Industrial charcoal making

FAO
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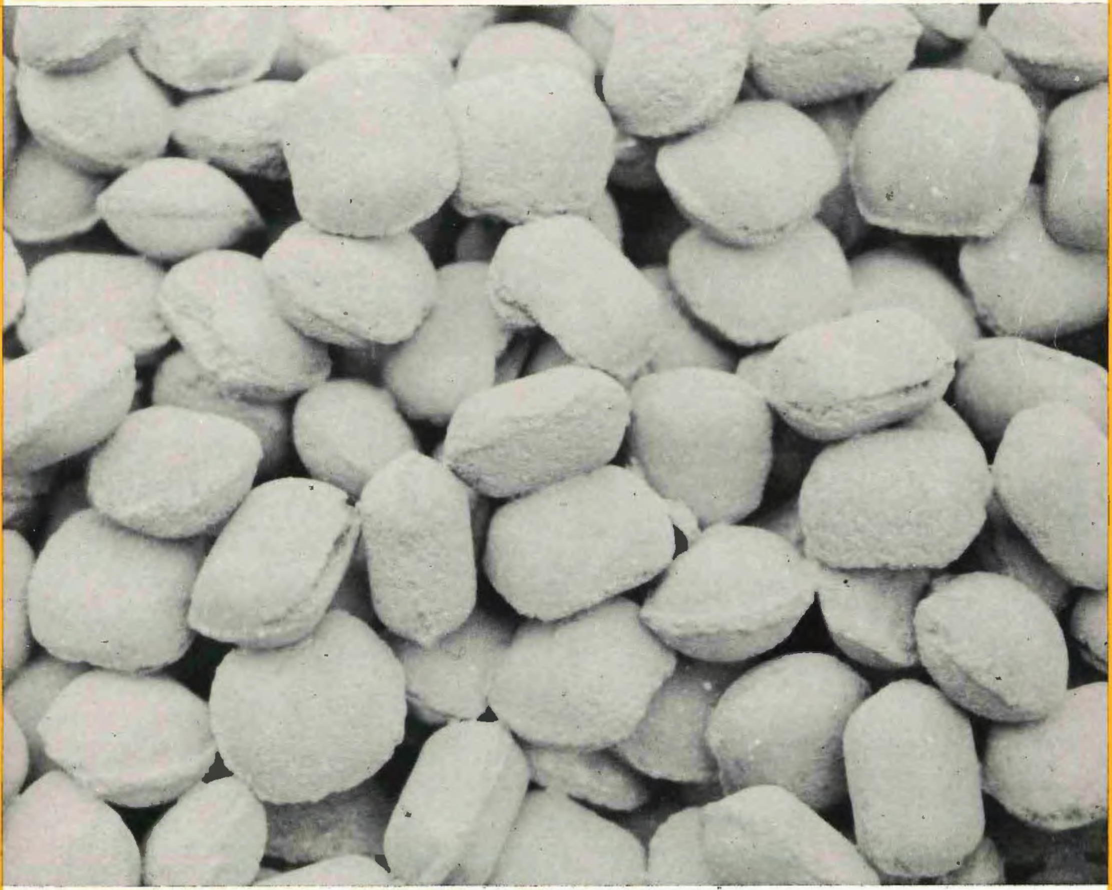

FOOD
AND
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Mechanical Wood Products Branch
Forest Industries Division
FAO Forestry Department

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INTRODUCTION

This manual on Industrial Technologies for Charcoal Making represents another step by FAO to help overcome fuel shortages in the developing world.

Energy is one of the most important commodities required to satisfy the physical needs of mankind. Over the years, limits in the availability, technological changes, locations of resources, prices and use of certain fuels have required the use of new sources of energy.

Furthermore, during the last years, the growing population, the continuing industrialization and economic growth of countries have led to an increasing demand of fossil fuels. The economic difficulties that most countries are facing, together with high oil prices, are bringing about a period of energy transition from an economy based primarily on hydrocarbons to one based increasingly on new renewable sources of energy. Although many technical solutions using new and renewable sources of energy have been tried during the last ten years, forest biomass, due to different technical, economical and social reasons, seems to be one of the most appropriate alternatives.

Sixty percent of all wood taken from the world's forests is believed to be burnt as fuel - either directly or by first converting it into charcoal. The proportion of fuelwood used to make charcoal can only be estimated but it is probable that around 400 million cubic metres are transformed into charcoal per year throughout the world.

In developing countries charcoal is mainly used as domestic fuel for cooking and heating but it is also an important industrial fuel. Large amounts are used in foundries and forges, in the extraction and refining of metals, especially iron, and in numerous other metallurgical industries as well as in cement factories and chemical applications. Also, in those countries with abundant forest resources the export of charcoal can be a profitable industry.

In most developing countries the traditional methods of charcoal making are the only technology known, but due to shortages and rising prices of raw materials in industrialized countries, new and improved technologies for charcoal production have been developed and taken into use during the last decades. Through technical achievements, the carbonisation of almost any type of forest, wood industry or agricultural residues became feasible and also higher energy yields were obtained by producing commercially valuable by-products. Progress was made in particular in carbonisation of small-sized biomass, in manufacturing charcoal briquettes and in the design of equipment for energy co-generation to produce mechanical, electrical or thermal energy, through the recovery of energy from pyrolysis gases.

The idea of this manual has been inspired by the Forest Industries Division of FAO with the purpose to inform and orient government agencies and managers of industries in developing countries concerned with improving the production and distribution of charcoal. The application of modern technology can make useful contributions in securing the supply of household or industrial fuels and in saving hard currency by substituting imported fossil fuels. The contacts with governmental planning authorities and private enterprises in developing countries show that the main factor obstructing the promotion and realisation of charcoal industries is the lack of knowledge of the existing charcoal technology. In many cases, assistance would also be needed in the preparation of a charcoal project.

This manual embodies the collective wisdom of charcoal makers of many countries and is offered in the hope that it will aid both to increase production of charcoal and, at the same time, to conserve forest resources by introducing more efficient methods of production.

The help of the consultants involved in the preparation of this manual is gratefully acknowledged, in particular that of Mr. Walter Emrich and Mr. Harry Booth who worked out the original ideas and to Mr. E. Beaumont who assisted in the final editing.

Chapter 1

INDUSTRIAL CHARCOAL MAKING TECHNOLOGIES

1.1 What are Industrial Charcoal Making Methods?

Charcoal making is an old and honourable trade. Its origins are lost in prehistory and the traditional methods of making it have changed surprisingly little from ancient times till now. The only new factors are that the simple methodologies have been rationalised and that science has verified the basic processes which take place during carbonisation and spelled out the quantitative and qualitative laws which govern the process.

New methods which have been introduced in some parts of the developed world have supplanted the old technology. Their newness does not reside in the principle of carbonisation itself but in the rationalisation of the use of heat, materials handling and labour and in some instances the recovery of by-products from the smoke given off during carbonisation.

These 'industrial' methods, for want of an easier name, in contrast to those described in (15) are certainly more complex in almost every way.

Since 'new' in the world of advertising is automatically assumed to mean 'better' it is not surprising that there has been an upsurge of interest in these new technologies by the developing world in attempting to increase the availability of charcoal and wood fuels. This Forestry Paper tries to supply a rational answer to the question:- "How can the industrial charcoal making systems make a useful contribution to charcoal production in the developing world?"

1.2 The 'New' and the 'Old' in the Industrial Technology

If one elects to make charcoal using one or other of the methods in this paper it will still be necessary to make use of the information in (15), specially chapters 1, 4 and 9, because with the Industrial technologies about 90% of the process from the growing and harvesting of the wood to the distribution and sale of the finished charcoal is still the same as with the traditional methods. The newness resides in the carbonisation step and the replacement of labour intensive methods of materials handling with capital intensive methods.

Some of the often-claimed advantages of the industrial methods are:

- The yield of charcoal from the wood is higher.
- Carbonisation is more rapid.

- Charcoal can be made from raw materials that cannot be processed by traditional methods.
- Industrial chemicals and heat energy can be recovered from the smoke given off during carbonisation.
- By recovering by-products from the smoke there is less pollution of the environment.

Let us take a closer look at these claims.

- The yield of charcoal is higher.

In traditional charcoal making part of the wood is burned to dry out and carbonise the remainder. During carbonisation there is also an exothermic production of heat as the wood structure decomposes to form charcoal and this supplements the heat derived from burning part of the charge. The most efficient of the retort sytems described later is capable of giving yields of about one ton of charcoal from about 3.5 tons of wood providing the wood is well dried and the retort operated properly. The best that can be achieved by brick kilns is about one ton from 4.5 tons of well dried wood.

Not all industrial methods however give such high yields and most will not work properly unless the wood is well dried. Traditional methods on the other hand will operate on substantially green wood but with much lower yield.

- Carbonisation is faster.

This is a rather meaningless claim. What one really needs to know about the system are answers to such questions as 'at what rate is charcoal produced per unit of capital invested?' or 'how much charcoal is produced per man year of labour employed?' That is to say at the end of the year how much charcoal do we have for how much investment in plant and working capital?

In the developing world capital is usually scarce and labour power abundant. When it is noted that industrial methods require massive investment, usually in off-shore borrowed funds and skilled labour; industrial methods lose a lot of their glamour and obviously call for careful pre-investment studies to see where they will really lead.

- New raw materials can be carbonised.

This is certainly proved for one industrial system, the multiple hearth rotary furnace. However, it is always necessary to ask if the new material can be 'successfully carbonised'. Many proposals have come to grief when this test has been applied. Nevertheless bark and sawdust and certain agricultural residues can be successfully carbonised now. But it is essential to ask before setting out to carbonise agricultural residues whether from all points of view this is the best use for them and if the resulting charcoal produced in the form of fine powder can be economically turned into briquettes and marketed in the particular developing country.

- Industrial chemicals can be recovered.

Most retort based industrial systems can allow the smoke given off during carbonisation to be captured and condensibles and gas recovered. The main problem in making this a success nowadays is the low price obtainable for these chemicals in relation to the high present day capital cost of setting up a recovery and refining system to process them.

- Industrial methods cause less pollution.

If the smoke from carbonisation is recovered then this source of environmental pollution is largely eliminated. This is a definite benefit where carbonisation is carried out in an urban environment. But industrial methods, especially where the smoke and fumes are captured for by-product recovery can pollute the environment in a more objectionable way. This can occur because inevitably in the process of by-product recovery, liquid effluents accumulate and have to be disposed of. If this is done carelessly then waste liquids toxic to fish and plant life escape into streams and waterways. Control of this pollution is not impossible - it just costs money.

1.3 The Trade-Offs in Charcoal Making

As in all industrial production processes, it is possible in charcoal making to trade-off part of an advantage in return for the reduction or elimination of a disadvantage.

To understand where such trade-offs may be worthwhile it is first necessary to understand clearly what the real objectives are in the charcoal making process. The first step to clearer thinking is to set-up a country-wide fuel energy policy or in this case a country-wide wood fuel energy policy which should be the framework within which all decisions of importance about charcoal making are made. The outline of how such a policy is drawn up is covered in (15) and will not be dealt with here since the main concern of this Paper is the carbonisation step and not the rest of the process which is more or less the same whatever carbonisation system is used. But the carbonisation step does reflect back and influence all other preceding stages and this has to be taken into account.

The factors which must be considered include: the yield of charcoal obtained from the wood; the capital investment required; transport economics for both the wood and charcoal; number of jobs created or lost; the relevance of attempting to recover by-products; the lift of the forest or other resource in relation to the time needed to recover the investment; the relative importance of the offshore content of loan and equity funds in the venture; and the capacity of the country to provide skilled technicians needed to operate the more complex 'industrial' types of charcoal making system. (34)

1.4 Yield - Investment Interactions

The most powerful decision making parameter in choosing a carbonising system for charcoal for most developing countries is the interaction between the yield of a process and the capital necessary to install it. A process which has twice the yield of a traditional one would obviously be chosen if the capital investment of both systems were the same both in amount and origin of the investment funds. But life is not usually so simple and there is normally a trade-off between yield and investment. For example if the high yield process requires substantial offshore loan funds to establish then it may be a better option in terms of local development to use locally available capital and labour to grow more wood in high yield plantations and avoid a committment to an offshore loan for a process which would probably generate far less jobs than the lower yield process. But if as is usual there is a shortage of either established forests or land on which to establish plantations then other factors being equal the capital intensive process may be attractive. Unfortunately in most developing countries which find themselves simultaneously short of land resource and foreign investment funds the decision is usually made for them and the best option they can follow is efficient use of available resources using the simple technology applied in the most efficient way. (15)

It is not proposed in this introductory note to pursue these difficult issues further but simply to emphasise strongly the need to be aware of the complexities of the situation which faces each country.

1.5 The Importance of Wood Preparation Costs

The final point requiring emphasis in this introduction is the matter of wood preparation costs.

Traditional methods are adapted to use wood in large pieces, in some of them whole tree trunks can be used. It is difficult to dry such large pieces before carbonising and so more wood is used up in the carbonising process to complete their drying before they carbonise. Thus the yield overall is lower but wood preparation costs are negligible. Industrial methods require the wood in small pieces of more or less constant size. Some retort systems even require the wood to be in the form of sawdust. Wood in smaller pieces is easier to dry in the air and hence the yield in carbonising is higher. Small dimension wood is also required for the mechanised feeding systems used in most industrial type carbonising processes. Where the wood is available already in finely divided form as sawmill waste, preparation costs are low. But in practice the amount of wood available in this form in the developing world in relation to the charcoal needed is quite small so that generally any industrial system adopted must face quite large wood preparation costs. This factor can never be disregarded.

Chapter 2

WOOD CARBONISATION AND THE PRODUCTS IT YIELDS

2.1 Carbonisation

Carbonisation is a particular form of that process in chemical technology called pyrolysis that is the breakdown of complex substances into simpler ones by heating. Carbonisation is the term used when complex carbonaceous substances such as wood or agricultural residues are broken down by heating into elemental carbon and chemical compounds which may also contain some carbon in their chemical structure. The term carbonisation is also applied to the pyrolysis of coal to produce coke.

2.2 Efficiency in Carbonisation

The carbonisation stage in the charcoal making process is the most important step of all since it has such power to influence the whole process from the growing tree to the final distribution of the product to the user.

Yet carbonisation in itself is relatively not a costly step. Even though retorts may be of high capital cost they do not require very much labour per unit of production. Typically the carbonisation step may represent about 10% of total costs from growing and harvesting the tree to arrival of the finished charcoal into bulk store. But the conversion efficiency of the carbonisation step works its way back to the point where the wood is harvested. A high yield in conversion means that less wood has to be grown, harvested, dried, transported and loaded into the retort or other carbonising unit.

The specific way the wood is carbonised is also able to effect overall yield because of the effect it has on the amount of fines produced. Fines may have no market at all or may only be saleable after going through a fairly costly briquetting process.

The three major factors which influence the conversion yield are:

(a) The moisture content of the wood at time of carbonisation.

(b) The type of carbonising equipment used.

(c) The care with which the process is carried out.

2.3 Measuring the Yield

Efficiency of carbonisation is expressed as the yield of charcoal in gross terms (at the side of the retort or kiln) expressed as a percentage of the wood charged or used-up to produce it. Normally only the wood actually used-up is reckoned. Thus unburnt wood which can be recycled is deducted from the wood used even though it represents a concealed form of inefficiency. On the other hand where indirect heating is used as in retorts or the Swartz type kiln, which employs an external fire grate, the amount of wood used-up in the heating must be included in the wood used to produce the charcoal. Account may be taken that in some cases this wood may be of lower quality.

Wood and charcoal must be measured using standardised methods. They need not be the same for both materials but they must be consistent so that results are comparable. In other words a consistent methodology of measurement must be adhered to. Properly measured conversion efficiencies allow different charcoal making methods to be compared. Also these measurements are essential in controlling large charcoal making enterprises.

The most accurate measuring system compares all quantities on a weight basis. To avoid complication due to differing moisture contents, the wood used is expressed on a bone dry basis and the charcoal is weighed bone dry and free of fines. Where moisture is present it must be determined and allowed for. To apply such a system, equipment for weighing and determining moisture content of wood and charcoal must be available. Unfortunately this is rarely the case in most charcoal-making situations. It is the method most suitable for research on processing and for the large industrial enterprise. Being free of inbuilt errors it is the final reference system.

A practical method which has been widely standardized in South America, particularly in the steel industry of Brazil uses volume measurement. Both the wood used and the charcoal produced are measured in cubic meters corrected for stacking and compaction errors. The wood is measured in steres (stacked cubic meters) and each stere is taken an equivalent to 0.65 solid cubic meters. The system allows for the effect of shrinkage of the fuelwood on drying and the reduction in volume which occurs when charcoal is transported and handled due to settlement. This settlement is the result of abrading of sharp corners of the lump charcoal and the formation of fine charcoal which has practically no commercial value.

The shrinkage allowance for fuelwood is based on experiments on the effect of drying and destacking and restacking as happens when a pile of dry wood is transported from the forest to the charcoal plant. The results show that a pile of 100 steres of eucalypt wood shrinks to 84 steres after 3-4 months drying and when the same pile is restacked its new volume is only

79 steres. Thus a reduction of 15% is allowed for drying and 21% for drying and restacking. The true contents of a pile of fuelwood are also greatly influenced by the method of stacking. Experience is the only way to overcome this problem in order to tell if the volume of the wood has been inflated by dishonest stacking.

The charcoal volume is measured by placing it in a wire basket having the base one meter square and height somewhat more than a meter. A commercial cubic meter of charcoal is considered to have a true volume of one cubic meter only when measured at the side of the blast furnace, that is to say, in the bulk storage depot. At the side of the charcoal kiln a cubic meter of commercial charcoal is considered to have a true volume of 1.1 cubic meter. In this way the contraction of the charcoal in transport and the production of useless fines is allowed for. The standard yield of Brazilian charcoal kilns using this system is reckoned as 1 cubic meter of commercial charcoal from every 2.2 steres of fuelwood. Volume measurement for determining charcoal yield is subject to certain intrinsic errors but it is a simple method, easily understood and can be performed 'out in the open'. It has a great advantage in the buying and selling of charcoal as it automatically discourages adulteration by wetting the charcoal and mixing it with sand and earth. The reason is that these actions have no effect on the volume. Further there is an incentive for the charcoal to be transported carefully so the reduction in saleable volume by settlement and production of fines is minimized. The temperature to which the charcoal is taken to in the kiln affects the measure of the yield by changing its content of volatile tarry material. Soft burned charcoal produced when the temperature does not rise above about 400°C can have a volatile matter content of about 30% and this is equivalent to a yield of about 42% on a bone dry weight basis. At 500°C the volatile matter is only about 13% and the yield about 33% on a bone dry basis. Hence, to compare equals with equals different kinds of charcoal must have about the same volatile matter content.

2.4 What Happens During Carbonisation

During pyrolysis or carbonisation the wood is heated in a closed vessel of some kind, away from the oxygen of the air which otherwise would allow it to ignite and burn away to ashes. Without oxygen we force the wood substance to decompose into a variety of substances the main one of which is charcoal, a black porous solid consisting mainly of elemental carbon. Other constituents are the ash from the original wood amounting to 0.5 to 6% depending on the type of wood, amount of bark, contamination with earth and sand, etc. and tarry substances which are distributed through the porous structure of the charcoal. As well as charcoal, liquid and gaseous products are produced which may be collected from the vapours driven off if the charcoal is made in a retort. The liquids are condensed when the hot retort vapours pass through a water cooled condenser. The non-condensible gases pass on and are usually burned to recover the heat energy they contain. This wood gas, as it is called, is of low calorific value (around 10% of that of natural gas).

The products other than charcoal are usually referred to as by-products. Years ago recovery of the chemicals they contain was a flourishing industry in many developed countries. Since the advent of the petrochemical industry this by-product industry has become uneconomic since in most instances the chemicals can be produced from petroleum more cheaply. More information is given on this problem later.

2.5 The Stages in Charcoal Formation

As the wood is heated in the retort it passes through definite stages on its way to conversion into charcoal. The formation of charcoal under laboratory conditions has been studied and the following stages in the conversion process have been recognised.

- at 20 to 110°C

The wood absorbs heat as it is dried giving off its moisture as water vapour (steam). The temperature remains at or slighly above 100°C until the wood is bone dry.

- at 110 to 270°C

Final traces of water are given off and the wood starts to decompose giving off some carbon monoxide, carbon dioxide, acetic acid and methanol. Heat is absorbed.

- at 270 to 290°C

This is the point at which exothermic decomposition of the wood starts. Heat is evolved and breakdown continues spontaneously providing the wood is not cooled below this decomposition temperature. Mixed gases and vapours continue to be given off together with some tar.

- at 290 to 400°C

As breakdown of the wood structure continues, the vapours given off comprise the combustible gases carbon monoxide, hydrogen and methane together with carbon dioxide gas and the condensible vapours: water, acetic acid, methanol, acetone, etc. and tars which begin to predominate as the temperature rises.

- at 400 to 500°C

At 400°C the transformation of the wood to charcoal is practically complete. The charcoal at this temperture still contains appreciable amounts of tar, perhaps 30% by weight trapped in the structure. This soft burned charcoal needs further heating to drive off more of the tar and thus raise the fixed carbon content of the charcoal to about 75% which is normal for good quality commercial charcoal.

To drive off this tar the charcoal is subject to further heat inputs to raise its temperature to about 500°C, thus completing the carbonisation stage.

2.6 Using Heat Efficiently in Carbonisation

In carbonisation there are substantial flows of heat into and out of the wood being carbonised. Correct control of them affects the efficiency and quality of charcoal production. The heat flows can be calculated and shown on a heat balance diagram of the process. This needs a knowledge of heat engineering but the basic principles are not hard to understand. A heat input must come from the burning of a fuel of some kind which will usually mean wood in the case of charcoal making. Even if we use the exothermic heat from carbonisation or the heat liberated by burning the off-gas from the retort any additional heat will come from burning some wood and hence represents a loss. Wood which is burned cannot be turned into charcoal.

The three main stages requiring heat inputs in charcoal making are:

- The drying of the wood.
- Raising the temperature of the oven dry wood to 270°C to start spontaneous pyrolysis which itself liberates heat.
- Final heating to around 500-550°C to drive off tar and increase the fixed carbon to an acceptable figure for good commercial charcoal.

An ideal carbonising process would be one which required no external heat to carry out the carbonisation. The exothermic heat of the process would be captured together with the heat produced by burning off-gas and liquid by-products and this in total would be sufficient to dry out the residual moisture in the wood, raise it to spontaneous pyrolysis temperature and then heat it to a temperature sufficient to drive-off residual tars. In practice due to losses of heat through the walls of the carboniser and poor drying of the feedstock it is almost impossible to achieve this aim. However some systems particularly the large hot rinsing gas retorts come close to the ideal where the climate of the locality permits proper drying of the wood raw material.

No wood will carbonise until it is practically bone dry. The water in green wood however is typically about 50% of the green weight of the wood and this must all be evaporated before the wood will start to pyrolyse to form charcoal.

It is most economic to dry out as much of this moisture as possible using the sun's heat before the wood is carbonised. In dry savannah regions this is fairly simple as the wood can be left 12 months or more to dry without serious loss due to insect attack or decay. In the humid tropics two or three months may be the practical limit before insect and decay losses become intolerable. The loss in charcoal yield due to excessive moisture content has to be balanced against the loss of wood substance due to biological deterioration.

The important factors in drying and storing the wood raw material are described in Chapter 4.

2.7 Continuous Carbonisation

One of the most important steps forward in the production of charcoal was the application of the concept of continuous carbonisers. By causing the raw material wood to pass in sequence through a series of zones where the various stages of carbonisation are carried out it is possible to introduce economies in use of labour and heat thus reducing production costs and increasing the yield from a given amount of wood.

The concept of a continuous carboniser where the wood travels vertically downwards as it is heated and carbonised follows fairly obviously from the idea of the iron smelting blast furnace. But it proved necessary in order to get charcoal in lump form to abandon the idea of obtaining the heat for drying the charge and heating it to carbonisation point by burning part of the wood charged. This proved too difficult to control. The heating process had to be changed to use of hot oxygen-free gas produced externally and blown through the descending charge of wood. In this way the operation was under complete control and it proved possible to produce properly burned charcoal and yet ensure that it still emerged in lump form. Furthermore, the charcoal was never contaminated with ash since the carboniser always operates at a temperature below glowing combustion point.

Recovery of the heat emerging from the top of the carboniser was achieved by burning the gas and vapours under controlled conditions in hot blast stoves similar to those used in iron smelting and then blowing this hot gas into the retort at appropriate points so that carbonisation was completed by the hot gas first impinging on the charcoal emerging from the spontaneous pyrolysis zone. The gas then passed up the tower giving up its heat in countercurrent form to the descending charge of wood. The finished charcoal in the lower part of the retort was cooled before it reached the base by blowing in cold oxygen-free fuel gas and extracting it just below the point of entry of the hot gas coming from the hot blast stove. The fuel gas, warmed through cooling the charcoal then entered the hot blast stoves to be burned with air to produce the hot rinsing gas to be blown back into the unit to strip the residual tar from the charcoal and then proceed up the tower giving up its heat to the descending charge of wood. The position of the different zones in the tower could be controlled by regulating the gas injection rate and its temperture and the rate at which wood was admitted at the top and the charcoal was removed at the base.

This type of retort known under the generic name of 'continuous vertical hot rinsing gas retort' is commonly called the Lambiotte retort after its inventor, (Lambiotte, 1942, 1952). It is probably the most sophisticated charcoal making process because of the quality and yield of the charcoal it produces but there are other continuous charcoal making systems which are in successful commercial use. The best known of these uses the continuous multiple hearth roasting furnace also known as the Herreshoff roaster after its inventor. Just as the rinsing gas retort borrows much of its technology from the blast furnace so the multiple hearth furnace is a simple transfer of technology from the chemical and metallurgical industries where it is a familiar unit used for roasting sulphide ores prior to further processing.

The Herreshoff roaster is at a disadvantage compared with the rinsing gas retort in that it can only process finely divided wood or bark, etc, and hence can only produce powdered charcoal which must be briquetted for sale. Such briquettes are of no use for ordinary metallurgical use. The only economic market is for barbecues which requires a fairly sophisticated consumer market.

The Herreshoff roaster produces powdered charcoal and a mixture of hot gases and vapours. This gas mixture is an environmental pollutant. Since it is uneconomic to recover by-products from it nowadays the only use is to burn it to produce process heat such as for driving briquettes or making steam which might be passed through turbines to generate power. If no economic use can be found for the heat then the gas is merely burned to waste in a tall chimney.

The Herreshoff roaster is of interest because of its simplicity. It operates continuously obtaining the heat needed for final drying and carbonisation of the feedstock by burning part of it by the controlled admission of air to the hearths as the material progresses from top to bottom. If it could handle wood in lump form it would be an ideal continuous system.

All other continuous systems proposed, and there are many, based on moving belts, screw conveyers, fluidised beds and the like, while they can produce charcoal, generally fail on economic grounds.

Recently, particularly after the rise in oil price of the seventies a number of systems emerged which aimed to produce hot gas for process heating to replace oil or gas. They are based on burning finely divided wood or bark, etc, in combustion chambers with controlled admission of air and using in some cases the combustion principle of the fluidised bed. With this system a bed of saw dust or other fuel is kept in suspension by blowing air through it and the wood is allowed to burn in suspension using the oxygen in the air blast. Such systems can produce charcoal in powdered form by arranging the rate of feed so that the carbonised wood particles are removed from the fluidised bed at a sufficient rate to prevent them from being entirely burned. Keeping the system operating continually without the furnace getting too hot or too cold with feedstock of varying moisture content and fineness calls for good control. Such systems may appeal because they can be built much smaller than the well proven Herreshoff roaster which needs about 100 tons of feedstock per 24 hours as a minimum input. Extravagant claims have been made for the benefits especially from by-product recovery to be obtained from such systems but it seems they have still to be proved industrially. By-products can be collected if desired from the gas stream issuing from the converter or the hot gas can be burned in a boiler or furnace. Since they can only produce powdered charcoal a material of rather limited commercial usefulness they are hardly a solution to the problems of making charcoal by improved methods in the developing world.

2.8 Classification of Retort Heating Systems

Carbonisers can be classified by the type of heating system employed. There are three different types.

Type 1. Heat for carbonisation is generated by allowing part of the wood charged to burn to provide the heat to carbonise the remainder. The rate of burning is controlled by the amount of air admitted to the kiln, pit, mound or retort. This is the traditional system used to produce most of the world's charcoal. It is the method used in the well-proven Herreschoff roaster. It is an efficient system if properly controlled as the heat is produced exactly where it is needed and there are no problems of heat transfer. Fluidised and other types of agitated bed carboniser also rely on this system. It's main disadvantage in simple equipment is that excessive amounts of wood are burned away because the air admitted is not closely controlled.

Type 2. Heat for carbonisation by this method is obtained by burning fuel, usually wood or perhaps wood gas, outside the retort and allowing it to pass through the walls to the wood contained in the sealed retort. Most of the early retort systems built to supply wood chemicals before the rise of the petrochemical industry were heated by this system. The system is rather inefficient in its use of heat energy since it is difficult to get a good flow of heat through the metal walls of the retort into the wood packed inside because the contact of the wood with the walls is so irregular. Overheating of the retort walls often occurs causing damage. The method is still used today for some simple type retorts such as the 'oil drum retort' which has been promoted in the Caribbean and the Constantine retort developed in Australia (19).

Type 3. In this system the wood is heated by direct contact with hot inert gas circulated under fan pressure through the retort. Heat transfer by this sytem is good since the hot gas directly contacts the wood to be heated. Since the gas is free of oxygen there is no combustion inside the retort and the heat transfer cools the gas which must be withdrawn and re-heated to enable it to be used again for heating purposes.

The best known examples of this system are the Lambiotte and the Reichert retort systems. The Lambiotte or continuous hot rinsing gas retort has been described in 2.7 above. The Reichert retort is a batch type retort which heats the wood charge to convert it into charcoal by circulating hot oxygen-free gas through the charge by means of a fan and a system of heating stoves. In many ways this system resembles a batch type rinsing gas retort without the advantage of continuous feed. Another example is the Schwartz kiln developed many years ago in Europe. This kiln has an external firebox or grate and the hot flue gas from fuelwood burned in this grate is passed through the charge to heat it. The combined effluent gases pass up the chimney of the kiln into the air.

This system of heating, while technologically excellent, is more complicated than System 1 (burning part of the charged wood) and unless there is a compelling reason for its use as is the case with the hot rinsing gas retort, the cost of using it cannot be justified compared with the simple process of System 1. More information is given on these aspects in Chapter 3 and Reference (33).

2.9 Properties of Carbonisation Products

Carbonisation of wood gives rise to a complex range of products; solid, liquid and gaseous. Dozens of chemicals could be extracted from the liquid condensate if it were economically practical.

Today, with the eclipse of the wood based distillation industry, the primary reason for carbonising wood is to obtain charcoal. Any benefits which can be obtained from the working up of by-products nowadays are marginal and in the case of new installations probably uneconomic. Below are given the properties of the main products which can be obtained from wood carbonisation. Charcoal because of its importance is treated in greater detail.

2.9.1 Charcoal

Most of the specifications used to control charcoal quality have originated in the steel or chemical industry. When charcoal is exported, buyers tend to make use of these industrial quality specifications even though the main outlet of the imported charcoal may well be the domestic cooking or barbecue market. This factor should be borne in mind since industrial and domestic requirements are not always the same and an intelligent appraisal of actual market quality requirements may allow supply of suitable charcoal at a lower price or in greater quantities beneficial to both buyer and seller.

The quality of charcoal is defined by various properties and though all are inter-related to a certain extent, they are measured and appraised separately. These various quality factors are discussed below.

2.9.1.1 Moisture Content

Charcoal fresh from an opened kiln contains very little moisture, usually less than 1%. Absorption of moisture from the humidity of the air itself is rapid and there is, with time, a gain of moisture which even without any rain wetting can bring the moisture content to about 5-10%, even in well-burned charcoal. When the charcoal is not properly burned or where pyroligneous acids and soluble tars have been washed back onto the charcoal by rain, as can happen in pit and mound burning, the hygroscopitity of the charcoal is increased and the natural or equilibrium moisture content of the charcoal can rise to 15% or even more.

Moisture is an adulterant which lowers the calorific or heating value of the charcoal. Where charcoal is sold by weight, keeping the moisture content high by wetting with water is often practised by dishonest dealers. The volume and appearance of charcoal is hardly changed by addition of water. For this reason bulk buyers of charcoal prefer to buy either by gross volume, e.g. in cubic metres, or to buy by weight and determine by laboratory test the moisture content and adjust the price to compensate. In small markets sale is often by the piece.

It is virtually impossible to prevent some accidental rain wetting of charcoal during transport to the market but good practice is to store charcoal under cover even if it has been bought on a volume basis, since the water it contains must be evaporated on burning and represents a direct loss of heating power. This occurs because the evaporated water passes off into the flue and is rarely condensed to give up the heat it contains on the object being heated in the stove.

Quality specifications for charcoal usually limit the moisture content to around 5-15% of the gross weight of the charcoal. Moisture content is determined by oven drying a weighted sample of the charcoal. It is expressed as a percentage of the initial wet weight.

There is evidence that charcoal with a high moisture content (10% or more) tends to shatter and produce fines when heated in the blast furnace, making it undesirable in the production of pig iron.

2.9.1.2 Volatile matter other than water

The volatile matter other than water in charcoal comprises all those liquid and tarry residues not fully driven-off in the process of carbonisation. If the carbonisation is prolonged and at a high temperature, then the content of volatiles is low. When the carbonisation temperature is low and time in the retort is short, then the volatile matter content increases. (33)

These effects are reflected in the yield of charcoal produced from a given weight of wood. at low temperatures (300°C) a charcoal yield of nearly 50% is possible. At carbonisation temperatures of 500-600°C volatiles are lower and retort yields of 30% are typical. At very high temperatures (around 1,000°C) the volatile content is almost zero and yields fall to near 25%. As stated earlier, charcoal can reabsorb tars and pyroligneous acids from rain wash in pit burning and similar processes. Thus the charcoal might be well burned but have a high volatile matter content due to this factor. This causes an additional variation in pit burned charcoal in wet climates. The resorbed acids make the charcoal corrosive and lead to rotting of jute bags - a problem during transport. Also it does not burn cleanly.

The volatile matter in charcoal can vary from a high of 40% or more down to 5% or less. It is measured by heating away from air, a weighed sample of dry charcoal at 900°C to constant weight. The weight loss is the volatile matter. Volatile matter is usually specified free of the moisture content, i.e. volatile matter - moisture or (V.M. - moisture)

High volatile charcoal is easy to ignite but may burn with a smoky flame. Low volatile charcoal is difficult to light and burns very cleanly. A good commercial charcoal can have a net volatile matter content - (moisture free) of about 30%. High volatile matter charcoal is less friable than ordinary hard burned low volatile charcoal and so produces less fines during transport and handling. It is also more hygroscopic and thus has a higher natural moisture content.

2.9.1.3 Fixed carbon content

The fixed carbon content of charcoal ranges from a low of about 50% to a high of around 95%. Thus charcoal consists mainly of carbon. The carbon content is usually estimated as a "difference", that is to say, all the other constituents are deducted from 100 as percentages and the remainder is assumed to be the per cent of "pure" or "fixed" carbon. The fixed carbon content is the most important constituent in metallurgy since it is the fixed carbon which is responsible for reducing the iron oxides of the iron ore to produce metal. But the industrial user must strike a balance between the friable nature of high fixed carbon charcoal and the greater strength of charcoal with a lower fixed carbon and higher volatile matter content to obtain optimum blast furnace operation. (33)

2.9.1.4 Ash content

Ash is determined by heating a weighed sample to red heat with access of air to burn away all combustible matter. This residue is the ash. It is mineral matter, such as clay, silica and calcium and magnesium oxides, etc., both present in the original wood and picked up as contamination from the earth during processing.

The ash content of charcoal varies from about 0.5% to more than 5% depending on the species of wood, the amount of bark included with the wood in the kiln and the amount of earth and sand contamination. Good quality lump charcoal typically has an ash content of about 3%. Fine charcoal may have a very high ash content but if material less than 4 mm is screened out the plus 4 mm residue may have an ash content of about 5-10%.

2.9.1.5 Typical charcoal analyses

To illustrate the range of composition found in commercial charcoal Table 1 lists the composition of random samples of charcoal from various kinds of woods and various kinds of carbonisation systems. In general, all woods and all systems of carbonisation can produce charcoal falling within the commercial limits.

Table 2 records the variations in charcoal composition as found in the blast furnace charge at a large charcoal iron works in Minas Gerais, Brazil. All of this charcoal was made using beehive type brick kilns. The wood used was either mixed species from the natural forest of the region or eucalypt wood from plantations.

Table 1. Some Typical Charcoal Analyses

Wood species	Production Method	Moisture content %	Ash %	Volatile matter %	Fixed carbon %	Bulk density raw kg/m^3	Bulk density pulverised kg/m^3	Gross calorific value kJ/kg Oven dry basis	Remarks
Dakama	Earth pit	7.5	1.4	16.9	74.2	314	708	32410	Pulverised fuel for rotary kilns 1/
Wallaba	"	6.9	1.3	14.7	77.1	261	563	35580	" 1/
Kautaballi	"	6.6	3.0	24.8	65.6	290	596	29990	" 1/
Mixed Tropical Hardwood	"	5.4	8.9	17.1	68.6				Low grade charcoal fines 1/
"	"	5.4	1.2	23.6	69.8				Domestic charcoal 1/
Wallaba	Earth mound	5.9	1.3	8.5	84.2				Well burned sample 1/
"	"	5.8	0.7	46.0	47.6				Soft burned sample 1/
Oak	Portable steel kiln	3.5	2.1	13.3	81.1			32500	2/
Coconut shells	"	4.0	1.5	13.5	83.0			30140	4/
Eucalyptus Saligna	Retort	5.1	2.6	25.8	66.8				3/

1/ = Guyana. 2/ = U.K. 3/ = Brazil. 4/ = Fiji.

Table 2. Characteristics of Charcoal for Blast Furnaces

Chemical and Physical Composition of Charcoal Dry Basis - by weight	Range Max.	Range Min.	Yearly Average	Charcoal considered good to excellent
Carbon	80%	60%	70%	75 - 80%
Ash	10%	3%	5%	3 - 4%
Volatile matter	26%	15%	25%	20 - 25%
Bulk density - as received (kg/m^3)	330	200	260	250 - 300
Bulk density - dry	270	180	235	230 - 270
Average Size (mm) as received	60	10	35	20 - 50
Fines content - as received (<6.35 mm)	22%	10%	15%	10% max.
Moisture content - as received	25%	5%	10%	10% max.

The ranges and yearly averages refer to charcoal used by the steelworks. This is a mixture of 40% eucalyptus charcoal produced in company operated kilns and 60% heterogenous natural wood charcoal manufactured by privately operated kilns. "Good to excellent" charcoal refers to that produced from eucalyptus wood in company kilns.

2.9.1.6 Physical properties

The properties described so far are referred to as chemical properties but physical properties, especially for industrial charcoal, are no less important. It is in the charcoal iron industry that physical properties have great importance. The charcoal is the most expensive raw material in the blast furnace charge. Charcoal's physical properties influence the output of the blast furnace whereas chemical properties are more related to the amount of charcoal needed per ton of iron and the composition of the finished iron or steel. (29)

Blast furnace charcoal must be strong in compression to withstand the crushing load of the blast furnace charge of "burden". This compression strength, always less than charcoal's rival, metallurgical coke made from coal, determines the practical height and hence efficiency and output of the blast furnace. The ability to resist fracturing when handled is important to maintain constant permeability of the furnace charge to the air blast which is vital in maintaining furnace productivity and uniformity of operations.

Various tests have been developed to measure fracture resistance; a rather difficult property to define in objective terms. These tests rely on measuring the resistance of the charcoal to shattering or breakdown by allowing a sample to fall from a height onto a solid steel floor or by rumbling a sample in a drum to determine size breakdown after a specified time. The result is expressed as the percentage passing and retained on various sized screens. Charcoal with poor shatter resistance will produce a larger percentage of fines when a sample is tested. Fine charcoal is undesirable in the blast furnace since it blocks the flow of air blast up the furnace. Fragile charcoal may also be crushed by the weight of the charge and cause blockages.

2.9.1.7 Adsorption capacity

Wood charcoal is an important raw material for activated charcoal. (See Chapter 6). Some data could be useful where charcoal producers are selling charcoal to be turned into activated charcoal by specialist factories. (27)

As produced, normal wood charcoal is not a very active adsorption material for either liquids or vapours because its fines structure is blocked by tarry residues. To convert the charcoal to "activated" this structure must be opened up by removing the tarry residues. The most widely used method today consists in heating the pulverised raw charcoal in a furnace to low red heat in an atmosphere of superheated steam. The steam prevents the charcoal from burning away by excluding oxygen. Meanwhile the volatile tars can be distilled away and are carried off with the steam, leaving the pore structure open. The treated charcoal is run off into closed containers and allowed to cool. Activation furnaces are usually continuous, i.e. the powdered charcoal passes continuously cascade fashion through the hot furnace in the steam atmosphere.

After activation the charcoal is tested to quality specifications to determine its power to decolorize, by adsorption, watery solutions such as raw sugar juice, rum wine, and so on; oils such as vegetable oil and to adsorb solvents such as ethyl acetate in air. Adsorbtive power tends to be specific. Grades are made for aqueous solutions, others for oils and others for vapours. The tests measure the adsorptive power. There are small differences in the finished product made from raw charcoals of different origin but generally all are useable if properly burned. A good basic charcoal for making activated charcoal can be made from the wood of *Eucalyptus grandis* in brick type kilns.

Charcoal for adsorption of gases and vapours is usually made from coconut shell charcoal. This charcoal has high adsorptive power and resists powdering in the adsoption equipment - a very important factor.

2.9.1.8 The Chemical Composition of Charcoal

The constituents of charcoal are carbon, tar and ash. The relative proportions of each reflect the ash content of the wood from which the charcoal was made and the temperature at which carbonisation was terminated. To give an idea of the way these values can vary the following data derived from work on Australian eucalyptus is given. See Tables 3 and 4. (11, 24). Although many species were studied only the results for two species of international interest, Eucalyptus saligna and camaldulensis are quoted here. A more complete tabulation of these results is quoted in (20).

Table 3 Volatile Matter and Yield of Charcoal at Various Temperatures

Species		Carbonization Temperature °C							
		350	400	450	500	590	700	800	950
Euc camaldulensis									
	% volatiles	39.4	35.8	31	26	16.7	4.4	0	0
	% yield	49.7	46.8	43.6	40.7	36.2	31.5	30.1	30.1
Euc saligna									
	% volatiles	40.4	37.8	30	24.9	15.8	4.1	0	0
	% yield	49.9	47.9	42.6	39.8	35.4	31.1	29.8	29.8
Mean of 15 spp									
	% volatiles	39.8	35.3	29.9	24.6	16.2	4.6	.5	0
	% yield	47.4	44.1	40.7	37.8	34.1	30	28.7	28.5

Table 4 Inorganic Content of Bark Sapwood and Heartwood

	Percentage		parts per million										
Species	% Ash	% Silica	P	Ca	Mg	K	Na	Al	Fe	Mn	Zn	S	Cl
Euc camaldulensis													
bark	9.65	1.768	385	32150	2765	4185	1060	130	70	415	15	-	2455
sapwood	.49	.004	155	675	220	1858	303	20	38	83	5	-	910
heartwood	.07	trace	14	235	100	53	33	8	18	7	4	-	-
Euc saligna													
bark	9.19	1.208	185	32030	1700	3250	1955	125	75	330	8	1660	2615
sapwood	.43	.056	100	550	250	900	215	15	50	15	9	660	440
heartwood	.07	.002	5	280	60	100	60	10	25	4	4	340	65

2.9.2 Pyroligneous Acid

The watery condensate of the vapours leaving the retort is known as pyroligneous acid. Water insoluble tars condense at the same time and separate from the watery phase on standing. The composition of pyroligneous acid is extremely complex and only the major constituents can be mentioned. The yield is important for determining the economics of recovery and varies with the type of wood carbonised. European beech, the hardwood which formed the based of the European industry, has a high content of pentosan sugars and this gives a high yield of the valuable acetic acid. Eucalypt wood on the other hand gives a much lower yield of acetic acid and other products. The type of carbonisation plant also influences yields. It is not possible to give definite predictions of yield; accurate large scale tests must be made before investing money in by-product recovery.

For guidance the following are typical yields obtained from pyroligneous acid produced by carbonising northern hemisphere deciduous hardwoods.

Yield per 1,000 kg of air dry wood	
Acetic acid	50 kg
Methanol	16 kg
Acetone and Methyl Acetone	8 kg
Soluble tars	190 kg
Insoluble tars	50 kg

2.9.2.1 Acetic Acid

Acetic acid is the most valuable product in terms of total cash return that can be recovered from the pyroligneous acid. Although the amount of acetic acid marketed as a by-product of wood distillation nowadays is rather insignificant the acid from wood distillation is sought after for certain uses because it is fairly pure. The method used to recover the acid from the condensate is usually by solvent extraction of the crude acid liquor using ethyl acetate after the soluble tars and the methanol/acetone have been separated. The acetic acid passes into the ethyl acetate phase. The ethyl acetate is recovered in a still and returned to the extraction column. The acetic acid is purified by distillation. Several grades may be produced which vary in their purity and acid content.

2.9.2.2 Methanol and Acetone

Because of the low prices ruling for these products made by the petrochemical route and the high cost of separating them as pure grades from the pyroligneous acid it is usual to recover them as a mixture which also contains methyl acetone. The mixture is sold as a solvent for use in the paint industry.

The mixed solvent is recovered by distilling the water phase after the insoluble tar has been decanted. The liquid is distilled in a primary still and the acetic acid, methanol, acetone, etc. is varpourised. The soluble tars remain in the still. The vapours are fractionated in a column and the crude mixed methanol solvent fraction (about 85% methanol) is separated from the mixture of acetic acid and water. This latter mixture is purified as described above by solvent extraction of the acetic acid. The crude methanol cut could be further purified but price does not allow it as a rule and it is sold as mixed solvent.

2.9.2.3 The Tars

The insoluble tar is a useful product in veterinary medicine as an antiseptic and as a wood preservation agent and caulking compound. When produced from softwood distillation it is usually called Stockholm tar. It's recovery by decantation from the condensate is simple. Aromatic substances valuable in medicine and perfumery can be separated from this tar by complex chemical processes. If this tar were produced in the developing world it would probably find local markets at a reasonable price.

The soluble tar is more difficult to market. This material is a complex mixture of highly condensed yet water miscible susbstances for which very few uses seem to exist. It has been used as an admixture with clay in brickmaking to produce porous bricks and of course can be burned as a fuel.

The tars from wood distillation must be recognised as pollutants of the environment and hence cannot be allowed to escape into streams. Waste liquors of all kinds from by-product recovery must be run into closed shallow ponds and the water allowed to evaporate leaving behind the tarry residues. These, after they have accumulated can be burned to remove the risk they pose to stream life, fish, water supplies and so on. This method works well in areas where the net evaporation exceeds the net precipitation, i.e. where charcoal is being made in a semi-arid climate but is an obvious failure in the humid tropics.

Alternatively the tars and all the volatile material except the water component can be burned as fuel. In many ways this is the best way of using the material rather than investing in by-product recovery schemes. Because of the large amount of energy needed to evaporate the water it is best to burn the mixture of gas and condensibles as hot uncondensed gas as close as possible to the carbonising equipment.

Chapter 3

MODERN CARBONISING RETORT SYSTEMS

3.1 Introduction

Wood distillation carried out by heating wood in a closed retort and recovering the vapours given off during the process became important with the growth of the chemical industry in Europe in the nineteenth century. At the time there was no shortage of charcoal or wood for making it. The interest was in the chemical products which could be derived.

The original systems used a cast iron vessel which could be sealed with a bolted lid, set in a wood or coal fired heating furnace. Cast iron worked well as it resisted the corrosive fumes of the acetic acid produced during distillation. It was soon found that the non-condensible wood gas given off towards the end of the cycle could be burned for heating the retorts. Further, where about six units were operated as a group it was found that the gas from those retorts approaching the end of carbonisation could be burned under others at an earlier stage of the cycle. This improved overall fuel efficiency and lowered the cost of recovering the chemical raw materials.

The need for these raw materials persisted into the twenties of this century and then began to decline with the growth of the oil industry with it's alternative methods of producing the basic products: acetic acid, acetone and methanol. By the end of the Second World War the decline of the wood distillation industry was complete.

However, the demand for charcoal in industrial countries for making activated charcoal, as a chemical reduction agent and in metallurgy continued and this kept up a demand for charcoal. It became worthwhile to produce charcoal from scrap and waste wood for the chemical industry even though the recovery of the by-products was of declining importance as an opportunity for new capital investment. The continuing need for high grade industrial charcoal focussed attention on finding ways to produce charcoal which were more efficient in conversion ratio and which were less labour intensive and polluting than kiln and mound techniques. Out of this need were developed the continuous and semi-continuous rinsing gas retorts of the Lambiotte and Reichert types described in this chapter. The Waggon or Arkansas retort arose earlier from attempts to reduce the labour intensity of traditional methods and collect chemical by-products.

A new factor arose with the need in the USA during the sixties to find a way to convert finely divided bark and wood waste from large pine sawmills to charcoal and sell this in the form of briquettes to a growing urban recreational market. From this need sprang the application of the Herreshoff multiple hearth roasting furnace to converting fine woody waste materials to charcoal. Recovery of chemical by-products was no longer of importance and the off-gases were merely burned to waste or passed through boilers to generate power.

The various systems which have proved commercially viable are now described. It is important to consider the particular circumstances under which each system developed because a system suited to one situation may be quite unsuited to another.

3.2 The Waggon or Arkansas Retort

The waggon or Arkansas retort used to be widely used in Europe and the USA. The process lost ground in the thirties due to the development of semi-continuous retorts which showed lower overall operating costs. The waggon retort was particularly noted for high maintenance costs on the steel waggons and the shell of the retort itself. Nevertheless, a couple of plants have survived in Europe despite high operating labour costs. (8,23,31). However, the process is now of mainly historical interest.

The operating principles and layout of the waggon retort are shown in Fig. 1. The usual raw materials are roundwood, split roundwood and slabs from sawmilling. Average length is about 1 to 1.2 metres. Some shorter material can be used but it tends to fall out of the waggons. The wood should be dried to about 25% moisture content maximum for good results. A year of air drying is good practice in a suitable climate.

The wood is charged into steel waggons with slatter sides. The waggons fit the dimension of the retort rather closely to ensure maximum volumetric efficiency. The waggons roll into and are removed from the retort on steel rails which connect with a cooling chamber of the same dimensions as the retort and built directly facing it so that the waggons after carbonisation can be drawn quickly into the cooling chamber and sealed for cooling.

The minimum number of sets of retorts and coolers to ensure a steady supply of wood gas for retort heating is six but much larger numbers were not uncommon. Railway tracks and transfers connect the retorts with the wood storage yard. Large systems had several kilometers of track and small locos for hauling the waggons. All this complication tended to multiply maintenance, supervision and operating costs.

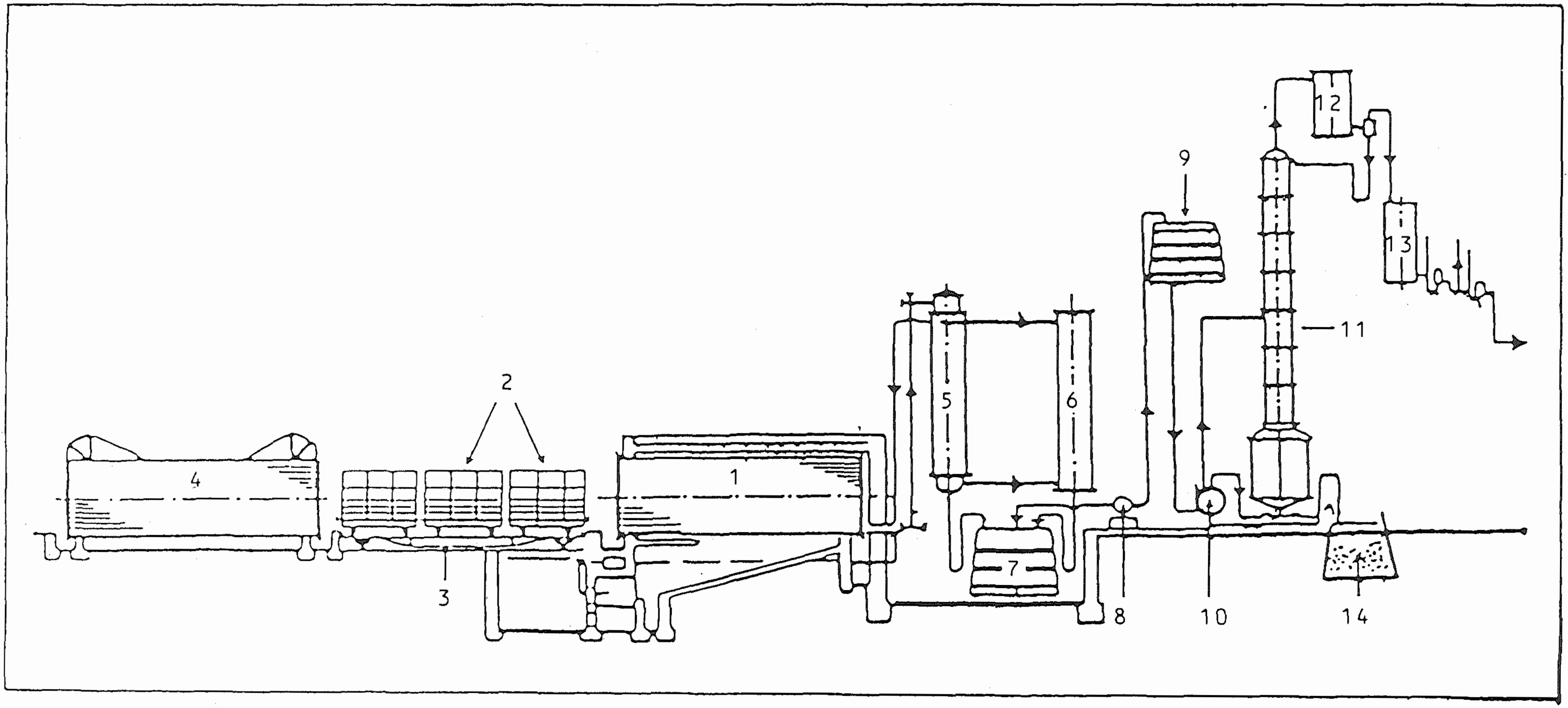

Fig. 1 The Waggon Retort Plant

1. Retort 2. Waggons 3. Siding 4. Charcoal cooling cylinder
5. Water cooler 6. Scrubber for residual gas 7. Pyroligneous acid vat
8. Oil pump 9. Intermediate Tank 10. Preheater for distillation column
11-13. Fractionation of pyrolisis acid 14. Settling vat for tar

Retorts were typically about 8 meters long holding two waggons but retorts up to double this length were used. The retorts were approximately cylindrical in shape to fit the loaded waggons as closely as possible. In fact it was found in Australia that despite the lower volumetric efficiency it paid to make the retorts circular in section and fit them with circular doors. The equalisation of heating stresses reduced maintenance markedly.

Also by burning the wood gas in a separate heating stove and circulating the hot gas around the circular retort in a helical duct heat transfer was improved and retort maintenance reduced. However, the weaknesses of the waggons remained and maintenance costs still tended to be excessive.

Waggon retorts were heated by burning wood gas and air under the retort. The gas was obtained from retorts close to the end of a carbonisation cycle and it is this need to obtain wood gas from other retorts which necessitates operating them in groups. The wood gas was obtained by drawing off the gases and vapours from the retorts by means of a fan and passing the gas through water cooled condensers which condense first the tar and then the pyroligneous acid. The non-condensible wood gas passes on and is directed to another retort for burning with air to provide heat for carbonisation. The tar and pyroligneous acid is stored in a tank to be separated and worked up for by-products in a refinery.

The carbonisation stage takes about 22 hours and as soon as it is complete the retort is opened and the waggons drawn across the short space to the cooler which is sealed to extinguish the charcoal which takes fire immediately it is removed from the retort. Cooling takes from 24 to 48 hours depending on climate and whether the walls of the cooler are sprayed frequently with water. This retort produces very small amounts of fines but careless handling of the finished charcoal can lift the total to 5% to 10%.

Summarized data on the retort system is as follows:

Retort dimensions:

8 to 16 m long by 2.5 m diameter.

Capacity:

35 to 60 m^3.

Wood input:

9 - 18 tons of drywood per charge or 270 tonnes per month.

Wood dimensions:

1 to 1.2 m long. Maximum diameter or thickness 12 cm.

Photo. 1. Wood residues used for charcoal making through the waggon retort system.

Photo. 2. Waggon retort system pre-drier

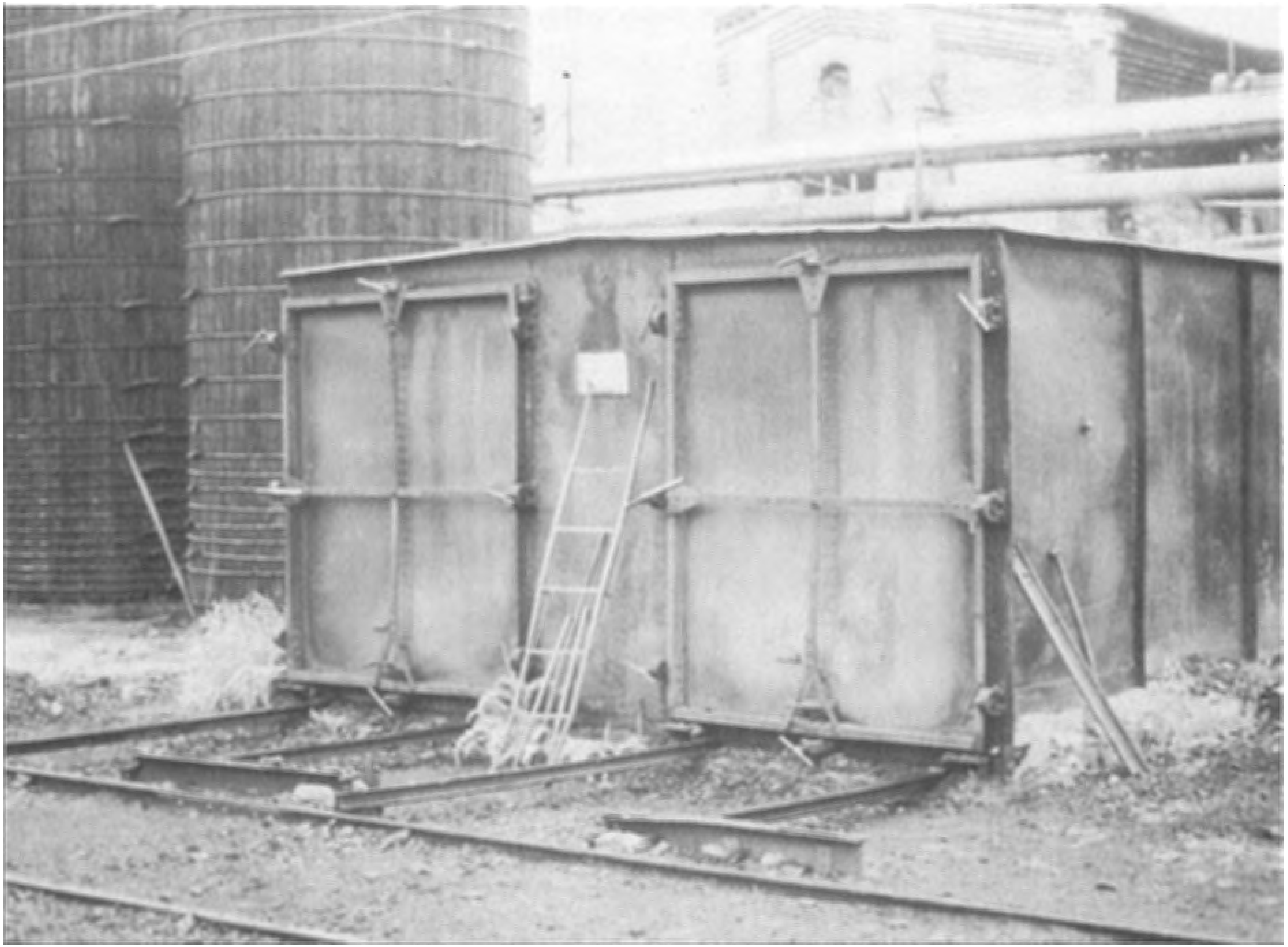

Photo. 3. The carbonisation chamber in the waggon retort system (Sweden)

Moisture content:

25%

Average yields:

Charcoal 30 - 33%, pyroligneous acid 20 - 25%

If the tar and pyroligneous acid are burned along with the wood gas there will be ample heat to operate the retorts and leave an excess for other purposes. Where by-products are recovered some additional heat inputs to the wood gas may be needed.

As in all charcoal making enterprises the logistics of the wood supply is the dominating factor in the cost of production. Additionally with this system the maintenance costs of the retorts and associated equipment can be a large component of costs.

The waggon retort system does have some advantages if maintenance costs could be controlled by better design of the retort. It is technically simple and unskilled personnel soon learn the operating skills. It produces lump charcoal with only a small amount of fines. Large pieces of wood can be used which reduces the cost of wood preparation considerably.

3.3 The Reichert Retort System

The Reichert retort represents the first successful attempt to eliminate the difficulties of transmitting heat to the charge inside the retort through the metal walls of the retort itself. It is this problem which is the root cause of the heavy maintenance costs of the waggon retort and its predecessors.

In the Reichert retort the heat is transferred to the wood by blowing recirculated heated gas through the charge inside the retort. The gas is either inert or reducing in nature to prevent the wood igniting and is typically a heated fuel gas of some kind. Flue gas is also quite suitable but the advantage of using a combustible gas is that the wood gas given off from the charcoal when combined with the heating gas does not dilute the mixture beyond the point of easy combustibility so that it can be subsequently burned to generate steam or other process heat. In this way the necessity to bleed off gas from the system without burning it is eliminated. The problem in most situations is to find a source of suitable fuel gas. Usually the wood gases and vapours from the retort are used and surplus gas is constantly bled off to keep the circulating gas volume constant (4).

The main unit of the system is a large steel vertical retort (Fig. 2) with a charge capacity of about 100 m3. The raw material is wood of maximum length about 30 cm and 10 cm thick. The wood must be small enough to 'flow' into the retort and yet not be so small as to impede the gas circulation. Large pieces of wood carbonise more slowly than small and this irregular rate of carbonisation tends to slow up production preventing optimum carbonisation time being achieved. There has to be a compromise between the cost of wood preparation and drying and the carbonisation time and hence the production rate achieved by the retort.

Whatever gas is used to heat the charge it must be burned with air under carefully controlled conditions in a special stove and its temperature raised above 450 - 550°C. It is then blown into the retort and gives up its heat to the wood. The gas being given off by the carbonising wood and the water vapour from drying and pyrolysis is added to the heating gas on its passage through the retort. For this reason it is necessary to bleed some of the gas to waste to maintain the volume of circulating gas constant. It is advantageous to pass the gas after it emerges from the retort to be reheated through tar scrubbers and condensers to remove the condensible portion of the gas as this can be burned as liquid fuel providing the wood charged to the retort is not too high in moisture content. By this means one avoids bleeding off a valuable fuel component.

When carbonisation is complete the bottom of the retort is opened and the charcoal dropped into closed steel containers to cool. If rapid cooling of the charcoal is required it can be cooled before discharge by passing cold inert gas through the retort.

This type of retort has been in successful commercial use for more than forty years. Providing adequate mechanisation of the handling of the wood and charcoal and the gas circulation controls are automated, the operating costs are satisfactory. However,the investment cost remains high and overall they are probably not as economic as the continuous rinsing gas retorts described in the next section.

3.4 The Lambiotte or SIFIC Process

This process originally developed by Lambiotte in the early 1940's (25) is perhaps the most successful technology for the continuous carbonisation of slab and roundwood to produce conventional lump charcoal useable for all purposes. (See References 1, 4, 9, 10, 16, 25 for more information on this system). The general arrangement of such a plant is shown in Fig. 4.

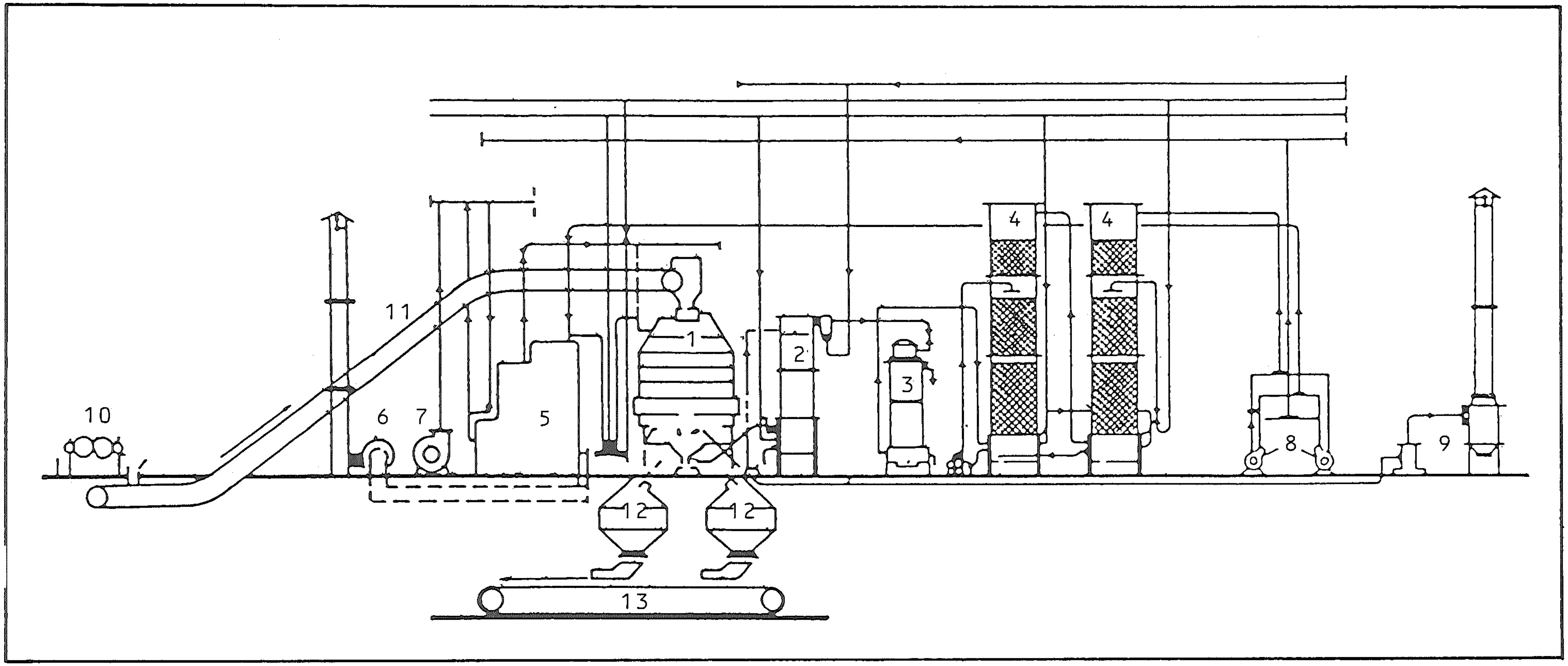

Fig. 2 The Reichert Retort Process

1. Large space retort 2. Tar stripper 3. Water cooler 4. Scrubber for residual gas
5. Combustion chamber and heat exchanger 6. Off-gas fan 7. Combustion air fan
8. Forced gas circulation fan 9. Dust collector 10. Wood preparation 11. Charging conveyor
12. Charcoal cooler 13. Charcoal conveyor

Continuous carbonising systems for the same capital investment give an increases output compared with complex technology batch type systems for the same investment, a higher yield than simple technologies and definite savings in fuel needed for carbonisation compared to any other system.

The operating principles (Fig. 3) are as follows. The predried wood is lifted to the top of the retort by means of a skip-car or conveyor and is dumped into a double bell gate which allows the wood to enter and yet prevents escape of significant quantities of retort gases. The level of the wood in the retort is monitored and loading controlled to keep the level constant by means of automatic controls.

During carbonisation the wood moves slowly down the retort encountering a rising countercurrent flow of inert hot gas which dries the wood and raises it to carbonising temperature. Typically the wood takes about eleven hours to pass through the retort and emerge as charcoal from the base through a pair of hydraulically operated interlocking gates which allow the finished charcoal to be removed in small batches about every twenty minutes. The time to pass through the retort and the intervals between removals of charcoal at the base are under the control of the operator and can be varied to suit the moisture content of the wood, required rate of charcoal output and fixed carbon requirement in the product. The movement of the charge down the retort leads to formation of undesired fines but by unloading intermittently as described above this effect is reduced and the percentage of fines is about the same as charcoal produced in conventional brick kilns.

The charcoal has to be cool when it leaves the retort as otherwise it would ignite on contact with the air. The cooling is accomplished by blowing either cool inert or combustible gas into the bottom of the retort and as it rises it extracts the heat from the finished charcoal as it passes down the retort to the discharge gates. The heated gas is drawn off at the middle of the retort just below the point where the hot gas for converting the wood to charcoal is blown in.

The correct circulation of the gas streams is assured by close control of the pressures at critical points (4). The hot gas is usually produced by burning combustible gas in a stove with air and this hot neutral gas at around 900°C is blown in just above the exit point of the cooling gas stream. This strips the remaining tar from the charcoal at this point and completes the carbonisation step. The gas passes up the retort, giving up its heat to the descending charge and picking up and 'rinsing' away the volatiles being given off by the descending wood.

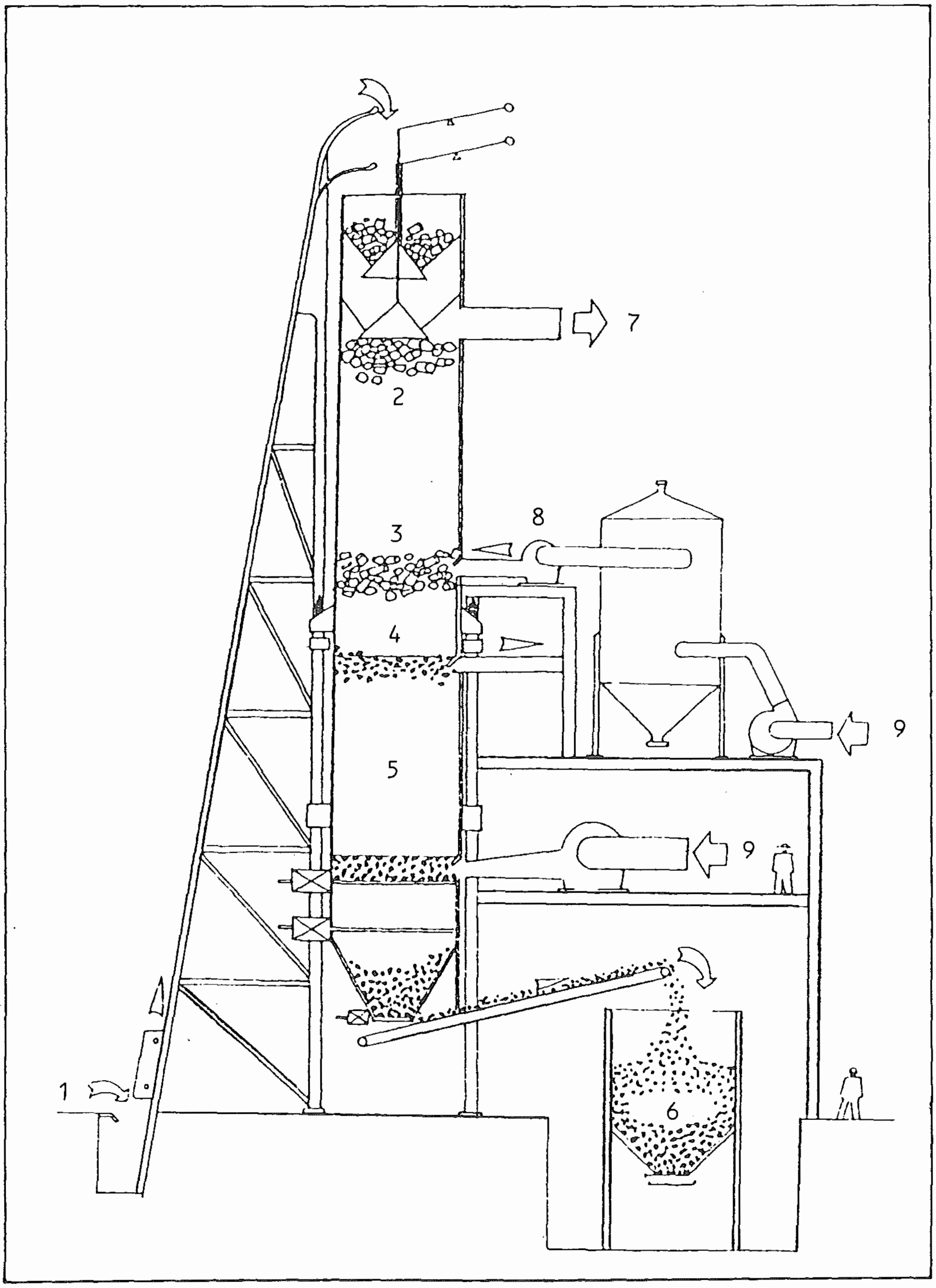

Fig. 3 Hot Rinsing Gas Retort - Sectional View

1. Raw material 2. Drying stage 3. Distillation stage
4. Carbonisation stage 5. Cooling stage 6. Charcoal
7. Retort gas 8. Hot stove gas 9. Cold inert gas

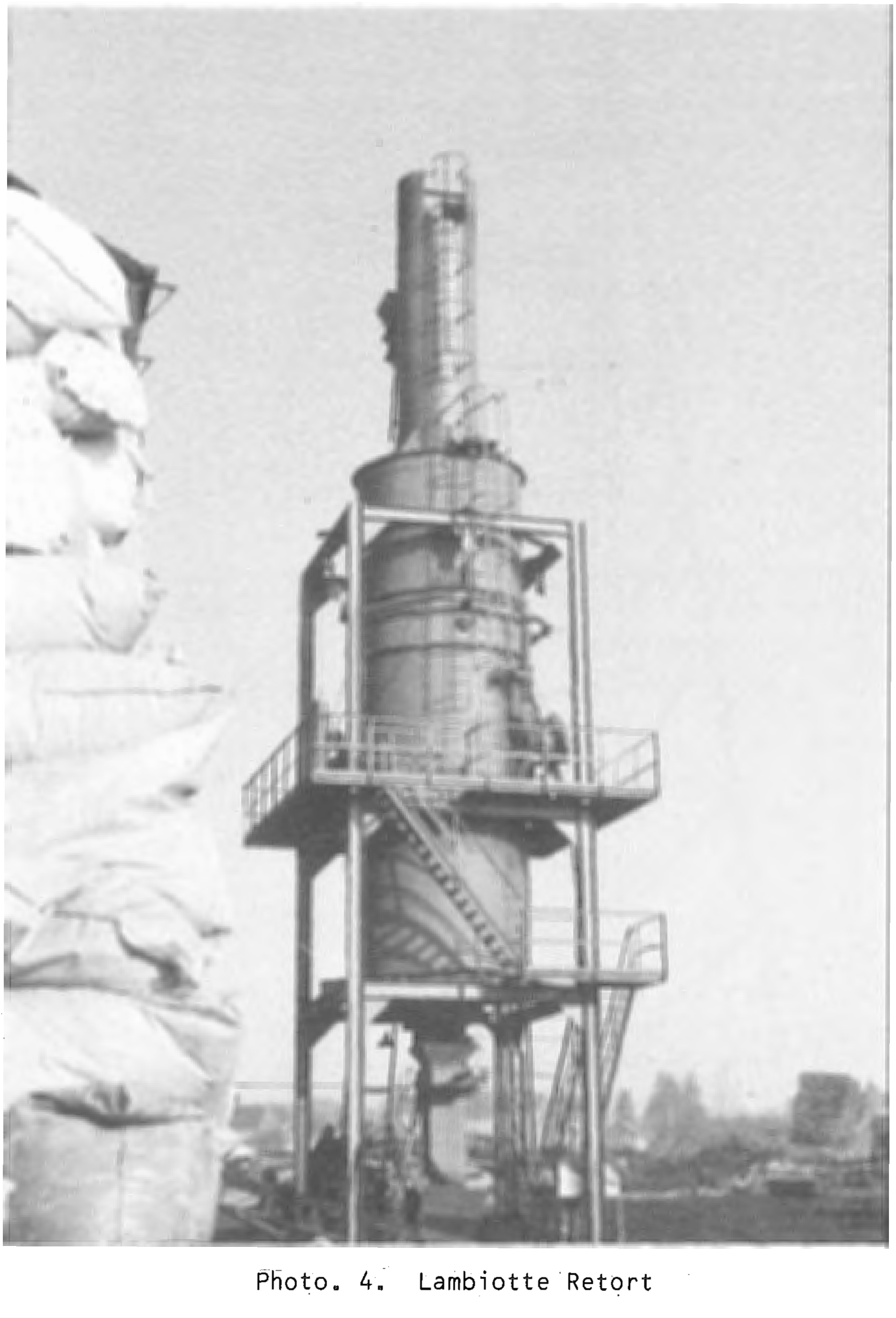

Photo. 4. Lambiotte Retort

The gas issuing from the head of the retort is maintained at a temperature sufficient to prevent condensation of tars and other volatiles at the top of the retort and in the associated pipework. The high thermal efficiency of the Lambiotte retort is due to the fact that the products of the system, charcoal and volatiles leave the retort at about the same temperature as the wood enters it. (4).

There are a number of options in disposing of the gas steam from the top of the retort. The most obvious one is to use this gas to heat the wood and to cool the charcoal. Providing the wood being carbonised is well dried there is enough heat in the effluent gas when it is finally burned with air to perform this (4).

The hot gas steam is divided, one part being burned directly in the stove to provide hot inert gas for heating the charge. The other portion is cooled and scrubbed to remove tar and then passed in at the base to cool the descending charcoal. This gas after leaving the retort is mixed with the rest of the gas and burned to produce the hot inert rinsing gas. Any deficiency of heat caused by use of wet wood, etc., has to be made up by burning extra fuel such as oil or natural gas in the furnace.

Alternatively the whole of the hot effluent gas can be burned to produce steam for power generation and the heat needed for retort operation obtained by burning another fuel such as oil, coal or natural gas. The advantage of this procedure is that it avoids handling the retort off-gases and their associated tar and other liquids. Some of the advantage is lost if these alternative fuels are costly which is usually the case nowadays. The large retorts at the Wundowie ironworks in Australia burned the tar-laded off-gases for power generation and used clean cold blast furnace gas as the cooling and heating medium for the retorts. The best method to use at any particular site depends on local factors. But the heat inputs have to be paid for and efficiency depends in the long run on drying the wood as effectively as possible before it is charged to the retort. (See Chapter 4).

In the original installations of these retorts in Europe the head gas from the retort was processed to recover chemical by-products. Fig. 4. This kind of retort is suited for recovery of chemical by-products. Well dried wood is essential to minimise extra fuel inputs and avoid excessive dilution of the pyroligneous acid. This reduces costs by avoiding subsequent evaporation of water.

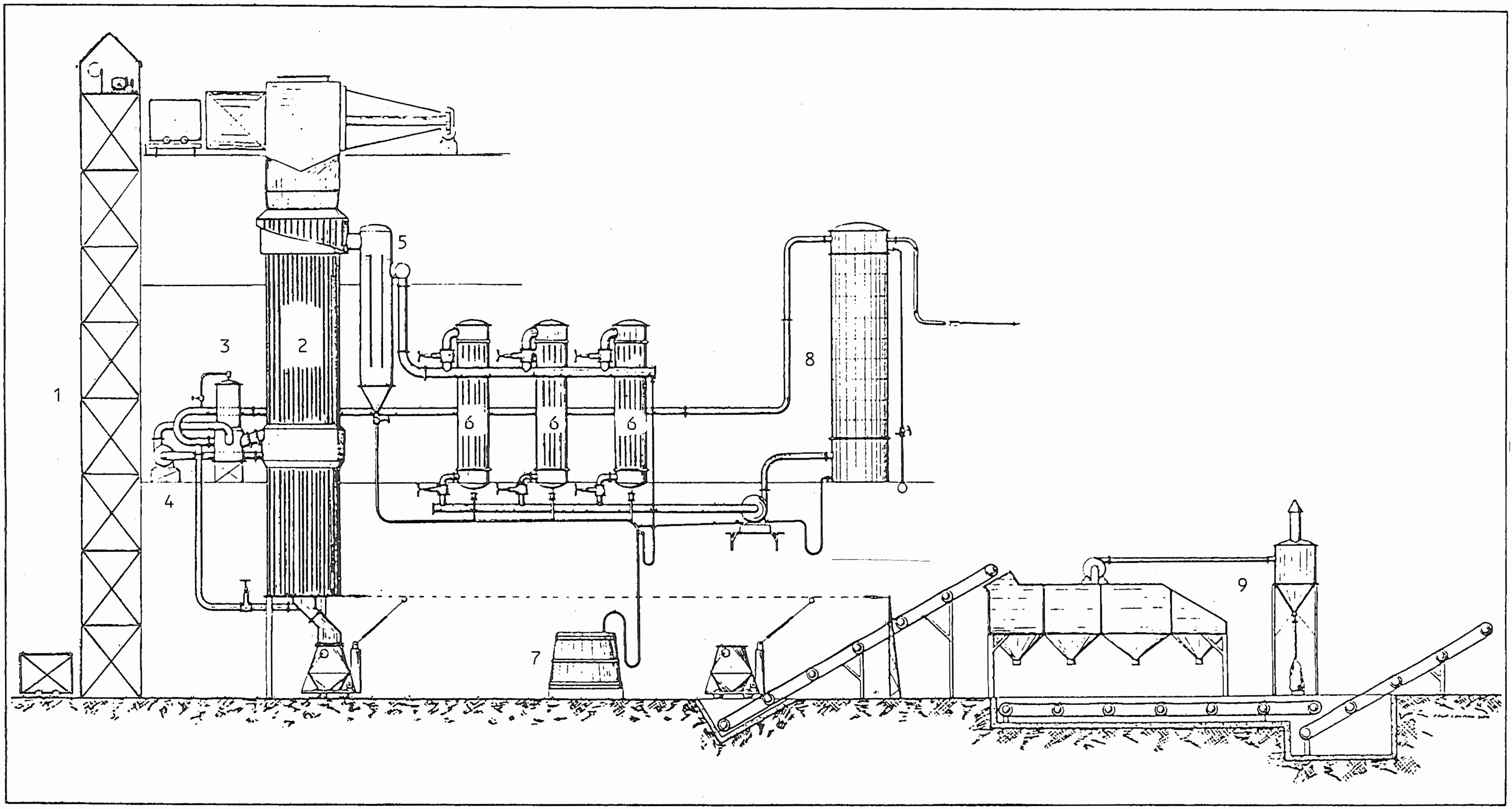

Fig. 4 Continuous Vertical Hot Rinsing Gas Retort - By-products recover

1. Wood elevator 2. Retort 3. Hot gas heating stove 4. Heating gas fan
5. Gas cooler 6. Pyroligneous acid cooler 7. Pyroligneous acid storage
8. Off-gas scrubber 9. Charcoal storage

EFFECT OF WOOD MOISTURE CONTENT ON ENERGY USE

Moisture %	Energy used MJ/m^3	Circulating gas m^3	Electricity kWh
5	35	210	2.5
10	40	270	3.2
15	154	490	4.4
20	293	770	5.2
25	460	1050	7.2
30	648	1400	9.0

The above data for European hardwoods shows the marked rise in heat and electricity use when the moisture content increases.

The sharp rise in energy consumption when the raw material moisture content rises is not the only problem. Increased moisture input to the system reduces the installed capacity of the plant and slows down production. These problems can be reduced if the wood is passed through a dryer before entering the retort. Raw material drying systems are described in Chapter 4.

Several attempts have been made to simplify the SIFIC process which is notable for its high investment cost. The most successful modification of the system is the smaller CISR-Lambiotte retort which has now been operating commercially for a number of years. Its major features are outlined below. (Photo 4).

The retort is heated by hot inert gas derived by burning part of the recycled retort gases and vapours. This provides the energy needed to complete the drying of the wood, raise it to spontaneous decomposition temperature, drive-off the surplus tar trapped in the structure of the charcoal and make up the various heat losses of the retort. The charcoal is cooled by passing the remainder of the retort gas after it has been cooled and cleaned into the base of the retort as in the larger SIFIC system. This gas becomes heated as it cools the charcoal and is mixed with the rest of the retort gas to be burned with air in a heating stove to provide the hot inert rinsing gas to be injected at the centre of the retort just above the exit point of the cooling gas.

It is important to keep the moisture content of the wood entering the retort to around 30% or less. Otherwise the gas coming from the retort is difficult to burn and will not produce the hot inert heating gas needed. The amount of air mixed with the gases in the heating gas must also be carefully controlled to achieve maximum temperature. If care is not taken it is difficult to recover enough heat from the carbonising wood to keep the process going and additional fuel such as oil must be burned to make up deficiency. The carbonisation temperature in the retort is set by the quality of the charcoal to be produced. If this temperature is not reached the charcoal will be underburned and the retort will gradually stop operating properly.

Some typical features of the retort are given below:-

- size of the retort
  height 18 meters, diameter 3 meters
- typical input
  approximately 7,000 tons of dry wood per year
- type of raw material
  roundwood and slabs, length 350 mm, thickness 100 mm, moisture not exceeding 30%
- typical yield
  approximately 2,500 tons of charcoal per year
- power requirements for retort operation
  about 25 kW of electricity
- cooling water for gas coolers and scrubbers
- oil or natural gas for start-up and emergency heating of inert rinsing gas.

A problem affecting all carbonisers constructed of steel is corrosion by acetic and related acids evolved during carbonisation. It particularly affects the vertical continuous type retorts because there must always be some part of the retort at a temperature suitable for attack by the acidic vapours and the continuous movement of the material down the retort removes any protective layer which may form on the surface of the metal, constantly exposing it to fresh attack. The corrosion can be readily overcome but at considerable cost by using stainless steel in those parts of the retort where attack is rapid.

3.5 The Rotary Hearth Furnace

The rotary hearth furnace is a proven method for carbonising small particle size wood and bark. The charcoal is produced in powdered form. This type of furnace is also known as the Herreshoff roaster. It was developed in the metallurgical industry for roasting sulphide ores many years ago.

Unlike the other two carbonisers described earlier the Herreshoff furnace will not operate with wood in slab or round form. The feed must be in the form of moderately fine particles such as sawdust or bark fragments. Agricultural residues such as seed hulls and shell fragments can also be processed.

The furnace (see Fig. 5) consists of four to six circular refactory hearths stacked one above the other. The hearths are about six to eight meters in diameter. The large furnaces (22) have six hearths and the smaller units four. The hearths are supported in a cylindrical refractory lined shell and are constructed with the underside domed so that the hearth is self-supporting. Each hearth has a central hole through which passes a hollow shaft and at each hearth, a set of rabble arms are fixed to it. These arms are hollow so that the whole raking system can be cooled by blowing air through it. The ploughs attached to the arms just clear the hearth surface and as the arms turn slowly, at one to two revolutions per minute, the ploughs turn the feedstock over and move it across the hearths. The ploughs are arranged so that those on one hearth move the material away from the centre towards the edge where it falls through an opening to the hearth below. The ploughs on this hearth cause the material to move to the centre where it falls through the central opening on to the hearth below. In this way the material slowly moves through the system whilst being constantly turned over to be exposed to the combustion air passing through the furnace from the bottom to the top.

The furnace is started using gas or oil burners on each hearth to raise the temperature to about 600°C causing the feedstock to ignite. When the furnace reaches normal operating temperture of 900 to 1000°C the burners are turned off. Once the furnace is lit it must operate continuously 24 hours per day. The rate of admission of air is regulated so that the wood carbonises and leaves the furnace as fine charcoal. The gases produced are a mixture of wood gas, tar, pyroligneous acid condensibles and water vapour and as such form a highly polluting mixture. After it emerges from the top of the furnace it can be burned directly under boilers for process steam or power. Otherwise the gases must be burned and the flue gas vented to atmosphere in tall stacks to avoid environmental pollution since installations of this kind for economic reasons are almost always located in closely settled areas.

The charcoal leaving the furnace must be cooled to avoid spontaneous combustion. This is carried out by passing the charcoal slowly through a horizontal steel cylinder equipped with paddles which lift

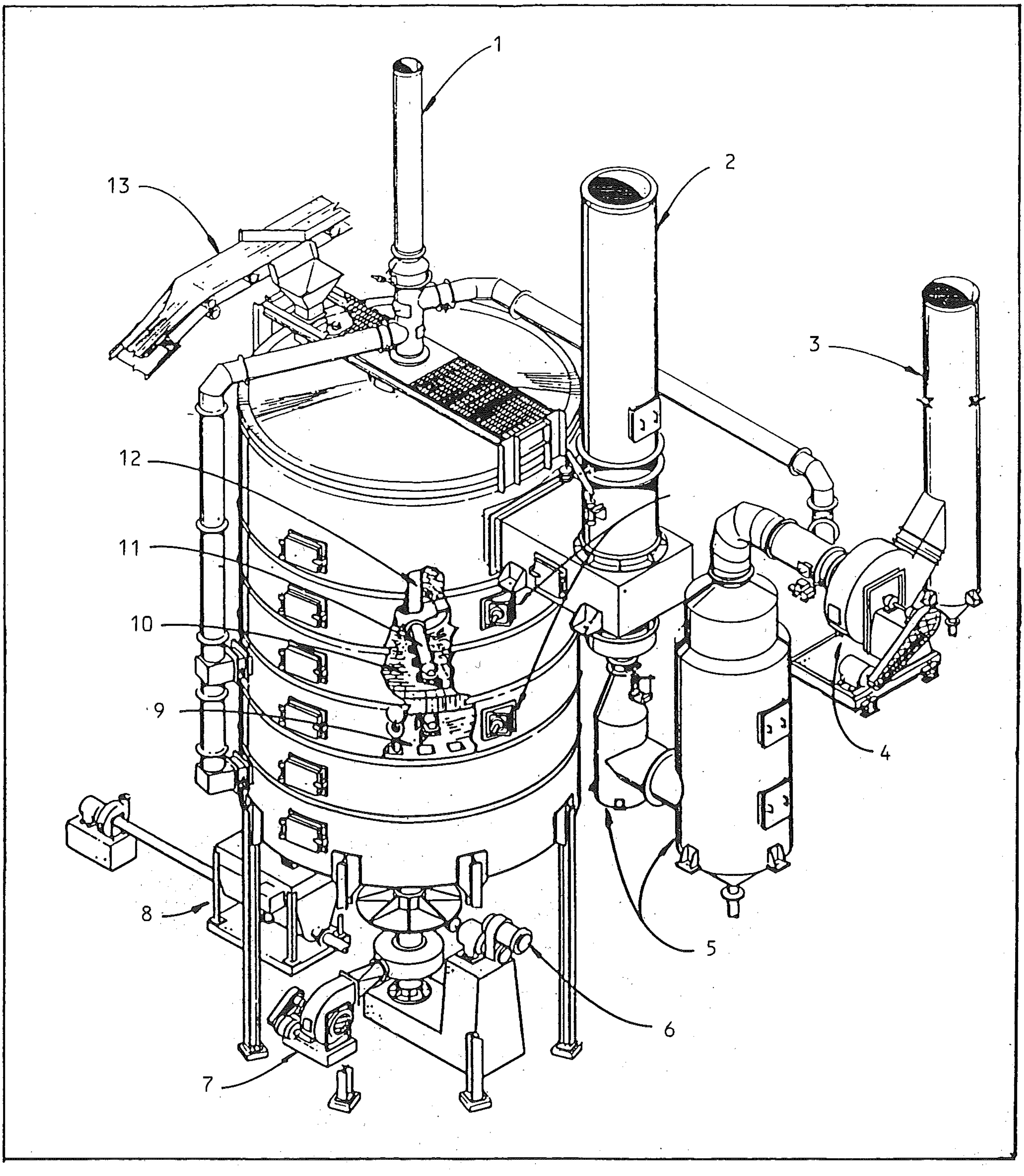

Fig. 5 Rotary Hearth Retort (Herreshoff)

1. Air stack to cool central staff 2. Emergency by-pass stack
3. Main exhaust stack 4. Induced draft fan 5. Air pollution controls
6. Centre shaft drive 7. Cooling fan for central shaft 8. Charcoal cooler
9. Out hearth 10. In hearth 11. Rabble arm and teeth
12. Centre shaft 13. Feed conveyor

the charcoal and allow it to contact the walls which are cooled with a water spray. The cooled charcoal is stored in a hopper sufficient to hold two or three days supply for the briquetting plant, a necessary adjunct to such a furnace.

The amount of wood or other residues needed to keep the furnace going is quite large. A small unit requires about 4 tons of oven dry residue per hour and the larger units about ten tons per hour. Capacity is influenced by the moisture content of the feedstock as in all carbonising systems. The above quantities will yield about 1 to 2.5 tons per hour of charcoal providing the moisture content is about 45% of the green weight. This adds up to about 9000 to 21000 tons of waste per year yielding 2200 to 5200 tons of fine charcoal.

This fine charcoal has few uses in this form and hence must be briquetted. As a rough rule the briquetting operation doubles the cost of the fine charcoal (see Chapter 6 and Refs 3 and 22).

Herreshoff roasters have been successful when attached to large saw and plywood mills in the south of the USA where the conjunction of an adequate raw material supply in the form of bark and sawdust and the proximity of a sophisticated urban barbecue market provides a profitable combination.

Although it would be theoretically possible to recover the pyroligneous condensates from the off-gas stream for chemical recovery economic factors seem unfavourable and hence the gases are either burned for power or merely burned to waste.

3.6 Fluidised Bed and Similar Carbonisers

Many proposals have been made for carbonising finely divided wood and agricultural residues by continuous methods which would operate on a smaller-scale than the well proven rotary hearth furnace and which would allow recovery of chemical by-products or at the very least waste heat for process heating or power generation. Despite sustained efforts and a good deal of promotion there has been little progress beyond the laboratory stage. Since these systems are not practical systems which can yet be recommended we cannot devote much space to them in a manual of this kind intended to be of immediate benefit to the developing world. Nevertheless, it is worthwhile to devote a few lines to the problem because those concerned with the fuel problems of particular developing countries are often assailed with proposals to invest in such schemes.

The appeal of such systems is understandable. They seem to offer a way, with relatively modest capital investment, of turning apparently useless wastes into useful charcoal plus important quantities of pyroligneous acid.

Since these systems produce charcoal in powdered form it is implied but not always emphasised that investment in such a carbonising system requires investment in a briquetting plant as well so that the charcoal can be marketed as household fuel.

To convert these wastes to charcoal requires that they be dried and their temperature raised to spontaneous decomposition point to form charcoal and then further heated to reduce the tar content to an acceptable level. Providing the residues are at least air-dry on entering the carboniser there can be a net positive output of heat but careful design and control is needed to realise these benefits.

The biggest stumbling block is the problem of separating the charcoal from the rest of the material in the apparatus and recovering it for briquetting for sale. This task has to be accomplished using a fairly simple system which does not require large energy inputs and conserves the heat outputs of carbonisation so that extra energy inputs from the burning of other fuels are not needed to carry the process on.

It is relatively easy to process finely divided wood and similar residues in continuously operating closed combustion apparatus where the objective is to merely produce hot gas for process heating. Here the problem of separating the charcoal from the not-yet-charcoal does not arise as the only solid residue is ash. A number of commercial units of this kind have been developed in the seventies and installed in the USA and other countries to provide alternative heating to replace oil and natural gas. The relative fall in oil energy prices however has taken away most of the incentive to use such systems but they remain a valid technical option despite the fact that they require electric power and fairly sophisticated instrumental control. Unfortunately, the same progress has not been made in the production of charcoal and we are not able to describe any commercially proven systems.

3.7 Recovery of By-Products from Carbonisation

As pointed out in Chapter 2, the development of the petrochemical industry has made the recovery of chemical by-products from wood carbonisation in most situations an economically unattractive activity for new investment. But there is still sufficient demand in some developed countries for the special chemicals which can be recovered from wood distillation and this sector of the industry will probably continue for some years.

The biggest obstacle to success in by-product recovery is the relatively great cost of the necessary refinery and the relatively low prices offered for the basic chemical products such as acetic acid and methanol. Where the investment has been made in previous years and the plant amortized then the economics of by-product recovery are more favourable. Closeness to markets is very important in ensuring a profitable result and this operates against the developing countries where there is no developed market for the chemicals produced.

The basic system used to recover the chemicals is described in Chapter 2. In this chapter some possibilities of recovering something from the otherwise waster gases and vapours of carbonisation is explored.

When the off-gases of carbonisation are merely allowed to escape into the atmosphere as occurs in the simple technologies the thermal and chemical energy these gases contain is merely wasted and this reflects back on the efficiency and cost of the charcoal making process.

The simplest way to recover something from this waste gas is to collect condensed tar from the flues of the carboniser. This wood tar has a definite economic value and is relatively simple to collect. Some methods for doing this are described in (15). Unfortunately to recover more from the gases requires a major investment step in the form of a full scale by-product refinery.

Where complex retort systems are used for charcoal making the simplest approach is undoubtedly to use the whole of the off-gases as a source of heat for carbonisation and if there is an excess to burn the gases for power or process heat generation. Some of the retort systems described earlier in this chapter recover the heat in the off-gases this way. There are a number of advantages which can be mentioned. The capital cost is fairly low, the technology requirements are minimial, pollution of the environment is minimised and the saving in fuelwood allows more charcoal to be produced from the same amount of wood. And making charcoal for people's needs is what this publication is really all about.

The only difficulty in operating this kind of heat recovery system is in recovering enough heat to eliminate the need to burn costly oil or gas fuels as make-up heat to keep the retort operating. This can turn an otherwise profitable installation into a loss maker. The key to success is proper drying of the wood before it enters the retort.

This calls for optimum use of the sun's heat to dry the wood as detailed in Chapter 4 and good management practice in retort operation to conserve heat and gas. Investment in a dryer fired with off-gas for the wood or residues being used may well be worthwhile. In general if the moisture content of the feedstock to the retort can be maintained at 30% or less there will be enough heat in the recovered off-gas to maintain carbonisation without added heat inputs (4). The heat quantities involved are quite significant. Actual figures will vary with the nature and moisture content of the feedstock. Approximately from one thousand kilograms of dry wood the following heat quantities are available in megajoules (MJ) in the final products.

Charcoal	9500 MJ
Wood Gas	1500 MJ
Condensibles including Tar	8000 MJ

The heat in the wood gas and the condensibles is made available for carrying out the carbonisation by burning them with air in a suitable stove forming part of the retort complex.

The retort off-gases with their content of tar are difficult to handle once they cool. The tar is sticky and clogs up gas mains and valves and cleaning them is difficult and costly. Where the off-gases are to be used for retort heating or for power generation it is essential to keep them hot as they emerge from the retort until they enter the furnace where they will be burned. This avoids deposition of tar. A temperature in the hot gas mains of about 300°C is typical and they should be as short as possible.

If recovery of chemical by-products is to be undertaken then the off-gases pass directly to the tar scrubbers and condensers. The liquid condensed with the tar at this stage is known as crude pyroligneous acid and it must be stored to allow the insoluble tar which it carries to separate so that it can be decanted. The wood gas passes on without change from the condensers and it merely carries some tar in the form of mist which may be separated in further tar scrubbers or the tar-laden gas may be burned directly for retort heating. Unfortunately the wood gas is of low heating value once the condensibles including the tars have been stripped from it. The total amount of heat it can yield is not enough, unless dry wood is being processed, to carry out the carbonisation process. This implies that additional heat inputs will be needed to operate the carbonisation process. The cost of these heat inputs whatever their source, wood, oil or natural gas has to be offset from the profits obtained from recovery of chemical by-products. Obviously before investing in by-product recovery careful studies are needed to ensure the financial viability of the investment. Fig. 6 gives a schematic outline of a charcoal plant with recovery of chemical by-products

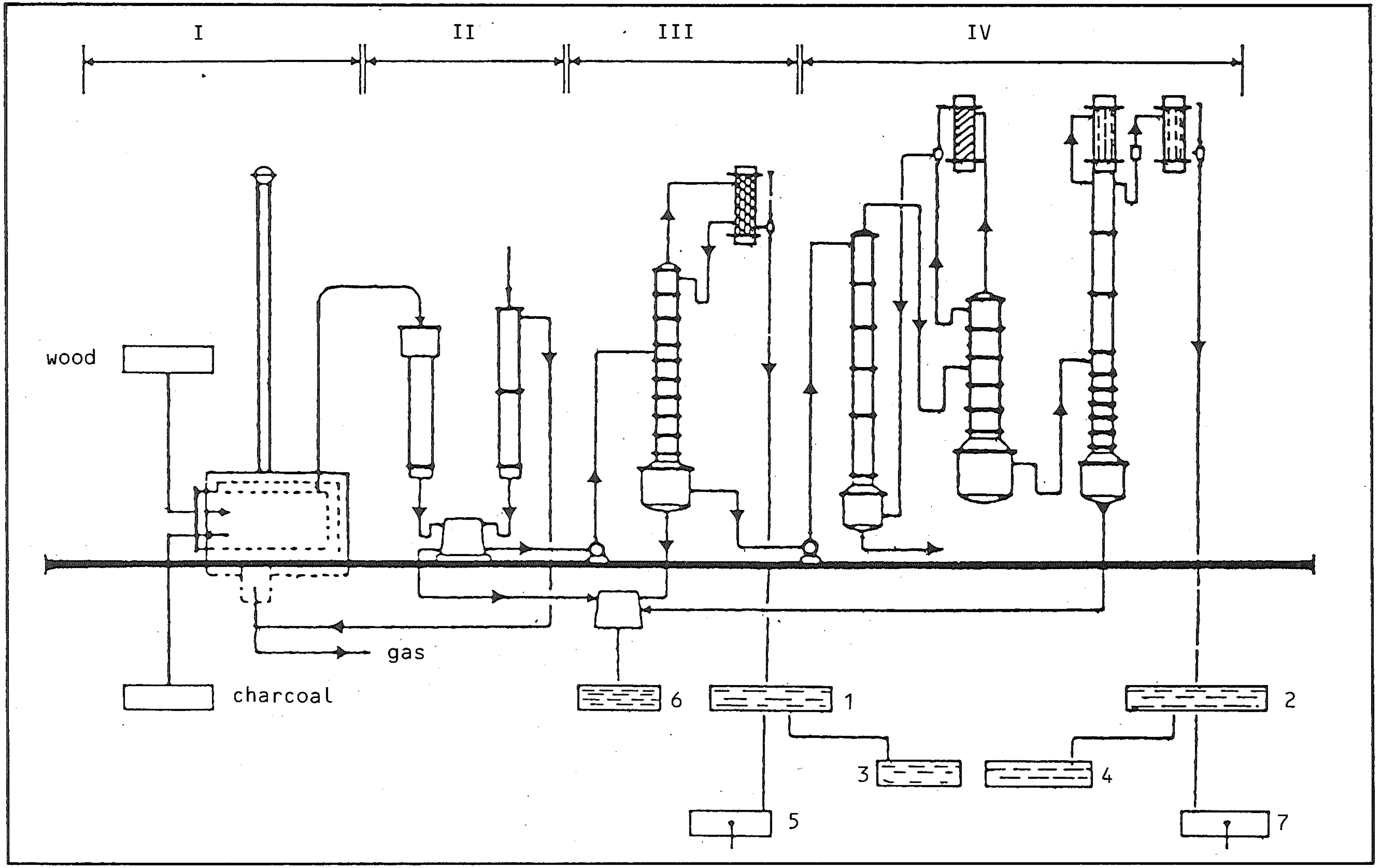

Fig. 6 Charcoal Plant with Refinery for Recovery of Chemical By-Products

I. Carbonisation II. Pyrolygneous acid recovery III. Crude methanol plant
IV. Acetic acid concentration

1. Crude methanol 2. Crude acetic acid 3. Methanol 4. Acetic acid
5. Methylating spirit 6. Tar 7. Waste water disposal

from pyroligneous acid and tar. The functions of the various units is described in the text below the figure. In Fig. 7 an integrated carbonisation process is shown.

Since tar can be recovered during carbonisation with comparatively little equipment it is worth saying something about the products which can be recovered from it.

First of all there are two kinds of tar produced - water insoluble tar and water soluble tar. Most of the water soluble tar is recovered from the base of the primary still where the methanol, acetic acid, acetone, etc. is separated from this tar as explained in Chapter 2. Unfortunately soluble tar is of little commercial use. Insoluble tar mostly separates out when the retort vapours first pass through the condensers and it is recovered by decantation from the mixture of water soluble tar and pyroligneous acid. Small amounts of this tar are recovered from various parts of the off-gas handling system and added to the rest.

The equipment needed to refine the tar if it is not to be sold simply as crude tar are two stills and a rectifying column. Referring to Fig. 8 it can be seen that the tar is separated into three fractions. I is only suitable as fuel. II and III contain useful materials and these can be separated in the tar distillation plant. This is a complex chemical process and requires skilled operatives and management and significant volumes of raw material to make the process worthwhile. It is for this reason that wood tar distillation plants buy in tar from a number of producers to increase the amount available for processing and hence tend to be found only in those countries which have a well developed chemical industry.

3.8 Criteria for Choosing Carbonisation Systems

Choosing a retort type carbonisation system requires great care because of the capital investment involved and the number of years for which the equipment must operate at a fixed location. If the resource within economic range of the plant proves to be inadequate then the investment may prove very ill-advised.

To provide background for selecting a carbonising system the relevant features of the systems are summarised below and the factors which must be considered are listed.

First of all certain technical and social factors must be considered. Presumably a decision has been taken to produce charcoal and that the situation rules out the use of the simple technologies which are dealt with in detail in (15).

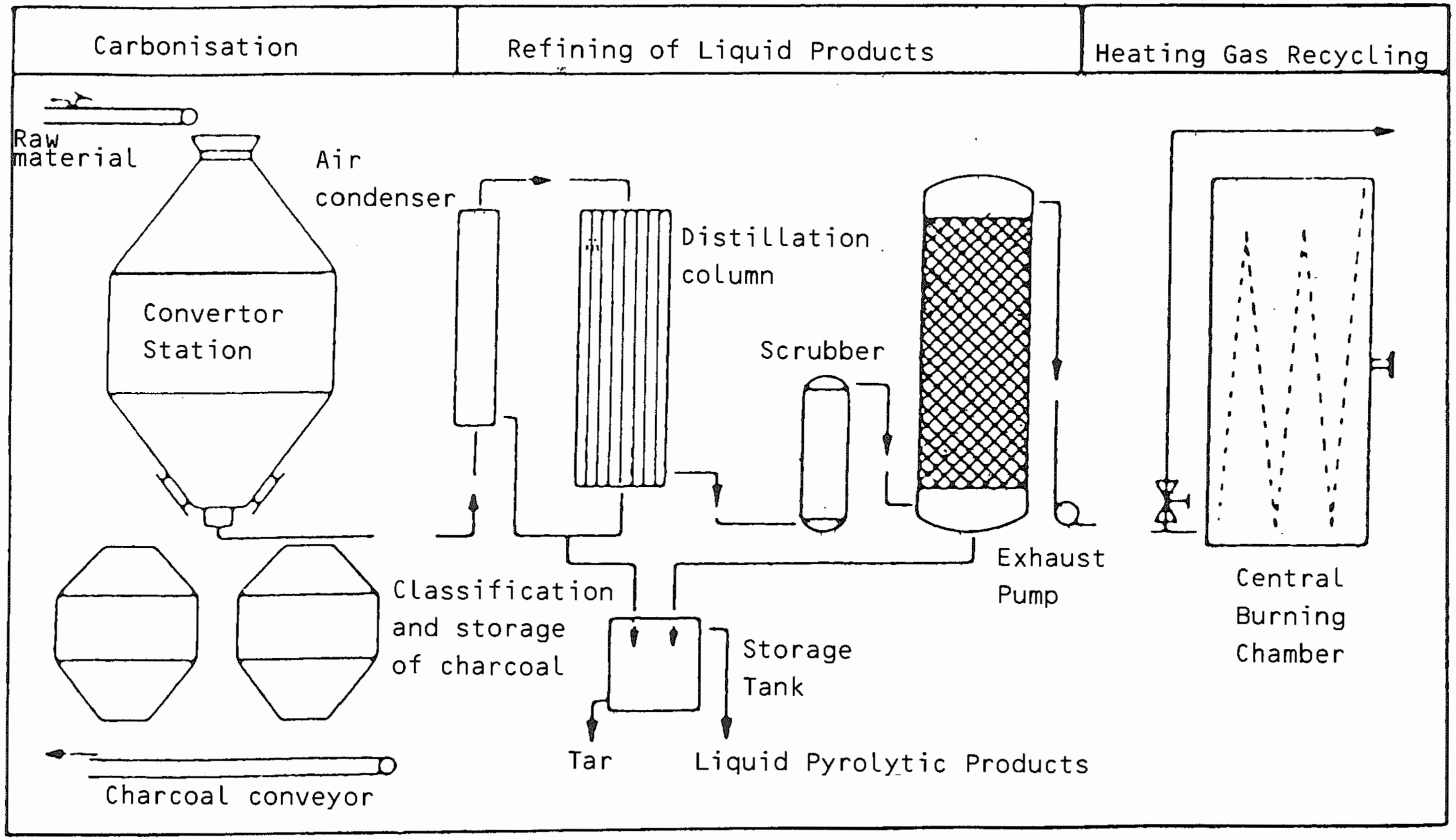

Fig. 7 Integrated Carbonisation Process - Schematic Outline

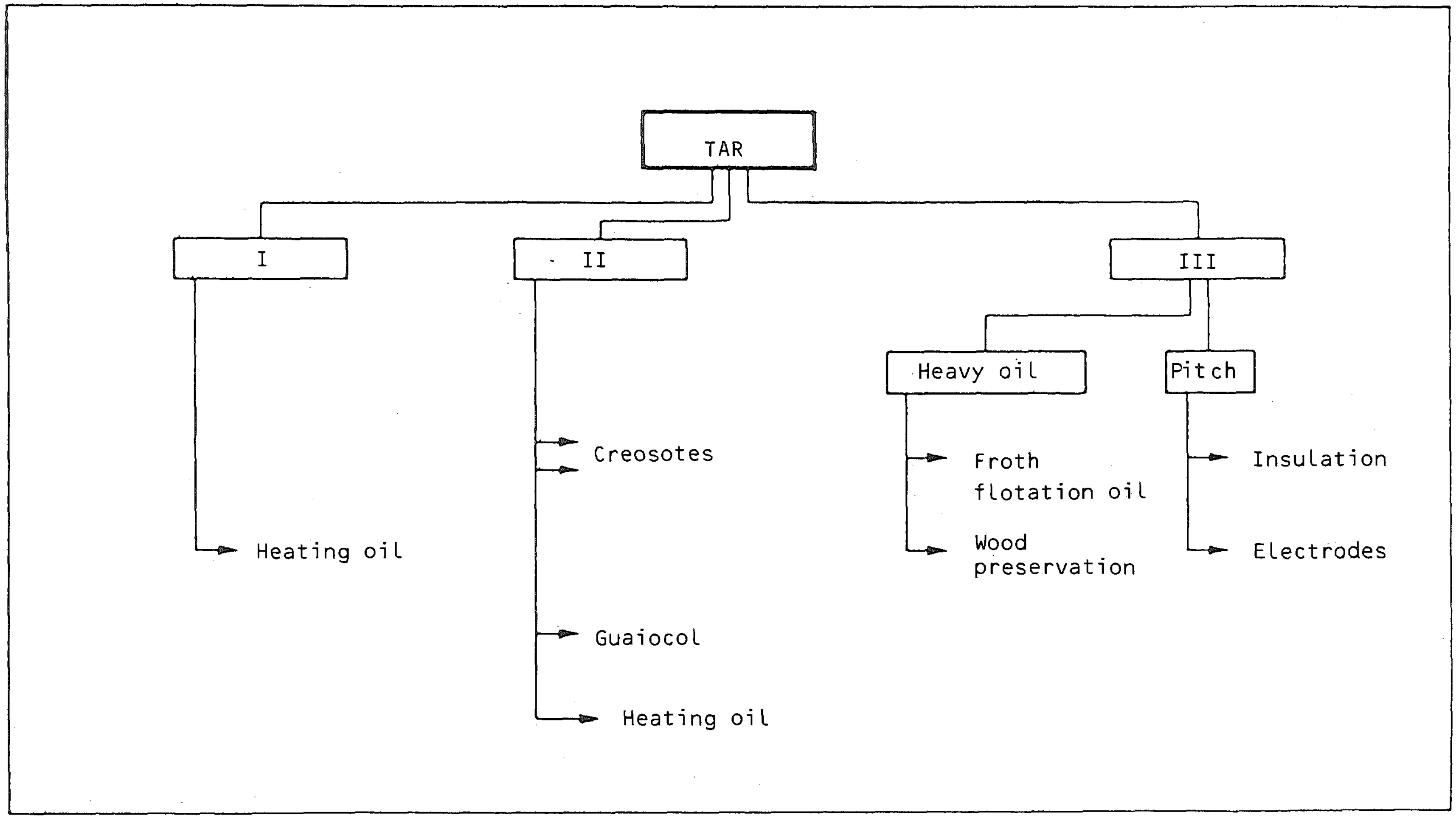

Fig. 8 Tar Fractionation - Schematic Outline

I. Light tar oil II. Heavy tar oil III. Residual tars from still

A decision of this kind cannot be undertaken lightly since in order that the investment may have a chance of being recovered, the resource area must be committed for twenty to thirty years into the future. The resource must also be managed in such a way that the needs of the charcoal retort system are adequately serviced. This precludes other uses for the land, a difficult decision where populations are rising and pressure on the land increasing. The use of complex retort systems introduces a degree of inflexibility in resource allocation which governments may find difficult to live with.

An important factor to be considered is the cost of transporting the wood from the furthest points of the allocated area to the carbonisation site. Retorts in general cannot be economically moved around the site as pits, mounds and brick kilns can and this may have a drastic effect on production costs.

Another factor is the type of material to be carbonised. Is it solid wood, finely divided residues, bark or agricultural wastes. Only solid wood can produce lump charcoal, other types of raw material with the possible exception of coconut shells will produce powdered charcoal usually requiring briquetting before it can be marketed. This means additional investment in a briquetting plant plus the cost of the binder and the briquetting operation. A supply of binder usually a starch of some type in quantity equal to about 8-10% of the weight of the charcoal produced must be available at the site. If the zone is not agricultural and/or food shortages occur, obtaining the binder can prove difficult and this adds another element of inflexibility to the overall system.

The next factor in making a decision is whether by-products are to be produced from the retort gases. If yes then finance to build the refinery is required. Under today's plant costs and the competition from the petrochemical industry a decision to produce by-products is rather unlikely. A refinery requires specialist technicians and plant operators and considerable periods of training before profitable operation could be achieved. Without careful planning and committment the refinery could well prove to be a lossmaker. It also introduces a further element of inflexibility into the system. It is therefore likely that the decision will be taken to merely use the off-gases as fuel either to directly assist carbonisation or to generate power or process steam. Fortunately a decision on a refinery unlike the briquetting plant can be deferred in most cases. The refinery can be added on at a later stage if shown to be worthwhile.

Chapter 4

RAW MATERIALS FOR CARBONISATION

4.1 Introduction

The raw material for carbonisation, its gathering and preparation constitute the single most important aspect of charcoal manufacture no matter what method of carbonisation is used. In this chapter raw materials are divided into two groups:- those derived from trees, i.e. wood in some form or other and those derived from agriculture, the so-called agricultural residues. Not all raw materials produce quality charcoal and the quality of the charcoal produced by a particular raw material should be checked to see if it fits proposed markets or end uses before any investment is made. There is an important point to take note of. Unlike coking coal which when it is turned into coke by carbonisation fuses together to form strong aggregates even if powdered coal is used, woody type raw materials when carbonised do not fuse and the charcoal has the form of the original raw material, i.e. lump wood produces lumps of charcoal and powdered agricultural waste or sawdust produces charcoal in the form of powder which is unsuited for many industrial charcoal uses even if it is briquetted in the usual way.

The mechanical strength of charcoal be it lump or powder also depends on the raw material. To possess a high crushing strength as is needed for use in blast furnaces the raw material must contain lignin and other lignin like extractives. These substances when carbonised give strength to the charcoal. High strength charcoal requires wood or nut shells as raw material. If lump charcoal is needed then wood is practically the only material though coconut shells produce strong charcoal suited for gas absorbtion purposes in a size adequate for this application.

All other raw materials produce fine charcoal which must be briquetted and is only economic when sold into the barbecue market to middle class consumers.

4.2 Wood for Carbonisation

This is the most important raw material by far and produces excellent charcoal. There are two broad types of wood, hardwoods produced by broadleaved species and softwoods produced by conifers. Both produce charcoal but hardwood charcoal is usually stronger than softwood charcoal.

There are also differences between the liquid condensate produced when the two types of wood are carbonised. Softwoods because of their resin content tend to produce more tars and there is less acetic acid and similar products in the pyroligneous acid fraction. Often where pinewood is available as waste it is more rational to extract first the rosin content of the wood by solvent extraction after reducing the wood to chips. The extracted wood may be then used for pulp, fuel or made into charcoal and the resulting fine charcoal briquetted. (Fig. 9)

4.2.1 The Unit Operations in Wood Harvesting

Wood occurs as natural forest or in man-made plantations. The management of natural forest and plantations is a technique requiring knowledge of forest science and cannot be dealt with here. More detailed information from the point of view of charcoal production is given in (12, 13, 14, 15).

The harvesting problem when making charcoal on a large scale, is the same as for the gathering of pulpwood except for the need to dry the wood as much as possible before it is carbonised.

The unit operations in harvesting wood are:- roading, felling, skidding, blocking, drying, transport to carboniser, stockpiling and final block preparation. These unit operations are discussed in the following paragraphs. (See also Chapter 7 and Figs. 9 and 14).

4.2.2 Roading

First the forest area which will provide the raw material for the life of the enterprise must be defined and secured in a legal sense. Then a roading and harvesting plan must be drawn up which will allow the wood to be felled, dried and extracted at minimum cost over the life of the enterprise. The road system needs to be planned to minimise haulage distance and decisions made as to where the wood is to be piled for drying, at or near the stump or at the charcoal making enterprise itself.

If the wood is obtained from plantations then the harvesting scheme must be coordinated with the plantation management and regeneration plan.

The quality of the road system needed depends on the type of logging trucks to be used. If as is common in charcoal wood gathering either flat top trucks or combinations of agricultural tractor and trailer are to be used a simple roading system will be adequate. But if large logs in full lengths are to be extracted as may apply if the charcoal making forms part of a larger integrated logging system then heavier roads and bridges will be needed.

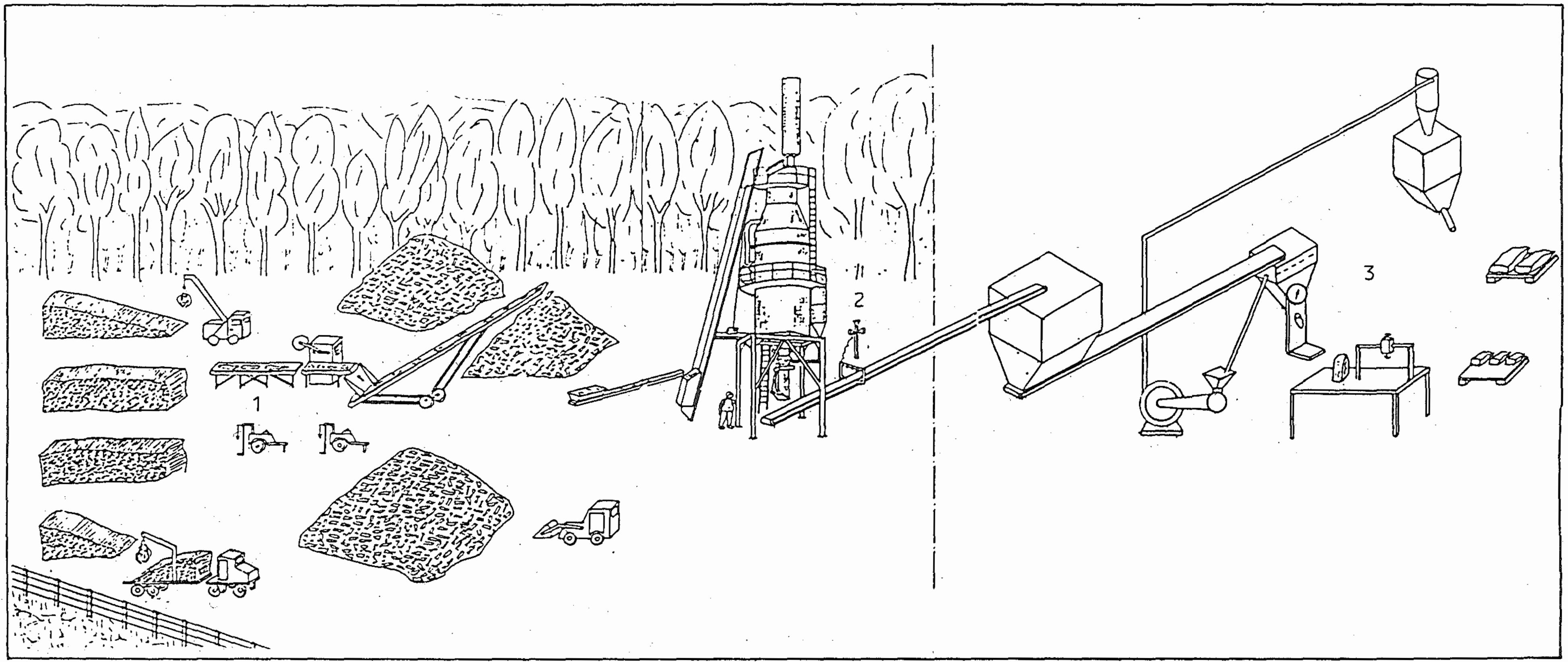

Fig. 9 Charcoal Making Installation - Lambiotte Process - General View

1. Wood preparation 2. Carbonisation retort 3. Charcoal processing and packing

The wood drying system also determines road layout. The best system is to allow maximum drying to be done as near the stump as practical as this reduces capital tied up in stock and reduces the weight of wood to be transported quite substantially. In plantations with good access right to the stump the trees are merely felled lying in the one direction and allowed to dry before being crosscut. This may be 3 to 12 months.

Otherwise the full length log may be skidded to the roadside and either loaded onto truck there or crosscut into blocks and piled for drying at the road side. In all cases the road system needs to be brought to about 100-200 m of the stump if the topography allows.

4.2.3 Felling and Skidding

Chain saws are universally used for felling nowadays where the logging operation is of large size necessary for any retort based charcoal making operation. Clear felling is preferred rather than selective operations. Where natural forest is being logged it is best to arrange that all the logs suitable for sawmilling, etc., are first removed selectively and then the wood destined for charcoal is felled as a clean-up operation to prepare the forest for regeneration or for agriculture, etc. In this way, access and drying conditions are improved and the felled wood can be left to dry in the forest or along the access roads without interfering with other operations.

The logging waste from the extraction of the sawlogs is also recovered at the same time. In natural forests the logs are then skidded to roadside together with other logging waste and there they are crosscut and piled for drying.

In plantation forests because of the easy access and the uniformity of growth it is often possible to fell the trees and allow them to rest on the branches and on the stump so that they dry out rapidly in this elevated position. The transpiration from the leaves which remain attached to the stem appears to aid the drying process. After sufficient time has elapsed the stems are skidded out to roadside and crosscut or may be cut into blocks at the stump and loaded directly into tractor drawn trailers.

The maximum amount of bark, leaves and twigs should be left on the forest floor in order to conserve nutrients and because this material cannot produce commercial charcoal.

4.2.4 Blocking and Drying

The kind of retort system in use determines the length of block which can be used. The longer the block the lower the cost of this operation. Conventional brick kilns have here a great advantage over retort systems in that they can economically handle stems up to about 0.5 m diameter and 1.8 m long. Rinsing gas retorts require blocks about 0.3 m long maximum and about 0.1 m diameter. Fluidised bed systems require the wood to be in chips or sawdust which makes the preparation cost prohibitive. These systems are only operable with waste wood which has been size-reduced in connection with some other operation, for example sawdust or bark flakes from softwood debarking operations.

To minimise the amount of capital tied up in the drying wood stock it should be blocked into its final length as soon as possible after felling and as close as possible to the stump. It should be dried as close as possible to the stump.

A compromise is often necessary. About 12 months drying to get the moisture content close to about 18-20% is desirable for maximum fuel economy in retort operation. This works well in dry savannah woodlands but in the humid tropical high forest the wood may well be rotted after 12 months and three months may be about the maximum practicable drying time. Rotted wood produces only useless powdered charcoal. The time allowed for drying must be chosen so as to reduce rotting and loss of wood by insect attack to an acceptable level and yet lower the moisture content as much as possible to improve the thermal efficiency of the carbonisation process. Locating the dumps for drying the wood so that insolation and air circulation are maximised to obtain the most rapid drying possible is well worthwhile.

4.2.5 Haulage to Carboniser

Road transport of the wood to the carbonising site is usually carried out with either trucks where the transport distance is more than a couple of kilometers or using trailers and agricultural tractors where the haul is short. Where the wood is to be transported as logs then orthodox log trucks are the best solution. Despite the disadvantages if the trees are large then it may be necessary to establish a central block cutting and splitting unit.

In planning the road haulage system regard must be paid to obtaining a steady supply of wood during wet weather by reserving dumps of wood accessible during wet conditions.

4.2.6 Final Block Preparation and Stockpiles

The amount of blockwood which must be held at the carbonising site depends on the size of the logs which are processed, drying conditions of the zone which will determine if a block dryer is needed and the amount of blockwood which must be kept on hand to maintain the retort in operation during prolonged wet weather, seasonal shutdowns or labour disputes.

From a cost point of view the wood should be stored in the forest and only brought to the carboniser when it is ready for use. In practice some stockpiling at the site is unavoidable. The normal system of storage is to bulldoze a large area about the size of a football field with good drainage and exposed to sun and wind and fill it with randomly dumped blocks about one meter deep with access for front end loaders to handle the blocks as required. The stock should be kept rotating to avoid decay and insect attack problems and ensure that the driest blocks are being used at all times.

A special problem arises where the trees being carbonised are of large diameter. As pointed out the conventional brick kiln systems easily handle logs up to 0.5 m diameter without splitting. The length can be more than 1.5 m. Retorts cannot handle big blocks and splitting the large logs is a costly and difficult problem.

A successful system at Wundowie in Australia for splitting logs up to 1.5 m in diameter consisted of two units. The first was a large trough into which the large logs could be dumped by log forks off the log trucks. When the trough was full it rolled sideways on tracks past two large circular saws mounted one above the other and capable of cutting a log 1.5 m diameter. At each pass of the carriage a plate pushed the logs forward along the trough the thickness of the discs of wood required. The cut discs fell onto a heavy conveyor which carried them under a reciprocating press armed with a wide wedge which split the discs into blocks of a size which could be fed directly into the rinsing gas retorts.

Preparing blocks for retorts in the huge volume needed can be a costly operation without a high level of mechanisation. This is especially so where large diameter trees are to be processed. The attraction of processing these trees is that they are often dry having died many years ago and useless for sawmilling.

Where large diameter logs are blocked on a smaller scale it is usually done with chain saws but the work is very arduous and without front-end loaders, etc. to manipulate the blocks almost impossible. Splitting the wood is normally done with hydraulic splitters driven from the power offtakes of agricultural tractors.

The cost of blocking the wood into a suitable size to be charged to retorts is a major cost. In addition the wood haulage cost tends to rise sharply with time because the retorts cannot usually be moved closer to the wood resource as is harvested often makes the whole operation uneconomic. These problems are discussed in more detail in Chapter 7.

It is good practice where possible to allow extra drying at the carbonisation site before the wood is charged to the carboniser. This can take place naturally by allowing the wood to remain stockpiled for some months before charging. Where waste heat is available it may well be worthwhile to dry the blocks in a continuous tower dryer fired with waste gas from the retort system. Fig.10 shows the principle of such a dryer, in this case developed for use with the Lambiotte type retort where the hot gases from the top of the retort are diverted and burned to produce the heat needed for the dryer. Dry wood produces a higher yield of charcoal and a greater throughput from the retort making drying one of the most beneficial options open to the charcoal maker. Figure 11 shows an installation designed by Lambiotte for carbonisation of pre-dried wood.

4.3 Agricultural Residues for Carbonisation

Agricultural residues attract interest as carbonisation raw materials because they are often available in large quantities around processing plants and appear difficult to utilise except as fuel. The use of these residues however is not without disadvantages for agriculture since using them this way removes organic and inorganic materials from the soil leading to impoverishment of farmlands and increasing the need for costly aritificial fertilisers.

Despite the above objections there are some situations where the use of agricultural residues is quite feasible. Nut shells are of particular interest because of the special properties of this charcoal. After activation (Chapter 6) it is an excellent adsorbent for gases and vapours. Coconut shells are the best known raw material of this type.

4.3.1 Processing Agricultural Residues

Except for nut shells agricultural residues are not a preferred raw material for charcoal making. Rather they are used because making them into charcoal seems to offer a method of realising a profit on an otherwise useless waste material. Generally the charcoal is produced as a powder and has a high ash content which limits its use for industrial purposes. The only important market for it is the barbecue market of the developed world. The high cost of ocean freight and the seasonal nature of demand tends to shut out charcoal of this kind made in the developing world. (For an analysis of this see Ref. 16). The increasing

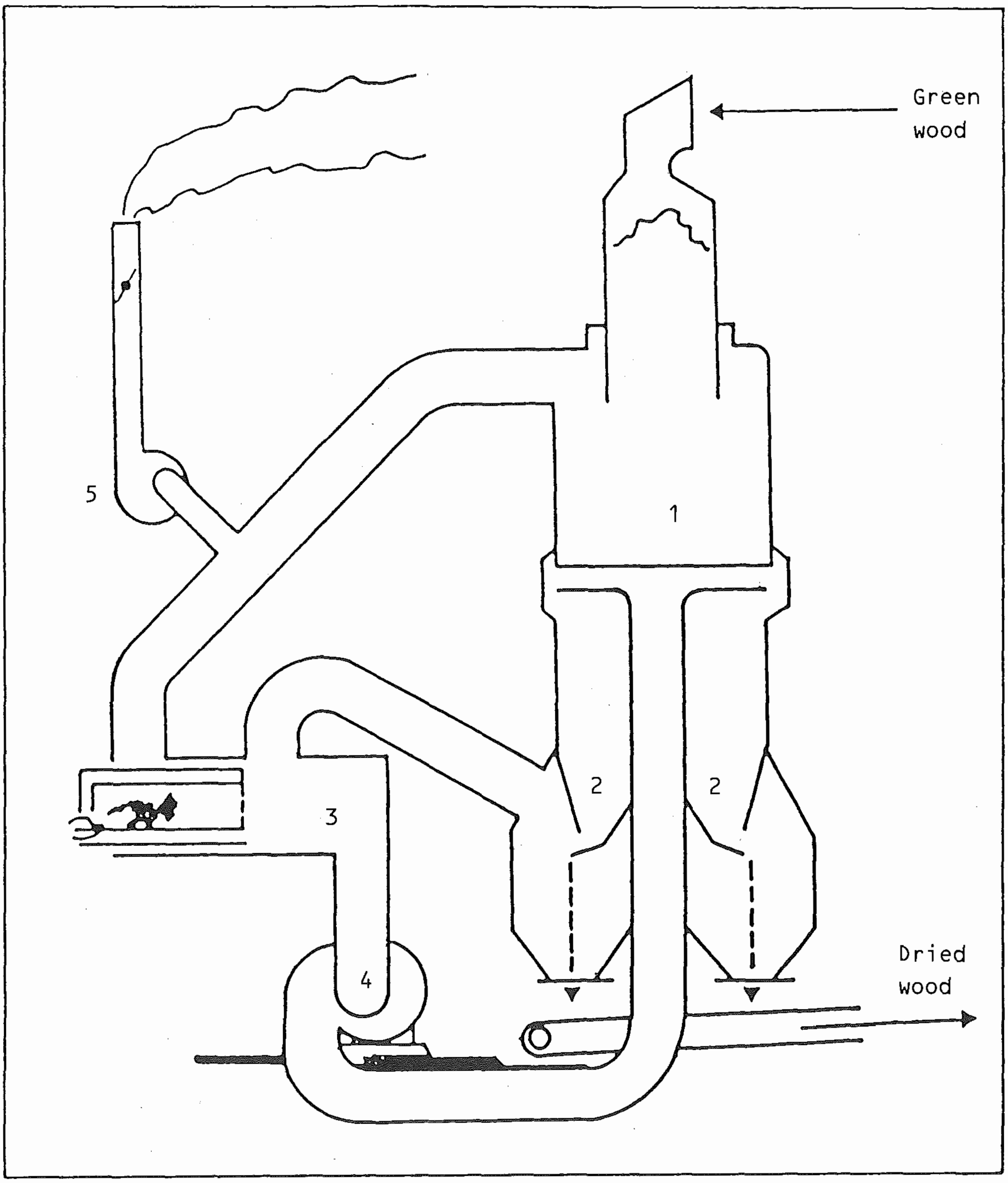

Fig. 10 Wood Drier for Continuous Operation

1. Drying cylinder 2. Discharge locks for dry wood
3. Combustion chamber for retort gas
4. Heating gas fan 5. Off-gas fan

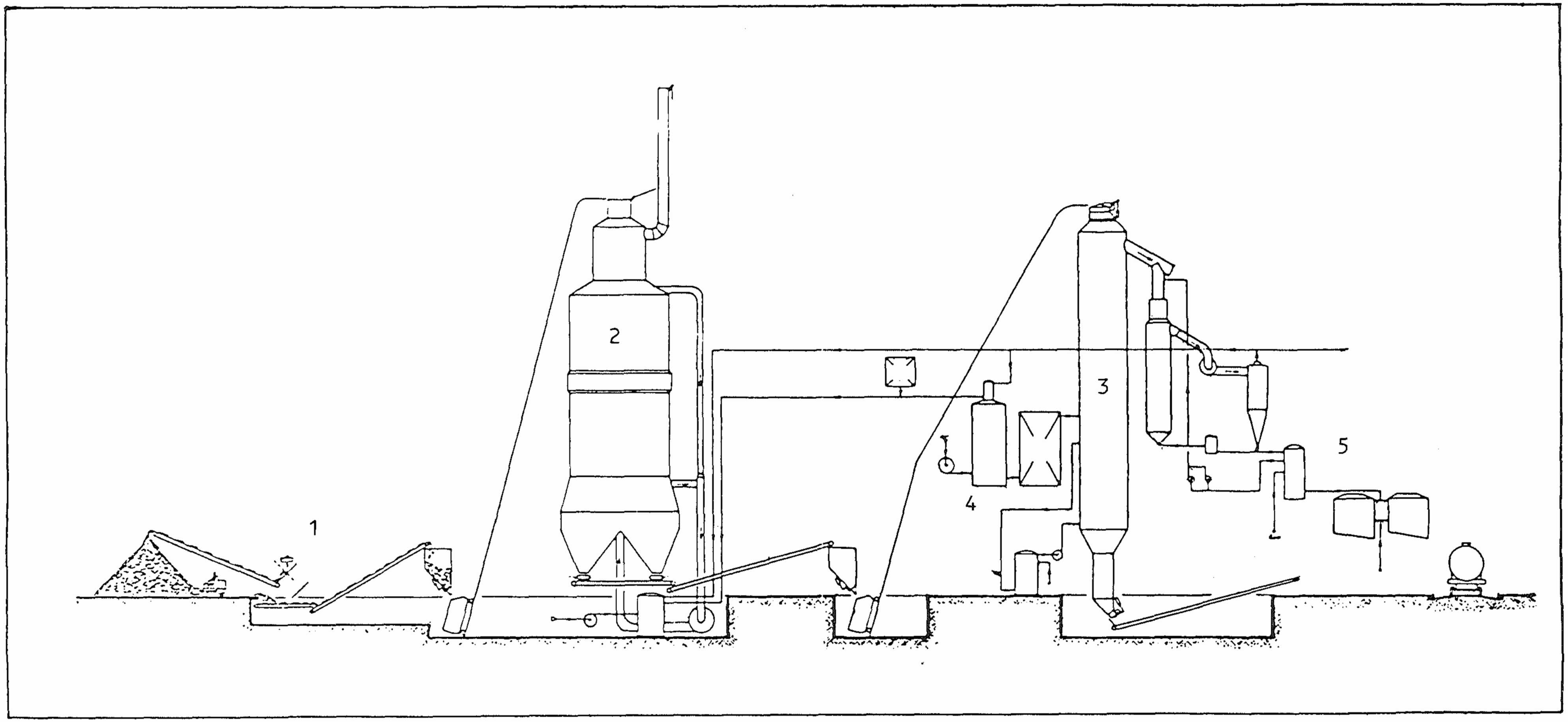

Fig. 11 Pre-dried wood continuous carbonisation system (Lambiotte)

1. Wood preparation 2. Continuous drier 3. Carbonisation retort
4. Hot gases recovery 5. By-products recovery

cost of fuels has tended to make it attractive to burn these waste materials directly as a substitute for oil and gas rather than convert them into charcoal and even when carbonised the offgas and condensibles are often just burned for process heating or steam generation.

Not much is known about by-products from the condensate produced by specific agricultural wastes when carbonised. But maize cobs have been studied extensively since they are used to produce the solvent agent, furfural, when heated with sulphuric acid to moderate temperatures.

Generally, one would expect the condensate to have a similar composition to that produced from the carbonisation of wood since the composition of most agricultural wastes is broadly similar, the main differences being a higher ash content and a limited degree of lignification except in the case of nut shells.

The list of agricultural residues which have been considered for carbonisation is long but the level of commercial success is limited to a few special cases. As mentioned the only attractive raw materials are the nut shells particularly coconut because of the high priced charcoal which they can produce.

The following list gives an idea of some of the various agricultural residues which have been considered as possible charcoal making materials.

- nut shells and husks
- residues from farm crop processing and canning
- sugar cane bagasse
- bamboo, scrub and cactus
- garbage wastes
- straw and reeds
- industrial wastes as from carpet factories and pulp mills
- processing residues from coffee, cotton and fruit canning

As a rule these proposals have foundered on economic grounds or a higher return from alternative uses.

The main conditions for charcoal making to be economically possible from these materials are:-

The material must be of low or zero value and concentrated at the proposed point of processing. There must be a market able to pay top prices for either powdered charcoal or briquettes, as a high ash product, ruling

Photo. 5. Carbonisation furnace for agricultural residues

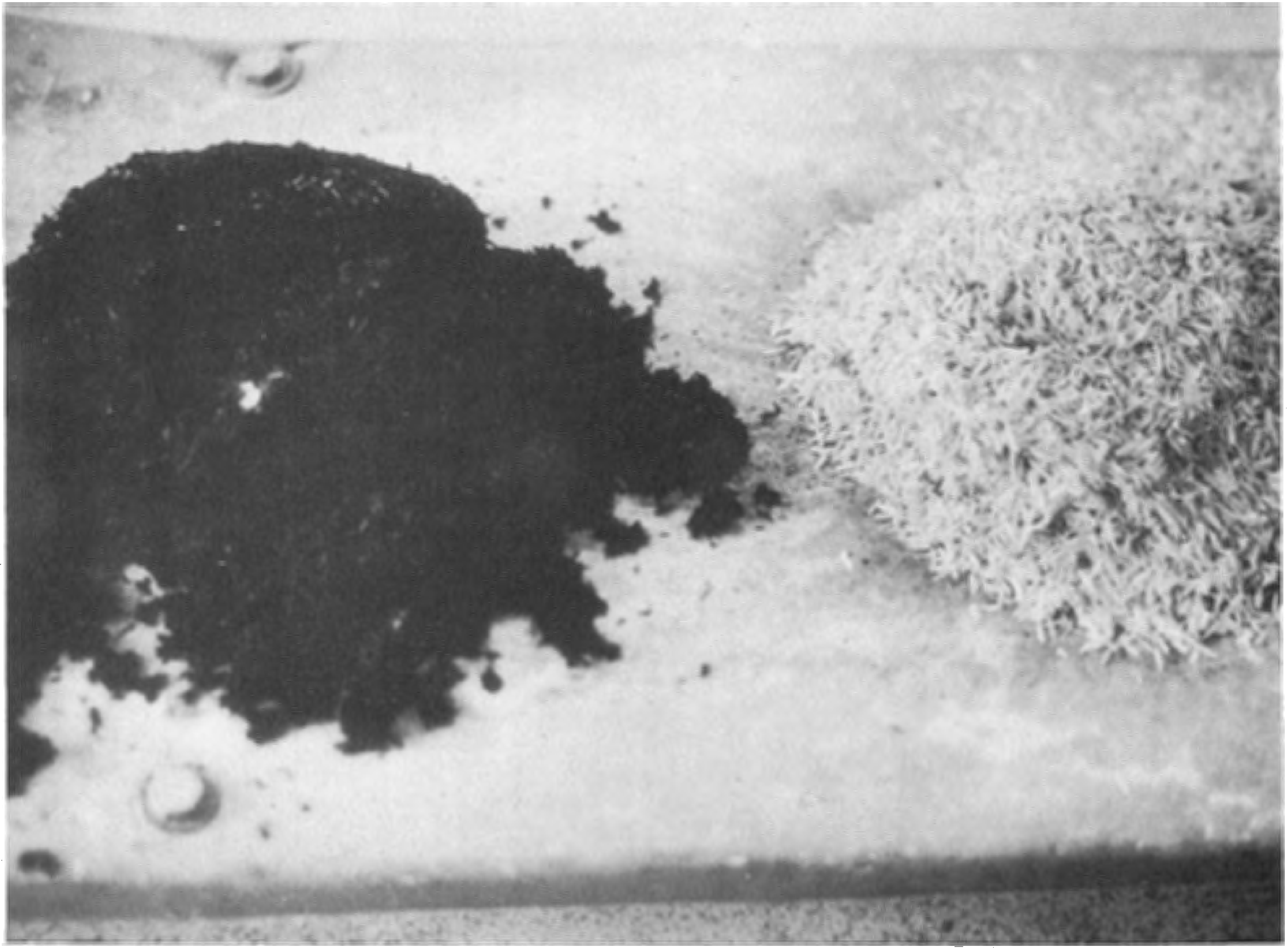

Photo. 6. Charcoal produced from rice husk and formerly used tor briquetting

out most industrial uses. Supply must be either year round or storage must present no problems or the processing method used must be so low cost that it can operate for only a short period of the year. There must be a continuous supply of material available for years ahead to allow the plant to be amortised successfully.

The three main reasons which attract attention to agricultural wastes are:- availability at apparently low cost, the material is dry, and transport costs are zero or very low since the material is concentrated at the point of crop processing.

4.4 Bark Waste

Although not strictly an agricultural waste it is convenient to discuss here the use of bark waste from timber processing as a raw material for charcoal. Logs typically carry about 10% of their volume as bark. Both softwood and hardwood bark can be made into charcoal, in both cases the charcoal is in the form of powder, and after briquetting can be sold for barbecue purposes.

The best known example of the use of bark waste is in the south-east of the United States in the southern pine processing belt. (22). In the large sawmills and other processing plants of the region it is the practice to debark the logs so that solid wood residues can be used for pulping and particle board production. Hence there is an accumulation of bark and sawdust which has rather limited econmic outlets. The price of charcoal in the USA is high along the East coast and hence it is not surprising that making charcoal briquettes from this waste became economic. The market is largely a barbecue one and hence powder charcoal of high ash content is quite acceptable after briquetting. The carboniser used to produce the charcoal is the Herreshoff multiple hearth roasting furnace described in Chapter 3. The minimum output of this kind of furnace is about one ton of charcoal per hour operating continuously the whole year round. Hence the minimum quantity of bark waste required is about 100 tons per day or about 5000 tons per year. This quantity of bark is produced from about 70000 m3 of logs per year which is the input to a very large sawmill. A combined sawmill and panel plant can easily yield the required quantity. The bark, and sawdust, if it is used as well is not usually dried before feeding to the furnace. The moisture content is typically about 40% based on the green weight of the feedstock.

This industry based on bark waste must always compare the relative profit of burning the bark directly for energy instead of turning it into charcoal briquettes because of the sharp rise in the price of oil which has occurred in recent years. But the proximity of a large high price market for barbecue charcoal tends to make the system still profitable even if coal is substituted for fuel oil. For economic studies on bark carbonisation see Ref. (22).

Under the conditions prevailing in most developing countries the major reason for considering complex systems for charcoal production is the increased yield which is possible with such systems. The increased yields need to be carefully verified and compared before committing expenditure. The present day brick kilns of the kinds recommended in (6, 7, 15) are capable under optimum conditions of achieving yields around one ton of charcoal to about 4.5 tons of air dry wood on a year round basis. The best of the complex technologies can do better than this. Well operated Lambiotte type systems can achieve a yield of one ton from 3.5 tons of air dry wood. But whatever the system, proper drying of the wood is essential for high yields and it may be better to spend money on proper organization of air drying and upgrading charcoal making to modern brick kiln methods than invest substantial sums in complex retort systems.

A further reason for choosing complex charcoal making systems could be the availability of an agricultural residue that might be processed to produce needed charcoal. The processing of finely divided residues calls for a complex technology system, the only proven one for fines at the moment being the rotary hearth furnace. But careful analysis of alternatives must be made. It may be better from an overall energy point of view in the country to burn the residues completely to produce electrical energy and concentrate on solving the charcoal problem by simpler means involving a much lower level of investment, more certain results and greater flexibility in land use and system operations. It must always be remembered that today's low cost residue immediately acquires an increased price as soon as it is to be used for some commercial purpose. Unless the carbonising plant has total control of its raw material resource it may find itself held to ransom over raw material supplies essential to obtain the return on investment required.

To summarize the position can be put in the following way. Where finely divided raw material such as agricultural residues, sawdust, bark and so on is available then it must be processed by complex systems of which the rotary hearth furnace with associated briquetting plant is technically viable given a sufficient quantity of residue available 24 hours per day 360 days per year. (Not an easy condition to fulfil).

The alternatives to carbonisation are return of the agricultural residue and its nutrients to the soil as part of the cropping cycle rather than removing them and discarding them as ash somewhere else. The needed charcoal would then have to be produced from wood grown in fast growing man-made plantations or natural forests if they exist.

In the case of solid wood there is a trade-off between the saving in wood needed to produce a given amount of charcoal and a capital investment involving foreign currency and probably foreign loans. To achieve this result one foregoes the jobs and activity associated with the growing harvesting and carbonising of this extra wood. Where land for forest purposes is not a limiting resource the advantage for most countries probably lies with making the charcoal by the modern brick kiln technologies (1, 5, 6, 7, 15). It is interesting to observe that despite the existence of the continuous vertical retort (4, 25) as a proven technology in the developed world for almost 40 years it has had almost no impact in the developing world even in such countries as Brazil (1) where huge amounts of charcoal are produced for the iron smelting industry and where investment in modern industrial methods is commonplace.

Chapter 5

SAFETY PRECAUTIONS AND ENVIRONMENTAL CONSIDERATIONS

5.1 Safety Precautions in Charcoal Operations

Whether charcoal is made in the traditional way or by industrial methods, three hazards are always present: fire of stored charcoal, gas and dust explosions and carbon monoxide poisoning.

Accidents can be greatly reduced by use of safety devices and safe working habits. In all plants where high-temperature operating conditions with combustible materials are normal, carelessness can be ruinous. Production hazards increase, and undesirable or dangerous conditions can arise if the operator neglects to pay close attention to such vital operational factors as the converter temperature, pressure indicators, structural conditions of the production equipment and storage bins. There are ample records of plant damage and destruction because of just such neglect and oversight.

5.2 Explosions

The causes of such accidents are often not clear but are probably most often due to mixture of pyrolysis gases with air.

In a batch-wise operated retort the presence of gas in the retort is greatest at the end of the cycle, the admittance of air can form highly explosive gas mixtures. In a continuously operated converter, the admittance of more air than needed may.cause first a sudden rise in temperature and then formation of explosive mixtures in the off-gas system.

5.3 Fires

Fire can result from the admission of large quantities of air to the retort, converter or off-gas system through cracks or badly closed doors. In other cases fire can result from explosions. Such events can arise through the operator's unfamiliarity with proper operating procedures or simple carelessness. In high temperature operations there is always the danger of wall swelling and the occurrence of unnoticed air inlets. The inflow of excessive amounts of air could easily change the temperature pattern. This may cause very high retort temperatures, either gradually or rapidly, creating a serious fire condition. The operator's familiarity with his equipment and necessary counter measures are the best insurance for safe practice and satisfactory production. Well established, periodic inspection of the industrial charcoal-making plant will determine the corrective measures necessary for proper control and reduce the possibilities of fire damage.

Improper sealing or structural leakages of air in the charcoal cooling bins during the cooling period can also lead to considerably reduced yields production of poisonous carbon monoxide gas and equipment damage. Such conditions may occur even in a well established operating plant and the importance of inspecting and maintaining cooling bins during the cooling cycles, controlling operational conditions and following safe practices cannot be overemphasized.

5.4 Hazards to the Public

Fire and gas leaks whether controlled inside the retorts or converter or uncontrolled, constitute a potential hazard for the public. Unauthorised persons should not be permitted in the plant unless guided. Safety helmets are a necessity for both workmen and visitors. Transport of wood, other raw material, charcoal handling and other essential work gives rise to operational hazards and safety measures and safe work habits must be considered of prime importance.

5.5 Safety devices and equipment

5.5.1 Pressure-relief doors

Explosions are always possible when handling a dusty material or one which contains combustible gases and vapours. Thus, the feed and storage bins are designed with explosion blow out panels which will vent gases when the internal pressure goes above 350 to 400 mm water. In addition, dead-weight relief doors are usually incorporated on the top of the bins and they lift at an even lower internal pressure.

5.5.2 Automatic temperature shutdown

In the event that temperatures inside the retorts, coverter or the off-gas system exceed preset limits, the air supply, the heating fans of the retorts or the fan of the converter gas system should be shut down. At the same time, the air supply of continuously operated converters should be cut off and the converter isolated. Residual gases should be vented through the emergency flare.

5.5.3 Electric Power Failure Devices

If a total power failure occurs, the air supply and the draft fan stop and all shut-off gates remain in safe condition. When the process becomes dormant the system is isolated from other plant units.

5.5.4 Temperature indication and control

Equipment that indicates the operating temperatures and controls the safety devices has to be selected very carefully. Regular inspection and proper maintainance are a necessity.

5.6 Precautions for Charcoal Storing

Customarily, charcoal demand is seasonal which makes it necessary to stockpile a considerable inventory.

A great deal of care must be taken in storing freshly produced charcoal. It has a tendency to absorb the oxygen from the air. Rapid absorption creates considerable heat, which builds up to a point where the stock-piled char will start burning.

Tightly packed masses of charcoal fines and charcoal with a high content of volatiles are more subject to spontaneous combustion than larger pieces of lump charcoal.

Self ignition may even occur if charcoal has been watersprayed for better cooling.

It is therefore advisable to place freshly discharged charcoal in the open, separate from previously cooled and conditioned charcoal for at least 24 hours. During this time, the char should be exposed to air circulation and protected from rain and wind, preferably in an open shed rather than under a tarpaulin. If there is no evidence of heat or active fire after 25 hours, the charcoal can be considered safe for storing in a specially designed warehouse (15, 28).

5.7 General Safeguarding of Charcoal Plants

5.7.1 Water Supply

A water supply is highly important to any charcoal plant. A hose with a nozzle should be kept ready for immediate use at assigned points of the plant. Back-pack water pumps or large capacity fire extinguishers provide some measure of fire protection.

5.7.2 Detection of poisonous gases

Poisonous gas (carbon monoxide) is present in retorts and storage bins that have just been cooled down or in the off-gas system that has just been shut off. There are portable detectors on the market which indicate the concentration of gas present in the production apparatus.

However, the best prevention is to ensure good ventilation before workmen or maintainance crews enter the bins or retorts and in the working environment.

5.7.3 Safety Manual

All safety instructions and changes to them have to be made known to the workmen. In all well organized plants every workman has to attend quaterly training classes, given by the plant engineer.

However, common sense remains most important in dealing with harzardous situations in the plant.

5.7.4 First Aid accessories

Adequate first aid kits including dust and gas (carbon monoxide) masks, should be available in a centrally located position.

5.8 Environmental Considerations for the Charcoal Maker

5.8.1 General Considerations

During the last two decades environmental control legislation has become an important factor for charcoal makers. There are numerous cases where plants operating for more than half a century, had to be shut down or completely altered as a result of legislative pressure.

Therefore, these aspects should be taken into consideration by the potential charcoal maker when the charcoal plant is designed.

The combustible gas generated by industrial systems will burn cleanly to waste in a stack, if not utilized otherwise for additional energy generation.

Another feature in favour of the industrial charcoal-plant with energy co-generation is the minimal liquid effluent discharge. Waste water does not occur except in plants where the by-products are recovered from the original condensates by distillation.

The environmental aspects of industrial charcoal making depend very much on the type of system, and the type of raw material. In general, the most important problems are odour and dust. The others can be eliminated.

5.8.2 Raw Material Preparation

Hogging machinery is usually noisy and may exceed local decibel allowances. Enclosure of the machinery reduces noise, and in residential areas machinery should not be operated during the night. It is good practice from all points of view to locate carbonisation plants at least 1 km from residential areas and preferably down-wind of them to avoid odour dust and noise pollution.

Dryer exhausts contain dust and the amount depends on the size of the feed (fines). Cyclonic equipment should be installed to reduce the dust exhaust and at the same time conserve raw material.

5.8.3 Retorts and converters

This equipment if well designed and built, does not present problems, but occasional escape of gases can be expected from industrial retorts when they are opened. In continuous operations due to the feed system and the fact that the retort or converter is opened only during the shut-down period, gas escape is minimal and therefore no preventive measures are necessary.

5.8.4 Char Handling

Conveyer belts are normally enclosed to prevent the wind scattering dust. The fumes of dust from the char hoppers are drawn by exhaust fans through bag filters which capture the dust. The dust is periodically shaken from the bags into the collecting bins attached. But disposing of the fine dust is a problem unless it can be mixed with the feedstock to a briquetting plant. The problem is more serious in smaller plants as it is not economic to install equipment to burn the fines as is sometimes done by blowing them into the base of blast furnaces or using them in a sinter plant in charcoal iron plants for example. On a small scale the fines may be wetted down with water and detergent and buried as land fill.

5.8.5 Retort Condensates and Gas

The direct loss of gas and vapour from the retorts must be avoided as much as possible to prevent direct air pollution. The condensates (pyroligneous acids and tars) are difficult to dispose of simply except where by-products are being recovered. The simplest way is to burn them for energy generation or to waste when they are converted into non-polluting carbon dioxide and water vapour. It is best to burn these substances as they emerge as hot gas from the retort before they condense. Where small amounts of condensate arise they can be collected in ponds and subsequently burned after the water they contain has largely evaporated. This can prove impossible however in areas of high rainfall.

Retorting systems are designed so that in the case of an unusual pressure rise within the system as may result from a fire the vapours are vented into the atmosphere. This is done for the safety of personnel and equipment. Based on long experience these events are uncommon and when they do occur they last only for a few seconds. Since the venting is to the open air the vapours quickly disperse.

5.8.6 Waste Water

The control of the discharge of waste water from carbonisation plants is of the highest importance as untreated waste water can be a serious environmental pollutant in streams used for drinking, stock watering and fishery.

A properly designed plant will include a waste water recovery system which meets the local pollution standards.

There are two sources of waste water; that used for cooling and that which is produced directly from the breakdown of the wood substance during drying and carbonisation. In the simple technologies this water is released directly into the air as steam and is dispersed along with the acidic vapours and tars. The problem with condensed water in the complex technology plant is that it is usually contaminated with acids and tars condensed from the retort off-gases and hence cannot be allowed to escape into streams without treatment.

Process water should be recirculated to the maximum extent so that the amount of water which has to be disposed of is limited. The process water system has to be monitored closely and surplus water should be allowed to evaporate wherever possible. Control is easier where the net evaporation in the zone is greater than net precipitation. The waste water can be accumulated in settling ponds and allowed to evaporate. The tarry residues remaining are periodically burned-off. Where there is a net gain of water in the zone through precipitation disposal is more complex. As much as possible of the tar is separated by settling and burned and the acidity of the clear waste water adjusted by lime treatment. After settling and dilution where possible with clean water it may be safe to run this water to waste. Specialist advice on the best methods of waste water disposal must be sought as each plant has its own special problems depending on the process used and the location.

Chapter 6

CHARCOAL UTILISATION AND MARKETING

The earliest industrial use of charcoal, more than four thousand years ago, was as a reductant for iron smelting to change iron oxide into metallic iron. But charcoal was already well known as a high grade smokeless fuel for cooking and domestic heating. With the emergence of industrial society as we know it today in the middle of the nineteenth centry new and expanding uses for charcoal in industry opened up to the charcoal maker at the same time as traditional industrial uses such as iron smelting began to decline with the widespread use of coke from coal as the principal reductant of the iron and steel industry.

Today two distinct markets for charcoal are recognised, the industrial and the domestic ones.

6.1 Charcoal as Household Fuel

Charcoal in some countries is the principal fuel for preparing food. In some others the price has climbed so high that only the wealthy can afford to use it everyday. It is this growing shortage and the desire to help alleviate it that is the motive behind the preparation of this manual. (5, 15).

In industrial countries charcoal is no longer the main domestic cooking fuel but has become a symbol of an affluent lifestyle through its use in leisure activities as a fuel in open-air barbecues for cooking meat.

6.1.1 Lump Charcoal

Ordinary lump charcoal is still the consumer's preferred form of charcoal since it is easy to handle and to ignite. It is sold by volume or by weight. Price is by far the most important reason for choosing one brand over another but users are becoming aware that there are differences in calorific value and ease of combustion between various types of lump charcoal.

The future trend in charcoal used domestically is difficult to forecast with precision due to inadequate statistics, especially in developing countries. (7). But the steady growth of population and the rising price of oil and gas based energy causes the demand for charcoal in the developing world to expand constantly.

6.1.2 Charcoal Briquettes

Charcoal briquettes appeared on the markets of developed countries as a serious alternative to lump charcoal in the early fifties with the development of methods for producing fine charcoal from sawdust and bark on a large scale (22).

Charcoal briquettes are composed of three main components - charcoal, binder and filler or burn-rate controller. This latter lowers production cost and enables the burning rate of the fuel to be slowed down compared to lump charcoal which is supposed to be advantageous for some kinds of cooking. But the net heat output depends on the amount of charcoal the briquette contains.

The most important advantages of the briquette are its relative freedom from dust and its ease of handling. Briquettes appear on the market in a wide range of shapes and sizes: oblong, egg-shaped, hexagonal and pillow shaped. The latter seems to be the most accepted with an edge length of about 50 mm and thickness of 25 mm approximately. The standard properties of briquettes are listed below.

Charcoal Briquette Specifications

	Weight Percentage	Lump Charcoal	Briquettes	
			Without Filler	With Filler
Ash	%	3-4	8	25
Moisture	%	5	5	5
Carbon	%	Balance	Balance	Balance
Volatiles	%	10-15	10-15	10-15
Binder	%	-	10	10
Calorific	%			
Value	kJ/Kg	28 000	25 000	22 000

6.1.2.1 Making Charcoal Briquettes

The raw materials for charcoal briquettes are charcoal in the form of fines, binder and filler.

Fine charcoal is used as it is unsaleable in this form and has a low price. The binder is the costly item. Filler is added to reduce costs especially as briquettes are sold by weight rather than volume. Claims are made that filler also helps to control the burning rate of the briquette.

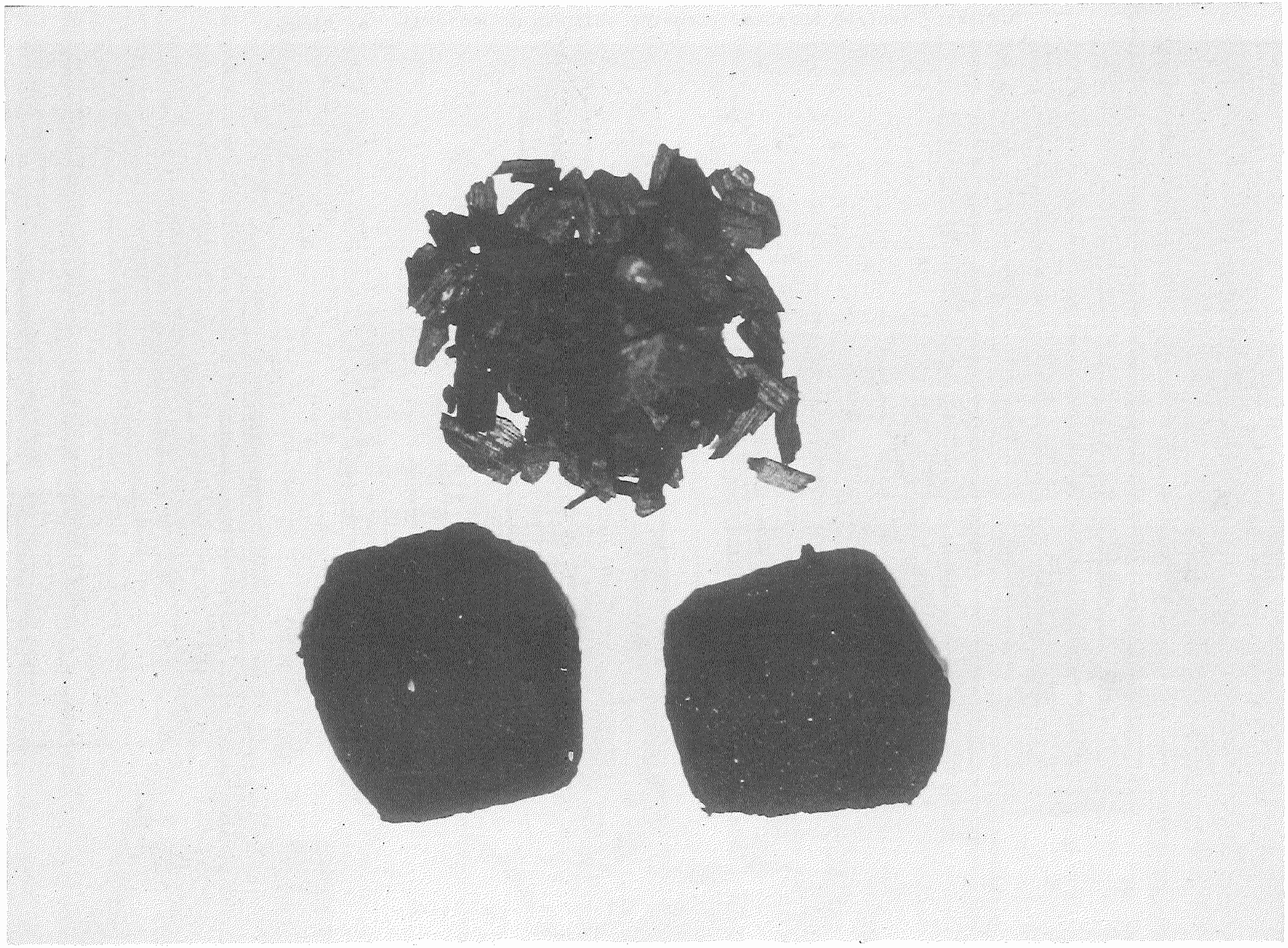

Photo. 8. Wood residues transformed into charcoal briquettes

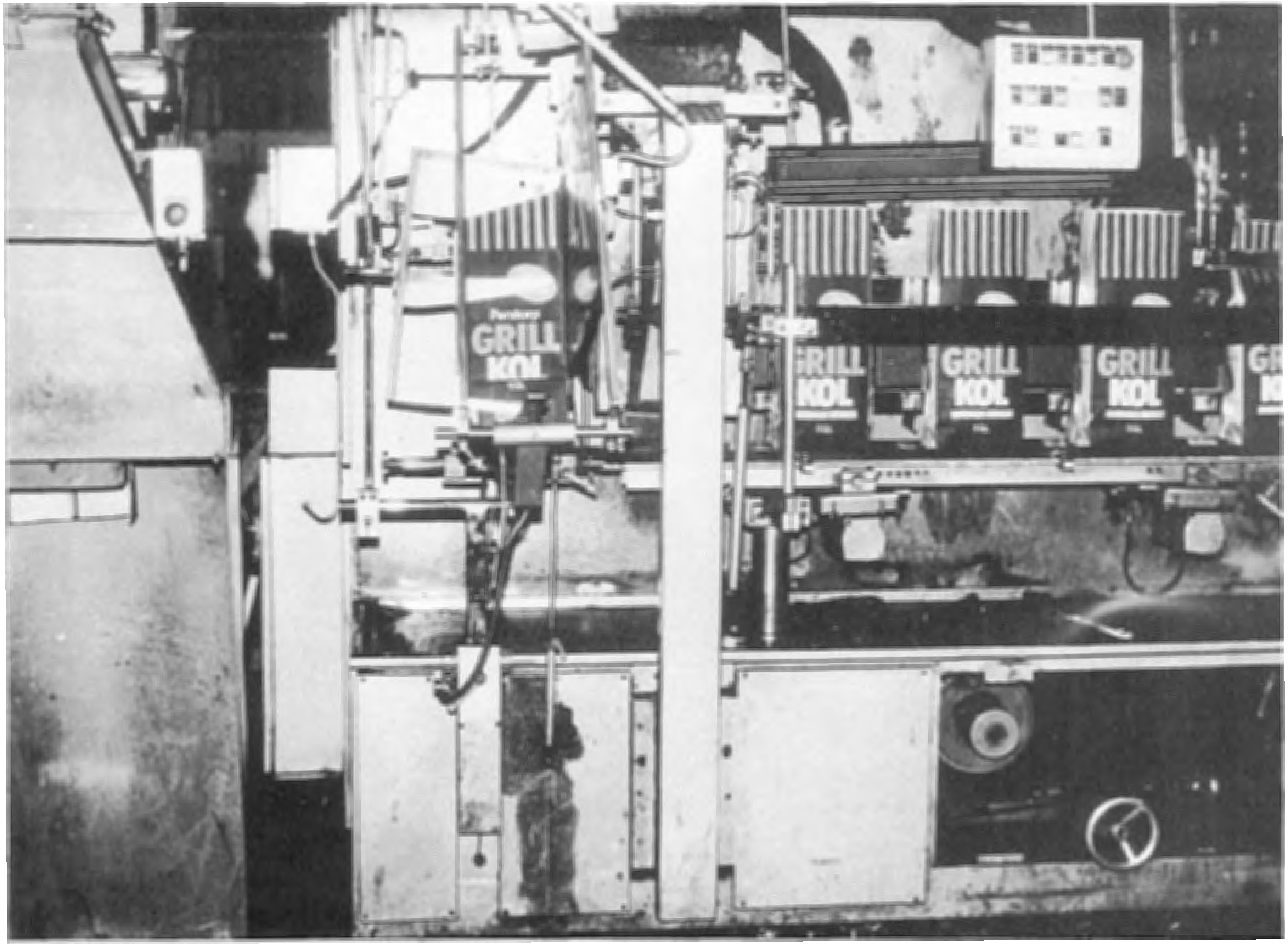

Photo. 9. Charcoal briquettes automatic packing device. (Sweden)

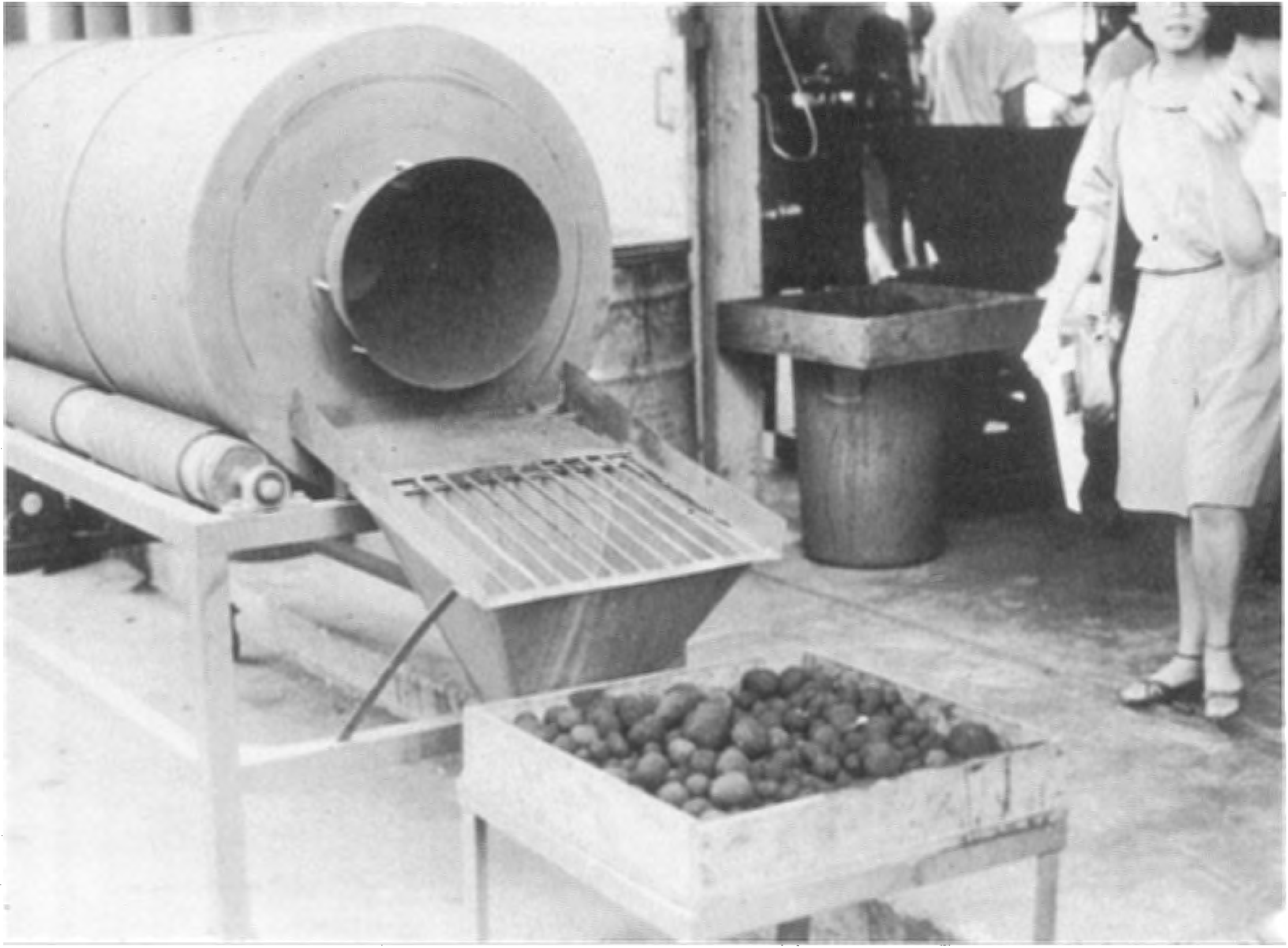

Photo. 10. Simple technology for charcoal briquettes production. (Thailand)

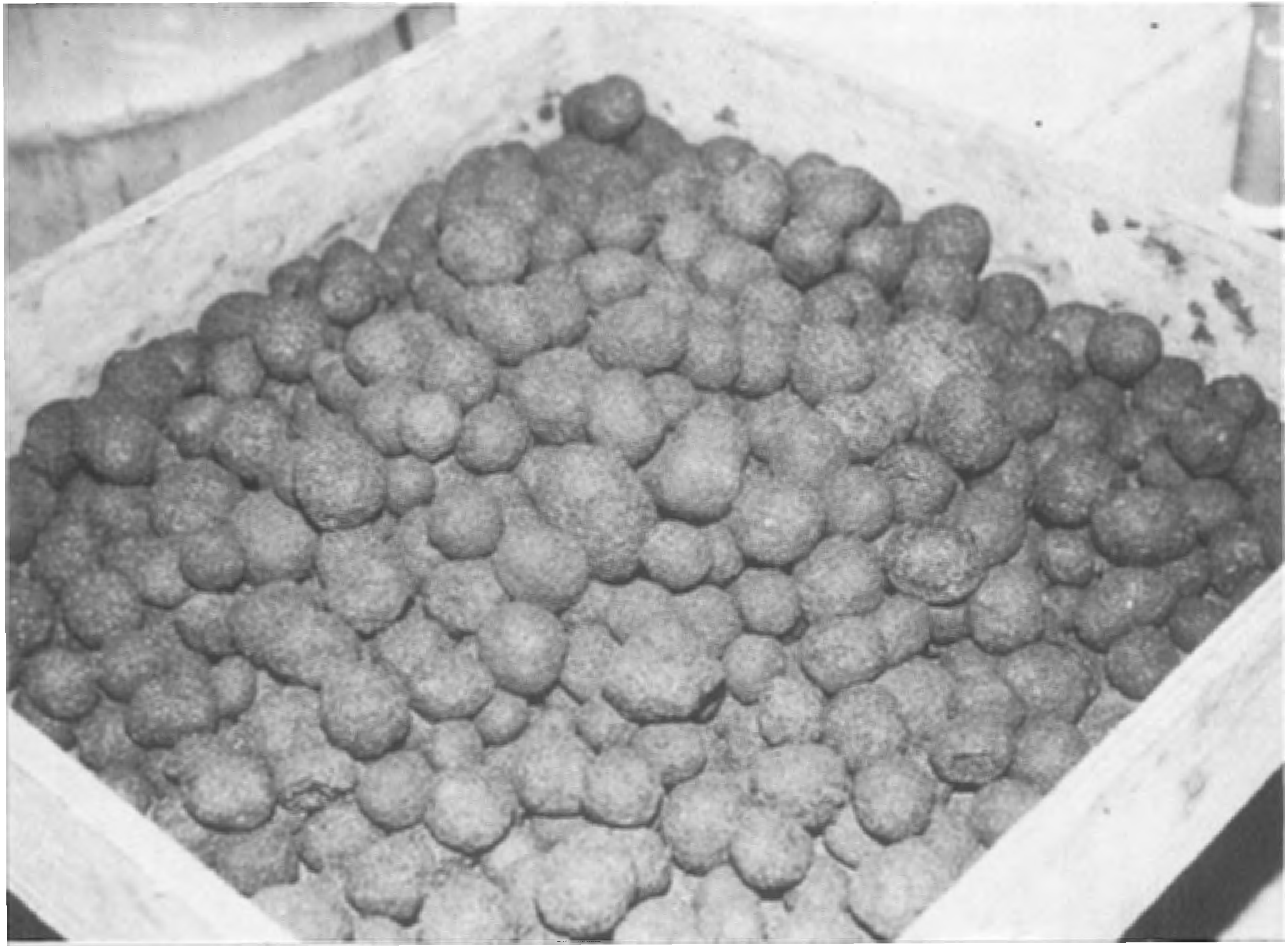

Photo. 11. Charcoal briquettes produced using starch as binder

The fine charcoal may be specially made from feedstock which can only produce powdered charcoal (22) e.g. bark or it can be residual fines from conventional wood charcoal making operations (3).

The usual binder is starch from any source, whichever is the cheapest. It doesn't have to be an edible grade. Although other binders have been used such as china clay and molasses these do not produce as satisfactory a briquette as starch. For special briquetting operation where the binder is to be carbonised later as in electrode manufacture pitch and tar can be used. Binders which produce an objectionable odour or smoke on burning are not acceptable for the domestic market. The binding agent also needs to be fairly resistant to fermentation and bacterial attack during storage to meet market fluctuations. All these considerations tend to favour starch as the best all-round binder.

The filler if used is selected on price - it has to cost less by weight than charcoal, be not abrasive to the machinery and free of objectionable odour on burning. Calcium carbonate in powder form fits the requirements. Sources are: ground limestone, chalk and ground shells.

Flame colourants and odour producing material such as hardwood sawdust have been used in order to obtain a distinctive product for high priced markets.

The manufacturing process is as follows:

First the charcoal must be pulverised and screened to reduce it to a uniform size and remove gross impurities. Hammer mills are used fed from hoppers via automatic feeding devices. The screen analysis of the ground charcoal is the coarsest which will give a satisfactory briquette with minimum binder usage.

The ground charcoal is next mixed with the binder and filler, if used, plus any other additives. If starch is the binder it must first be cooked (gelatinised) with hot water before adding to the mixer. A ribbon type mixer is normal and proper mixing is essential to reduce binder consumption to the minimum.

The mixture then passes to the briquetting press. Photo 7 shows a typical press installation. The accepted type of press is the roller type adjustable for speed and pressure. The press illustrated has moulds for making pillow shaped briquettes.

Photo. 7. Charcoal Briquetting Press

The wet pressed briquettes are next dried to complete the binding operation. When the water is dried out from the gelatinised starch it sticks the charcoal particles together to form a stable briquette which will retain its form right up to the point of combustion. The briquettes usually contain about 10% of binder and about 30% of water before drying down to about 5% moisture content. The normal dryer is a continuous tunnel dryer which carries the briquettes through without allowing them to tumble. Heat for drying out the water is a significant operating cost. (Fig. 12)

When the briquettes are cool they can be packed for the market in paper or plastic sacks of about 5 kg. to take account of the seasonal nature of the briquette market in industrial countries there must be provision for storing the briquettes in hoppers awaiting packaging. This adds considerably to operating costs (3) and is one of the principal obstacles to success in briquetting operations aimed at using up waste charcoal fines.

When considering the profitability of charcoal briquetting the retailing component of the marketing chain must not be overlooked. It can easily amount to 30% of total costs as a minimum and in the developed world will be the final determinant of commercial success or failure. Charcoal briquettes in this market are not a need but a luxury.

6.2 Charcoal as Fuel for Industry

In the developed world charcoal is an almost indispensable industrial commodity, especially in metallurgy and as an adsorbent.

With the development of the chemcial industry and the increasing legislation concerned with the control of the environment, the application of charcoal for purification of industrial wastes has increased markedly.

Whereas in the barbecue fuel market charcoal has little competition, in almost all other applications charcoal could be substituted by coal, coke, petroleum coke or lignite. The advantages or charcoal depend on six significant properties which account for its continued use in industry.

- low sulphur content
- high ration of carbon to ash
- relatively few and unreactive inorganic impurities
- stable pore structure with high surface area
- good reduction ability
- almost smokeless

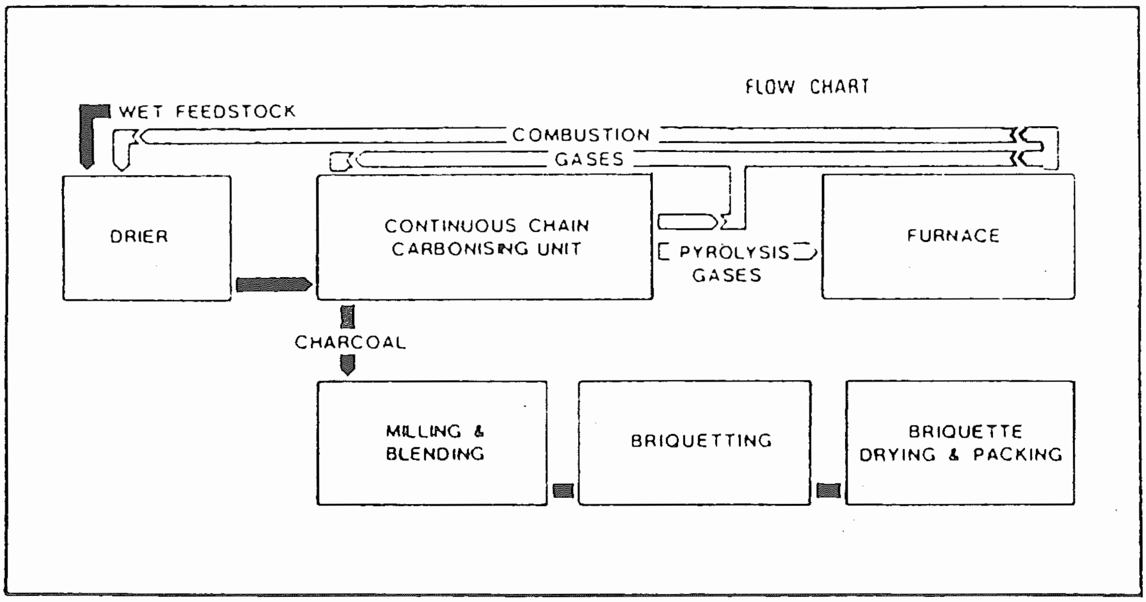

Fig. 12 Continuous Carbonisation with Hot Gases Recovery and Briquettes Manufacture - Schematic Outline

Up to 1960, charcoal was widely used by the chemical industry for the production of carbon disulphide and sodium cyanide.

Although these markets have declined, they were off-set by the enlarging demand for reducing and adsorbent agents.

Some applications of charcoal in various industries are as follows:

Chemical industry

- manufacture of carbon disulphide, sodium cyanide and carbides.

Metallurgy

- smelting and sintering iron ores, production of ferro-silicon and pure silicon, case hardening of steel, purification agent in smelting non-ferrous metals, fuel in foundry cupolas, electrodes.

Cement industry

- as a fuel, (34).

Activated carbon and filter industry

- water purification, dechlorination, gas purification, solvent recovery;
- waste water treatment, cigarette filters.

Gas generator

- producer gas for vehicles and carbonation of soft drinks.

The chemical and activated carbon industries prefer lump charcoal. This is partly due to their process requirements. Fine charcoal particles behave more reactively, but airborne losses in processing make fines an undesirable raw material. Fines usually have a higher ash content than lump charcoal and may be more contaminated generally.

Therefore, the market for charcoal fines and powder are restricted in industry to processes where cells for powdered material such as in sintering processes and case hardening of steel.

6.2.1 Specifications

Each application has its own charcoal specification and must be studied to determine both present process requirements and future modifications due to possible alterations in the process technology.

Such alterations have frequently had effects on the charcoal industry in the past and led to changes in production technique or to shut-down of plants. Charcoal quotations usually specify the content of fixed carbon, ash, volatiles, density, bulk density, moisture and the sieve analysis.

It is not possible to list here all specifications and variations. They can be determined by a careful market study, which should be carried out before engaging in industrial charcoal production.

6.3 Charcoal in Metal Extraction

Since iron was first made by man, charcoal has been used widely as a reductant.

Today the charcoal based iron industry still exists in a number of countries and continues its expansion and modernization (15, 28, 29).

The focus, however, has moved away from developed countries. Today, Brazil's charcoal based pig iron industry is considered by far the biggest in the world. Malaysia and Argentina are other significant producers.

Charcoal has strong reducing properties. When heated with metallic ores containing oxides and sulphides, the carbon combines readily with oxygen and sulphur, thus, facilitating metal extraction.

Most of the charcoal used in blast furnaces is made from hardwood species (29). Although charcoal is generally acknowledged to be a better reductant than coke, there are practical difficulties in operating very large blast furnaces with charcoal in the large iron and steel mills.

It is only in countries with extensive forests and deficient in coking coal that the use of charcoal for iron-smelting is likely to be profitable.

6.4 Activated Charcoal

6.4.1 Introduction

The use of charcoal for producing activated carbon is fairly new when compared to its utilisation in metallurgy or the chemical industry. The first markets started to develop in Europe around the beginning of this century.

Activated carbons are carbons which have undergone an intricate treatment to increase their adsorption properties. (17, 18, 26, 30, 32).

Activated carbons are available in powdered, granular and pelletised form and are used in liquid and gas phase adsorption processes.

More than seventy types of activated carbons are currently marketed.

Although the surface area of the pore structure and the adsorption capacity of all activated carbons are interrelated, the size of the surface area is not the only determinant on the adsorption capacity of a given carbon for a specific purpose.

In other words, activated carbons with large total surface areas but with a microporous structure may be effective in removing slight odour causing impurities from gases, but ineffective in adsorbing large colour-forming compounds from solutions.

This may explain the great number of types, grades, and shapes of activated carbon available.

6.4.2 Production of activated charcoal

Estimated production capacities for activated charcoal 1979

North America	160 000 t
Western Europe	105 000 t
Eastern Europe	20 000 t
U.S.S.R.	70 000 t
Japan	80 000 t
Total	435 000 t

Charcoal was initially the only raw material for producing activated carbon, but it has been partly replaced due to price considerations and the limited availability of charcoal, by other carbon materials such as coals, lignite, petroleum coke, peat and moss.

Experience has shown that there are no basic differences in the quality of activated carbons made from other raw materials, except that, in the gas/vapour applications, charcoal-based activated carbon is superior. Activated carbon production is a low yield process in relationship to the raw material input, whether or not charcoal is the base.

6.4.3 Applications

Treatment of liquids

Drinking water purification, municipal waste water and industrial waste, water treatment plants, swimming pools and acquaria are examples.

Purification of fats, oils, beverages, water purification in breweries, cleaning of bottles and tanks in wineries, cleaning of tanks for insecticides and pesticides, spraying, cleaning of electroplating baths, dry cleaning. Decolourization of cane and beet sugar solutions, vitamin solutions and pharmaceuticals and high fructose syrup are also important uses.

- Treatment of Gases and Vapours

Important applications are:-

Purifcation of exhaust emissions of recirculated air purification. Recovery of solvent from printing machines and processes where highly volatile matter is continuously being released. Reduction of toxic and harmful vapour levels and objectionable odours in air. Air purifiers for commercial and domestic kitchens. Gas masks for military and civilian purposes.

- Miscellaneous Uses

Some of these myriaduses include pharmaceutical, cigarette filters, catalysts for chemical processes, support for platinum and palladium catalysts, food additives, depolariser in electric batteries, additives in rubber tyres, evaporation control systems and evaporative air coolers.

Legislation on water and air pollution control in industrialised countries, particularly since 1977, has been a great stimulant to the activated carbon market and this trend is expected to continue.

6.4.4 Manufacturing Processes

Ordinary commercial charcoal has very limited ability to adsorb substances in the liquid or gas phase. To give charcoal this property it must first be activated by removing the tarry materials which block the structure of the pure carbon skeleton of the charcoal. When this is done the surface area of the porous carbon skeleton is increased literally millions of times providing equally large numbers of sites where molecules of other substances can be 'held' or 'adsorbed' and thus removed from gases or from liquids in which the treated charcoal is placed. Charcoal processed in this way is called activated charcoal. Charcoal is not the only type of carbon used for activation but it is an important raw material for activated carbons.

The activated carbon industry uses many variations in basic processing methods to achieve activated carbons having optimum properties for the various end uses. These variations mainly relate to the final stages of processing rather than the basic activation process which is usually nowadays carried out by heating the charcoal to a temperature of about 800°C in an atmosphere of superheated steam which permits the breakdown and removal of the tars blocking the microfine structure of the charcoal. Fig. 13 shows the general features of the activation process.

There are several kinds of equipment used which depend mainly on the volume of charcoal to be processed. For large throughputs the multiple hearth roasting furnace as used for producing charcoal from bark and sawdust on a large scale is often used. Smaller volumes are often processed in a vertical furnace in which the charcoal cascades over refractory baffles which allow the charcoal to be fully exposed to the atmosphere of the activating furnace. The principle, whatever system is used is the same: the charcoal is heated and stirred in an atmosphere of superheated steam to burn out the tars. Although in principle other gases can be used steam is the most widely used.

The hot charcoal leaving the furnace is allowed to cool in steel drums or containers until it reaches room temperatures. The charcoal which is now about the same size as sand grains is finely ground to reveal the active structure to the maximum extent. At the same time specialised treatment is given to the activated carbon to adapt it for its particular use. For example activated charcoal intended for purifying vegetable oils is treated differently to charcoal to be used for decolourising wines. All these processes are kept as confidential as possible by the factory to improve its competitive position in the market.

Exact details of these processes are not relevant to the charcoal producer who is looking to the activated carbon producer as a buyer for his charcoal. Experience has shown over many years that charcoal is a good raw material for activation. Providing it has a low ash and a low volatile content almost any charcoal is suitable providing it is available in dependable quantity and quality. There is one notable exception and that is the charcoal used to make activated carbon for purifying gases as for solvent recovery in printing and related processes and in gas masks for military and civilian use.

Experience has shown that for gaseous adsorbtion processes the most suitable charcoal is that from coconut shells since the high strength combined with a fine porous structure of this charcoal allows it to be recycled many times in the equipment without losing its granular structure and impeding the gas flow.

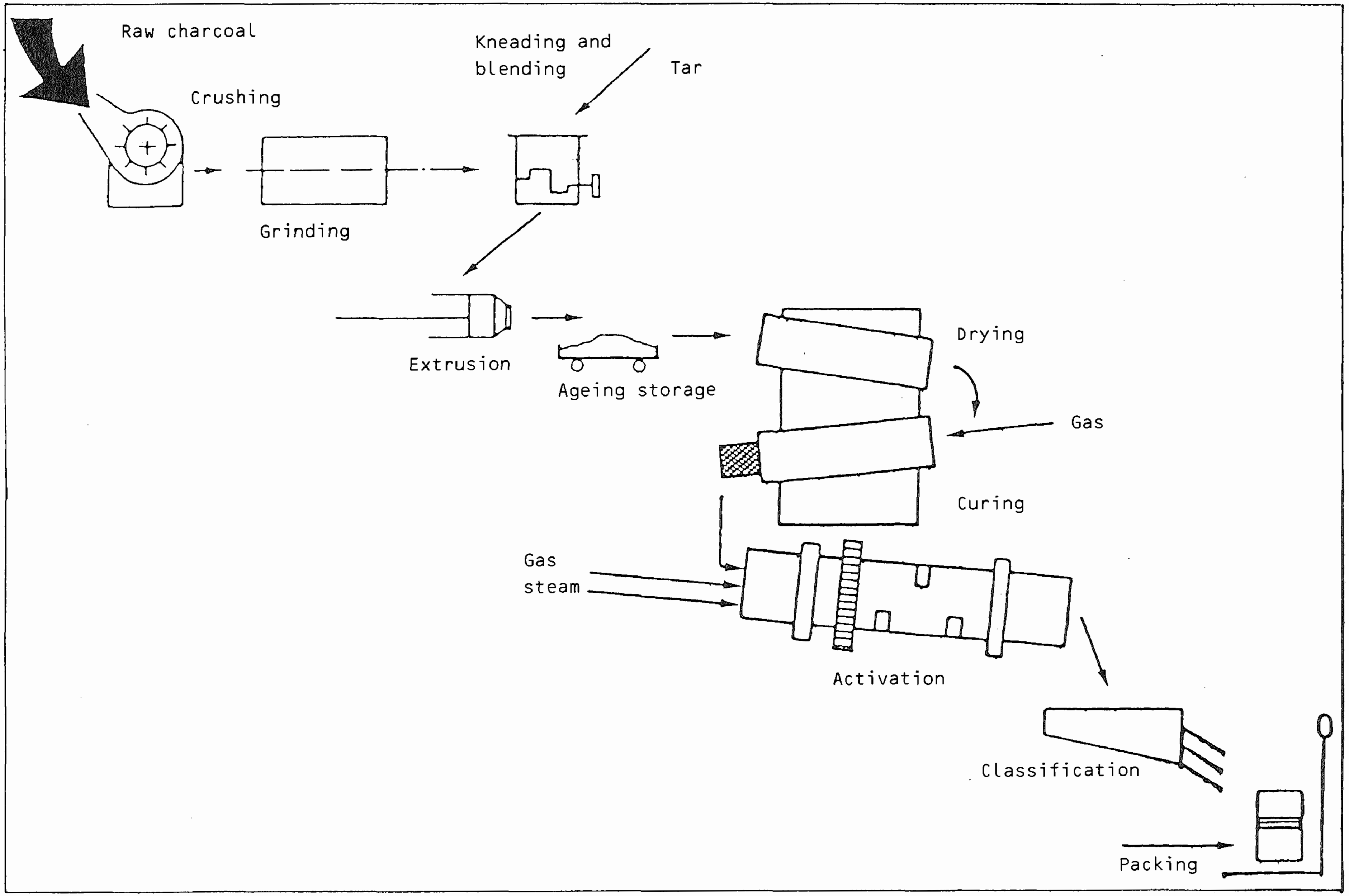

Fig. 13 Manufacture of Activated Charcoal - Schematic Outline

6.4.5 Specifications

The charcoal which the activated carbon producer buys will be to a specification derived from tests in the plant to determine limits of acceptability.

The useability of wood charcoal depends on its low ash content and availability in consistent quality.

Exceptionally good activated carbons can be produced with charcoal made from coconut shells, hardwood and even, sawdust and wood waste. However, bark is of no use.

Each activated carbon producer will set his individual standard determined by his own production process.

However, the requirements will not vary much whether the finished activated carbon is made for liquid, gases and vapours or other applications.

Although the charcoal from a new supplier offered to the activated carbon producer may meet all criteria specified, the purchaser is not likely to accept it before testing its behaviour in a pilot plant and testing of the final product.

These tests are complex and aimed at determining the adsorption capacity of the finished product on model substances. The industry has developed such indicators as the 'molasses figure', 'methylene-blue value', 'benezene, isotherms', etc.

The charcoal supplier does not need to become involved in these tests nor does he usually have the facilities and skilled staff to do so.

Listed below are average requirements for charcoal for activated carbon production.

Fixed carbon	82% minimum
Ash	4%
Volatiles	10%
Moisture	4%
pH [1/]	4 - 10

[1/] pH refers to an acidity test of a water extract of the charcoal.

6.5 Speciality Markets

Horticulture

Charcoal is used in different grades as a top dressing for the improvement of lawns and bowling greens. These top dressings act as mulch and also provide valuable trace elements and sweeten the soil.

Pottery mixtures used in nurseries often contain fine charcoal.

Poultry and Animal Feeds

These are sometimes supplemented with charcoal fines to control certain diseases.

Pharmaceuticals

Charcoal is used for controlling infections of the digestive tract.

Pigments

Vegetable (charcoal) blacks are dead black and of great strength.

6.6 Charcoal for Producer Gas

A promising means to improve the fuel energy situation in many developing countries is to use wood or charcoal to produce gas as fuel for diesel and gasoline engines.

Producer gas as it is called is made by passing air through a bed of granular carbonaceous fuel contained in an air tight shell. Most producer gas is made from coal or coke but wood and charcoal can be used. Charcoal in fact is an optimum fuel as it is low in ash and produces a clean gas free of tars. As well its energy content is comparable with good quality coal.

The air passed through the bed first contacts the burning layer of charcoal in the bottom of the producer and the charcoal burns to produce carbon dioxide. The carbon dioxide is reduced by contact with hot charcoal next to the combustion zone and is reduced to carbon monoxide. If water vapour is present it is also decomposed by the hot charcoal to form hydrogen and carbon monoxide. The hot gas is cooled as it passes further up the fuel bed and the gas emerging is a combustible mixture of carbon monoxide, carbon dioxide, some hydrogen and the residual nitrogen from the air. The gas burns readily but has only about one fifth the calorific value of natural gas. Despite this it is a useful fuel for gasoline and diesel engines especially the latter.

To be economic as a replacement for oil fuel the following cost relationships must apply. If diesel or gasoline costs about US $0.50 per litre of US $500 per tonne and taking into account the relative efficiency of use of the fuels charcoal must cost at the side of the gas producer about US $300 per tonne. In most developing countries charcoal costs less than this but as there are some disadvantages in use of charcoal compared to the convenience of a liquid fuel there needs to be a fair margin to make it worthwhile to install the equipment to make use of charcoal. Amortization costs for the producer equipment are not serious if the equipment is in constant use but can be uneconomic if the fuel is used sporadically. For best results the engines used should be specially designed to be used with producer gas. This is impractical because of the limited market.

Producer gas is probably most successful as a partial replacement for diesel fuel. The producer gas is drawn in with the air and it is possible to get good running with a replacement up to 70% of the diesel fuel, a worthwhile saving and especially suited for stationary engines.

Use in vehicles is practical but more complicated. The extra weight of the producer must be carried and refuelling points with charcoal must be available. Acceleration compared with liquid fuels is sluggish and this limits the use of charcoal to public transport and delivery vehicles where slow acceleration can be accepted without loss of face.

Although the advantage of replacing some imported petroleum with producer gas is fairly easy to see, in practice it is very difficult for users to give up the convenience of liquid fuels. There are some notable examples to be found of successful local replacement of some liquid fuels by producer gas. However one must still wait and see how far this development will be able to spread.

6.7 Summary of Industrial Markets

Chemical Industry

- carbon disulphide
- sodium cyanide
- metallic carbides
- silicon carbide

Iron and Steel

- iron smelting
- high purity irons
- ferro silicon
- silicon
- sintering and ore benefication

Metallurgy

- foundry operations
- copper smelting
- tin smelting
- specialised metal smelting and casting
- electric furnace electrodes
- sintering operations

Activated Carbons

- water purification
- pollution control
- gas purification
- solvent recovery
- distillation columns
- ageing of distilled spirits
- pharmaceuticals
- food industry
- softdrinks
- catalyst
- wine processing
- electric batteries
- cigarette filters
- sugar industry

Gas Generators

- gas for motor vehicles
- gas for stationary engines
- gas for carbonated drinks

Miscellaneous

- animal feed additives
- soil conditioners
- tobacco curing
- fruit drying
- arts and printing industry
- fireworks
- black powder explosives

6.8 Pyroligneous Acid as a Fuel

The condensate produced from distillation of wood is called pyroligneous acid. Water is the main constituent ranging from 20 to 80% depending on the moisture content of the wood being carbonised and the stage in carbonisation at which the sample is collected. The other components comprise water insoluble and water soluble tar, acetic and related acids, methanol, acetone and small quantities of complex esters and similar compounds which may have uses in flavouring.

If the condensate is heated to near the boiling point of water it is possible to ignite it and it can be burned as a fuel in a similar way to oil fuel. However its net calorific value is rather low since most of the heat energy it contains is used to evaporate the contained water. The heat in this evaporated water can be recovered by allowing the vapour in the flue gases to condense but only at a temperature below 100°C. Consequently the use of the condensate as liquid fuel is hardly practical even if the insoluble tar is burned as well.

A proven process for recovering the heat content of the condensables is to burn them as they emerge as hot vapour from the retort. Burning the material this way eliminates the polluting effects which accompany recovery of liquid pyroligneous acid since all the non-water components are converted to water and carbon dioxide and pass harmlessly into the atmosphere as ordinary flue gas. Pyroligneous acid is a highly corrosive substance and by avoiding handling it in the liquid state this problem is also eliminated.

The rise in oil prices throughout the world in the seventies encouraged interest in the possibility of using pyroligneous acid in liquid form as a substitute for fuel oil. To aid promotion of various schemes of dubious economic worth there was a tendency to rename 'pyroligneous acid' to 'pyrolysis oil' in order to make this noxious liquid seem more palatable and useful.

The correct way to take advantage of the heat content captured in wood as a result of photosynthesis is to burn it as such in properly designed furnaces. Alternatively where a technically complex system of carbonising wood has been installed all the condensable and non-condensable off-gases from the retorts should be burned in a boiler or similar industrial furnace as described above.

6.9 Utilization of By-products from Hardwood Carbonisation

6.9.1 Introduction

Recovery of chemicals from the vapours given off when hardwood is converted to charcoal was once a flourishing industry. However, as soon as petrochemicals appeared on the scene, wood as a source of methanol, acetic acid, speciality tars and preservatives became uneconomic. Whereever charcoal is made the possibility of recovering by-products is discussed. Present high costs of petroleum are advanced as an argument. Unfortunately the price of wood rises correspondingly removing most of the price advantage. Although the outlook for recovery of by-product chemicals from wood distillation does not appear promising, there are possibilities of recovering tars and using the wood gas as fuel to assist in making the carbonisation process more efficient. The economics, however, appear to be rather marginal but since recovery of by-products does reduce atmospheric pollution from wood carbonisation, the combined benefit makes it worthwhile having a close look at the possibilities. (2), (21).

When wood is heated above 270°C it begins a process of decomposition called carbonisation. If air is absent the final product, since there is no oxygen present to react with the wood, is charcoal. If air, which contains oxygen is present, the wood will catch fire and burn when it reaches a temperature of about 400-500°C and the final product is wood ash.

If wood is heated away from air, first the moisture is driven off and until this is complete, the wood temperature remains at about 100-110°C. When the wood is dry its temperature rises and at about 270°C it begins to spontaneously decompose and heat is evolved. This is the well known exothermic reaction which takes place during charcoal burning. At this stage evolution of the by-products of wood carbonisation starts. These substances are given off gradually as the temperature rises and at about 450°C the evolution is complete. The solid residue, charcoal, is mainly carbon (about 70%) and small amounts of tarry substances which can be driven off or decomposed completely only by raising the temperature to above about 600°C.

In the common practice of charcoal burning using internal heating of the charged wood by burning a part of it, all the by-product vapours and gas escapes into the atmosphere as smoke. The by-products can be recovered by passing the off-gases through a series of water cooled condensers to yield pyroligneous acid. The non-condensable wood gas passes on through the condensers and may be burned to provide heat. The wood gas is only useable as fuel and consists typically of 17% methane; 2% hydrogen; 23% carbon monoxide; 38% carbon dioxide; 2% oxygen and 18% nitrogen. It has a gross calorific value of about 10.8 MJoules per m^3 (290 BTU/cu.ft.) i.e. about one third the value of natural gas.

6.9.2 Pyroligneous acid

Pyroligneous acid is the name of the crude condensate and consists mainly of water. It is a highly polluting noxious corrosive liquid which must be either worked up properly to produce by-products for sale, or burned with the help of other fuel such as wood or wood gas to dispose of it.

The non-water component consists of wood tars, both water soluble and insoluble, acetic acid, methanol, acetone and other complex chemicals in small amounts. If left to stand, the pyroligneous acid separates into two layers comprising the water insoluble tar and a watery layer containing the remaining chemicals. Recovery of the water insoluble tar, often called wood or Stockholm tar, is simple - it is merely decanted from the water phase. This wood tar has uses as a veterinary antiseptic, a preservative for wood, a caulking agent, and as a substitute for road tar. Generally the quantity available and its price and physical properties make it a poor substitute for tar derived from the oil and coal industry for use in road-making. It does, however, have limited markets as a speciality industrial chemical. If it cannot be sold it can be burned as liquid fuel. One ton of dry wood, however, only produces about 40 kg of tar, i.e. about a 4% yield.

The water layer contains water soluble tars which are complex tarry chemicals, acetic acid, methanol, acetone and methyl acetone and small amounts of more complex acids and other substances.

6.9.3 Yield of Pyroligneous acid

The economics of by-product recovery depend on the yield of the more valuable components, especially the acetic acid, but also the mixture of methanol and acetone. Yield varies greatly with the kind of wood distilled. Wood with a high pentosan content such as European beech (Fagus spp.) gives a high yield of acid, eucalyptus wood gives low to intermediate yields. The yields from wood distillation quoted by various authors vary widely. Not only the kind of wood but the type of plant, its condensing efficiency, efficiency of the by-product refinery and so on all effect yields. Therefore it is of the utmost importance before investing in by-product recovery to be quite sure what sort of yields can be expected. For example, a plant in Europe working with beech and close to good markets for pure acetic acid may be economic. But a plant working with eucalyptus or mixed tropical hardwood far from markets for its products and obtaining only about half the yield of acid may be quite uneconomic. Therefore, proper full scale tests are necessary to find out what the yields are likely to be from the actual wood which will be carbonised. Careful market and plant design studies are essential. For guidance, the following yields can be taken as typical of northern hemisphere deciduous hardwoods:

Yield per ton (1 000 kg) of air dry wood

Acetic acid	50 kg
Methanol	16 "
Acetone and methyl acetone	8 "
Soluble tars	190 "
Insoluble tars	50 "

6.9.4 Refining pyroligneous acid

To recover saleable by-products from the pyroligneous acid a refinery somewhat similar to a small oil refinery but built of stainless steel or copper is required. The cost would nowadays be of the order of US $5-10 million but it is rather difficult to give a precise figure since such a refinery must be specially designed and built. They are not available as a stock item.

The whole process resembles quite closely in plant and technology an oil refinery but on a very small scale. Unlike oil refining, however, which uses a feedstock which is theoretically 100% saleable, the refining of pyroligneous acid involves throwing away about 50% of the feedstock as contaminated, unsaleable water. The whole of the pyroligneous acid, less the insoluble tar must be evaporated to separate the methanol and acetic acid from the soluble tars. Evaporation of water is costly as it requires a large fuel input. Furthermore, the acid products are very corrosive and the plant must be built from copper or preferably stainless steel, adding greatly to its cost. The products are sold in competition with products of the huge petro-chemical industry and competition is therefore difficult. On the credit side, the quality of the acetic acid is high and it usually can be sold easily. But the distance from major markets reduces profitability. Although the continued operation of existing wood distillation by-products recovery plants may be marginally profitable, the construction of new by-product recovery plants seems unlikely. The future will probably see some increased recovery of tar and the use of the off-gases and vapours from carbonisation plants for heating of retorts and boilers. How to do this effectively without investment in costly plant, however, still remains largely an unsolved problem.

The crude condensed liquid is decanted to separate insoluble tar which is sold usually without further processing. The watery phase must now be processed to recover three products: methanol-acetone, acetic acid and soluble tar. The acetic acid is the most valuable. The liquor is distilled in a primary steam heated still to separate the methanol acetone and acetic acid from the soluble tars. The soluble tars remain in the bottom of the still and the vapours consisting mainly of methanol acetone, acetic acid and water pass to a distillation column which separates crude 85% methanol containing acetone from the mixture of acetic acid and water. The crude methanol can be sold as a solvent.

The acetic acid is nowadays solvent extracted from the liquid phase using a solvent, usually ethyl acetate or ether. These solvents do not mix with water and dissolve or strip the acetic acid from the water phase, leaving only a trace of acetic acid in the water phase. After the recovery of any ethyl acetate or ether dissolved in the water phase, it is run to waste. It may still contain about 0.1% acetic acid. The ethyl acetate or ether solution of acetic acid (about 3%) must now be processed to recover the solvent for recycling and the acetic acid for sale. The solvent is distilled out in a fractionating column, the crude acetic acid (70%), freed of its solvent, is run from the base of the column and is purified by fractional distillation to 90% or more concentration, depending on market requirements. The solvent is recycled to extract more acetic acid from fresh feedstock. There is a small loss of solvent, which is topped up as needed.

6.10 Using Retort or Converter Gas

This gas is given off by the decomposing wood in the retort or other conversion equipment. It is called non-condensable gas since it passes, without condensing, the water cooled condensers which collect the tar and pyroligneous acid.

The composition of this gas varies within wide limits. The gas given off from conventional kilns changes composition as carbonisation progresses and is diluted by the products of combustion of the wood inside the kiln which is being burned to dry, heat up and carbonise the remainder. On the other hand the gas from a continuous retort system is more uniform in composition and heat content. It changes as carbonisation proceeds and with operating temperature. The off-gas from rinsing gas retorts will also be diluted by the inert rinsing gas which lowers the total calorific value of the gas.

Thus it is difficult to give exact figures for gas composition and heating value. A typical retort gas could have the following composition by volume:- methane 17%, hydrogen 2%, carbon monoxide 23%, carbon dioxide 38%, oxygen 2% and nitrogen 18%. Offgas from rinsing gas retorts could be diluted more than its own volume with inert rinsing gas.

The calorific value varies widely. Undiluted retort gas has a calorific value of about 11 MJ/m^3 but would be less than half this when diluted with inert rinsing gas being approximately equal to producer gas. The gas will burn easily but the heat output is limited. For every tonne of charcoal produced about 0.25 tonnes of non-condensable gas is produced having a heat content about 10% of that of the charcoal produced.

Recovery of the heat is worthwhile if it can be carried out simply and if the pyroligneous acid and tars are burned at the same time the total recoverable heat is about 20% of the heat content of the charcoal produced. (4)

The simplest way of using the heat in the gas is to divert it back and burn it under the retorts themselves. (15) Alternatively it can be burned under a steam boiler and the steam used as such or in a large installation used to generate power. The gas can also be burned in a wood predryer in much the same way as in a steam boiler. Best results are obtained when the tar and pyroligneous acid are burned at the same time with the gas. It is essential to burn the gas close to the retort system because if the gas cools too much the flues become blocked with condensed tar requiring costly shutdown to clean the gas mains.

6.11 Synopsis of Major Usages for Charcoal and By-products

Product	Raw Material	Application
Charcoal, lump	hard wood, soft wood	activated carbon, ferro-silicon, cooking, metal working, sodium cyanide, carbon disulfide, iron and steel, silicon.
Charcoal, granular	charcoal, lump	activated carbon, additive to animal food, filling compound for bottled gas, steel hardening compound.
Charcoal dust	charcoal, lump	activated carbon, lining of moulds in metal foundries, production of briquettes, cementation granulate, pyrotechnics, explosives, electrodes, batteries.
Soluble or pyrolytic tars	hard wood, soft wood, agricultural wastes	fuel for steam boiler, furnaces, metallurgy, fire brick making, raw material for chemical industry, electrodes.
Wood gas	hard wood, soft wood, agricultural wastes	heating gas for all types of operations, gas engines.
Wood vinegar	hard wood	food preservation and flavouring of meat and smoked fish, perfume and aroma industry.
Wood tar	hard wood	rope industry, veterinary medicine, pitch, creosote.
Crude methanol	wood alcohol	methyl acetate, solvent, denaturant.

Synopsis of Major Usages for Charcoal and By-products

Product	Raw Material	Application
Solvent	wood alcohol	cellulose esters and agglutinants, synthetics, lacquers.
Methyl formate	crude wood vinegar and crude methanol	cellulose esters and agglutinants, synthetics, lacquers.
Methyl acetate	crude wood vinegar and crude methanol	cellulose esters and agglutinants, synthetics, lacquers.
Acetic acid	crude wood acid	chemical, pharmaceutical, food, rayon, textile and film industries, vinegar.
Propionic acid	crude wood acid	pharmaceuticals, flavour and fragrances.
Butyric acid	crude wood acid	pharmaceutical and perfume industries.

Chapter 7

ECONOMICS AND PLANNING IN CHARCOAL PRODUCTION

Charcoal producers fall into two groups. The first are subsistance producers who only market charcoal to acquire cash needed to buy goods or pay taxes, etc. Economics and cost control are of little interest to this producer. He needs the cash and selling some of his charcoal is a way to acquire it.

The second group produce and sell charcoal as a business in which the circulation and growth of the capital they have invested in the business is their main concern. Economics and cost control are important for them.

Although the first group is personally not much concerned with economics, government authorities concerned with improving the charcoal industry must study the economics of subsistance charcoal production. An economic analysis must be the basis of any assistance programme to enable these producers to make more and better charcoal. In many countries subsistance produced charcoal is a major part of total charcoal production. Economic analysis is important to define the future of this sector of the industry, reveal its positive and negative features, and its long term viability.

7.1 Economic analysis and cost control

It is difficult to draw a sharp line to divide these two activities. Generally, economic analysis is of direct use in the planning phase of the development of the enterprise to project the cost of constructing and getting it into production. The objective is to demonstrate the economic feasibility of the proposal, then mobilise the investment funds required and lay down how they will be managed and repaid. Cost control, on the other hand, is concerned more with an enterprise which is up and running. It is the management tool which enables the enterprise to remain economically viable.

Production cost control is built around and forms part of the operations of a producing enterprise. It can be carried out with a background knowledge of accountancy or even just bookkeeping. The main requirement is to always use production data and statistics which are measures in the plant itself. On the other hand, economic analysis of projects requires a deeper knowledge of economics and a technical background of the processes which will be used. A large project calls for a team of technicians, some more qualified in economics, others in technology and engineering.

7.2 The Methods of Economic Project Analysis

The process of economic analysis of projects is often called a feasibility study but, strictly speaking, this is only one step along the road to setting up a complete project. For large and medium-size charcoal projects (4, 28) a team of professionals is required who must cover the fields of economics, forestry, building and civil engineering, technology of the process of production, finance and marketing. The complete study for the charcoal industry has the following aims:

1. To prove that a market or end use of adequate size exists for the charcoal and any by-products and to quantify it in detail.

2. To prove that suitable and adequate wood raw material exists and can be harvested economically for the expected life of the plant or to prove that a suitable raw material resource can be economically generated by forest plantations.

3. To choose the production technology to be used and to design the entire production system from wood harvesting through to packaging and marketing of the finished charcoal.

4. To prepare complete financial projections showing the method of financing, detailed expenditure budgets for land, plant, site preparation, infrastructure, construction, start-up and training costs. The financial projections must be carried forward approximately twenty years to a point where debts incurred in construction of the plant have been liquidated and the enterprise is functioning as an established business. For the manufacturing enterprise about twelve to fifteen years projection may be sufficient but, if the enterprise is to establish plantations for wood supply, then it is necessary to extend the financial projection till the plantation has gone through a complete rotation, involving replanting which could be twenty years or more. The financial projections will be in the form of a financial model showing profit and loss, sources and expenditure of funds, taxation and cash flow.

5. To prepare documentation for negotiations with government agencies on questions of forest resources, plant site, power and water supplies and other tax concessions, infrastructural needs, control of pollution, etc.

6. Prepare documentation and negotiate with financing agencies, both national and international, to secure financing for the project.

The list of requirements is formidable and costly and time-consuming to accomplish. Fortunately, more or less routine procedural sequences for accomplishing this work have been worked out by international finance authorities and the process is divided into a number of steps which are designed to test the feasibility of the project before committing funds for a complete technical and financial study. Normally the complete project study is preceded by at least two steps called a pre-feasibility and a feasibility study. If the results of these studies are positive, then it is worth committing funds for a full project planning exercise leading to the financing and construction of the enterprise.

The value of the complete study depends, in the long run, on the quality of the basic data on which the study rests. A study based on false premises is useless. Only experience in the field can indicate whether the data base is reasonable or not. As a guide to the effect of errors in basic assumptions, it is usual to test the complete financial model of the project, using varying values of key assumptions such as selling price of charcoal, percentage of fines, charcoal yield during carbonisation, cost of wood delivered, growing and harvesting costs, growth rates of plantations, and so on. The degree of risk entailed by variations in principal cost factors then becomes clearer and enables key factors to be more closely scrutinised. Once the financial model has been prepared and programmed on a computer, such studies are relatively simple to carry out. Planning is relatively simple: the difficult task, especially nowadays with high interest costs, is to construct the plant and get it operating profitably within the available financial resources. If there are serious cost overruns or construction delays, a situation can easily arise where the project cannot be completed or can never operate profitably. Hence the need to seek solutions in charcoal making which require minimum capital investment

7.3 Cost Control in Established Enterprises

Procuring finance for and constructing a large new enterprise for making charcoal nowadays is a difficult and costly proposition. As stated earlier, capital and interest costs are so high that a few construction delays can transform a profitable project into a permanent loss maker. Therefore, more attention needs to be given to improving and developing established charcoal making operations by building on the intrinsic expertise and resources they possess, eliminating or reducing constraints which prevent them from functioning at maximum efficiency. It is usually easier and often more successful financially to expand an existing enterprise than to construct a completely new, large scale one and expect it to operate profitably without difficulties.

Established enterprises and traditional production systems are not all successful or soundly based. Nevertheless there always exists a structure of skill and experience within the system which can often be mobilised to work more effectively by proper cost control.

7.3.1 The Unit Operations

The first step in cost control is to set down the unit operations of charcoal making and decide on a system of cost centres, usually the same ones as the unit production operations. The following example is taken from operations in the Chaco forests of South America (4) where charcoal is made on a large-scale by traditional but well organised methods. The unit operations are shown in Fig. 14. These unit operations can be used as cost centres and unit costs calculated for each one. As total production cost is the sum of each unit cost, providing they are expressed in a common unit of measurement, e.g. per ton of charcoal at the side of the kiln, the relative importance of each unit operation becomes clear. For example, the unit cost of harvesting wood and delivering it to roadside may be calculated as five dollars per stere. This cost must be expressed in dollars per ton of charcoal at side of kiln before its contribution to overall costs can be clearly seen. This cost depends on the yield of subsequent unit process steps. In general, the only significant one is the loss during carbonisation. The cost of five dollars per stere must be multiplied by the number of steres needed to produce one ton of charcoal free of fines. A typical figure could be 7.3 steres of wood produce one ton of charcoal free of fines. The cost of the wood at side of the road per ton of charcoal is then $5 x 7.3 = $36.50 per ton of finished saleable charcoal at side of kiln. This process must be applied to all unit costs to determine their overall effect on product cost. Technical knowledge of the process as well as cost accounting skill is needed for this and to decide whether efforts to reduce the effect of a particular unit operation on costs could be worthwhile; e.g. yield of wood per hectare could be raised, by gathering more small diameter branchwood. But if this wood mainly produces only fine charcoal in the kiln, the effort could be counterproductive. Tests would be necessary to clear this point. Hence the need to combine the efforts of the technician and the cost accountant to control costs.

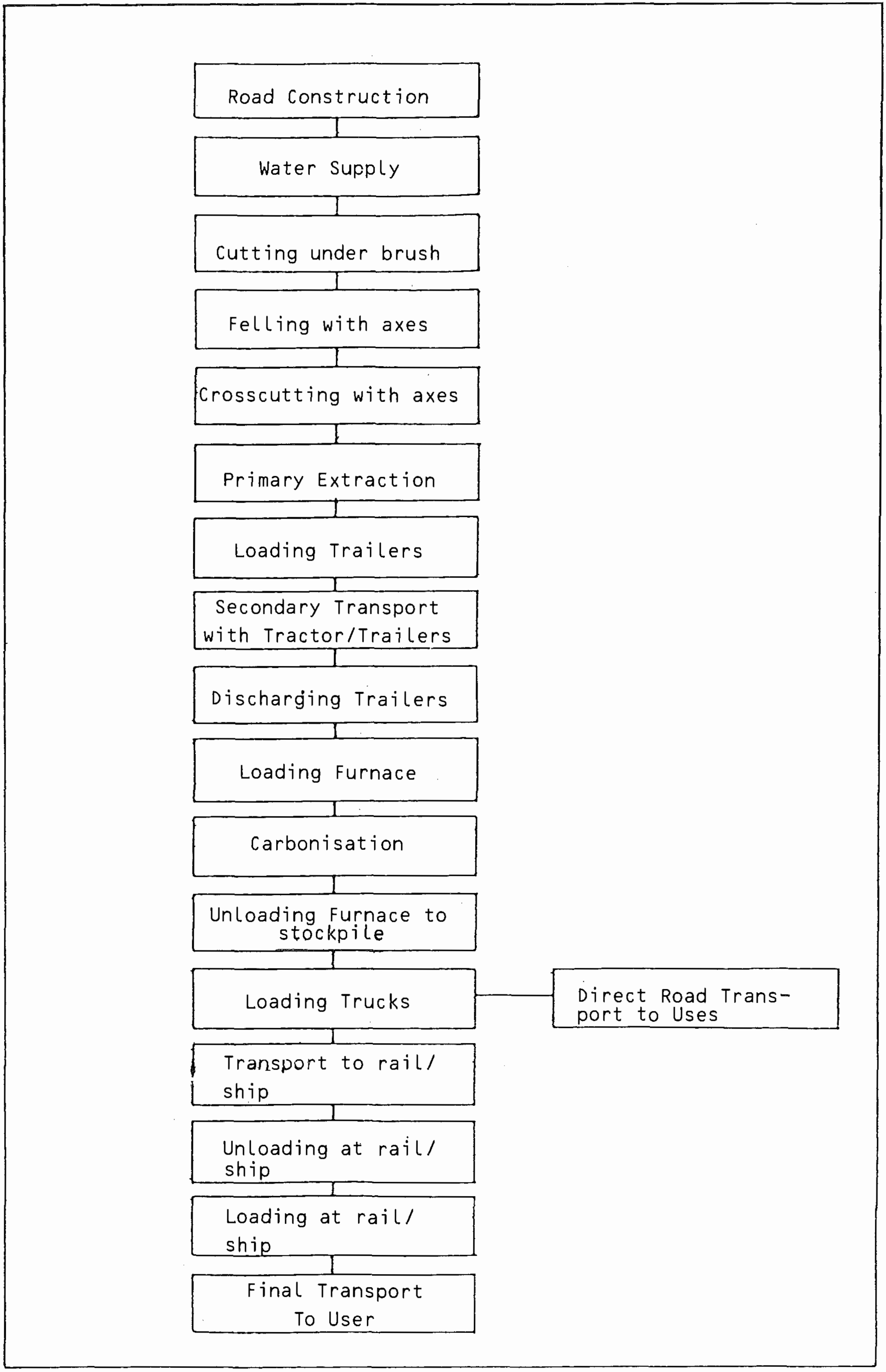

Fig. 14 Unit Operations in Charcoal Production

7.3.2 Unit Costs and Budgeting

Cost targets have to be set up in the budget for cost control. It is easier for each sector if its budgeted costs are set in the unit of measure it uses at that point, e.g. stere of fuelwood, ton of charcoal, ton/kilometre of charcoal, and so on. These figures are combined by management using appropriate conversion indices to check on overall performance in terms of the budget for the whole enterprise. To measure performance for the whole enterprise it is necessary to carry out process inventories on a regular basis, about every one to three months. The physical stock of raw material, semi-finished and finished charcoal, when combined with the input of wood and shipments of charcoal over the inventory period, enable the overall results to be calculated. In addition, records must be kept in each department of the material used, output achieved, number of kiln cycles. Unusual events such as floods, prolonged rainy periods, very dry conditions, labour shortage, equipment breakdowns, and transport delays also need to be noted in the production records of each department. Means to weigh and measure are essential.

7.4 Costing Models for Charcoal Production Enterprise

As an example in costing a charcoal making proposal in tables 5, 6, 7, 8 and 9 the layout is given of a costing model for an actual enterprise.

This model has been developed for the brick kiln technology as a basis to compare alternative systems based on continuous rinsing gas retorts. Since this model can be run on a computer it is a simple matter to study the effect of any change made in the system. This is convenient but grave errors will occur if the technical interpretation of the changes is not correct. The computer cannot judge the truth or falsity of the new assumption hence the need to ask plenty of questions before the results of such studies are put into practice.

7.5 Prefeasibility Cost Study for Charcoal Production

The objective of the study is to explore the feasibility of producing about 3,000 tons per year of charcoal from wood and forest residues as raw material. The first phase of the project is assumed to run for five years when results would be assessed to see if further investment in a charcoal making project having a higher output and an investment in continuous retort systems could be justified.

The cost studies show that at the offered price the project cannot be profitable using wood as raw material in the continuous retort system. The price offered was US $140 per ton for industrial use. If the charcoal final use is different, the price will also be different, rising to US $200 for iron production in shaft furnaces or to US $300 for residential use. Using forest residues as raw material, both options, i.e. kilns and continuous retorts are profitable.

7.5.1 General Considerations

Charcoal making costs can be best understood by separating the process into its unit operations. In the attached cost study this has been followed and the incidence of the various unit operations on total costs clearly seen. The relatively minor incidence of the carbonisation operation on total costs is notable and typical of successful charcoal operations in general.

Some special aspects of the proposed scheme need emphasis. An advantage is the availability of forest residues because this implies no stumpage cost.

A general idea of the scale of the enterprise can be gained as follows. The annual input of wood needed to produce the target quantity of charcoal is about 20,000 m^3 which is about the input of a large hardwood sawmill. If the production target would be greater (i.e. 10,000 t/year of charcoal) the advantages of the continuous system would be undeniable. To show this, table 9 presents an economic study for a 16,000 t/year continuous retort system using wood as raw material. Of course these cost studies are very simplified and can only be used as a first approach in order to start a prefeasibility study.

7.5.2 The Resource

Although adequate raw material exists in the area to provide the quantity needed for the project it is important to get as accurate an idea as possible as to how this wood is distributed since this influences the choice of location for the carbonising site(s) so that haulage costs are minimised. Information on the diameter class of the resource is also needed though it is probably not available in detail. If low ash is required in the product it compels a preference for large diameter wood to reduce the proportion of sapwood. But there is no cheap small-scale technology for preparing this wood for carbonising.

7.5.3 Wood Harvesting

The best wood harvesting policy to be followed in the resource area is integrated logging. This is more or less essential to obtain adequate regeneration of the logged areas and to extract the pulp, sawlog and charcoal in the most economic way.

If there is a large chipmill in the area it would be an adequate supply of logging contractors. This means there will be no problem in arranging for logs to be supplied to the carbonising sites. At the same time it tends to set the price at the going rate for pulpwood harvesting. The cost calculations have been made on the going rates for pulpwood harvesting and a nominal stumpage of US $3.00 per ton has been allowed.

7.5.4 Carbonisation

The choice of carbonisation system has to conform to the limitations of the project especially if a relatively short life of the enterprise is expected and the cost of labour in the zone has also to be taken into account. Although there are successful continuous and semi-continuous charcoal plants in operation in the world, in general they are much too costly in capital investment and that fact must be seriously considered in any actual project. There are many proposals for continuous charcoal making plants but there are only three industrially proven systems; the Herreschoff type rotary hearth furnace, the Lambiotte vertical continuous retort and the semi-continuous Reichert retort (see Chapter 3).

Portable steel retorts are used in Europe to produce lump charcoal of good quality but only as a forest clean-up operation. They have been tried in a number of countries but are unsuitable for sustained charcoal production as they require a larger initial investment than brick kilns for the same production and their working life and labour productivity is much lower.

The only advantage which they possess is an ability to be brought to the side of the standing tree and hence are useful in forest and parkland clean-up operations, the low cost of the wood at the side of the kiln offsetting their other disadvantages. They could be of use in the early stages of the project to prove methods of block preparation, quality, yield and so on. In some projects they would not be permitted in the forest because of fire hazard and therefore are only useful for experimental burns outside the forest.

However, any serious attempt to make charcoal would require brick kilns. The Argentine or Brazilian types are the logical choice. The Argentine half-round kiln is cheap and easy to use. About 22 kilns in two charcoal production centres would be adequate. Each group of eleven would require a carbonising crew of four with some overtime. Depending on the way the wood resource is distributed it may be feasible to locate two groups of kilns at one site which would bring operating economies offsetting a higher wood transport cost. For maximum efficiency it is necessary to operate the kilns in groups of 10-12 because of the way labour for carbonising is organised. All other services such as wood preparation and shipping of charcoal can be combined in one site.

7.5.5 Packing and Shipping

After being unloaded from the kiln and before it can be shipped charcoal must be 'cured' by allowing it to adsorb oxygen from the air. If this is not done then it can spontaneously ignite. Hence there must be provision for storage of two days production on the ground and double handling into the containers. With luck it may be possible to avoid a screening operation. Most of the high ash charcoal is in the fines fraction but there is a possibility that even including fines the charcoal may still meet the ash specification. If not a simple gravity coarse screening operation at the time of loading may be required. About ten percent of the charcoal will be fines and the cost calculations assume this loss. If fines can be sold then production costs will be reduced correspondingly.

There are two sources of significant ash in the product, mud and sand picked up on the logs during skidding and earth picked up from the surface of the charcoal-making site during handling operations. Fortunately after the site has been in use for a short while it becomes covered with a compact layer of charcoal fines, admittedly of higher ash content, and this more or less prevents mineral contamination. At an early stage in project development the amount of mineral matter being carried along with the wood needs to be checked by sampling and analysis to see if special precautions are needed. This matter of contamination needs stressing because every kilo of mineral is 100% ash. One percent ash by weight is only about 0.16% by volume and is easily picked up without detection.

Carbonisation of wood produces smoke and a strong odour of wood tar and other substances in the vicinity which can be carried downwind for some kilometers. Therefore any selected site should be at least three kilometers from residential areas to avoid pollution and 'environmental impact problems'. The direction of prevailing winds is important in deciding on a potential site.

7.5.6 Cost Analysis Models

Two cost models were studied, one for the brick kiln technology and one for the portable steel kiln system. The latter is not recommended on cost considerations and the fact that this system requires all the wood to be reduced to a uniform size, it cannot cope with large diameter sections about 0.5 metre in diameter as can the brick kiln. Only the model for the brick kiln technology is presented here.

The cost data is based on practical charcoal making experience. More careful studies would be made when the project has advanced further to correlate these cost projections more closely with actual conditions. The structure of the models is such that sensitivity studies and the effect of changes in any of the cost parameters are easily made.

The next stage in a project study of this kind is to substitute the capital and operating cost data of a retort system for the brick kiln system. The cost model remains basically unaltered.

The retort system needs only one charcoal making centre and reduces the labour required for carbonisation slightly. The yield is higher meaning less wood has to be harvested and cut into blocks. But the retort requires smaller blocks of wood and this may increase the block preparation costs. The retort also requires a more costly site and better power and water facilities. The retort, assumed to cost US $600,000 has been depreciated over 15 years instead of the five years allowed in the brick kiln model. But the capital and interest charges are high and the overall effect of using a retort system is to raise the cost of the charcoal. In this analysis it is not possible to allow any benefit from the recovery of by-products. The cost of a refinery would be too high for the sales realised and there is insufficient need for power to make it worthwhile to generate steam or electricity by burning the off-gas in boilers. It would be recycled to the greatest possible degree back through the retort. If the wood to be used is not already dry maybe some benefit could be obtained in using the by-product gas to heat a wood dryer. The results of the two models are given in tables 5, 6, 7, 8 and 9. The calculations are estimates for the production cost for the first year when interest charges are at their maximum.

7.6 Wood Transport Cost and Fixed Retort Systems

The wood transport cost is a serious factor with all charcoal making systems requiring high capital investment in fixed retorts. Since the retorts cannot be moved during the life of the enterprise because of the capital tied up in their construction the enterprise must face a constantly rising wood transport cost which may become crippling. Often assumptions are made that carbonising wood is similar to the refining of oil or the coking of coal. In the case of oil the yield of product from the crude entering the process is close to 100%. Oil is concentrated and easily transported hugh distances in liquid form. Coal is mined from thick seams which can be typically two or more meters in thickness. On the other hand, a mature tropical forest may yield only about 50 m^3 per hectare of wood which has no higher priced use than making charcoal. This is equivalent to a continuous seam of coal underlying the forest about 2.5 millimeters thick which is only one thousandth of the thickness of a coal seam. Hence one must harvest an area one thousand times greater to yield the same amount of finished product. Consequently the harvested area expands rapidly, leading to prohibitive transport costs. These costs have little impact if the wood for carbonising is waste at a sawmill and the wood transport cost has been paid for by some other product. The problem here however is that the quantity of waste available may be quite insufficient to feed the high technology carbonising retort.

The wood transport cost can be acceptable where the retorts are integrated with high yielding plantations. A modern rinsing gas retort may produce 10,000 tons/year of charcoal. With a conversion ratio of four tons of air dry wood per ton of charcoal, 40,000 tons of wood must be transported after drying at the stump each year. If the plantations have a Mean Annual Increment of 18 m^3 of wood per hectare than a plantation area of about 5,000 ha would be sufficient to supply this wood in perpetuity once the plantations were fully established after about twelve years. If the retorts were established in the centre of such a complex then the mean haul distance would be about five kilometers in a well laid out plantation. Such a system can continue indefinitely providing the following conditions are met:- regeneration of the harvested area must be practical; soil fertility must be able to be maintained under successive rotations; the cost of producing the wood under plantation conditions must be acceptable.

Establishing plantations to produce charcoal makes sense where the charcoal is required for a vertically integrated operation such as production of iron and steel. Here a higher than average cost for the charcoal can be absorbed within the overall economic goals of the enterprise. But when charcoal for the market must be produced the problem of the emergence of higher priced alternative uses for the plantation wood as the years pass may develop.

For example, eucalypt wood from plantations is a good raw material for either paper pulp or charcoal and it may be found later that the wood can be sold for a higher price for making pulp rather than charcoal. Hence a firm committment on the part of governments to use the wood for charcoal must be in place before funds can be invested. Complex technology methods to produce charcoal require a large investment of capital and a long cycle of investment as compared with simpler technologies. The latter pose less risk should higher priced alternative uses for the wood arise after a number of years. A lot can be learned about the problems and possibilities of using high technology methods for charcoal production by studying the experience of the Brazilian iron and steel industry which produce millions of tons of charcoal each year mostly by the brick kiln technology (15, 28). This industry has closely studied the possibilities of making at least some of this charcoal by advanced methods. A report of studies (1) made at the ACESITA steel works in Belo Horizonte, Brazil concludes that capital costs remain the principal obstacle to adoption of advanced methods.

The steel industry has a special problem in that it must have charcoal in lump form suitable for use in blast furnaces. Rinsing gas retorts have proved their technical suitability for making this kind of charcoal at the Wundowie Iron Works in Australia. This production, until the works closed recently was economic, though wood transport costs were reaching their limit. Wundowie's advantage lay in having made the capital investment in a pair of large retorts many years ago when capital costs were far lower.

7.7 Summary

The economic and planning problems of using advanced methods of charcoal production can be summed up in the following way.

Technically at least two proven methods exist today which will produce charcoal continuously and permit recovery of by-products lost when traditional methods are used.

But the factors which have an inhibiting effect on investment in this area are:-

- Rising wood transport costs caused by the fixed location of the high capital cost retorts required.

- The excessive investment cost needed especially in developing countries for the equipment which originates in the developed world. This excessive cost is mainly due to the distorted terms of trade between the developing and the developed world.

- The low value and high cost of recovering by-products of carbonisation accentuated by the lower cost of producing the same or similar products in the petrochemical industry. This makes it necessary to burn rather than refine the carbonisation by-products in the off-gas stream to produce heat. This recovered heat makes only a small contribution to the profitability of the enterprise.

- Research and good management in the operation of brick kiln charcoal complexes has tended to close the gap between the production of charcoal by this method and the complex technology routes. This has left complex technology methods dependent on the value of the by-products to reduce production costs which as mentioned is not sufficient to justify the capital investment needed.

TABLE 5

CHARCOAL PRODUCTION COST ANALYSIS - CASE: BRICK KILN SYSTEM (Wood as Raw Material)

A. PROJECT CONSTANTS.

CASE: Brick Kiln System with two Charcoal Production Centres (11 kilns each)

	Unit	Value
NET CONVERSION RATIO INTO CONTAINER:	t charcoal/t wood	0.2
ANNUAL PRODUCTION TARGET:	t	3 000
PROJECT LIFE:	years	5
PROJECT INTEREST RATE:	%	0.15
STUMPAGE:	U$S/t wood	3.0
CUT,SKID and LOAD:	U$S/t wood	5.0
ROAD HAULAGE:	U$S/t wood	5.0

B. CAPITAL COSTS.

ITEM	Unitary Cost	Total Cost	Depreciation per year	Interest per year	Total per year	Total per charcoal t
	U$S	U$S	U$S/year	U$S/year	U$S/year	U$S/t
SITE PREPARATION	2 000	4 000	800	600	1 400	0.47
POWER AND WATER	10 000	20 000	4 000	3 000	7 000	2.33
EQUIPMENT: BRICK KILNS (22)	700	15 400	3 080	2 310	5 390	1.80
TOOLS	8 000	16 000	3 200	2 400	5 600	1.87
LOG FORK/END LOADER	20 000	40 000	8 000	6 000	14 000	4.67
VEHICLES	30 000	60 000	12 000	9 000	21 000	7.00
SUB TOTALS (Capital Cost)		155 400			54 390	18.14

C. PRODUCTION COSTS.

ITEM	Unitary Cost		Total per year	Total per charcoal t
	U$S/t		U$S/year	U$S/t
STUMPAGE	15.0		45 000	15.0
LOGS AT DUMP	25.0		75 000	25.0
HAULAGE	25.0		75 000	25.0
CARBONISATION	10.0		30 000	10.0
MANAGER	6.0		18 000	6.0
FUEL AND LUBRICANT	4.0		12 000	4.0
VEHICLE MAINTENANCE	2.0		6 000	2.0
GENERAL MAINTENANCE	3.0		9 000	3.0
INSURANCES	5.0		15 000	5.0
WORKING CAPITAL COSTS	3.0		9 000	3.0
SUB TOTALS (Production Cost)			294 000	98.0

TOTALS (Total Cost)		155 400			348 390	116.14

ROAD HAUL TO MARKET	Distance (km):	200	U$S/t	20

COST PER t CHARCOAL IN THE MARKET	U$S/t	136.14
OFFERED PRICE (For Industrial Use)	U$S/t	140

Table 6

CHARCOAL PRODUCTION COST ANALYSIS - CASE: CONTINUOUS RETORT SYSTEM (Wood as Raw Material)

A. PROJECT CONSTANTS.

CASE: Continuous Retort System at one site

	Unit	Value
NET CONVERSION RATIO INTO CONTAINER:	t charcoal/t wood	0.3
ANNUAL PRODUCTION TARGET:	t	3 000
PROJECT LIFE:	years	5(15 for retort)
PROJECT INTEREST RATE:	%	0.15
STUMPAGE:	U$S/t wood	3.00
CUT,SKID and LOAD:	U$S/t wood	5.00
ROAD HAULAGE:	U$S/t wood	5.00

B. CAPITAL COSTS.

ITEM	Unitary Cost	Total Cost	Depreciation per year	Interest per year	Total per year	Total per charcoal t
	U$S	U$S	U$S/year	U$S/year	U$S/year	U$S/t
SITE PREPARATION	70 000	70 000	4 666	10 500	15 166	5.05
POWER AND WATER	20 000	20 000	1 333	3 000	4 333	1.44
EQUIPMENT: RETORT	600 000	600 000	40 000	90 000	130 000	43.30
TOOLS	12 000	12 000	2 400	1 800	4 200	1.40
LOG FORK/END LOADER (2)	30 000	60 000	12 000	9 000	21 000	7.00
VEHICLES	30 000	30 000	6 000	4 500	10 500	3.50
SUB TOTALS (Capital Cost)		792 000			185 199	61.70

C. PRODUCTION COSTS.

ITEM	Unitary Cost		Total per year	Total per charcoal t
	U$S/t		U$S/year	U$S/t
STUMPAGE	10.0		30 000	10
LOGS AT DUMP	16.7		50 000	16.7
HAULAGE	16.7		50 000	16.7
CARBONISATION	-		-	-
MANAGER	4.0		12 000	4.0
FUEL AND LUBRICANT	7.0		21 000	7.0
VEHICLE MAINTENANCE	3.0		9 000	3.0
GENERAL MAINTENANCE	7.0		21 000	7.0
INSURANCES	8.0		24 000	8.0
WORKING CAPITAL COSTS	3.0		9 000	3.0
SUB TOTALS (Production Cost)			226 000	75.4

TOTALS (Total Cost)		792 000			411 199	137.1

ROAD HAUL TO MARKET	Distance (km): 200	U$S/t 20.0	

COST PER t CHARCOAL IN THE MARKET	U$S/t	157.1
OFFERED PRICE (For Industrial Use)	U$S/t	140

TABLE 7

CHARCOAL PRODUCTION COST ANALYSIS - CASE: CONTINUOUS RETORT SYSTEM (Forest Residues as Raw Material)

A. PROJECT CONSTANTS.

CASE: Continuous Retort System at one site

	Unit	Value
NET CONVERSION RATIO INTO CONTAINER:	t charcoal/t wood	0.3
ANNUAL PRODUCTION TARGET:	t	3 000
PROJECT LIFE:	years	5(15 for Retort)
PROJECT INTEREST RATE:	%	0.15
STUMPAGE:	U$S/t wood	0
CUT,SKID and LOAD:	U$S/t wood	2
ROAD HAULAGE:	U$S/t wood	2

B. CAPITAL COSTS.

ITEM	Unitary Cost	Total Cost	Depreciation per year	Interest per year	Total per year	Total per charcoal t
	U$S	U$S	U$S/year	U$S/year	U$S/year	U$S/t
SITE PREPARATION	70 000	70 000	4 666	10 500	15 166	5.05
POWER AND WATER	20 000	20 000	1 333	3 000	4 333	1.44
EQUIPMENT: RETORT	600 000	600 000	40 000	90 000	130 000	43.3
TOOLS	12 000	12 000	800	1 800	2 600	0.87
LOG FORK/END LOADER (2)	30 000	60 000	4 000	9 000	13 000	4.33
VEHICLES	30 000	30 000	2 000	4 500	6 500	2.17
SUB TOTALS (Capital Cost)		792 000			171 599	57.16

C. PRODUCTION COSTS.

ITEM	Unitary Cost		Total per year	Total per charcoal t
	U$S/t		U$S/year	U$S/t
STUMPAGE	0		0	0
LOGS AT DUMP	6.7		20 000	6.7
HAULAGE	6.7		20 000	6.7
CARBONISATION	-		-	-
MANAGER	4.0		12 000	4.0
FUEL AND LUBRICANT	7.0		21 000	7.0
VEHICLE MAINTENANCE	3.0		9 000	3.0
GENERAL MAINTENANCE	7.0		21 000	7.0
INSURANCES	8.0		24 000	8.0
WORKING CAPITAL COSTS	3.0		9 000	3.0
SUB TOTALS (Production Cost)			136 000	45.40

TOTALS (Total Cost)		792 000			307 599	102.56

ROAD HAUL TO MARKET	Distance (km):	200	U$S/t	20
COST PER t CHARCOAL IN THE MARKET			U$S/t	122.56
OFFERED PRICE (For Industrial Use)			U$S/t	140

TABLE 8

CHARCOAL PRODUCTION COST ANALYSIS - CASE: BRICK KILN SYSTEM (Forest Residues as Raw Material)

A. PROJECT CONSTANTS.

CASE: Brick Kiln System with two Charcoal Production Centres (11 kilns each)

	Unit	Value
NET CONVERSION RATIO INTO CONTAINER:	t charcoal/t wood	0.2
ANNUAL PRODUCTION TARGET:	t	3 000
PROJECT LIFE:	years	5
PROJECT INTEREST RATE:	%	0.15
STUMPAGE:	U$S/t wood	0
CUT,SKID and LOAD:	U$S/t wood	2.0
ROAD HAULAGE:	U$S/t wood	2.0

B. CAPITAL COSTS.

ITEM	Unitary Cost	Total Cost	Depreciation per year	Interest per year	Total per year	Total per charcoal t
	U$S	U$S	U$S/year	U$S/year	U$S/year	U$S/t
SITE PREPARATION	2 000	4 000	800	600	1 400	0.47
POWER AND WATER	10 000	20 000	4 000	3 000	7 000	2.33
EQUIPMENT: BRICK KILNS (22)	700	15 400	3 080	2 310	5 390	1.80
TOOLS (2 kits)	8 000	16 000	3 200	2 400	5 600	1.87
LOG FORK/END LOADER (2)	20 000	40 000	8 000	6 000	14 000	4.67
VEHICLES (2)	30 000	60 000	12 000	9 000	21 000	7.00
SUB TOTALS (Capital Cost)		155 400			54 390	18.14

C. PRODUCTION COSTS.

ITEM	Unitary Cost		Total per year	Total per charcoal t
	U$S/t		U$S/year	U$S/t
STUMPAGE	0		0	0
LOGS AT DUMP	10.0		30 000	10.0
HAULAGE	10.0		30 000	10.0
CARBONISATION	10.0		30 000	10.0
MANAGER	6.0		18 000	6.0
FUEL AND LUBRICANT	4.0		12 000	4.0
VEHICLE MAINTENANCE	2.0		6 000	2.0
GENERAL MAINTENANCE	3.0		9 000	3.0
INSURANCES	5.0		15 000	5.0
WORKING CAPITAL COSTS	3.0		9 000	3.0
SUB TOTALS (Production Cost)			159 000	53.0
TOTALS (Total Cost)		155 400	213 390	71.14

ROAD HAUL TO MARKET	Distance (km): 200	U$S/t	20
COST PER t CHARCOAL IN THE MARKET		U$S/t	91.14
OFFERED PRICE (For Industrial Use)		U$S/t	140

TABLE 9

CHARCOAL PRODUCTION COST ANALYSIS - CASE: CONTINUOUS RETORT SYSTEM (Wood as Raw Material)

A. PROJECT CONSTANTS.

CASE: Continuous Retort System at one Site

	Unit	Value
NET CONVERSION RATIO INTO CONTAINER:	t charcoal/t wood	0.3
ANNUAL PRODUCTION TARGET:	t	16 000
PROJECT LIFE:	years	5(15 for retort)
PROJECT INTEREST RATE:	%	0.15
STUMPAGE:	U$S/t wood	3.0
CUT,SKID and LOAD:	U$S/t wood	5.0
ROAD HAULAGE:	U$S/t wood	5.0

B. CAPITAL COSTS.

ITEM	Unitary Cost	Total Cost	Depreciation per year	Interest per year	Total per year	Total per charcoal t
	U$S	U$S	U$S/year	U$S/year	U$S/year	U$S/t
SITE PREPARATION AND BUILDINGS	100 000	100 000	6 666	15 000	21 666	1.35
POWER AND WATER	80 000	80 000	5 333	12 000	17 333	1.08
EQUIPMENT: RETORT	1 500 000	1 500 000	100 000	225 000	325 000	20.31
TOOLS	50 000	50 000	10 000	7 500	17 500	1.09
LOG FORK/END LOADER (4)	30 000	120 000	24 000	18 000	42 000	2.62
VEHICLES (3)	20 000	60 000	12 000	9 000	21 000	1.31
SUB TOTALS (Capital Cost)		1 910 000			444 499	27.76

C. PRODUCTION COSTS.

ITEM	Unitary Cost		Total per year	Total per charcoal t
	U$S/t		U$S/year	U$S/t
STUMPAGE	10.0		160 000	10.0
LOGS AT DUMP	16.7		267 000	16.7
HAULAGE	16.7		267 000	16.7
CARBONISATION	-		-	-
MANAGER	2.0		32 000	2.0
FUEL AND LUBRICATION	4.0		64 000	4.0
VEHICLE MAINTENANCE	2.0		32 000	2.0
GENERAL MAINTENANCE	5.0		80 000	5.0
INSURANCES	6.0		96 000	6.0
WORKING CAPITAL COSTS	3.0		48 000	3.0
SUB TOTALS (Production Cost)			1 046 400	65.40
TOTALS (Total Cost)		1 910 000	1 490 899	93.16

ROAD HAUL TO MARKET	Distance (km):	200	U$S/t	20
COST PER t CHARCOAL IN THE MARKET			U$S/t	113.16
OFFERED PRICE (For Industrial Use)			U$S/t	140.00

Chapter 8

QUALITY CONTROL OF CHARCOAL AND BY-PRODUCTS

8.1 Introduction

Traditional charcoal makers rarely apply quality control, but industrial producers often contract a laboratory to analyse the product, in order to meet the quality required by the customer. Large consumers, such as the steel or electrical industries, have their own quality control laboratories staffed by trainee operatives.

The laboratory staff must be familiar with the different standards used for quality control of charcoal and by-products.

The buying specification of large industrial users and others will refer to various parameters measured in the process of quality control. The acceptability of the product will be determined by it's compliance with the values laid down in the specification. Price variations may also apply where standard quality indicators are not met. An example is the practice of Altos Hornos Zapla in Argentina who increase the buying price by 1% for each percentage point moisture content below 8% and decrease the price by 1% for each percentage point of moisture above 8%.

Fixed carbon content is an important parameter in steel making charcoal since this is the agent which reduces the iron ore to metallic iron and limits which must be met are often specified. Screen size, ash content and friability are also often specified by large buyers.

Standards for charcoal testing are derived from fuels such as coal or coke and, in some cases, are modified to apply specifically to charcoal analysis. Such modifications must be mentioned in the charcoal analysis report.

Testing must follow standardized methods in all cases to ensure that the results can be compared and the analysis repeated.

8.2 Standard Methods for Quality Control

Various countries have developed their own standard methods for quality control of solid fuels and these are applied with some modifications to the testing of charcoal. The testing methods for by-products are derived from standard analytical procedures for liquid chemicals and gaseous fuels. It is not necessary to detail all the standards which are used but merely to indicate a typical system. Such a system which is widely used is that of the American Society for Testing Materials (ASTM). The most important of these test methods which apply to charcoal testing are listed on the following page.

- Collection and preparation of samples. ASTM D 346-75.
- Measuring the resistance of charcoal to degradation by impact and abrasion - tumbler test for coke. ASTM D 294-64 usually modified for charcoal.
- Determination of the relative size stability of charcoal pieces. Drop shatter test ASTM D440 -49. Used for charcoal briquettes.
- Sieve analysis.
- Moisture content of charcoal and wood ASTM D 2016-74.
- Proximate fuel analysis of charcoal ASTM D 271-48.
- Heat value, inflammability of barbecue-briquettes ASTM D 2677, D 3172-73.

8.2.1 Moisture Content

Method for raw material, such as agriculture residues, bark, etc.

Accurately weigh 10 grammes of the sample and dry it in an electric drying chamber at a constant temperature of 105°C for three hours. Continue drying and reweigh at one-hour intervals until the loss is not more than 0.25% in one hour's drying.

The loss of weight will be calculated as a percentage of the initial wet weight. In the case of solid wood, pieces of an approximate size of 5 x 5 x 5 cm. are cut and then split into slivers to provide the sample.

Method for charcoal and charcoal briquettes.

Crush sample in a porcelain mortar and accurately weigh 3 grammes. Drying and weighing procedures as above.

8.2.2 Ash Content

For raw material.

Crush or grind sample and weigh accurately 3 grammes in a platinum or porcelain crucible with a lid. Heat to 700 - 800°C in an electric muffle oven. Check weight and temperatures at intervals until weight loss is under 0.25%.

The difference between initial weight and weight of sample after combustion will be expressed as a percentage of the initial weight and represents the ash content. A correction can be made for moisture content to express ash on a moisture free basis.

For charcoal and charcoal briquettes.

Prepare sample as above. According to estimated ash content accurately weigh three or five grammes in a platinum or porcelain crucible with lid.

Continue procedure as described for raw material above.

If the charcoal does not burn away completely apply several drops of hydrogen peroxide (3% solution) and re-heat the crucible in the muffle furnace.

8.2.3 Volatiles and Fixed Carbon

This method is applied to all charcoal products - lump charcoal, charcoal fines, granules, pellets and charcoal briquettes. By heating charcoal with exclusion of air (oxygen) volatile matter and gases are expelled. These gases are called volatiles and consist of tarry vapours and non-condensible gases.

There are several standards (ASTM, DIN, etc.) but only the general procedures are given here.

Preparation of charcoal sample.

Crushing is done manually in a porcelain mortar with a pestle. Grinding is not recommended because the heat generated would already drive off part of the volatiles. Dry the sample at a temperature of 105°C (not higher) to reduce moisture content to zero.

Accurately weight one gramme of the powdered sample in a platinum (preferable) or porcelain crucible with a lid with the following dimensions: bottom diameter 22 mm upper, 35 mm height without lid 40 mm. The lid should have a hole in the centre of a diameter of 1.5 mm (not larger). The rim of the lid must comfortably overlap the rim of the crucible to prevent intake of air.

Place the crucible in a wire triangle firmly on a tripod and heat the bottom gently with a Bunsen burner, placed at a distance of not less than 6 cm from the crucible. After 2 - 3 minutes, open the gas adjusting screw and the air control of the Bunsen burner to full capacity and continue heating until the small flame above the pinhole of the lid has ceased. This indicates that all volatile matter has been driven off. Put the hot crucible into a desiccator with calcium chloride as a desiccant, until the sample has cooled. Weigh as usual.

The difference between the initial weight represents the volatile content. The value for the fixed carbon is calculated as follows:
% C = 100 - (volatiles + ash).

8.2.4 Sulphur

Sulphur may be measured for all charcoal products. The most common method being calorimetric combustion of the charcoal with the addition of diluted sodium hydroxide to convert sulphur to sulphates, which are largely precipitated with barium chloride as barium sulphate.

Accurately weigh one gramme of the dry powdered sample and insert it into the calorimeter following the instructions given by the equipment supplier. Combustion takes place under an excess of oxygen and the pressure is kept at 20 atm. After ignition, the calorimeter has to be shaken for about half an hour.

Release pressure and discharge the combustion residues by several rinsings with water into a beaker (the contents of the calorimeter must be completely transferred).

Heat beaker to boiling point and add 10 cm^3 of barium chloride solution (approximately 250 g $BaCl_2$/1 000 cm^3 distilled water). A white precipitate of barium sulphate will immediately appear.

After cooling, the contents of the beaker are poured through a weighed glass filter which collects the barium-sulphate precipitate. After rinsing the filter several times with distilled water, oven dry it and weigh. Calculate barium sulphate content by weight difference.

Use the following formula to calculate the % sulphur content of the sample for a one gram sample as follows:-

$$\% \text{ sulphur} = \frac{\text{weight of dry barium sulphate} \times 32 \times 100}{233.5}$$

8.2.5 Screen analysis

Charcoal fines and charcoal powder are classified by the distribution of grain sizes. For analysis, a set of standard screens with different mesh sizes are used. The most common set is:

number	mesh size mm	wire thickness mm
4	3.3	1.0
3	2.5	1.0
2	1.5	1.0
1	1.0	0.65

Assemble the set in order with screen No.4 on top and No.1 at the bottom. Accurately weigh 100 grammes of dried sample and put it on screen No. 4.

Shake the whole screen set for two minutes. Then weigh the residue remaining on each screen. Note down the different weights in percentage of the total initial weight in the following order:

grain size IV = 3.3 Retained on screen 4
" " III = 2.5 - 3.3 " " " 3
" " II = 1.5 - 2.5 " " " 2
" " I = 1.0 - 1.5 " " " 1
" " 0 = passes screen No. 1

8.2.6 Friability test

This test measures the case with which the charcoal fractures into smaller pieces, when subjected to repeated handling and, thus, indicates the extent to which pieces will break up during transport, or during descent in a blast furnace.

The figures in per cent indicate the reduction in size suffered during the test.

Therefore, the lower the per cent figure the better the charcoal.

8.2.7 Tumbler test

This test is derived from the R-556 of the MICUM standard for coke of the International Organization for Standardization (ISO).

10 kg of charcoal are placed in a steel test drum 1,000 mm long, 1 000 m diameter fitted with four steel angles, fixed lengthwise inside the drum. The drum is rotated at 24 rpm for one hour (total 1,400 rev.).

The effect of tumbling on the charcoal is tested as follows. The charcoal is first sieved by hand to remove material which passes a 1.25 inch (31.75 mm) screen. This is to prevent the finer charcoal cushioning the effect of rumbling on the coarse material during the test. After rumbling the charcoal is sieve-analysed to measure the size reduction which has occurred. These results are combined with the sieve analysis of the fine material excluded from the tumbler test to give a total evaluation of the charcoal's quality.

8.2.8 Bulk Density of Charcoal Fines

This test indicates the weight of the charcoal fines, per unit of volume, and is important for shipment calculations.

Pour the charcoal sample as received from the plant, or storage a little at a time into a 100ml calibrated cylinder. After each addition tap the cylinder vigorously on a wooden board until the volume is constant. When the 100 ml calibration mark has been reached stop and weigh the charcoal fines.

The weight obtained multiplied by 10 gives the bulk density per litre. The procedure can be facilitated by using a machine for the shaking.

8.2.9 Viscosity of Pyroligneous Acid

Several standardised apparatus for measuring viscosity are available on the market. They all operate according to the general scheme of comparison of the sample with a liquid of known viscosity.

The most common test used in viscosity determination of pyroligneous acid is the Engler-scale.

Instructions are provided by supplies of laboratory equipment.

8.2.10 Flash Point of Pyroligneous Acid

This is the lowest temperature, at which the liquid in an open vessel, gives off enough combustable vapour to produce a momentary flash or fire when a small flame is passed near its surface. Special apparatus can be purchased.

8.2.11 Calorific Value

This is the number of heat units obtained by the complete combustion of charcoal, charcoal fines, charcoal briquettes, condensate or off-gas. An oxygen calorimetric bomb is necessary for this test.

8.2.12 General Remarks

The list of analytical procedures given above is by no means complete. But there are many which will be required only once a year or even less, particularly in a small plant. The test would be done by contract with a commercial testing authority, perhaps a university.

Small-scale charcoal producers for economic reasons, engage the services of an existing laboratory, either through a university or privately. The new charcoal producer quickly learns what can be done by himself and which part of the laboratory work can be contracted.

The charcoal maker engaging in export business may rely on his partners abroad, who are normally well equipped, and have capable staff to deal with problems which arise and provide customers with advice.

8.3 Bench - scale carbonisation tests

It is useful in developing charcoal industry based on the use of alternative raw materials to carry out small-scale carbonisation tests to evaluate yield, quality of charcoal and possible by-products.

A simple apparatus for these tests is shown in Fig. 15. A capacity of about 1-2 litres is adequate. The container is made of copper or stainless steel and constitutes in effect a small closed retort. A thermocouple capable of reading temperatures up to about 550-600°C is inserted through the lid. An offtake pipe leads through a condenser which collects the tars and pyroligneous acids produced from the thermal decomposition of the wood. Non-condensable gases may be collected and analysed but more usually are simply burned to waste. The yields of charcoal and liquid products can be easily measured and the effect of carbonising temperature studied.

The retort is filled to about 0.8 of capacity with the prepared raw material sample and the lid closed. The retort should be heated gently with the burner flame to allow the moisture to be driven off and avoid overheating of the charge at any point. The rise in temperature is monitored with the thermocouple and allowed to rise to final temperature over a few hours. When the required temperature is reached the retort is allowed to cool to room temperature and the yield of charcoal, tars and pyroligneous acid measured by weighing.

The conditions in the small retort are not very similar to continuous large-scale retort systems. However, they have great value for comparison between various raw materials since the behaviour of known materials can be compared with new type raw materials or the effect of changing carbonisation temperature can be studied in a comparative way. The extensive data on the carbonisation of the various species of eucalypts quoted by (20) were obtained in this way and show how comparative studies of this type can serve as a guide in choice of raw material.

Small retorts of this type are conveniently heated by electricity which allows close control of temperature.

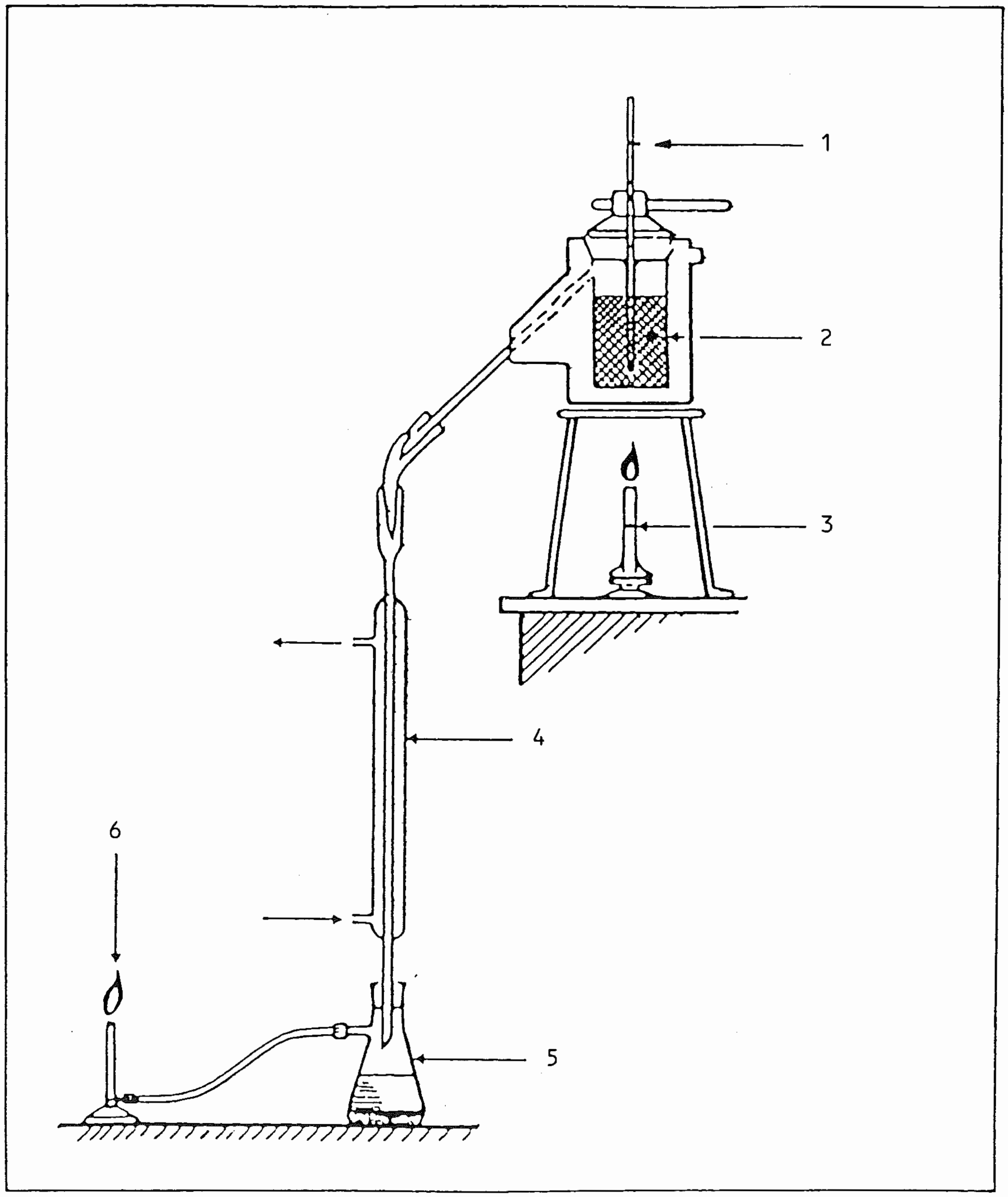

Fig. 15 Carbonisation Test Apparatus

1. Thermometer 2. Container made from wire cloth
3. Bunsen Burner 4. Water cooler 5. Charcoal condensate
6. Burning charcoal gas

Appendix

USEFUL CONVERSION FACTORS

Length:

1 centimetre = 0.3937 inches

1 inch = 2.54 centimetres

1 metre = 1.0936 yards
= 3.2808 feet
= 39.370 inches

1 kilometre = 0.6214 miles

1 mile = 1.6093 kilometres

Area:

1 hectare = 10 000 square metres
= 0.1 square kilometres
= 2.471 acres
= 11 960 square yards

1 acre = 0.4047 hectares
= 4 047 square metres
= 4 840 square yards
= 43 450 square feet

1 square kilometre = 0.3861 square miles
= 100 hectares
= 247.1 acres

1 square mile = 2.5898 square kilometres
= 254.98 hectares
= 640 acres

Volume:

1 litre = 1 000 millilitres
= 61.026 cubic inches
= 0.21998 imperial gallons
= 0.26418 U.S. gallons

1 imperial gallon = 4.5460 litres
= 1.20096 U.S. gallons

1 U.S. gallon = 0.83267 imperial gallons
= 3.78528 litres

1 U.S. barrel = 42 U.S. gallons
= 34.972 imperial gallons
= 0.15899 cubic metres

Energy:

1 kilowatt = 1.3405 horsepower

1 horsepower = 0.746 kilowatts

1 kilojoule = 0.2389 kilogram calories
= 0.948 British thermal units (BTU)
= 0.001 megajoules
= 0.00027778 kilowatt hours

1 kilowatt hour = 3 412 British thermal units
= 1.34 horsepower hours
= 3 600 kilojoules
= 3.6 megajoules

Prefix table:

10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deca	da

Heating Value: (See conversion factors to calculate values in other units)

Fuel	High Heating Value KJ/Kg
Green wood*	15 000
Dry wood*	19 000
Charcoal	31 000
Coke	30 000
Bituminous coal	27 000
Fuel oil	44 000
Kerosene	46 000
Wood tar	20 000
Natural gas	45 000
Producer gas	5 000
Wood retort gas	6 000

* Influence of moisture on heating value of wood:
Net heating value (MJ/kg) = 19 000 - 220 M where M is moisture content in percentage of total weight.

1 cubic metre = 1 000 litres
= 35.3148 cubic feet
= 1.30795 cubic yards
= 219.97 imperial gallons
= 264.18 U.S. gallons
= 6.290 U.S. barrels

1 m^3 solid = 750 kg. fuelwood with 40% moisture

Mass:

1 kilogram = 2.2046 pounds
= 1 000 grams

1 pound = 453.592 grams
= 0.4536 kilograms

1 ton, English = 2 240 pounds
= 1 016.05 kilograms
= 1.01605 tonnes (metric tons)
= 1.12 U.S. tons
= 20 hundred weight (cwt)

1 tonne = 1 000 kilograms
= 0.98421 tons (English)
= 1.10231 U.S. tons
= 2 204.62 pounds

1 U.S. ton = 2 000 pounds
= 17.8572 hundred weight (cwt)
= 907.184 kilograms
= 0.907184 tonnes
= 0.89286 tons (English)

Density:

Bulk density of commercial charcoal = 250 to 300 kilograms per cubic metre

Approx. weight of a stacked metre (stere) of:

- Plantation grown radiata pine (partly seasoned) = 550 to 650 kilograms
- Plantation grown Eucalypt wood (partly seasoned) = 600 to 700 kilograms
- Medium density tropical hardwood (partly seasoned) = 700 to 800 kilograms
- Dense tropical hardwood = 900 kilograms

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