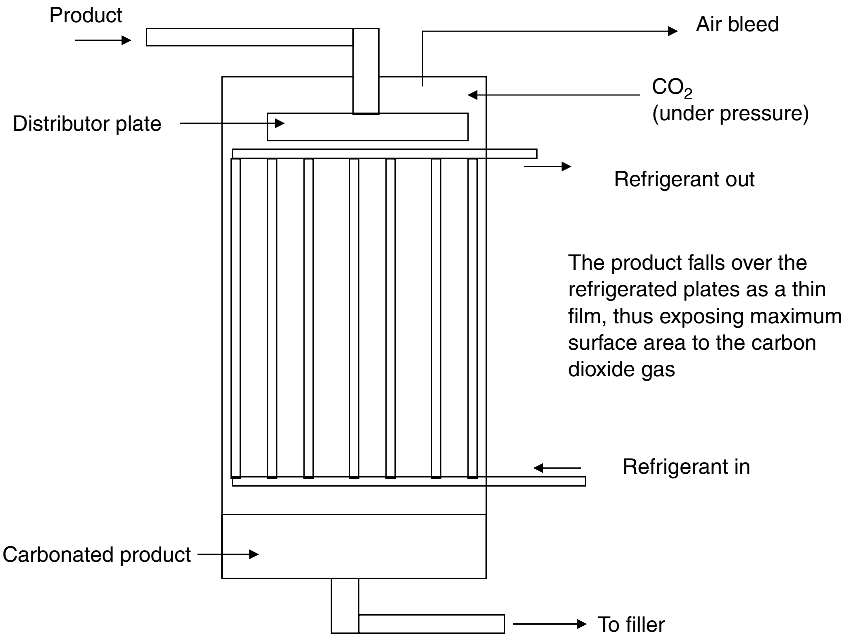

Figure 5.8 Refrigerated carbonation system.

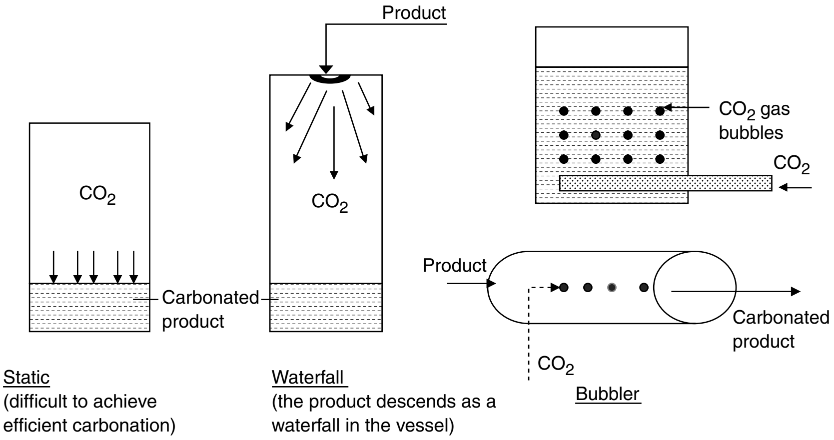

Figure 5.9 Typical carbonation system.

used during the carbonation process. This implies that higher carbonation values must be achieved with the water, as when it is mixed with the syrup to form the product the carbonation levels will be diluted by the throw ratio of the mix and also by small losses which will inevitably occur during any process. The rate of flow and the pressure of the carbon dioxide are critical to ensure that the correct carbonation

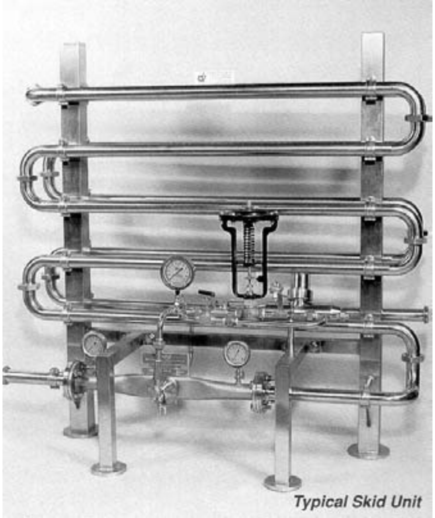

Figure 5.10 Simple in-line carbonator (courtesy Canongate Technology).

level is reached. The greater the liquid surface area exposed to the carbon dioxide the higher the rate of absorption of the carbon dioxide by the liquid.

In-line carbonation methods are being used increasingly. These either sparge carbon dioxide into the liquid or inject the liquid into a gas stream. When the gas is sparged into the liquid this allows small bubbles of gas to be formed which can be easily absorbed by the liquid. The higher the pressure the smaller the gas bubbles formed at the sparger and the greater the gas bubbles surface area made available for the gas to be absorbed by the liquid. Most modern systems inject the liquid into the gas as this achieves faster dissolution. These injectors can be simply cleaned prior to a product change, therefore ensuring that no product contamination will occur. They often use a venturi to ensure more contact area and employ specially designed nozzles to maximise the carbonation efficiency, with claims in excess of 99% being made. A typical simple in-line carbonator is shown in Figure 5.10.

5.8.2 Gas bubble sparging

On the one hand, the formation of gas bubbles at orifices under constant flow conditions occurs when the volumetric flow rate of gas into the bubble remains constant whilst the bubble grows. On the other hand, under constant pressure formation the pressure at the orifice remains constant whilst the pressure within the bubble changes. Between these two regimes there is a transitional region in which resonant effects play an important role.

The idealised model of constant flow bubbles was proposed by Kumar and Kuloor, which can be seen schematically in Figure 5.11 where the two development

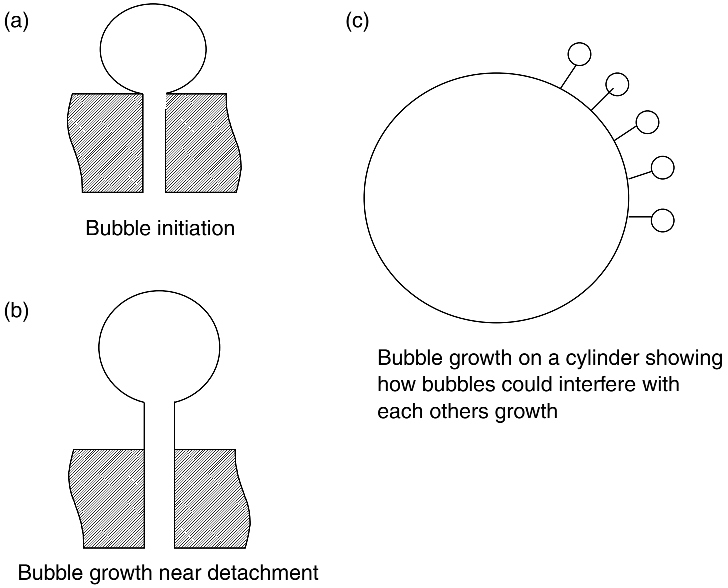

Figure 5.11 Bubble growth.

stages of formation and detachment are shown. During the expansion stage the bubble is formed at the orifice, where it grows until it reaches the steady-state force balance value of the bubble diameter. The bubble is slightly deformed at the orifice. Thereafter the bubble moves from the orifice, but is still attached by means of a stem through which gas enters the bubble. Eventually detachment occurs, but not before the bubble has grown significantly. This detachment stage is governed by an unsteady-state force balance. The forces affecting the bubble formation are:

1. viscous forces due to the drag on the expanding bubble
2. inertial force needed to accelerate the bubble and the effective mass of liquid above it
3. buoyancy force
4. force due to surface tension.

Clearly the smaller the bubble diameter for a given volume of gas the larger the surface area would be for the gas to be absorbed by the liquid. Typical sintered candles have 10–40 μm pores such that the bubbles formed will always be larger than this. The coalescence of such bubbles is undesirable as this could lead to degassing problems. In general, the higher the flow rate the larger the bubble diameter and the smaller the number of bubble sites. To effect improved carbonation it does help to mix the bubbles with the product using a static mixer. As the bubble diameter cannot be made small enough under factory conditions it is preferable for maximum carbonation effectiveness to stream the liquid into a carbon dioxide gas stream.

Hence, unless the carbonation level required is fairly low the use of spargers is normally avoided.

5.8.3 Bubbles in a glass of carbonated liquid

A carbonated beverage is a weakly saturated liquid. Bubbles need pre-existing gas cavities with radii of curvature greater than the critical radius in order to overcome the nucleation energy barrier and grow freely. Once a bubble is formed at a nucleation site it will rise through the liquid and grow in size as it travels. If we consider a glass full of a carbonated drink it can also be seen that the distance between the bubbles also increases as the bubbles rise. Plate 5.1 shows bubbles rising in a liquid. Hence bubble accelerate as they rise. On the free surface the bubbles collapse. It has been found by Liger-Belair and Jeandet that the bubble ruptures in under 100 μs. During this brief initial phase, the bulk shape of the bubble has been frozen. An open cavity remains at the free surface. As the bubble collapses the bubble cavity gives rise to a high speed liquid jet. Above the free surface this liquid jet soon becomes unstable and breaks up into small jet droplets. In the final phase droplets form a quasi-spherical shape. Capillary wave trains centred on the bursting bubble are propagated at the free surface. As hundreds of bubbles are bursting every second during the initial pouring of a carbonated drink into a glass the free surface of the liquid will be spiked with cone shaped jets. However, since the jet life is short they are difficult to discern; this is termed effervescence.

5.8.4 Process control

Feedback control systems are required to ensure that the product carbonation is kept within specified limits. One system uses a silicone rubber membrane through which the dissolved carbon dioxide permeates into a sealed, evacuation chamber. The partial pressure and temperature of the gas are then measured, allowing the carbonation volumes to be calculated. Most systems include a vacuum exhauster to regulate and evacuate the dissolved carbon dioxide. They operate within ±0.04 g/l. Despite the lower permeability of the membrane to oxygen, any dissolved oxygen in the product will exert a high pressure relative to the dissolved carbon dioxide, which will lead to significant errors. This is obviated by the evacuation of the chamber. The problem is also reduced when the product is well de-aerated. The feedback control system then allows more or less carbon dioxide to be added to the product.

5.9 Filling principles

We have considered how to carbonate a beverage to a given specification. Now we will look at the principles involved in filling a carbonated beverage into a container at

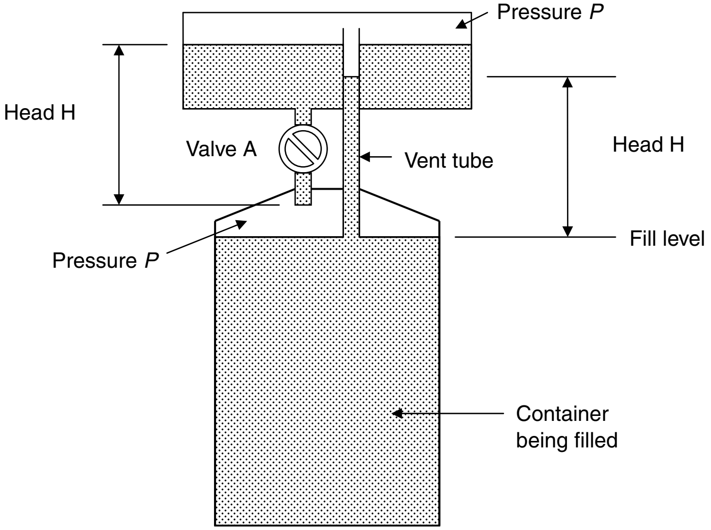

Figure 5.12 Principles of gravity filling.

a commercially viable filling rate. If we could equate the pressure of the carbonated beverage with the pressure in a container then filling can be achieved under gravity, the rate of flow being dependent on the head difference between the filler bowl and the container. The rate of flow will increase if an over pressure is introduced. Referring to Figure 5.12, the pressure differential between the top of the filling bowl and the outlet of the filling valve provides the driving force to fill the container. In this example a bottle is used though it could just as easily have been a can or carton. The rate of flow to fill the container is a function of the over pressure applied to the top of the filling bowl (p), the viscosity of the liquid to be filled (μ), the diameter of the filling tube (d) and the length of pipe (l). For simple flows this is given by the Poiseuille formula as

$$\text{Volumetric rate of flow, } V = \frac{\Pi \cdot p \cdot d^4}{128 \cdot \mu \cdot l}$$

This is a much simplified equation for very low speed laminar fluid flow. In actual practice the rate of flow would probably be turbulent and proportional to $\sqrt{p}$ rather than to the pressure alone. It does, however, demonstrate that for viscous liquids it is necessary to either open up the filling tube diameter or increase the driving pressure to maximise the flow rate through an orifice. Some of the problems facing the filler designer can be seen if we consider the process in some detail. This is especially so with regard to how the process is controlled. It is simple to envisage how the container is filled under gravity conditions. It is the same as putting a bottle beneath the kitchen tap and turning it on, where the natural pressure in the water system provides the over pressure. A bucket of water with a tap fitted to the base will give a good flow of water from it initially due to the head of water within the bucket. As the bucket empties the rate of flow will decrease as the head of water decreases. However, to control the process under pressure with carbonated product is more complex, which is why the pressures within the filling bowl and the container are equated thereby allowing gravity filling conditions to apply.

5.9.1 Gravity filler

The first criterion that needs satisfying is to seal the container, whether it is a glass bottle, plastic bottle or can, to the filler bowl such that no leakage can exist via the seal. The filler bowl is filled to a given level, which by means of float valves is maintained within close tolerances. This ensures a near constant pressure head during the filling process, an important factor if constant flow conditions and repeatability are to apply. As shown in Figure 5.12, once the container is sealed to the filler bowl we can open valve ‘A’ to allow filling to commence. The gas within the container, which for carbonated products is normally carbon dioxide though nitrogen can be used, needs to exhaust somewhere as the liquid filling the container displaces the gas. This is achieved by means of a vent tube, the rate of flow of liquid into the container being proportional to the rate of flow of gas displaced. When the liquid reaches the vent tube it will start to fill this until such time as the pressure within the vent tube equates to the filling tube pressure. When this equilibrium condition is achieved the liquid flow will stop. Then the filling valve can be closed. Following this the container can be lowered from the filler bowl. During this process the liquid within the vent tube will drain back into the container, just small amounts of liquid being left in the vent tube due to surface tension effects dependent on the characteristics of the liquid being filled. The process cycle is shown in Figure 5.13.

Clearly this process requires certain standards for the container as well as the filler. A bottle must have a standardised neck finish to allow it to seal effectively at all times with the filler bowl and this finish must be produced to a minimum standard. It must also have sufficient top load to withstand the forces involved during the filling process. Most modern bottle fillers now lift PET bottles by the neck to overcome deformation problems during the process. This also allows light weighting of the bottle, which is advantageous for both environmental and commercial reasons. To achieve commercially acceptable filling speeds the majority of fillers are rotary, though some in-line fillers have been produced. The latter have neither been very popular nor commercially viable. They tend to be for the lower output filling range. Bottles are fed into the filler by conveyor to an in-feed worm and star-wheel in single file. This star-wheel incorporates a clutch-operated bottle stop, which under normal conditions rotates freely. Should the filler be stopped for some reason the bottle stop will engage automatically. From the star-wheel the bottles are fed to a bottle-lift stirrup, sited below an individual filling valve, and lifted by the neck to the seal with the filler bowl. Older fillers use bottle lifts on which the bottle rests, and then lifted to seal with the filler bowl. Such lifters are used for glass bottle fillers. The filling valves are sited at equal intervals around the base of the filling

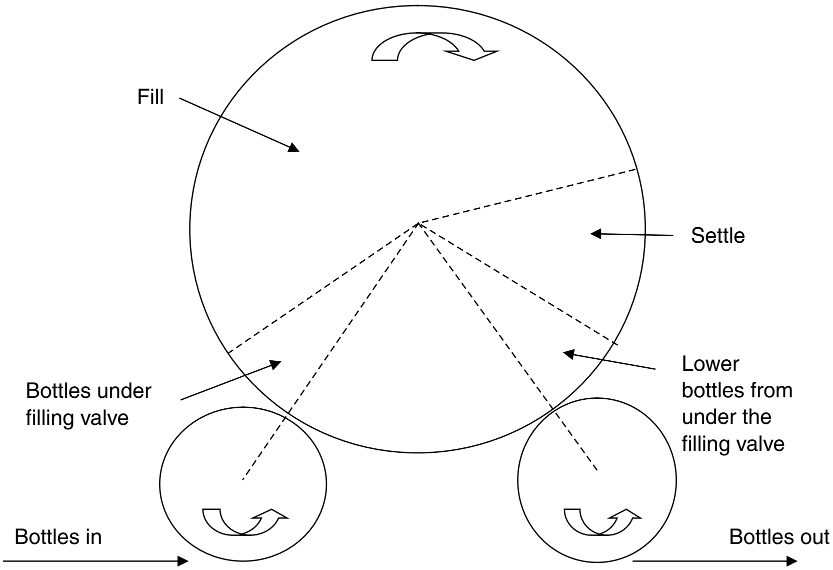

Figure 5.13 Gravity filling cycle.

bowl. The filling bowl itself is annular to allow all the feed pipes and central drive to function. The complicated motion due to the rotation of the filling bowl, giving rise to a centrifugal force and the flow through apertures into individual valves, is very complex. The flow paths are short so that the flow through a valve is never fully developed. Consequently, design is based on experimental results and experience with fillers in practice rather than using computational fluid mechanics. The filler pitch is usually governed by the maximum container size to be filled. It can be imagined that the closer the filling valves on a small pitch filler the more the flow into individual valves is influenced by the flows into adjacent valves. For each filling valve a centring bell acts as the seal for the bottle, this seal being made of a food grade rubber. The hardness of the rubber, any defects on the bottle sealing surface, the state of the sealing rubber and the sealing pressure all affect the performance of the seal. The effectiveness of this seal is critical to good filling. Each filling valve is opened and closed by an actuating lever from cams fitted to the stationary filling frame. The valves are actuated when the filling bowl, and hence the valve-actuating lever, pass the cam. If no bottle is in position this is sensed, as the centring bell has not been lifted into position, thus achieving a no bottle–no fill condition. The actual flow through a valve is complex. For example we could have some 100 valves sited around the base of the filling bowl. The liquid has to flow through each of these orifices and then via an annulus between the vent tube and the side of the valve into the container. A spreader is usually fixed to the vent tube to deflect the product onto the container sidewall to minimise turbulence conditions in the liquid within the bottle. Each bottle has a defined filling level, which should be as close to the sealing surface as possible commensurate with the expansion of the liquid during

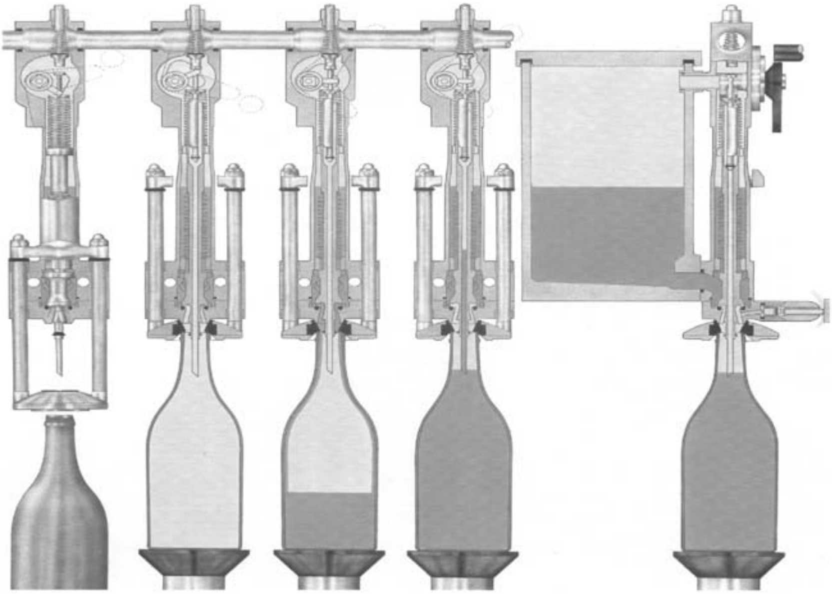

Figure 5.14 Counter-pressure filling cycle diagram.

its possible life cycle due to high temperatures or freezing conditions. Once filling is completed a short settling period is necessary before the bottles are lowered from the filling bowl and passed to the capper to seal the container. This period can be minimised by reducing the amount of agitation within the liquid during the filling process.

5.9.2 Counter-pressure filler

The above process forms the basis of counter-pressure filling of carbonated liquids into a container. To achieve gravity filling the pressure within the filling bowl and the container must be equated. A typical process cycle is shown in Figure 5.14. Once the container is sealed to the filler bowl, the gas valve is opened and the gas within the filling bowl head space flows under pressure into the container displacing air at atmospheric pressure. In modern fillers this air is displaced out with the filler. However, in older fillers it is often vented to the filler bowl headspace causing problems associated with gas mixtures discussed previously, even though as air is lighter than carbon dioxide the majority of the air can be vented off. The example shown in Figure 5.15 illustrates how evacuating the air from the bottle can reduce the air content prior to filling. It can be seen that it is not feasible to completely eliminate all the air within a bottle prior to filling, though it can be minimised if the air within the bottle is evacuated away from the filler and not into the filler headspace. For oxygen-sensitive products this is a necessary requirement.

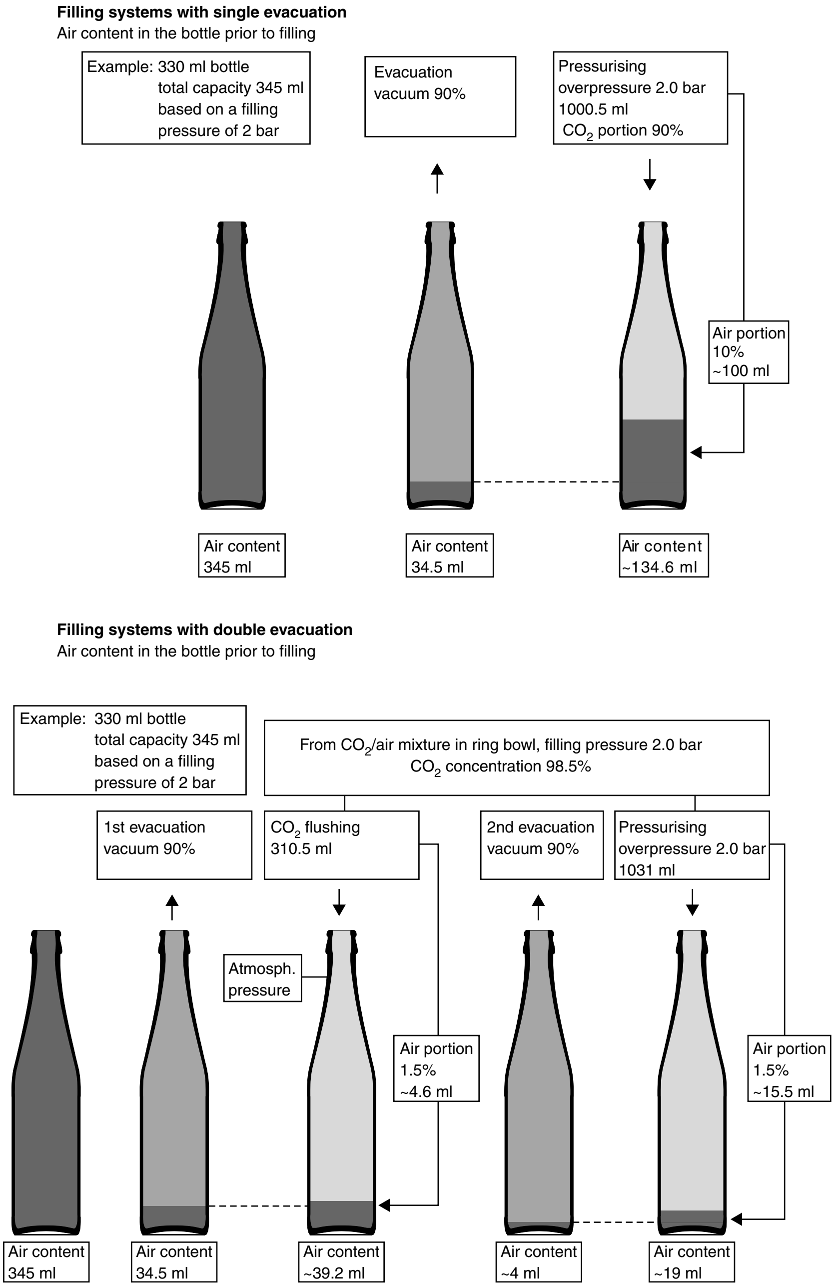

Figure 5.15 Bottle evacuation.

Once the pressures are equated, the gas valve is closed and the liquid valve opened. Flow commences until the pressures are equated and flow stops. A short settling period is then allowed before the liquid valve is closed and the gas within the container headspace allowed to escape in a controlled manner. This process is known as snifting. This is required as once the container is lowered from the filler bowl the gas within the headspace will be pressurised but exposed to the atmosphere. Clearly this will result in severe fobbing of the product within the container until equilibrium conditions are reached. To overcome this, the pressure within the headspace is gradually reduced by snifting the gas off externally to the filler. The rate of flow of the gas is controlled by the diameter of the snift valve orifice. Often this process is repeated in short bursts several times, allowing a short rest period between snifts. It is the most difficult part of the process to control, especially if the product itself is lively such as cream soda. Care when snifting off to atmosphere has to be taken as the snifted gas often contains a product mist, which can cause contamination as it condenses onto the surface of the filler and surrounding plant. A conventional filling cycle is illustrated in Figure 5.16, whilst a diagrammatic representation of how bottles are fed through the system using an infeed worm and star-wheels is shown in Figure 5.17.

One of the most important considerations during the process that must be taken into account is to keep the filling process as quiescent as possible, otherwise 'fobbing' will occur. The term 'fobbing' is generally applied to a carbonated product that is still lively and has not reached a state of equilibrium. It can be induced by excessive agitation during the filling process and too fast a snifting action. For this reason great care must be taken to ensure that the process is under control at all

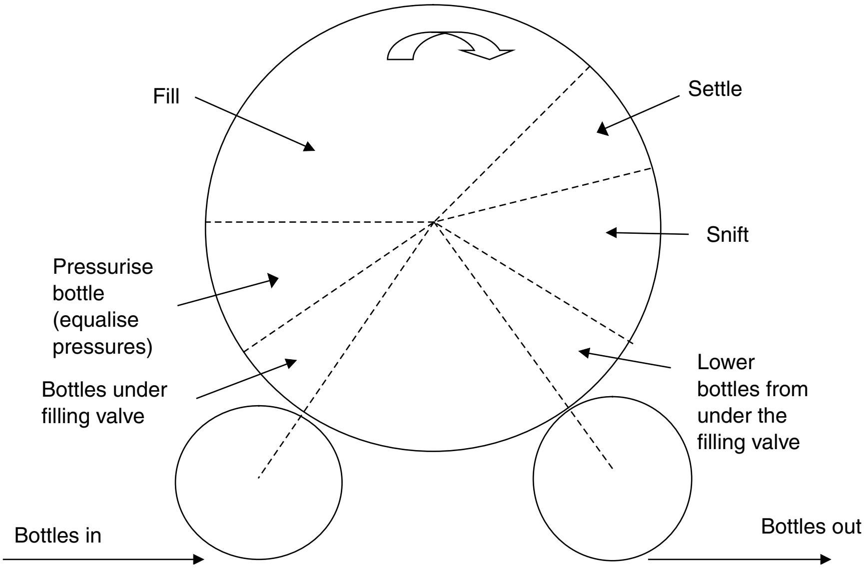

Figure 5.16 Counter-pressure filling cycle.

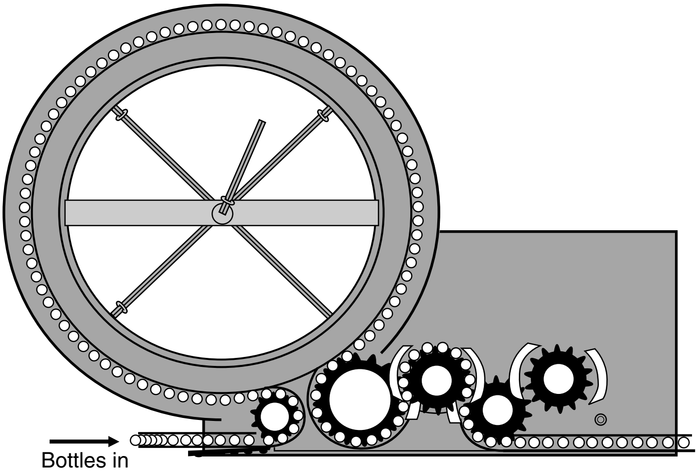

Figure 5.17 Infeed worm and starwheel.

times. Carbon dioxide wants to come out of the solution the higher the temperature, as well as at higher volumes carbonation. Most modern fillers can operate at up to 22°C, though any liquid temperature above 20°C will tend to increase the risk of fobbing. The optimum filling temperature is normally around 14°C, which has been found by experience to be a good compromise temperature when considering energy consumed to cool the product and the efficiency of the filling process, as the lower the temperature the easier for carbon dioxide to stay in solution. Filling down the sides of a bottle will reduce the level of fobbing as will a carefully designed container. This is achieved using swirl-type valves that impart a tangential force on the liquid, thereby forcing the liquid to the sides of a bottle. Any discontinuity along the sidewall of a container will cause the liquid to 'jump' off the inner surface side-wall and fall directly onto the product in the base of the bottle, thus increasing the level of agitation and hence fobbing. Likewise too high a shoulder on a bottle will not allow the liquid to flow along the inside walls of a bottle as early as possible, giving rise to increased agitation of the liquid and loss of carbon dioxide from solution. In addition, the shape of the bottle shoulder can visually exaggerate any inconsistency of fill level control, especially with tapered bottle shoulders. This has an undesired effect when different products are side by side on the supermarket shelf. Bottle top load is a critical factor. On older fillers that use bottle lifters, whereby the bottle is lifted on the base, any bottle with a low top load will tend to buckle during the snifting process thereby causing some loss of product, especially if fobbing is induced, and hence a reduced fill level in the container. This problem will always increase the level of fobbing and make the snifting process that much more difficult to control. When filling carbonated products with fruit cells it is usual to use siphon-type valves on older fillers as these allow a smoother passage through the filling valve, though with a loss of performance and a requirement for

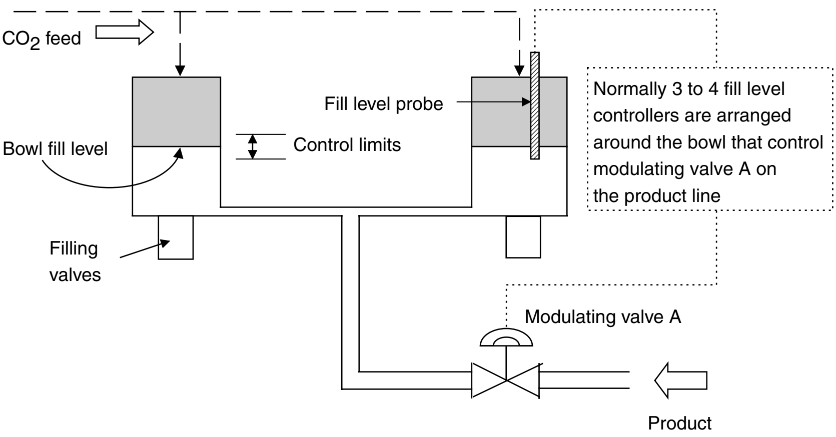

Figure 5.18 Filler bowl level control.

a lower carbonation level. Modern swirl valves will accommodate most fruit cell containing products through improved design and larger flow passages.

The choice of filler depends on the number of bottle sizes being considered to use on it. For example, if 3 l PET bottles are to be filled a 126 mm pitch between filling valves is required. If only small bottles up to 500 ml are to be filled then a 70 mm pitch will suffice. Clearly this has a direct effect on the size of the filler and the footprint on the factory floor. Unless the filler bowl level is kept within tightly controlled limits, pressure head variations will affect the rate of flow into the container. Systems such as shown in Figure 5.18 need to be employed. Wherever possible there should be the minimum amount of contact of any instrumentation with the product. Conventional float valves should be avoided and simple capacitance probes, which are easily cleanable, small and very effective, should be used. It is not uncommon in older fillers to only have one float valve. This often gives rise to filler bowl flooding and the consequences that gives of inconsistent fill level and poor counter-pressurisation of the container pre-filling.

The construction of a filler is usually in 316 stainless steel, to ensure all surfaces can withstand the chemical attack from both the product and cleaning processes, as well as being easily and effectively cleanable. The annular bowl is supported on a central frame, which also includes the drive motor and pipe work supports. Each valve is individually piped to the central frame, being connected via a rotary valve. Most drives are now invertor controlled through a plc, giving a wide range of possible operating outputs. Valve design has improved greatly over the last few years, such that swirl valves now have sufficiently large passage ways to enable many fruit, or cell, based drinks to be processed instead of using the slower siphon valves, with their tendency to give rise to fobbing. Even so due to the nature of the design of counter-pressure fillers the vent tube will always contain some product, which is inevitably carried across to the next fill cycle unless blown out prior to the new cycle commencing. This cut-off with the vent tube occurs at the full filling rate, thereby never being perfect due to the momentum of the liquid product during filling. Clearly the traditional filling valve with its inherent springs can be easily contaminated as they are submerged in the product itself. This can cause cross contamination from one product to another following a flavour change unless care is taken to have an effective cleaning regime.

5.10 Nitrogen

Nitrogen was discovered by Rutherford in 1772 and experimentally isolated by Cavendish in 1785. Nitrogen gas is slightly lighter than air and only slightly soluble in water. This low solubility is because the two nitrogen atoms that make up a nitrogen molecule are held firmly together by a triple bond which is exceedingly difficult to break. Because of this bond, nitrogen gas simply does not participate in any reactions at room temperature, or even at the higher temperatures as found in small fires, and is therefore described as inert. Only at extremely high temperatures, such as those found near a lightning bolt or in a car engine, or through the use of 'nitrogen fixing' bacteria, which use a complex set of enzymes instead of heat, can this triple bond energy be overcome, making nitrogen gas momentarily reactive while in an excited state.

Nitrogen is often used as an undercover gas in can seaming as well as providing over pressure when filling still products using a counter-pressure filler. It is used in beer canning through the use of widgets to produce a creamy texture as found in traditional draught beers. These widgets work by jetting a stream of nitrogen gas into the beer once the can is opened. Liquid nitrogen injection is used in the canning of still drinks to provide can rigidity through the presence of gas pressure once the liquid nitrogen is heated up to the gaseous state.

Nitrogen can be produced using pressure swing adsorption, where air is passed through a vessel containing one or more adsorbed materials, the nitrogen being allowed to pass through while selectively removing other components. Another production method is cryogenic distillation. The liquid nitrogen is stored on site in a refrigerated vessel, delivery being by road tanker. The nitrogen gas is vaporised using an air vaporiser. Like carbon dioxide all deliveries require a certificate of quality conformance and a laboratory analysis. It is always advisable to filter the gas on line as a final fail safe mechanism.

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6 Modern filling systems for carbonated soft drinks

Andrew Wilson and John Medling

6.1 Introduction

Modern filling systems for carbonated beverages are based on simple yet well proven principles, although these can be applied in many different ways depending on the filling system. Optimum performance during filling, high filling accuracy and the preservation of maximum product quality are simple enough requirements for the complexities of a filling process. Different factors, which in their turn will vary depending on product type, have a direct influence on the quality of the product to be filled. The essential factors to be considered are:

1. the gas constituents present in the beverage and the influence those gases exert during the filling process – for example, carbon dioxide and oxygen
2. pressure and pressure characteristics during filling
3. temperature
4. viscosity.

By examining these variables and changing them whenever necessary, filling conditions can be optimised, filling speed can be maximised and product quality can be preserved.

The most important considerations for effective filling of carbonated beverages are maintaining the content, controlling beverage temperature during filling and preventing oxygen pick-up. As a result of carbonation, CO_2 is present in the beverage in a dissolved state. In an enclosed system, such as a pressurised beverage buffer tank, equilibrium will exist after a certain time between the pressure of the gases in the liquid and the corresponding pressure in the tank. CO_2 must be prevented from coming out of solution during filling by setting the filling pressure in the filler bowl approximately 1 bar higher than the saturation pressure for the required beverage CO_2 content. Even if saturation pressure is maintained, extreme care must also be taken to ensure that the beverage has been allowed sufficient time to settle prior to filling and that it is filled gently into the container. The profile of the container can also be a critical factor in the gentle filling of the beverage. In most filling systems, the beverage is transferred to the inside surface of the container at the highest possible level and then flows to the bottom of the container. Smooth container contours will allow the gentlest flow of the beverage.

Following this procedure ensures that:

1. CO_2 loss in the beverage, with the resultant reduction in quality, is avoided.
2. CO_2 consumption during carbonation can be more accurately adjusted, and therefore reduced.
3. The filling, settling and snifting times are optimised.
4. Product losses as a result of fobbing during snifting are prevented.

Although the CO_2 content of the beverage has the primary effect on the performance and cost efficiency of the filling process, CO_2 consumption, settling and snifting times and the oxygen content in the beverage all have a major influence in the preservation of beverage quality. Oxygen is present in the beverage in dissolved form and also as a constituent of the air in the container prior to filling. For soft drinks, the consequences of excessive oxygen pick-up during filling are well known. Oxidation of beverage ingredients may cause adverse changes in colour and taste.

Oxygen pick-up by the beverage can be controlled at three stages:

1. oxygen load at the filler inlet (initial load)
2. oxygen pick-up during filling
3. oxygen contained in the residual air in the container headspace after filling.

Oxygen pick-up upstream of the filler inlet can be caused by several factors:

1. air inclusion in pipes
2. insufficient syrup storage time
3. over agitation during the mixing process of the beverage
4. inadequate de-aeration at the carbonation stage.

Oxygen pick-up during filling is directly correlated to the purity of the CO_2 as pressurisation gas in the filler ring bowl and air in the container prior to filling. In order to reduce the content of air in the container, flushing with CO_2 can be performed immediately before filling. For flexible containers, such as PET bottles and aluminium cans, this takes place as the container is presented to the filling valve, before sealing, when CO_2 from the filler ring bowl is flushed into the container to replace as much of the air as possible. This process can be substantially improved when using rigid glass containers, after sealing to the filling valve, by evacuating gas from the container using a vacuum prior to pressurising with CO_2. This process can be repeated when filling particularly oxygen-sensitive beverages and an almost pure CO_2 environment can be produced in the container.

The filling pressure depends on the required CO_2 content of the beverage. Setting the correct filling pressure in the filler bowl will prevent CO_2 coming out of solution in the beverage during the filling process. If the temperature of the beverage is lower, CO_2 solubility will be better. Good solubility of the gas at low temperatures requires a lower saturation pressure and hence a lower pressure in the filler bowl. The consequence of this is that shorter times are required for pressurisation and snifting and the occurrence of fobbing will be reduced. Gas consumption will also be reduced.

The fourth factor to be considered is beverage viscosity. Higher-viscosity products require a different approach to the filling process. However, carbonated soft drinks usually have a low viscosity and are free flowing, so this is not a consideration here.

The container and beverage characteristics form the basis of the appropriate design for a filling system, and the filling process must not alter or impair the beverage characteristics. It is important when planning the filling system that the appropriate filling steps are matched to the beverage characteristics and container. The filling process can be split into several phases:

1. evacuation
2. flushing with gas
3. pressurising with gas
4. filling at one speed or two speeds
5. fill level correction
6. settling and snifting.

Evacuation is used only on rigid containers, where the container is subjected to a vacuum to remove 90% of the air content before pressurising with gas. This is a significant process when filling particularly oxygen-sensitive beverages as the step can be repeated after pressurising with gas, thus removing 90% of the mixed gas, leaving a highly concentrated gas atmosphere in the container.

Flushing with gas is used primarily for flexible containers such as PET bottles and aluminium cans, which cannot be subjected to vacuum. This step is carried out as the container is presented to the filling valve, using either gas from the filler ring bowl or pure gas.

Pressurising with gas is carried out after the container is sealed to the filling valve. Gas from the filler ring bowl flows into the container until both pressures are the same.

Filling takes place in a tubeless filling system when the filling valve opens and beverage flows over a vent tube into the container. A liquid spreader, or deflector, causes the beverage to flow on to the inside wall of the container. Gas in the container is displaced by the beverage and flows through the vent tube into the filler ring bowl. In the now less common tube filling system, suitable for tall containers, beverage flows into the container through a tube located close to the bottom of the container. A two-speed fill can be used here, with slow fill until the beverage reaches the tube, then fast filling to the top. When the fill quantity is reached, either the beverage reaches the gas return point of the vent tube, stopping the filling step, or the vent tube can contain an electronic probe to stop the filling step. Other filling systems using the volumetric principle pre-measure the quantity of beverage into the container.

Fill level correction is used when product cost is high, the container is very narrow at the fill point and fill level accuracy is particularly important. There are various methods used to perform this step, but most commonly the container is first overfilled then product is extracted via the vent tube, using vacuum.

Settling and snifting serve to gently lower the pressure in the container and allow the beverage to settle to prevent fobbing of the beverage as it is lowered from the filling valve.

6.2 Modern carbonation systems

The most important considerations for effective filling of carbonated beverages are maintaining the content of carbon dioxide, controlling beverage temperature during filling and preventing oxygen pick-up. In the carbonation process, CO_2 is injected into the beverage in an enclosed carbonation tank pressurised with the gas. Equilibrium between the gases in the liquid and the corresponding pressure in the tank will exist after a certain time. CO_2 will be absorbed into the beverage and will remain in a dissolved state while the beverage is maintained under pressure. The content of CO_2 which can be absorbed by the beverage is dependent on the pressure in the carbonation tank and the temperature of the beverage. The higher the CO_2 content required, the higher the saturation pressure required at a given temperature. Conversely, the lower the temperature for a given content, the lower the saturation pressure required.

The basic system for carbonation of water is indicated in Figure 6.1. Water is pumped into a carbonation tank which is pressurised with carbon dioxide. Between

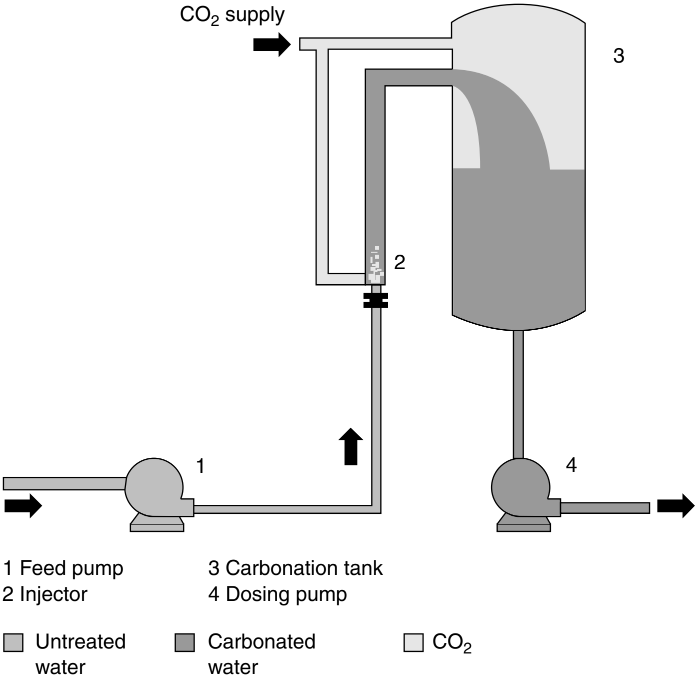


Figure 6.1 Basic carbonation system.

the pump and the tank it passes through a CO_2 injector, an efficient and faster method of promoting absorption than simply exposing the beverage to a CO_2 atmosphere.

The CO_2 content of the beverage has the primary effect on the filling performance and cost efficiency of the filling process, CO_2 consumption and settling and snifting times, and the oxygen content in the beverage has a major influence on the preservation of beverage quality. Also, the lower the air content of the beverage before carbonation, the higher the effectiveness of the carbonation process.

The system for the de-aeration and carbonation of water is indicated in Figure 6.2. Water is pumped into a de-aeration tank, which is subjected to a vacuum. This step removes air from the water, which is then pumped into a carbonation tank pressurised with carbon dioxide. Between pump and tank the water passes through a CO_2 injector.

Carbonated beverages are most commonly prepared in a beverage mixer/carbonator which combines the de-aeration of water with blending and carbonation of the beverage. Water is pumped into a de-aeration tank under vacuum which removes air from the water. De-aerated water and syrup are then pumped through

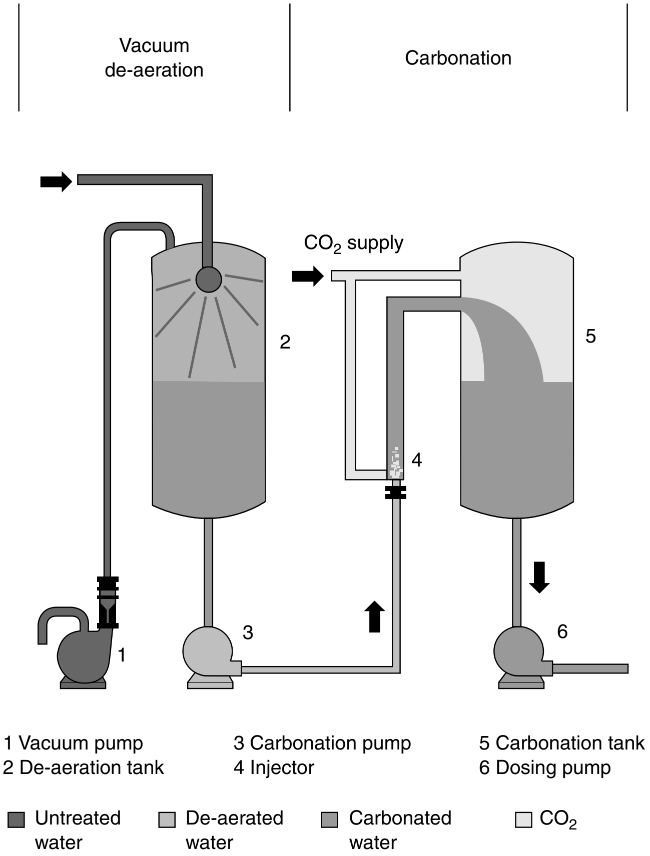


Figure 6.2 De-aerator and carbonator.

a blender, in this case using flow meters, to obtain the required blend ratio. The blended beverage then flows into a carbonation tank pressurised with carbon dioxide. Between the blender and the tank the product passes through a CO_2 injector. Although the blending and carbonation processes are continuous, sufficient volume of the beverage is held in the carbonation tank for settling prior to filling.

6.3 Counter-pressure fillers

6.3.1 Operation

In the process of beverage carbonation, CO_2 is absorbed under pressure and will remain in solution while it is kept under pressure. The pressure required to maintain CO_2 in solution depends on the content required in the beverage and the temperature. Higher CO_2 contents require higher pressures at a given temperature and, conversely, lower temperatures for a given content require lower pressures. The filler bowl must, therefore, be kept under the appropriate pressure during the filling process.

Figure 6.3 indicates the solubility of CO_2 in water at various temperatures and pressures. During the filling process, it is important that the beverage is handled gently to prevent CO_2 coming out of solution as a result of agitation. As some disturbance of the beverage is inevitable during filling, it is common practice to set the head pressure in the filler bowl 1 bar above the beverage saturation pressure.

In order to maintain the beverage under pressure throughout the filling process it is also necessary to pressurise the container to the same pressure as the filler bowl.

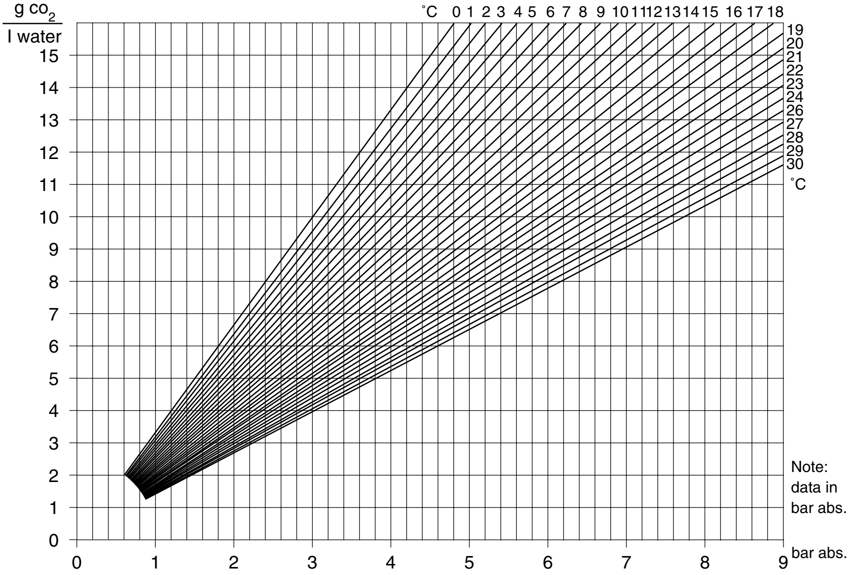


Figure 6.3 Carbon dioxide solubility in water (courtesy Krones UK Ltd).

This procedure is carried out on a counter-pressure filler. The complete filling process on a counter-pressure filler can be split into the following phases:

1. evacuation
2. flushing with gas
3. pressurising with gas
4. filling
5. fill level correction
6. settling and snifting.

Each of these phases on a Krones VKPV-CF filler will be examined. This complete filling process is used when filling beverages which are particularly sensitive to oxygen and which can also be susceptible to foaming. Other types of counter-pressure filler utilise only some of the above phases. Figure 6.4 shows a cross-section of the filler bowl and filling valve with a glass bottle in position. Some of the steps described can be carried out only on rigid containers.

The VKPV-CF is a counter-pressure filler with short vent tubes and electro-pneumatic valve control with vacuum chamber and fill level correction. Referring to Figure 6.4a, the electro-pneumatic operations control the following functions:

1. gas needle
2. snifting
3. vacuum/clean-in-place (CIP)
4. liquid stem
5. correction.

The various ring channels are as follows:

1. snifting/CIP
2. vacuum/CIP
3. pure gas.

During the filling process, bottles enter the filling machine and are lifted to the filling valve by the lifting cylinder and sealed against the centring bell and filling valve. In this position the gas needle and the liquid stem in the filling valve are closed.

Figure 6.4b shows the evacuation phase. Following an electronic pulse, the vacuum valve opens and produces a connection to the vacuum channel. The bottle is subjected to vacuum and the air content in the bottle is reduced to approximately 10% of atmosphere.

Figure 6.4c illustrates the gas flushing phase. A pneumatically controlled gas needle opens the connection to the ring bowl and, as a result, almost pure CO_2 flows out of the ring bowl into the bottle, equalising pressure between bottle and ring bowl.

Figure 6.4d shows the second evacuation phase. The pneumatically controlled vacuum valve opens again and produces a second vacuum in the bottle. The vacuum thus generated in the process reduces the percentage of air in the bottle to approximately 1%.

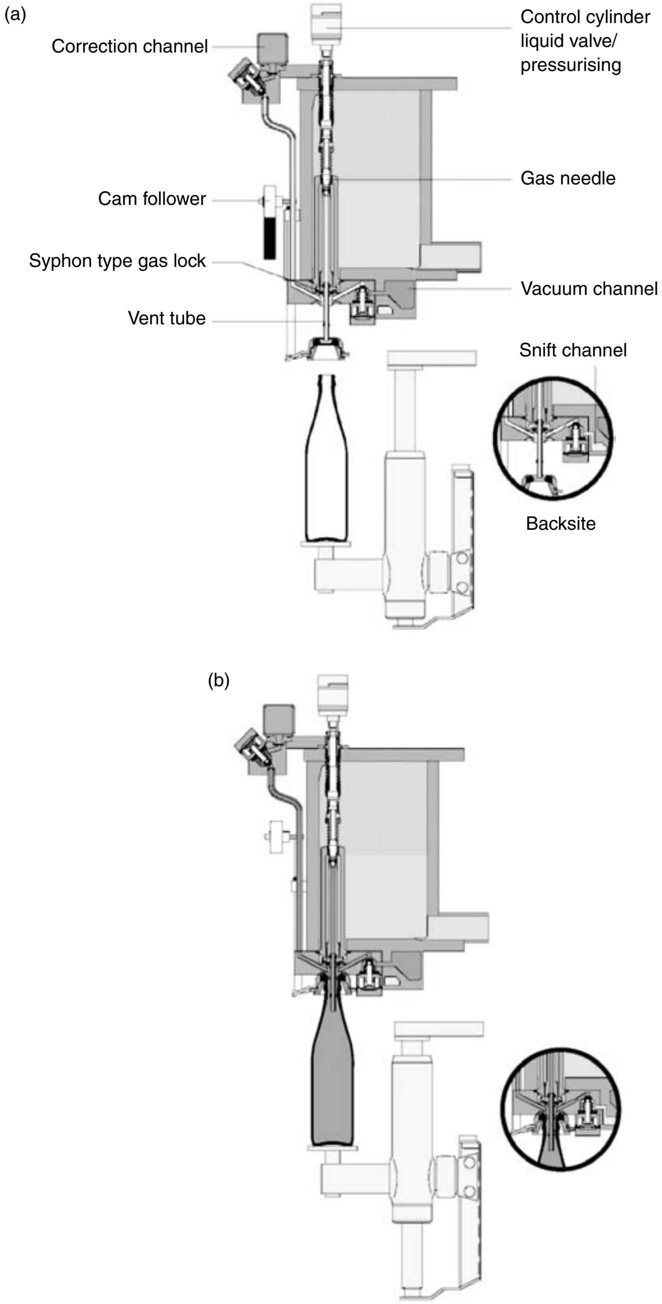


Figure 6.4 Krones VKPV-CF counter-pressure filler. (a) Basic position. (b) First evacuation. (c) Flushing phase. (d) Second evacuation. (e) Pressurising. (f) Filling. (g) Completed filling cycle. (h) Correction phase. (i) Completed correction phase. (j) Snifting (courtesy Krones UK Ltd).

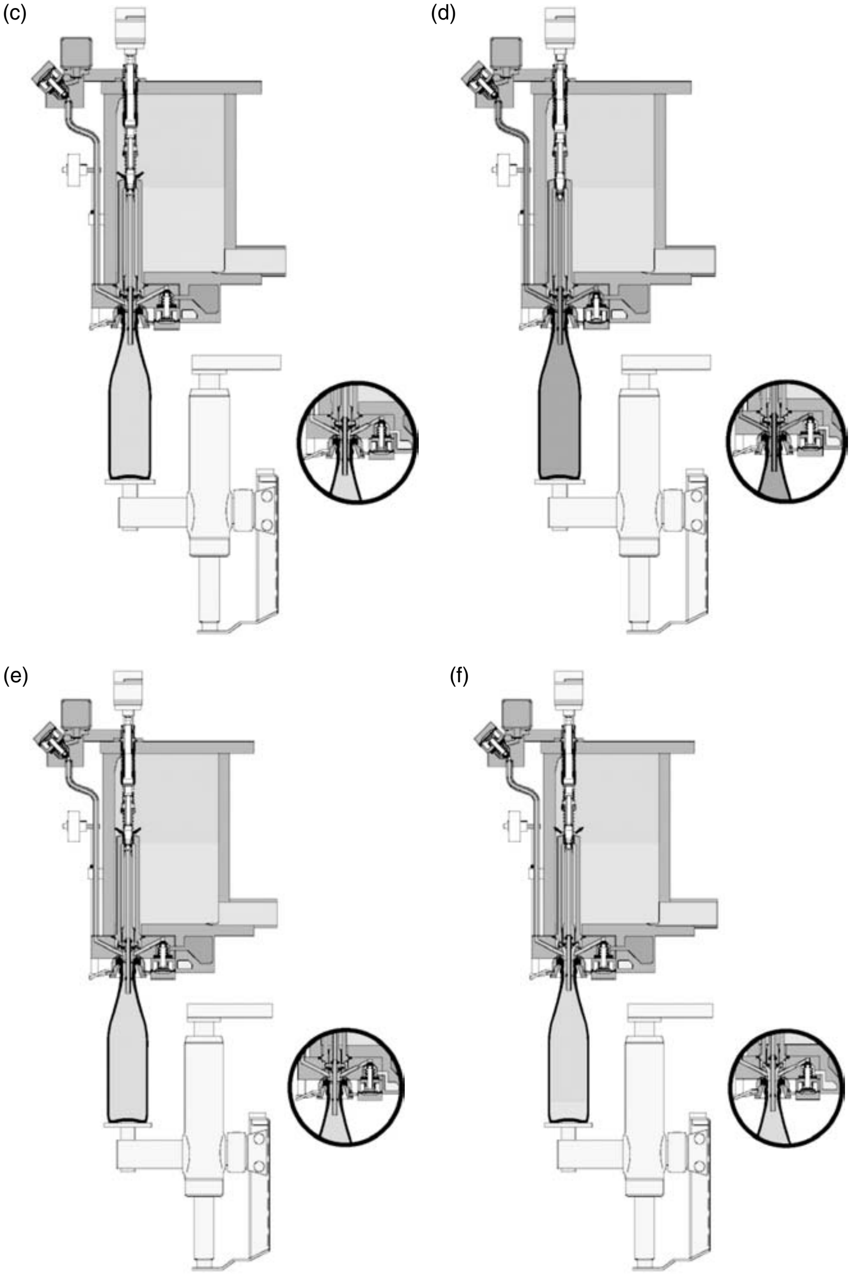


Figure 6.4 Continued.

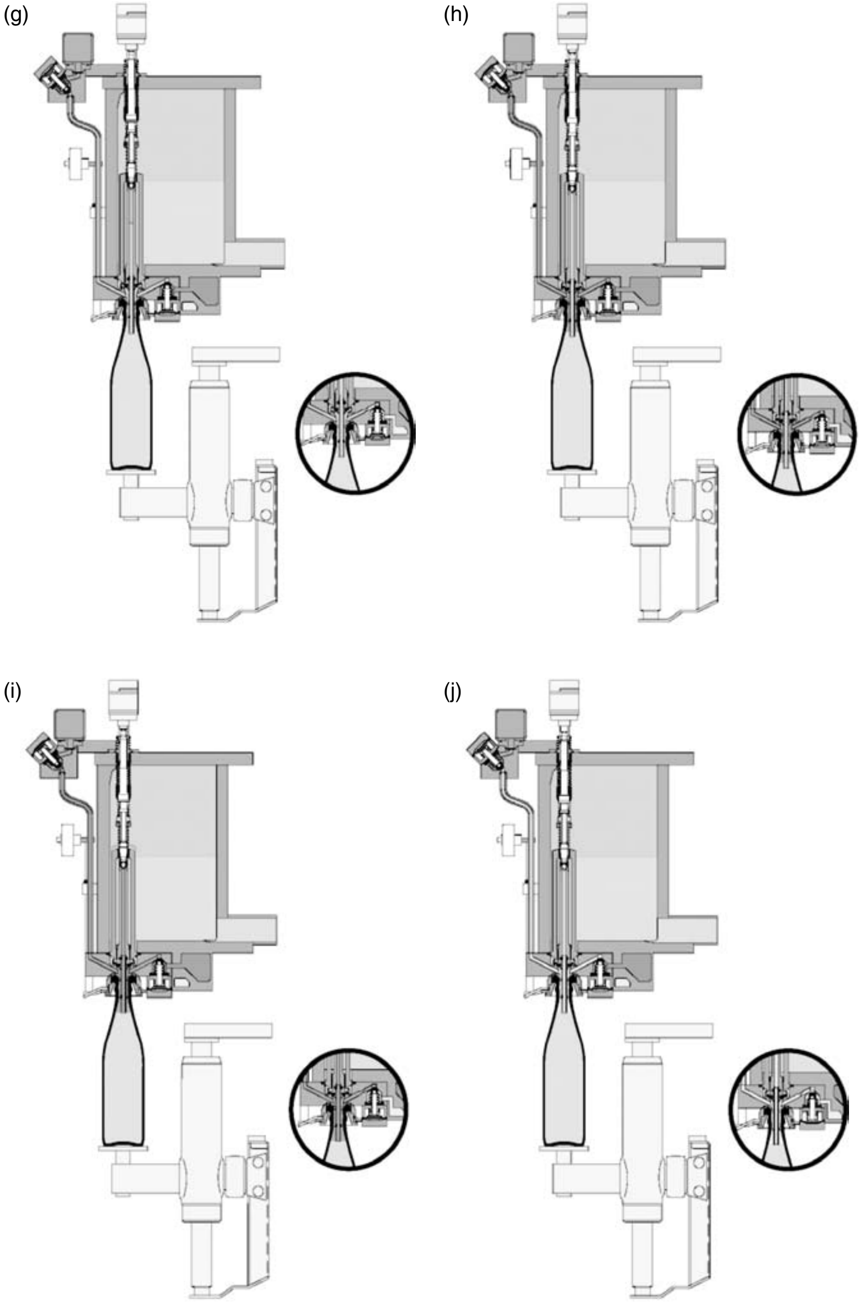


Figure 6.4 Continued.

Figure 6.4e illustrates the gas pressurising phase. A pneumatically controlled cylinder opens the gas needle, allowing gas mixture from the ring bowl into the bottle via the return air tube. This causes the filling pressure to be built up in the bottle. As a result, the pressure in the bottle and the ring bowl are the same.

Figure 6.4f shows the filling phase. When the pressure is equal, the liquid stem opens under spring control and the filling process begins. Product flows into the bottle along the return air tube and the small spreader, mounted on the return air tube, deflects the liquid to the inside bottle wall to ensure a gentle product flow. The pressurisation gas is forced out of the bottle during the filling process and flows back into the ring bowl via the return air tube.

Figure 6.4g illustrates the filling completed phase. As soon as liquid reaches the lower edge of the return air tube, the gas return flow is interrupted, ending the filling process automatically. The bottle is purposely over-filled here. The pneumatic double-lifting cylinder closes the product stem, and the gas needle remains open.

Figure 6.4h shows the correction phase. Following an electronic pulse, the correction valve opens and pure CO_2 flows into the bottle. With a slight over-pressure of approximately 0.2 bar, the over-filled liquid is forced back into the ring bowl via the return air tube.

Figure 6.4i illustrates the correction completed phase. Owing to the over-pressure of pure CO_2, the liquid is completely removed from the return air tube. As the quantity of CO_2 used is exactly defined, a precise filling level can be achieved.

Figure 6.4j shows the snifting phase. The snift valve opens the connection to the snift channel. As a result, the pressure present in the bottle neck can escape until atmospheric pressure is reached again. The lifting cylinder moves downwards, and the bottle is lowered and transferred to the discharge starwheel.

6.3.2 Level filling

In this section, the development of the mechanical filling valve in a level filler through electro-pneumatic technology is examined. The mechanical filling valve is an extremely efficient piece of technology and still a popular choice when filling carbonated beverages. Figure 6.5 indicates a mechanically operated valve in which all movements are controlled mechanically. Component parts of the filling valve which are inside the filler bowl, the product valve and gas needle, are operated by a control lever which, in turn, is raised and lowered by cams external to the ring bowl. Pressurisation and filling phases are controlled by this operation.

The snift phase is operated by the snift button located at the base of the filling valve being activated by an external cam. As the filling phases are controlled by cams, this type of filler has to be set up to operate at a fixed speed for optimum filling.

The operation of the mechanical filling valve was modernised when electro-pneumatic control was introduced, and Figure 6.6 indicates the mechanical filling valve with pneumatic control. The well-proven filling valve now has the product valve and gas needle controlled by a pneumatic cylinder on top of the filler

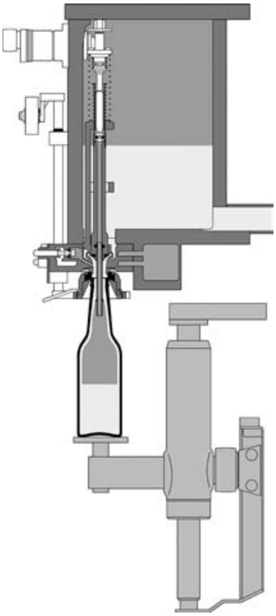


Figure 6.5 Mechanically operated valve (courtesy Krones UK Ltd).

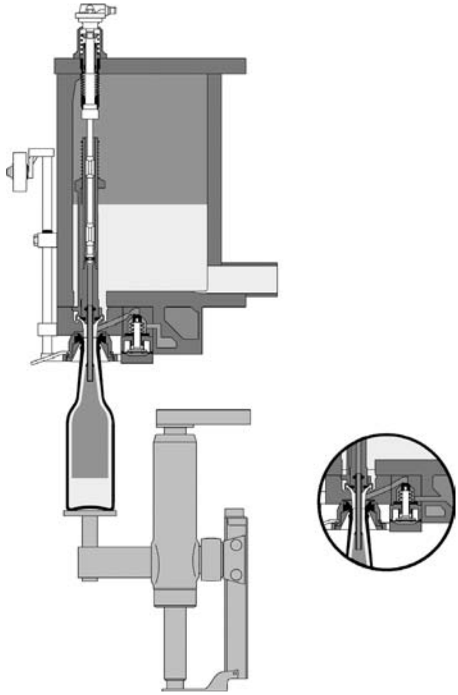


Figure 6.6 Mechanical filling valve with pneumatic control (courtesy Krones UK Ltd).

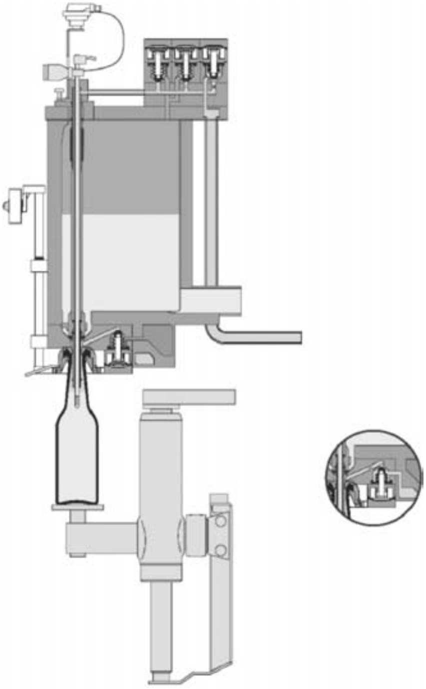


Figure 6.7 Filling valve pneumatically actuated with level probe (courtesy Krones UK Ltd).

bowl. A pneumatic diaphragm valve operates the snift phase. All operations are electronically controlled, eliminating the control cams on the outside of the filler bowl. As filling phases are now controlled electronically, optimum filling is possible at varying speeds. Fill level is controlled by the vent tube and it is still necessary to change the tube for bottles with different fill points, as with the mechanically controlled valve.

A further development in electro-pneumatic control of the filling phases was to integrate a level probe into the vent tube. This allowed the mechanical filling valve to be replaced by a completely new streamlined valve as level control was now operated from the level probe. Figure 6.7 indicates this type of filler, which is particularly suitable when bottles with different fill points are being filled as the fill level can be adjusted electronically.

6.4 Glass bottle filling

6.4.1 Operation

Having examined in detail the filling phases available from the modern-day counter-pressure filler, especially the electro-pneumatically operated type, we will now consider the particular requirements for the filling of glass bottles:

1. bottle handling to the filler infeed
2. bottle handling around the filler
3. lifting the bottle to the filling valve
4. air removal from the bottle prior to filling.

Bottle handling to the filler infeed must be carefully controlled to minimise noise yet still avoid bottle-to-bottle contact as bottles enter the infeed scroll. Intelligent conveyor systems which follow the speed of the filler with line sensors and variable-speed drives go a long way towards gently controlling bottles into the filler. Filling speeds for glass bottles of 800–1200 bottles/min are now commonplace, so even greater care is necessary to positively control the infeed to the filler. One example of this, in the form of a decelerating bottle stop, is shown in Figure 6.8.

This device is used on a filler which operates at a constant filling speed and uses a pneumatic cylinder for bottle control. Bottles are allowed to enter the filler

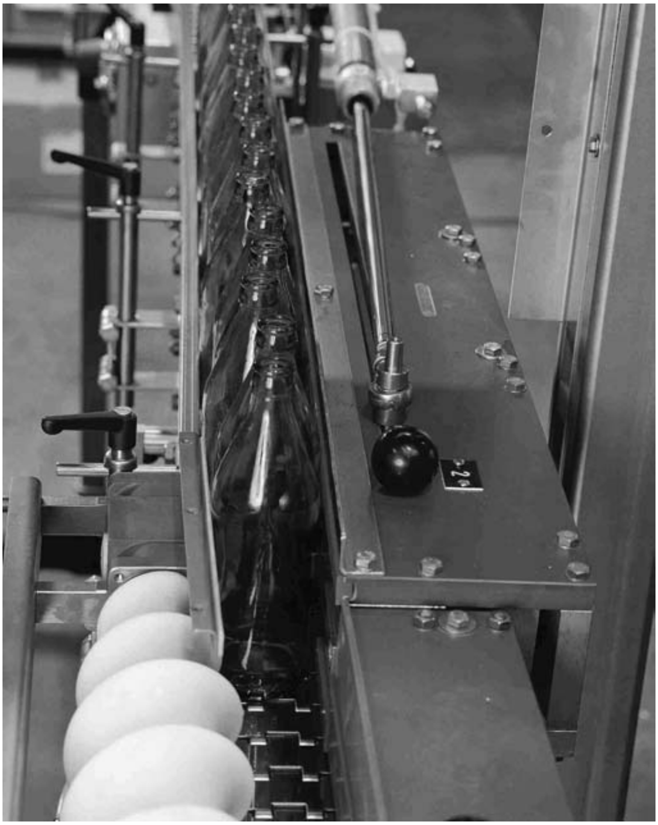


Figure 6.8 Decelerating bottle stop (courtesy Krones UK Ltd).

Figure 6.9 Bottle transfer in filler (courtesy Krones UK Ltd).

from rest by releasing the bottle stop starwheel and accelerating both filler and infeed conveyor to operating speed when the first bottle reaches the filling valve. The piston holding the bottle stop starwheel then retracts against the flow of bottles to its park position upstream of the infeed scroll. When the filler is required to carry out a controlled stop at speed, the now freely rotating bottle stop starwheel is locked and the force of conveyed bottles causes the cylinder to extend. Cylinder movement is dampened and slows the moving bottles until they come to rest in front of the infeed scroll.

Bottle handling around the filler must be under complete control to ensure stability, accurate positioning to the filling valve and gentle transfer to the discharge bottle conveyor, as per Figure 6.9. Bottles from the infeed conveyor enter the infeed scroll and are pitched to match the filler pitch and then transferred to the infeed starwheel. This transfers the bottles to the filler carousel, where the centring bell is lowered on to the bottle neck before it leaves the starwheel. Bottles are discharged from the filler carousel in the opposite way, by lifting the centring bell from the bottle as it enters the discharge starwheel before transferring to the discharge conveyor. As the bottles enter the filler carousel they are raised to seal against the filling valve by a lifting cylinder, as seen in Figure 6.10. The cylinders are precisely controlled to gently but quickly raise and lower the bottles.

As described earlier, one important factor when filling oxygen-sensitive beverages is the removal of air from the bottle prior to filling. This step can be performed

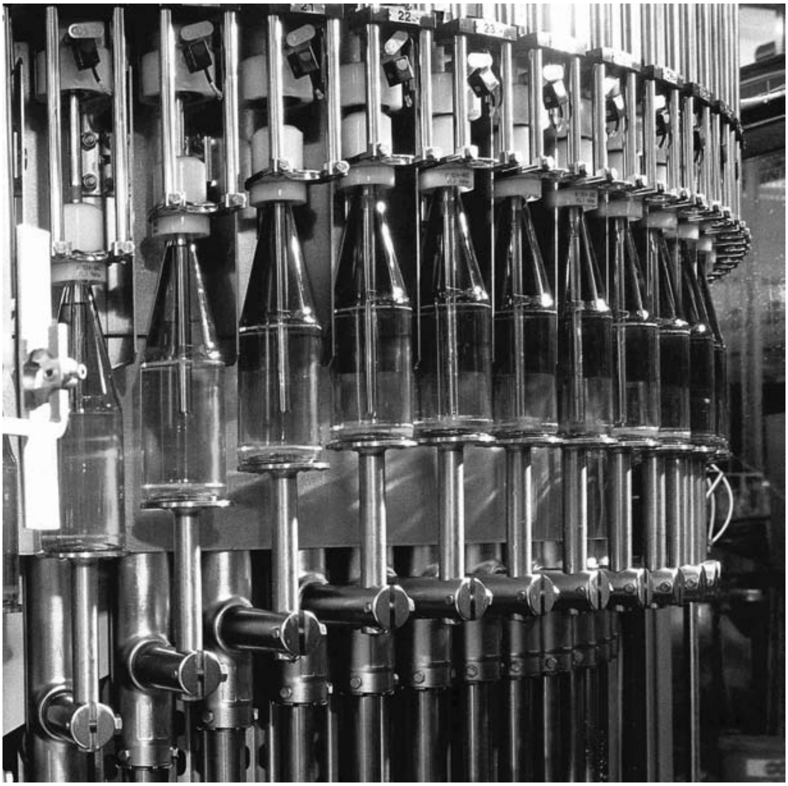


Figure 6.10 Bottle lifters (courtesy Krones UK Ltd).

by flushing the container with CO_2. However, for a more efficient removal of the air, an advantage of filling a rigid container is that a vacuum step can be introduced before flushing, as illustrated in Figure 6.11.

6.4.2 Bottle burst protection

When carbonated beverages are filled into glass bottles, there is a risk of bottles bursting in the filling machine under pressure. This usually occurs if a bottle has a weak point or has been damaged in some way. It is necessary to protect other bottles from ingress of glass fragments when a burst occurs on the filling machine, so that the risk of a consumer finding a sliver of glass in the product is minimal.

Filling machines for carbonated beverages in glass bottles are fitted with stainless steel protective divider plates between the filling valves. These are matched to the optimum bottle height and protect neighbouring bottles in the event of a bottle bursting.

The most likely place for a bottle burst to occur is at the point of pressurisation. Protective stainless steel guards are fitted around the filler carousel at the

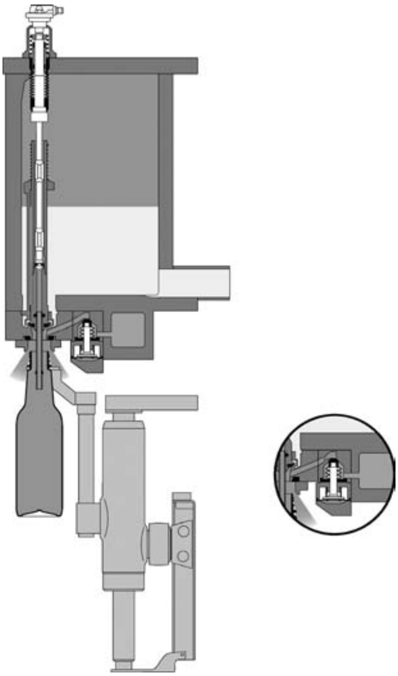


Figure 6.11 CO_2 flushing (courtesy Krones UK Ltd).

pressurisation area. These guards are commonly lined with rubber for shock and noise absorption and fit closely to the protective divider plates. This minimises the risk of glass fragments reaching neighbouring bottles, and the majority will fall to the floor.

It is essential that any remaining glass in the filling valve area is removed to prevent ingress into bottles. This can be done by manually flushing the area with water, but it is more commonly an automatic process. A filling machine equipped with a burst bottle protection system will incorporate a high-volume water shower on the carousel and programmable bottle rejection at the filler discharge. A typical bottle burst protection system is shown as Figure 6.12. On a bottle bursting, the water shower will be automatically triggered and the whole of the filling valve area will be flushed for several turns of the carousel. At the same time, a number of bottles from either side of the filling valve where the burst occurred are rejected from the discharge conveyor. Subsequent bottles from the filling valve where the burst occurred are also rejected for several rounds of the carousel. Typically, three or four bottles on either side of the particular filling valve will be rejected for two rounds and bottles from the filling valve will be rejected for five rounds.

During the filling process, bottles are pressed against a rubber seal in the centring bell. This seal is of special food-quality rubber which is flexible enough to form a seal with the bottle yet hard enough (typically 75 shore hardness) to resist

Figure 6.12 Bottles on the filler carousel sealed against centring bells (courtesy Krones UK Ltd).

penetration of glass. However, it is an important part of maintenance to have a routine programme of regular seal replacement.

6.5 PET (polyethylene terephthalate) bottle filling

6.5.1 Operation

The PET bottle was introduced to the beverage industry more than 30 years ago. It brought new challenges for the equipment suppliers to the industry. The benefits of a heavy, rigid container were no longer available, but in its place was an extremely lightweight, flexible container which could be easily deformed.

Conventional slat-type bottle conveyors can be used to transport PET bottles, although they are used primarily for the transport of filled bottles. Filled PET bottles, especially with carbonated beverages, become very rigid and are easily conveyed, as seen in Figure 6.13.

Empty PET bottles, however, can be difficult to handle on a slat conveyor, especially when conveying into the filling machine. It did not take equipment designers very long to realise that these bottles could be transported in air conveyors using the neck support ring. Air conveyors are now the most common method used to transport PET bottles to the filling machine, and considerable space can be saved when they are installed high up, freeing up valuable floor space. A typical system is shown in Figure 6.14.

Early methods of transferring bottles into the filler were adaptations of conventional starwheels. However, the same principle as was applied to conveying the bottles was applied to handling in the filler. Figure 6.15 shows the transfer of PET

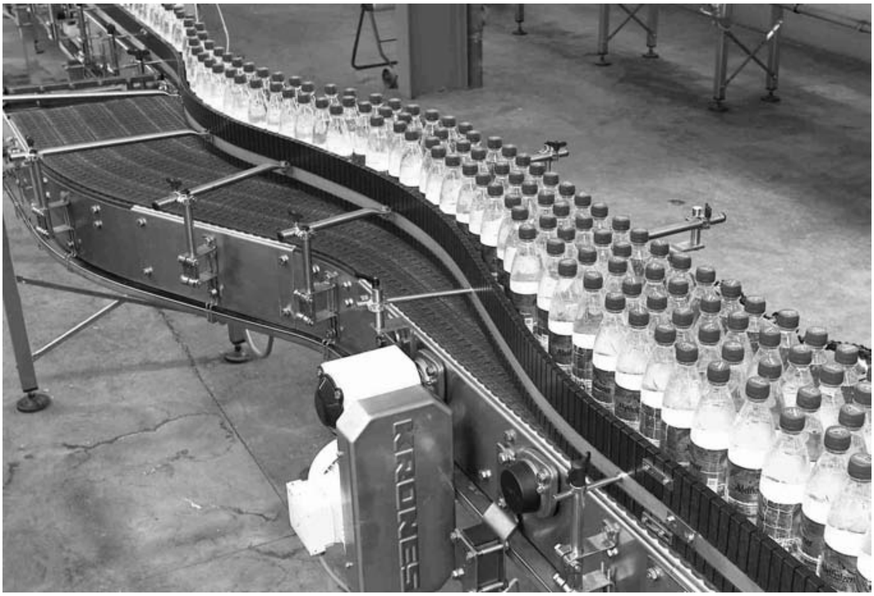


Figure 6.13 Full PET bottle conveying (courtesy Krones UK Ltd).

bottles from an air conveyor to a starwheel, using a pitching starwheel. Once inside the filler, bottles are transferred from the neck-handling starwheel on to the filler carousel, as shown in Figure 6.16. In the case of multiple starwheels, bottles are transferred from one to the other, alternately gripping the bottle above and below the neck support ring.

As bottles enter the filler carousel, they are raised to seal against the filling valve. The bottle must be pressed against the filling valve to maintain a seal, and early methods to achieve this were adapted bottle lifts incorporating a neck-support extension. It was this support that applied pressure under the neck support to seal the bottle to the filling valve. Modern neck-handling systems transfer bottles into neck lifts at each valve position, as illustrated in Figure 6.17. Bottle lifts grip the bottle under the neck-support ring and are then raised by a cam until the bottle seals against the filling valve, in the same way as conventional bottle-lift cylinders are used for glass bottles.

As described earlier, one important factor when filling oxygen-sensitive beverages is the removal of air from the bottle prior to filling. This step can be performed by flushing the container with CO_2. When flexible PET bottles are filled, this step is carried out as the bottle is raised to the filling valve.

6.5.2 Size changing

Modern filling systems for PET bottles handle bottles by the neck throughout the filler and capper. At the infeed to the filler, bottles are transferred from the neck-handling air conveyor using a pitching starwheel. This pitching starwheel has

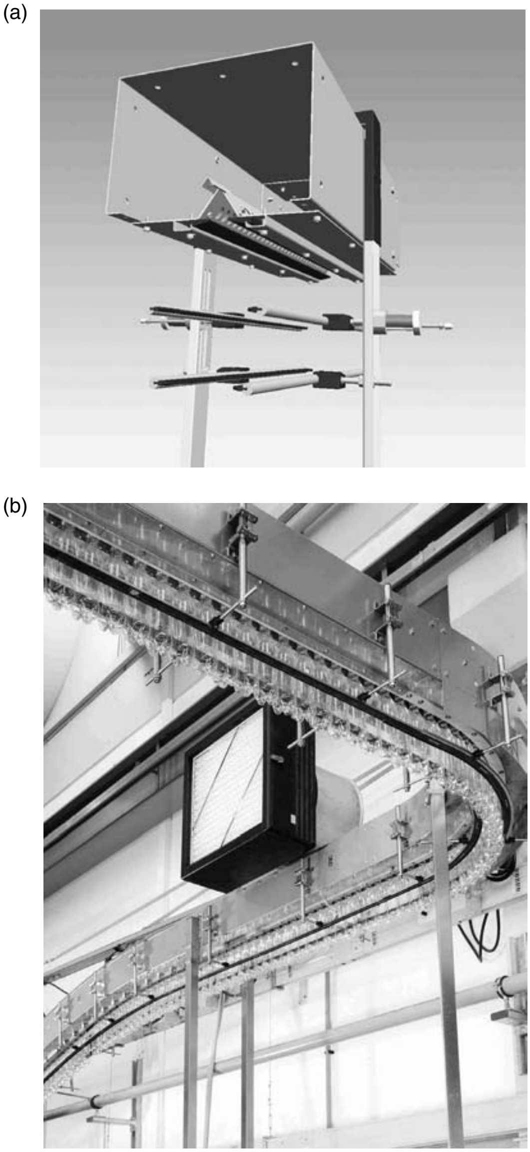


Figure 6.14 Two views of airveying empty PET bottles (courtesy Krones UK Ltd).

replaced the traditional infeed scroll, which had to be changed for each different bottle diameter.

As the pitching starwheel rotates, a specially shaped point of the starwheel passes between two bottle necks and forces the bottles apart until they are at the same pitch as the starwheels and filling valves. This process is repeated for each

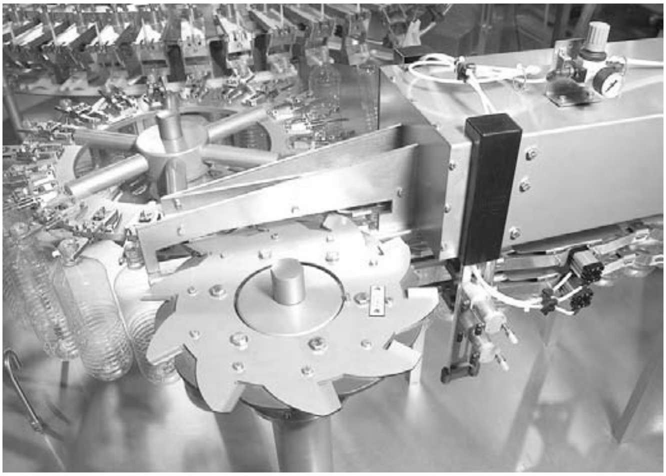


Figure 6.15 Empty PET bottle transfer into the filler (courtesy Krones UK Ltd).

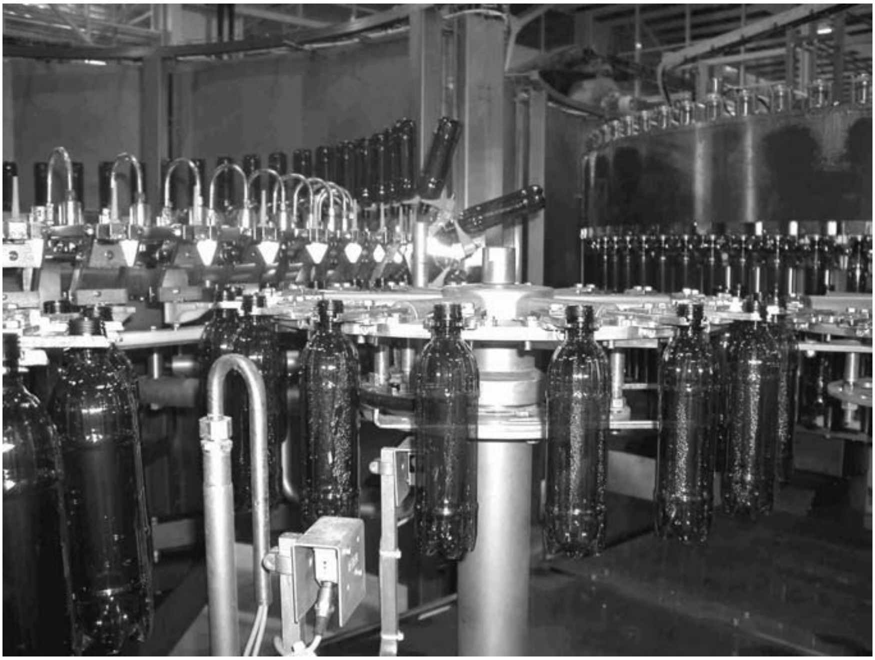


Figure 6.16 Filler carousel (courtesy Krones UK Ltd).

bottle and, as the bottles are handled by the neck, there is no need to change the starwheels for different bottle diameters.

Starwheels have individual grippers for each bottle, and each gripper transfers a bottle from the pitching starwheel. If transfer is required from starwheel

Figure 6.17 Neck lifts (courtesy Krones UK Ltd).

to starwheel, then alternate starwheels grip the bottle below then above the neck-support ring. Bottles are transferred from a starwheel to the filler carousel on to neck carriers under each valve, which then raise the bottles to seal against the filling valve. Bottles are then transferred from the carousel to a starwheel.

It is common practice to ensure that all bottles handled on such a filling system have the same neck finish. As bottles are handled by the neck, the filling system is set up in terms of height to suit the tallest bottle being filled, thus allowing all other bottles to be handled without height adjustment.

At the capper, bottles are discharged on to a conventional slat chain conveyor. The conveyor is set up to suit the height of the tallest bottle. All other bottles of shorter height or different diameter will then have an individual discharge starwheel which incorporates a ramp to lower the bottle to the height of the discharge starwheel.

The considerable benefit of this system is the minimum changeover requirement between bottle sizes. The need for cumbersome change parts to be fitted every time the bottle size changes is diminishing. In the past, such change parts were often damaged during handling and storage, causing downtime during the filling operation.

6.6 Can filling

6.6.1 The volumetric can (VOC) filler

When, in 1994, Krones introduced a new generation of electro-pneumatically controlled volumetric can filling systems, the main objective was to provide the brewing and beverage industry with a way of filling cans within a very tight volumetric tolerance. This development was highly appreciated, particularly by breweries in countries where beer is subject to taxation when leaving the brewery gate and so brewers are most anxious to avoid unnecessary 'over-fills'.

The flexibility and multi-functionality of the VOC-type filler became very obvious when it was demonstrated that the filling of canned draft beer required a special filling technique. The requirements of brewers are not dissimilar to those of manufacturers of soft drinks in that high filling accuracy, low product loss and very low levels of oxygen pick-up are deemed essential requirements in the packaging of high-quality beverages. After the first fillers were put into operation, it was found that apart from its unprecedented filling accuracy, this filling system perfectly met the increasing demands of the industry with regard to improved quality control of the filling process.

What enables the VOC filler to achieve significantly lower total package oxygen (TPO) than the conventional, mechanically controlled can filler? The entire filling process is controlled by a micro-processor positioned in the centre of the filler carousel. All process steps, such as two-stage flushing with CO_2, pressurising, filling valve opening/closing and snifting, are controlled not using mechanical cams but through pneumatic control elements comprising well-proven components guaranteeing long service life. These pneumatic control elements are activated via solenoid valves housed in class IP 65 protection stainless steel terminal boxes. The solenoid valves receive time-dependent control impulses from the central processor and the cycle times are parameterised very simply using the liquid crystal entry terminal on the machine's control panel. The volumetric system utilises a process of maximised inherent accuracy and consistent reproducibility.

All parameters are displayed in plain text. All product-specific requirements in combination with the can size being handled are simple to program, store and recall. In addition to the required fill volume, the duration (in milliseconds) of the individual filling phases can be programmed to suit perfectly the filling characteristics of different types of beverage with varying levels of carbonation and gravity. This offers many ideal properties:

1. Optimum setting of the CO_2 flushing phases is possible, starting with a thorough sweep of the can at filling pressure (2.0 bar) prior to sealing (duration 150 ms), followed by a flushing of the differential pressure

chamber (duration 50 ms) as part of the telescopic centring sleeve being pneumatically lowered to the rim of the can, providing a gas-tight seal.

2. Compared with a mechanically controlled filler, the VOC filler's differential pressure chamber is about 40 ml smaller in volume (160 versus 120 ml), resulting in a reduced consumption of flushing gas.
3. The volume of CO_2 used for the second step of flushing (i.e. with the can in the sealed position) is forced into a gas-collecting channel incorporated into the valve support ring, which is used also as the CIP main return during cleaning. The total volume of CO_2 ending up in this channel (78 kg/h based on two thousand 330 ml cans per minute, including the vented CO_2 resulting from the final snift operation) is available at a concentration of 80–90% for possible recovery.
4. The processor-controlled duration of both the flushing cycles is set independently from the ramp-up and ramp-down speeds of the filling machine, thus ensuring (unlike a cam-controlled filler) constant CO_2 flow and CO_2 consumption.
5. After the can has been pressurised, the processor control ensures the product valve stem will not be released until a complete pressure equilibrium between the can and the CO_2 supply chamber has been reached. This is different from a mechanically controlled filling valve, where the opening function of the product valve is spring operated, allowing product flow to start. As the pressure has not completely balanced in this case, there is the risk of fobbing.
6. Another big advantage offered by electro-pneumatic control is the way the equally important snift function can be carried out via two separate pneumatic control valves. To complete the filling after a pre-programmed time for settling (depending on the product type to be handled), a two-stage snift operation is initiated. The pressure in the valve-incorporated gas channel will first be reduced to ambient pressure; this is followed (after a delay of some milliseconds) by the pressure relief of the can's head space, including the gas volume inside the differential pressure chamber.
7. The flexibility of the processor control system allows for smooth single- or multi-stage snifting, or even a very simple parameterising for a pulsing mode of the lower snift valve.
8. In fine-tuning the snift cycle while the filler is running at nominal speed, a perfectly uniform blanket of high-density foam will be generated above the liquid level in the discharged can. This layer of foam minimises the risk of the product in the filled can making contact with atmosphere after the filling valve has been lifted and the can is conveyed towards the downstream seamer to receive treatment by the covered gassing system.

A further advantage of this filling system, related to low-oxygen filling, is the gentle and smooth handling of the beverage not only when charging the metering chamber but also during product flow into the can.

The pneumatically controlled product inlet valve is located behind the metering chamber, providing a link to the flood-filled product ring main integrated into the valve support. The variable switch points of the ultrasonic level probe can be set to ensure that there is always a defined low level of product present inside the metering chamber, as seen in Figure 6.18. The filling valve compartment is always flooded with product, and the product entering for the next can to be filled flows gently into the metering chamber as an absolutely bubble-free beverage column. This below-surface filling process guarantees that the metering chambers are gently filled without any turbulence or fobbing, a procedure that can be observed at individually installed transparent metering chambers made of pressure-resistant glass.

The actual filling valve, which could be referred to as the 'metering chamber outlet', is designed without any springs in the product passages. This is of substantial importance when considering stringent CIP requirements. Of equal importance is the achievement of a laminar flow, which is assisted by means of the filling valve's unbroken 360° annular ring-type product discharge orifice.

In a continuous liquid umbrella configuration, product flows down the walls of the can. The discharge geometry would also allow for flow property variations between different shapes of can. A pre-calibrated volume is 'drained' into the can, and the lower trigger point of the probe in the metering chamber generates a signal to close the valve stem pneumatically. This feature is a clear advantage of the volumetric filling system when compared with conventional height filling systems with a vent tube and siphon-type gas lock.

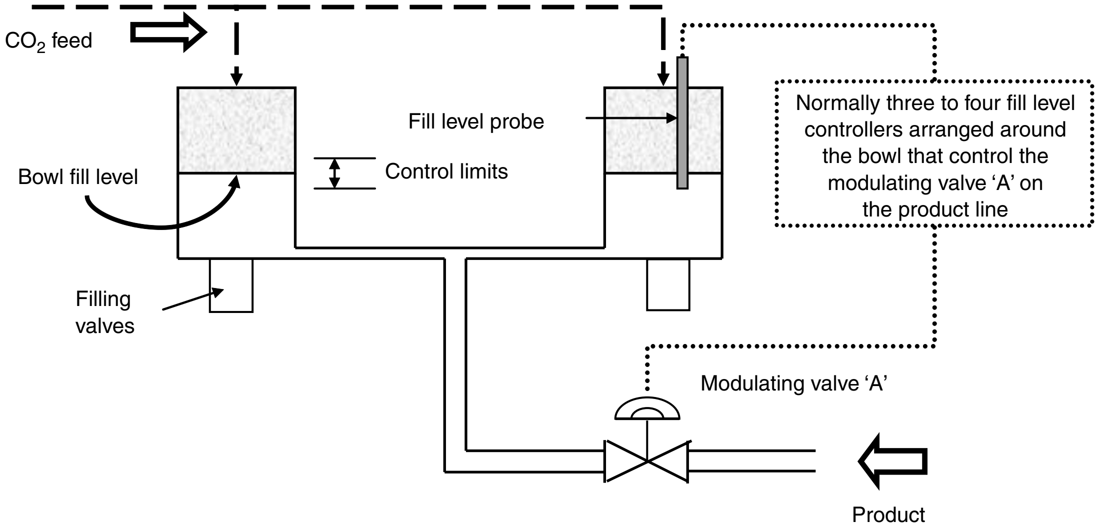
Unlike in the case of a mechanical vent tube filler, there is no valve component making contact with the final liquid level in the can. No product can rise into the return gas passage. Thus this can filler operates without the need for a scavenge function, which again helps to achieve a gentle filling process because no residual product will be atomised into the empty can during initial CO_2 charging. In addition, it reduces the overall CO_2 consumption significantly.

The essential VOC system advantages leading to lower TPO figures can be summarised as follows:

1. extremely flexible programming of the flushing mode to achieve the highest possible CO_2 concentration in the can
2. absolute turbulence-free laminar product flow into the can
3. utmost flexibility in adjusting the snift process
4. no scavenging required.

6.6.2 System expansion – the VOC-C can filler

The second 'C' stands for an additional gas channel next to the normal pressurising channel to which pure CO_2 at the required filling pressure is supplied. All volumetric fillers operate according to the single-chamber principle. This means that the initial pure CO_2 cushion in the first pressure channel (connected to the gas compartment of the free-standing product tank) is gradually diluted by the CO_2/air mixture returned from the can during filling.



Normally three to four fill level controllers arranged around the bowl that control the modulating valve 'A' on the product line

Figure 6.18 Filler bowl level control.

To ensure optimum filling quality, the slightly reduced CO_2 concentration from the first channel (approximately 98%) is used only for can flushing prior to filling. For can pressurisation, pure CO_2 from the second channel is used. This results in a further slight reduction of the TPO figure. During filling, displaced pure CO_2 flows back into the first gas channel. The two gas channels of the VOC-C-type machine incorporate separate pressure-control systems and can meet all process requirements in this respect.

6.6.3 Product level- and pressure-control system in a free-standing product tank

6.6.3.1 Level control

The annular product channel incorporated into the filling valve carrier ring is connected via a rotary distributor to a free-standing product tank adjacent to the filler, with a total volume of 750 l (product and gas compartment). The tank's fill level is likewise regulated using an ultrasonic metering probe. The signal is transmitted via a central slip ring unit to an electro-pneumatic converter. The pneumatic signal then activates the modulating valve in the product supply line. After the product inlet valve has been opened pneumatically, filling of the metering chamber is governed by the static pressure gradient to the fill level in the free-standing tank. A level-control instrument on the operating panel enables variable adjustment of the product supply level in the tank, even during operation, and is independent of the set filling pressure. By changing the product supply level, the re-charging speed of the metering chamber can be influenced.

6.6.3.2 Filling pressure control

The filling pressure in the gas compartment, which is connected by pipe to the filling valve metering chambers via a rotary gas manifold and the annular gas main, is matched to the product type concerned by a sensitive, responsive pressure-control system. A pressure transmitter records the filling pressure, and the value set at the pressure controller incorporated into the operator panel is held constant by a so-called split range control system. Two fine-tuned modulation valves ensure proper pressure relief. The ultra-sensitive control system allows for pressure fluctuations within a range of only ±0.1 bar. Filling pressure is also regulated independently of the product supply pressure. This combination of level and pressure control enables the fundamental rule to keep filling pressure as low as possible and only as high as necessary to be followed.

6.6.4 Procedural steps of the filling cycle

Before a can is placed under the filling valve, the centring unit is raised under cam control by specific venting of the pneumatic cylinder. Thus all that needs to be lifted is the weight of the can-centring element itself, without any counter-forces generated by spring or gas pressure. Compared with conventionally controlled can fillers, wear and tear on cams, rollers and their bearings is thus substantially reduced.

An empty can is positioned exactly under the filling valve by the infeed starwheel and can table guide pockets. Cam-follower controlled, and assisted by the force of the meanwhile re-activated pressurised pneumatic cylinder, the can-centring unit is positively lowered on to the can rim to provide a gap of 2–3 mm and to prepare for the first operational step.

6.6.4.1 Flushing phase I

The pneumatically opened gas valve ensures thorough CO_2 flushing of the empty can through the centre bore of the valve stem at the adjusted filling pressure, forcing ambient air out of the can. During this initial flushing phase, the majority of the CO_2 volume used escapes to atmosphere. A flushing-position-installed 'funnel-type' exhaust system could remove CO_2 from the production area, although its concentration would be too low for worthwhile recovery. As the flushing/CIP-return valve is opened during this phase too, a small portion of CO_2 is forced into the gas collection/snift channel piped to the rotary distributor.

6.6.4.2 Flushing phase II

In order to carry out intensive flushing of the lower valve section, which incorporates a differential pressure can sealing system, allowing the handling of lightweight cans, the centring sleeve is completely lowered to provide a gas-tight seal between can and centring unit. The pneumatic cylinders with pressure-controlled air supply ensure seal and can-conserving preliminary contact with a top load of approximately 23 kg.

Both gas valves still being open, the CO_2 flow into the sealed can is returned, thus flushing the differential pressure chamber. The total volume of flushing gas is forced into the gas collecting channel for recovery via a relief path incorporated into the valve.

6.6.4.3 Pressurising

In this phase, the previously mentioned differential pressure system (or pressure-balanced system) becomes effective. The difference between the can rim diameter and the diameter of the telescopic centring sleeve allows the full filling pressure to be generated with minimum axial load on the can rim after the valve has been closed.

The product valve stem is pneumatically released to allow for its automatic lifting once a pre-set time has elapsed, which ensures that a complete pressure equilibrium between the empty can and the gas compartment in the metering chamber has been reached. The lifting operation is supported by an externally located spring.

6.6.4.4 Filling

Once the valve cone is lifted, product flows unimpeded by valve internals (no in-built springs) turbulence free into the can along its side wall. A liquid umbrella is formed by the filling nozzle's enclosed annular gap. In line with the single-chamber principle, gas displaced from the can is fed back into the system through a pressurising channel. The lower trigger point of the Transsonar probe in the metering chamber generates the closing signal, which the processor converts into an electro-pneumatic valve-control operation.

Fill volume accuracy, cautiously guaranteed with a standard deviation of 1.5 ml when the system was first introduced, has already been tightened to one standard deviation of only 0.8 ml for a 330 ml can, owing to excellent results in the field. This is conditional on a dependable fill quantity monitoring system with filling valve assignment at the discharge of filler and seamer. Violated limit values can thus be referenced to the valves concerned and quickly corrected at the liquid crystal terminal using the individualised fine-calibration feature of the Transsonar metering system. A standard deviation of 0.8 ml equates to a fill level accuracy of ±0.25 mm for conventional vent tube filling systems when applied to a can filling machine.

6.6.4.5 Snifting

After a pre-programmed time for settling (dependent upon product type), the filling process is completed by the snift phase. An upper valve and lower snift valve reduce the head space gas pressure in the can and the connecting gas channels to ambient pressure. Primarily for reasons of loss-free CIP cleaning, both the relief paths lead into the collection channel in the valve support. This means that gas volumes resulting from the snift operation can also be recovered. In this important phase of the filling cycle, the flexibility of the pneumatic control allows for single- or multi-stage snifting.

6.6.4.6 Recharging the metering chamber

When considering filling valve design, the metering chamber, which supplies the correct quantity of beverage to the valve, is the most striking feature. The Transsonar ultrasonic probe provides very accurate dosing in this chamber. A ball-type stainless steel float incorporating a magnet is used as the fill level transmitting element. This level probe provides an extremely high resolution, that is, for each 0.12 mm of travel of the float-incorporated magnet, a trigger signal will be generated.

Product is supplied to the measuring chamber by means of a valve connected to the annular product channel. The valve is released or closed by means of a pneumatic cylinder. Lifting of the valve cone is again assisted by an externally mounted spring. As soon as the filling of the can is completed, the metering chamber inlet valve will be opened for the recharging process. The product level travel in the chamber contributes considerably to the success of this type of filler. The lower level trigger point is set to ensure a certain residual product volume remains in the chamber/valve block at the end of each filling cycle. Recharging of the chamber is carried out from the lower end through the residual product volume, thus eliminating turbulence and bubble and foam formation.

6.6.4.7 CIP cleaning

As with conventional mechanical fillers, the VOC filler is designed to allow for full closed-circuit CIP cleaning (Figure 6.19). To this end, the CO_2 supply channel as well as the snift-gas-collecting channel are integrated within the filling valve support ring and used as the CIP return line. All product and gas contact passages are manufactured from materials resistant to the entire range of commercial cleaning agents, chemicals and disinfectants, hot water and saturated steam. The cleaning circuit between the filling valve with its metering chamber and both the CIP return channels is closed by automatically applied CIP cups.

Swivel-mounted CIP cups, waiting behind each filling valve, are positioned precisely underneath the filling valve by a control cam installed between the can infeed and the tangential discharge at the filler's front table. In CIP mode, the can-centring units descend on to the CIP cups under pneumatic control to seal off the flushing pressure. The machine can be switched over to cleaning mode within a few minutes.

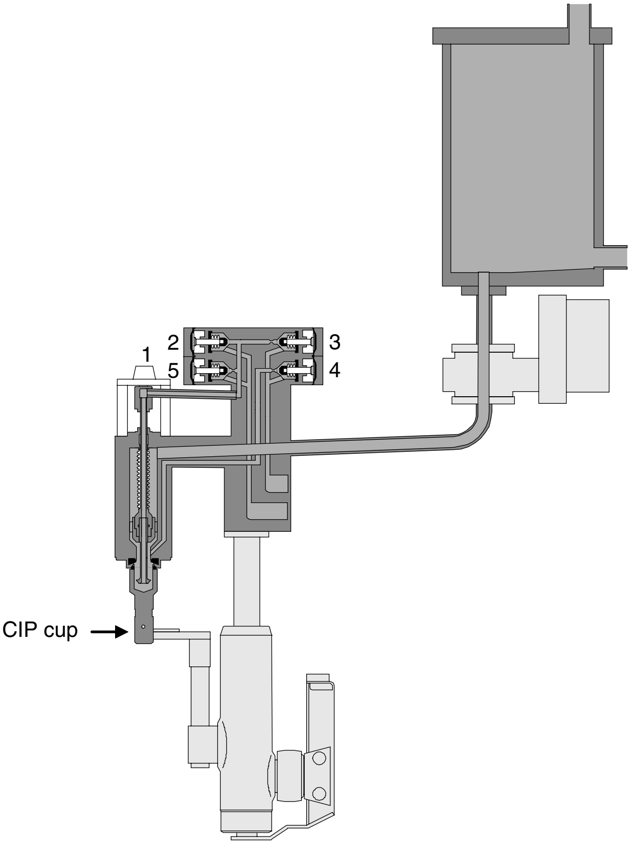


Figure 6.19 CIP cleaning phase. All areas that could be in contact with product are cleaned with a continuous flow during the CIP cycle.

6.7 Other filler options

For filling PET bottles, various types of level fillers are available but, ultimately, the amount of beverage in the container is controlled to a level in the bottle. Fill level accuracy is stated in terms of standard deviation. Typical values will be shown as sigma 1, sigma 2 or sigma 3. A standard deviation of sigma 1 indicates that 68.3% of a sample of measured containers will be within ±1 mm of the target fill point. This type of filling system gives particularly good filling accuracy in terms of the volume in the container when the fill point in the container is of a small diameter. However, when containers with a large diameter at the fill point are filled, the level filling system becomes very inaccurate in terms of volume.

Two types of volumetric filler are in use. The volumetric filler with a metering chamber, as discussed in Section 6.6, utilises metering chambers to pre-measure the volume of beverage before filling the container. The typical filling accuracy of this type of system is sigma 1.5. This system is particularly suited to large-diameter bottles. As the beverage is measured by volume, the bigger the bottle diameter, the more accurate the fill height. This system is used when the range of filling volumes is relatively small, typically 1.5–3.0 l, in order to maintain the level of accuracy.

A volumetric filler with flow meters utilises individual flow meters on each filling valve. Beverage volume is measured as the container is filled. The filling accuracy of this type of filling system depends on the accuracy of the flow meter. Typical accuracy is in the order of 0.2% of the measured volume. This type of filling system is particularly useful when filling a wide range of volumes. However, in terms of fill volume accuracy, the greater the volume, the greater the inaccuracy. Figure 6.20 indicates the fill volume accuracy of this type of filling system in relation to rated volume.

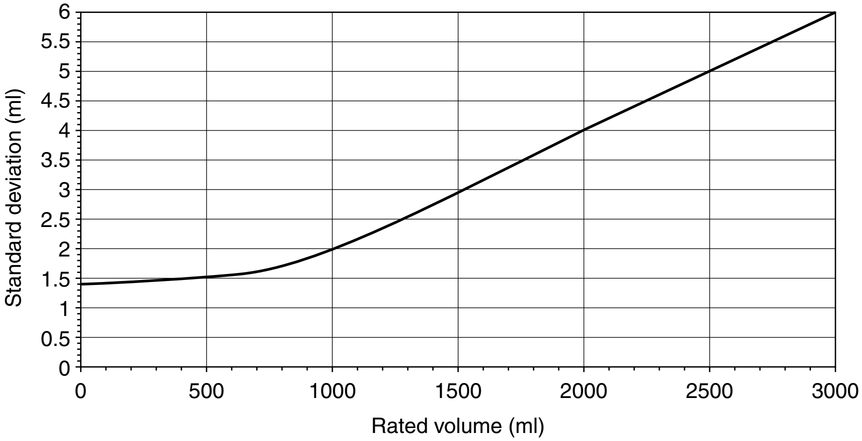


Figure 6.20 Fill level accuracy in relation to rated values (courtesy Krones UK Ltd).

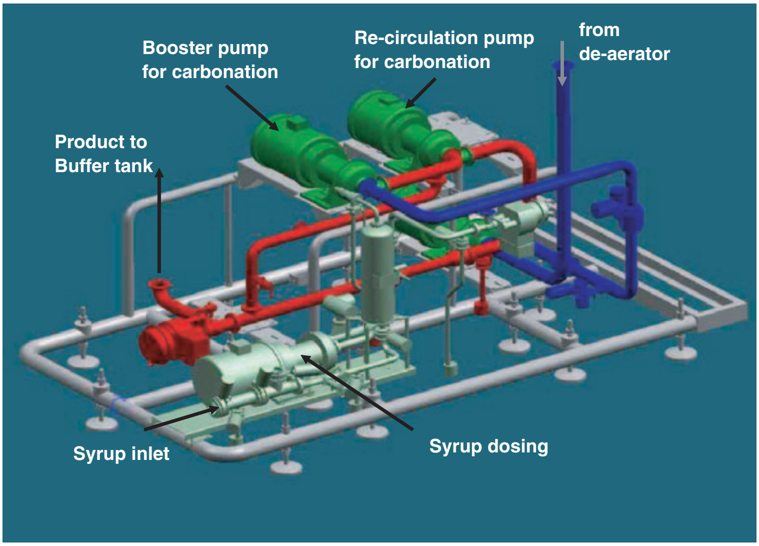


Plate 4.1 Schematic of a syrup mixer and carbonator.

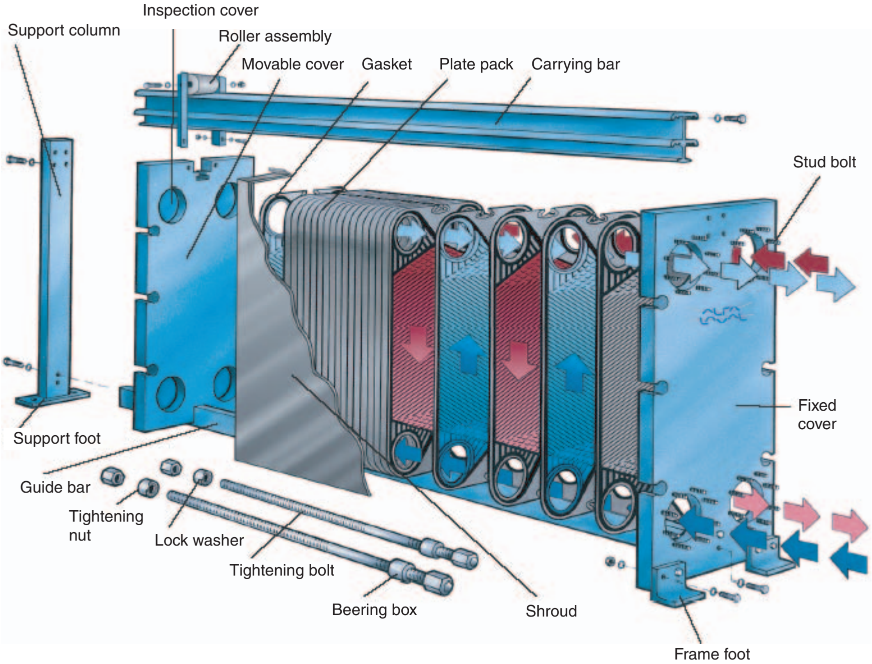


Plate 4.2 Flash pasteuriser exploded drawing (courtesy Alfa Laval).

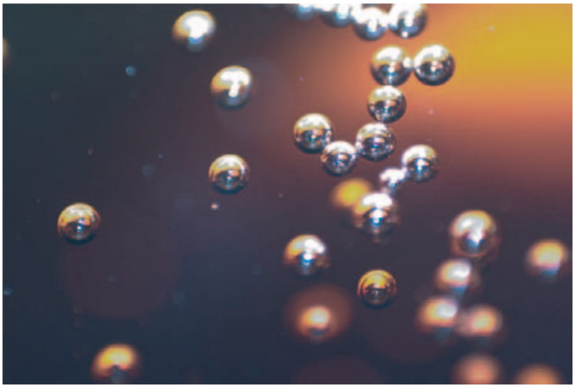


Plate 5.1 Carbonated bubbles.

Plate 9.1 Airveyor.

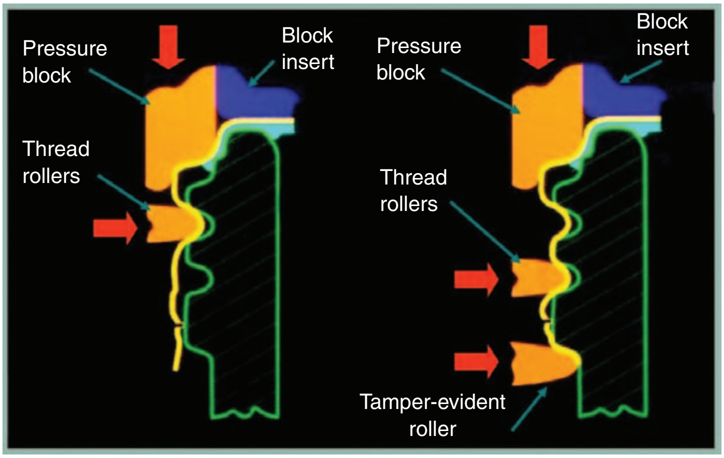


Plate 7.1 Aluminium roll-on closure — BSDA.

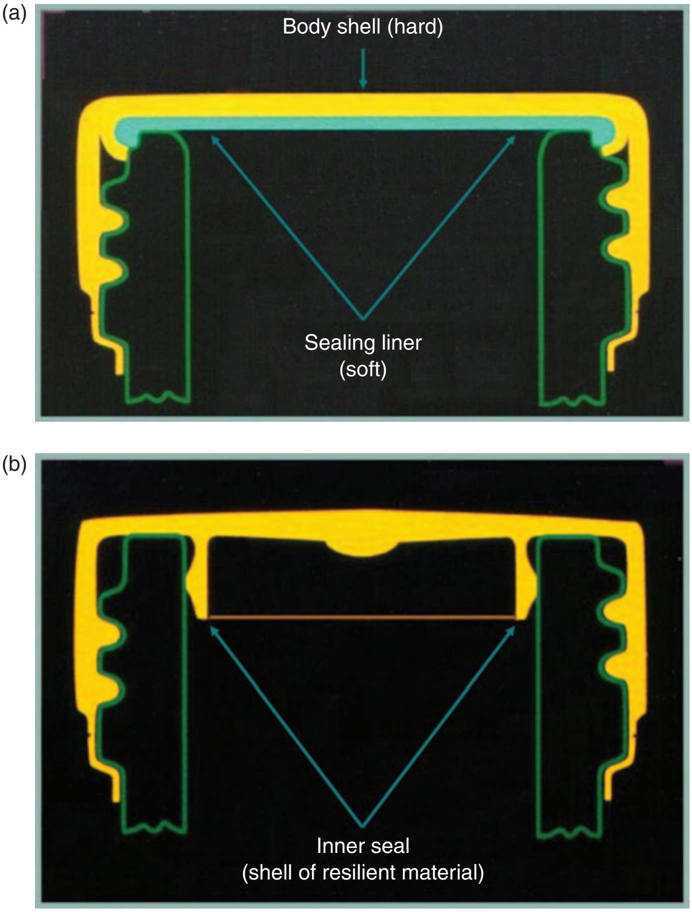


Plate 7.2 Two piece closure — BSDA.

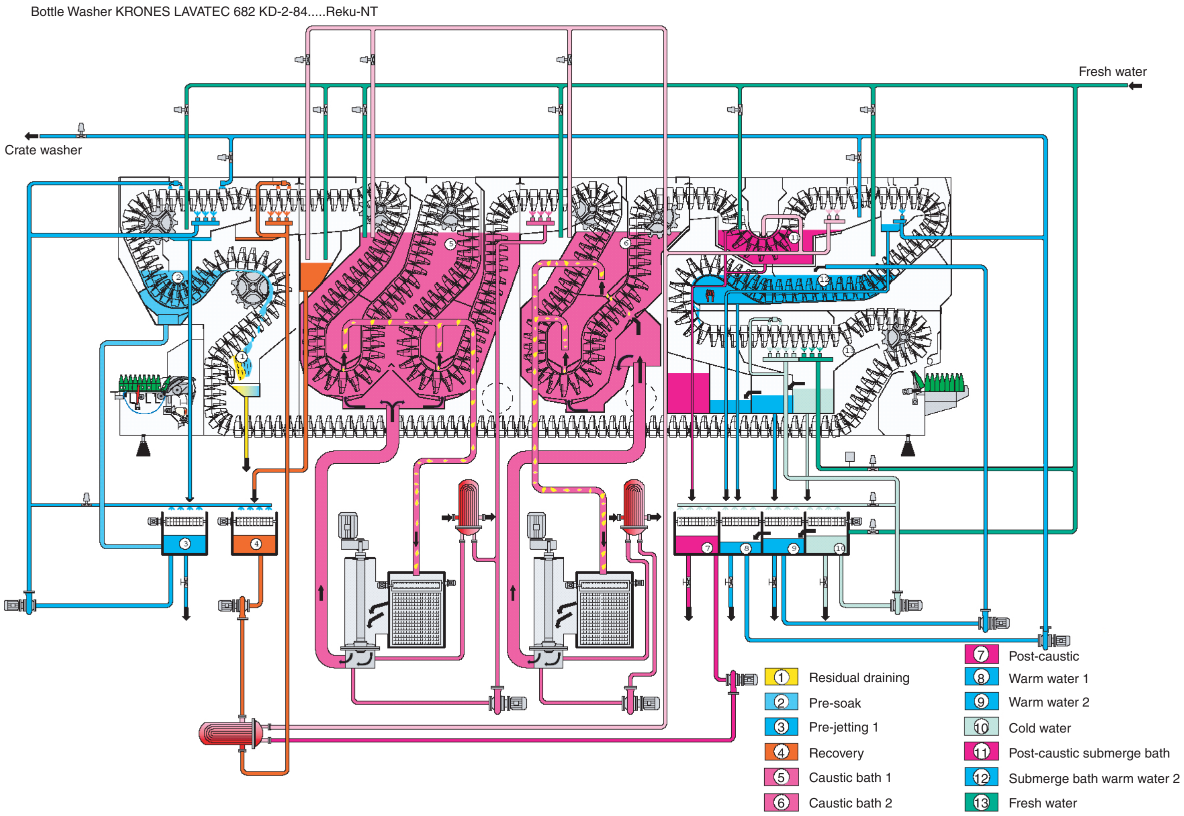


Plate 9.2 Returnable glass bottle washer (courtesy of Krones UK Ltd).

A capacitance probe filler uses, as its name implies, a capacitance probe to detect the point at which filling should cease. The probe is sited in the centre of the filling aperture of the valve and is calibrated along its length so as to detect when the fill level is being approached until the actual shut-off at the end of filling. This sophisticated type of filler allows the initial fill through the swirl valve to be slow to minimise the effect of fobbing; it then allows a fast fill until the fill level is approached. When the fill level is approached, the probe senses this and allows the fill rate to be reduced, enabling a very accurate end-of-fill cut-off. The use of electronic valves within the system ensures the whole operation can be electronically controlled. The snift can be more finely controlled than in counter-pressure fillers by applying a small back-pressure for the initial snift, followed by a normal snift operation to atmospheric pressure. Owing to the fact that it is more complex than traditional fillers, this requires a fuller understanding of the physics of the operation to achieve the best results.

The valve matrix before the filler allows ease of changeover from product to water rinse to CIP. Valves in the matrix can be automated to open and close according to signals from a PLC in the filler. Programs are designed to create different routes through the filler for product preparation, filling and CIP. These routes can be set up from a single push-button or, in the case of CIP, selected automatically from the CIP system. A typical valve matrix is shown in Figure 6.21.

Semi-aseptic filling is for acidic carbonated products. Aseptic fillers for carbonated products require contact to be made between the filler and the bottle, which is not required for still products. It is in this contact area that concerns over true sterility arise. It is highly debatable whether the extra expense for such a system is justified over stringent hygiene with a conventional volumetric filler, say. The use of an aseptic filler does allow the production of aseptic products, both still and carbonated, while still allowing normal carbonated drinks to be filled in the available production time.

6.8 Clean-in-place

As discussed under can filling, the majority of modern fillers are designed for CIP to ensure the sterility of the system. These operate from a centrally located CIP system that is piped to the filler. They include a return cycle to the CIP set from the filler, the temperature of the return liquor being sensed at the filler outlet. Specially designed CIP cups are attached to each filling valve to allow the CIP process to act throughout the filler bowl and filling valves and all associated pipework at sufficient velocity and contact time to ensure effective cleaning. In some cases these cups can be applied automatically. A typical operating cycle would be as follows:

1. The filler and filling valves are rinsed for a set time using rinse water to drain. This removes particulates. The rinse water used is often the final rinse water from the preceding CIP operation to conserve water.

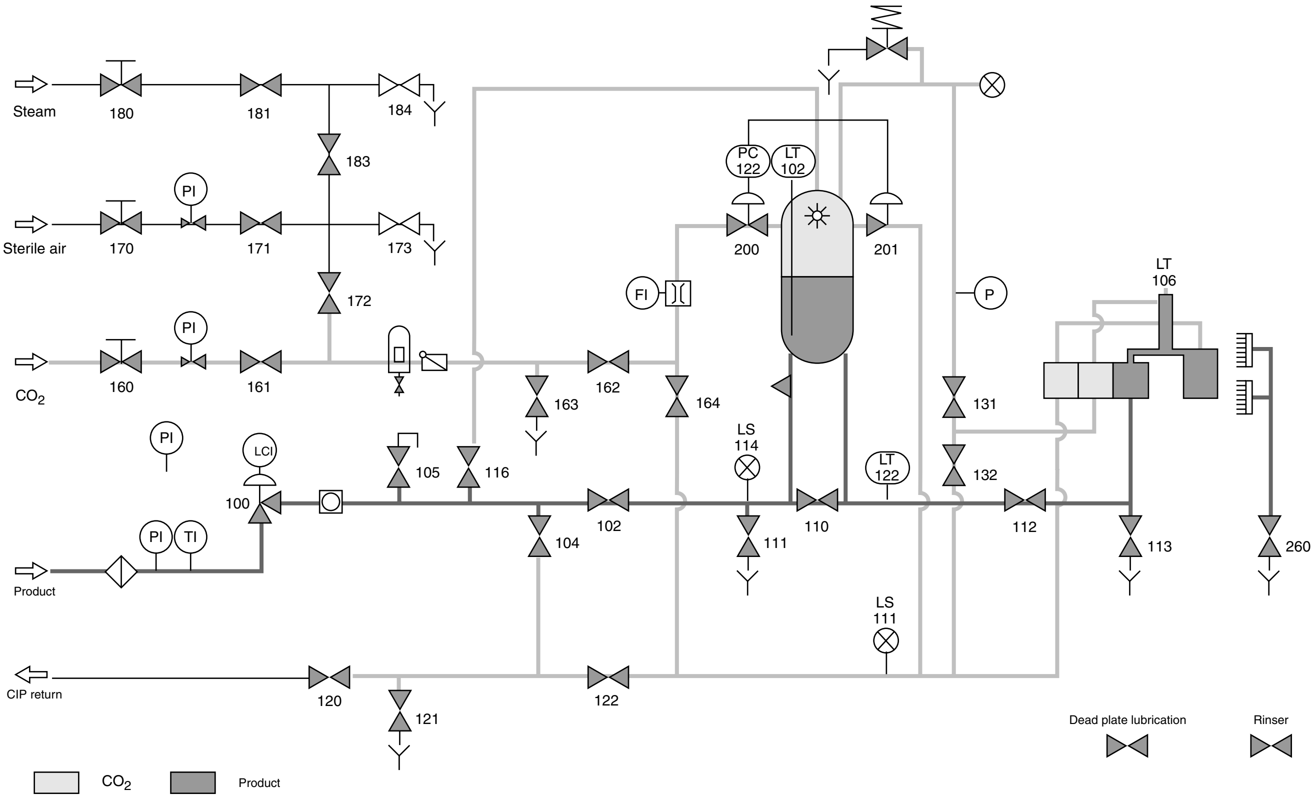


Figure 6.21 Valve matrix (courtesy Krones UK Ltd).

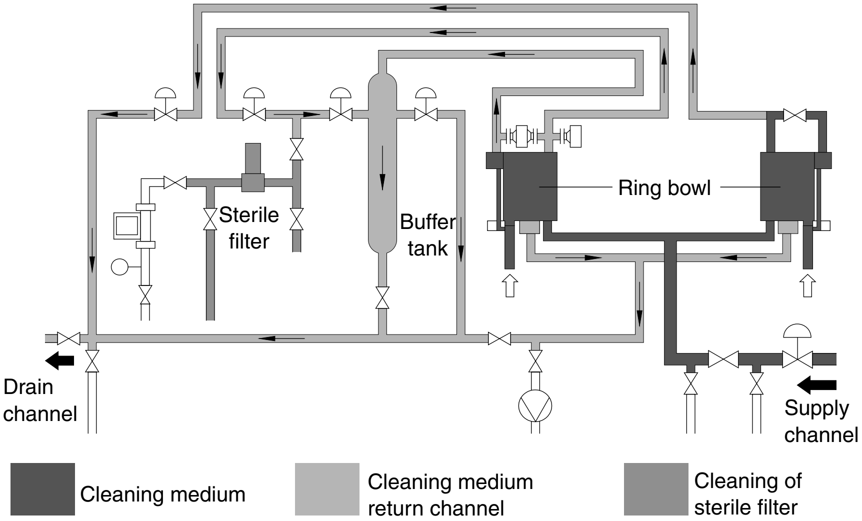


Figure 6.22 CIP process.

2. Approximately 1.5% hot caustic soda solution at 80°C (as recorded at the filler outlet) is circulated for 15 min. The caustic soda is returned to the hot caustic tank through filters.
3. Hot water at 75°C is then circulated for 15 min to allow the interface with the caustic to flow to drain. A conductivity probe is included within the circuit to ensure that all the caustic lye has been removed. Hot water is re-circulated to conserve energy.
4. Cold water filtered to less than 2 μm absolute and UV treated is used as a final rinse.
5. Often the system is left with a sterilant solution in place until the next production is required. This is then flushed through until all traces of sterilant have been removed using clean, cold water before production can commence.

Careful records of all CIP processes are needed in case of product problems to prove that the cleaning was effective. A typical CIP process is shown in Figure 6.22. The design of the filler, valves and CIP cups ensures that all surfaces are effectively cleaned, as all surfaces are smooth and have large radii.

6.9 Filler hygienic design

Older fillers had flat surfaces and areas where water and product could pond. In many cases some surfaces were of cast iron, which rusted. The surfaces of the modern filler have large radii, and all flat surfaces are tilted to be self-draining, so that all detergents and product can run off. They are constructed of 316 stainless steel to allow chemical cleaning. All seals are flush mounted so that the area for microbial growth is minimised. Washing down a filler is now simple and rapid, as well as being very effective. Indeed, sprays for washing down the table are often built into the machine. Jetting of guide rails is often included. Some manufacturers prefer to mount the machine on several pedestals, whereas others use a single tilted metal sheet to cover the innards of the filler, where the shafts, gears and drive motor are sited. So that they do not harbour bacteria, even the machine feet are constructed of stainless steel for ease of wash-down. The machine is designed to allow ease of cleaning of the floor below, with plenty of space to enable debris to be easily noticed and removed. The main PLC control for the filler is often centrally sited in a separate panel above the filler. Ideally, these should be protected in at least an IP 55 enclosure, where the first '5' stands for protection against dust and the second '5' for protection against water sprays. (The designation '6' indicates ability to withstand high-pressure water jets.) The main control panel is usually sited well away from the filler, whereas the operator SCADA panel is sited in front of the filler. All electrical cables are waterproof and enclosed in easily cleanable trunking. All pneumatics and wiring to the parts of the filler are usually installed in stainless steel conduit that is well sealed and external to the filler, thus allowing ease of access and cleanability. Machine guards are often pneumatically operated vertical lift units for ease of filler access. These are easily washable and are constructed of a polycarbonate resin, or more often nowadays of frameless, multi-layer safety glass.

All this is for a normal carbonated filler. The requirements for aseptic filling are much more stringent. Infeed and outfeed conveyors, worms and starwheels are of open design so that they can be easily cleaned and often incorporate their own jetting systems. The days of harbouring bacteria in conveyors owing to difficulties of access for cleaning are over. Lubrication lines are in plastic and sited so that they are cleanable. Often a central lubrication system exists that overcomes the problem of staff leaning over a machine to grease and lubricate bearings and the like. A typical modern filler with a tilted table and ease of access for cleaning is shown in Figure 6.23.

6.10 Conclusions

The ultra-high level of competition prevailing in the packaging industry, mechanical and electronic technological advances and increasing consumer demands will naturally lead to further advances in the technology available for beverage filling and its application in various market sectors.

Recent trends for health drinks have resulted in a massive growth in aseptic systems for the filling of both low- and high-acid products which are sensitive and have tended to have a short shelf life. Aseptic filling methods allow the extension of the shelf life without the use of carbonation or preservatives, thus providing the consumer with a health drink with the convenience previously afforded only by carbonated beverages or by beverages utilising traditional preservatives. Aseptically filled products are without carbonation and as such are not covered by

Figure 6.23 Filler showing easily cleanable surfaces (courtesy Krones UK Ltd).

this book; however, their progress cannot be ignored when considering the future developments of filling technology.

Ongoing refinements to existing systems will continue, and revolutionary new concepts will emerge. Zero product loss, instant size changeover, 100% efficient systems are the utopia of every end user, and there can be no doubt that all manufacturers of filling machinery are fully aware of their customers' goals. Hygienic, aesthetically pleasing designs, servo control, adaptable minimum change parts and ease of operator interface are areas which are constantly in focus. Filling lines will become even more modular in design, with the advent of the so-called smart lines reducing the overall area required to install packaging lines by the implementation of specialist buffer systems and synchronised machinery segments. All of these developments will enable manufacturers to respond to a changing market-place.

With increasing transport costs as a result of oil price rises, the return of smaller production units strategically located to minimise the cost of distribution is likely. Clearly an overall cost balance will decide what an individual company might do, but with distribution claiming some 25% of the overall cost of a beverage, due consideration needs to be paid to any cost increases in this area. If such an option were to be considered, then the requirement for smaller, flexible filling lines would increase. Whereas the distribution costs of small-run-length items will be low compared with those of major brands, it is small run lengths that are best suited to so-called cottage industry lines. Quick size and product changeovers are a prerequisite of such production facilities. Although they would not give economies of scale, the use of modern plant would allow hygienic manufacture of carbonated beverages economically with low labour content. As stock levels would be lowered by the use of supply chain management, and raw and packaging materials could be specified and purchased centrally, warehousing space would also be low. Hence the size of a site and the personnel to staff it would not be much more than currently exists for large, centrally sited plants. This is yet another challenge that must be met by the manufacturer of beverage plants.

7 Bottle design and manufacture and related packaging

David Syrett

7.1 Introduction – the objectives of packaging

The objective of any packaging, be it primary – the focus of this chapter in terms of bottles (glass and plastic), cans, closures and labelling – secondary or tertiary, applies equally in that it is designed to contain, protect, market, identify and sell a product to bottler's customers, retailers and their consumers, whilst ensuring that it has been developed and made with consideration for the environment and all at a minimum cost.

Before considering specific aspects of primary packaging in detail, each of the elements mentioned above will now be considered in a little more descriptive manner.

To contain, thus preventing leakage of the product that the packaging (container and closure) is designed to contain, whilst holding the stated nominal quantity of the product declared on the label.

To protect, by preventing contamination from the environment, atmosphere and sunlight, from the risk of pilferage and the rigors of the distribution supply chain. There is also a need to protect the consumer from the product.

To identify the product to the customer, retailer, and the consumer as well as the bottlers own and his customer's distribution systems. To detail on the label declaration as required by law, for example, ingredients, product description (this could well be different to the Brand Name) and hazards, for example in terms of handling or opening the package. To give the consumer instructions for use and product shelf life (best before end) information. To provide information on manufacturing traceability, for example bottlers production location, date, time of production and batch/lot number.

To market to consumers with attractive packaging and label designs. It may be important to consider consumer acceptability and their restrictions in dexterity. Additionally, there is a need for production and distribution compatibility.

The environment: packaging must be suitable for correct disposal after it has been used, by recycling, reuse or by returning to the supplier to be refilled. Consideration must be given for the use of recycled materials, reduction of source materials by lightweighting and improvements in manufacturing processes.

All at minimum cost, by considering all aspects of the packaging price, that is, the cost of handling, equipment compatibility and ensuring appropriate production line and distribution efficiency. The contribution of secondary packaging direct product costs and hence profitability must also be considered. If an element of the packaging fails before the consumer uses the product then the packaging may have been incorrectly specified or under specified so whilst including the cost requirements of the basic materials, additional costs due to the failure of the package to be sold to the consumer may also have been incurred.

In summary, for any soft drinks bottler it is critical to ensure that packaging materials are correctly specified and jointly agreed between supplier and bottler.

7.2 Glass

7.2.1 History of glass making

The origins of glass in its natural form of Obsidian (rock of volcanic origin) can be traced back to use by man to form arrow heads and knives thousands of years before he found a way to make it for himself for use as a container or bottle. It is believed that glass was first produced in ancient Egypt to make glass beads and hollow vessels around 1500 to 1350 BC.

Glass bottles were first used for wine and water from around the start of the AD 1600s. However, after Joseph Priestley's discovery of a practical method of making artificial mineral water in 1772, early soft drinks pioneers like Jacob Schweppe initially used earthenware bottles. These were not impermeable to high pressure, so soft drinks bottlers turned to glass. Initially an egg-shaped glass bottle (designed to lay on its side to keep the cork moist) devised by Nicholas Paul, partner to Jacob Schweppe was used. It was in use before 1809 when William Hamilton described it in his patent for a continuous carbonation process. Paul explained in his report to the National Institute of France his preference for glass bottles over earthenware: 'Glass, though more expensive, retains the gas and can be transported more safely three or four hundred miles by land, or on a voyage to the East or West Indies'.

The glass bottle was initially blown by hand. A gob of molten glass was taken on a blowing tube, put into a mould and blown to shape. A metal rod called a pontil was then attached to the base of the bottle. The blown bottle was knocked off leaving a rough edge at the neck. Using the pontil to hold the bottle a second workman reheated the neck and applied molten glass for the 'finish' or neck ring, which he shaped with moulding tools. Finally the bottle would be taken off for annealing.

This method was used to produce a 'large' bottle which contained 10 fl oz, $\frac{1}{2}$ pint (approx. 275 ml). In about 1870, a half-sized bottle was introduced called the 'split', it held a $\frac{1}{4}$ pint, 5 fl oz (127 ml) The name 'split' is still in use today where it is associated, in the UK, with the 180 ml returnable glass bottle used in the licensed trade for soft drinks. The egg-shaped bottle remained popular until the turn of the century and was still in use until 1916.

Hiram Codd of Camberwell patented his glass bottle with integral glass marble stopper in 1875 as seen in Figure 7.1. The glass stopper contained in the neck of the bottle is forced by the pressure of the gas from the carbonated product up against the rubber ring thus forming a seal. When the marble was pushed down by a finger it opened the bottle and the glass marble fell into a recess formed as part of the shoulder of the bottle. The bottle was popular because it was easily filled and closed

Figure 7.1 Codd bottle (courtesy of British Soft Drinks Assoc.).

and remained in use in the UK until the 1930s, although it is still possible to find them in use today in places such as parts of India. For more than twenty years around the turn of the twentieth century it was the most popular of all the early glass bottles available for use with soft drinks.

William Painter invented the crown cork in 1892 and during the early years of the twentieth century, bottles of cylindrical, champagne and egg shapes were produced in increasing numbers with the special lips required for the crown. By this time, the egg-shaped bottle had developed a flat bottom since there was no longer a need to store it on its side. The modern bottle with a crown cork finish was first produced in the 1920s and is still in use today. As glass technology and design developed so other neck finishes and closure systems were introduced, such as the continuous screw thread using aluminium closures which allowed bottles to be resealed by the consumer.

By the 1960s there were, in the UK, some 40 factories making glass bottles. These factories were located in Scotland, Lancashire, Yorkshire, Nottinghamshire, Kent and the London area. Today there are less than 10, mostly in northern England and Scotland.

7.2.2 Bottle supplier identification marks

In order to aid traceability of glass bottle manufacture, producers have traditionally included a maker's mark, known as a 'Punt Mark', embossed on the glass. In the UK these marks have, over time, been supplemented with the addition of a letter and number which identifies the factory. For a complete reference, Emhart Glass Zurich have historically published a booklet of worldwide marks, which can be seen by registered users on the website www.emhartglass.com. Usually the marks are embossed around the in-sweep heel of the bottle with the mould number and the measuring container bottle identification requirements. The alternative place is on the bottle base. There may also be a collection of dots as part of the markings; these are used by glass manufacturers for automatic on-line reading of moulds which allows stock to be rejected if required.

7.2.3 Bottle design and headspace considerations

When first developing a glass bottle design for carbonated soft drinks there are a number of things to consider. To assist there are some basic guidelines to follow:

1. Bottles must be of circular cross-section, they are all required to contain pressure, be it for high or low carbonation products. If the product requires in-pack pasteurisation, higher pressures will be generated and restrict the carbonation level achievable for the product.
2. The headspace needs to be set within defined limits, ideally the minimum given for all potential products for which that bottle design could be used.
3. The product's final carbonation level and bottling processing conditions.
4. Internal pressure resistance, as the bottle needs to have sufficient strength to withstand the pressure that results. The levels for various carbonation conditions are shown in Table 7.1.
5. Thermal shock, if the product requires pasteurisation (there are well-defined standards for glass bottles).
6. Final bottle and pack palletisation by the bottler for shipment to their customer. Modern automated distribution and warehousing systems mean the bottle and the selected secondary packaging format must fit the standard 1000 mm × 1200 mm pallet minimising any overhang and minimal underhang (±20 mm).

Table 7.1 Internal pressure resistance specifications.

Carbonation level for soft drink products (at 20°C)	Internal pressure resistance (minimum)	
	Non-returnable bottles	Returnable bottles
<3 bar	12 bar	N/A
3–4.7 bar	14 bar	16 bar
4.7–5.3 bar	Not permitted	17.5 bar*

*(115 and 180 ml only)

For carbonated soft drinks there are two UK publications to consult and to consider when designing glass bottles; these are:

1. British Glass booklet *Strength and Performance Standards for the Manufacture and Use of Carbonated Beverage Bottles* (TEC 7).
2. British Standard publication BS 7367:1991 *Specification for Manufacture of Glass Bottles for Carbonated Soft Drinks Including Carbonated Water.*

Reference may also be made to British Standard BS 7488:1991 *Recommendations for Handling Glass Bottles, Containing Carbonated Soft Drinks or Carbonated Water, in Filling Plants, Warehouses and Retailers' Premises*.

Figure 7.2 shows the typical names for parts of the glass bottle.

Glass bottle design performance and quality can ultimately be monitored by bottlers by the number of breakages seen on the line during the filling process.

1. In the 1970s a failure rate of 1 bottle per 1000 bottles filled was considered realistic.
2. Today that rate could be expected to be well below this, and 1 bottle per 10,000 bottles filled would be considered a minimum.

Bottlers often have automated inspection systems on line both prior to, during and after the filling process so monitoring bottle performance on line can be relatively straightforward.

7.2.4 Glass bottle manufacturing processes

7.2.4.1 The melting process

Glass for bottles is manufactured by melting together sand, soda ash, limestone and other minor ingredients. In addition, dependent on the colour required, cullet (recycled material) is added to the mix.

Typically the materials are added in the following range of levels:

Sand (as silica)	69–72%
Lime (as limestone)	ca. 11%
Soda (as soda ash)	14%
Other ingredients include alumina, magnesia, potash	0.5–3%

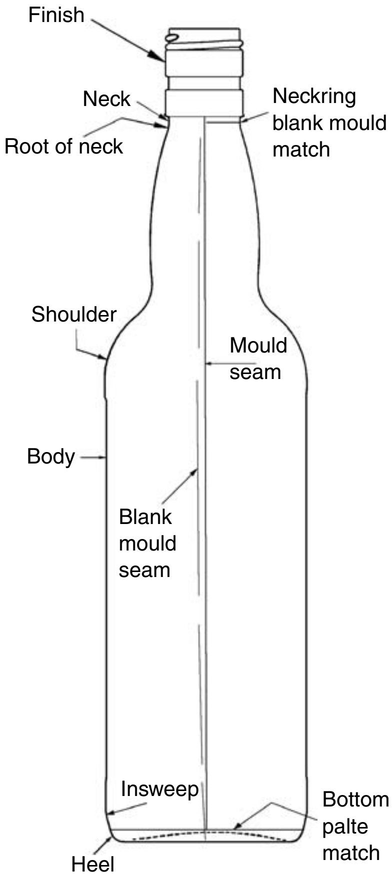


Figure 7.2 Typical names for parts of a glass bottle (courtesy of British Soft Drinks Assoc.).

If green or amber glass is manufactured, dependent on shade, then the level of cullet that will make up the composition mixture could form at least 90% of the batch.

Materials are mixed in powder form and fed to the furnace in a continuous stream, while molten glass is drawn off from the other end of the furnace. The furnace resembles a small swimming pool with a domed roof, constructed from heat and corrosion resistant materials. During day-to-day operation the furnace is filled to a depth of 1.25–2 m with molten glass and the fuel used to melt the glass (oil or gas) is injected into and burned in the space between the molten glass and the furnace roof. The temperature required to melt and fuse the materials into molten glass is about 1500°C, but can be made lower by the use of glass cullet. This shows one environmental impact of glass recycling. Glass production must be continuous from the furnace and once it goes into operation it normally remains in production for its entire life, which can last in the order of 8–10 years.

Molten glass is taken from the furnace through individual channels, known as throats, leading to the bottle forming machines. One furnace will normally provide molten glass for several forming machines, which can be producing different bottle designs. The flow of glass is controlled by passage through an orifice and immediately below the orifice is a pair of metal shears that cuts the flow of glass into 'gobs' of the predetermined weight for the bottle design, each gob falling into a mould in the bottle forming machine.

7.2.4.2 Glass bottle forming

Once a gob enters the forming machine, glass bottles are formed in two stages. In stage one, known as the 'blank' or 'parison' mould, the gob of glass is blown with air to take up the shape of the mould, in particular the neck and thread finish for the closure. This is known as the 'blow/blow' process. Alternatively, the gob is pressed into shape with a metal plunger, this being known as the 'narrow neck press and blow' process.

In stage two of both processes, the 'blank' is then held by the neck and transferred to the second or final mould in which air pressure is used to blow out the bottle to its final design shape as defined by the metal mould.

As mentioned both 'blow/blow' and 'narrow neck press and blow' can be used as alternate methods for forming glass bottles. The latter method was first developed for use with wide mouth containers such as jam jars (and is simply known as 'Press and Blow') but has over time been developed to work on narrow neck bottles such as those used for soft drinks and is now preferred for lightweight non-returnable soft drinks bottles because the pressing stage gives greater consistency in bottle-wall thickness.

The moulds are made from cast iron, which are machined accurately to give the desired shape and size of the bottle. When the surfaces of the mould are polished and any lettering or decoration required on the bottle is machined into the mould surface.

After the bottle is moulded, it is taken out of the mould and placed on a heated conveyor belt. When the outside of the bottle has cooled to about 300°C and is sufficiently rigid to be handled with appropriate tools, but the inside is still very hot and the glass is soft. Due to this uncontrolled cooling, stresses build up in the glass that would leave the bottle too fragile to be useful. The next stage is to pass the bottles through the annealing oven or 'lehr' in which the bottles are reheated to a uniform 550°C, a temperature at which glass can flow slightly allowing the removal of stresses in the newly formed bottle. The bottles are then allowed to cool uniformly during their passage slowly through the remainder of the lehr. The strength of a bottle lies in its skin and when first formed it is stronger than steel. However 90% of the strength is lost through minute scratches resulting from contact with the mould and other equipment on the manufacturing line. Resistance to this surface damage can be improved by the application of surface coatings, known as hot and cold coatings for obvious reasons. For example, before entering the lehr the bottles can be sprayed with a solution of stannous chloride, the hot end coating. When leaving the lehr after cooling they are sprayed again with a lubricant, known as the cold end

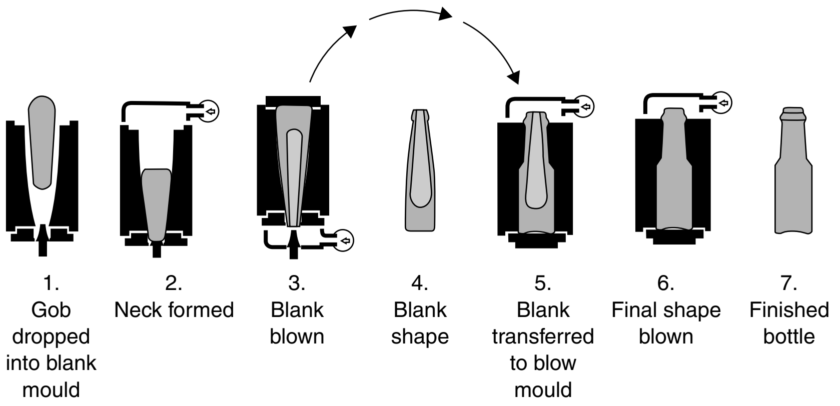


Figure 7.3 The blow/blow process (courtesy of British Soft Drinks Assoc.).

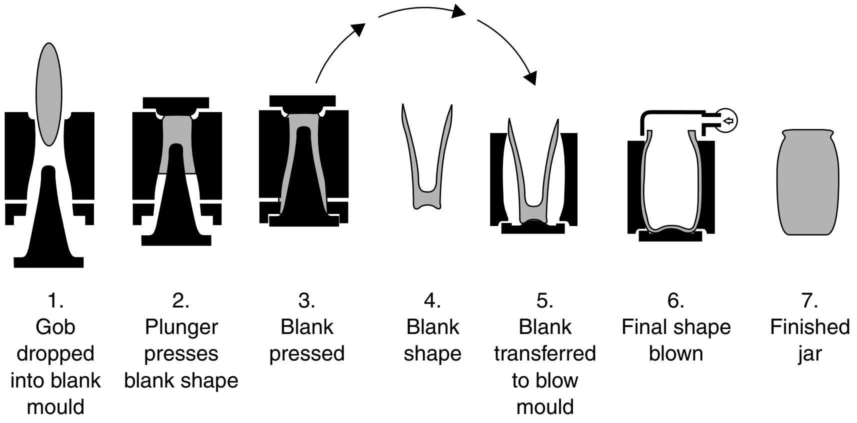


Figure 7.4 Press and blow process (courtesy British Soft Drinks Assoc.).

spray, this typically is a polyethylene-based material. The second coating is applied primarily in order to reduce friction between the bottles due to contact with each other both at the glass supplier and on the filling line at the bottlers. Coatings may be altered or not used if additional decoration processes are required as control of application can be critical particularly at the cold end around the bottle neck finish. Incorrect application of coatings can give rise to closure removal issues for the bottler. In Figure 7.3 the blow/blow manufacturing process is shown whilst in Figure 7.4 the narrow neck press and blow process are illustrated.

Before packing on pallets and shrink wrapping for storage and distribution to the bottling plant every bottle is inspected by a range of automated machinery to check for potential manufacturing quality faults. Those quality checks that can be checked by machine include wall thickness for bottles without embossing, neck ring damage, etc. Bottles are also sampled for on-line and laboratory examination to predetermined sampling plans. It is important for the bottler to be sure that sampling plans meet their requirements for their product.

7.2.5 Glass quality faults

Glass manufacturers have historically split glass manufacturing quality faults into three categories dependant on their considered level of severity: critical, major and minor. Additionally with the major and minor categories bottle manufacturers would expect to apply acceptable quality levels (AQLs) to certain of the examples.

An alternative view for the bottler to consider with respect to quality and/or manufacturing faults could be:

1. Could the fault result in health and safety and/or legal issues?
2. Could the fault affect consumer perception of the product but is not a bottle safety issue?
3. Could the fault directly affect filling line runability?
4. Could the fault affect either the product or production process?

7.2.5.1 Critical defects

A critical defect is defined as one that could result in hazardous or unsafe conditions for an individual using the glass bottle and which could be injurious to his or her health. Figure 7.5 illustrates typical critical defects. A ‘birdcage’ (also known as aerial, birdswing, monkey swing) is a thread of glass on the inside of the bottle extending between two points of the body or neck. A ‘stuck plug’ is a piece of glass, usually sharp, projecting inwards just inside the mouth of the bottle. ‘Fused glass’ is a piece or pieces of glass which could drop inside a glass bottle whilst hot and adheres to the inside surface. ‘Ring finish damage’ is a small fragment of glass on the bottles sealing surface that has broken away without causing the finish to break which has left a sharp edge that could cause injury.

7.2.5.2 Major defects

A major defect is one which could result in either failure of the bottle to pass successfully through the filling line or failure of the bottle to perform its intended purpose. These fault types are normally functional in nature. Figure 7.6 shows major defect examples. ‘Large body tears’ are large fissures which can occur anywhere on the bottle where sections of the external glass surface have been torn away. ‘Deformed necks’ are where the bottle neck is visually out of vertical and is likely to result in the filler head/tube breaking the bottle or the head/tube being damaged. An ‘under filled neck finish’ is when the bottle neck finish has not been fully formed so whilst the closure and crown could be applied ultimate performance of the bottle is affected and could result in product spoilage. ‘Spinners’ occur when the centre of the bottles base has dropped below the standing/bearing surface such that the

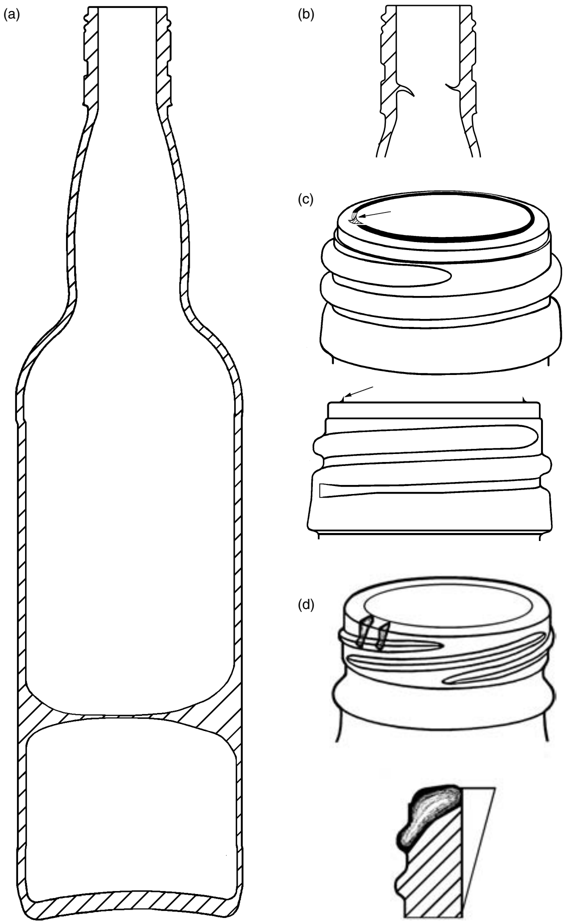


Figure 7.5 Glass bottle critical defects. (a) Birdcage, (b) stuck plug, (c) high top and (d) ring finish damage (courtesy of British Soft Drinks Assoc.).

bottle spins freely on a flat surface, which could result in handling issues on the production line or handling issues of the customer/consumer.

7.2.5.3 Minor defects

A minor defect is one which will allow the bottle to pass successfully through the filling line and will allow it to fulfil its intended purpose but is a departure from the agreed accepted visual standard that a bottler should have agreed with their supplier. Figure 7.7 shows minor defects. These examples include the 'wedge bottom' where the glass in the base of the bottle is thick on one side and thin on the opposite side. It is unsightly but not thin enough in the corner to give concern of failure on the production line or rejection on delivery. An 'oil mark' is a streaky

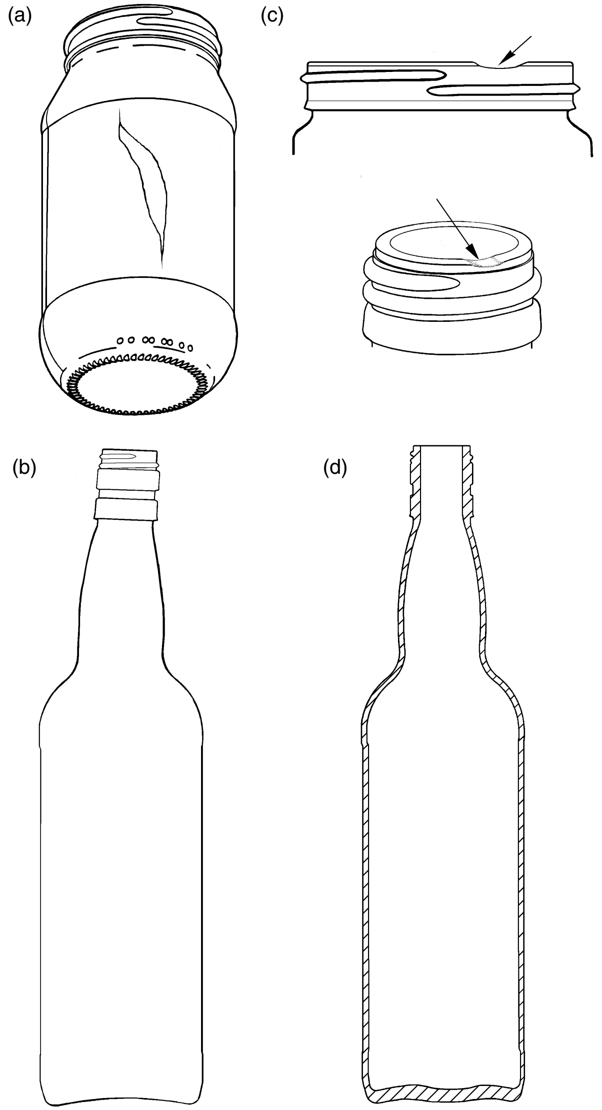


Figure 7.6 Glass bottle major defects. (a) Large body tear, (b) deformed neck, (c) under filled neck and (d) spinner (courtesy of British Soft Drinks Assoc.).

brown/black discolouration usually found in the body of the bottle. 'Seeds and blisters' are bubbles in the body of the bottle, but not on the surface of the container, which exceed standards that the bottler has agreed with the supplier as commercially acceptable.

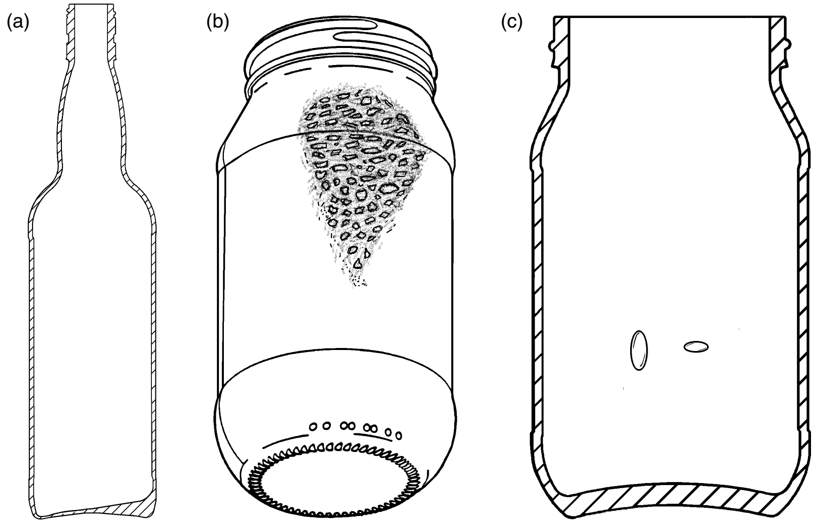


Figure 7.7 Glass bottle minor defects. (a) Wedged bottom, (b) oil mark and (c) blisters (courtesy of British Soft Drinks Assoc.).

7.2.6 Single and multiple trip bottles

Originally bottles for soft drinks were designed and manufactured to be used more than once and hence were known as multi-trip or returnable bottles. They would be designed to be heavier and would be tested during manufacture to higher test standards. At the bottler this type of bottle needs to be washed and cleaned, which involves the use of caustic soda solution and hot water rinses whilst this cleans the bottle it can damage the surface of the glass. This with the abrasive nature of bottle to bottle contact on the filling line results in scuffing of the bottle over time, particularly at the main contact points making them visually unacceptable in terms of consumer appeal, as well as lowering the bottle performance. In the UK, since the late 1970s, returnables have primarily been used for the licensed (pubs) and restaurants trade, where the infrastructure exists to distribute filled bottles and collect the empty returns. In Europe it is not uncommon still to find returnables in supermarkets used for both soft drinks and beer.

Single trip bottles are as the term suggests designed to be made, filled by the bottler and sold to the consumer, the product drunk and ideally the bottle returned for recycling. Therefore they are lighter in design and the production standards are refined to reflect those requirements. Within the UK soft drinks industry there are now very few bottlers of returnable bottles and these are limited to 115 and 180 ml sizes used for fruit juices and mixers and 750 ml used mainly in Scotland for products such as lemonade.

7.2.7 Lightweighting

One of the first lightweight bottles was the 250 ml non-returnable glass bottle for soft drinks which was introduced in the 1970s. The improvements in bottle manufacture that allowed the introduction of the lightweight bottles are as follows:

1. Designs being closer to a spherical shape, as the strongest structure in glass will be a sphere.
2. A reduction in the glass defects during manufacture.
3. The introduction of the rounded heel in bottle design. The bottle heel was traditionally the weakest point in a glass bottle where originally it was a sharp angle joining the sidewall to the base.
4. Stippling on the bearing surface; this prevented sudden cooling of the base and thermal shock defects.
5. Glass distribution, the use of narrow neck press and blow for soft drinks bottles allows more control over the evenness of thickness of sidewalls, shoulder and base on bottles.
6. Surface strengthening, the strength of glass lies in its skin, hence the application of stannous chloride spray at the hot end of the lehr which increases the surface strength.
7. Lubrication, such as sprays at the cold end which coat the bottle and reduce surface scuffing causing damaging abrasion due to bottle-to-bottle contact.

Plastic sleeves which are part of the final label design can offer some degree of protection to the surface of a bottle both during transportation to the bottling plant, during the filling process and then through onward distribution to customer and consumer. In the 1970s and 1980s this was usually in the form a polystyrene sleeve known as ‘Plastishield’, which was offered by one glass supplier in the UK. It only covered two-thirds of the bottle height and the quality of print of the label was somewhat limited. Today heat shrink sleeve labels covering the full bottle height offer high quality graphics, these can be made from plastics such as PET and PVC. These are reverse printed, the printed sleeve being applied to the bottle and shrunk to match its shape using hot air usually combined with steam to achieve the correct application. Other premium decoration processes include ACL (applied ceramic label), this process uses inks used to print branding and other information on to glass bottles, the process consists of treating unpainted glass bottle by flame cleaning, screen printing up to three colours, one at a time, then finally heat treating the printed bottles to set the ink indelibly. For PSL (pressure sensitive labels), the design is usually printed on a clear plastic label material, the labels are self-adhesive and usually used to maximise the effect of the product branding, and coloured coating exist for glass bottles, but not all suppliers offer all options. All these applications involve additional processes thus costs for the bottler are likely to be higher.

7.2.8 Recycling

In the UK, the 'Producer Responsibility Obligations (packaging waste) Regulations 1997', as amended, impose obligations on all parties in the packaging chain, be that the packaging manufacturer, the packaging user, the customer and to an increasing degree the consumer. For the packaging supplier and bottler part of the obligations are to ensure that the minimum amount of packaging is used to contain the required product and that packaging which is used is recycled or recovered as far as possible.

Today, recycled glass from bottle banks, bottling factory line failures, bottle quality rejects and scrap from the glass manufacturers' own processes, collectively known as cullet, can be used to make new glass. Using cullet has a number of environmental advantages; it helps preserve the countryside by reducing the need for quarrying of glass's basic raw materials and it melts more easily than sand, the major ingredient, therefore saving energy and reducing furnace emissions. Almost any proportion of cullet can be added to the raw material mixture (known as the batch), provided it is in the right condition and that includes the required colour. Glass made from batch containing 95% of cullet is now not uncommon but is often limited to green and amber bottles due to the difficulty in controlling impurities in the cullet sourced via bottle banks when it is added to white flint (clear) glass. Although the glass collected through bottle banks may come from manufacturers worldwide, it can be used anywhere, as container glass compositions are very similar.

However, it is important that glass colours are not mixed and are free from impurities, especially metals and ceramics. In the UK, there is an excess of green cullet due, in part, to the level of imported wine bottles. It has been known to export cullet to glass manufacturers abroad to countries as far a field as Brazil. Alternatively it can be used by the construction industry for such things as laying pavement slabs on in place of traditional sand.

7.3 Plastic bottles

7.3.1 Introduction – advantages and limitations

Before looking at the principal material used for plastic bottles for carbonated soft drinks, namely PET, it is useful to consider by way of introduction some of the general advantages and limitations of plastics materials to allow the reader to consider the differences with other similar primary packaging, such as glass.

7.3.1.1 Advantages

1. Plastics are lighter in weight when compared with glass; for example a typical 1 l PET bottle weighs 38 g, against a 1 l glass bottle of 600 g.
2. No corrosion problems when compared to cans.

3. Versatility in design terms.
4. The offer of a larger pack format, for example a typical PET bottle is 2 l in size, the largest glass bottle offered for soft drinks is 1.1 l, and dimensionally they would appear similar in size.
5. Impact strengths can be greater than glass and where breakages do occur there are no splinters.
6. Quietness in use in the bottling plant.

7.3.1.2 Limitations

1. Plastics are not complete barriers to either gases or water vapour, this means carbonation can escape and oxygen ingress can occur over time.
2. Some chemicals attack plastics; for example silicone sprays, often used to lubricate conveyors, can induce stress cracking in PET bottle bases.
3. Resistance to abrasion can mean a poor bottle surface appearance, particularly if returnable plastic bottles are being considered.
4. There is a potential liability for the build up of static electricity, which can give rise to two key issues in terms of soft drinks bottling. First, if a bottler blows their own bottles on site then bottles may stick together on the air conveyor system on route to the filler causing intermittent supply. Second, if the bottles are pre blown or preforms used for bottling on site are not 100% clean then static can attract minute particles of dust which may coat the internal surface of a bottle causing product to fob during filling.
5. When comparing plastic and glass bottles of the same volume then visually the plastic bottle will look smaller giving a consumer the perception of getting less.

7.3.2 Polyethylene terephthalate

Polyethylene terephthalate (PET) is a polyester polymer consisting of alternate units of ethylene glycol and terephthalic acid. The chain length is about 30,000 double units, depending on application. PET used for carbonated soft drinks has a different requirement to that used for still drinks.

7.3.3 History

PET was developed as a textile fibre in the 1940s and is still used as such for carpets and clothing. Its use in packaging was initially in the mid-to-late 1960s for packaging films. The use of PET for carbonated soft bottles started in the early part of the 1970s, when it was first introduced as a bottle that comprised of two parts. The main body section, which contained the product, had a cylindrical body section with rounded shoulders and a hemispherical base. In order that the bottle could stand up, a base cup, usually black and made from high density polyethylene

(HDPE) was stuck to the hemispherical bottle base with hot melt adhesive. The main disadvantage of the two-piece bottle was the fact that gluing of the bottle and base was a critical aspect of the process which was often its weakest link in terms of final pack quality. Those first bottles weighed about 65 g excluding the base, which compares with today's modern five foot petaloid 2 l bottle which weighs only 43 g.

7.3.4 PET bottles today

PET bottle production starts with pellets of resin which are moulded into a preform. These are then used to make a bottle in what is typically a two-stage process for carbonated soft drink bottles.

7.3.4.1 Preforms

In stage one a preform is produced by high-pressure injection moulding in which the pellets of resin which have initially been dried are melted at temperatures of about 275°C. If colour is required for the final design, then it can be added during the melting process at the required dosage, just prior to being injected into the mould. Once melted the molten plastic is injected into a precision mould; the mould is cooled with chilled water, which solidifies the PET. At this point in the process the bottle neck finish, to which the closure will eventually be applied by the bottler, is produced very accurately. From this point on the handling of the preform through packaging, distribution to the bottler and the bottle blowing machine are important in order to prevent the finish from being damaged, as this can ultimately affect, as a result of micro leakage, not only capping but product performance through to the point of consumption by the consumer. A preform can be made and stored for up to six months before it is converted into a bottle suitable for filling, beyond this time period production of consistently good quality bottles becomes more difficult due to the preforms attracting moisture from the atmosphere.

7.3.4.2 Bottle blowing

In the second stage the bottle is produced, this can be done by the preform manufacturers but for larger soft drinks bottlers it is now more common for bottles to be blown on the filling site, either by the bottler themselves or by a third party. The latter reduces the cost of transportation of what is in the main air on lorries, for example a site accepting 100 trucks per week of empty 500 ml bottle could see this reduced to three or four trucks per week with the equivalent number of preforms if bottle blowing is on the filling site.

At the start of the bottle blowing process, the preform is heated to about 90°C. At this stage it is critical that the neck finish is protected in the oven, as the incorrect positioning of heat shields could result in distortion of the neck finish which in turn will affect handling on any air conveyor system on route to the filling and closure application after filling. Once heated the preform is transferred by the neck to the bottle mould. The preform is then initially stretched with a metal rod to elongate the preform lengthwise so the tip of the preform is located into the centre of the base section of the mould. Low pressure air at ca. 7–8 bar is applied at the same time in order to form a balloon inside the mould and then finally high pressure air of up to 40 bar is applied to stretch the material sideways into the final shape of the bottle mould. These two operations must be done sequentially in order to get maximum biaxial orientation of the polymer chains.

Orientation is the process of aligning the polymer chains in an orderly fashion by stretching, in biaxial orientation the amorphous polymer (the random arrangement chains) is stretched in both longitudinal and transverse directions simultaneously. Biaxial orientation improves both the tensile strength and the stiffness of the PET bottle. Water vapour and oxygen permeability, critical aspects of achieving good quality bottles to maximise product shelf life, are thus reduced.

As mentioned already, the early PET bottle had a base cup, which was made separately and required assembly with the bottle prior to filling. Today the base cup has been replaced by the ‘petaloid’ base; typically these are of a five foot design, although examples of the older six foot version still exist and some lower carbonation products may use four foot or champagne base designs. Generally, these bases are not as stable as other forms of bottle and manufacturers have found it necessary to replace their slatted conveyor belts with a smoother design. However, base design has progressed over time and today there are a variety of options available in terms of the width and depth of each foot. Although best practice recommends that empty bottles are best conveyed suspended by the neck ring, bottle base design is perhaps one of the most critical aspects of PET bottle blowing and it is important for bottler, preform supplier and mould maker to have a detailed and clear agreement of the production line and product requirements when specifying its design. A typical blow moulder installation is shown in Figure 7.8.

Figure 7.8 Typical blow moulder (courtesy of SIG Corpoplast).

7.3.5 Multilayer and barrier coating

In order to improve bottle barrier performance there are an increasing number of options to be considered for the bottler. All have implications, not least that of cost, and limitations which require consideration in relation to the product and bottle-making process. These include multilayer preforms where the centre core can be made with the addition of nylon and oxygen scavenger systems as either addition of material to the PET resin to form a monolayer preform or as part of a barrier coating. Other systems such as Sidel's 'Actis' and SIG's Plasma coating technologies are being developed.

7.3.6 Carbonation loss

When considering the use of PET bottles for soft drinks a critical aspect to be considered is the rate at which a bottle of a particular size will lose carbonation over time. The smaller the bottle size the higher the rate of loss due to the relation between the surface areas of the bottle and the liquid volume it contains.

The rate at which carbonation is lost is dependent on a number of factors but in the first instance most bottlers increase the level of carbonation in the package at the point of production when compared to a can or glass bottle of the same product. For a cola product this increase is typically in the order of 0.5 volumes. Other factors that affect the rate of loss include the PET resin selected for the bottle, the weight of the bottle and the distribution of the material within the bottle, particularly in the sidewall. For example in the UK the most common weight for a 2 l PET bottle with a PCO neck finish is 43 g, this is typically 5 g lighter than that used in Europe. Typically for this 2 l bottle the expected loss of carbonation over a 12 week test period would be ca. 15–16%. Some of the modern 'fast reheat' resins available today can improve carbonation retention by about a week when compared with the standard material. For a typical 500 ml PET of 26 g that 15–16% loss could be expected to occur within 8 weeks of bottling and for a 250 ml bottle this would be reduced to 6 weeks. Obviously the factor of carbonation loss has an impact on the length of time a product can be produced and stored prior to delivery to the consumer.

It is generally believed that with respect to where loss occurs ca. 80% is lost through the bottle's sidewall and 5–10% is lost via both the bottle base and the neck finish/closure system. Figure 7.9 shows typical carbonation loss with time for a high carbonation product.

7.3.7 Permeability of polymers

While considering carbonation loss, PET is not a perfect gas barrier, though it is much better than polyethylene or polyvinyl chloride. Carbonation loss occurs as carbon dioxide permeates through the PET walls. Table 7.2 compares the permeability of a range of common packaging plastics to oxygen, carbon dioxide and

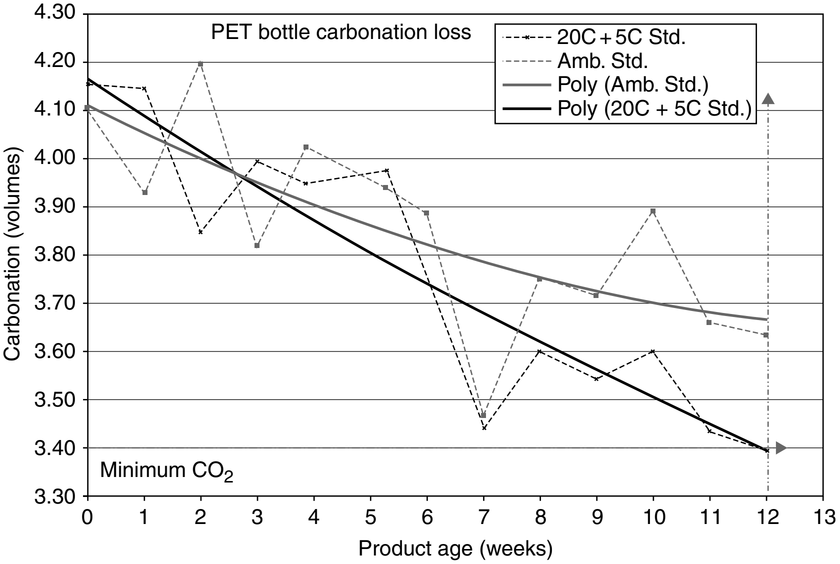


Figure 7.9 Carbonation loss graph (courtesy of David Syrett).

Table 7.2 Permeability comparison.

Permeability	Oxygen	Carbon dioxide	Water
Polystyrene (PS)	6000	17,000	100
Low-density polyethylene (LDP)	6000	3000	20
Polypropylene (PP)	3600	9500	8
High-density polyethylene (HDPE)	2800	9000	5
ABS	2000	6000	70
Copolymer polyester (PETG)	400	2000	60
Polyvinylchloride (PVC)	120	240	20
Biaxially stretched polyester (PET)	62	310	17
Barx (PAN)	12.4	17	78
PVDC	1.6	4.7	1.6
EVOH	0.4	1.3	60

water. If carbonation is critical due to product or market conditions then multi-layer or coated PET bottles may be considered essential, in these cases PET can be married with a material such as EVOH (copolymer of ethylene and vinyl alcohol).

PET bottles are now in use in countries where there is a returnable distribution system. The PET polymer is stronger and the bottles heavier so they can stand up to multiple trips and repeated passage through a washer. The washer conditions must be carefully controlled with reduced alkalinity and temperature. Plastic is more likely to absorb odours and contaminants than glass so special gas-chromatographic ‘sniffers’ are installed on the line to check all bottles before they are refilled.

The lightness and unbreakability of plastic is a major advantage over glass, be that returnable or non-returnable PET bottle; for example a 2 l non-returnable PET weighs 43 g and a returnable version, which would be expected to survive 5–10 trips, weighs about 100 g.

7.3.8 Recycling methods

Used PET, from post-consumer waste, the preform, bottle blowing manufacturing processes or the bottling operation can now be incorporated into new bottles after processing by one of several schemes available today. Unused PET from the preform manufacturing processes can be re-granulated and incorporated up to about 20%, by the injection moulder into new preforms. However, reprocessing reduces its strength and not much more than 20% can be recycled. Process control is thus critical.

Where post-consumer PET waste is involved it can be broken down back to its constituent chemical parts, terephthalic acid and ethylene glycol, which can be re-polymerised. So as a bottler thinking of using recycled material it is important to consider the potential sources of the recyclate to be used and testing against target products and filling operation is a critical element of any approval process.

7.4 Closures for carbonated soft drinks

7.4.1 Introduction

Cork has been used for closing containers since antiquity, the cork bung being the first closure used for carbonated soft drinks. The Romans certainly used it as it came from their provinces in Spain and North Africa. Its flexibility was ideal for sealing the irregular openings of the handmade vessels of the time. By forcing cork into the bottle neck they achieved a reasonable fit and used pitch to affect an airtight seal. The most famous and enduring use of the tied on cork was started by Perignon who, in the 1660s, discovered how to make champagne. His method of containing the pressure was to use strong bottles and tied on corks, then a novelty on the European continent.

The package was ready for the advent of the highly carbonated artificial mineral waters when Jacob Schweppe started business in Bristol around 1794. Handmade bottles (see Section 7.2 on glass) had wide-ranging dimensions of the finish so the flexibility of the cork to adapt to these variations in size and shape was essential. Egg-shaped bottles, introduced in 1814 by William Hamilton, had to be stored on their side ensuring that the liquid stayed in contact with the cork and prevented it from drying out and shrinking. The corks were applied by hand; when the bottle was sufficiently full the bottler drove in the cork with a mallet and passed the bottle on to a wiring stand where the wire would be attached. The bottles had a ‘string ring’ incorporated into the neck. An experienced man could turn out 150 dozen bottles a day. Hand corking continued into the twentieth century although machines had been invented which filled the bottle, applied and hammered home the cork which were then delivered ready for wiring by hand. It was equally difficult for the customer to remove the cork with the preliminary process of untying the wire. The drinks were called ‘pop’ because ‘pop goes the cork when it is drawn’.

Something less tedious had to be invented and many ingenious ideas were put forward like the ‘Lightening’ beer stopper still used by Grolsch and others. As mentioned previously in 1875, Hiram Codd invented a bottle with a marble stopper in the neck and filled it with ‘Coddswallop’ and this survived, much modified, until about 1930. It was left to William Painter in Baltimore to invent the universal successor to the cork. Internal stoppers had serious drawbacks, they were difficult to clean, harboured bacteria, the costs were high and they could not be considered reliable by today’s standards. What was needed was something cheap, quick to apply and remove and above all, reliably gas tight. Painter hit upon a top seal, a metal cap containing a compressible packing material with a corrugated flange to crimp on to the bottle neck. Painter envisioned a powerful downward force compressing the packing when applying the closure to form a seal. The corrugations in the tin plate would adapt to the outside of the finish and lock the closure into position. He tried various materials to line the closure including a composite like linoleum but eventually settled on cork for its flexibility and sealing power. Painter patented his invention and called it the ‘Crown Cork’ because it ‘gives a crowning and beautiful effect to the bottle’. He also had a machine to fit the closures, hand fed, foot powered, and one at a time crowner. He had tools and gauges to supply to the bottle manufacturers so they could produce the correct contours to the bottle finish. In time Painter produced a steam powered multi-head rotary capping machine with automatic feed. For automated high speed capping to be fully effective, a machine was needed to eliminate the handmade bottles and turn out bottles with the same uniformity as the closures. The invention to match Painter’s crown was made by Michael Owens who, in 1903, produced a fully automatic machine for moulding bottles, which were all the same size, weight and capacity. Today, Owens’ blow-moulded glass bottle and Painter’s crown closure are still amongst the most popular packages for carbonated soft drinks and beers in the world.

7.4.2 Headspace pressure

In a carbonated soft drinks bottle the gas in the headspace is under pressure, the degree being dependent on the carbonation of the product and its temperature. This pressure must be reduced to ambient atmosphere pressure before the threads of the closure are released from the bottle. If this is not achieved; there is the possibility that the closure could fly off and cause injury. The bottler’s ideal is to use closures that form a seal with the bottle and a closure that can be removed by hand without the need for any implement yet replaced and resealed when only the bottle has been partly used. The PCO PET bottle neck finish with vent slots and the plastic closure with its interrupted threads come close to the ideal in terms of venting performance to release the gas contained in a bottle’s headspace and effect sealing despite being opened on numerous occasions.

7.4.3 Roll on metal closures

If a bottle is intended to be multi-serving or offers consumer convenience in the form of a degree of resealabilty, then a simple, hygienic closure is required which can be resealed. This will allow a portion of the bottle contents to be poured out then resealed to keep the remainder of the contents in good condition and retain the carbonation. A screw closure, which was commercially competitive with the crown cork, was the rust proof aluminium roll on closure.

This closure is delivered to the top of the bottle without a formed thread, top pressure is applied to deform the closure liner to exactly match the bottle finish and thus form a complete seal. Rollers then encircle the closure, pressing the pliant aluminium into the grooves of the screw thread of the bottle neck finish. The result is a closure that is formed exactly to the dimensions of the bottle on which it has been placed. There is no need for careful matching of the dimensions of the screw thread of the bottle finish and the closure as each closure's thread is purpose made for the bottle on which it has been applied. The closure can be used to reseal the bottle for a considerable number of times, although chipped glass on the finish will scratch the lacquer from the closure eventually. This convenience gave rise to a new problem, there was no way of telling whether the closure had been taken off and the original contents removed or contaminated. Today's version of the closure has been modified to incorporate an extra band on the bottom of the closure skirt, which is attached to the main body of the closure by a number of thin bridges. Extra rollers are needed on the capping heads and these tuck the tamper evident band under a new feature at the bottom of the bottle finish, the tamper evident ring. Aluminium closure formation is shown in Plate 7.1. When the closure is first opened, the bridges break and the band falls away from the main body of the closure. Typically for non-returnable bottles the tamper-evident ring remains on the bottleneck and clearly indicates that the closure has been removed. Although alternative designs are available where the tamper-evident band has splits which open out as the bridges are broken, the downside of this type of design is reduced effectiveness of the tamper evidence.

The adaptability of the roll on closure means that it can be used for a variety of bottle finishes. The 28 mm diameter closure is by far the most common but alternatives such as 38 or 43 mm diameters exist for certain products. When PET bottles were initially introduced aluminium closures were used. These had limitations; most notably was they were more difficult for the consumer to remove from the bottle as the aluminium was often drawn into the vents within the neck finish design due to poor capper set-up.

7.4.4 Plastic closures

If a closure could be made with the threads already formed to the same close tolerances achieved on the bottle finish, then it could be applied to the bottle and form a good seal in a simple manner. The closures, which fulfilled these requirements, are made of a rigid plastic, which can be either polypropylene or high density polyethylene depending on supplier and their production processes, compression or injection moulding.

Plastic closures come in two forms. The first is known as the two-piece closure, which is made of rigid polypropylene and has a liner similar to those used in the aluminium roll on closure. When compressed, the liner forms a seal with the bottle finish. The seal forms over the top surface and down the exterior of the finish. The second version is made from slightly more flexible grade of plastic such as high-density polyethylene that permits it to form a seal with the bottle without the need for a liner. The closure is designed to have an internal seal or seals which form in the bore of the finish and additionally over the top of the finish. Plate 7.2 shows two- and single-piece plastic closures. Both forms of the plastic closure perform well, and provided bottle handling conditions are of the highest standards selection could be a matter of a relatively simple commercial choice. To allow carbon dioxide to vent from the bottle headspace when opened, plastic closures usually have some of interruption to the threads.

The plastic closure is easier to apply at high speeds in the bottling factory and the consumer finds it easier to remove these than compared to aluminium closures. However, there are a number of different tamper-evident band designs for plastic closures, depend on the type selected and the PET bottle neck finish design BPF'C' (British Plastics Federation Version C) or PCO then the speed of application and the capping machinery set up can have a significant impact on successful closure application.

Perhaps the single design constraint of the plastic closure that is left for the closure supplier and bottler to solve is the need for a closure that can be used for pasteurised carbonated soft drinks, as it is important to remember that soft drinks bottlers use higher processing temperatures and higher product carbonation levels than those used by brewers for beers.

7.4.5 Development of the PET bottle finish

In the UK and USA, the introduction of PET bottles in the 1970s saw a need to adapt existing neck finishes designed originally for glass bottles and aluminium roll on closures. In the USA they used the Alcoa 1716 design as a starting point whereas in the UK the MCA 2 was used; both continued to use aluminium closures where the thread form was formed by the bottler on the capping machine.

After a relatively short period of commercial use bottlers became aware of a potential hazard from the PET bottle. When an aluminium closure was initially unscrewed the pressure within the PET bottle occasionally did not escape. A consumer could unscrew the closure and if it was not held tightly then the closure could fly off at speed propelled by the gas and potentially injure someone. The phenomenon was called 'tail end blow off' (tebo), as it occurred at the end of the neck thread. Realising the seriousness of the risk the bottlers worked to address the issue. When comparing glass and PET bottles, two potential causes of the issues with PET were identified. On a glass bottle the first movement of the aluminium closure releases the screw threads and allows it to rotate freely. Whilst being removed gas from the headspace is released by flowing over the threads. However, for PET the first issue was the fact that the volume of gas to be released was greater due to the larger sizes being used (1.5 up to 3 l compared to a typical 1 l on glass). The second issue was the accuracy with which the injection-moulded neck finish was being made, it was acutely round, whereas glass was more likely to have some degree of ovality, this eccentricity and imprecision meant wider spaces to allow gas to escape.

In 1982, vents slots were first introduced into the PET finish to allow the headspace gas to escape as soon as the consumer started to release the closure while it was still engaged on the bottle finish, this was considered a necessary safety mechanism. However, the use of aluminium closures restricted the width of the vent slot, so preventing material going in the slot, making it difficult for the consumer to remove the closure on opening due to the crystallised syrup. By 1984, following information from the USA on finish performance, bottlers and packaging suppliers working through the BPF (British Plastics Federation) developed a finish with improved venting performance by making three improvements. These were extending the length of the vent slot through the total height of the finish, increasing the slot depth slightly into the body of the finish and finally increasing the thread length by a quarter turn by use of a flat top at the start of thread thus preventing any interference with the seal surface. This final change made it increasingly impossible for the consumer to remove the closure in one single motion, thus it had to be released and then gripped again, hence allowing extra time for the gas to escape. The neck design became known as the BPF'C' finish, as it was suitable for both plastic and aluminium closures and is still in relatively common use today.

By the start of the 1990s plastic closures, be they single- or two-piece designs, on PET bottles had in the main replaced aluminium roll on closures. This gave interested parties the opportunity to review all the aspects of the existing finishes, integrating the best elements of each into a design that became known as the PCO (plastic closure only) neck finish. The work was coordinated by the International Society of Beverage Technologists (ISBT). The most common version in use today for carbonated soft drinks PET bottles is the 1810 version. When compared to the BPF'C' finish it is 1.8 mm shorter, the height between the neck support ring and tamper-evident bead being reduced as there was no longer a need for clearance to allow the capping machine forming rollers to push the aluminium into this part of the thread to form the tamper evidence. This offers improved effectiveness of the plastic closures tamper-evident band from interference. The vent slots for the PCO finish were widened and shaped like valleys rather than at right angles, also the slots were deepened to the same depth as the thread. Both these changes offer further improvements in venting performance as the consumer releases the closure on opening, thus increasing the degree of safety. Furthermore, length of the overall thread has been increased from the BPF'C' design meaning it takes the consumer longer to remove the closure. The neck support ring was optimised in size and other aspects altered to ensure that the finish was not suitable for aluminium. An unplanned advantage of these changes was a reduction in weight of at least 1 g for the neck finish itself.

Detailed specification drawings of the latest versions of the BPF'C' and PCO PET neck finishes are freely available on the internet on the ISBT website at www.threadspecs.com.

7.4.6 Crown corks (pry off/twist off)

For small bottles, typically up to 330 ml in size crown corks still offer an attractive commercial solution for single serve products and they may be applied on bottling lines at high speeds of over 1000 bpm. Known as 'Pry Off', they require a tool to remove the crown. Crown corks are typically made in three stages, the metal sheets are printed and lacquered on both sides, the sheets are then stamped into crown shells and finally lined, before being packed for shipment. Originally the crown shell was lined with cork; this was replaced in the 1960s with a foamed plastisol liner, which since the 1990s has gradually been replaced with a moulded plastic liner. Today a range of plastic lining materials are offered to cater for a variety of needs and therefore can be made with the requirements of the product and processing conditions with increasing accuracy thus offering improved shelf-life benefits when compared with its predecessors. The alternative to the Pry Off version is known as the 'Twist Off' crown, but it is rarely seen in the UK. As the name suggests it can be opened by hand. It uses a different neck finish on the bottle which is more prone to damage and application control is closer to closure application than crowning. This design is widely used in the USA and to a limited degree in Europe, but in the UK it is highly likely that the consumer would still use an opener to remove the crown which increases the risk of the glass finish being damaged; not ideal when drinking of the product direct from the bottle has recently become more commonplace.

Generally there are two major drawbacks for crown corks. Firstly it needs a tool to remove it, secondly it can only be used once although this is not a major disadvantage for single serve sizes of bottles. Some bottlers may consider it necessary to have an additional feature such as a tamper-evident label as part of the package which incurs extra expense to the overall package.

Discussions on the compatibility of the glass bottle crown finish and crown liner designs continue today as experts from interested parties review the interaction of the two variables whilst being applied at increasing bottling speeds. Since August 2005 the agent used to create the foam liner effect in one of the crown liner options has changed. However most bottlers now use non-foamed moulded liner materials, so this change has little impact. This has proved more challenging for soft drinks bottlers particularly for products requiring pasteurisation as typically they use higher processing temperatures than beer bottlers.

7.4.7 Other closures (vacuum lug/rip off)

Other closure designs, such as vacuum lug or rip off, do exist but their potential for use with carbonated soft drinks are limited, although they could be considered depending on product and processing characteristics. Typically, vacuum lug closures are wider in diameter than often found on soft drinks bottles and are commonly used on jam and baby food glass bottles. As their name suggests they are in principle designed to hold a vacuum, as the type of product on which they are used are filled hot then cooled. Rip off closures are similar in terms of what they are designed to do, namely hold a vacuum but rather than being unscrewed in order to remove them a tab is pulled (ripped) across the top of the closure, thus it can be used to reseal a bottle. It can also leave sharp edges which gives bottlers concerns of exposing the consumer to the risk of cutting themselves during the opening process.

7.5 Cans and ends

7.5.1 Introduction

Cans were originally designed for food preservation rather than soft drinks and were the result of a competition in 1810 for which Napoleon offered a prize to develop a package for that purpose. Initial package ideas were corked glass. Handmade 'canisters' made from tinplate followed shortly afterwards and the name was shortened to 'cans'. Cans used before 1900 were manually produced in three parts, a cylindrical body and two ends and joins were made and sealed by dipping the parts in hot solder. The food was filled through a hole in one end, then a small plate was soldered over the opening. At the start of the 1900s a manufacturing process was developed that saw the introduction of the three piece can and with its introduction came the double seam, which is still in use now.

Today soft drinks cans are made in two pieces and use the 'drawn and wall ironed' process, which has seen continued development since the 1960s. They come in three traditional sizes in the UK, 330 ml, 250 ml (used mainly for energy and premium value drinks) and 150 ml used on aircraft.

Can diameters are to this day still quoted in imperial units, for example the 330 ml can has a body diameter known as 209, which stands for 2 and 9/16 in., 65.09 mm in metric. The current end diameter is known as 202 (2 and 2/16″), this has been reduced over the last 15 years as part of lightweighting exercises from 209 via 206, this latter diameter is still in use with beer canners. In the UK today cans are made in both steel and aluminium, however all ends are aluminium.

7.5.2 The can making process

7.5.2.1 Front-end processes

The can maker takes incoming material in coil format which is rotated through 90°, lubricated and fed into a cupping press in a strip form. The blank and draw press produces cups which are wider in diameter and the shallow wall is thicker than the final can itself. The cans are discharged and accumulated, whilst the remaining scrap material is taken for collection for recycling.

Cups are passed into the wall ironer, more commonly known as the bodymaker; the process at this stage determines the basic characteristics of the finished can structure. The cup is carried on a punch and forced through the redraw, then the first, second and third ironing rings, which reduce cup diameters and thin the body walls to their final specifications. At the end of the stage the can base, known as the dome, is formed. On exit from the wall ironer, the can will have a rough top edge as a result of the forming process; this is then trimmed to the required final height and given an accurate cut edge.

The cans are then washed to remove all the lubricants that are added during the cupping and wall-ironing processes, the final washing stages also prepare the external can surface to take the required decorations for the brand and product.

7.5.2.2 Decoration processes

Dried bright cans from the washer are ready for decoration, this typically is a two-stage process, first a base coat is applied, this can be a white, clear or colour-tinted base coat. Cans are placed on free spinning mandrels and come into contact with the blanket cylinder on which blankets carry the required film thickness of base coat, each can receiving between two and five wraps of basecoat to ensure an even coating. The cans then pass through an oven on a pin chain which fully cures the coating.

Once the can has a cured basecoat it passes on to the decorator, which applies the final graphics design; typically this will be in up to six colours although eight is now becoming possible. The decorator will have separate ink stations for each colour. The ink for each colour is applied in turn on to a latex blanket until all the colours are assembled. At this stage the basecoated can is introduced to the decorator on a mandrel, and during one rotation the can comes into contact with the blanket and full decoration is transferred from the blanket onto the can surface. The decorated can then enters a second pin oven to cure the inks.

7.5.2.3 Back-end processes

The decorated can now has to pass through a series of finishing processes before it can be shipped to the bottler for filling. In the first of these processes the cans receive an internal coatings applied by a lacquer spray machine, these coatings are water based, and after spraying the coating is cured in an internal bake oven. All cans at this stage are tested to ensure full internal coverage of the base material, any failures being automatically rejected. The final forming stage for the can is to form the neck profile and the can's flange so that it can accept the end after filling. There are different processes for forming the neck profile dependent on the can supplier, but in the UK the final stage results in a spun neck to give a smooth profile. The final can, now fully formed, passes through a light tester to look for pinholes in the sidewalls or damage to the flange, so that all defects are rejected. Thus every can from the process is individually inspected. Cans are then palletised for shipment to the soft drinks filling plant; this can be via truck or a 'hole in the wall' operation.

7.5.3 Graphics decoration

When considering designs for can decoration it is important to consider the shape of the can itself including the size of fonts for critical/legal text and the potential distortion of the design in the neck after the diameter has been reduced and shaped. It is important to consult the can supplier for any new design as they will be able to provide guidelines for design layout for each can size.

7.5.4 Ends

The can end is made of aluminium. A shell is formed from coil, the curl is then formed to match the can flange and allow the packer, after filling, to bring can and end together to form the double seam.

A tab is formed from a separate coil and introduced to the shell and a rivet formed to join the two together.

A compound is then applied into the side area of the curl. When the double seam is formed by the packer a hermetic seal, and hence product integrity, is ensured.

7.5.5 The double seam

The seal is formed by the soft drinks bottler after the can has been filled on the production line and an end applied within a seamer. Once in place, a two-stage operation takes place to form the seam. In the first stage the can flange and end curl are loosely wrapped around each other, in the second stage of the operation the two elements are rolled closely together to ensure that the compound is squeezed tightly over the exposed edges to ensure an adequate seal as shown in Figure 7.10.

7.5.6 Can end stress corrosion

As has been mentioned the can end is made from aluminium and under normal conditions will give no cause for concern. However under certain conditions of filling and warehousing there is a risk of external corrosion of the end around the opening. If this does not occur then the end may open and product spoilage and/or leakage may occur. This type of failure is commonly known as stress corrosion and typically occurs when cans are packed in shrink-wrap film in storage or as a result of poor drying of the cans during production to remove any trace of water from the end which may have built up to rinsing etc. following filling and seaming. The risk increases significantly with rises in storage temperature and humidity and it can occur in a days or equally it can take several months. One potential indicator of the risk is that the tab on the end will show visible staining. It is an important consideration for the bottle as it can result in loss of stock.

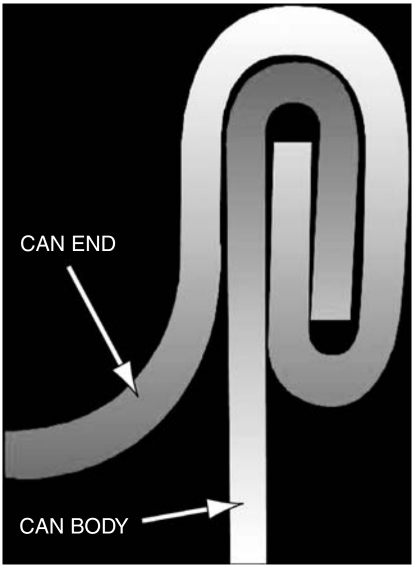


Figure 7.10 Can and end double seam (courtesy of Ball Packaging).

7.6 Labels and labelling

7.6.1 Introduction

Traditionally soft drinks bottlers have used paper to label and brand their products. Whilst it is still the largest single material substrate used for this purpose, other materials have become available to use in addition to paper. In this section some of those options and the formats in which they are used and applied will be considered.

A label or sleeve will provide the required legislative information in addition to the primary requirement of marketing the product. Many different types of container decoration now exist, including paper and plastic labels that can be applied to a container as wraparound or patch, sleeves and neck foils. On modern soft drinks filling lines labels and sleeves are normally applied at relatively high speeds. Due to the very nature of a label or sleeve the interaction between the substrate of the label, the container, the adhesive and the application machine is critical. Sleeves are often applied to the empty bottle by the manufacturer; however, some bottlers are starting to do this operation in house. In certain cases bottles are also supplied pre-labelled. These include pressure sensitive labels (PSLs), for specific purposes such as promotional packs, normally requiring short production runs. A bottler may consider changing the labelling format, that is, it may be possible to apply a shrink sleeve to a bottle that would normally have a PSL, for a promotion.

7.6.2 Paper manufacturing

As paper is the most used label substrate a brief look at how it is manufactured follows. In making label papers the raw materials, such as break pulp, are mixed with large volumes of water and other ingredients in order to suspend the fibres. The next phase in the conversion of pulp into paper involves reducing the water content; this is done in the wire section. The pulp is passed over a moving wire-gauze belt through which the water runs, leaving the fibres behind. As pulp passes along the wire belt the fibres become arranged in parallel to the direction of movement. At the end of the wire belt the pulp is sufficiently solid to hold together. It is then transferred to the next phase in the process, pressing. The paper web is pressed between rollers, which extract more water, and increases the adhesive strength of the paper. Finally, the paper is transferred to the drying section in which the water content is reduced still further by evaporation using either hot rollers or hot air. When the paper is wound into rolls the water content is down to 5–10%. Less than this makes the fibres stiff and fragile and the paper loses strength.

In paper the qualities of strength and whiteness are fundamentally opposed. Whiteness can be improved but only at the expense of strength and vice versa. This is overcome by combining different grades of paper. One paper web can be superimposed on another even in the wire section. For example, a thick layer of unbleached stiff, strong fibres can be laid on a thin layer of fully bleached white fibres that are weaker. The fibres in these two layers intermingle so the layers cannot be separated. The product has a white face suitable for printing while the inner side gives the package stiffness and stability. Furthermore, the amount of recycled content will affect the overall paper strength.

7.6.3 Labelling

Labels applied with wet glue predominate the soft drinks industry as they offer a cost effective means of delivering the required marketing and legal requirements. They can be applied with cold glues as patch or neck labels to bottles or using hot-melt adhesives for wraparound labels. The label must be suitable for the intended purpose. For returnable glass bottles, it is important that the wet strength of the paper is sufficient to ensure that the label will be removed within the bottle washer but will not pulp. The recent preponderance of small PET carbonated drinks bottles, that are often sold from chill cabinets, requires a greater need for wet strength papers that can withstand the condensation that arises when a container is cooled below the dew point. They must also not split due to any subsequent expansion of the bottle diameter girth because of ‘creep’ in the material. After filling and capping it is important that the bottles are well rinsed. They are not always fully dried prior to labelling, especially when the labeller is monoblocked to the filler/capper. So the label must be capable of being applied to a wet surface without any deleterious effect. The grain direction needs to be with the axis of curl and parallel to the grain direction as seen in Figure 7.11. The label shape must be such that it can be easily

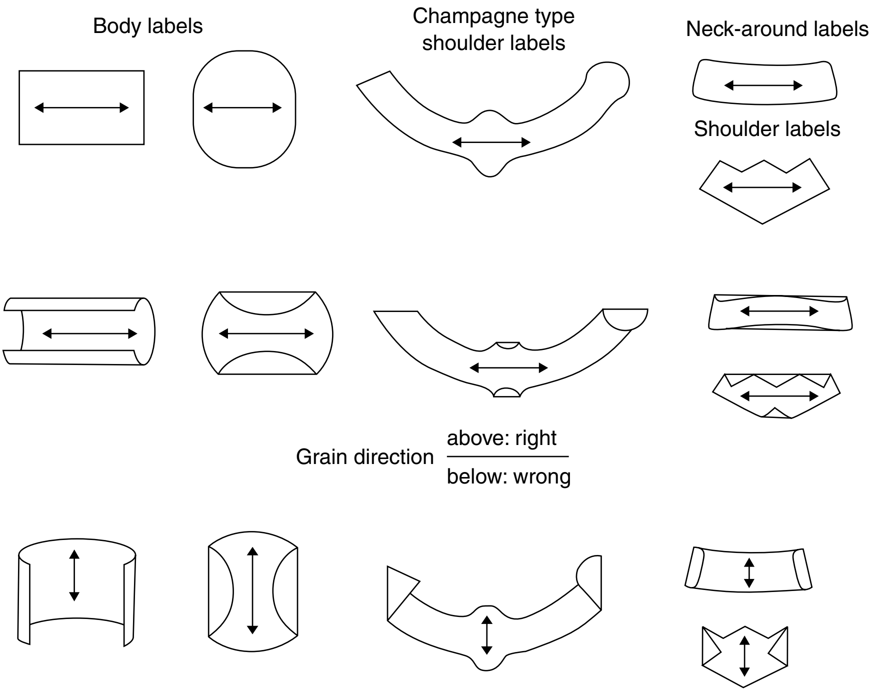


Figure 7.11 Label grain (courtesy of Krones UK Ltd).

Figure 7.12 Plastic labelling (courtesy of Krones UK Ltd).

formed to the bottle. Paper labels should only be applied to cylindrical, conical or rectangular surfaces. In general, plastic labels should be applied only to cylindrical surfaces as seen in Figure 7.12.

The paper grammage, texture, permeability and printability all need to be defined and agreed with the supplier to match the line and supply chain requirements with regard to visual appearance. The type of varnish used on a label will affect its application performance. The type of adhesive used also needs to match the system.

7.6.4 Patch labellers

These are normally indirect transfer machines where pre-cut labels are removed from the stationary label magazine by means of a controlled cold glue film applied to the front surfaces of the glue segments (often referred to as glue pallets and made mainly of aluminium individually profiled to the size and shape of the label to be handled). A new label shape will usually require new machine parts. Labels are removed from the pallets by a mechanical gripper cylinder that transfers them to the containers on the main carousel. Patch labelling is shown in Figure 7.13. A system of brushes and sponge rollers then smooth the label onto the bottle. Labellers can be in-line or rotary, though rotary machines are preferable due to the positive clamping of the bottle allowing the bottle and label to be in control at all times. The glue handling system allows starch, casein based adhesives or a growing number of synthetic polymers to be applied precisely in a controlled manner to the glue pallets. The glue is continually recirculated to minimise mechanical 'stressing',

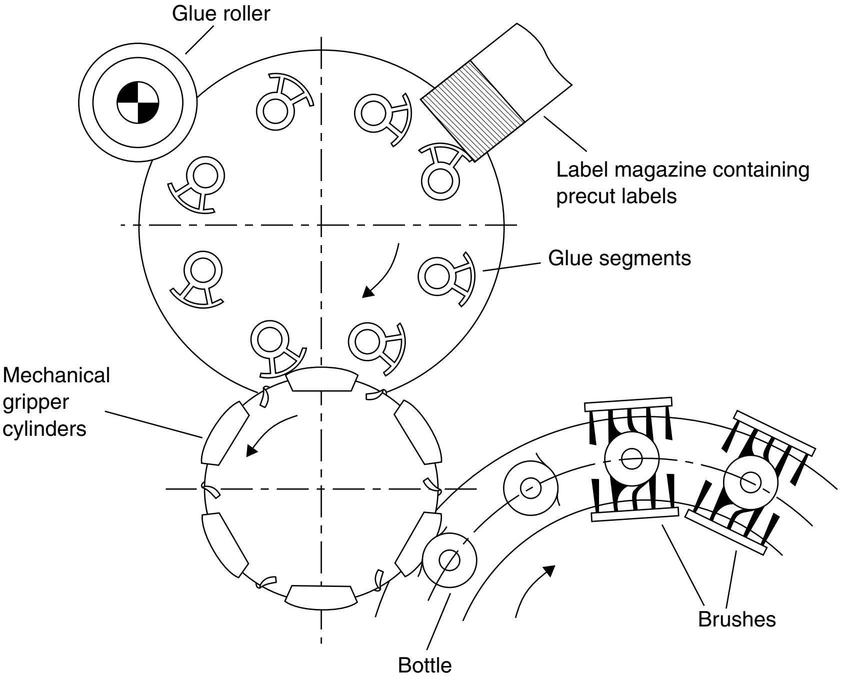


Figure 7.13 Patch labelling (courtesy of Krones UK Ltd).

which can give rise to poor adhesive properties. Glue thickness control on the glue application roller is crucial. To maximise the effectiveness of the gluing operation the glue pallets are made with many small horizontal grooves to allow many small contact points to be formed to aid the gluing of the label to the bottle. Both body and neck labels can be applied at high speeds of up to 80,000 bottles/h in this way. Modern label magazines tend to be powered allowing far more labels to be held at a time. The most commonly used glues are casein based due to their ability to label cold, wet glass whilst at the same time minimising glue usage especially when held at a temperature of 26–30°C. For this purpose a heater is often incorporated in the glue supply system. Good consistent control over the thickness of the glue as applied is critical to good labelling.

7.6.5 Wraparound labellers

These labellers directly transfer the label from the magazine to the container. A wraparound labeller is shown in Figure 7.14. The magazine contains a stack of labels whilst two gluing stations are used. The first station applies a controlled amount of glue to the container in a narrow vertical strip. It is to this glue strip that a label is 'pulled' from the label magazine onto the bottle. A second glue station applies another vertical strip of glue to the trailing edge of the label by a small diameter glue roller. As the bottles are continually rotating at a controlled speed during this process the labels flow on to the container and are brushed on to form a full wrap around the container. The width of the glue strips, in total, cover less than 10% of the label area. The adhesives used are normally hot melt, as a fast bond on to the container is required due to the nature of the application of the label. The open time of cold glues is too long for this in normal practice. Great care has to be taken to ensure that the correct glue is used for the purpose. With modern PET carbonated drinks bottles the bottle creep due to the pressure within the bottle is a direct function of the initial carbonation volumes and the temperature range to which the container is subjected. The problem with bottle creep is that the label panel on the bottle will expand often causing either the paper label to rip or at worst become detached from the bottle. This can be overcome by using so-called pressure-sensitive adhesives which allow a degree of slip. When the bottle creeps, the label will slip on the glue. Whilst this leaves the label still attached to the bottle it does give rise to an unsightly and tacky glue surface. These labels cannot be used for returnable bottles as the glue is not water soluble.

Reel-fed labellers are becoming the norm, particularly for PET bottles. These machines generally use plastic labels though paper labels can also be supplied on the reel. The advantage of reel-fed machines is the large number of labels on the reel that in theory will require less operator interfacing with the machine, for example a twin station machine running a 2 l bottle could hold up to 36,000 labels, enough for 2 h production at typical line speeds. The graphics available on plastic labels do tend to be better than those available with paper labels though the use of modern varnishes and metallic surfaces have narrowed the gap. Plastic labels do have some

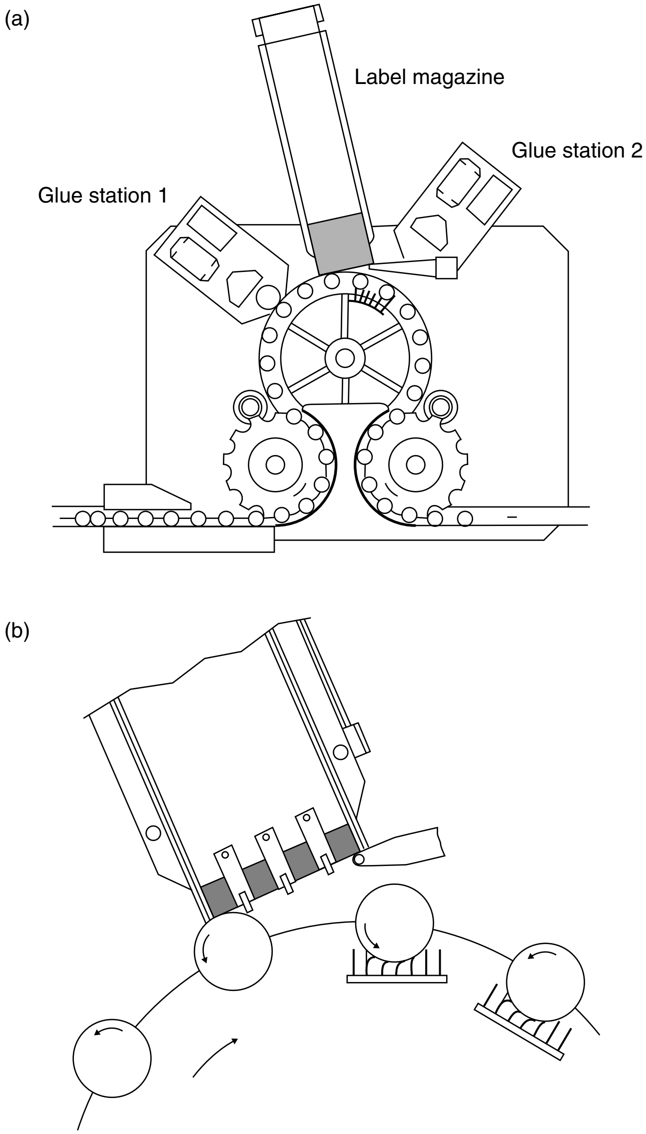


Figure 7.14 Wraparound labelling (courtesy of Krones UK Ltd).

elasticity built into them which go part way to overcoming the bottle creep problem. However, they can have higher label origination costs than paper labels depending on the printing process selected and are thus best suited to long-run products. Some label suppliers are now providing cut plastic labels for conventional wraparound labellers. This process is still in its infancy but must be considered as a specialist market for specific applications. They cannot at present compete, cost wise, with conventional paper labels or reel-fed plastic labels.

7.6.6 Sleeving

This is again a specialist market that has gained in popularity for small glass and plastic bottles. Preformed sleeves, normally produced in PET and PVC, are slipped over the container on-line. They are then either shrunk in a heat tunnel or the actual label will relax onto the bottle itself. The method required is a function of the bottle shape and the duty it has to perform. A complex bottle shape will generally require the sleeve to be shrunk to the contours of the bottle. If a product is to be hot filled it is normal practice only to partly shrink the sleeve onto the bottle as heat within the product will naturally provide the final shrink. Failure to do this will result in split sleeves due to the initial heat of the product shrinking the sleeve unduly. Care has to be taken in handling these sleeved containers. Any protruding items are likely to cause the sleeve to tear. It is bad practice to fully sleeve petaloid base bottles due to the risk of tearing the sleeve in the vicinity of the bottle feet, hence alternative base designs such as champagne are often seen for this application. Practice has shown that for a correctly sleeved bottle, little risk exists, after filling and packing, of residual liquid remaining behind the sleeve. After filling the bottle naturally expands leaving no real gap between the container and the sleeve, hence naturally forcing any liquid out.

7.6.7 Labelling in production

To achieve good labelling consistently it is important that not only is the labeller correctly installed but that the operatives and engineers are fully trained. The choice of adhesive in relation to the label material and the conditions under which the product will be used is a critical factor and must be taken into account. Strict cleaning regimes must be set up to ensure that the machine is always operating in a clean environment with the brushes in a good state. When hot melt adhesives are used regular calibration of the glue temperature controllers is required to ensure that the adhesive is used within the correct operating regime particularly as supplier introduce products with lower melting temperatures and therefore a narrower operating window. Space within the conveying system is required to allow the labeller to ramp up and down with the demands of the production line. Several schools of thought exist in relation to whether the labeller should be placed in the production line; it could be monoblocked to the filler/capper, downstream of the filler with plenty of bottle accumulation, the more traditional placement, and a more recent trend for smaller size PET bottles is to label the bottle before filling. If only one bottle size is being used then monoblocking will work. However, if regular bottle-size changing occurs the production line is regularly disturbed and a degree of buffering of at least 5 minutes between the filler/capper and the labeller or the blower for PET is recommended.

7.6.8 Date coding (ink jet/laser)

There is in most countries a legal requirement to mark products with a 'Best Before End' date. A number of options exist from coding the bottle, the closure or label on the production line to pre-printing the date on the label.

The common practice is to code on line, as it is more cost effective, this is typically done by machine that generates as a series of dots, and this can be done with ink, although the current trend is to use lasers as it offers a more permanent code.

Within UK product labelling regulations the legal requirement is for the product name, contents volume and best before end instruction to be in the same field of vision. Therefore, when on-line ink jet coding is used the best before end instruction is often worded as 'See side of cap or neck of bottle'.

Most bottlers use a similar format for coding the bottle starting with the Best Before End 'month and year' indication, followed by the production location identification, the actual date of production in a close code format such as the Julian code format, that is, 5032 = 1 February 2005, and finally the time of production. Correct date coding like so many aspects of bottling soft drinks is an important part of the production process as it offers full product traceability as and when required.

7.7 Future trends – putting it all together

It is often said that packaging will sell the product to the consumer only once, after that repeat purchase by the consumer will be dependent on whether the consumer likes the product contained within the packaging itself.

However, if the packaging fails to give the consumer the functionality expected then no matter how good the product may be the consumer may choose an alternative brand in similar or even a different packaging format.

It is important that product and packaging are considered together and not in isolation, ensuring that the packaging supplier is fully aware of the product, production and supply chain requirements; soft drinks for distribution and sale within the UK are highly likely to have different requirements to those being sent for export.

Documented and agreed specifications for each material are needed, and a regular review with all parties involved should take place. Challenge to historical 'norms' for a specification may be needed.

So what does the future hold for primary packaging? There will be continuing pressures to optimise package weights that may mean a degree of additional complexity/number of material variants for soft drinks bottlers, for example one preform weight may be used for a number of bottle sizes rather than an optimised weight for each size. In the UK, we have seen increases in the use of colours for

PET bottles, the introduction of new decoration processes to decorate glass bottles, these are trends which will continue, but need to be carefully considered due to the impact on the materials ability to be recycled by the consumer after use.

Production line speeds will increase, thus meaning a reduction in the specification tolerance or production operating window for a packaging material.

Packaging is a dynamic, challenging and changing aspect that needs critical consideration as part of the soft drinks production process.

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8 Secondary packaging considerations

David Rose

8.1 Introduction

Secondary packaging is often forgotten or only given scant attention in the development of new products or primary packs, with companies paying little attention to level of packaging, which is often never seen by the ultimate consumer. These transit or distribution packs are commonly referred to as traded units and, depending on the nature of the primary pack, the complexity and type of the supply chain, these may take a range of formats. The aim of this chapter is to explain the growing importance of secondary packaging and the increase in customer requirements of packs through the supply chain. A well-designed secondary pack, considered as part of the overall development process can significantly contribute to, or even make or break, a new launch or promotion. The best bottle or can in the world is of no use if the secondary packaging is not capable of getting it to a shop shelf in a condition which is acceptable to a consumer. However, this position is beginning to change with the increased use of self-contained display units in major supermarkets and printed packs for Cash & Carry outlets.

The main function of secondary or collation packaging is to contain or collate a number of primary packs for distribution from the filler to the retailer and point of sale. An individual primary pack may be distributed in a number of different secondary pack sizes or formats depending on the nature of the supply chain and the retailer.

Although not required to protect a product from microbiological spoilage and gas retention to the same level as primary packaging, secondary packaging must protect the former from damage, label scuffing, contamination and theft. The modern supply chain covers a wide variety of systems. It varies from efficient major multiple chains, where rapid stock turnover will move a pack from initial delivery to final sale in a few days, to sales via a Cash & Carry outlet, where stock may stay with the final retailer for several months. The conditions are also likely to vary significantly from clean, dry warehouses to damp, dirty storage sheds. Packs are likely to be exposed to rain during loading/unloading of vehicles. The manual operation of load picking and assembly and delivery to the retail outlet will involve manual handling with an inherent level of drops and single-handed pack movement.

As with primary packs, secondary packaging must also inform, but to a different recipient with different information. During the pick operation in a distribution centre, it must inform the load assembler as to the contents, size, flavour etc. In the modern supply chain, this does not just mean informing people, but it also includes the bar codes used for picking in automated warehouses, some of which are 100% reliant on these codes for identification of packs on conveyor systems.

Again, just as in primary packs, secondary packaging must also sell but to a different customer. While not applicable to the major multiple, in Cash & Carry outlets it is the secondary pack that a retailer sees and that influences the decision to buy. It may be that the product is a new flavour or promotional variant, but without clear communication, this may be overlooked. Pack quality could also be considered part of the selling function. Poor secondary pack performance during previous visits, such as packs splitting when picked up, may be the only difference between two competing products that affects the final decision to buy.

8.2 Requirements of the supply chain

8.2.1 Overview

Before looking in more detail at the different supply chains, materials, packs and formats, the various sectors in the supply chain and their requirements will be considered. In Chapter 10 the supply chain in terms of production planning and distribution rather than in the pure packaging context will also be examined.

While there is considerable overlap in the various distribution sectors, each also has its own particular requirements and emphasis on different functions. This difference is sometimes significant and can lead to conflicts between requirements which in turn can result in added complexity (different pack formats) or additional costs, for example, the graphics for Cash & Carry packs used on packs for major multiples. When developing secondary packaging, it is vital to understand these requirements and conflicts. This can only be achieved by visiting a range of customers from each sector and then using this information and building these requirements when developing packs.

The requirements of the manufacturer are to minimise complexity and reduce costs. This includes material reduction. Ideally, common materials should be used across a range of packs. Pack sizes and formats should minimise machine changeovers. Pack dimensions and common palletisation patterns should be used wherever possible. The packs need to comply with local labelling legislation and must satisfy legal and ethical requirements. This includes, in the UK, the Packaging Waste Legislation and recoverability requirements as well as health and safety pack handling considerations. In this context, the weight of traded units needs to be considered.

The brand owner needs to have the flexibility for ‘on pack’ information, which can either highlight consumer promotions for Cash & Carry outlets or retailer offers. This flexibility drives volume and delivers consumer benefit without additional cost as well as maximising shelf presence and allowing differentiation from competitors' products. It is recognisable as part of the brand. For co-packed drinks, the manufacturer may not be the brand owner.

Distribution covers the whole supply chain. These requirements may not all be under the same control as it covers the fillers' distribution to the customers' regional distribution centre (RDC) and then on to the individual store. Minimal inventory is sought through reduced stock keeping units (SKUs), a traded unit by which a consumer product and pack type is distributed to a retail outlet. Stable palletised loads requiring no special handling are vital. With reduction in the distribution turnaround times, there is no time to correct unstable pallets. Packs must be capable of being distributed in stable part pallets and as packs in mixed loads as the final stage of delivery is often a mixed load, either in a cage or on a pallet. Odd-shaped packs and those that do not protect the unit will create difficulty. Robust cases appropriate for the level of manual handling will prevent pack damage. The load picking operation, which packs must survive, is also being reduced, with many pickers on bonuses for speed and accuracy.

As the retailer is often responsible for part of the distribution supply chain, some of the requirements around mixed loads are also requirements of the retailer. The traded unit size must suit actual shop facings. The display may vary from six or eight (consumer) units in large multiple outlets through two or three units in smaller convenience stores to a single unit in an independent outlet. Easy opening and disposable materials are an important requirement. There is a continual drive for material minimisation and/or the use of a single material to reduce disposal volumes. Shelf ready units are required for key packs. Unpacking individual primary units and placing them on the display shelf is laborious, time consuming and in today's 24-h world intrusive to a customer. These packs are a development of the two points mentioned above, resulting in a quick operation to give rapid replenishment of shelves. Packs need to be robust to protect the product.

Generally the ultimate consumer does not see the secondary packaging, but is well aware of these issues if it fails in the supply chain. This is usually in the form of pack damage. However, the consumer does see display units and shelf ready units (e.g. yoghurt, dry food sachets) in a store and this can influence his or her purchase if removal of the individual unit is difficult or the secondary packaging just looks poor. It is important that this packaging looks appealing and enables brand recognition. Another important factor is that packs must be easily removable from any secondary packaging. They may perceive the outer display as additional cost or unnecessary, believing it to be excessive packaging that simply adds cost with no real consumer benefit and therefore may not make a purchase as a result.

The three primary supply chains are:

1. Major multiple, that is, supermarkets with their own (or contracted) distribution networks.
2. Cash & Carry, that is, trade/bulk outlets catering to an independent retailer (and some consumers).
3. Bulk break/multi-drop, that is, retailers' own distribution depots and group distribution centres, for example, Golden West (McDonalds), Beer Seller.

While there is considerable overlap in many areas, each has its own particular requirements. The first sector covers some 95% of the supply chain and its requirements generally include most of the key requirements.

8.2.2 Major multiple

8.2.2.1 Pallet receipt

Larger retailers now use either fully or semi-automated systems, designed for speed of operation, many using automated gauging for acceptance of pallets. These systems rely on pallets requiring no special handling and have an absolute requirement for stable palletised loads and accurately measure pallet dimensions on receipt. Loads that are only millimetres over the limit are likely to be rejected. Some multiples now have twice daily deliveries from suppliers, with only 48-h stock holding in their distribution centres. With reduction in distribution turnaround times, there is no time to correct unstable pallets.

8.2.2.2 Pallet breakdown and load picking

Once in the picking area, a robust case appropriate for the level of manual handling is an absolute requirement to prevent pack damage. To improve case throughput, the time available for the load picking operation is being reduced. Many pickers are on bonuses for speed and accuracy, operating on pre-planned routes with the pick rate/time on a bonus scheme, which in some cases can be substantial. In these circumstances, pack strength and handling performance are critical; if a pack fails when picked, it is often just dumped. Shrink film bullseyes will be used as handles despite advice to the contrary; small packs will be picked single handedly or in multiple lifts. Packs will be pulled and dragged across the top of others. As cages or conveyors are generally close to the pick location (less than 1 m), it is likely that smaller packs will be thrown.

Following the pick operation, the packs must stack in a mixed delivery cage or pallet, without splitting/crushing. While the pick order may be controlled to some degree, there is still no absolute control over the orientation of packs in the cages. Tall cases may often be laid on their sides if it helps the pack fit, and there is also no absolute control of what may be stacked on top. In these circumstances, pack strength and handling performance are critical to performance and continued failure will result in financial penalties or even in a product being de-listed.

8.2.2.3 Bar codes

Many of the larger multiples now rely partly or even solely on bar codes for identification and are demanding a minimum of 98% identification on first-time scans. Where the initial recognition is still manual, many then use the bar code to confirm the identification. Continual failure may result in a product line being temporarily de-listed, or a handling fee charged if a case bar code has to be entered manually.

8.2.2.4 Store delivery

More retailers are looking to simplify and speed up the shelf replenishment end of the supply chain. This is becoming the time critical area in the supply chain and with more stores opening for 24 h, needs to be done while the store is open. Many are actively looking for easy opening packs with the elimination of knives, scissors etc. by the use of tear strips or perforations. There is a continual drive for material minimisation and/or the use of a single material to reduce disposal volumes. Combining these two requirements has resulted in an increasing focus on shelf ready units for key packs, resulting in a quick operation to give rapid replenishment of shelves.

Figure 8.1 shows an example of traditional multiple RDC, storage racks and pick area. These have storage racking, typically three or four pallet bays high, above

Figure 8.1 Traditional RDC. (a) Pick area and (b) storage racks (courtesy British Soft Drinks Assoc.).

the ground level pick locations. All operations are manual, using forklift trucks, but most have computer-controlled allocation of put away location and most now use the case bar code for confirmation of product ID. An automated RDC is shown in Figure 8.2. These photos show an example of the latest new generation of multiple

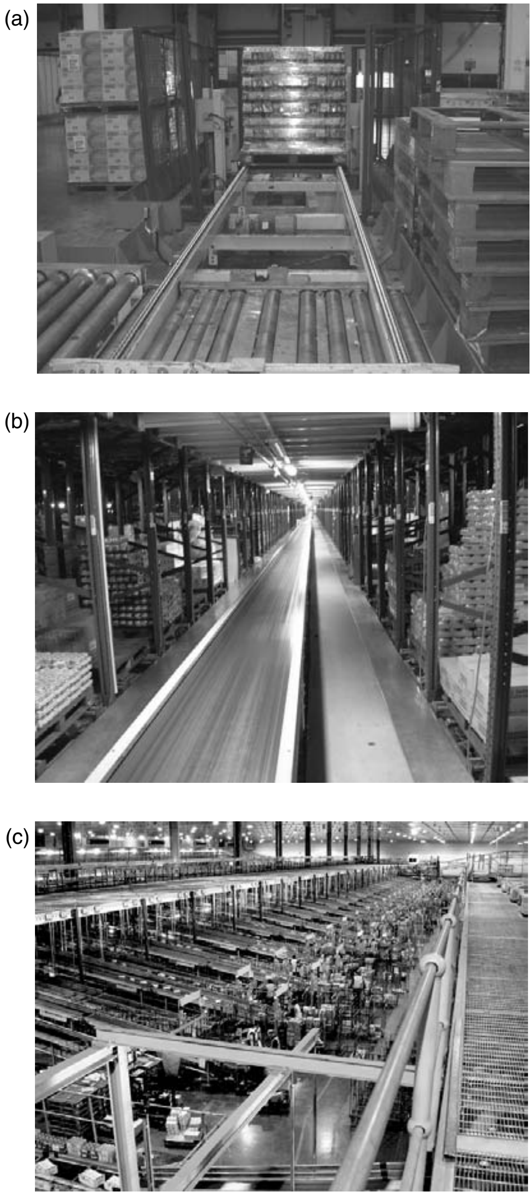


Figure 8.2 Automated RDC. (a) Intake, (b) pick and (c) sort (courtesy Sainsbury).

RDC at Sainsbury's Hams Hall. These have fully automated pallet receipt and put away into storage racking, up to ten pallets high, with a separate ground level pick locations. All operations rely fully on the pallet and case bar code for product ID and confirmation.

8.2.3 Cash & Carry

8.2.3.1 Pallet breakdown and load picking

While these outlets may not have the speed pressure and the absolute pallet dimension requirements of a multiple RDC, they do have the same requirements for stable pallets. However, there are differences in the pallet breakdown operation in that it is carried out by a greater variation of 'untrained' pickers, many of which are retailers. Customers often remove packs randomly, without the logical, pyramid un-stacking usually seen in the multiple RDC. There is also a degree of additional pack handling (pallet to trolley, trolley to trolley at the checkout, trolley to vehicle and vehicle to store).

8.2.3.2 Pack graphics

In Cash & Carry, the case is the salesman to the retailer, much as the primary pack is to the consumer. While this may not be to the same level, as the retailer will also be considering the primary packs that his customers want – his profit margins, stock holding etc. – a good looking pack can make the difference. A well-presented pack, maybe highlighting a promotional retail pack or a retailer-based promotion (e.g. two packs free), will influence a sale. A typical Cash & Carry is shown in Figure 8.3, demonstrating that a good display with attractive pack graphics will attract a customer's attention.

8.2.3.3 Bar codes

Bar coding is also becoming more important, with many Cash & Carry outlets now using the bar codes for the checkout operations. They also require a minimum of 98% first-time scans; repeated failures may result in a supplier being de-listed.

8.2.4 Bulk break

A bulk break warehouse has a similar pallet receipt requirement to a traditional multiple RDC. They do not have the higher level of automation but the requirements for standard, stable pallets remain the same. The main difference is in the pick operation. While some may pick a mixed load for a single outlet, much as in a multiple RDC, many will pick for a delivery route, aggregating all the individual deliveries into one pick operation. This will result in a number of mixed pallets, which will then be loaded onto a single vehicle. The driver will then 'pick' the individual customer deliveries on arrival. This results in additional handling as

Figure 8.3 Two typical Cash and Carry displays (courtesy British Soft Drinks Assoc.).

other packs may be moved several times to facilitate reaching the required pack for a specific delivery.

8.2.5 Poor packs – no sale?

Figure 8.4 shows photos of typical pack damage as seen in distribution warehouses. This level of minor damage, while not affecting the primary pack or product quality, does detract from the overall appearance and will affect the pack performance when picked and loaded onto the trolley and then into a car or van. Repeated bad experiences here can make or break future sales if similar or competing products are available and look or perform better.

8.2.6 Material – performance versus specification

In today's supply chain, the balance between pack cost and supply chain performance is absolutely vital and cannot be ignored. On the one side there is a continual

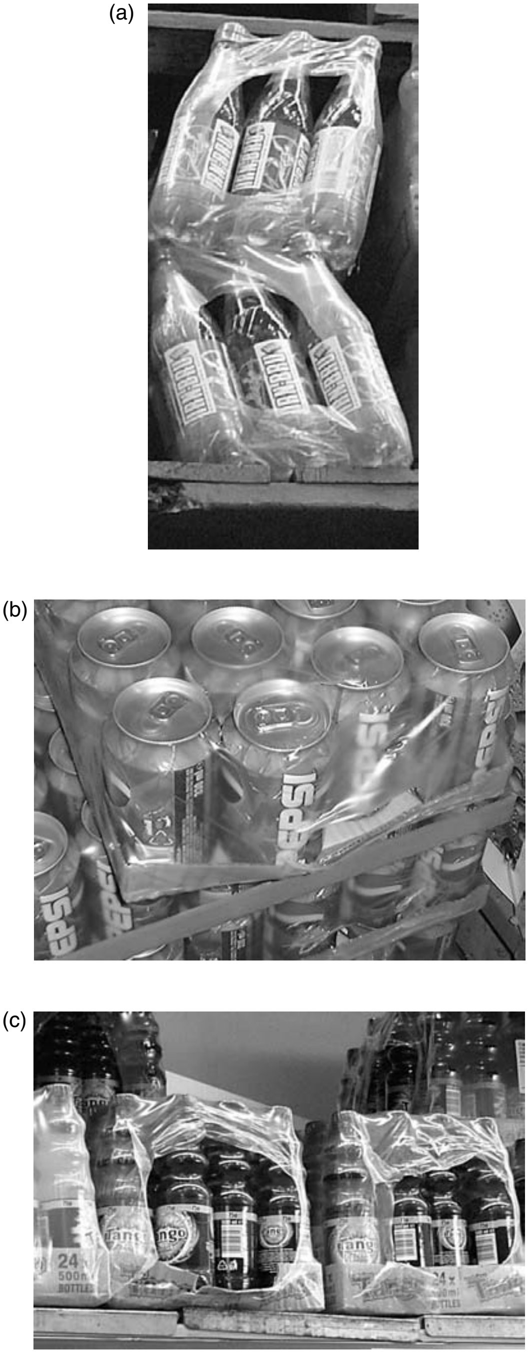


Figure 8.4 Poor packs – no sale. (a) Loose packs, (b) loose and split film and (c) broken trays (courtesy British Soft Drinks Assoc.).

drive for cost reduction and volume/disposal benefits, in addition to increasing pressure being applied as a result of the requirements of material reduction and waste regulations. On the other side there are increasing performance requirements from distribution handling and throughput as well as increasing health and safety standards. There is a balance between these two opposing forces, the optimum of overall pack cost versus supply chain loss. Inappropriate or excessive material reductions can compromise the supply chain performance of secondary packs, a mistake often made in the past where material performance on the production line was the only consideration. The cost of the whole supply chain, from end of line to customer shopping must be taken into consideration. Sometimes an increase in secondary packaging, and thus cost, can reduce breakage and losses in distribution, resulting in an overall reduction in total cost. This area is becoming more important as the pressures for improved performance and cost reduction increase. Recent developments in multi-layer (co-extruded) shrink wrap films giving improvements in film performance have allowed improvements in performance or a reduction in material usage with no loss of performance. These materials have now largely been implemented; further improvements in polymer technology or film production are required to enable further progress in this area. Other areas such as trade ready units or merchandising units are also being developed to make further improvements. These demand of the retailers brings issues around the costs of improved packaging for increased supply chain performance and who bears them, whereas soft drinks bottlers are under continual financial pressure to reduce material costs. A greater degree of collaboration and co-operation among packaging material suppliers, soft drinks fillers and retailers will be required to jointly develop integrated systems to benefit everyone. Some degree of standardisation (unit dimensions, performance standards) will also be required to enable a degree of commonality across the various competitors and avoid unnecessary costs.

8.3 Pack styles

There are three main secondary packaging types used for carbonated soft drinks. Each has its benefits and is used for a variety of reasons.

8.3.1 Shrink wrap

This material is probably the most common pack used today considering cost, line speed and pack performance. There are three sub-variants: (a) shrink wrap film and corrugated tray, (b) shrink wrap film and corrugated pad and (c) shrink wrap film on its own. Shrink wrap trays, pads or film-only packs are used where the primary pack has sufficient strength for load support and impact resistance and where low cost is important. The choice between the three sub-types is often dictated by the capability of the packing machine used.

The more modern flow-wrapping packers are capable of running without any tray or pad, this ability being dictated by the bed/transfer system in the collation section of the machine. Retro fitting this capability is often expensive, or not possible, and so is generally not cost effective. Thus, the same pack made on different lines sometimes varies in style.

Similarly, the tray style and depth will depend not only on the packing machine but also on certain supply chain requirements. These include the need for readily visible print (product flavour/branding) on the tray, any best before coding or traceability details or where bar coding is printed on the tray (bar code minimum size) and the primary pack design, particularly around label height and visibility of the label graphics/image.

High-quality labels, or important product identifying graphics, are often hidden by a generic or even a plain tray. This can make product selection difficult where the label (or product) colour differentiation is minimal. Therefore, it is vital to consider the primary pack graphics or label design and height in conjunction with the secondary packaging during the design process. Corrugated cases are still widely used but usually where specific supply chain requirements exist such as where the primary pack has limited strength (e.g. where low carbonation products are packed in HDPE bottles, pouch packs etc.). These primary packs require the use of heavier duty board so the case can provide the bulk of the strength/support required within the palletised load and subsequent pick and mixed load supply chains. Another use is where the product can be considered a ‘premium product’, for example, energy drinks, squash and cordials. The brand image, price category etc. allow such packaging where a premium look is beneficial and the additional cost can be covered. These will use higher quality board (white) and print; varnishes may also be used to enhance further the appearance. Under certain conditions where the packs are in extended supply chains, with either additional handling or environmental extremes, corrugated cases are often used. Export packs are often loose packed into containers or subject to repeated manual handling. The corrugated board can also act as a buffer to environmental variation and extremes of temperature and humidity. Such packs may also include the use of internal dividers to further separate and protect the primary packs, especially if additional manual handling is experienced where an increase in drops/throws is likely. In some parts of the world, it is not unknown for dock workers to climb over cases stacked on the dockside. This is becoming more uncommon with the advent of containers.

8.3.2 Trade ready display unit (TRDU)

Trade ready display units or merchandising units is a broad term generally taken to describe complete sales/display units designed to ship through the supply chain to the retail outlet as a complete load. These units can give significant reduction in shelf replenishment costs (the so-called last 50 yards), but units can be expensive if they utilise quality graphics, header boards etc. The term can also cover smaller shelf ready display units, similar to current cases/packs but with enhanced opening/graphical functions, designed to speed shelf replenishment and the incorporation of a degree of 'point of sale' display functionality. With major supermarkets now beginning to focus on the last 50 yards as their most costly part of the supply chain, this area will continue to develop and grow. As their use increases, combined with technical developments and capital investment in automated systems, the unit cost will fall. However, whether they will become cost effective as a straight replenishment system has yet to be decided. This whole area is still developing, with many issues around standardisation of sizes, cost allocation etc. still to be resolved. For example, a number of designs are in use for 2 l PET bottles, differing not only between the different soft drinks manufacturers but also between different retailers. These differences may not be immediately obvious but are significant for automated handling and packing systems. Issues such as this will need to be resolved if the significant capital investment required is to be justified.

Returnable 'dollies' are modular, consisting of a wheeled base and a number of layer trays, are often bespoke to a particular primary pack style (e.g. 2 l PET) and are usually hired from a logistics supplier, for example, CHEP. They are not visually appealing but are effective for 'commodity' products where speed/volume throughput is critical and visual appearance is not a major requirement, for example, milk, eggs, sugar etc. An example is shown in Figure 8.5. These are usually automatically palletised on very specialised systems often using robotics to allow rapid changes between different dolly types.

Non-returnable corrugated TRDUs have a greater potential to be visually appealing, but this comes at a price. For this reason, they are often used as part of a promotional or new launch strategy. Many such items are manually built off line, or as a contract pack operation, although some similar looking display units are actually built and filled in the store rather than being shipped through the supply chain.

8.3.3 Shelf ready packing

Shelf ready packing is another area being driven by major supermarkets. The aim is to reduce the time taken for shelf replenishment, using pack styles that can be quickly and easily opened (without the use of knives) and placed on the shelf as a complete unit, so these could also be considered as a development of the traded unit case. Advantages are again speed/cost of shelf replenishment and the ability to include point of sale graphics, but depending on design, the cost can be significant. Currently they are mostly corrugated board cases with the inclusion of perforations/tear tapes. Such perforations are used to open the case in such a way so as to produce a display unit that allows the case to be placed on the shelf in one go and individual primary packs to be removed. There are also film developments and machine options that, combined with certain tray styles, can also serve the same function. Some film wrappers can be fitted with mechanical perforation units and there are now laser units being developed. However, implementation often comes down to the cost of machine upgrade/replacements and the evaluation of cost and benefit. Using specialised film polymers and controlled production, it is possible

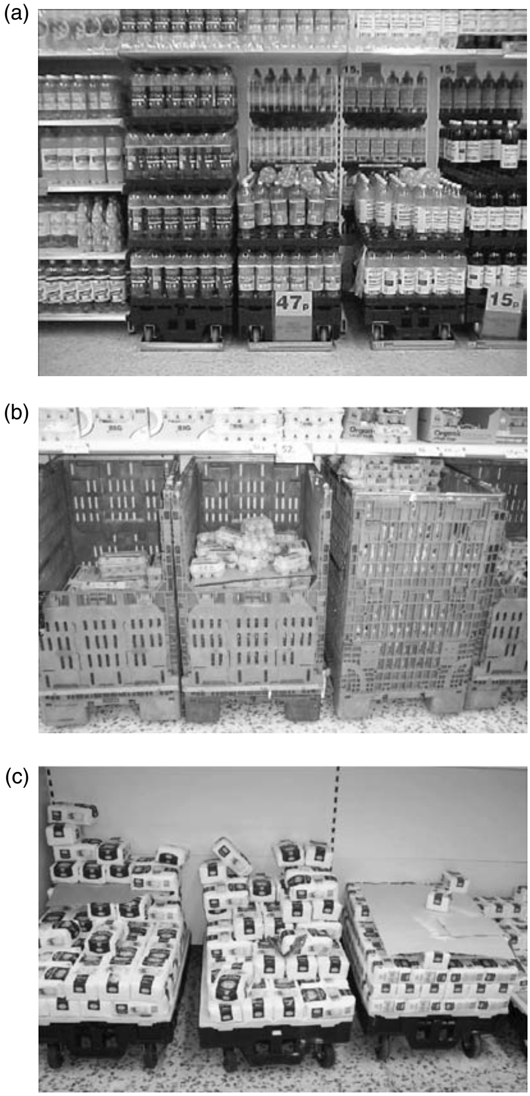


Figure 8.5 Trade ready units. (a) Soft drinks dollies, (b) egg containers and (c) sugar pallets (courtesy British Soft Drinks Assoc.).

to produce shrink film with specific tear properties, such as films that tear easily in one direction but not another and which need a small initiation point (perforation) to start. However, these film polymers are approximately three times the price of standard polymers and the tear can be initiated even by small cuts or bruises which can occur during the distribution picking operation, resulting in pack splitting. Again, this is an area which has a potential for development, but cost issues may be problematic.

8.3.4 Returnable crate

This is the traditional pack for returnable bottles which was the major secondary pack for soft drinks for many years. However, its use continues to decline as the returnable market declines in favour of NRBs (non returnable bottles). Originally wooden crates were used, later to be replaced by injection moulded plastic. However, many of these plastic crates in use are 25 years old or more and are worn and damaged, which is beginning to affect their stability in high-speed automated systems. Often, due to company mergers, a high degree of non-uniformity of crate design exists. This can give rise to instability problems in pallet loads.

8.4 Shrink film production

8.4.1 Film considerations

Shrink film is a blend of polyethylene (low, medium and high density) using the variations in polymer chain length and degrees of cross-linking to give specific material properties. The pelletised raw materials are blended and extruded through a circular die. Air is blown up into the ‘bubble’, stretching it outward around the circumference (transverse direction). At the same time, the material is pulled away (hauled off) from the die, stretching it lengthwise (machine direction) as shown highlighted in Figure 8.6. The air is chilled, cooling the film while stretched. The bubble is brought together to produce a flat tube, the edge trimmed off to produce two webs which can then be slit to multiple reels of the required width. Changes in the die gap, haul off rate and bubble diameter will give film of different shrink ratios and thickness. A standardised set of grades is issued by the Packaging and Industrial Film Association (PIFA) and is used by most UK-based film manufacturers. This is shown in Table 8.1.

Film slip is designated as low, medium or high, though only low slip film is used for secondary packaging to assist with the stability of palletised loads. Co-extruded films, typically using three layers, are now commercially available. The overall film performance is improved by the use of different material properties in the different layers for improved pack performance or same performance for lower overall cost (less film). For example, the centre layer can use longer chain, high-density material for stiffness and tensile strength, with low-density film on the outer layers for tear and puncture resistance.

There are several important factors when considering film performance and specifications. Hot shrink forces are the forces that act on the film when in the shrink tunnel allowing the wrap to conform to the pack contours. Optimum hot forces are generally low to prevent holing when film is soft under heat. Cold holding forces are the reason packs tighten on cooling providing pack stability. Optimum cold forces are generally high to give maximum pack tightness as the film cools. The ultimate aim, therefore, is a film with a combination of both low hot and high cold forces to give the greatest pack quality. Tear strength is a particularly important property

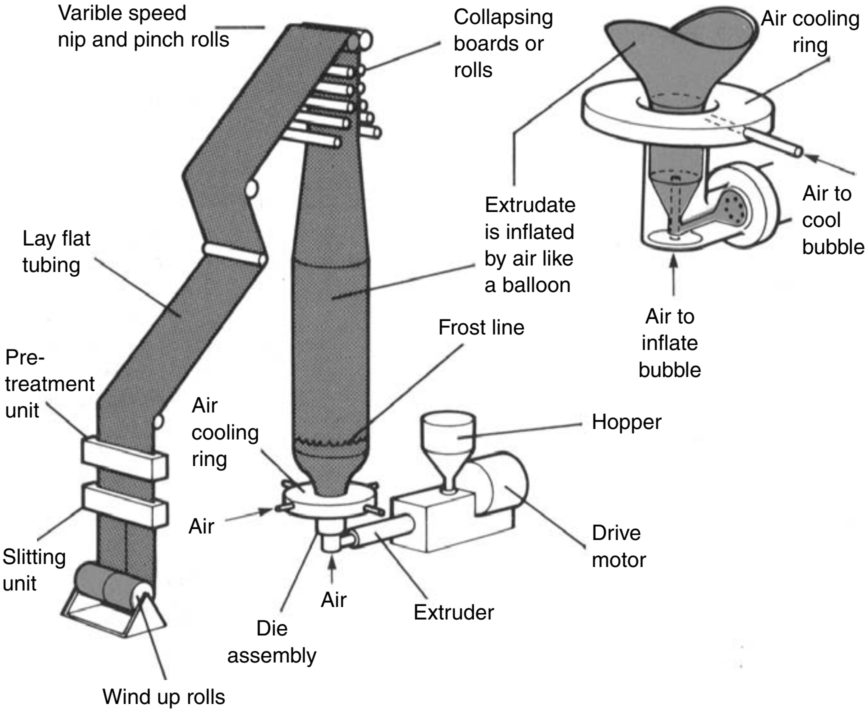


Figure 8.6 Shrink film production (courtesy Taco).

Table 8.1 Shrink film grades.

Code	Transverse shrinkage	Code	Machine direction shrinkage
SA	Less than 10%	W	Less than 40%
SB	10–20%	X	40–50%
SC	20–35%	Y	50–60%
SD	Above 35%	Z	Above 60%

across the pack width (transverse direction) as many packs are lifted by the open ends (bullseyes) and a low tear figure can cause pack splitting. Puncture resistance is another necessary property. Many diverse products are collated using shrink films and the wrap must withstand the sharpest corner or the longest bottleneck. In addition, the film must have high resistance to puncture when lifted. Modulus, or stiffness, is an important property for two reasons: first, single over wrap units require films of high stiffness to cut, feed and wrap on the high-speed packaging systems. Second, higher stiffness results in less film stretch under the weight of the pack, which can be up to 20 kg. The exact film specification used depends on several factors; the primary pack type, size (weight of the pack) and the number in the collation (pack stiffness) are the key factors to determine the film grade and gauge. Other factors are:

1. The primary container shape where considerations such as whether the film will have to form around long, thin bottle necks. This defines the film grade to be used.
2. Primary pack rigidity, that is, whether they are firm (high carbonated) or soft (low carbonated).
3. Collation machine type (sealing requirements). This defines the film grade, gauge and stiffness.
4. Supply chain requirements where the number of handling operations, visual appearance etc. need to be taken into account. This defines the film gauge and grade.

Table 8.2 illustrates the film gauge typically used for different primary packs (Figure 8.7).

8.4.2 Shrink wrap packers

There are two basic types of shrink wrap packing machines, flow wrap and twin web. In a flow wrap machine, a single length of film is cut and wrapped around the pack, the overlap sealed by the heat in the tunnel and belt. Such machines are continuous flow machines, collating the primary packs, forming the tray around or aligning the pad to (if used) the collation while pre-cutting a length of film. This is then wrapped around the pack and passed through the tunnel. These are generally high-speed machines up to 120 packs/min, but are more expensive. A typical machine is shown in Figure 8.8. Many modern machines are built on a modular basis as shown in Figure 8.9. This reduces the cost of manufacture (standard modules can be pre-made) and facilitates the addition of modules at a later stage. However, this does not apply to all manufacturers. Cheaper or older machines may not be modular.

Table 8.2 Film gauge versus pack.

Pack	Weight (kg)	Film gauge (μm)
12–24 small (330 ml) PET bottles or cans	10	50
6–12 large (2 l) PET or (1 l) glass bottles	15	60
12–24 medium (500 ml) PET or (330 ml) glass bottles	15	70

Film usage per pack is defined as

$$\text{Cut length} = (2 \times L) + (2 \times H) + \text{seal},$$

whilst

$$\text{Film width} = W + H$$

where L is the pack length, W is the pack width and H is the pack height as shown in Figure 8.7.

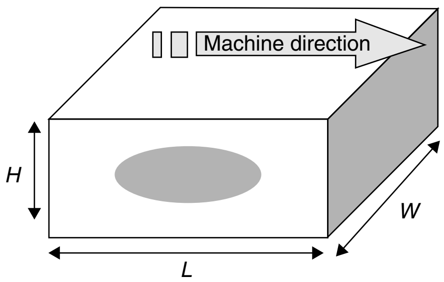


Figure 8.7 Pack dimensions (courtesy British Soft Drinks Assoc.).

In the twin web machines, the ends of two reels are joined to form a web; a pre-collated pack is pushed through the web, which is then sealed behind the pack by two sealing bars. At the same time the film is cut free, creating a new web for the next pack. These are lower speed machines, up to 30 packs/min due to the stop/start motion, but are less expensive. The sealing bar is the key area for maintenance; it must be kept clean and well maintained. A typical machine is shown in Figure 8.10.

Tray formation may be by hand or machine, with manual, semi-automatic or automatic packing, but the tray is formed prior to packing. In this type of packing operation, as the tray is filled after formation, tray size tends to be slightly larger than for a flow wrapper where the tray is folded around the pack collation.

8.4.3 Printed shrink wrap

The development of higher quality flexographic printing and higher speed presses over the past few years has resulted in the increased use of printed shrink film for collation as well as for consumer multi-packs. While there are great similarities in the two, this section will focus on the use for collation packs.

There are two pack styles, registered and unregistered (random) print, both being used for secondary packs. Registered film requires specific machine capabilities, requiring the addition of sensors and film drive units to control the film feed and align it with the pack. This film can only run on flow-type wrappers. On new modular machines, this is one of the module options and can sometimes be retrofitted to older machines. The design is aligned to the pack faces with a clear seal area to maximise strength. An eye mark is used to control alignment to the pack, a photocell ‘reads’ the eye mark and controls the cut point and the film feed to align the pack to film during wrapping. This eye mark can be an integral part of the design or may be a separate mark, away from the main print in a less conspicuous area. On almost all machines, the eye mark is on one edge of the film, ending up in the bullseye area on the finished pack, which may not often be obvious. The colour of the eye mark needs to give a good change in transmission so a clear signal can be generated.

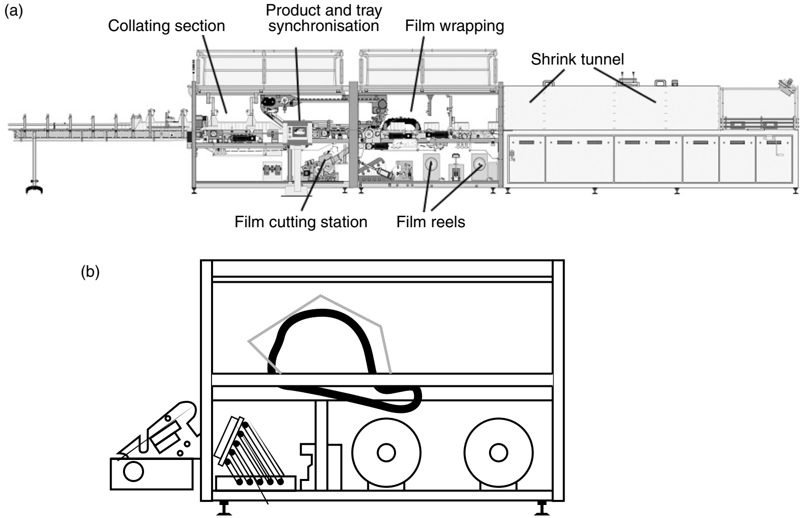


Figure 8.8 Flow wrapper (courtesy Kister).

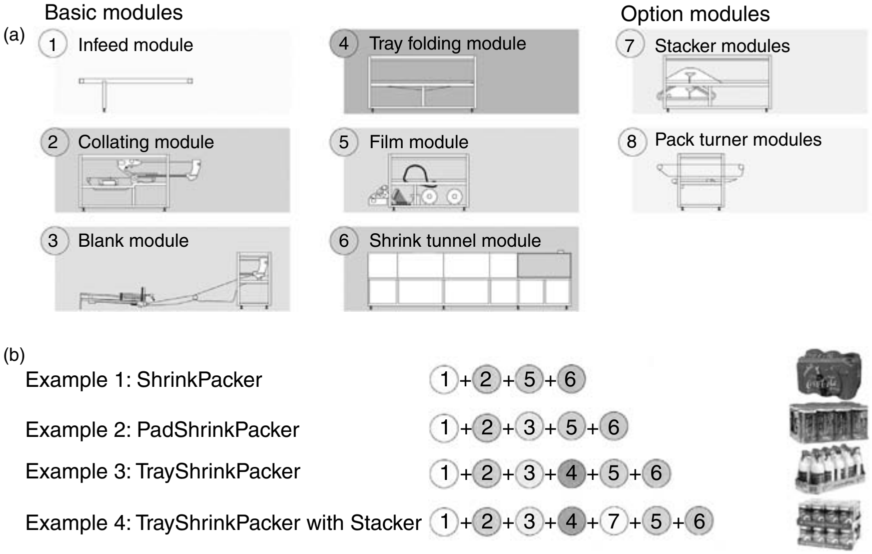


Figure 8.9 Modular machine overview. (a) Basic modules and (b) combining modules to give desired final pack format (courtesy Kister).

The two common eye marks are:

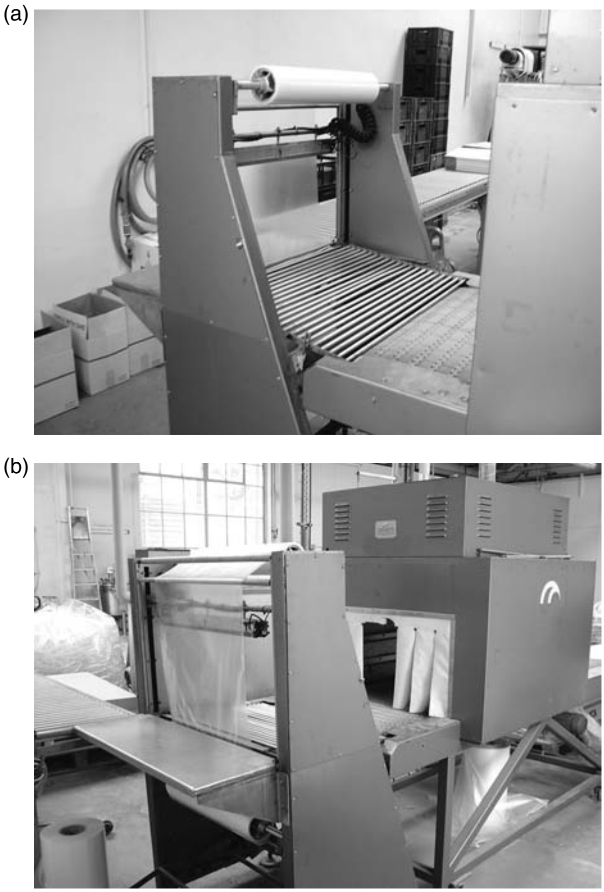
1. Strip eye mark, which is a continuous band of solid colour along one edge, where a single change of transmission triggers the film registration.
2. Block eye mark, which is a small block of solid colour at a key position along one edge. This requires greater control of the photocell to recognise the change in transmission and trigger the film registration.

Unregistered (random) film uses a simple repeating pattern spaced to allow a seal, but still ensuring visibility on the pack. While various designs are used, the critical point is to use a design that still allows at least 75% of the available seal to form as no lap seal will form on the printed areas. Two basic designs are used:

1. A longitudinal strip, which appears as a stripe around the pack. As a rule, the strip should be no wider than 25% of the pack length (machine width).
2. Diagonal strips, angled between 25° and 35° to the transverse direction (film width) and spaced equally apart to appear on the pack faces. The two key rules are to leave a minimum of 20% film width clear along each edge and the spacing along the film length is not less than the width of the under pack seal.

It is vital to ensure that pack sealing is not compromised to maintain supply chain performance.

The use of printed film, especially registered film will give improved pack appearance over plain film. Printed film is commonly used for multi-packs, premium products and promotions, launches etc. The material itself is a similar cost,



(c) Twin web – ends of two reels joined to form a web

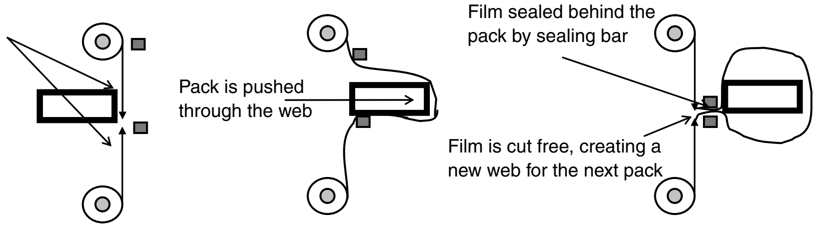


Figure 8.10 Twin reel wrapper (a) and (b) two views of film wrap section and (c) forming the wrap (courtesy British Soft Drinks Assoc.).

depending on the number of colours and quantity of film, the additional cost will be between 50 (two colours) and 80% (six colours) compared to plain film. The film used may be standard shrink wrap, or a high clarity, high gloss blend which can be used to enhance pack appearance (these are often co-extruded films to optimise the film properties). The key areas to consider for registered printed film are:

1. Film to pack alignment. The positioning of pack graphics such as logos, branding, promotional and legal text (ingredients) and bar codes.
2. Shrinkage on the various faces. This will vary from pack to pack and between machines.
3. Areas of maximum distortion: both shrinkage and stretching.

The machine manufacturer will be able to prepare an outline drawing, detailing the various panels, positions of eye marks, the film winding on the reel (how the film is wound to ensure correct alignment to the pack). The addition of ink on the film will retard the film shrinkage by approximately 10–20%. Before printing a full design, use a gridded film (10 mm squares) with a full coverage white background and relevant panel lines, eye mark etc., to check the dimensions and to indicate areas of maximum shrinkage. These can then be considered and incorporated into the finished pack design. Unfortunately, printed film is not suitable for twin reel type machines due to sealing issues. The ink builds up on the sealing bars, resulting in poor welds, seal failures and broken packs.

It is important that operating line checks are carried out regularly to ensure that packs are well presented. The high cost of such film as well as the high capital investment necessary to produce them require that the secondary pack not only meets the functional specification but is also presented to the consumer in the best possible way. Parameters (and tolerances) such as film alignment, pack squareness etc. will be agreed with the machine and film suppliers and are easily measured using jigs made of clear Perspex, as shown in Figure 8.11.

Figure 8.11 Film jig (courtesy British Soft Drinks Assoc.).

8.5 Corrugated fibreboard

8.5.1 Specifications

Corrugated fibreboard, often called cardboard, is used for trays, pads and cartons (boxes). It is composed of three or more layers of paper, two outer layers with fluting fixed between the inner and outer liner. The outer layer or facing may utilise higher quality material, sometimes white, for printing. The fluting, which gives corrugated board its cushioning characteristics and also achieves excellent rigidity and structural strength, uses lower grade or recycled material. The inner layer or lining may be of lower grade (recycled) board as visual appearance is less critical. These layers are bonded together using adhesives, usually starch based.

Different grades and weights are used for each layer depending on the end use of the board. Virgin material (Kraft) is the highest grade of paper, comprising 80% virgin chemical pulp. The long fibres give better visual appearance and are mechanically stronger. However, it is more expensive and is available in bleached, unbleached, mottled and white top forms.

Recycled material (Test) is cheaper, but has less mechanical strength (reduced fibre length due to the use of recycled material) and less consistent visual appearance. There are two grades of test materials: Test Liner 2 and Test Liner 3, with Test Liner 2 being the higher grade (made predominantly from Kraft waste material) with similar performance to Kraft material. While Test material is available in the same forms as Kraft, the surface finish cannot meet the same visual standards.

Fluting is made by two processes. Semi-chemical fluting is made predominantly from 100% virgin fibre using a combination of mechanical and chemical pulping methods. Waste-based fluting uses 100% waste material reinforced with starch-based adhesive. The use of virgin material in semi-chemical fluting gives it greater strength over other mediums.

Different paper grades, weights and flutings are used for each layer depending on the end use of the board. For heavy use such as bag in box, a double flute or even triple flute may be used. The papers used for each layer are referred to by their weight in grams per square metre and type (Kraft, Test etc.). For many soft drinks trays/pads, both the facing and liner are made from recycled board as visual appearance is not critical.

The standard flute range includes the coarse ‘A’ and ‘C’ flute, fine ‘B’ and extra fine ‘E’ and ‘F’ flutes. The ‘B’ flute is the most widely used. It is very robust (difficult to crush) and has good compression strength. It is also compact, so less space is required during transit or storage. The ‘C’ flute is larger with greater compression strength but offers less crush resistance and requires more space. The latest construction is the ‘N’ flute, which is 48% thinner than ‘E’ fluting and 20% thinner than the ‘F’ flute. The non-standard range includes mini and micro ‘F’ flutes. Flutes come in different combinations: single-face web, single-wall board with single- or dual-arch fluting and double and triple walls. Double wall packaging combines ‘B’ and ‘C’ flutes, for applications where compression strength is more important than storage space. More recent innovations have combined ‘E’ and ‘F’ flutes. Triple wall is a more rigid board that provides excellent stacking strength with good shock and puncture resistance. Typical board and flute details are shown in Figure 8.12.

8.5.2 Corrugated board manufacture

There are essentially three main processes involved in the manufacture of corrugated board. The first operation is the making of single-faced board. The fluting material is passed through pre-heated rollers and then steamed to make it pliable. It is then passed between a pair of corrugating rollers to form the flutes. Starch-based adhesive is applied to the flute tips, which are then brought into contact with the liner material (also pre-heated) forming the single-faced board. This flexible board then passes onto the bridge section which acts as a buffer to the second part of the process.

The single-faced board travels with the corrugations downward over a second adhesive applicator again applying adhesive to the tips. A second liner (again pre-heated) is applied to the tips to form single-wall corrugated board.

The formed board is dried by passing it over a heated table under a compression belt before passing through a cooling section. If required for the finished product, machine direction creases are added before the board is cut into sheets for converting.

Simple cases can be finished on a case maker or printer slotter. However, more complex cases or high volume items are finished on either flat bed or rotary die cut machines as illustrated in Figure 8.13.

8.6 Stretch wrap

8.6.1 Material

As with shrink wrap, stretch wrap is a blend of low-, medium- and high-density polyethylene. However, the materials and blends are different with long chain/cross-linked polymers formulated for high puncture resistance, tensile strength and elasticity. The resulting film must be able to wrap around pallet corners, pack edges and angles and resist abrasive forces through the supply chain.

The force applied to the load is a combination of the amount of film (wraps and thickness) and the tension applied. Stretch wrap cannot compensate for poor pack formation or pallet stacking and if the packs are loose or slack, or there are uneven gaps between them, the stretch wrap will not prevent load movement.

Blown film production is produced in exactly the same way as shrink film. However, the polymers, blow ratio and haul off rates are different, as the properties required for the finished material are completely different. Cast film is made using

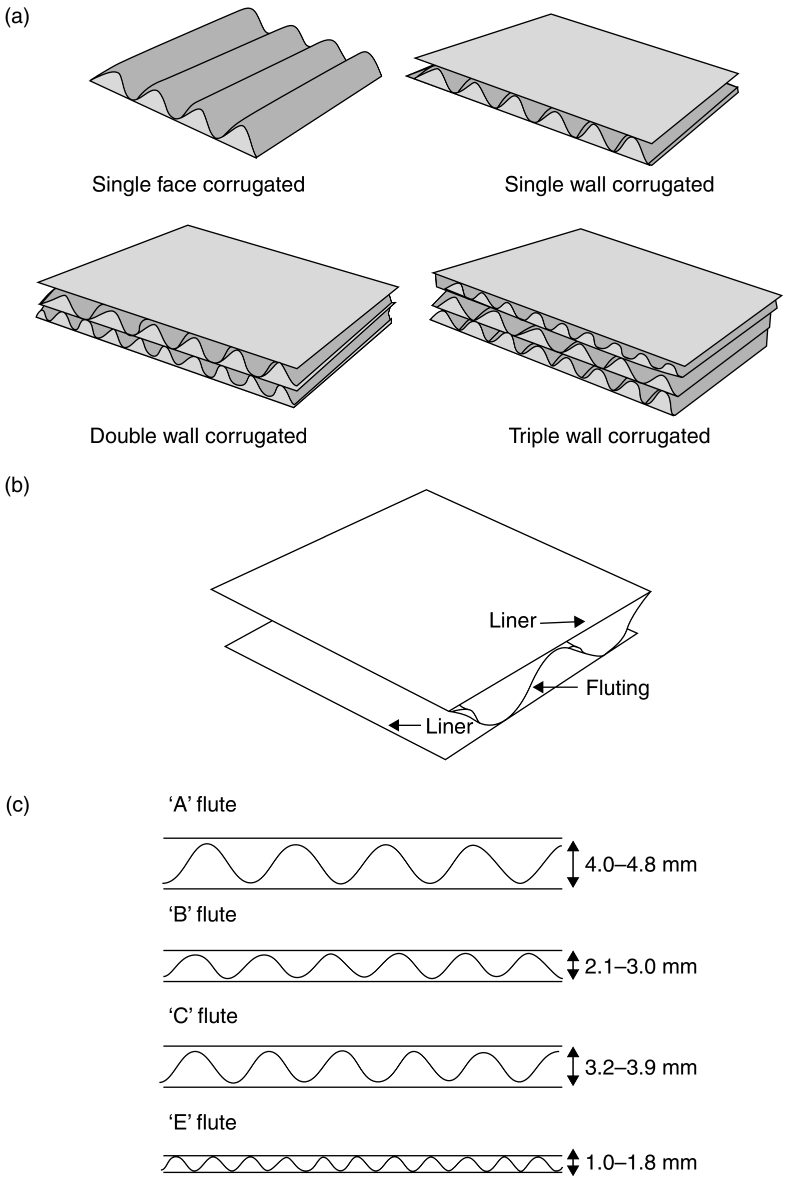


Figure 8.12 Board and flute details. (a) Corrugated construction, (b) flute layers and (c) flute types (courtesy Linpac).

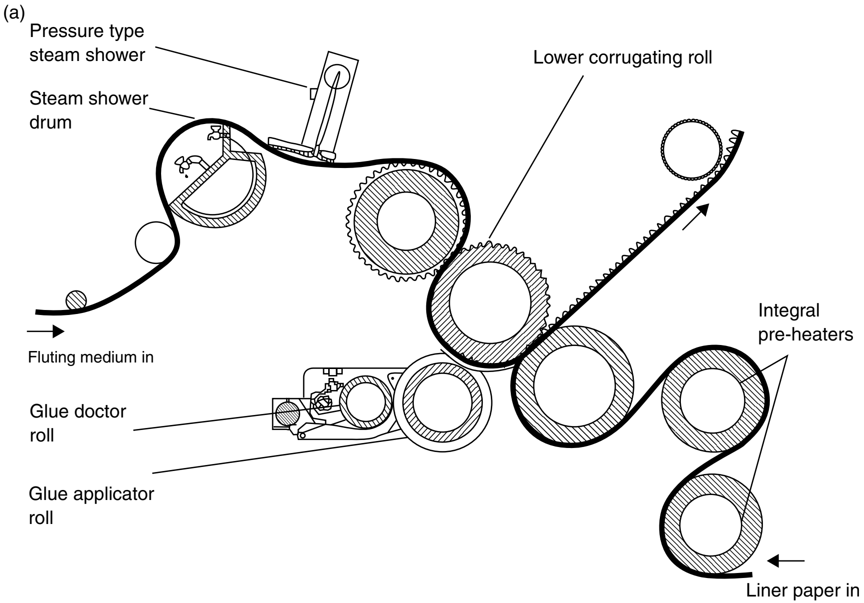


Figure 8.13 Corrugated manufacture. (a) Single facer, (b) double backer and (c) creasing/slitting (courtesy Linpac).

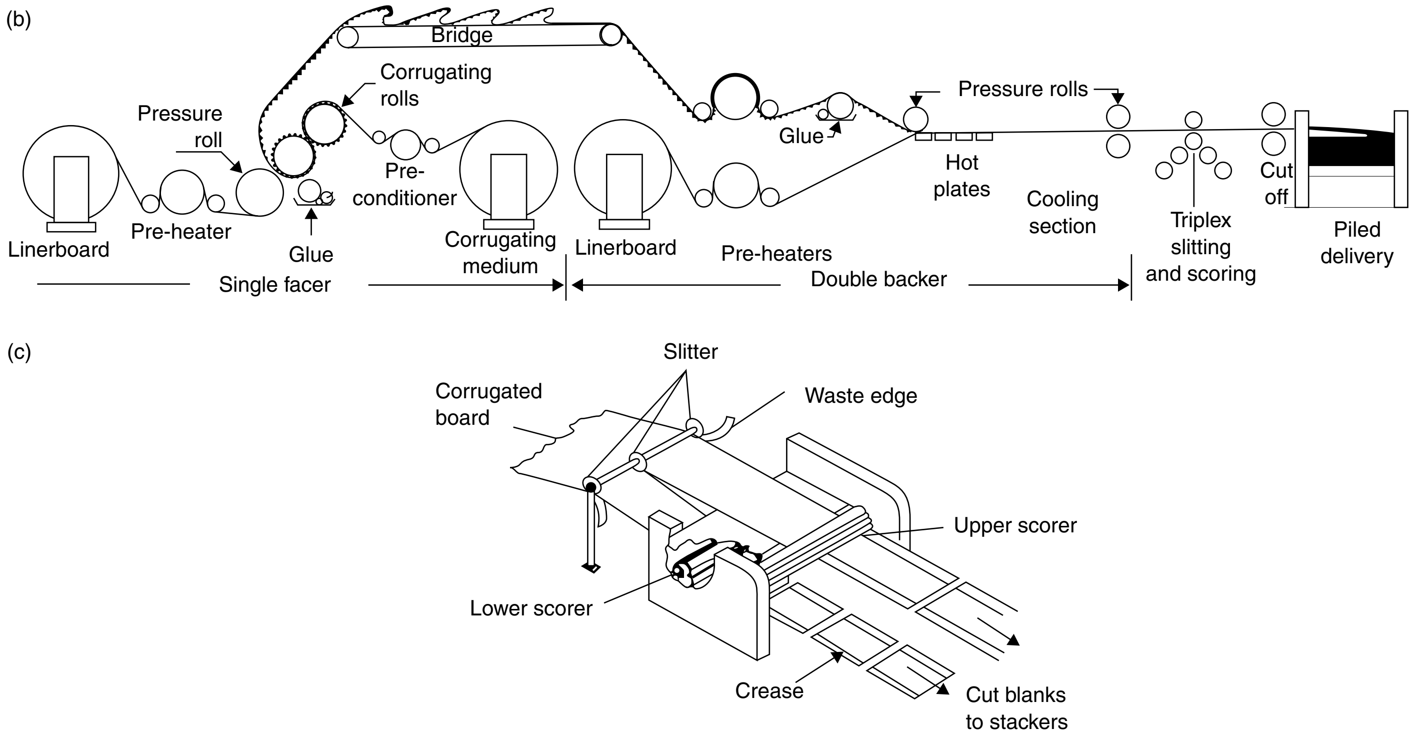


Figure 8.13 Continued

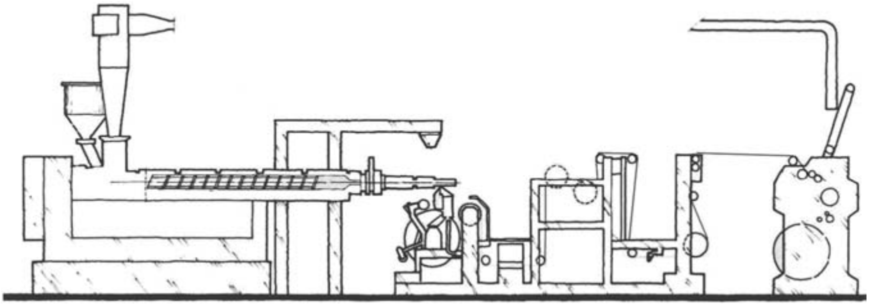


Figure 8.14 Stretch film production (courtesy Mima).

a different process. The material is extruded through a straight die (at 250–280°C) onto a chilled roller at 40°C, then wound onto reels. This is shown in Figure 8.14.

During wrapping, the most important properties are tensile strength and puncture resistance. The film must withstand the stretching forces while being applied to the pallet and resist failure on load protrusions, pallet corners etc.

In transportation, load stability is the most crucial factor. The yield point of the film should be high and its elongation to yield point low. A low value for stress relaxation is also required to maintain the wrap tightness and load rigidity.

Different films have different properties and it is vital to match the film specification to the wrapping machine and the load being wrapped. This will vary according to individual pack types and dimensions. While the graph shows typical differences between cast and blown films, the resin blend and processing will also have an effect. The properties of stretch film are shown in Figures 8.15 and 8.16.

Film suppliers will assess the machine, pack to be wrapped and advise the most suitable material and recommend a wrap pattern. This can then be evaluated by trialling.

8.6.2 Stretch wrapping systems

There are two basic types: pre-stretch and brake stretch as shown in Figure 8.17. In the pre-stretch system, the film is pre-stretched between two differentially geared rollers before being applied to the load. These rollers can be driven by the film or by a separate drive motor, when it is known as power pre-stretch. Tension is controlled by varying the differential gearing between the reels and the feed rate to the palletised load. The film feed system is driven independently from the rotary carriage, which generally rotates around the stationary load. This gives very good tension and application control and can apply high stretch forces to the load. No force is applied to the load during wrapping, so it is suitable for less robust loads. This type of machine is generally high speed, up to 2 pallets/min, but is more expensive.

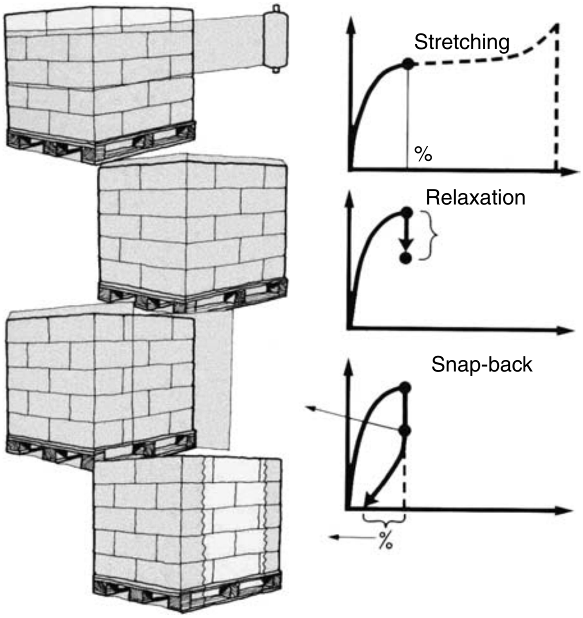


Figure 8.15 Stretch film properties (courtesy Mima).

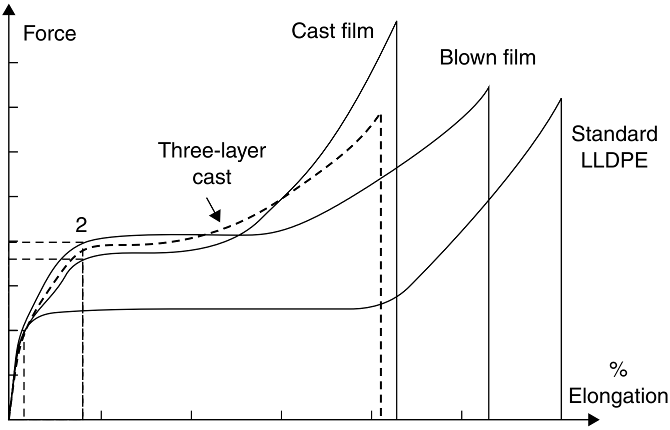


Figure 8.16 Stretching properties (courtesy Mima).

The films used for pre-stretch machines are formulated with higher stretch properties, up to 700% and can control film stretch up to 300% on the load. Films formulated for brake stretch machines would be destroyed at these forces.

With a brake stretch system, the film is stretched between the film reel and the load. Tension is controlled by varying the braking force applied to the reel as the film is drawn from the reel. This type of machine can operate either by rotating

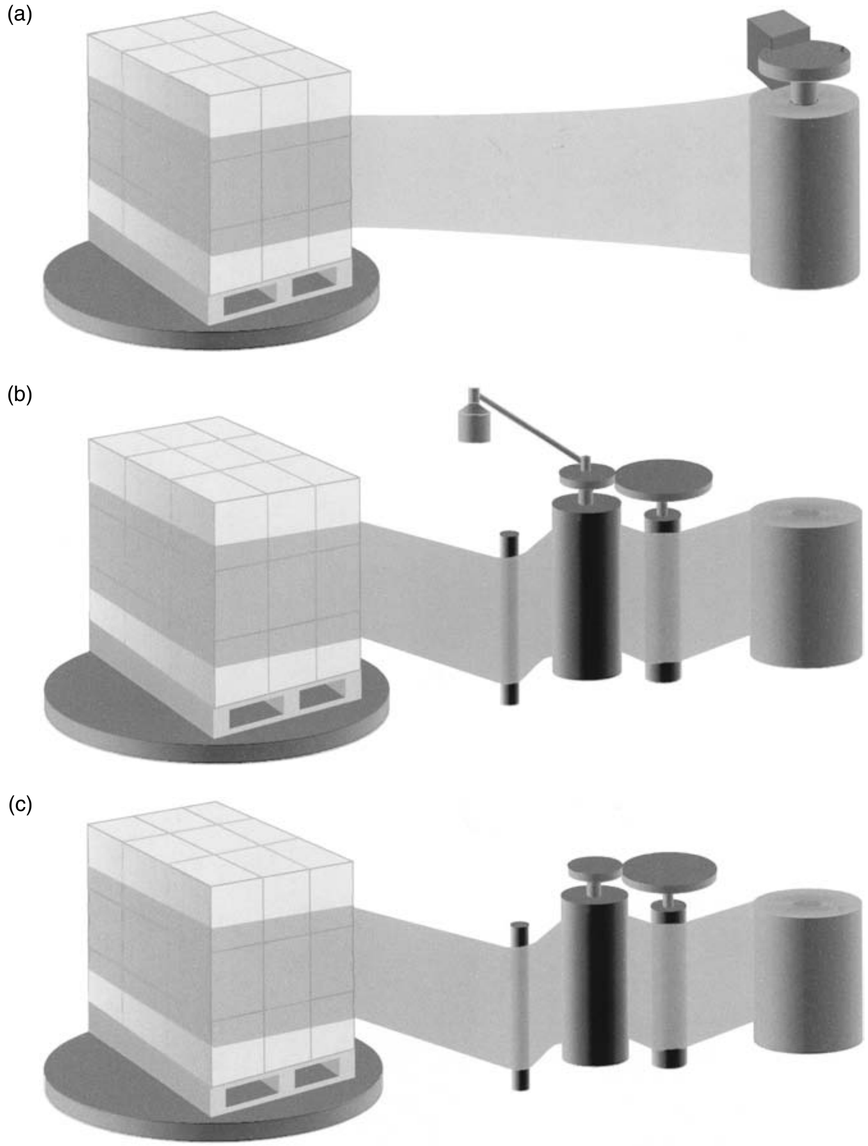


Figure 8.17 Pre-stretch and brake stretch wraps. (a) Core brake-stretch, (b) pre-stretch and (c) power pre-stretch (courtesy British Soft Drinks Assoc.).

the pallet and pulling the film from the static carriage (which raises and lowers to wrap the pallet height) or the film feed system can rotate around the stationary load. Modern systems give good tension and application control but are limited in the forces applied to the load. This is due to the force being applied to the load during wrapping which is not suitable for less robust loads. They are generally slower speed machines up to 1 pallet every 2 min but are less expensive. The films used for brake stretch machines are formulated with lower stretch properties. If film formulated for power stretch machines is used on brake stretch machines, lower load stability will result as the film will not be stretched to its optimum load holding capability. This is generally overcome by using excess film.

8.6.3 Pallet wrapping

The key aims and attributes are:

1. The load is secured to the pallet, with the film overlapping the pallet by at least 50%. This is absolutely vital to prevent load shift during transit. Many customers will reject pallets where the film is not around the pallet. However, wrapping fully over the pallet can also create difficulties with pallet sensors in automated systems.
2. The wrap pattern locks layers and prevents shearing. Typically this occurs on the second layer. Apart from the bottom layer, this layer has the highest vertical load, but the cases stand on the layer below. With narrow neck containers such as bottles, this creates a pivot point for the second layer. Biasing the wrap pattern to give an increased restraining force is often vital here.
3. The top layer is secured. It is vital to ensure cases are not dislodged, particularly when operating a fork lift truck (FLT) three or four pallets up in racking. However, care must be taken to avoid excessive wrapping or tension causing damage to the primary pack.
4. There are no loose tails, loose ends or excessive film over the top of the load. Loose stretch wrap ends must be removed from empty pallets before re-use. Wrap starts must not be tied to pallet blocks, but trapped between the pallet and the load. Film ends must not be left loose or trailing but brushed, sealed or trapped under film wraps. Tails are likely to snag on FLTs, trailers, racking etc., and are critical rejects for most customers. One dislodged case (or several if the tail snags) can severely damage a crane in a high bay automated warehouse as well as all the stock in the bays below. The repair bill and lost time claim could be several thousand pounds.

While achieving the above, it is important to ensure that film tension does not damage primary containers. This is often a potential problem when handling still products, cartons or pouches and is a balance between load restraint and damage.

Stretch wrap is not like an elastic band. It can be stretched beyond its elastic limit and then it loses most of its load holding force. It is vital to match the film specification to the wrapping machine and the load being wrapped. Increasing the number of wraps, using thicker film or altering the bias in the wrap (areas of heavier wrap) may be better than just increasing the tension (assuming the tension was not too low).

Different packs and palletised loads also have different properties and it is vital to match the film specification to the wrapping machine and the load being wrapped. This will vary according to individual pack types and dimensions. The wrap is normally biased to key areas to maximise the load holding force of the film. A minimum of three full wraps should be placed around the bottom of the palletised load. These must overlap the pallet blocks by a minimum of 80 mm below the top boards.

Individual wraps ascending and descending the palletised load must overlap by a minimum of 40%. A minimum of two full wraps should be placed around the top layer of the palletised load. For some materials, particularly shrink wrap packs of bottles, additional wraps around the second layer act as a band to further stabilise this area which is the layer most prone to shearing (herring-boning) due to the combination of high vertical force and the packs standing on the bottom layer.

The wrap tension and the number of wraps will also vary depending upon the nature of the product, distance travelled, number of handling stages etc. Low carbonated products will require less tension but a greater number of wraps to stabilise. The greater the number of fork truck handling operations, the greater the stabilisation required.

8.7 Pallets and pallet stacking

8.7.1 Pallets

Almost all UK distribution systems are now based around the use of returnable, 1200 mm × 1000 mm × 162 mm, four-way entry wooden pallets. Almost exclusively, these are used on a transfer hire system, where the pallet hire costs are transferred to the customer on delivery. These returnable pallets are ostensibly to an agreed standard and quality. However, as with pack and palletised load requirements, the standards required by the latest generation of automated warehouses are increasing. Currently there are ongoing discussions among the major multiples, the pallet suppliers and the users regarding the current quality standards in the pallet pool.

For imported goods, non-returnable pallets are used sometimes. These should be to the same dimensional and quality standards as for returnable pallets. The use of ‘slave’ pallets (simply placing the non-returnable pallet on a returnable pallet) is not accepted by any distribution systems.

8.7.2 Pallet stacking

This is often only an afterthought but it is a vital part of the supply chain and is becoming more critical. The key aims and attributes of a good stacking pattern are:

1. A good interlock of packs helps lock the load together and helps to maintain stability when the wrap is removed which improves stability in the break/pick warehouse and minimises health and safety risks.

2. Achieves perimeter stacking. Excessive overhang does not fit pallet racking or defined bays, as most systems are limited to a maximum 20–30 mm. However, it is vital to check as some systems will not tolerate any overhang at all. New automated systems use laser measurement to gauge pallet dimensions and will reject any pallet with overhang. These systems will also reject loose labels, stretch wrap etc. as these break the same detector beams. Excessive under hang (greater than 20 mm) will result in load shift in transit. With 26 pallets on a vehicle, there is $13 \times 20 = 260$ mm of potential movement.

Matching the primary container size to the pallet is vital to facilitate pallet stability. Therefore, it is vital to consider the pack dimensions and type when designing and specifying the primary pack diameter. This may restrict the design, but the importance must be emphasised during the briefing process.

A good stacking pattern gives a good interlock of cases to aid stability in transit. This also helps between palletiser and stretch wrapper, as well as in the warehouse when stretch wrap is removed. However, the formation must be capable of being stacked, either manually or automatically. Patterns which are too complex or irregular should be avoided. The fewer the number of cases that need to be turned by automatic palletisers, the more reliable the line is. Figure 8.18 illustrates a typical pallet wrapping pattern whilst Figure 8.19 shows some good stacking patterns.

8.8 Case and pallet labelling

Bar code identification is now an absolute requirement of most customers, both major multiples and Cash & Carry outlets, with many now rejecting goods and/or levying handling charges for pallets and cases that fail. Some major retailers now require a minimum 98% first-time scanning for case and pallet labels.

International standards are in place via the European Article Number (EAN) international and the Unified Code Council (UCC) and must be followed at all times.

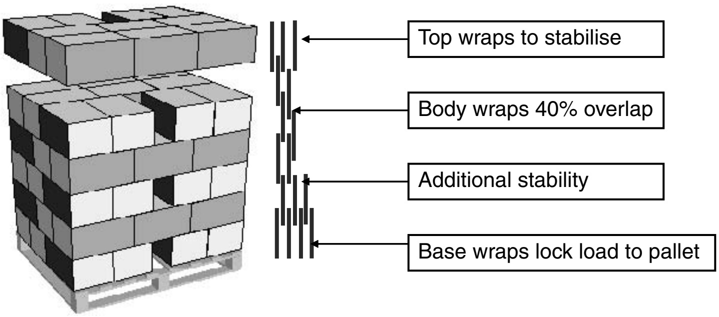
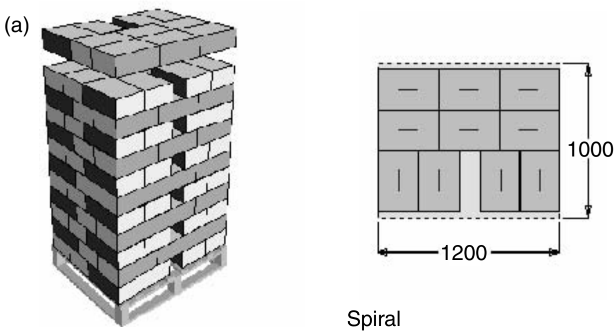
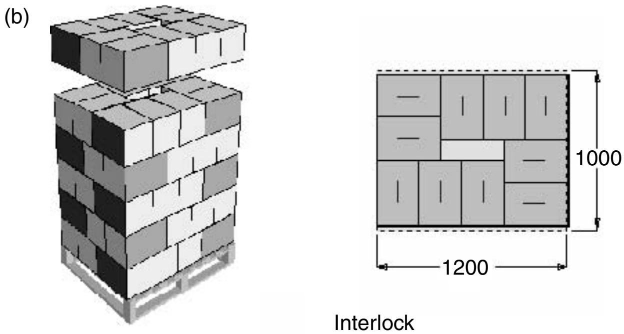


Figure 8.18 Pallet wrapping patterns (courtesy British Soft Drinks Assoc.).



Spiral



Interlock

Figure 8.19 Good pallet stacking patterns (courtesy British Soft Drinks Assoc.).

These standards are used by all the major users, details of which are available from GS1 UK (formerly the e-centre) www.gs1uk.org. Briefly the current standards are as follows:

1. Each case must carry a minimum of one global trade item (bar code) number, encrypted in the appropriate symbology. The bar code must be positioned on a long side and must be visible when the pack is standing in its normal upright orientation. Packs distributed through normal ambient systems will use a simple 14-digit ITF code. EAN 128 codes are generally used where additional information such as BBE dates is required, usually only where the shelf life is less than 48 days.
2. Each pallet must carry two supplier shipping container code (SSCC) labels with bar codes in EAN 128 symbology. This carries the pallet global trade item (bar code) number and a unique pallet identification number. Additional information such as BBE date and batch information are also included. The SSCC number is composed of the supplier (or retailer in the case of own label goods) identification code together with a pallet number, allocated by the manufacturer to give an 18-digit number, unique to each pallet.

All the relevant details are available from the GS1UK booklet *Bar Coding Getting it Right* or their web site. These cover:

1. printing quality and verification standards
2. label dimensions, bar code symbology and position
3. number creation and allocation.

Bar coding is a whole subject in its own right and realistically cannot be covered in any detail within this chapter. GS1UK runs a series of 1- or 3-day courses, from basic to advanced level. These are ideal to gain the necessary understanding of bar code symbology and quality standards.

Trays and cases can have the bar code pre-printed by the board supplier, or the packer may print the bar code using ink jet printers or apply self adhesive labels (either pre-printed or on-demand print) on the packing line.

Pre-printed items have the advantage of cost and operational simplicity on the production line but have the disadvantage of logistics complexity as a different tray/case is required for each individual SKU produced. This can result in a significant inventory of packaging materials. They will also still require printing of traceability data such as Best Before dates, lot numbers etc. usually with ink jet or roller print. The use of on-demand printed self-adhesive labels add to operational complexity (another machine to set up and maintain) but simplifies the inventory of packaging materials. They can also include all the traceability information on the same label. A 'halfway' point is to use pre-printed self-adhesive labels; the application machine is simpler and while a stock of labels by SKU is required, these take up much less space. A developing alternative is ink jet printing of bar codes on corrugated trays or cases. At present, the speed of this system is not capable of meeting the bar code quality requirements at the higher line speeds on the bigger production lines but it is a viable alternative on smaller lines. However, due to the quality issues, most major multiples currently require two bar codes on each case to ensure that 98% readability is maintained. When using film and pad or film-only packs, self-adhesive labels are currently the only viable option as ink jetting onto film is not yet possible at line speeds and the film treatment/printing to accept the ink makes the process not cost effective. The only exception is when using registered printed film when the bar code can be pre-printed on the film, but the code must be positioned correctly in an area of minimal and equal distortion.

For pallet labelling, the use of self-adhesive labels is the only realistically viable option. Labels cannot be tucked into or placed behind the stretch wrap or held on with adhesive tape as this will compromise bar code readability. The two options are either on-demand printed self-adhesive labels (has the same advantage and disadvantage as with case labels) or pre-printed self-adhesive labels, but these will require adding the traceability details at the time of production. Whichever system is used, there is an absolute requirement for the unique SSCC number so strict controls must be in place to allocate numbers and ensure no duplications (the retailer automated systems will reject pallets with duplicate numbers).

For both case and pallet bar code labels, a robust QA process as part of routine daily checks is vital for checking accuracy and quality to ensure bar code compliance to the required standards. A good quality code ISO standard bar code verifier is a worthwhile investment as part of this process. A £0.20p charge per case doesn't sound much, but at 10 m cases per year, 1% failure equals £20,000, a good bar code verifier costs £2,500.

Bar code based systems have now developed to be fairly sophisticated logistics management operations. However, there is now a new emerging technology which is likely to replace bar codes in the next 10 years. Radio Frequency Identification (RFID) involves the tagging of products (pallets, cases or items) with electronic barcodes (data carrying micro-chips, with in-built aerials that can transmit information about the product to a remote reader several metres away). The aim is to facilitate visible, efficient and collaborative supply chains by tracking products through all the stages of the product life cycle that is, from manufacturer to consumer, for example, storage, delivery, shelf fill, point of sale. This technology has been available since the Second World War (used for bomber guidance control), but it is only in the past few years that it has been developed to a point where the chip size is suitable. Within the constraints of this book, it is not possible to go into the details of how RFID works, but in essence, the system consists of the following:

1. RFID tags which are attached to the product/case/pallet; these contain the electronic product code (EPC) – globally unique item identification number – and communicate this to the reader.
2. RFID tag activators and readers, which use radio frequency to write information to and read information from the tags. The data is written at the point of packing, and then read at subsequent distribution stages.
3. A network of computers, both local and remote, which processes the information received from the reader and communicates onwards the detailed product information.

However, there are a number of technical and commercial issues to be addressed. Tag and frequency standards are still being finalised. The latest version for tags (Generation 2) has recently been published but now needs to go through a lengthy ratification process (12–24 months). Equally manufacturers are now frantically trying to produce compatible tags and readers in sufficient quantities that actually work. There is also a view that the global standards are unsustainable in the medium term. This is supported by the understanding that no manufacturer etc. has yet agreed to the data and information transfer protocols. It is difficult to see where new standards development could come from on the basis that all interested parties are represented in EPC Global. This reflects a general uncertainty around standards. Also, the physical aspects of liquid and metal, which can severely disrupt radio waves and subsequent tag read rate accuracy are yet to be resolved. This presents specific issues for soft drinks producers, where the products, factories and warehouses have high density of liquid and metal substances (packaging and equipment). On the wider social aspect, there are major concerns over the quantity and security of the data. Consumer groups have concerns over the data held on the tags and links to individuals. The majority of these are based on a misunderstanding of how the tags work and the data held on them. Talk of 'spy chips' being read by satellites are completely unfounded; the tags have a read range of a few metres and do no more than identify a product, although they can also carry the BBE information and production batch details. However, these issues must be addressed before widespread tag use is accepted by the public in general. Equally, RFID creates huge quantities of extra data which suppliers are struggling to make any value-add real time use of, without significant extra resource.

Through the retail supply chain, it is possible to see where implementing RFID could drive benefit, for example, reducing shrinkage, lowering inventory and cutting out of stocks. However, in order for this to work in retail it is necessary for the supplier to apply the RFID tag. It is for this reason that retailers are encouraging suppliers to produce their own internal business case. The major issue is that it has not been possible to find a single robust supplier benefits case. In fact, the general view is that RFID will add no additional benefit to an effectively implemented bar code 'track and trace' system.

8.9 Getting it wrong

Some examples are shown in Figure 8.20.

Loose film on pallets and stretch tails will jam in conveyors, cranes and racking causing fallen cases, damage etc. Offset and sheared loads may not look too bad, but are disastrous for an automated system. These will jam in cranes and racking causing fallen cases, damage etc. Multiple pallet labels as illustrated show what you can see but the bar code scanner cannot. A shot load occurs when truck drivers sometimes have to brake hard. While mixed delivery technically is the retailer's responsibility, it can be helped by pack design and materials. Where packs are susceptible, adequate handling guidelines should be given to the warehouse staff and load assemblers to assist in the correct pick order.

One issue is the varying standards applied by the various multiples regarding pallet quality, number and position of labels, palletised load dimensions, tolerances and methods of measurement. On one side, there are a few major multiples that have fully automated systems which apply consistent measures to the many where the delivery FLT driver makes a judgement on each load. Figure 8.21 shows a whole load rejected by a major multiple; the arrow indicates the single pallet rejected due to 'insufficient shrink wrap'.

While some retailers have very comprehensive documentation covering pallet and case quality and acceptance criteria, others have very little. Also, in some cases, these standards are not applied consistently within individual retailer's depots. This adds to the pressure on the suppliers in developing specifications and standards that satisfy all customers. There is a growing need for one or more of the industry bodies such as the British Soft Drinks Association, the Institute of Packaging or the British Retail Consortium to jointly create a standard to cover delivery of filled goods from the packer filler to the customer distribution centre. While it could never specify every parameter, a code of practice outlining key requirements, dimensions and tolerances, acceptance standards etc. is required to minimise these difficulties.

Figure 8.20 Poor palletisation. (a) Load offset on pallet, (b) stretch wrap tail, (c) loose stretch wrap, (d) load shifted on braking, (e) multiple pallet labels, (f) effect of severe braking, (g) bad stacking of mixed load, and (h) typical mixed cage (courtesy Linpac).

Figure 8.20 Continued.

Figure 8.20 Continued.

The whole supply chain would benefit as any degree of over packaging could be minimised and unnecessary returns reduced. This would allow greater focus on key issues.

A balance is required between health and safety on the one hand and the cost pressures being brought to bear by the major multiples. For example, currently most beverage cans (singles and multi-packs) are not stretch wrapped. However,

Figure 8.21 Reject load (courtesy British Soft Drinks Assoc.).

one major retailer has recently requested wrapping on all pallets of cans due to an incident.

8.10 Developments and testing

A controlled, documented test method, based on actual supply chains is vital to evaluate secondary and tertiary packs and palletised loads as part of a development process. The aim is to simulate the likely route for the packs under evaluation. As you have seen, it is vital that the appropriate distribution channel is selected or if considered applicable, several supply chains are used for the evaluation. For extended journeys, particularly overseas distribution, the use of a travel test simulation should be considered. This may be more practical (and cheaper) than an actual travel test. Equipment is available at packaging consultants which can simulate any journey (takes data from loggers on vehicles) and some have a database of various typical/worst case journeys from internal lorry to container at sea/vehicle etc. Pallet stability and case handling trials may be carried out using the same full goods. Initial trials will consist of one or two pallets, which can be tested internally using fork lift truck handling and through inter-site road shipment (minimum 100 miles each way). Pallet stability should be monitored at each stage. After this initial trial, the second stage of the pallet stability trials should be onwards shipment to the final destination using 10–20 pallets as part of several mixed loads. These should also involve manual handling and be subject to order picking process and manual handling evaluation through all relevant supply chains (multiple DC, Cash & Carry etc.).

One major concern is that currently there are no UK industry standards for travel tests or handling trials through the supply chain. Individual companies carry out testing to a varying range of degrees, from almost nothing to very detailed and comprehensive levels. However, with the range of supply chains and differing standards at the various retailers, there is a need for co-ordination of test methods and acceptance criteria. Currently there is some work being done by the UK Packaging Industry Research Association (www.piranet.com) to develop some test and acceptance criteria which may form the basis of a set of industry-wide guidelines. However, to facilitate and optimise future developments and to ensure consistency across the industry and supply chain, there is a need for a set of standard test criteria to be officially accepted by the IOP/BRC, which could then form part of the quality and acceptance criteria referred to above.

8.11 Putting it all together

It is vital to control secondary and tertiary packaging to the same degree as product and primary packaging. At each stage, it is important to ensure that documented operating procedures, which include key machine settings, are in place and operators cannot change them without documenting who, why etc. For shrink wrapping this includes tunnel temperatures, baffle control settings, machine speed. For stretch wrapping this includes wrap tension settings, machine speed and timing settings.

It is imperative to have agreed material specifications with suppliers, which are not changed without prior notice. This includes purchasing changing to a new supplier without successful trials. Any new supplier must have a positive audit and agreed specifications in place before they are used.

It is necessary to have agreed and documented pallet specifications for a customer acceptable pallet, which includes dimensions, overhang and wrap quality. It is also necessary to ensure that the producing factory is aware of them and monitors performance.

Supply chains should be measured with a system in place to measure and monitor trends in reject loads at depots and customer deliveries. The system should be regularly reviewed for key issues, packs etc. Responsibility for adherence to standards, performance and improvements is owned jointly with the producing factory.

Customer feedback should be obtained regularly by visits to the distribution centres, rather than head office, and their involvement in trials which can be controversial if aimed at saving money.

9 Production systems

David P. Steen

9.1 Introduction

If a container is to be filled efficiently then the complete filling line and other necessary processes must be correctly designed. This is achieved through a brief. Such a brief could well take several weeks, or even months, to develop correctly. Questions such as what production is wanted now and in the future, the current sales pattern and volume and what is expected in 10 years' time need to be answered. Technology is continually advancing and consumers' needs are constantly changing. Any design specification must, by its very nature, be flexible. The factory of today is very different from the one of 50 or even 20 years ago. Likewise, the factory of 20 years hence will probably bear little relation to what we have now.

The current trend appears to be 'big is beautiful'. Large factories operated by large companies. Is this going to last or will we see the return of small companies and/or factories dotted around the country to minimise distribution costs? All that can be done now is view the situation as any individual company sees it and use that as the basis to progress.

In this chapter, the layouts of can lines, glass lines, both returnable and single trip, and PET lines will be discussed. From this, each process operation, such as syrup preparation and water treatment, warehousing for incoming raw materials, packaging and outgoing goods, personnel requirements, will be developed into an idealised total factory layout. This involves considerations not only of production processes, but also of people movement and facilities, material flows and hygiene considerations. Included will be considerations of inspection systems, both in line and off line, line control systems and factory management systems. It is an attempt to provide a picture of how present and future factories could develop.

9.2 Philosophy of line layouts

Having first listed what and how much production is required, next comes the question of working out how many production lines are required and the output at which each line should be rated. For low throughput applications, should these be produced inefficiently on high output lines, or should specifically designed so-called cottage industry lines be used? How much spare space needs to be kept for new production lines using new technology, such as an aseptic filling line? Would such a line replace an existing production line or would it be incremental business? These are all questions, with a multitude of others, which must be addressed when a new factory rationalisation of existing factories or the annual review of current production facilities are being considered or when the cash flow for the following year is being planned.

Some designers consider that conveyor buffering, so-called accumulation, is not needed; others go to the extreme and put in great lengths of accumulating conveyor. If a dedicated line is used, then it is possible to minimise accumulation with a compact design such that the few operatives that are manning the line can access any problem immediately. This is then a form of accumulation in itself, as the speed of response of the operative acts as the buffer so that production stoppages are minimised. Accumulation is only present to ensure that the filler never stops unless it has to. It is the prime mover in any production line, though in lines fed from an on line bottle blower it is often the bottle blower which is considered the line controller. To this end various designs of accumulating conveyor have been developed over the years. A typical design is shown in Figure 9.1.

Machinery manufacturers are increasingly supplying plants in modular form using standardised components to keep costs under control yet satisfy market demand. Such modularisation can include coupling the filler, capper, labeller into one unit or adding a tray tiering unit to a wrapper. Each filling line has a defined maximum output for a given beverage and bottle size. This could range from 5000 to 120,000 containers/h. All lines in basic concept are similar in principle and the structure of a typical PET bottle compact filling line is shown schematically in Figure 9.2.

It is vital that not only the filling line but also the package being filled are fully considered within the design process. The package or its elements, be it the closure, decoration format or assembly into the shipper, are all designed to have minimum impact on the whole filling line as the components are brought together by the conveying system. The packaging technologist needs to have a good appreciation of the engineering of the filling line so as to understand the aspects which affect the conveying of the components though the line. The efficient transfer of a package from one machine to another, across dead plates, over slatted conveyors, round bends in the plant layout, is vital to maintain the smooth flow of the line to operate at its designed capacity.

9.3 Glass bottle filling lines

A typical glass production line is shown in Figure 9.3. The first operation is to unload the empty bottles or crates onto a conveyor. For very low speed operations this is still done manually, but as this activity is very labour intensive, most modern production lines do this automatically. Returnable glass bottles are packed in plastic crates, in 12s for 750 ml bottles and in 24s for small bottles, which have been stacked on the pallet to a pre-determined stacking pattern. The de-palletiser consists of a gripper head which is lowered over the layer on the pallet. This gripper head either grips the sides of the pallet stack tightly or interlocks into the holes of the crate. The layer is then removed completely from the pallet onto a table where each layer

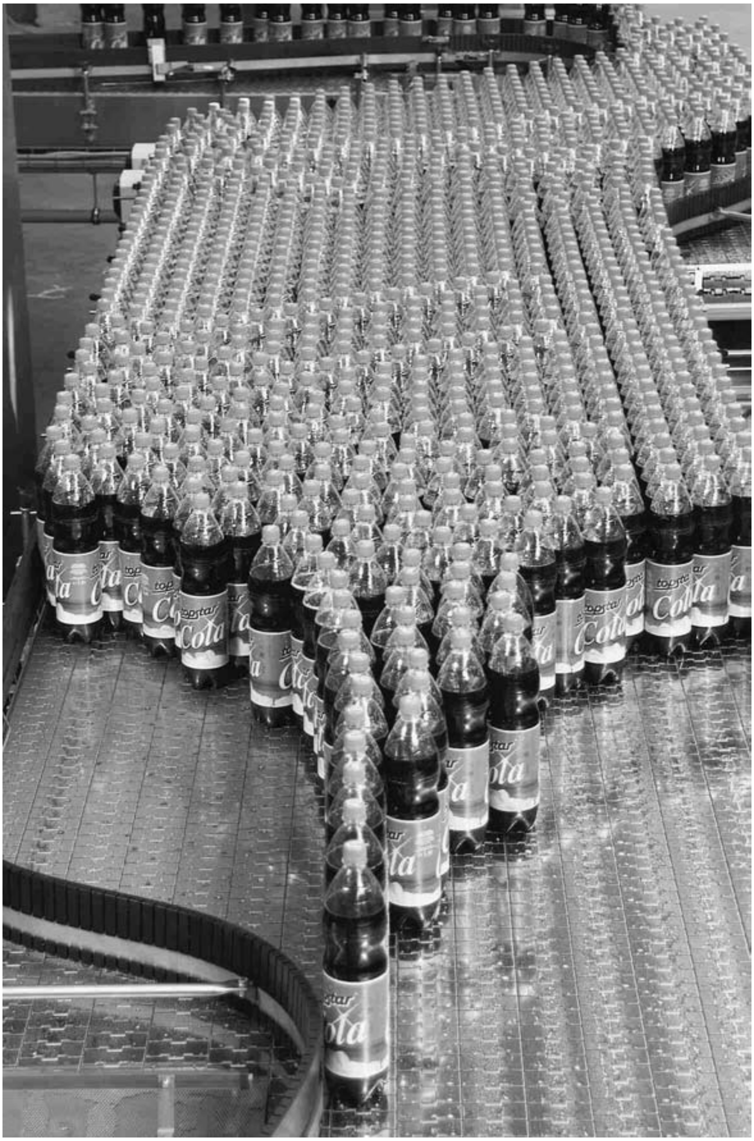
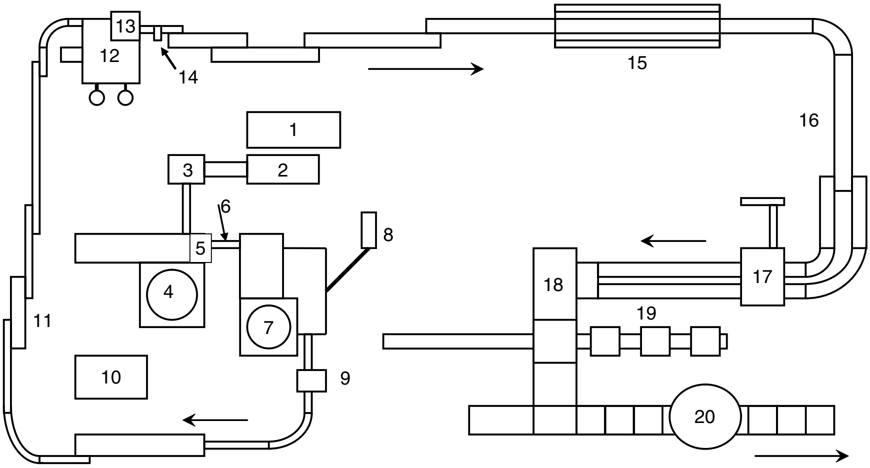


Figure 9.1 Accumulating conveyor designs (courtesy of Krones UK Ltd).

is then swept off onto the conveying system, the crates being brought into single file by this process. As crates are often arranged in a pattern at right angles to each other to effect a locking pattern on the pallet to aid pallet stability, it is necessary to turn those crates which are broad face on within the conveying system so that all crates are facing the correct way. Most crate systems are well established. Due to the number of crates within the population, and the fact that the use of returnable



1 Preform loading system
2 Preform feed unit
3 Preformcheck unit
4 Blow moulder
5 PET bottle inspector
6 Airveyor transfer to filler
7 Bottle filler and capper
8 Cap feed
9 Fill level detection unit
10 CIP system
11 Conveying system
12 Plastic labeller
13 Laser coder
14 Label inspector
15 Shrink wrapper
16 Pack conveyors
17 Handle applicator
18 Palletiser
19 Pallet conveyor
20 Stretch wrapper

Figure 9.2 Structure of a typical PET bottle compact filling line (courtesy of Krones UK Ltd).

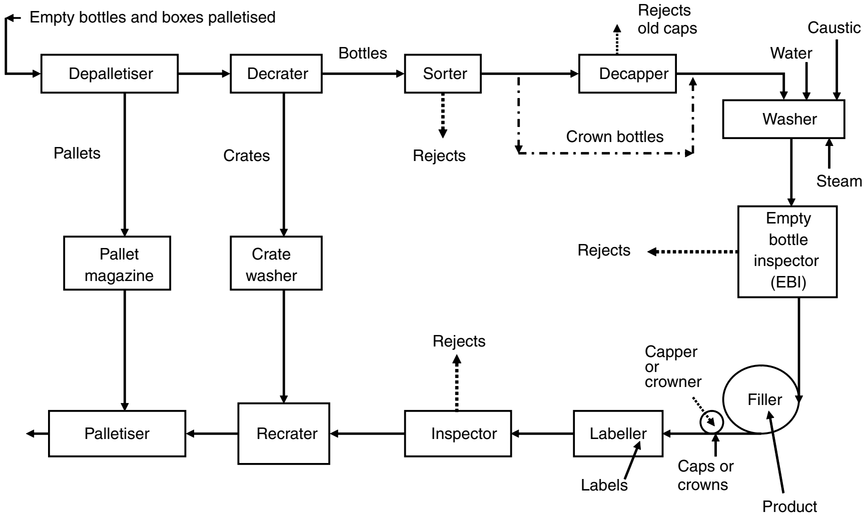


Figure 9.3 Typical returnable glass production line schematic.

glass bottles is declining, it is not often economically feasible to re-design and optimise the number of cases per pallet and to carry out lightweighting to minimise distribution costs or reduce the risk of bottle damage within the crates by keeping bottle movement in the crate pocket to a minimum.

For single trip containers these are mostly delivered to the bottler's factory palletised. The bottles are closely packed on pallets in layers with trays or layer pads between each layer. By this means bottle-to-bottle contact on the neck of the bottle is avoided and the weight of each layer is spread more evenly over the bottles thus minimising axial load problems. Two main types of de-palletiser are in use. These are the lift off and sweeper types. On the lift off de-palletiser, the layer of bottles is normally gripped by the neck over the whole layer. For example, if a layer of bottles on the pallet is in a 14 × 14 format, then 14 rows of grippers are lowered onto the bottles and activated, often pneumatically. The gripped bottles are then elevated and swung onto a discharge table where they are conveyed away to some type of bottle combiner, which brings bottles into single file or how many bottles wide the conveying system is designed to operate. The other, now more common, type of de-palletiser operates with a 'sweep off' action. The pallet is brought into position on an elevating platform. The platform elevates the pallet until the first layer of bottles is flush with the outfeed conveyor. The top layer pad is removed either manually or automatically and stacked in a pile. After this action, the row of bottles is swept off onto the outfeed conveyor. The next layer of bottles is then elevated into position until the pallet is fully emptied. At this point, the pallet is lowered and conveyed to an empty pallet stacker. Newer de-palletiser designs use robots for this purpose, as they are easily re-programmed for different application, and hence are a more flexible option in this era of constant development. A typical robot is shown in Figure 9.4.

The maximisation of the number of bottles per pallet involves carefully designing the bottle to suit, not only in terms of bottles per layer but also the number of layers. This will also depend on the size of pallet in use, whether the UK standard of 1200 mm × 1000 mm or the European standard of 1200 mm × 800 mm. Such considerations also include final packs sizes and standardisation of bottle diameters on filling lines to minimise change overs .

In the empty bottle sorting area, prior to bottle washing, it is normal to inspect the bottle to ensure that it is the bottle required and remove any other manufacturers' containers. From the combiner, bottles are fed to a bottle washer/rinser, which will simply rinse the bottles using treated water, rinse using ionised air, or in the case of returnable bottles, fully wash. For sensitive products, ozone treatment is often used. The aim of this process is to minimise microbiological contamination of the product to be packaged by the container, ensuring that no extraneous objects such as pieces of glass, etc. are present, and removing any old labels, ink jet coding and small particulates such as sand and dust. The washing process must relate to the purpose to which the bottle is to be put. For example, the risks associated with a low preservative content product in a glass bottle will be higher than those for a high preservative level product. It is not economical to over engineer a process when it is not required.

Figure 9.4 Robot palletiser.

After washing it is necessary to inspect bottles for soiling, chipped necks, residual liquid and foreign objects usually down to some 2.5 mm which is the optical limit of most bottle inspectors. Such bottle inspectors need to be tested every few hours to ensure that they can pick out clearly defined faults. These tests must be recorded as part of the due diligence requirement. It is possible to remove scuffed bottles, as excess scuffing of the bottle impairs its internal pressure resistance. However, as the bottle is overdesigned anyway, this is rarely done. The principles of empty bottle inspection are illustrated in Figure 9.5.

Consider the returnable glass bottle washer shown in Plate 9.1. These can be either single- or double-ended. Bottles are fed by conveyor en masse into the washer infeed, where they are channelled into rows and hence into the washer bottle pockets which are manufactured from either steel or plastic. Bottles are conveyed throughout the washer in these pockets which are attached to an endless chain. A typical

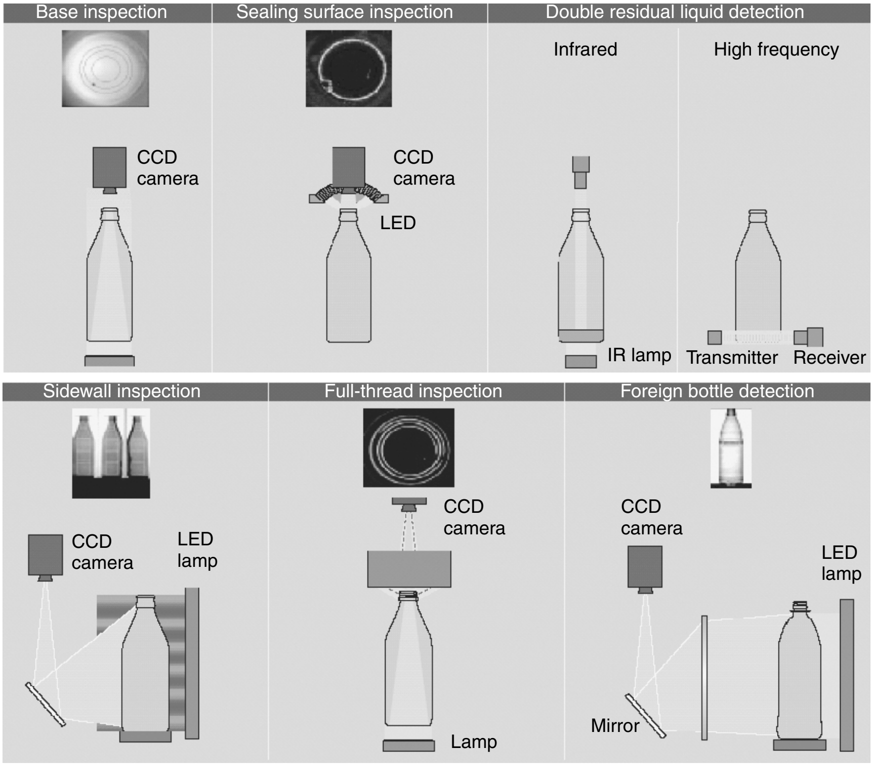


Figure 9.5 Empty bottle inspection principles.

treatment, where the carrier chains dip in and out of soak tanks, cycle allowing sufficient time to 'soak' in each part of the cycle, would be:

1. pre-warm the bottles to 30°C by rinse water,
2. empty the residue from the bottles,
3. pre-rinse using warm water at ca. 55°C,
4. invert the bottles to empty them,
5. immerse the bottles in a ca. 1.5% caustic solution at some 60°C,
6. rinse the bottles at some 60°C and then empty the caustic solution out,
7. repeat steps 5 and 6 at some 80°C,
8. rinse with warm water at some 60°C and invert the bottles to empty the contents,
9. rinse at some 50°C and empty the bottles,
10. repeat step 9 at 30°C and empty the bottles,
11. final rinse with clean treated water and empty the contents of the bottle.

When using glass, it is most important that the rate of temperature rise and fall of the bottle is well controlled so as not to introduce thermal stresses which could lead to bottle bursting. These are normally given as no more than an increase of

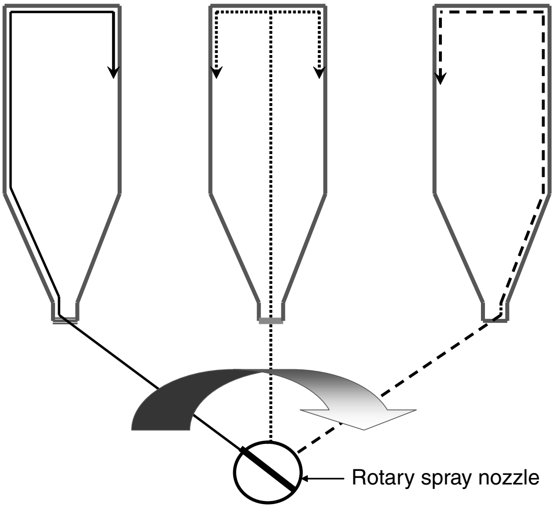


Figure 9.6 Bottle jetting action by rotating cross-flow spray nozzles.

42°C or a decrease of 28°C in any individual step. Within the washer old labels are removed during the soak operations and conveyed away from the machine to a compactor. Pumps circulate caustic lye, which assists the flushing of label material into the drum filters, thus minimising the build up of paper pulp in the soaking baths. A sluice system allows broken glass to be deposited into bins. Bottles are jet washed internally by rotating cross-flow spray nozzles, the bottles being self-centred in the pockets to maximise this jetting action within the bottle, as shown in Figure 9.6. The caustic lye is normally delivered by tanker and pumped to a storage tank, such that the caustic can be metered to the washer on demand.

Whilst the bottles are being washed, crates go through an ultrasonic case washer that removes any debris and attempts to keep the crates in reasonable condition. After the washer the bottles are fed by conveyor through an empty bottle inspector to the filler/capper. Closures are fed to the capper by pneumatic transport in a pipe and separation through a centrifugal separator or by belt conveyor to the capper hopper. The latter system is preferred as less damage to the cap is likely, especially to the tamper evident band. Often the patch labeller is monoblocked in this operation. In the filler it is important to thoroughly jet wash the bottle neck prior to capping to avoid syrup sticking. Failure to do so normally means closures that cannot be undone without applying higher torques than most people are capable of and the subsequent risk of an accident. After labelling, the bottles and crates meet up and the bottles are re-crated and subsequently palletised. Even though the returnable glass will remain within the operations of the bottling company, bar codes are normally attached to pallet lots to aid traceability.

For single-trip glass bottles, a rinser replaces the washer and packing is done either on a wraparound shrink wrapper or packed into a case prior to palletisation. All secondary packs are bar coded. With all glass handling care has to be taken to modulate the conveyors to minimise bottle-to-bottle contact and the risk of bottle damage. This will also reduce the noise level as keeping sound within any statutory limits is difficult without hampering the efficiency of the line by installing too much sound muffling equipment. Operatives need to wear safety glasses when working on a glass line due to the risk of flying glass should a bottle break.

9.4 Can filling lines

A typical canning line is shown in Figure 9.7. Cans are normally delivered on pallets, though for large users they are delivered on live bed trailers which hook up with the receiving factory pallet conveyor system. The other scenario is when the can making factory is sited next door and cans are delivered ‘through the wall’. Palletised cans are usually some 22 layers high. The incoming pallet has a bar code label with all the relevant information regarding its history attached. This is scanned into the factory system just prior to being de-palletised. Due to the height of the pallet stack, these de-palletisers are normally high level units. The pallet is conveyed to the lift station and then elevated into position. The top layer board is removed automatically and a layer of cans swept off onto an accumulating conveyor. The cans are then conveyed away and combined into single file on the transfer conveyor to the filler. Conveyors handling up to 1500 cans/min can be cable, plastic slat band or airveyor although in modern operations slat conveyors tend to be used. At faster speeds, airveyors predominate. Cable is mainly used at line speeds below

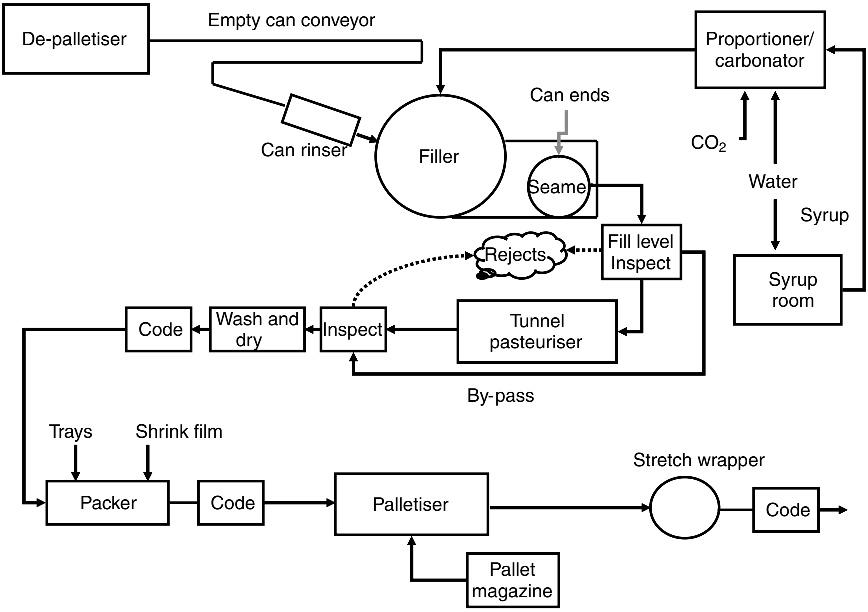


Figure 9.7 Typical can line.

1000 cans/min. Cans are then conveyed to a rinser placed on the down-chute to the filler. In this gravity rinser, normally at a decline of 30–40°, cans are internally sprayed with filtered water to remove any possible debris that may have collected in the can since manufacture. Sufficient length is required to ensure all the rinse water drains from the can. The excess water is normally filtered and recycled. The design of these units is specialised to ensure that efficient rinsing occurs without any can damage. Can damage has to be carefully considered, as the light weighting that has gone on over the last few years has made the side walls susceptible to denting. All conveyor systems must be designed to take this into account, this includes guide rails, minimal accumulation pressure and dead plate transfers between conveyors. The filler and seamer have been considered in Chapter 6. The carbonator is usually sited just behind the filler. Ends come in bags, each bag identifiable by a bar code, which are stored on pallets. Automatic end feeding units are available. Quite often the system uses a scissor lift to enable the operator to easily feed the ends into the seamer whilst attending to the main duty of operating the filler. After seaming, the cans are conveyed through a fill check unit, which often incorporates a valve check monitor. Any fill level problems are immediately highlighted, allowing remedial action to be taken. Often an accumulating conveyor is installed downstream giving up to 10 min buffer. Cans then go direct to the tunnel pasteuriser, as described in Chapter 4, or bypassing this, direct to coding. A further level check, to see if the pasteurising process has given rise to any leaking cans and packing may be implemented. Careful rinsing and air knife drying of the cans will minimise any problems associated with end corrosion. Finally, cans are palletised, often without a layer pad, and very often with no stretch wrap, and delivered to the warehouse. A quality control station is normally sited adjacent to the filler, where seam checks, as well as the normal product tests, are carried out.

9.5 PET bottle filling lines

Consideration of the optimum layout for a carbonated beverage PET bottle filling line includes the bottle sizes or a design for just one bottle size. Bottle diameter and how much accumulation should be built into the design also need to be incorporated.

The above list is by no means exhaustive, and a multiplicity of layout possibilities exists. A typical design is shown in Figure 9.2. Some modern designs, based primarily on one bottle size, operate with very little bottle accumulation. For the throughput required, they tend to be overspecified in terms of each machine output. The layout is very compact such that each person working on the line can see how each individual machine is operating and, if necessary, can quickly intervene if a problem arises. Other designs are more conventional. They include significant accumulation between the filler and labeller, labeller and packer and between the packer and the palletiser. Where PET bottles are blow moulded directly onto the filling line, the latest philosophy is to buffer the bottles between units. For small bottles up to 500 ml capacity, this is primarily done with empty bottle silos holding several hours production, whilst for large bottles they are either buffered on line with a bottle accumulator of order 10 min capacity or the bottles are palletised and then de-palletised onto the filling line. Buffering on an airveyor can only be considered for short time filler stoppages up to a few minutes at most. Whilst a filler can start virtually instantaneously after a stoppage, a blow moulder has to first reach its operating temperature, even though during a stoppage it may only go back to half heat conditions to allow for more efficient re-starts. Any stoppage of the blow moulder will inevitably cause preform and bottle losses. As this machine is probably one of the most efficient on any bottling line, it should not be stopped unless essential. It should be considered the lead machine for the line.

In the early days of stretch blow moulding, blow moulder and filler were rarely directly coupled, primarily due to the infancy of airveyors, which regularly jammed, and the fact that the blow moulder rarely ran as fast as the filler. Often this jamming was caused by electrostatic effects. During the early 1980s, filling lines had the blow moulder feeding either a silo or a palletiser. The blow moulder would run 24 h/day, 7 days/week at some 4000 bottles/h. The filling line would, on 2 l bottles, run at 8000 bottles/day on two shifts. The overall efficiency of blow moulding would be some 90% against 60% for the filling line in total. As the output of blow moulders increased, filling lines tended to have the blow moulder directly coupled using an airveyor to provide minimal buffer. It is not feasible to feed both a silo and a filling line, as bottles tend to shrink during storage. New and older bottles will have differing fill levels, a situation often not appreciated by marketing departments who evaluate consumer reactions.

Silos are designed to minimise the risk of bottles being crushed; they should allow a good distribution of bottles within the silo with almost complete emptying being possible. Silos employ catch nets within to lessen bottle damage. Such a silo design allows blow moulding to take place 24 h/day if required to keep a two shift filling line operation fully operational. Any change of bottle size or preform colour will not affect filler downtime as that will run off the silo whilst the blow moulder produces the new bottle to another silo. From a silo, bottles are fed to an unscrambler which produces an outfeed of bottles in single file to an airveyor. As the risk of bottle contamination within the silo exists, all bottles need to be rinsed prior to filling although silo sites must be kept as clean as possible to minimise such contamination.

Bottle rinsers, often mono-blocked to the filler/capper, are normally rotary machines that inject filtered water into the bottles in a prescribed manner to ensure good rinsing of all the bottle internal surfaces. Bottles are usually fed to the rinser by airveyor supported on their neck rings. They are transferred to the infeed worm and starwheel of the rinser with the neck gripped and held by this throughout the whole rinsing operation. The bottles are rotated into a vertical upturned position and rinsed, with pre-set cycle time for jetting with a cleaning agent, followed by sterile water jetting and draining. The timing of these can be made variable, depending on the speed of the line and the contact times required. These units have a clean-in-place facility using dummy bottles.

After filling and bottle drying, the bottles are labelled. It is necessary to ensure that the bottles are rigid during labelling in that the headspace pressure has equilibrated with the product carbonation volumes. On mono-blocked units, a bottle ‘knocker’ is sometimes used for this purpose. The labels used are primarily plastic, as this allows for bottle creep with the small amount of give in the plastic that paper does not have. The packaging end of the line after labelling is increasingly becoming more automated. A wraparound shrink wrapper using film only, film and pad or film and tray is usually included in the line. For small bottles, a multi-pack shrink wrapper is often installed prior to this. Such operations are discussed more fully in Chapter 6. As the multi-packer is not used all the time, it is necessary to have divert systems installed in the conveyor system, as probably for a good percentage of the time it will not be used. For larger bottles 2 × 2-l and 3 × 2-l sleeved multi-packs with handles can now be produced automatically on line using sleeving units. Again these are only used for a small percentage of any lines output and must be on divert. The use of display pallets by the multiples for major brands, using half pallet dollies, has also been automated often using robotics. Such a packing operation would be as a bleed off from the main palletiser, which is often also a robot superseding the more traditional palletisers. Following palletisation, the pallet lots are then stretch wrapped and delivered either by conveyor, automated guidance vehicle (AGV) or fork lift truck (FLT) to the warehouse. During this process, the bottle will have been coded, as will the pack and the pallet. This gives full traceability throughout the supply chain. A degree of buffering between the packaging operations is required. Run out space after a shrink wrapper is needed to ensure that no packs back up into the heat tunnel and consequently ‘cook’. Easy divert systems are needed depending on whether a multi-pack option is chosen. Often pack conveyors elevate and then descend to allow personnel ingress into the area. One of the problems with the increase in multi-pack options is the space taken by these machines and associated conveyors. In many installations insufficient space has been allocated for such possible plant when the line was originally laid out resulting in rather tight operating conditions and subsequent loss of efficiency.

Bottle design needs to be compatible with good filling and it needs to be optimised in terms of bottles per case on a pallet without overhang or underhang. Computer programmes are available that determine optimum pallet patterns for a given traded unit and bottle size. The shape of the bottle can affect filling performance. Any discontinuity in the bottle can cause turbulence and fobbing during filling. The packaging technologist, preform supplier, blow moulder supplier and the engineering manager need to work closely together to realise an optimum solution.

9.6 Conveying systems

The four main types of conveyors used within the soft drinks industry are airveyors, slat, pack and pallet conveyors. They are inverter controlled to suit the conditions that may occur and can ramp up and down to suit on a fully programmable logic controller (plc) controlled line.

Airveyors have developed significantly since they first came into being some 30 years ago. The systems rely on conveying a bottle on its neck ring. The problem is they can jack knife and lock in position. Problems can also occur due to the electrostatic forces present in the PET. This was apparent in the early systems where water jets played on the bottles. With the improved PCO neck finish and the latest designs of neck guides on the airveyors, this is largely overcome. Airveyors convey bottles that are neck supported, by applying low pressure, high volume air jets to provide the driving force to convey them, as shown in Plate 9.2. The air pressure is generated by small centrifugal fans which blow air into a rectangular duct that have louvres punched into the top and side faces. Due to the transport method such systems have great design flexibility. The layout allows for the bottles to be conveyed above personnel level to provide good access and increased production space. Vertical elevation and decline units are available. As most bottles now use the 28 mm PCO neck finish, there is rarely a need to change this feature of the conveyor. However, the plastic neck ring support guides can be manually or automatically adjusted to suit a variety of bottle neck diameters if so desired. Lanes can be combined and split by gate arrangements. Similarly the bottle body guide rails, which have low friction guide material, can be either manually or automatically adjusted to suit different diameters and shapes. A degree of accumulation can be achieved using airveyors, as queuing pressures are low. This is enhanced due to the high velocities that can be achieved on airveyors, any gaps that occur being easily filled. Air filtration on the infeed to the plenum chamber of the airveyor ensures minimal problems due to air contamination affecting the bottles. Dust in the neck of a bottle will promote product fobbing during filling. The whole system allows controlled line pressure at all times causing no discernable bottle damage. Aseptic designs have now been developed which include air filtration to 0.3 μm, CIP interfacing and full conveyor covers.

The choice of slat type varies with application. For glass bottles it is normal to use steel slat whereas for the softer material of PET containers, plastic slat is used. A variety of suppliers have a multiplicity of options available. The key to success is to ensure that the conveyors are well designed and that the belt is always controlled. Slat lube in moderation is a necessity. Before packing to cardboard trays or pads, it is always necessary to wash the lubricant from PET bottles to minimise the risk of stress cracking, which is enhanced by the presence of solidified lubricant that is reactivated in a humid environment. If the floor area is correctly designed, drainage drip trays to collect excess lubricant are probably not needed. Dry slat lube is sometimes used, whilst slat manufacturers claim that certain plastic belts are suitable for lubricant-free conveying. Care must be taken with the use of dry slat lube as any that falls on the floor will make this area very slippery and a possible danger area for operatives. This can only be ascertained by trials and tests with the manufacturers concerned. The type of slat to be used needs to be proven before use. So many designs exist for different applications. For bends magnetic slat band are often used. Often a plant is provided with a central lubrication system that is pumped around the factory with nozzles fitted to each conveyor section. Due to the lubricant, the design of the conveyors needs to allow ease of cleaning. In older designs mould growth was often seen. The more open modern designs overcome this. However, it is important to clean conveyors internally as part of the regular factory schedule. The automatic rejection of fallen bottles is included in most system designs, either by putting guide rails above the bottle diameter or using angled conveyors and gravity.

The actual design of a bottle conveyor buffer falls into three basic categories. Accumulation exists on a conveyor belt which should normally only run some 50% full. Alternatively, the buffer can be designed where the containers are fed onto a conveyor at right angles to the flow. To outfeed containers back onto the conveying system, the conveying direction is reversed. The other type is to utilise part of the conveying system that only fills up as accumulation when the containers back into it. Each system has its own pros and cons. Often the table consists of several belts all individually controlled by an inverter, such that they can run at differing speeds and so minimise any accumulation pressure that normally builds up in such systems.

Tray conveyors ideally use a slat rather than a roller bed as less vibration which could affect pack stability is imparted to the pack. Some systems still use belt conveyors, which though good with regard to pack stability do not give much accumulation unless sections are designed with very short lengths when dead plate transfers may cause problems. Shrink wrap packs need to be kept tight, and vibration can easily loosen these leaving skewed packs which will cause problems in the palletiser as well as through the distribution chain. Whilst such conveyors do not offer the buffering capability of rollers integrity of the secondary packaging is of prime consideration. However, small roller slat is now available which gives the best of both worlds. When a conveyor section becomes full due to an upstream stoppage, this will stop when the packs build back to the sensor. This is completed throughout the system until eventually the filler will have to stop. The amount of required accumulation is normally in the region of 5 min, this being dependent on the palletiser breakdown characteristics. The palletiser must be capable of ramping up to clear any accumulated packs in the system, thereby leaving space for future buffering.

Pallet conveyors need to allow accumulation and are often designed with slipping rollers or in short sections that transfer the pallet from section to section. Soft start is a necessary requirement as otherwise the stretch wrap around the pallet will loosen giving rise to possible pallet collapse on those palletised loads that are not well interlocked.

9.7 Inspection systems

Within the EU, all packages must be marked with the weight or volume of the contents. In the UK, they must conform to the three rules contained within the Weights and Measures Act 1985 and secondary legislation including the Weights and Measures (Packaged Goods) Regulations 1986. These are currently being reviewed. Conformance to these regulations, denoted by an ‘e’ mark on the label,

Table 9.1 Tolerable negative errors.

Quantity (g or ml)	TNE (%)	TNE (g or ml)
0–50	9	–
50–100	–	4.5
100–200	4.5	–
200–300	–	9
300–500	3	–
500–1000	–	15
1000–10000	1.5	–

Note: As laid down in section 2.4 of Directives 76/211/EEC and 75/106/EEC.

is as required by EU directive 71/316/EEC. The three rules are:

1. The contents of the packages must not be less on average than the nominal quantity as marked on the label.
2. Not more than 1 package in 40 may contain less than the nominal quantities, by more than an amount known as the tolerable negative error. This varies according to the quantity stated on the package.
3. No packages are allowed to contain less than the nominal quantity by more than twice the tolerable negative error.

The tolerable negative errors (TNE) for packages are listed in Table 9.1. It is clear that sometimes the consumer will be getting less than what is stated on the package, whilst at other times they will get more. From this it is important to have measuring equipment on line that is much more accurate than the regulations for the tolerable negative errors. The rule of thumb is that they should be accurate to at least 20% of the TNE. It is also important that the characteristics of the filler for each pack size and product is known so that the performance can be optimised and the best commercial situation exploited within the legislation.

Fill level control just after filling is an obvious on line requirement. Most installations have the inspector placed just after the filler/capper for cans, glass and PET bottles. Due to bottle creep, the fill level accuracy will not be as great for PET bottles as for glass bottles. However, modern fill level detectors do work to very precise limits and for PET bottles give readings on which remedial action can be taken. Image processing systems have improved greatly over the years both in terms of camera technology and computation. Image processing implies that sufficient time exists for each image to be carefully analysed to ensure that a fault is detected and not recorded as an allowable manufacturing tolerance. Due to the improvements in this area, the producer has to continually evaluate the needs for improved inspection equipment and whether it is commercially justifiable. The level after filling is normally measured by either gamma ray, infrared or X-radiation. These units also have a ‘cocked’ cap detector. Label checking, for no label or poorly applied labels, is carried out using a similar unit, which can even detect whether the date code is present as well as reading bar codes for legibility. It is also important to ensure that the correct number of bottles is packed into a case, which can be done by photocells. For fill level control, up to six cameras and other sensors such as infrared, X-ray or radiometric detection can be integrated into the system. Such units can also monitor individual filling valve performance. Can fill levels are traditionally inspected using gamma ray technology. These provide very accurate readings but have the downside of requiring radiological protection. X-ray units are being introduced which go some way to alleviate this problem.

For a returnable glass line, great care must be taken to ensure no risk to the consumer. The returned crates can be inspected for the number of bottles per case, foreign bottles and bottles on their side, the latter causing problems at the de-crater. Such systems use real-time image processing with a CCD camera based on incidental and transmitted light and ultrasound measurement to evaluate the height profile. New glass is supplied under an agreed technical specification that is regularly reviewed and the suppliers audited. Returned glass has to be thoroughly washed and then inspected using an empty bottle inspector as illustrated in Figure 9.5. Due to the associated possible risks, such a machine must be of a modern specification and regularly maintained. Such machines use CCD cameras to detect chipped necks, foreign bodies within the bottle, foreign bottles and, a double check with both infrared and high frequency, for any residual liquid within the base of the bottle. These view internally through the neck of the bottle, with a separate unit being used to inspect the bottle for external faults.

Camera systems exist to check filled glass bottles for fragments as small as 0.5 mm × 0.5 mm × 0.5 mm even in coloured bottles. Preforms can be checked prior to use when blow moulding on line. Filled PET bottles can be checked for leaks using a system that guides the containers by a belt drive that exerts a precisely measured pressure. If there is a leak in the bottle, gas escapes from the headspace and the fill level in the bottle rises. If the bottle is leakproof, the fill level remains almost the same because the gas is only slightly compressed. Even the smallest leakage in a plastic container can be detected by comparative fill level measurements. It is not always the bottle that leaks as this is often associated with a capping problem. Such a system can, if several bottles leak, highlight quick remedial action before the problem gets out of control. Filled bottle inspection can now achieve detection down to particle sizes of 0.5 mm × 0.5 mm × 0.5 mm, which is important for glass bottle filling where the possibility of small glass fragments will always exist within the filled product. This is achieved through the use of high resolution cameras viewing through the bottle base, strategically placed lighting and modern image processing technology.

Working with systems such as Six Sigma, the number of defects can be analysed and minimised, with the ultimate objective being zero defects.

9.8 Breakdown characteristics

If the filler never stops, maximum output is achieved from a given line. The breakdown characteristics of a production line determine how well it will perform. Major

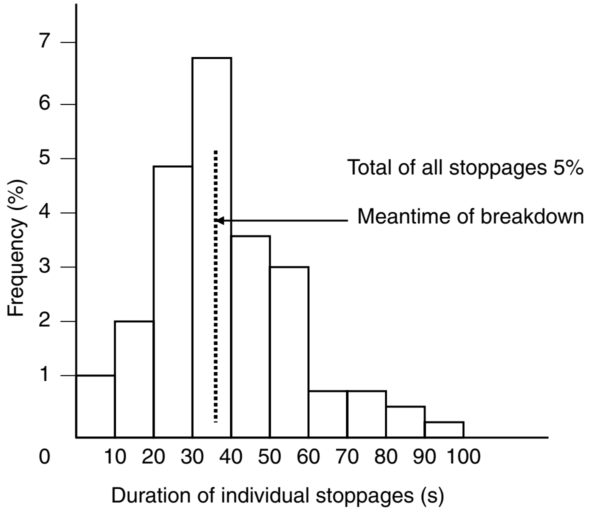


Figure 9.8 Typical labelling breakdown profile.

breakdowns are rarely of interest as these occur infrequently and no amount of buffering would resolve this issue. If major breakdowns occur regularly on a filling line, then the problem must be resolved by detailed study of the machine causing the problems and then acting on these results. It is the short duration breakdowns that are the norm. A typical machine breakdown profile for a labeller is shown in Figure 9.8. A new line, or even if an old line is to be revamped, should be rated as per Figure 9.9 with the filler rated at 100%, and the minimum percentage rating figures given for each plant item. For products and packaging that are difficult to handle, filling line equipment that is not as reliable as one would like due to age and condition, or for complex or new technology where the risk of short duration breakdowns are likely, higher ratings should be used. The design should be put through a simulation programme such as Simple ++ (now Technomatix eM), Automod, Arena, Modsim, Taylor II or Witness. These programmes require data on the short-term breakdown characteristics of each item of plant on the line. Such data is obtained from either the experience of the machine supplier or from monitoring the actual frequency of in plant breakdowns. This is ideally done by management information systems which build up a history of breakdowns on each machine or by attaching a data logger to the PLC on the machine. Otherwise the information has to be gleaned from painstakingly recording all breakdowns manually, a method that, by its very nature, is inaccurate as it is dependent on writing down each and every machine fault with the cause. Experience shows that the data so obtained may be of little value as recording every stoppage of a few seconds is acceptable for a few minutes but very tedious after an hour. Such data has to be collected automatically and suitably recorded and analysed. By feeding this data into a simulation programme, the effect of buffer capacity between machines can then be obtained.

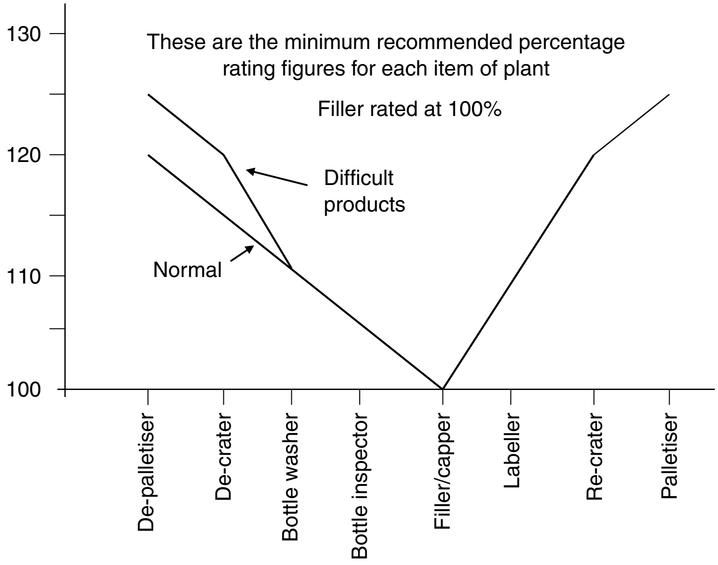


Figure 9.9 Typical line rating for a returnable glass bottle line.

Such simulation programmes can also be applied to an installed line to upgrade performance on an ongoing basis. This does not preclude resolving problems, which are often packaging orientated, as they occur. The interface between a machine and the packaging used on it is often the reason for poor production performance.

Considering the hypothetical breakdown frequency distribution for a labeller as shown in Figure 9.8, it can be seen that this machine has a fault for 5% of its operating time with a mean time of breakdown of 35 s and a mean time between breakdowns of 3 min. The labeller runs 10% faster than the filler/capper. Due to the very nature of a labeller, the effect of packaging materials on the performance is quite marked. Bottles could be wet due to a problem with the bottle drier, the labels could curl due to the high humidity prevailing or high temperature might cause more bottle creep than normal. These, as well as purely machine problems, must be taken into account when designing the accumulator. However good the operators, the cleanliness of a machine cannot always be guaranteed. This is especially true on a labeller, where fallen off labels, glue and sticky brushes are common problems which interface directly with the operator. In our example, it is decided that a 5-min buffer will be used. This is more than the data shows is required, but builds in a factor of safety as well as catering for the mean time between breakdowns and for the line that is normally operating with an empty buffer to be returned to this state. Whereas too much buffer capacity will cause few problems, insufficient buffer capacity will inevitably lower the performance of a filling line. This has to be offset against the argument that too much distance between machines, due to masses of accumulation on a line, makes it more difficult to operate. However, the design of an accumulator and associated conveyor layout can take this into account to ensure

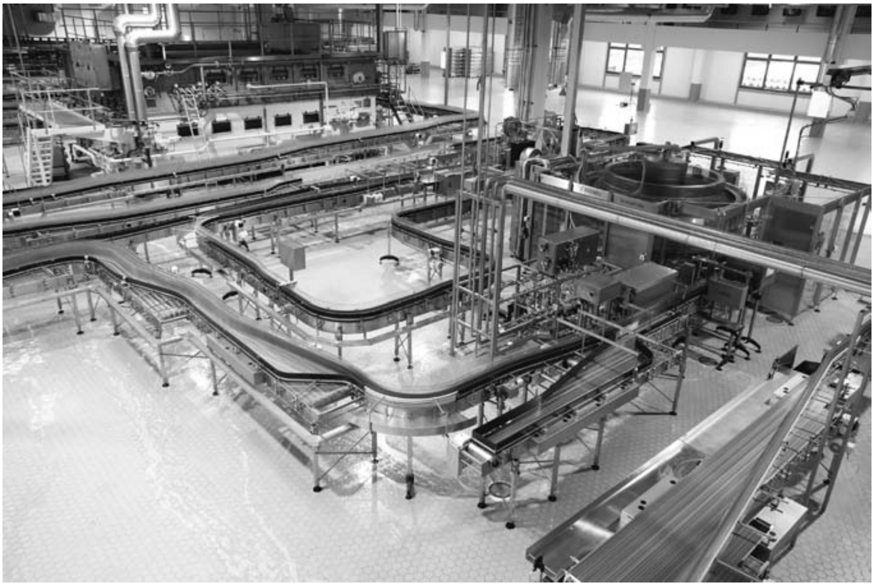


Figure 9.10 Typical conveyor configuration.

that a line is more compact than at first seems possible by looping the line back and forth as illustrated in Figure 9.10. Accessibility without resource to steps over conveyors needs to be considered at all times. There is nothing more frustrating than an operator unable to access a machine breakdown due to not being able to easily get over a conveyor. Good design in the first place would have resolved this problem. Often it is necessary for the designer to think three dimensionally and envisage the situation so as to come up with an ideal solution. The use of a three-dimensional computer aided design (CAD) system helps in this respect.

9.9 Line control and management systems

Most lines are now PLC controlled, though the tendency appears to be moving towards more PC control. The latter is simpler to programme than conventional plcs. They use sensors to feed information into a central controller which ensures that the line stays in balance at all times. If the labeller stops then the container infeed will build back towards the filler. When a sensor notes that the bottles are backing up at a certain point, this slows the filler down whilst a sensor further upstream will stop the filler. They allow ramp up and ramp down of conveyors and machines to suit circumstances, all these being pre-programmed into the plc. The logic required to control a modern day filling line is well known to most software houses that deal with this industry. Each machine has its own control system which is interfaced with the line control system. In this way the lines' 'intelligence' is distributed amongst the individual machines and conveyor sections. The fine adjustments required to balance the ‘slave’ machines to the prime machine, either the filler or the blow moulder, need to be done through the control system. The system calculates the movement of bottles relative to the filler taking into account the line accumulation and adjusts the speed of the individual machine to suit. This allows the filler to run at the highest speed it is capable of for the particular bottle and product. Counters fitted throughout the line monitor conditions, as do line sensors when back up conditions prevail. Closed loop control also applies to individual machines, which receive signals from line sensors.

A typical control hierarchy is shown in Figure 9.11. The components of a factory management system normal fall into the three levels of control system, supervisory control and a management information system (MIS). Integration at the control system level involves the transfer of information between equipment and conveyors to effect efficient and reliable operation for process co-ordination, material handling and activity synchronisation. It also provides the interface to the higher level systems. Present day operations tend to use bus systems to provide communication; these are quick to install and provide fast transfer rates. The supervisory control level acts as an intermediate processing stage for control information transferred from the MIS level to the control level and vice versa. As an example, production orders received from an MRP system may be processed to the supervisory control level to allocate specific factory resources to each production schedule. The supervisory control system may also monitor and record production information on a real-time basis, transferring summary information back to higher level systems at the completion of a specific order. This system also integrates operatives and production management with other control systems in the process. Computer-based interfaces are used to monitor the system and fine tune process parameters, such as ramping up or down an individual machine to optimise line output, and issue management instructions during the production process. Typical functions performed include process monitoring and supervisory control, real-time schedule feedback, real-time product tracking, operator reports, resource planning, detailed scheduling and control, production instructions, set up details, quality systems and recipe management. SCADA (supervisory control and data acquisition) is the most common form of supervisory control system. The operator interfaces in such systems are diagrammatic representations of the process. These are updated using real-time information from the control system level. Colour and animations are often used to ensure that the user comprehends the current process status. In most production halls LED displays give the current production rate against plan. Sometimes these are represented as overall effective efficiency (OEE) or some such similar measure, so that everyone is aware of the current status and is involved. Often the maintenance manual for a machine can be pulled up on screen on the factory floor, as well as the spare parts listings, often with blown up drawings, planned maintenance and lubrication schedules. Modem links are provided to the machine supplier, which is especially useful when dealing with complex control systems. This allows software problems to be dealt with by the originator, often in another country. Spare parts and other service information are also available by such links.

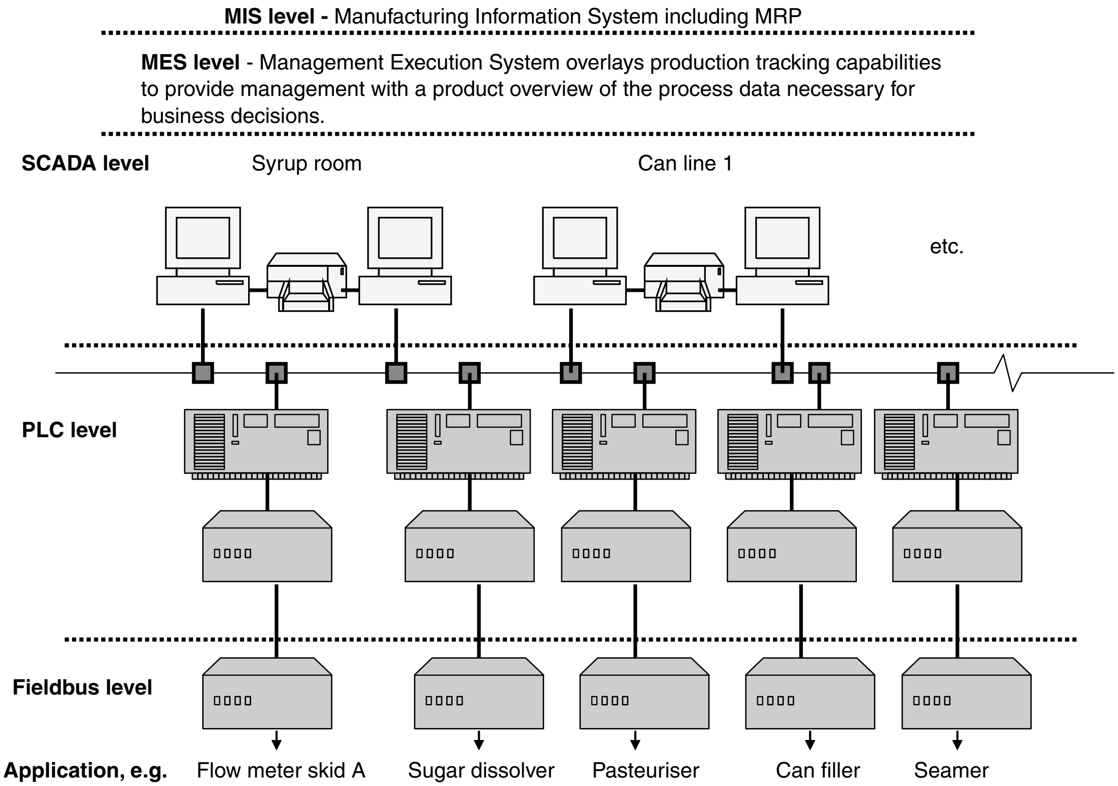


Figure 9.11 Typical control hierarchy.

The two systems so far discussed can then integrate with the MIS level of a company. The objective of this is to allow operating decisions to be made and implemented in real time on the basis of accurate, up to date information. The development and integration of such systems is beyond the scope of this book. The integration at the MIS level will involve computer services personnel skilled in this area.

These systems can be very useful in determining the reliability of individual processes. Breakdown data can be generated which will help in re-designing parts of a production line that can be identified as problem areas. The use of such data fed into simulation programmes will highlight where small improvements can be made. This will lead to an improved OEE.

One important lesson in all this is not to overcomplicate systems. Too much information can blind most people to the actual picture. It is also wise to use well-proven systems rather than develop ones based on paper systems that the company has always used. These inevitably lead to failure. A clearly defined brief is required to define what is actually required. It is important to have a good working relationship among head office management, factory management and the IT professionals to ensure that all understand this brief fully.

9.10 Complete factory layouts

The individual components of a filling line have been considered in this chapter and elsewhere in this book. It is now necessary to pull all these together. If we consider the schematic factory layout shown in Figure 9.12, it can be seen how it all comes together. The layout must conform to industry standard good manufacturing guidelines. It is necessary to have a logical flow for raw materials, packaging materials, through the various processes to finished goods, the warehouse and despatch. Personnel movements are key to this, as are peripheral requirements such as washrooms, rest rooms, canteen, offices, transport parking and roadways, staff car parking and site security. Environmental aspects need to be carefully considered, as does current and proposed future legislation. This is clearly an idealised state that is only possible with a green field site. Hygiene considerations play an important part in layout development. This includes how waste is handled through the plant and is taken off site. As discussed by Lea (2004), it is necessary, for an aseptic facility, to control each of the operations to minimise the risk of cross-contamination. However, for carbonated beverages this is too elaborate and expensive. Such aseptic processing needs to be done in a separate facility built specifically for the purpose. Existing plants have usually evolved such that it is often difficult to expand unless certain compromises are taken. It may be necessary to demolish old buildings and erect new ones more suitable to the modern day food factory environment. Often warehousing is totally inadequate, with no space existing for future expansion, for example, into aseptic filling.

In the development of any site, room for possible expansion is necessary. There is a limit to how cramped production lines can be before line efficiencies will

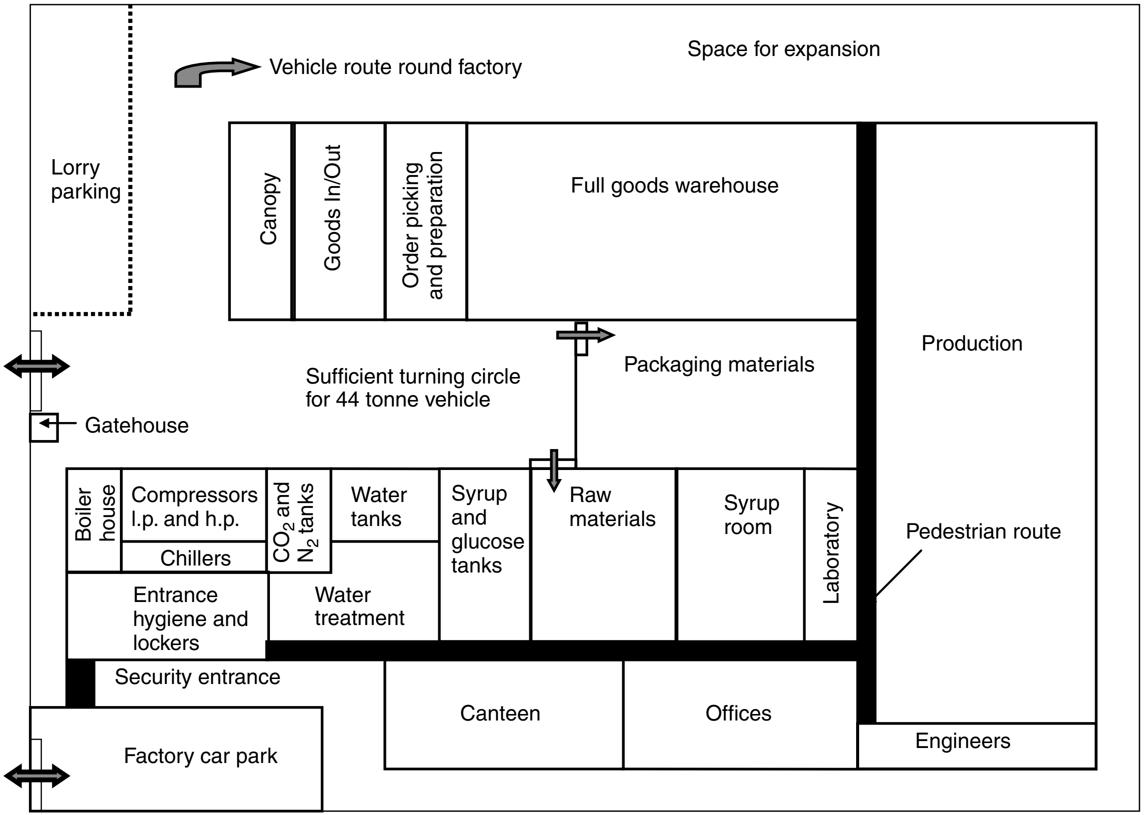


Figure 9.12 Schematic of a factory layout.

drop. If it is difficult to access raw and packaging materials to a specific plant, and the operators have problems running the plant due to similar access problems, the only solution is to expand the facility. As an example this problem has arisen in the last few years with the advent of more and more multi-packing options.

Staff need to enter the premises from the car park through a security gate and then proceed to the factory entrance where lockers for changing and wash stations are sited. Only after they have changed and washed can they proceed to the plant. Designated walkways are required through the factory, especially when AGVs and FLT movements occur. Canteen facilities should be sited adjacent to the entrance, as in this way the deliveries do not affect the factory operation. Raw materials and essences should be delivered to a small store adjacent to the syrup room, so that they can be easily accessed through an airlock. Packaging materials, which tend to take up space, should be sited adjacent to the finished goods warehouse and also to the production lines. Empty cans are normally stored in their own area adjacent to the can lines, as delivery is normally on the day of use. Ends are stored in the same facility. For a PET facility, blow moulders can operate in the same area as the production lines, in fact some are close coupled to the fillers. Where silo storage of small bottles are used, these should ideally be in a separate room that is kept as dust free as possible to prevent bottle contamination. Glass lines should be kept well away from can and PET filling lines to reduce the risk of cross-contamination by broken glass. Ideally they should be sited in a separate room. Personnel movement areas should be designated and clearly signed to minimise any possible cross-contamination problems.

Services should be sited external to the factory. These include low- and high-pressure compressors, water chilling, water treatment and water storage, carbon dioxide and nitrogen storage vessels. Factory offices should have a view over the production facility. A walkway round the inside of the factory is good for visitors and PR. Quality control facilities should be provided adjacent to the production lines in specially designed rooms, which are visible to operating staff. No food or drink facilities should be provided in production areas. Small areas for refreshment should be sited around the factory with vending machines in separate but highly visible areas. The engineers' workshop and stores should be sited in an enclosed area adjacent to the production lines as well as the services. This too should be open to view from the production hall.

Warehousing will probably be high bay using cranes. This should be sited at the end of the production lines with material flow towards the order picking and despatch area. An entrance for heavy goods vehicles (HGVs) should be provided, which ideally is separate to the staff and visitors entrance to minimise any safety risk. This improves safety and security. Sufficient space for lorry parking is required.

The whole site must have room for expansion. Such an eventuality should be built into the site plans such that additional bays for production and warehousing can be added if required, as well as increases in service requirements. Roadways should also be designed with this in mind.

9.11 Buildings

As the requirement for higher hygiene standards grows, the need to improve the state of the buildings in which the products are manufactured has to improve. Nowadays it is not good enough to have holes in concrete floors that have been eaten away by the aggressive nature of sugar. Such areas can be potential microbial hazard areas giving rise to such problems as *Zygosaccharomyces bailii,* a key spoilage organism resistant to preservatives. It is good practice to use architects and engineers who work in the food industry and come with a recommendation. They will be used to working with food quality materials and be able to design, cost and manage the installation on behalf of the client. Ideally they should be evaluated based on their past work and by talking to their clients.

Having agreed the line layouts and the overall factory layout, it is necessary to agree the fabric for each area. Areas which require filtered air, if any, must be listed and whether positive air pressure environments will be required if dealing with sensitive products. The specification of the drainage system is key to ensure that there is no hold up of effluent anywhere in the system that can possibly lead to microbial growth. Floors need to be adequately drained, with falls so designed to ensure that liquids flow towards the drainage channels. No standing pools of water can be allowed. Where possible drains should be constructed in stainless steel, with removable grids for ease of cleaning and should be half round in section. The apertures of such drains need to be small enough to prevent the ingress of large debris without restricting flow. If high-risk areas have been highlighted, then drainage flow should be from high- to low-risk areas. Plant items should not be placed directly on top of drain covers, nor should they be placed next to walls. A distance of 80 cm is recommended to allow personnel access and to aid cleaning. Debris traps should be incorporated in the drainage system that can be easily accessed. Drainage at entry and exit of a building must be pest proof. Floors must be properly constructed of a non-absorbent material such as tiles or food grade epoxy coverings that have no pitting, cracks and open joints. Any expansion joint needs to be carefully designed, as does the finish between the drains and the floor. These materials must withstand the products being used, as well as the cleaning chemicals, without breaking up. The surface must be non-slip and safe to walk on when wet, dry or greasy. All floors should be coved to the walls. The design of the floor must take into account the loads to be placed on them. Where plant vibrates, it needs to be mounted on a specially designed plinth that is easily cleanable. An example is the high-pressure compressors required for blow moulding. Adequate space under the plant is required to facilitate cleaning.

Interior walls must be finished with a hygienic, easy to clean continuously bonded surface. Corners and joints must be sealed with a food grade impervious sealant. Any pipes or services going through walls should be mounted in suitable fittings and sealed against vermin ingress. If these services are subject to expansion or contraction such as for steam pipes, then suitable expansion fittings should be used. No horizontal surfaces must be used as these are not self-draining and could harbour contaminants. If notices have to be used, then these should be glued rather than nailed to the wall. Suitable hygienic protection to walls must be provided in FLT areas where possible damage could occur. Such protection is best done in tubular stainless steel. All external doors should be of food quality. This can pose a problem with fire doors. Automatic rapid roll doors are ideal for vehicular traffic. The ingress of birds and insects is a problem that must be addressed, even if a stuffed owl is used. Self-closing doors are ideal. For entry to sensitive areas such as the syrup room, security locking systems should be used that log the persons using them thereby restricting access to relevant personnel only.

Windows, if installed, should be fully sealed to prevent vermin ingress. No glass is allowable; they should be constructed of a polycarbonate type material. Any window sills or ledges must be sloping and easily cleanable. They must not be suitable for placing objects on them.

Adequate wash facilities are required at the entrance to all key production areas, such areas being so designed that personnel are guided to the hand wash facilities. These facilities need to be trapped and plumbed directly to the drain. In a carbonated beverage factory, the risk from dirty footwear is slight, though in an aseptic processing area, foot wash facilities are required.

All frameworks should be tubular to minimise the accumulation of debris and to ease cleaning. This will also reduce the risk of infestation by moulds, ants, etc. All main building steelwork should be covered with a false ceiling, especially where traditional girders rather than tubular is used. Many soft drinks factories actually use this space to site services such as pipework, electrics and air conditioners. Wood or glass is not allowed in the construction of food factories. Any painted surfaces, where they are unavoidable, must be finished in a non-flaking paint suitable for food area use. Any service pipework from this ceiling area should be kept in stainless tubing and be installed vertically to maximise cleaning effectiveness.

Good lighting levels are required throughout production. Modern fluorescent lights are now energy efficient and should be installed with plastic diffusers flush mounted into the false ceiling. In inspection areas, natural daylight tubes should be used, and if this is not practicable, then special light boxes need to be sited in these areas.

Adequate temperature and dust control is essential. Ideally all production areas should be air conditioned to a set temperature in a positive pressure environment. All low-pressure compressed air should be filtered and passed across water and oil traps. The high level system must have adequate falls and automatic drainage included. All pipework lagging should eliminate any risk of pipework condensation, which could fall onto product, by suitable insulation with food grade aluminium or mirror effect stainless steel sheeting covers. They must be readily cleanable. All services should be suitably marked as per BS 4800 and BS1710:1989. Electric trunking and cable trays must be kept clean by using hygienic designs that are readily accessible by the electrician and the cleaning crew.

A centralised cleaning system for external cleaning of machines and conveyors is often installed in beverage factories. These incorporate chemical dosing and hot water that can be plugged in at strategic points around the factory to provide high-pressure cleaning through hand-held lances. Sweeper/scrubber machines are used for the main alleyways and accessible parts of the factory. Sweepers are used to keep the factory external roadways clean. Such roadways need to be fit for purpose to take the modern 44 tonne vehicles. Adequate drainage and petrol interceptors are required.

The warehouse should be a high bay unit. This needs to be designed in conjunction with specialist companies that can provide the building, racking, cranes and warehouse control system.

9.12 Performance measurement and benchmarking

It is always important to benchmark performance against business competitors. Studies have shown that it is not always necessary to invest in the latest plant to be efficient. This is to do with the fact that it takes time for plants to bed in as well as the staff that operate it to fully understand the new technology. Staff know the old plant and can achieve high output efficiencies from it. An OEE of over 85% is considered to be of world class manufacturing standard. Generally companies in the EU, USA and Japan that achieve this are those with the least advanced technological process control systems.

$$\text{Plant efficiency for a bottling line} = \frac{\text{Bottles into warehouse} \times 100}{\text{Filler speed} \times \text{run time}}$$

This efficiency is influenced principally by the materials fed to the plant, the state of the machines within the plant, the workforce capability and morale, the number of production variants and run lengths. Machines must run effectively and staff must know how to operate, fault find and rectify problems promptly on them. The aim is to minimise production downtime whilst still maintaining the product quality. Consider a simple cost model for a production line as per Table 9.2. This example is for a line running one size of bottle with several flavours to produce at 10,000 bottles/h 28 million bottles per year. This gives an ex-works cost of £0.39 excluding overheads. This is equivalent to an overall line efficiency of 65%. An increase in efficiency would reduce costs and increase profits. The more breakdowns the less time there is for production. Obviously some point must be reached whereby the costs of maintenance outweigh the advantages. This is illustrated in Figure 9.13(a, b), where the optimum cost can be seen.

Performance indicators come in many forms. They include OEE, line efficiency, mean time between failures, planned maintenance task completion rate, ex-works production cost, labour cost, maintenance cost per plant item, maintenance cost per production line, ratio of planned to breakdown costs and the number of consumer complaints. From Table 9.2 we can see that depreciation represents 12.4% of our costs. If the plant is not maintained well, it will be necessary to reinvest sooner than anticipated. This will cost further depreciation plus interest costs which could well come to some 20% of costs. It would be wrong to just use cost as the main indicator of productivity. It is necessary to ensure that all the routines and corrective measures

Table 9.2 Simple line cost model.

Plant depreciation	315
Buildings depreciation	168
Raw materials	979
Packaging materials	830
Energy	326
Administration	148
Labour	421
Maintenance	708
Total £000s	**3895**

Note: This is a very simplified model of a product costing to illustrate a point.

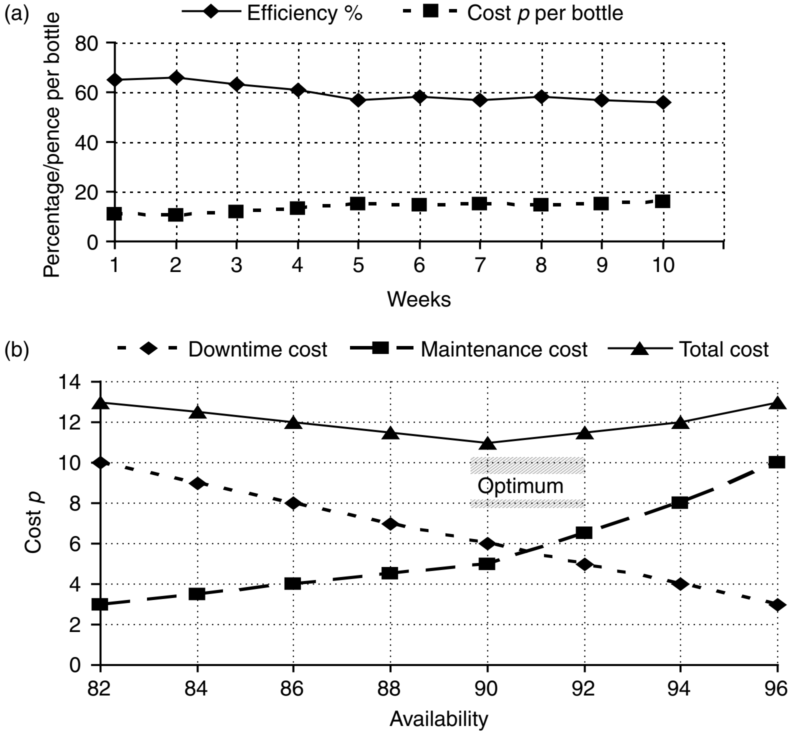


Figure 9.13 Optimum cost model. (a) Efficiency cost model and (b) optimum cost model.

are being progressed. In all, some 10 measurements are required, all needing to be updated regularly on a trend graph. Too high a maintenance cost without a decrease in ex-works cost indicates that the process is going out of control.

Anyone who has worked in a factory environment will know that the thrill of putting a new plant in is soon mellowed during commissioning. No new plant goes

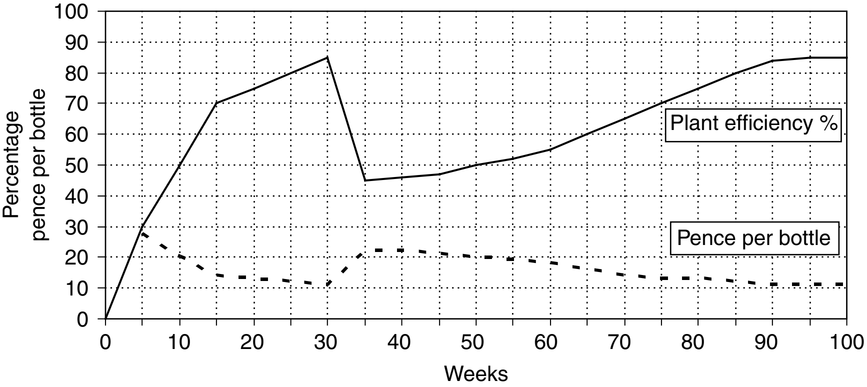


Figure 9.14 Typical plant commissioning scenario.

in as well as expected. Even if the new plant meets the contractual performance criteria, the staff still have to learn how to operate it and take ownership. Experience shows that on a completely new soft drinks line, it takes at least 12 months, usually 18 months, to meet the required efficiency levels. During this time the staff have to learn how to operate the plant as well as how to fault diagnose and maintain it. Figure 9.14 shows what often happens. Whilst the contractors are on site, the plant soon improves and meets the contractual performance conditions. The contractors leave site and the efficiency falls. Extra training is given to staff, the contractors assist with the maintenance and slowly the plant performance improves. This always costs more than anticipated. This should be allowed for in the original capital proposal.

If existing plant can meet the foreseeable sales demand, why invest? Surely it is more economical to maintain and improve the performance of the present plant. No increase in depreciation is happening which adds a burden to the ex-works cost of the product. The key is to motivate staff, ideally through total planned maintenance (TPM) programmes, to not only ensure that the plant is kept in as good a condition as the day it was purchased, but also to operate it even better than anticipated. Clearly there are times when new investment is required such as for a new product range, cost reductions through improved output and new multi-packing options.

Trend analysis is a valuable tool. However, no decision should be based on it unless complete faith can be had in the base data. Ideally non-dimensional parameters should be used. If these cannot be devised, then cost per bottle is a better parameter to use than total cost as it is relative to something positive.

How are benchmarking partners found? For a soft drinks manufacturer, it can be achieved by visiting competitors' operations and similar plants such as a brewery as they deal in bottles and cans at high speeds but lower carbonation levels. Involvement with industry associations, attending industry seminars and visiting exhibitions as well as discussions with plant suppliers are all valuable. On a benchmarking visit, it is important to make clear that benchmarking is the objective and that a reciprocal facility is offered. The best measure to use is the OEE (overall effective efficiency) which is defined as:

$$\text{OEE} = \text{availability} \times \text{performance} \times \text{quality}$$

where availability = actual run time ÷ planned run time, performance = actual output ÷ maximum possible output in the actual run time and quality = right first time ÷ total produced.

It is best discussed using an example. A production line is designed to run at 10,000 bottles/h for 5 days at 24 h/day. This defines the planned run time as 7200 min. Change overs take 320 min whilst the unplanned downtime is 426 min. The total unproductive time is then 746 min, giving the available production time as 6454 min. Availability is then 89.65%. In this time the line should have produced 1,075,666 bottles, but actually only made 876,024 bottles. This gives the performance as 81.4%. Of these bottles produced, 24,806 were put on hold and 756 were waste. The units right the first time were then 876,024 bottles giving a quality rating of 97.1%. The OEE then calculates as 70.8%, a long way off world class. This example highlights some of the main problem areas. Change overs need to be minimised. Target times should be set for these which need to be monitored and a trend graph drawn up that is constantly updated and reviewed. Downtime is another important parameter to be analysed. The factors that influence it are high-speed packaging equipment, a good proportion of whose problems are the interaction between the packaging suitability and the machine, and the shortage of skilled technicians. In the UK, the virtual demise of apprenticeships and the rise in the number of graduates trained academically but not practically has not helped this situation. The age of the graduate apprenticeship seems to have unfortunately gone. Getting the quality of the product right the first time is one of the main keys to success. Low yields are often caused by poor packaging and raw materials. It is important that the specifications for these are carefully written and agreed with the suppliers, that the buyer actually buys to these agreed specifications, and that these specifications are regularly reviewed with specific regard to line performance with the supplier.

9.13 Future trends

It is most likely that factories will become even more hygienic. Machine designs are available that are much more compatible with hygiene requirements, with sloping surfaces and no deadleg areas where microbial problems can rise. Often the main working area of a machine, in the wet part of the factory, is sited above the actual frame to aid cleanability. Cabling is in easily cleanable stainless steel trunking of cable trays, often sited on the sides on conveyors or overhead. Many soft drinks factories have a high level walkway to enable visitors to see the process without disrupting it. Platforms often exist to house the machine and system control panels. This allows staff ready access to them without hindering production. This also provides a degree of security. Buildings will be purpose built for food production rather than the typical warehouse shell of 20 years ago. They will be sited with borehole water availability, ideally with natural mineral water recognition.

Aseptic filling is going to come even more to the forefront and developments will include near-aseptic carbonated drink filling, where low preservative level and new product innovations can be produced. This will in turn require upgraded syrup room facilities where aseptic product can be prepared.

The elimination of production labour by automation is now a thing of the past. Very few capital proposals can claim any major labour saving. A small reduction in unskilled and semi-skilled personnel will be seen, but a large increase in the skilled workforce will occur. This needs government and industry to ensure that the supply of funds to educate the next generation is available. At present the future in this area looks rather bleak, with a lack of interest in technology especially with university entrants. Apprenticeships for both craft and graduate entry are required. The days when a graduate can walk into an office job without first learning the rudiments of how, for instance, to operate a soft drinks production line or syrup room should be behind us. The chemist should know how the process works technically as well as understand the chemistry of the process. He needs to have worked for a period in a syrup room. He also needs to visit his material suppliers and understand how their processes work and what improvements can be made. The packaging technologist needs to fully understand the relationship between materials and machines.

New product and packaging development will be a continuing process, probably at a faster rate than in the last 10 years. This will see a growth in development costs and the need for more flexible production systems. Short run length for specialist products must be catered for as much as long run lengths for the major brands. Both must operate at high OEEs with low ex-works costs. This will require careful attention to factory design and layout as well as the facilities installed.

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10 Production planning and distribution

Philip A. Wood

10.1 Introduction

This chapter will concern itself with the disciplines of logistics and the supply chain of soft drinks. At first glance this may represent to many readers a deviation from the main thrust of this book as it is not particularly concerned about formulation or manufacture. However, as you will discover, just being able to formulate and manufacture carbonated soft drinks effectively will almost certainly not be enough to succeed in today's marketplace. Qualities within a company required to maintain a sustainable competitive advantage in the soft drinks marketplace will include being able to deliver not only to its customers and consumers both a good consistent product at the right price but also to a high level of customer service. It is to this latter quality that this chapter directs its attention.

What is meant by a high level of customer service? This requires the definition of customers and consumers of soft drinks. The consumer is the individual who drinks the product. The customer is either the direct retail outlet or an independent wholesale distributor to independent retailers or a multiple retailer/supermarket chain, whose individual stores are either served directly or via a distribution centre. Today's customers expect to have 99.5% or more of the cases they have ordered correctly delivered to them on the date and, more frequently, time expected. Customers typically order on day one for delivery on day four (i.e. three days later), however, some with high levels of buying power demand the ability to order with only 12 h lead time nationally.

It may be considered that this should be relatively straightforward to achieve by simply having full stock ready in anticipation of customers' orders. There are a number of issues that a manufacturer has to deal with logistically for carbonated soft drinks. First, the product consists of mainly water which is relatively heavy and bulky. Consequently, warehousing (the physical buildings and people to run them) and distribution charges (large goods vehicles (LGVs) can only carry around 26 tonnes of product on UK roads and a 1000 l of water weighs a tonne) can have a significant impact on overall product cost. At today's prices in the UK, these charges represent between 20 and 25% of the total product supply chain costs (i.e. those from raw materials supply to product delivered to the back door of a retail outlet and without overheads such as marketing, etc.). The second problem is product flavour deterioration as a function of time and temperature. Carbonated soft drinks have a shelf life, normally about 12 months from the date of manufacture (see Chapter 7).

However, after about 3 months, consumers may be able to differentiate this from freshly manufactured product. Many retail customers are aware of this and insist upon minimum shelf life requirements for their consumers. Besides these issues, manufacturing lots of product to be held in stock also means that the business will tie up a lot of its capital/cash in this way. What has therefore developed is a balancing act between the need for low stock levels and that of high levels of customer service.

This should be very achievable if there is a good understanding of what customers want. However, forecasting customer demand is extremely difficult for soft drinks due to its seasonal nature. Firms have developed some direct correlations with the average climate temperature and the volume of soft drinks consumed. In the summer, consumer uptake rates can be over five times the normal rates. The other significant problem is that of competitor activity between both different manufacturers and customers.

For manufacturers, time-to-time promotional activity associated either with the launch of a new product or a brand re-launch or simply a new marketing campaign where significant price reductions or multi-buys, such as ‘buy one get one free’ or ‘three for the price of two’, can have a dramatic effect on the volumes of any products sold. Such activity can be focused on one or more specific sectors of the market or even with specific customers within a sector. Some carbonated soft drinks are treated by customers as commodity items. That is those which they normally have to stock because consumers expect to find it on their shelves and consequently consumers are well aware of the traded prices. Some customers choose then to compete by lowering the retail price themselves to encourage additional consumers into their stores. Such products are known as ‘loss leaders’.

Through this chapter how a soft drinks manufacturer can manage these issues and what has to be considered after the product leaves the end of the packaging line will be considered.

10.2 Supply chain principles

Figure 10.1 describes some of the different terms used to describe different parts of the supply chain and its management which is taken from Slack *et al.* (2001). This provides a simple introduction to the topic using a single operation in the chain as a focal point. This diagram can be expanded for an individual business where there are more factories with different products such as cans, glass or plastic bottles.

The efficient control of this aspect of the business is known as supply chain management (SCM). SCM has also been described in the context of the value chain (Christopher and Ryals, 1999). Value chain analysis is a tool to breakdown a business into its strategically relevant activities in an attempt to identify the sources of competitive advantage for an organisation. Broadly the value chain becomes a design for the business mission, SCM offering the strategic direction with logistics management the operational implementation vehicle (Christopher and Ryals, 1999). SCM can drive shareholder value through:

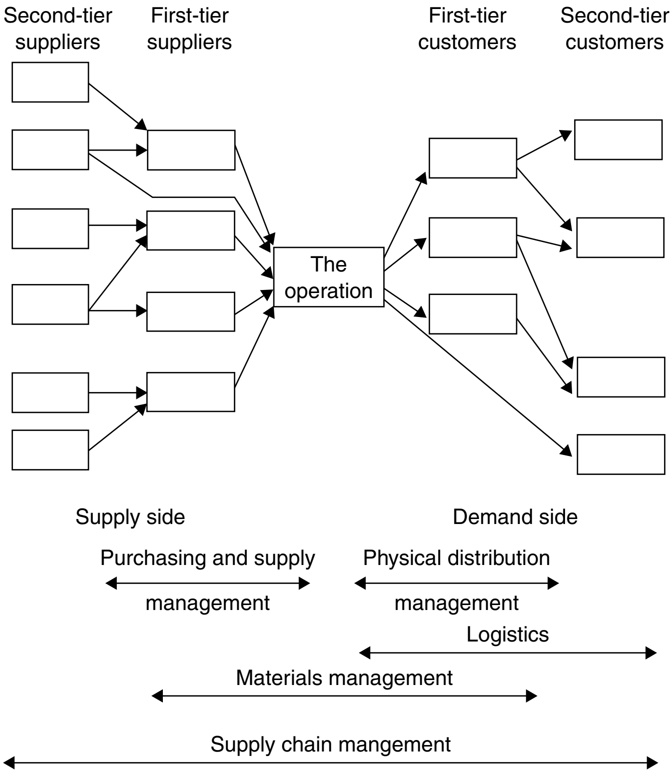


Figure 10.1 Typical supply chain model taken from Slack *et al.* (2001) as detailed in Durham University Business School, 2003.

- revenue growth – through high service levels impacting on shelf availability, thereby increasing sales volumes and customer retention
- operating cost reduction
- working capital efficiency
- fixed capital efficiency.

10.2.1 Make versus buy

One of the basic questions that a business needs to ask itself when reviewing its supply chain is the 'make versus buy' question. Put simply, should the business produce a raw material or component, carry out the task of assembly or manufacture and provide the associated services internally or purchase some or all of these activities from suppliers. For example, should a carbonated soft drinks business be in the flavourings manufacture business? Should they mix the flavourings and generate the syrup? Should they manufacture all the different pack types of a product as demanded by the customer and consumer? This is especially relevant for some specialist packs where volumes may be very low. Should the business carry out warehousing, transport and services such as vehicle maintenance itself or contract some or part of these activities from outside the business? Whatever decision is reached, such an evaluation is not a one-off decision as having outsourced an activity it is always possible to bring it back 'in house' (Monczka *et al.*, 1998). In fact, a review should occur:

- following a review of business strategy
- as a result of a change in demand for products
- with changing technology life cycles (e.g. IT)
- when there is poor internal or external supplier performance
- following new product development.

The difficulty in carrying out these reviews is to fully understand all the relevant costs associated with an activity. For example, if delivery service of products was outsourced and the contractor provided poor service, what could be the value of the lost sales and the deterioration in customer relationships that would ensue? Could all these costs be fully recovered from the contractor?

10.2.2 Make to order or make to stock

Having determined what aspects of the supply chain the organisation will actually operate 'in house', the next question is whether the products will be made when a specific order is received from the customer or will products be manufactured to a pre-determined stock holding level such that orders can normally be satisfied by that stock?

This question is tackled in the theory by asking whether the product is functional or innovative. Carbonated soft drinks are viewed as functional having been around for well over a hundred years. Many brands are seen by customers and consumers as essential for their shelves in stores or at home. Functional products are not those which are viewed by customers and consumers as particularly special, and consequently the supply chain can gear itself up to produce with maximum efficiency because it is likely that demand is there and any stock manufactured will not wait in warehouses until the shelf life expires and it has to be destroyed.

Innovative products on the other hand are by their very nature new to the market. Market research should have informed the business how the consumer will react to them. However, unless the company spends large sums of money to establish whether the product will sell, innovators must just put the product into the market and await the consumer reaction. Consequently, limited quantities are produced and more will only be made as further orders arrive. In order to avoid shortages, production capacity may be required at short notice and so innovation is invariably expensive and the consumer normally pays a premium for such products.

For carbonated soft drinks, the answer should be make for stock. This is normally correct; however, the industry does launch new innovative products and it also uses a range of promotional packs to attract customers and consumers. A good example is the so-called price marked packs where normally, if a larger than normal volume is purchased, a discount is indicated on the packaging. For the manufacturer this may appear to represent a good deal for the consumer. However, will the customer view the deal as good value? More volume may be sold but will retailers make as much profit overall?

The reaction of the customers can usually be gauged by the sales force. Frequently because the organisation is ‘funding’ the activity from a budget, quantities of the promotional package are often allocated to the customer by fixed volumes only. Most retailers will normally understand consumer reaction following the first day that the offer is available.

10.2.3 Purchasing

Soft drinks manufacturing companies spend a high proportion of their business costs on materials and services. As a consequence this aspect of business is developing from a clerical ordering style activity into a core function that can contribute to a business’ strategic competitive position. For example, in a typical manufacturing company with an 8% profit margin and 55% material costs, a reduction in material costs by 5% would improve the overall company profitability to the same extent as a 29% increase in sales (Durham University Business School, 2003).

The aspects of the role of the purchasing function can vary within an organisation. Whether it is identified separately or working across different functions, there will be individuals charged with:

1. identifying sources of supply
2. evaluating possible suppliers and selecting them
3. providing material specifications and technical agreements with suppliers
4. carrying out contract negotiations covering prices, service and payment terms
5. raising purchase orders
6. receiving ordered goods
7. matching receipts with supplier invoices and authorising payment
8. supplier management – ensuring the costs and services contracted for are delivered
9. supplier development and improvement including building closer relationships, for example, to assist with new product development
10. supplier audits.

Supplier selection will normally be primarily based on cost, quality and delivery comparisons and criteria. There are secondary factors associated with technical support, business stability and flexibility.

Historically, the buyer–supplier relationship was based on adversarial transaction-based theory (marketplace bartering/haggling type relationship) and not that of co-operation for mutual benefit. This is because such relationships are pretty

Table 10.1 Differences between historical adversarial transactions between buyer and seller and buyer–supplier relationships.

Adversarial transaction based	Buyer–supplier relationship
Suspicion	Mutual trust
Someone wins	Win–win/shared goals
Structured communications	Open communications
One-off sale/buy	Long-term commitment
Responsibility for failures	Team problem solving
Limited involvement	Involvement at all levels
Penalties for performance problems	Joint Improvement development
Independent entity	Mutual growth
Relationship strictly to the contract Terms	Working together, contract hardly ever referred to
Business secrets	Shared technology

straightforward. Both parties place their efforts in limited selection, selling/buying and negotiating activities. The goods or service is exchanged and utilized and if the buyer is satisfied, then the seller can hope for further future business.

Organisations are coming to recognise that by undertaking a programme of supplier development, which entails developing buyer–supplier relationships with an increased use of the organisations resources in contrast to an adversarial relationship, then there is greater potential for increased value and profits. To achieve these new buyer–supplier relationships, a paradigm shift is necessary to generate the full benefits for both parties (see Table 10.1).

Adversarial relationships however still take place in modern business. The issue for buyers who cause suppliers to go out of business as a result of this kind of relationship is a reduction in future supplier competition because there will be fewer organisations in the marketplace. Further, there is the potential for a ‘backlash’ from the trade and general public, particularly if the alternative sources are foreign or with businesses which have poor ethics or worker relations.

Relationships can be ‘dual sourcing’ with more than one supplier able to deliver a resource to the organisation. Here the element of trust need not be high, quite simply because if one supplier fails then there is always another. In ‘single sourcing’ or ‘cross-sourcing’ (where a supplier delivers two or more products to a buyer), the relationship trust levels need to be higher. This is because, for both parties, the business relationship is likely to be more significant in terms of overall value. A further relationship type is where a supplier delivers a ‘portfolio of arrangements’ where many different resources are bought from only a few different suppliers. Therefore, the number of suppliers tends to be limited and here the trust levels in these relationships need to be very high. Frequently this type of buyer–supplier relationship is often developed as an outcome of a supply base reduction exercise. This exercise allows firms to limit the number of invoices processed and allows its management to focus on the relationship between fewer organisations. Relationship development between companies is time consuming so if it can be limited to a few then expensive management time will be saved.

The first key issue for a company which wishes to develop strong buyer–supplier relationships is the selection of suppliers and resources. This is because the development of strong buyer–supplier relationships requires time and effort from the people in both organisations and this may simply not be practical. In some organisations this need to work with many suppliers may be outsourced to one ‘primary’ supplier who manages all the other suppliers on behalf of the buyer. The development of a relationship where mutual trust exists is one of the main contributors to the expenditure of time and effort and an integral part in the development of long-term buyer–seller relationships.

A further critical component must be communication. In the adversarial relationship, communication is between a few individuals in both organisations. Broadly the buying organisation supplies details of the requirement, supply and payment terms with a forecast volume, with the supplier providing quality and price details. Discussions take place over a few meetings with those parties only reconvening should one of the parties have encountered a problem. In buyer–supplier relationships, the above discussions still take place, but subsequently regular reviews consider an exchange of key performance indicators as well as cross-functional meetings incorporating other departments such as Marketing, Research & Development, Manufacturing, Logistics and Finance. Regular updates of forecast demand, market trends and opportunities for mutual cost saving by either need to be considered as do developing the resource or service.

10.2.4 The soft drinks supply chain

Key materials and services required for the manufacture of carbonated soft drinks are water, packaging materials, CO_2, sugar, energy, flavourings, colourings and preservatives, fruit juice in its various forms, marketing design services, effluent and waste disposal. Product formulation, packaging development and subsequent shelf life testing for a new product are likely to take the longest time. Figure 10.2 provides a typical example of a business with a product development cycle.

For established products, the longest lead time can often be for the development and approval of new promotional packaging with subsequently the production of the new design material. The lead time for some items can be as long as 12 weeks before receipt at the factory.

Understanding the longest lead time and the value of a component for a pack is very important when determining the desired stock levels to be held within the business. This will be as either full goods or as a raw material held by either the supplier or the manufacturer. Critical path analysis can be used for this purpose.

A further key question in the carbonated soft drinks supply chain is to determine the trade off between manufacturing capacity and stock holding? Is it more cost effective to have very low full stock levels with spare manufacturing capacity where

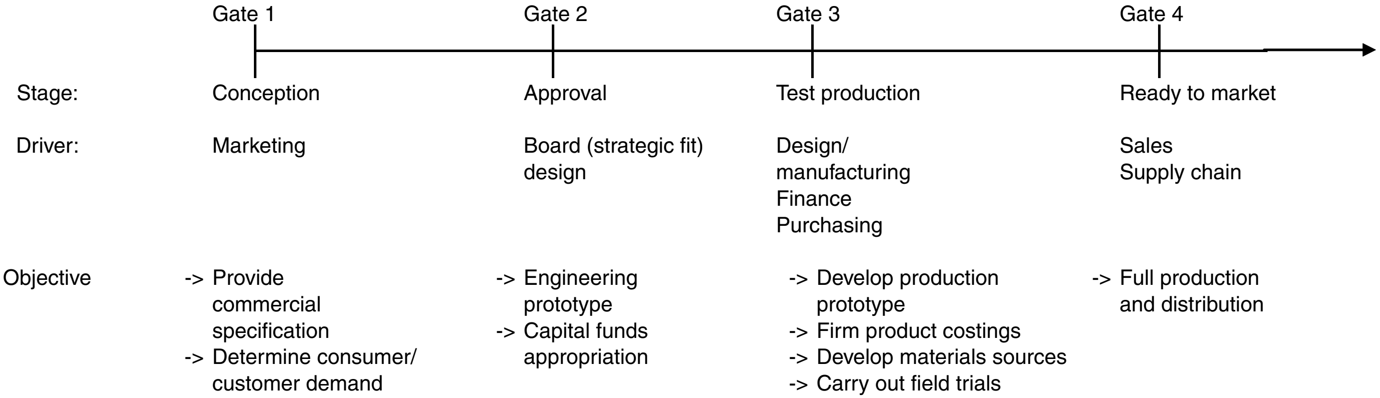


Figure 10.2 Staged process for product development. (Adapted from information in Handfield, R.B. (1994) Effects of Concurrent Engineering on Make-to-Order Products, *IEEE Transactions on Engineering Management*, Vol. 41, No. 41, November 1994, pp. 1–11, and Monczka, R.M., Trent, R.J. & Handfield, R.B. (1998) *Purchasing and Supply Chain Management*. South-western College Publishing.")

‘make to order’ can be effective or using high stocks to act as a buffer when the manufacturing capacity is exceeded in periods of high demand?

Some manufacturers have fully dedicated packing lines for a specific brand and/or pack/stock keeping unit (SKU) with only limited graphic design changes to the packaging (for promotional packs) being undertaken. Such lines tend to be less complex and so run extremely efficiently and are in factories where the workforce can move between the different lines. The advantage of this strategy is that in times of sudden increases in demand, the manufacturing capacity is available to respond, and it is simply a case of availability of people to run the lines.

An alternate strategy is to install lines capable of producing a large range of products and SKUs. These lines tend to be more complex, costing a lot more than the simpler packaging lines described above and furthermore they run less efficiently due to increased complexity and increased downtime due to size changing.

Carbonated soft drinks fit into a group of products known as fast moving consumer goods (FMCGs). The market in some developed countries is rapidly becoming dominated by a few supermarket chains known as major multiple retailers who have greater market buying power. The alternatives are the impulse sector, including kiosks, garages and corner shops, and the trade sector, comprising pub, restaurant and entertainment chains.

These major multiple retailers normally require delivery directly into their distribution centres of full truck loads (FTLs). Such loads tend to be to the maximum weight that can be legally carried on public roads. Their distribution centres will then sort the stock into specific store deliveries and deliver carbonated soft drinks with other similar so-called ambient products directly to their stores.

The impulse sector can be broken down into two groups, those that purchase from wholesalers (Cash & Carry outlets) and those that purchase directly from the manufacturer. Volumes for these retailers are often much lower and as a consequence the product cost is higher. Manufacturers also maintain product dispensing machines at, for example, leisure centres or amusement arcades or places where the retailer is not open 24 h.

Distribution costs can have a significant impact on the overall cost of the product. A 400 mile journey for an FTL will normally cost about three and a half times more than a 100 mile journey. So it is important to locate production facilities near to the centres of population with good access to the transport infrastructure.

10.2.5 The bullwhip effect

A phenomenon associated with some of the supply chain principles faced by the soft drinks industries is called the bullwhip effect.

This phenomenon was discovered when order patterns for a consistently supplied product were examined, it was found that while retails sales fluctuated, they could not be described as excessive. However, distributor’s orders were found to be highly variable and further that orders to materials suppliers showed even

Table 10.2 Summary of relationship among lead-time distribution, bullwhip effect and supply chain performance for supply chains with constant lead-time taken from (Impact of lead-time distribution on the Bullwhip effect and supply chain performance).

Increase in	Bullwhip effect	Inventory cost	Backorder cost	Total cost	Order fill rate
Information shared	Significantly decreases	Increases	Significantly decreases	Slightly decreases	Increases
Skewed decentalised information	Decreases	Decreases	Decreases	Decreases	Increases
Skewed centalised information	Exactly the same	Approximately the same	Approximately the same	Approximately the same	Approximately the same
Skewed with the same division but upstream	Approximately the same	Slightly decreases	Slightly decreases	Slightly decreases	Slightly increases
Number of tiers	Increases	Increases	Increases	Increases	Approximately the same

greater swings. Demand variability became amplified up the supply chain. The phenomenon was described as the ‘bullwhip effect’.

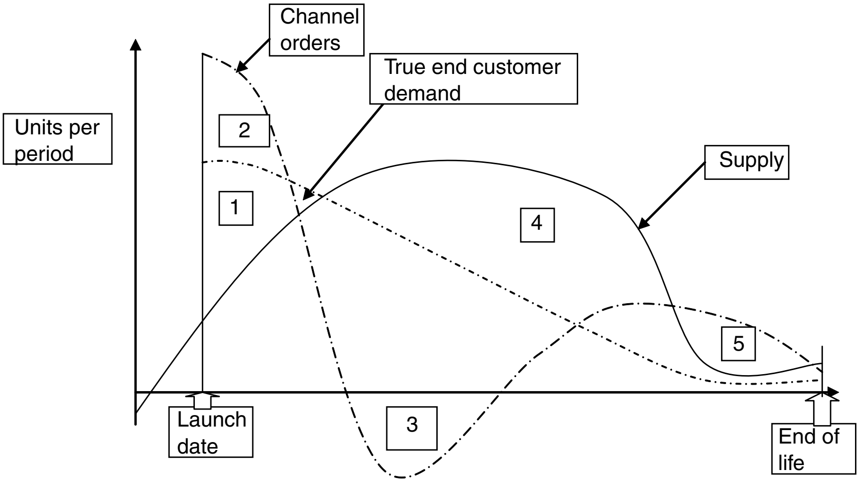
This effect can cause excessive inventory stocks, poor customer service, reduced productivity, poor usage of transport capacity and unnecessary production re-scheduling. This often leads to substandard quality and hence returned products. Four main causes have been identified for this effect. These are the act of delaying orders until an economic lot is accumulated, price fluctuations and promotions, product demand exceeding supply and forecasting. Many models have been produced including the lead-time distribution as shown in Table 10.2.

The bullwhip effect can also travel down the supply chain. When demand exceeds supply, customers react by raising their orders to ensure that they have a sufficient amount to cover their needs (Donovan, 2001). However, it may be a false picture compared to the true consumer demand or usage. The effect has been considered through product life cycle (Derrick, 2001) as shown in Figure 10.3.

It has also been found (Reddy, 2001) that the longer the lead times for information and material, the stronger the bullwhip effect.

10.3 Forecasting

As discussed earlier, if a carbonated soft drinks manufacturer knew exactly the demand for its products then it would almost certainly be able to operate its supply chain with maximum efficiency. Full product and material stock levels would be virtually non-existent. The reality is that this is never achieved as the future cannot be predicted with certainty. The best that an organisation can achieve is to make an estimate of the likely demand. In SCM this prediction is known as a forecast of demand. What it predicts can be measured in terms of accuracy and this performance



1 Supply cannot meet initial demand resulting in real shortages

2 Channel partners over-order in an attempt to meet demand and stock shelves

3 As supply catches up with demand, orders are cancelled or returned

4 Financial and production planning are not aligned with real demand, therefore production continues

5 As demand declines, all parties attempt to drain stocks to prevent write offs.

Figure 10.3 The bullwhip effect through product life cycle. Taken from Donovan, 2001.

result should be reviewed at the highest levels within the organisation as it has significant implications on the overall efficiency of the business.

10.3.1 Forecast breakdown or types

A forecast for carbonated soft drinks usually comes in three distinct parts which are subsequently used for different purposes within the company. Sometimes these parts can be issued or developed as three separate forecasts; if this is the case, then cross-referencing must take place.

The first part is the long-term forecast. It is depicted at the highest level, frequently detailed as litres of a brand sold per annum running for at least 5 but occasionally 10 years. This part of the forecast is often accompanied by a narrative which discusses demographics and consumer trends for different product attributes and drinking occasions. They are used to strategically plan the business in terms of new product development and for capital investment decisions in plant and facilities.

The second part is the medium-term forecast. It normally covers a rolling 12–18 months or so and attempts to define the number of cases expected to be sold of each brand and pack type each month. This plan is most frequently used to plan labour and logistics equipment needs. Further, it is also used by accountants to forecast business financial performance, as well as by purchasing to supply volumes to materials suppliers during contract negotiations. It will normally be issued on a monthly basis.

Finally the short-term forecast nominally covers a rolling 13-week forecast and details the specific SKUs to be sold each week. The first 2 weeks can also be broken down by day. The purpose of this is to allow for the detailed planning of the supply chain in terms of transport and warehousing of full product, factory planning and materials ordering and call off. This forecast will normally be created or updated on a weekly basis.

10.3.2 Forecast preparation and accuracy

The long term forecast is normally prepared annually by Marketing, often in consultation with a consumer research organization. They use sales data from a number of different sources to give a picture of what consumers are buying now. The medium and short term forecasts are developed for each brand and SKU. This is based on historical data plus a feel for the demand for each individual SKU. From these sales databases the forecaster will then use market intelligence to refine the forecast, often using sophisticated computer programmes to give short term daily requirements. Geographical demand is also part of the forecasters role.

Due to material lead times, it is normal to make the first measure of a forecast's accuracy seven weeks ahead of demand. The second measure is taken two weeks before the demand, giving sufficient time for the supply chain to react to the available information. Often the first measure is about 20% accurate whilst the second is normally within 10%.

10.4 Planning

This is the process where the demand information presented by forecasting is combined with other information from the business namely stock levels, warehouse capacities, transport capacities, existing production plans, production capacities, production run speeds and product and size change over times, existing material orders and material order lead times. The planning process produces an output, the plan which shows the production and necessary stock movements that should take place to satisfy forecast demand.

10.4.1 The planning and order cycle

In the same way that three different forecasts can be generated, three different types of plans which reflect those forecasts should be produced. The interrelationship between the various plans and their uses is shown in Figure 10.4.

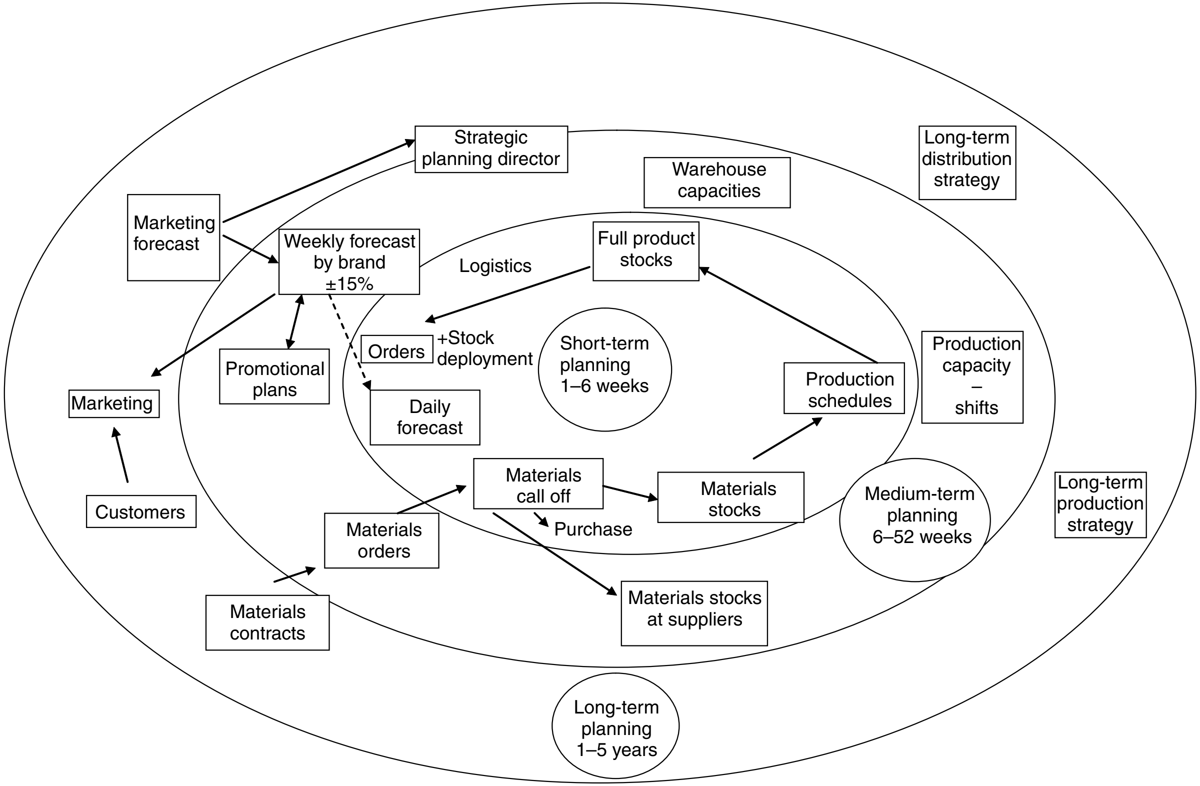


Figure 10.4 Interrelationship between various plans and uses.

To accommodate the complexity of data, various computer Information Systems have been developed to support the planners in their decision making. This family of applications was called 'Materials Requirements Planning' or MRP systems, and these were used to calculate dependent demand requirements using a 'bill of materials' which details what components go into a product and existing inventory records. Such systems were extended to more complex MRP II systems which stood for manufacturing resources planning and were used to gather live inventory data from complex processes together with capacity, human resources and financial information. The more recent development has been Enterprise Resource Planning systems enabling data to be shared across an entire organisation.

The process of gathering the necessary information and producing a plan is termed a planning cycle. The frequency of this activity is most often geared to the production of a new forecast. Thus, long-term plans based on the output of the long-term forecast are produced and reviewed often annually. The plans that they generate are used to:

1. Match production and warehousing capacity and facilities to the anticipated demand. For example, the planning and approval, design, purchase, manufacture, delivery installation, commissioning of a new packaging line to being fully operational would normally take around 18 months.
2. The purchasing of materials is commonly via a contract. Often there is an annual negotiation but for some materials, for example, cans, extended agreements of 3 to even 5 years are possible. To commit to these sorts of contracts, the purchasing professional requires a forecast of likely demand.
3. Capital investment decisions around materials handling equipment and vehicles are normally taken assuming a 5-year investment and depreciation.

Strategic decisions based on the above are normally taken or reviewed and confirmed at the board level.

The medium-term plan is produced following the issue of the medium-term forecast on a monthly basis. It will provide factory production volumes normally by month. Modern MRP II and ERP systems can also provide bills of materials to support those plans. The information is used to:

1. prepare budgets and monitor, review and manage financial performance,
2. plan the shift patterns of the labour force,
3. used for annual materials contract preparation,
4. provide material demand forecasts to suppliers,
5. plan for plant maintenance overhauls and shutdowns,
6. smooth peak demands by building stocks or raising requests to contract pack volumes elsewhere,
7. plan for transport needs and any third party contract requirements,
8. plan for warehousing needs and any third party contract requirements.

Finally, the short-term plan is produced on a weekly basis, even though the forecast is only formally updated monthly. It is produced weekly to reflect the following:

1. the latest update of stocks in the business
2. known significant changes in demand, for example, a major promotion with a customer may be pulled forward or pushed back
3. any operational issues, for example, packaging lines running below normal theoretical output rates
4. allow for the detailed planning of, for example, maintenance and training at the factories
5. raise purchase orders for materials
6. to schedule the factory's production, that is, the order that packaging will run during the week.

A daily review process of the previous day's sales, current stock levels and existing plans is shown in Figure 10.5. Planners review the status of the supply chain at each stock holding point, making decisions to move stock from one warehouse to another to meet the changed demand or to produce more stock. This inventory management or stock deployment can result in additional costs as every additional movement requires the product to be loaded transported and unloaded at the new stock holding location. Further, as you can imagine, it is not unheard of for mistakes to be made and for the product to have to be returned to its original location. Such activity is very expensive. The most efficient supply chains will therefore be those that limit the number of stock movements and stock holding locations. A typical major multiple customers supply chain is depicted in Figure 10.6.

A more efficient relationship would be where the product moves immediately from the line directly to a central warehouse to serve all customers or a national distribution centre or NDC as seen in Figure 10.7, with a simpler solution (only three stock holding locations) in Figure 10.8.

A 'just-in-time' relationship is one where just the right amount of stock is shipped to the customer to meet his or her requirements and removes one of the stock holding locations as shown in Figure 10.9.

A further option is the so-called vendor managed inventory. In this relationship, the customer provides the supplier with stock and sales data and basically hands over the responsibility of maintaining stock cover to meet sales within agreed boundaries to the manufacturer as shown in Figure 10.10.

The advantage of this relationship for the customer is that the administrative resources to manage ordering are avoided. While the supplier has to provide this resource, they are in control of the supply and can flex stock holding to meet the most efficient manufacturing on their lines.

10.4.2 Central or local planning

As already discussed, the forecasting function needs to work very closely with the sales and marketing teams within the organisation. In today's modern organisation with high-speed communications this may mean that teams are based in different

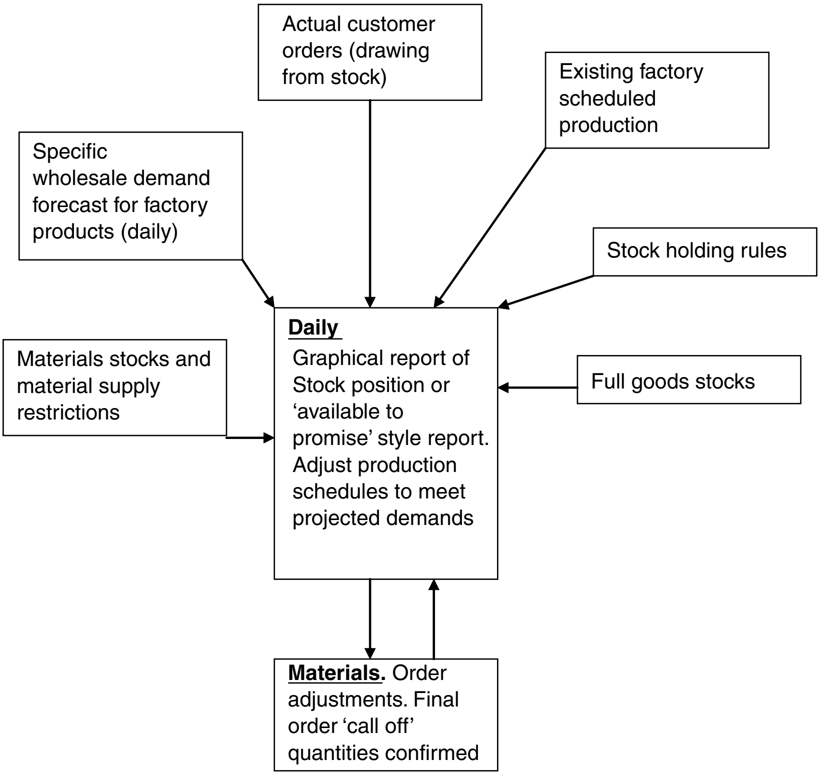


Figure 10.5 Daily planning based around the order cycle.

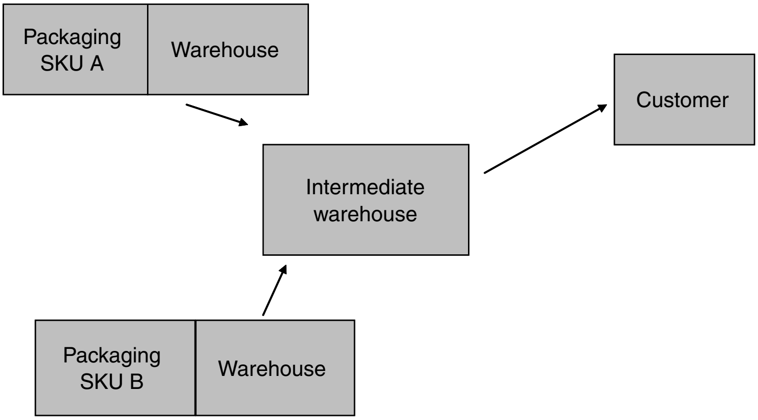


Figure 10.6 Typical major multiple supply chain.

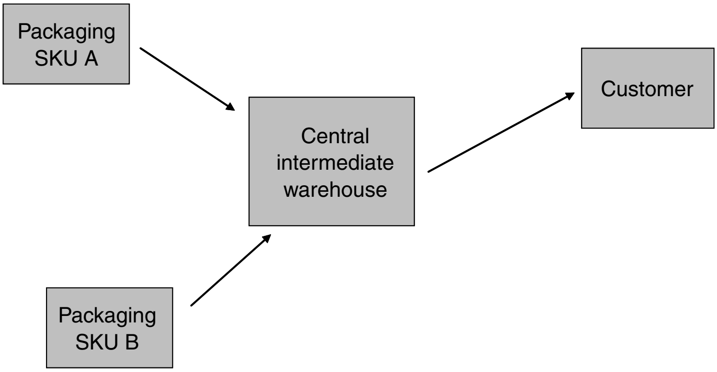


Figure 10.7 National distribution centre.

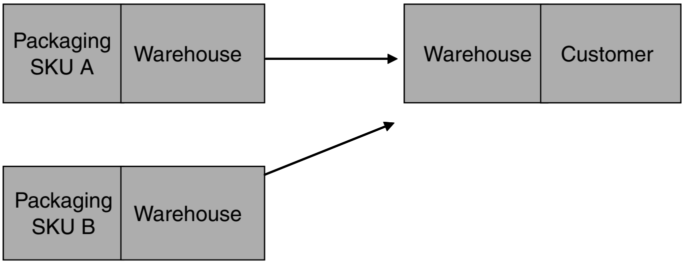


Figure 10.8 Simplified movement.

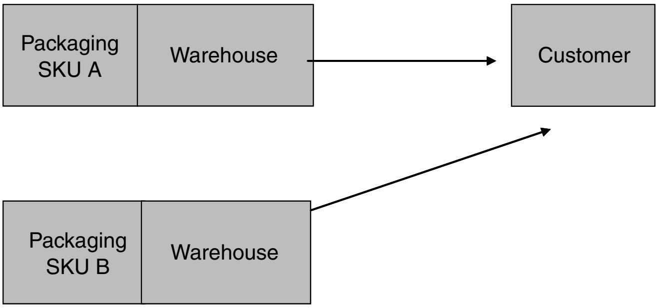


Figure 10.9 Just-in-time.

locations. In the preparation of short-term plans, weekly production schedules and material call offs, there is a strong argument that those individuals should be located close to their customers and so based at the factory.

A local planner must be provided with up to date data associated with the stocks, orders and forecasts for each SKU at every stock holding location within the organisation manufactured by their factory. To allow easy display of the information and to ensure that the short-term planner only reviews those SKUs at those locations

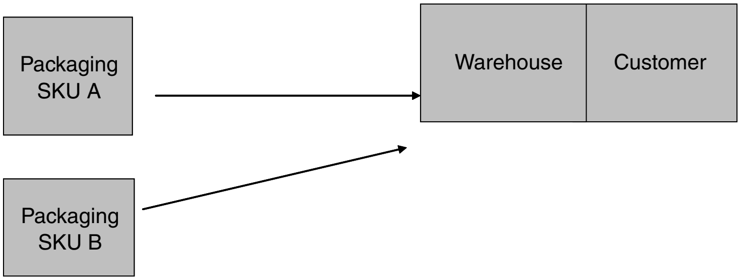


Figure 10.10 Vendor managed inventory.

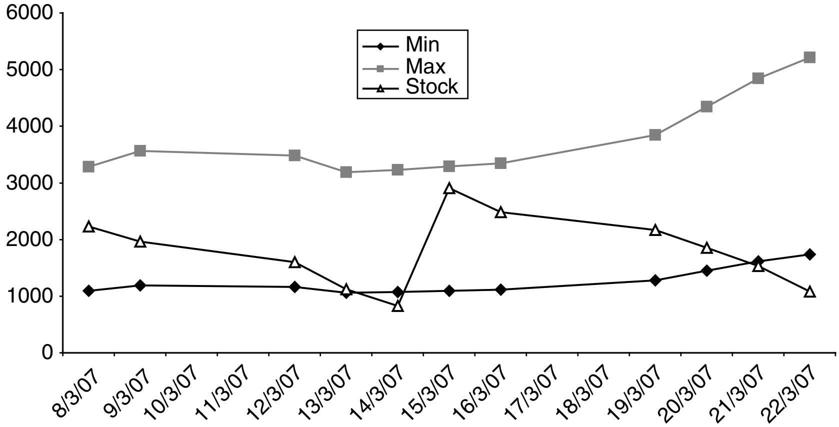


Figure 10.11 Brand V 330 ml cans – Middlesborough.

which require his or her attention that day, the information is often presented by the IT system in a graphical form as shown in Figure 10.11.

10.5 Warehousing

This section is concerned with carbonated soft drinks after the packaging line. Because the product is carbonated, even in fairly weak packaging such as low weight PET, carbonation provides the package with an internal pressure generated rigidity. This is very helpful when looking to store and stack the product.

The main customers of carbonated soft drinks receive the product in cases which are in turn assembled on pallets. Pallets of each SKU are assembled on a pallet by the palletiser and presented ready for collection. The pallet is normally labelled on two sides. The normal standard for this label in the UK and Europe is EAN 128. A typical bar code is illustrated in Figure 10.12.

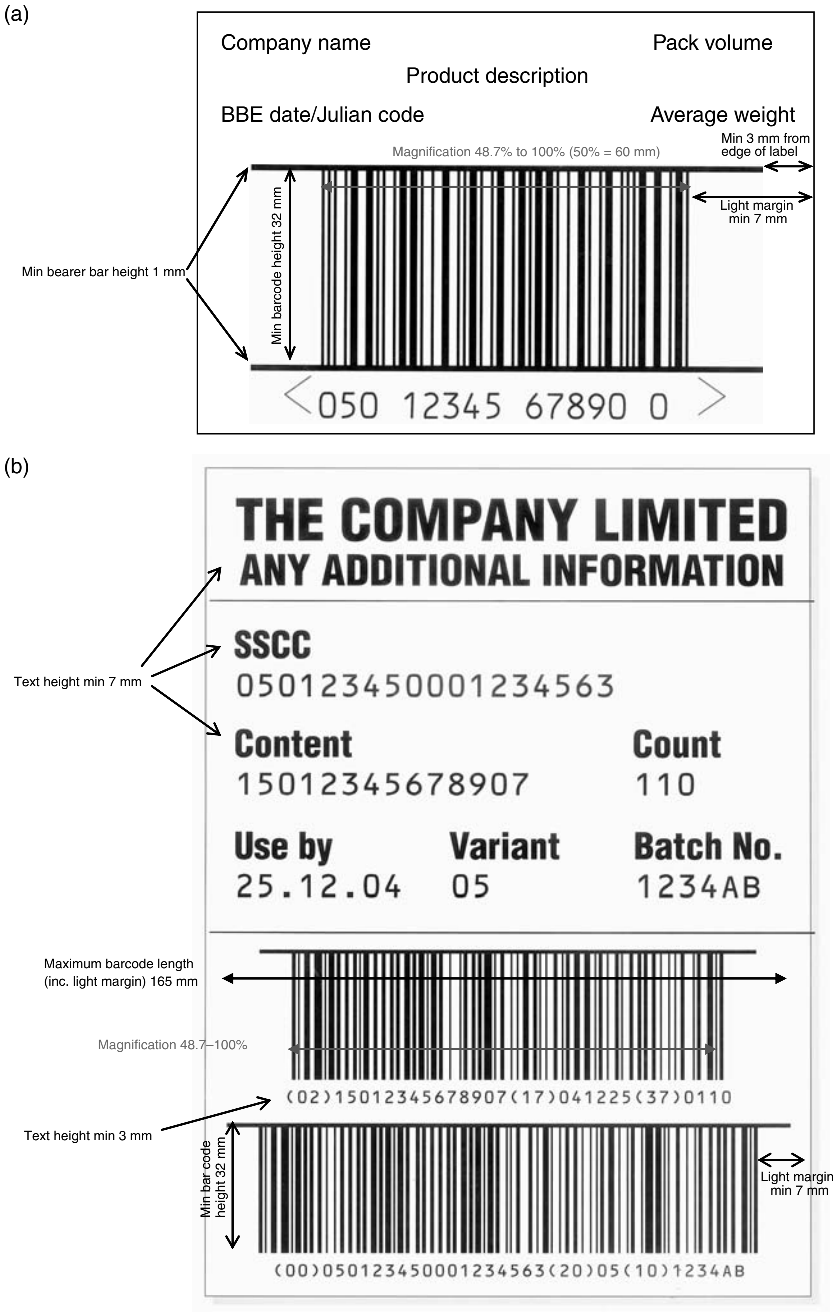


Figure 10.12 Typical barcode label: (a) ITF-14 bar code illustration, (b) EAN-128 bar code illustration.

Product is usually collected from the packaging line by some form of mechanical handling equipment (MHE). This is more often than not a fork lift truck (FLT) or in modern larger factories by an automated guidance vehicle (AGV). At this stage the product is freshly made and is normally taken by the MHE to a warehouse which is either adjacent to the packaging line or very close to it. Occasionally because lines are housed in premises which have insufficient space for a warehouse, they are immediately loaded onto vehicles and moved to a nearby warehouse facility.

There are three possible types of warehouse or store: manual, semi-automated and fully automated.

Manual stores involve the 'free' movement of product in and around a warehouse by MHE totally by humans such as the equipment shown in Figure 10.13.

Advantages of manual warehouses are as follows:

- Low tech – if a piece of MHE breaks down, it can be replaced easily
- Any reasonable building with a solid flat floor will be satisfactory
- Lowest cost vehicles
- Very low lead time – can hire trucks today for tomorrow
- Easy to flex operation by adding men and trucks
- Paper stock control acceptable.

Disadvantages:

- High level of semi-skilled labour required
- Not secure
- High floor area for stacks – some products cannot be stacked more than 1 pallet high
- Low utilisation – only 60–70% practically achievable
- 5–7-year truck replacement.

Semi-automated stores have both a manual element and some automation in the form of pallet conveyors, or automated picking machines or narrow aisle wire guided typically by 'man riser' FLTs (see Figure 10.14).

The advantages of a semi automated warehouse are as follows:

- Low land area – medium bay racked systems, 5–7 high racks
- High utilisation – theoretically 99.9% plus
- Lower cost
- Fairly short lead time: 3–6 months.

Disadvantages:

- High level of unskilled labour required
- Not secure
- Slower operation – 2–3 min to store or retrieve a pallet
- Specialist equipment – maintenance etc.
- Specific building – height and floor
- 5–7-year truck replacement

Figure 10.13 Various types of mechanical handling equipment. (a) Fork lift truck (FLT). (b) A walk with powered pallet truck (PPT). (c) Ride on PPT. (d) Hand pallet truck.

- Computer stock control system required – bar code readers and radio data terminals (RDTs).

Automated stores do not involve people with pallet movements. IT-controlled systems are used to automatically store and retrieve products (automatically store

Figure 10.13 Continued.

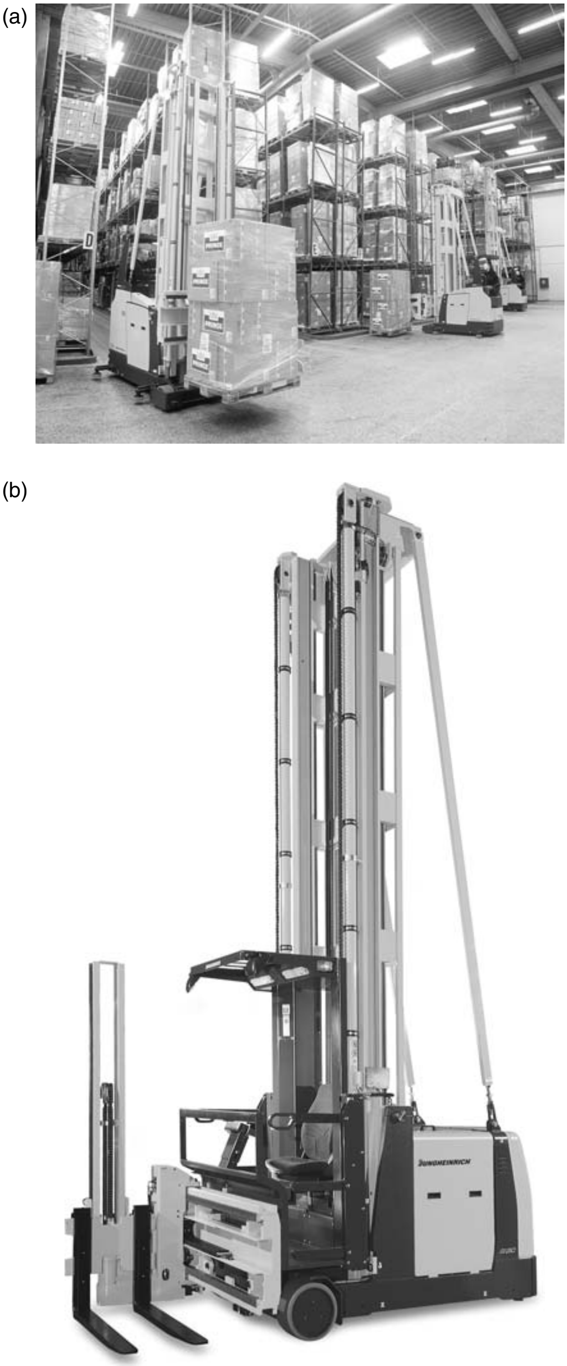


Figure 10.14 (a) Reach truck, (b) “man-riser” FLT (courtesy Jungheinrich).

Figure 10.15 Typical automated warehouse operation (courtesy Jungheinrich).

and retrieve system – ASRS). A typical automated warehouse system is shown in Figure 10.15.

The advantages of automatic warehouses are as follows:

- Low land area – high bay racked system
- High pallet utilisation, theoretically 99% of pallet spaces can be utilised
- Few people – limited employee relations problems
- Secure
- Non-stop no labour breaks/weekends. 24 h/day, 365 days/year bar maintenance time typically 99% plus.

Disadvantages:

- Very expensive
- 20-year investment – fixed maximum input and output rates
- Specialist tall building required
- Specialist equipment maintenance

- Long lead time – 2 years from the initial concept
- High pallet quality required or use slave pallets
- Sophisticated control systems and interfaces.

A further aspect of warehousing is its location for which the considerations are:

- relative location of stock supply
- main customer locations (range and possibly regional significance)
- avoidance of 'doubling back'. Journeys should always be away from the point of receipt
- space required and storage type
- cost of facilities in the area
- cost of labour
- access of vehicles.

Other issues to be considered in the warehouse are temperature, humidity, the environment, stock control, health and safety and stock rotation.

Product staling or ageing will increase with temperature. Thus, in hot conditions, every effort should be made to keep the product cool or cold. If cardboard packaging becomes damp, it loses rigidity and strength. Cardboard used in packaging, therefore, should be used in the UK within a few months of receipt from the supplier or it will start to perform badly in the packing machines with more frequent line stoppages and high material wastage. It is normal practice to keep such packaging materials in a plastic sleeve so as to minimise any moisture movement. Most packaging converters actually do so in a humidity controlled environment. Once packed, particularly with shrink film around the package and built onto pallets, there is protection from moisture.

10.5.1 Environment

Carbonated soft drinks are classed as food. Consequently, product protection from vermin and weather-borne particles, such as dust or fallen leaves etc. is essential. Warehouses holding carbonated soft drinks are commonly fitted with rapid roller doors to external locations. These doors operate by detecting the approach of an FLT using sensors (normally in the floor). The door typically opens within a few seconds and following a fixed time period, closes again quickly. The seal at the base of the door must not be big enough to allow a pencil to pass under it. This is approximately all the space a mouse would need to enter the building! Even with these measures, birds are often a significant issue and must be culled as they can foul on product.

10.5.2 Stock control

Stock control requires disciplined standard procedures which must be constantly maintained while the warehouse is in operation in order to keep the physical stock under control using either a paper or a computer system. To that end locations on this system must represent physical locations in the warehouse.

Common processes to adopt are:

1. In – Check using weighbridge or pallet weighing scales + audited. Bar code scanning. Random management checks of received stock.
2. Internal – Movement of stock with documentation/on system only. Perpetual stock checks. Full stock checks (weekly/monthly/quarterly).
3. Out – Check using weighbridge + auditor, bar code scanning, random vehicle searches. Leaving driver responsibility, discipline if mistakes.

Warehouse health and safety issues must be considered at all times. Risk assessments and other controls must be put in place in warehouses and transport yards bearing in mind the following:

- Vehicles are responsible for 70% of fatalities at work
- Over 50% occur when reversing
- Pedestrian control and access – why are people walking around?
- Collapsing stacks of full products and materials
- Picking and movement of cased product – good manual handling training is essential.

Stock can be taken out of the warehouse or rotated according to a variety of different rules or types, for example:

- FIFO – First stock (in the warehouse) first out
- FEFO – First expiry first out
- LIFO – Last in first out
- Smallest location first out
- FEFO with customer specific on shelf life remaining.

FEFO is becoming the industry norm, as many customers now require at least 70% of a product's shelf life remaining.

10.6 Transport and legislation

Transport and related legislative issues vary from country to country and should be set up in compliance with local needs.

A variety of vehicle body types are available. Ideally on multi-drop deliveries, the carbonated soft drinks manufacturer service driver wants to be able to access the load quickly at the delivery point. Manual handling on and from the vehicle should be minimised so that the product is as close to the floor as possible. Various bodies can accompany this. Figure 10.16 shows a typical vehicle used for delivering product to multiple drop customers.

Figure 10.16 A "drinks" multistop delivery vehicle.

10.7 Measuring supply chain performance

The overall measurement of performance in the carbonated soft drinks supply chain can be fairly complicated. It is essential that a balance is struck between service and cost. The performance of people and resources used in the supply chain must also be balanced.

10.7.1 Service

On time and delivered in full – the standard service measure is to deliver the order with no mistakes or damage at the time specified to the customer. Factors include:

- delivery time
- quantity in full – and the handling of customer errors and changes
- the quantity that can be legally carried on a vehicle
- out of stock problems.

Complaints:

- what constitutes a complaint? Will the complaint be written or verbal?

Production line downtime – lost time due to shortages of materials or because the full product is not taken from the line in time before the line stops. Production time lost due to changeovers.

1. Does the line need to be changed over because it was running behind programme and a product scheduled for later in the plan to be brought forward to satisfy customer demands?
2. Were the materials short because the manufacturer had given the supplier a shorter lead time than was agreed upon for the materials?

10.7.2 Costs

Cost per case/pallets/tonne – The costs over a period of time divided by the number of cases/pallets/tonnes delivered to customers.

10.7.3 People

Productivity – cases/orders handled/transported per warehouse/driver/administrator man hour.

10.7.4 Resources

Warehouse utilisation – expressed as a percentage of the capacity of the location.

10.8 Conclusions and future developments

This chapter has attempted to cover some of the many topics and issues that the carbonated soft drinks manufacturer must consider when servicing his or her customers. To survive in today's modern marketplace, efficient execution of the issues described above is essential for a business that wishes to survive. How best to cost effectively meet the customers' needs and remain in control of the supply chain is a difficult challenge but certainly achievable.

Future developments not discussed include Radio Frequency IDentification (RFID) tagging where bar codes, initially on pallets and high value SKUs, are being replaced by these tags which can either transmit or reflect a 96-digit number back to a receiver. It means that the bar code on products does not have to pass the scanner in a specific orientation for the coding details to be read. Developments are currently stalled while international standards are developed and agreed. The potential is for the ending of most of the manual intervention to read labels on products both in the supply chain and within retailer's stores.

Increases in fuel and energy costs are important factors and could have significant implications on a national distribution centre and the modern centralised economy of scale factory. Small local factories may in future be able to undercut rivals due to significantly reduced distribution costs!

Traffic congestion is also becoming a real concern in many countries.

The apparent unstoppable rise of major multiple retailers with the apparent decline of local and corner shops must also be a cause of concern in some countries. Strong brands will be all the manufacturers can lever to ensure that their products stay on their shelves although many supermarkets now favour their own label products in preference to other brands.

The final development considered is that of the internet linking the supply chain in ever closer co-operation and company relationships and interdependencies.

This will allow raw material manufacturers access to actual consumer demand for the carbonated soft drink manufacturers products and their plans so as to further optimise their stocks and production capacity.

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11 Quality, environment and food safety systems

Ray Helliwell

11.1 Why have systems?

11.1.1 Definitions

Normally, if a job is to be completed properly, then 50% extra time needs to be allocated to it. This may be mundane, but worthwhile, because that extra effort avoids repetition of those parts that went wrong. Attention to detail; not just completing an action, but recording the fact so that everyone can establish that it has been done, reviewing the consequences to make sure the correct result was obtained, changing the way it is done to make it better, easier, cheaper, quicker next time and informing or training those who need to know. It takes a special sort of temperament to design and implement operational, sensible and cost-effective systems. Persistence and patience, suspicion and cynicism are all needed whilst maintaining a logical approach to achieving the corporate objectives.

Some definitions are as follows:

Quality = Consistency

Environment = Waste produced

Food safety = Risk of hurting someone

Management = Giving instructions

Systems = Getting the job done properly and efficiently

In summary – making good drinks consistently, wasting little and hurting no one.

That puts the very important systems part in perspective. It is easy to say that employing someone to design management systems is a pure overhead cost and is money off the bottom line, but *not* designing them takes much more money off the bottom line, and much more unpredictably.

11.1.2 Space shuttle fails

Looked at from another point of view, not only is the unpredictable bill or court appearance unacceptable but the benefits are also legion, primarily because if the procedures have been designed at the correct level (i.e. starting with the Chairman), and are agreed by the team below, and implemented by properly trained personnel, then they will cope with, almost, any circumstances. Why ‘almost’? – human error caused even the space shuttle to fail. If too complicated, with many tiers of decision making, communications fail and accidents happen more often. Manufacturers are only asked to be ‘reasonable’ and ‘duly diligent’, not perfect. The skill in this field is to know how minimalist an operation can afford to be, yet still protect against multiple concurrent human omissions and errors. The term ‘minimalist’ is used because, if a system is designed to be inexplicably labour-intensive or complicated, you can be confident that it will not be carried out properly or, worse, not at all, not to mention being over-expensive. Systems need to be logical, easily understood and have a reason. An additional benefit is that each company can now more easily control the input performance from its suppliers because the systems used demand records of all critical information, thus providing an audit trail.

11.1.3 Risk management

Another related issue, ‘risk management’, is applied to all company activities. This has always been an issue in product quality but, more recently, food safety and environmental issues have been added. Quality is a ‘given’ because formalised management control systems have been applied to it in most companies for a decade and more; these other issues now need the same treatment. Food safety concerns (real and imagined) have destroyed major brands and negated profits. Product recalls are now so frequent that there is a web site to list them. However, because recalls are now more common, the stigma of product failure is less and rarely means the demise of a brand or company. Nonetheless, the impact on company profits is often severe, and the resulting internal company conflicts are often ‘career-changing’. The environment has been largely ignored by most of the industry over the decades. Now it has been pushed up the political agenda and the consequences are to be seen in legislation and on budgets in all manufacturing areas. The new EU style of reporting company results means that the company environmental risks (and performance) will need to feature in annual reports.

11.1.4 A solution?

In order to address all these concerns, soft drinks companies need a solid management control structure, expert technologists, and sound, cost-effective management systems to implement the board’s objectives. The author’s perspective is from factory and production control, but there is always an impact on the consumer, customer or the environment for every activity. Achieving control through management systems is the only way forward and the International Standards Organization products can be used throughout the world.

11.2 Management control

11.2.1 Constraints – legislation

Much of this book is about machinery, technology and the intricacies of the formulation and production of soft drinks. From the beginning of product formulation, much legislation needs to be understood and translated into making safe and compliant products. This inexorable introduction of legislation is a feature that will continue. Having understood every other aspect of soft drinks, there is no point in starting a filling machine until it is possible to make millions of packages, all identical, and within specification, with no errors or defects and to continue to do so with certainty to the last bottle or can; this is the crucial point. In addition, it is no longer acceptable to be in a manufacturing industry if the environmental impacts of the process or, to a lesser extent, products, are outside acceptable limits. Consumer awareness and public access to company activities and performance have provided unprecedented pressures in this respect.

Once this fact is accepted, it quickly becomes apparent how ineffective efforts are if not implemented in a controlled way. One can see, above, how there is the first inkling of the constraints put on the industry – 'within specification', and 'no errors or defects'. These are expected in the products we buy each day, but how can this be made to happen in the beverage industry? If these product quality principles and targets are used, we will automatically meet the requirements of UK legislation, even the most recent Food Hygiene Regulations 2005. The legislation is designed to protect the consumer and the public at large but falls far short of any defining management systems' requirements. These regulations though, for the first time, spell out the obligation to be able to trace the materials used back to the supplier. It is hard to imagine a soft drinks company that has not done this for many years. There is, also to be implemented in the UK in 2005, the Pollution, Prevention and Control Regulations providing the additional constraint of managing and minimising the environmental impact of manufacturing. Though the legislation cannot be ignored, it can only realistically provide a minimum requirement, not act as a leading light for good practice.

11.2.2 Stakeholders determine your future

There is a much more exacting, unwritten, agreement with all the stakeholders – consumers, customers, employees and shareholders – based on their expectations of product quality, product image and, ultimately, the company image. Often this provides the means to differentiate between products and between companies in the public's perception. To work at the limits, with weak principles (and systems), just about meeting legislative requirements, and sometimes compromising on quality is an uncomfortable place to be. In the lowest margin businesses, it may be born of necessity. To be ahead of the legislation, taking pride in meeting increasingly challenging quality, environmental and food safety targets, whilst minimising all aspects of corporate risk, can only be achieved by strict management control of all company activities.

11.2.3 Size matters

The size of a company makes a considerable difference to the management techniques employed. Management control in a small company is by a close-knit and dedicated management team, with a consistent approach and common (or, business) sense. Often, such a company can see no point in a systems approach because the staff has also been there for many years; control of the processes is achieved through regular personal contact with the management team. It also requires a close relationship with suppliers, customers and with the local authorities. This team may be the owners or board of directors who will be dedicated to the success of the company (and directly rewarded in relation to that success). This management method quickly breaks down as a company increases in size. Besides having to maintain the effort 24 h a day, the management team has to contend with not just local but national and international legislation, and similarly widespread customers. Procedures carried out personally also need to be carried out by others and, thus, need to be communicated.

11.2.4 Experts, but not owners

For a larger company, the concept of a dedicated management team is just as valid – a team of experts, often with many years of soft drinks experience, but now more remote from the day-to-day operation and more remote from the ownership of the company. The outputs of this team are specifications and documented procedures to be achieved and implemented by others in the development, production and distribution of consistently high quality and safe drinks. The result is still management control of the company, except with this additional layer of communications. It is this need for communications between employees who rarely, if ever, see each other that makes the difference between needing and not needing management systems to achieve the necessary degree of control. That is not to say that management systems are not applicable to, or cannot help, smaller companies; the discipline of applying the principles of a management system can assist in the efficient running of any company. Returning to the crucial aspect of ‘success or failure’ – the main criterion, regardless of size, is how the principles and controls are communicated and implemented. This chapter will offer an insight into the main management systems related to control in the beverage industry. It cannot, however, help much with implementation – that remains the domain of the readers (and, if necessary, the management gurus).

11.3 Management systems

11.3.1 Four stages

Any management system has four stages: the generation of a compendium of management decisions (policies and procedures in a manual), assistance with the method of implementation (training in the procedures), a list of data requirements (forms or computer records) that must be kept to verify that the management decisions have been implemented and the review of the outcome (to act as an improvement mechanism).

11.3.2 Decisions

Decisions provide a formula on how to not just survive, but to prosper within a *tough legislative framework*, to meet the *exacting specifications* and to *control the processes*.

The management decisions taken in any company, without a system to communicate them, become just a dusty file on the shelf (or, these days, an unopened file on the computer). The word ‘decisions’ can mean specifications, work methods, equipment use, procedures, information-gathering requirements and system maintenance reviews. They will not all be in the one manual, or in just one location though they are often referred to as ‘The Manual’. One way to help is to make sure that the decisions include informative content and are linked to the forms (or other information-gathering method) to be used. The keys to a good management system is to have the correct persons taking the decisions, the correct accessibility of them by trained staff and, critically, a culture such that personnel, at all levels, have confidence in them. On the other hand, staff must be made aware of the limits of their freedom to act, that is, to know when circumstances are outside normal operating parameters, how to refer back for new decisions. Once all the decisions are collected together and written down, we have the wherewithal to run the company – the start of a management system that no-one has any excuse for not complying with. It remains for this team of decision makers to maintain them in a current and unambiguous state.

11.3.3 Make the product

Next it is necessary to provide resources, the correct equipment and personnel, and to communicate the decisions fully. Communication alone is sometimes not enough. There is always an awareness of the need to train new employees, right from induction into the company. The fact that new procedures sometimes need more than just a briefing and a new form printed out is often missed. It is necessary to demonstrate how the system fits together, what the logic is, why certain measurements need to be taken so frequently, why the start-up procedure has to be carried out in a set order. This sort of communication event forces the decision makers to question their output, receive criticism on it, and provide credibility and confidence in the decisions. No matter how experienced, there is always something new to learn.

11.3.4 Test and record results

Gathering results from tests and confirmation of actions taken during production (or any other process) provide a permanent record of the conditions that pertained at the time any action was taken or can/bottle was produced. This often results in, later, being able to identify the most likely cause of failure. The most common occurrence is when a product goes out of specification, then the production team identify and isolate the product(s) affected. The plan is always to isolate slightly more than is strictly necessary and to re-check it later to see exactly at which point the process failed. Many errors can then take place. First, the cut-off and re-start points can be miscalculated, particularly, for example, if some of the product went into a tunnel pasteuriser. Then, the order of packing onto pallets probably does not quite stay the same as when filled – for example, mixing on the multi-lane conveyor. Then, the person testing misunderstood the pallet numbering sequence, particularly as the last pallets were removed before getting a pallet label, just to get them out of the way. Not to mention that whilst waiting for the last of the product to come out of the pasteuriser, the first pallets were despatched before being isolated because the product was desperately needed and it happened at shift change and no-one passed on the information. It is always a sad conclusion to an investigation when it is found that everyone knew there was a problem, the product was isolated, but some of it still escaped to the customer. The system should protect against this.

11.3.5 Review

The final stage is that of review. To complete any system, it is essential that all reports of system failure are gathered. These can be where new circumstances arose and the system was not yet in place. It is the breakdown of communication, the production of a defective product, out-of date specifications or procedures being used. Some of this will be reported internally and some by the auditing of the system and, sadly, some will be reported by the customers. A review of all these items will give rise to amended procedures and, occasionally, a team may need to be gathered to work on an improvement programme for the more intractable problems. This review is crucial to the well-being of the system.

Those already familiar with the International Standards will, hopefully, recognise that I have described the ‘Plan, Do, Check, Act’ cycle for continuous improvement that is a common feature of the International Standards, of which more later, which is tabulated in Table 11.1.

Table 11.1 Plan, Do, Check, Act.

Plan	Do	Check	Act
Put management decisions in a manual	Train personnel and make it happen	Do the tests and produce the records of events	Review and improve

11.4 International management systems – why?

11.4.1 Notice board systems

Before the introduction of international management systems, written confirmation of decisions was often a notice to employees on a notice board, and was only used for the most important issues. The 'notice board approach' was mainly used to protect the management, on the basis, 'you have been warned'. Now, the written confirmation is a 'procedures manual'. It would be erroneous to assume that the real purpose is anything more – the prime objective in a current litigious world is to carry on the business without resulting in directors spending time in court (or jail!). Fortunately, this is achieved by carrying on our businesses in such a way as to protect our customers from harm – mutually beneficial objectives. The procedures manual is needed because the notice board was not large enough to hold all the essential information. It is now fairly rare to see a notice board with a sign informing that,

> 'All employees are responsible for tidying their own work area'

as was the case less than twenty years ago. This sort of information is now more frequently included in the induction training. The more positive aspect of the procedures manual is that it is written by the 'dedicated management team', whose wide experience and certain knowledge that the 'customer is king' keep it indispensable.

11.4.2 Detect and protect

The method universally accepted for implementing decisions and for ensuring management control is 'documented management systems'. For example, a manual may say that all sales orders must be reviewed for completeness. Alone, this is sound advice but is useless unless the mechanism is provided. Entering a sales order onto a computer system from a written order form, the next text in the manual may say that each order must be entered twice. The computer system will have been set up to prompt and accept the data twice. There will always be an awareness of how difficult it is to type long lists of numbers with consistent accuracy; a computer cannot check against the paper copy, but it can match two sets of data to detect input or 'keying' errors. If it is particularly important, the procedure may be made more fool-proof by ensuring that the order is entered from two different computer operators so that anyone with a particular tendency to make a particular type of mistake is not given the chance to make the same mistake twice. This sort of system is assisted by the computer's inability to move to the next stage – not registering the order without the matched inputs. The system needs to be designed with human failings foremost in mind, and the machinery (or computers) must be set to detect and protect against them.

11.4.3 Automation = automatically wrong

There is a different problem in a factory where the process continues automatically until someone intervenes. Having the latest technology is no guarantee that the output can be expected to be within specification. Neither can a set of finished product analyses provide a guarantee. Many circumstances arise between the tests to catch out the unwary. Nevertheless, a test regime needs to be set to ensure that the process is producing within specification. The frequency of tests is based on two criteria: first, based on the level of confidence in the particular aspect to remain within specification, and second, based on the cost if a particular test shows that a defective product is being produced.

The first is one that most machine operators can see and agree with. The second is much more difficult to decide upon. This sort of cost information is rarely available at the factory floor level but is essential to understanding the reason for the test regime. Automation does not mean automatically right.

11.4.4 Quantity and quality

The history of how such management systems have come about is distant and intricate. Following the industrial revolution, it was necessary to improve the efficiency of physical labour input. The term 'work-study' came into use but it was rarely rated for the end result. It did, however, often result in the finding of more efficient ways of performing a task – parallel running, multi-tasking and automation. Automation: once physical effort was made less relevant by the accelerating stages of automation, many companies restructured to remove their 'work study departments'; getting the maximum physical effort from an employee was no longer important. The politics of labour relations also played its part. Change, brought about by improving technology, reduced manning but increased the skill levels required. It is certain that this has been a factor in redirecting progress as the 'people skills' lagged behind technological advance, producing the so-called skills gap. The emphasis moved to one that made the newly automated systems maintain their own performance, with machine setting specifications, tighter tolerance ranges, preventive maintenance techniques, quality control measurements, action limits and acceptance criteria – all targeting process control. 'Quality control' becomes 'quality assurance' when the process becomes the subject of our attention. It is essential to ensure that we get quantity and quality.

11.4.5 Systems converge

Many countries have been working on management systems. The individual efforts have been coordinated by the International Standards Organization (ISO), bringing today, common elements and a convergence in concepts used in each of the standards. The International Standards Organization has taken ownership of, and developed, the systems that now need to be examined more closely. The three management systems have each followed a different route to becoming internationally recognised, but are now known simply as ISO 9001 (Quality), ISO 14001 (Environment) and ISO 22000 (Food Safety).

There is another simplistic way of looking at these standards that might assist with understanding their raison d'être. ISO 9001 is designed to prevent customers and consumers from prosecuting the company or its employees, ISO 14001, neighbours and environment watchdogs, and ISO 22000, the food enforcement authorities. No matter how these standards are viewed or implemented, nor how we evaluate them, each one has come about through public and political pressure. ISO 9001, came about when we (as a country) could not produce quality goods and imported too much, ISO 14001, when environmental groups were activated by seeing the unsustainable exploitation of the earth's resources, and ISO 22000 when globalisation of the food industry meant we affect many more people when a production mistake is made. These three standards were a sensible and measured response to the problems facing the country, also enabling industry to demonstrate that it is both 'reasonable' and 'duly diligent'.

11.5 The standards – a brief background

11.5.1 ISO 9001 is the master

Note that the reason for the three sets of letters is that each is a British Standard (BS), a European Standard (Norme Européenne, or commonly called EuroNorme – EN) and an International Standard (International Standards Organization).

The requirements for a quality management system provides a series of controls over all the aspects of a business (any business), and often known just as ISO 9001. It would certainly be erroneous to think that the title refers to just product quality; it represents all the customer-specified aspects of business: product, delivery, service, invoicing and complaints, that is, the quality of the management system, and thus the quality of the company.

11.5.2 Customer pressure

Earlier it was demonstrated how industry has moved forwards from the belief that automated processes are perpetually under control. It is now rarely acceptable for a retailer to simply replace a defective bottle or can. The complainant has been

Table 11.2 Audit types.

Type	Auditors	Subject to be audited
1st	Internal auditor	Internal systems
2nd	Senior internal auditors	Supplier's systems
2nd	Customer's auditor	Internal systems
3rd	Independent auditor	Internal systems

inconvenienced, sometimes frightened and, occasionally, physically harmed. This reflects badly on both the retailer and the manufacturer. The retailer's response to the consumer reflects the degree of commitment to creating a quality corporate image. The response is always going to be more generous in those instances where the manufacturer is going to pick up the bill and more generous still if the retailer is trying to maintain a high level of customer confidence and, thus, loyalty. The policies drawn up by larger retailers on the handling of complaints and, more importantly, the allocation of the costs are often seen by manufacturers as draconian. Letting customers or consumers down is not an option.

11.5.3 Customer audits

The soft drinks industry has been subjected to a plethora of second party customer audits (Table 11.2). These should be fine if based on knowledge of the industry, the specifications and the risks; an opportunity to see things differently and improve controls. Unfortunately, for many years, there was no common standard against which to audit. Each manufacturer had to divert resource from an 'action' rôle to a 'tour guide' rôle as successive auditors needed attention. The risk of either not appearing to take the customer seriously, or not being able to answer the questions, meant that top technical staff spent weeks every year repeating the same information. The motivation for these audits was initially to protect the retailer from the law – selling products 'not fit for purpose' – but also to provide a quality image. If they provided a better product and service than their competitors, they could justify a higher price. The pressure seen by the retailers from their customers for better quality products came to industry through this route. The response was to devise a common quality system.

11.5.4 A standard is born

The UK Government tasked the British Standards Institute (BSI) and manufacturers to produce a set of quality procedures. In 1979 it became BS 5750 (now known as ISO 9001). This was at a time when British goods could not compete with other nations' goods because of a perceived quality deficit. Its original target was to create consistency for 'Kite-marked' products. Many products had a British Standard and gained a Kite-mark status. The credibility of the Kite-mark was at stake because the factories did not maintain the same standard for all their commercial production as they did for the samples submitted to BSI for testing purposes. All manufacturers realised the benefits and their customers were desperate for improvement. The difficulty for BS 5750 was that hygiene standards were not specifically mentioned and were left to each manufacturer. The only guidance up to this point had been the Codex Alimentarius – a post-war (1961) European food standard devised jointly by the World Health Organization and the Food and Agriculture Organization. The particularly important extract from this, which was groundbreaking, was the development of the concept of Hazard Analysis and Critical Control Point (HACCP) food safety studies. But, eventually, the British multiple retailers, through their industry body – the British Retail Consortium (BRC) – came together to set food industry hygiene standards. Although the BRC Standard is also not universally accepted, it is sufficiently established to have independent accredited auditing bodies carrying out audits against it with the intention of one audit providing the necessary information and certification for all the retailers. The International Standards Organization (ISO) have, at last, gone one step further, providing the text for a Food Safety Management Standard – ISO 22000 – which includes the requirement for a HACCP study. It may be that these two standards can co-exist in the UK. The BRC Standard is audited by reference to a very prescriptive audit checklist, whereas ISO 22000 is audited on the basis that (as with ISO 9001) the company will identify what is important, then demonstrate how to control it. This leaves the auditor and manufacturer more flexibility in their approach. Only time will tell whether ISO 22000 will provide the extra confidence and protection required, or whether the retailers will continue to insist on maintaining their own system. All the systems need to spell out: what to do, how to do it, who is responsible, how you know when things have gone wrong, how to stop things from going wrong and, essentially, what to do when things go wrong.

11.5.5 Is ISO 22000 necessary?

Anyone writing an ISO 9001 system for food manufacturing management control would find it very difficult without having carried out a Hazard Analysis and Critical Control Point (HACCP) study. In the ISO 22000 and BRC systems, it is required to use the HACCP system. This provides the key controls to establish the safety of the food product. It may be considered that this rather makes the Food Safety Management System (ISO 22000) redundant if only HACCP were to be specifically included in ISO 9001. Unfortunately, many industries require some unique set of controls. ISO 9001 would be an encyclopaedia if it included them all. So why does ISO 22000 exist? It is also the difference between product quality and product safety that is at stake. Although ISO 9001 should automatically take care of product safety, meeting the specification to produce a quality product diverts attention from very basic issues relating to product safety and it is important to recognise the difference.

11.5.6 Other standards

It is useful to point out here that there are other systems for other aspects of soft drink businesses. The main two are

OHSAS 18001 – Occupational Health and Safety Management System, which appears to be slowly becoming an international standard and has been made compatible in format. In terms of job function, this one joining the other standards will certainly provide motivation for more companies to employ Management Systems Managers to cover all the critical risk areas. Currently, because this is not part of the ISO group, it is considered to be 'special' in some way, often resulting in companies employing a Health and Safety Advisor (Supervisor, Manager etc.) in addition to the routine Quality Manager or Quality Systems Manager. ISO 17799 – a guidance document for companies wishing to manage information security. IT control? Certainly a desperate need here, but it is understandable that this standard is still in its infancy. There are so many aspects of computer usage and so many problems. The industry is still developing and new risks arise with each new phase of the information and communication boom. Company objectives have changed from one of IT being a wonderful means of doing business better and quicker, to one of finding new ways of slowing it down and restricting access to maintain control. The standard arose as BS 7799 Part 1 – the guidance, and Part 2 – the formal standard to be met.

11.5.7 Systems director

It is impossible to discuss all of the related quality, environment and food safety standards within this chapter and so, below, the emphasis will be on the ISO versions, see Table 11.3. This is not to say that these are the best in all circumstances, but the principles of all will be very similar because there is little to disagree about with basic management techniques. The main difference, for example, between ISO 14001 and the European Union's Eco-management and Audit Scheme (EMAS) is fundamentally that a public statement of environmental performance is required in EMAS. In ISO 14001, each company can choose how much information to share with the public providing that there is a procedure to spell out how it will be done. Through the new corporate reporting regulations, the ISO 14001 companies will

Table 11.3 The international standards.

System no.	Common name	Latest revision	System title
BS EN ISO 9001	ISO 9001	2000	Quality management systems – requirements
BS EN ISO 14001	ISO 14001	2004	Environmental management systems – specification with guidance for use
BS EN ISO 22000	ISO 22000	2005	Food safety management systems – requirements for organizations throughout the food chain

soon find that this difference is eroded or removed. There is much talk of integrating the standards at the implementation stage, and many companies have achieved this. It is perhaps time for the standards to become one, with appendices for each aspect of company activity. Perhaps the main standard should simply be called Corporate Management Systems, and be controlled by the Management Systems Director.

11.5.8 Standards improvement mechanisms

The standards go through regular 'updates' and this is a feature of all the British and international standards, about every 6 years. There is intended to be a convergence between these standards as the principles and many of the management control features are common to them all.

The standards set out the requirements which, when applied, can be subjected to independent audit to establish an organisation's ability to meet customer, regulatory and the organisation's own requirements – as stated at the beginning of ISO 9001. They also include a process-driven approach to continual improvement.

A chart relating to the 'Plan–Do–Check–Act' process is present in both ISO 9001 and 14001, but embedded within ISO 22000. The text is slightly different to take account of the different objectives, but in summary:

Plan: Establish the objectives and processes necessary to deliver results in line with the company's policies.

Do: Implement the processes.

Check: Monitor and measure processes against policies, objectives, targets and legal requirements and report the results.

Act: Take actions to continually improve the process performance.

It can be seen from this alone that the 'dedicated management team' spoken of earlier needs to consist of a wide range of skills; without these skills, a company will not be able to produce a manual of procedures to be implemented. Considering the credibility of the management system, if the management team is not aligned with the company aspirations or image or, equally, not in tune with the production capability, or available resources, then any management system they design will fail. The executive will consider it an expensive and unnecessary luxury, or the teams implementing it will consider it to be out of touch with reality. Evidence of both of these is easy to see when auditing. Communication skills are, therefore crucial to maintaining a cycle of improvement.

11.6 ISO Standards – common elements

Many elements are common to all the Standards. It is not proposed to go into the detail of these as they are fundamental to good management. Included are the allocation of responsibility for key actions, allocation of adequate resources, calibration of key measuring equipment, document control, corrective and preventive action mechanisms, training, audits and reviews.

This section now discusses the elements that are different in each standard from an auditor's point of view.

11.7 The quality management system (QMS) – BS EN ISO 9001

Note: **For cross-referencing purposes, square brackets [ ] provide the relevant ISO Standard paragraph nos.**

11.7.1 Resource management [6]

Human resources are important [6.2] and the 9001 Standard deals with the physical infrastructure associated with them [6.3]. This clause has the inbuilt control that the process equipment and buildings must be to the standard needed to achieve conformity to product requirements. It is subjective unless there is evidence that some lack of infrastructure has caused product failure. For example, there are rat droppings in the syrup room and there is no pest prevention contract in place, or, the bottling plant roof has a rusty/flaky painted girder framework and there are no empty bottle covers prior to the filler and capper in-feed.

11.7.2 Contract review [7.2]

The review of a contract is a case of checking understanding with the customer. The supplier needs to ensure that the customer's requirements are understood – specification, quality, quantity and service requirements. This is often carried out during a telephone conversation or from a direct computer link. By this time, the specification and quality issues will have been agreed; the call is to say how much, when and to where it should be delivered.

11.7.3 Purchasing [7.4]

This is difficult territory with great potential for misunderstandings. Put simply, the raw materials, packaging materials and processing aids must all have an agreed specification – agreed by the best technical minds a company can afford. Too slack a specification can lead to the purchasing team downgrading the materials to reduce the price (believing the specification provided) with subsequent costs in production line inefficiencies as the materials fail to perform, customer dissatisfaction as the packs fail by tearing open and, worse still, consumer dissatisfaction when they find the lemonade is pink and tainted (hopefully, harmlessly) from cheap materials.

11.7.4 Product realization [7]

The production process is crucial; the need here is to have specifications for the products [7.1], a testing regime and the acceptance criteria. In other words, the tests

Table 11.4 Record retention periods.

Controlling influence	Time required
Financial	7 years
Legal (product-related)	3 Years
Legal (other)	Specific to regulation
Internal communications	1 week–1 year

each product must go through successfully in order to be released for sale must be detailed. Records of the test regime and the results of the tests need to be retained. The testing regime is based on predicting what can go wrong, then testing that it hasn't (Table 11.4).

11.7.5 Product development [7.3]

Despite new brands being relatively rare, great effort goes into packaging redesign to make existing products stand out as different. New artwork, new materials, light-weighting and multi-packing: all of these changes need to be carried out in a controlled way. The standard requires a good development brief [7.3.1] from marketing functions, the functional and legal constraints on options [7.3.2 and 7.3.3] and then review against the 'brief' [7.3.4]. Finally the test and trial to check out uncertainties [7.3.5].

11.7.6 Control or test [7.5.2]

The most important concept of the ISO 9001 standard gives producers a stark choice: control or test. 'The organization shall validate any processes for production . . . where the resulting output cannot be verified by subsequent monitoring or measurement'.

Interpreting ISO 9001 is a matter for auditors, but in essence, the above statement is saying that if each item is not (or cannot be) analysed or measured, then the company must ensure that the process is under control. Quality control (QC) is the final measurement of output against specification; quality assurance (QA) is about controlling all the known process variables to guarantee that the output is assured to be within the specification. In the beverage industry, QC checks cannot be carried out on every can or bottle, as most are destructive, which leaves us with QA, and sample testing as a QC backup system.

11.7.7 Quality assurance – process control

The process needs to be understood. Then, any combination of possible circumstances needs to be accounted for. Take as an example a tunnel (walking bed) pasteuriser. The plant has been designed to take a fixed length of time to transfer a can or bottle from one end to the other. This, at the temperature set, will provide the necessary pasteurisation units (PUs) for this package and product. The tests have been done, with time and temperature parameters set to provide perfect product. A development chemist then accounted for the possibility that the pasteuriser will break down, and put a ‘maximum time’ in the specification (the point beyond which the product is detectably ‘cooked’ to taste). How can it be guaranteed that every pack that goes through it has had the minimum temperature and time, but not more than the maximum time required?

Thus, the failure modes of the pasteuriser have to be considered. What if one set of hot water jets fails, or just operates at reduced pressure? What if the walking bed stops and starts many times in the length of a single cycle (typically about 30–45 min)? What if the temperature is not even across the width of the pasteuriser? Add the possible human errors – for example, if the in-feed and discharge conveyors run next to each other and samples for an average weight test are taken from the in-feed and returned when tested, to the discharge.

11.7.8 Quality control – sample testing

The concept of sampling has been needed ever since mass production came about. Sampling can be very wasteful. It is always a result of a statistical risk assessment but it is necessary to understand the modes of failure. This introduces the concept of ‘positive release’. The product must not be released from factory control as ‘fit for sale’ just because it is in a warehouse.

The rules are:

1. decide how it will be physically prevented from leaving control until declared as ‘fit for sale’,
2. decide what parameters of the specification are essential (CCPs + key quality features),
3. decide who is competent to make the ‘fit for sale’ decision and give them the authority and responsibility,
4. decide which tests need to be done to establish that the product meets these parameters and make sure they happened.

How can a sampling regime be decided upon? The answers can be different for different products and for different production lines, or even on the same production line as it deteriorates with age.

Considerations must be given to the natural variability of the process, the frequency with which it goes out of specification and the ability to detect when it is going out of specification (including the predictability of this event). Factors such as this will determine the frequency and range of checks. The quantity of product for which loss can be afforded will also contribute to the test frequency decision.

11.7.9 Warehousing [7.5.5] and distribution [7.5.1]

Warehousing of products needs to ensure that the product is subjected to no conditions likely to accelerate deterioration, so, for example, stacking three pallets high is not always a good idea. A decision such as 'stack one pallet high' needs to be communicated to all – easiest by including this information on the pallet label. Still possible to ignore, but such problems with distribution can cause significant difficulties.

11.7.10 Control of non-conforming product [8.3]

Despite all best efforts, this is still bound to occur, and it needs to be planned for. It is necessary to identify clearly any product that is not within specification. This can be by location – in an isolation zone – or by labelling differently. The system used to establish good product from the non-conforming needs to be approved by the appropriate person and the decision-making process documented. The sampling regime, or stringency of test, needs to be given great consideration. There are three outcomes:

1. Scrap the non-conforming product
2. Separate and return the good for sale
3. Sell non-conforming as sub-standard product (if safe to consume).

These decisions need to be based on both food safety grounds and legality. Any product that is 'reworked' in any way must go, again, through at least as challenging a test regime as any normal product.

11.8 The food safety management system (FSMS) – BS EN ISO 22000

11.8.1 The standard of the future?

This food safety management system is the most recent to come under the ISO banner – in 2005. It will, if accepted widely, supplement (or possibly even supersede) the British Retail Consortium's Global Standard for Food. It is, however, difficult to imagine a company with a sound and well-established ISO 9001 system that does not already meet all the requirements of this standard because of the link through HACCP.

11.8.2 Policy [5.2]

The starting point for this standard is to have a food safety policy. It must be relevant to the company's position in the food chain and meet the requirements of both customers and regulatory bodies. Having decided on policy, it must then be supported by measurable objectives.

In addition to the food safety policy, a Food Safety Team Leader [5.5] must be appointed who, regardless of other duties, must head up a Food Safety Team. This team must have multi-disciplinary knowledge of the products, processes, equipment and food safety hazards. In effect, this is the Hazard Analysis and Critical Control Point (HACCP) team but now with wider responsibilities.

11.8.3 Pre-requisite programmes [7.2]

It would be easy to assume that the ISO 22000 standard merely enhanced the requirement for HACCP studies; however, it also includes what it calls pre-requisite programmes (PRPs). These programmes must be determined and implemented to, in effect, give the factory a chance of achieving its hygiene targets. Generally, these can be categorised as controlling the environment in which production takes place. Layout of buildings, utilities such as air, water and energy, and many others are listed specifically. This is quite a departure for a standard, to be so detailed [7.2.3].

11.8.4 Product characteristics [7.3.3]

As an early part of hazard analysis, it is necessary to establish all the characteristics of the materials to be used in the making of the drinks, and those in contact with them [7.3.3.1]. Besides the material specification, this can include delivery packaging, storage conditions and any other factors that may influence the safety of use. This information-gathering exercise is one input to the HACCP study.

Further, the end-product characteristics [7.3.3.2] need to be listed in a similar fashion, providing a full picture of the correct use and storage characteristics, including shelf life and storage criteria.

11.8.5 HACCP [7.6]

The need for an assessment of the hazards associated with each material used is required [in 7.3 and 7.4 in general terms]. However, the standard then goes on to a prescriptive approach, based on the Codex Alimentarius technique. As this is crucial to ISO 22000, it is summarised here. There are seven principles and twelve steps required to complete and implement a HACCP approach. The first principle is to carry out the study of hazards and it incorporates the first six steps.

Principle 1 – Conduct a hazard analysis (identifying potential biological, chemical or physical contamination that can affect health) A team of experts is assembled to draw up a full product specification, including its preservative regime, packaging and distribution method [7.3.3.1]. Mode(s) of use for the product and potential misuses or uses by particularly vulnerable groups of the population must be identified [7.3.4]. A flow diagram of all the steps in the production process must be constructed [7.3.5.1] and an on-site verification of the flow diagram carried out [7.3.5.1]. All the potential hazards that may reasonably be expected to occur at each step of the process up to the point of consumption must be listed [7.4.2.1].

Principle 2 – Determine the critical control points (CCPs) A decision tree should be used to identify whether any particular point is a CCP or not. If there is no control measure in place at a CCP (or elsewhere to the same effect), then the process should be changed to implement one [7.6.2].

Principle 3 – Determine the critical limits Limits should be set for each critical control point, sometimes several limits at one point [7.6.3 and 7.4.2.3].

Principle 4 – Establish a system to monitor control of the CCPs It is necessary not only to monitor but also to control, that is, to take corrective action if trends show that the limits may soon be exceeded, or alternatively, the responsible person notified [7.6.4].

Principle 5 – Establish the corrective action to be taken when monitoring indicates that a particular CCP is not under control Once a CCP limit has been exceeded, the corrective action is two-fold (as identified in ISO 9001). First, to identify the action to bring the process back into control. There is often a dilemma – does production continue to make a defective product because it is easier to adjust the process whilst it is running or, is the process stopped and a wasteful start-up procedure carried out after fixing the fault? Second, what to do with the product manufactured during the 'out of control' period. Such a product will need to be isolated, but how much and what can be done with it? [7.6.5, or 8.3 in ISO 9001].

Principle 6 – Establish procedures to verify that the HACCP system is working effectively Auditing the controls is an obvious verification activity but random tests or spot-checks can also reveal deficiencies [7.8].

Principle 7 – Establish documentation concerning the procedures needed and keep appropriate records. The tests carried out to demonstrate that CCPs are being monitored and are in control are the most obvious records. Procedures and training records for the persons carrying out the CCP monitoring need to be retained. In addition, those who carried out the HACCP study, their findings and decision-making process need to be documented [4.2 and others].

11.8.6 Decision tree

The 'decision tree' is an interesting device to enable clear thinking as to whether a particular control is a critical control point, or not. This is a logical series of

Table 11.5 Decision tree (for each step, ask the questions to establish whether it is a CCP or not. Remember to apply this at each step for each designated type of contamination).

No.	Question	Yes? Then take this action:	No? Then take this action:
1	Do control measures exist at this step?	Go to question 2	If not necessary for food safety, then not a CCP. If control is necessary for food safety then modify the step to include control and go to question 2
2	Will a subsequent step eliminate or reduce food hazard to an acceptable level?	Not a CCP	Go to question 3
3	Do the control measures eliminate or reduce the food hazard to an acceptable level?	Establish this as a CCP and apply control limits	Adjust the control measures, apply control limits and establish as a CCP

questions leading to a decision. The objective of this ‘tree’ is to push the critical controls as late in the process as possible. This seems to contradict the central belief for quality – rubbish in, rubbish out. So, for food safety, there may be no interest in ensuring that the sugar we are using has no nuts and bolts in it, that cable ties that the engineer dropped in the product tank when re-wiring were found or that the pump seal broke at the carbonator. The reason is that the HACCP study decided that the pre-filler filter, which will take all of these out before bottling the product, was the critical control point. This filter must, therefore, get a lot of attention – in particular, regular removal, sanitisation and inspection. In most of the food industry, this final filtration step is crucial. Unfortunately, failure of such filters has proven to cause the most serious problems in the beverage industry. In Table 11.5 the idea can be visualised. Food safety measures may appear to be almost completely the opposite of good business practice as the emphasis is on putting the control measure in as late as possible in the process.

The types of contamination are easily defined as:

- physical – for example, spanners, wasps, filter housings, cable ties, gaskets
- chemical – for example, orange juice (in your apple drink), c.i.p. chemicals, rinse-water
- microbiological – for example, from raw materials, employees, primary packaging.

It is also worth including production faults that can result in consumer injury, for example, chipped necks on glass bottles, sharp edges on a can seam.

The inclusion of an apparently insignificantly small amount of contaminant can have a long-term deleterious effect (particularly important for microbiological assessment).

11.8.7 No foolproof systems

On the basis that no matter how much effort goes in to create a foolproof system, this never eliminates human failings and the unexpected. The standard takes this into account and insists on having ‘contingency preparedness and response’ [5.7] so that, ‘not if, but when’ the unexpected happens, some forethought has gone into the process required to protect both the public and the company from the effects.

There is no specific requirement to maintain a record of the rationale behind documented changes in ISO 9001 but, in ISO 22000, there is.

11.9 The environmental management system (EMS) – BS EN ISO 14001

11.9.1 Drains and skips – duty of care

The UK government has tightened the controls on industry, starting with the large offenders and larger companies but, now, tackling smaller and smaller companies. All soft drinks companies are now affected by the legislation in one way or another. What was once British Standard 7750, a particularly unsuccessful Environmental Management Standard (EMS) in terms of uptake, succeeded, however, in providing the template for ISO 14001. The difference between EMS and QMS is that for EMS it is essential to delve into the detail of many pieces of legislation. Most environmental legislation in the UK has until recently been dealt with on a reactive basis. Liquids went down a drain and solids in a skip. A simplistic but frequently true state of affairs. The UK Environmental Protection (Duty of Care) Regulations have for many years controlled how we handle the general waste and the small amounts of ‘special waste’, but this has, more recently, been supplemented by much more specific and penal regulation. The control of liquid trade effluent, except in the largest soft drinks plants, is left entirely to the local wastewater treatment works. Consents required can prove difficult to comply with because of the pH of beverages. Cleaning materials also cause pH problems at the alkali end of the scale. The other key pollutant, mainly from spilt product and syrup and sugar tank washing, is chemical oxygen demand (COD). Most organic matter (e.g. sugar) provide a high COD. This source of sugar is an excellent medium for micro-organisms.

11.9.2 Producer responsibility

A general principle has been established that ‘the polluter pays’ and this has resulted in a series of regulations in the UK. An important and early addition was the UK Producer Responsibility (Packaging Waste) Regulations 1997. This was a complicated system of shared responsibility (throughout the supply chain) for the waste arising from businesses, resulting in a cost to recover and recycle post-consumer packaging. As beverage producers are too far from the end user to retrieve packaging directly, the result was the introduction of 'compliance schemes' (e.g. Valpak) who carry out this task through third party recyclers, but at industry expense.

11.9.3 Climate change levy

Climate change levy was applied in the UK to all corporate energy bills and meant approximately a 15% increase in, primarily, gas and electricity. The rationale was to provide an incentive to industry to reduce their carbon dioxide emissions. The Kyoto Protocol is an internationally enforceable agreement to reduce emissions. The UK solution was to provide 80% relief of the levy in return for a commitment to reduce energy usage.

11.9.4 Pollution prevention and control permits

This is the most significant and far-reaching piece of UK legislation for years which started as a European Directive – Integrated Pollution Prevention and Control – and has now been implemented in UK legislation as Pollution Prevention and Control Regulations 2000 – requiring sites above a certain tonnage output (300 tonnes of product per day, averaged over any 90 consecutive working days, excluding the weight of packaging) to apply for a PPC permit. The basis upon which the soft drinks industry has become involved is rather tenuous – as processors of vegetable material. The inclusion of sugar in beverages has been construed by the UK Environment Agencies as sufficient reason, although water bottlers are excluded.

11.9.5 EMS policy [4.2]

In ISO 14001, a policy statement must additionally include a commitment to pollution prevention. This is in line with the concept of continuous improvement, but becomes an increasing challenge once all the easy gains have been made.

11.9.6 Aspects and impacts [4.3.1]

The standard uses two terms 'aspects' and 'impacts' that need defining. In implementing and maintaining an EMS, these need to be generated for an operation. They are simple lists. The 'aspects' part is a complete list of activities. It is easy to forget some activities, particularly waste disposal, which can cause its own problems. It is often useful to break the mainstream activities into smaller, more specific activities, then list the environmental 'impacts' associated with each. Each activity can have several impacts, for example, the aspect of bottle blowing will have an impact on effluent (cooling water), refrigerant use, noise from the compressors, releases to air from the cooling towers and energy use.

11.9.7 Significance [4.3.1(b)]

Once a list of impacts is completed, each needs to be assessed for significance and the system decided upon to do this needs to be documented. The mechanism used is entirely your own decision. Typically, there ends up being three simple categories of 'action required' and so, the mechanism needs to be designed to put the impacts into these categories:

A. Active monitoring and control (mainly where there is a legal obligation, planning permission requirement or 'consent')
B. Less frequent monitoring, probably has impacts with a large cost to the company
C. Listed impact, with small cost and small impact (with potential to be upgraded if the activity or company focus changes).

Those in Category A require most attention, with a monitoring frequency, targets [4.3.3], a control mechanism [4.4.6], review [4.5.1] and corrective action plans [4.5.3]. They include any regulatory monitoring, such as trade effluent consent parameters.

Category B is a cash generator – looking at the expensive, but not necessarily regulated, utilities and services. This can be a useful target for cost savings if benchmarked against other companies. A way of reducing the bills is to break down where the cost is incurred, and apply tighter controls.

Category C is the 'just for completeness' list. Minimal cost, minimal impact. At any time, though, a change in legislation or the business can bring one of these up into the other categories.

The above is a simple approach which works, but you can definitely design more complicated ones. In essence it is A = legislation, B = financial, C = the rest. The assessment of the relevant legislation is crucial to understanding the controls we apply, or the data we collect, and the significance rating.

11.9.8 Legislation updates [4.3.2]

In all countries there is a requirement to establish a mechanism to keep abreast of the relevant legislation.

11.9.9 Emergency preparedness and response [4.4.7]

This standard demands that the business must attempt to predict what is likely to go wrong in terms of accidents and emergencies, eliminate or reduce the risk, and prepare to minimise the impact if it still happens. Some precautions are obvious, and some easy. For example, if a sugar tanker turns up and its hose bursts, where does the spillage go – to surface water or trade effluent? If to surface, then a simple drain cover mat in place during deliveries can prevent contamination of the local streams. Spill kits where vehicles re-fuel. Bunded pallets for caustic, acid and oils are expensive, but provide lasting solutions.

11.10 Systems – a summary

This chapter started with the simple problem of management control in companies and now has explored an assured and verifiable control of quality, food safety and our environmental impacts. In future, information technology, health and safety and, possibly, accounts may be controlled with similar systems.

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