8
Bakery Waste Treatment

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8.1 INTRODUCTION

The bakery industry is one of the world's major food industries and varies widely in terms of production scale and process. Traditionally, bakery products may be categorized as bread and bread roll products, pastry products (e.g., pies and pasties), and specialty products (e.g., cake, biscuits, donuts, and specialty breads). In March 2003, there were more than 7000 bakery operations in the United States (Table 8.1) with more than 220,000 employees. More than 50% of bakery businesses are small, having fewer than 100 employees [1].

The bakery industry has had a relatively low growth rate. Annual industry sales were $14.7 billion, $16.6 billion, and $17.7 billion in 1998, 2000, and 2002, respectively; the average weekly unit sales were $9,890, $10,040, and $10,859 during the same periods. Industry sales increased 6.5%, only 1.6% ahead of the compounded rate of inflation, according to *www.bakery-net.com*. Production by large plant bakers contributes more than 80% of the market's supply, while master bakers sell less than 5% [1].

The principles of baking bread have been established for several thousand years. A typical bakery process is illustrated in Figure 8.1. The major equipment includes miller, mixer/kneading machine, bun and bread former, fermentor, bake ovens, cold stage, and boilers [2–4]. The main processes are milling, mixing, fermentation, baking, and storage. Fermentation and baking are normally operated at 40°C and 160–260°C, respectively. Depending on logistics and the market, the products can be stored at 4–20°C.

Flour, yeast, salt, water, and oil/fat are the basic ingredients, while bread improver (flour treatment agents), usually vitamin C (ascorbic acid), and preservatives are included in the commercial bakery production process.

Flour made from wheat (e.g., hard wheats in the United States and Canada) contains a higher protein and gluten content. Yeast is used to introduce anaerobic fermentation, which produces carbon dioxide. Adding a small amount of salt gives the bread flavor, and can help the fermentation process produce bread with better volume as well as texture. A very small quantity of vegetable oil keeps the products soft and makes the dough easier to pass through the

Table 8.1 Bakery Industry Market in the United States

Number of employees	Number of businesses	Percentage of businesses	Total employees	Total sales	Average employees/ businesses
Unknown	1,638	23.65	N/A	N/A	N/A
1	644	9.30	644	487	1
2–4	1,281	18.50	3,583	505.5	3
5–9	942	13.60	6,138	753	7
10–24	1,117	16.13	16,186	1,208.1	14
25–49	501	7.23	17,103	1,578.7	34
50–99	287	4.14	18,872	23,51.7	66
100–249	305	4.40	45,432	10,820.5	149
250–499	130	1.88	43,251	6,909.1	333
500–999	70	1.01	45,184	3,255	645
1,000–2,499	7	0.10	8,820	N/A	1,260
2,500–4,999	2	0.03	7,295	760.2	3,648
10,000–14,999	1	0.01	11,077	N/A	11,077
Total/Average	6,925	100.00	223,585	28,628.8	32

Note: data include bread, cake, and related products (US industry code 2051); cookies and crackers (US industry code 2052); frozen bakery products, except bread (US industry code 2053); sales are in $US.
Source: Ref. 1.

manufacturing processes. Another important component in production is water, which is used to produce the dough. Good bread should have a certain good percentage of water. Vitamin C, a bread improver, strengthens the dough and helps it rise. Preservatives such as acetic acid are used to ensure the freshness of products and prevent staling. The ratio of flour to water is normally 10 : 6; while others are of very small amounts [3–6].

During the manufacturing process, 40–50°C hot water mixed with detergents is used to wash the baking plates, molds, and trays. Baking is normally operated on a single eight-hour shift and the production is in the early morning hours.

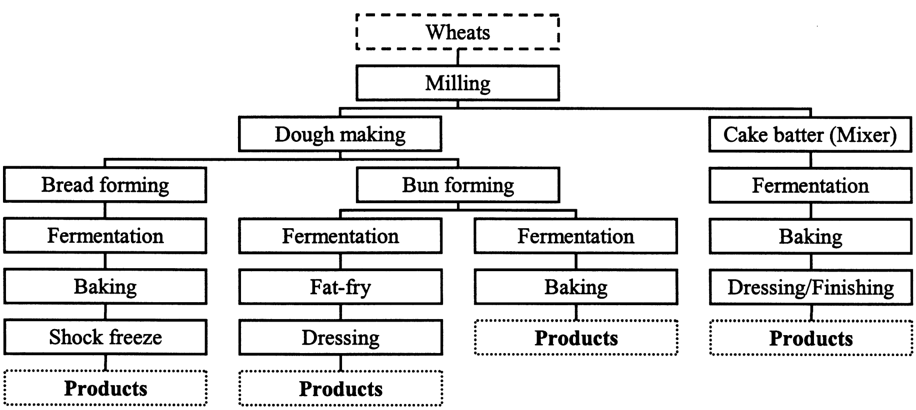

Figure 8.1 General production process diagram of bakery industry.

8.2 BAKERY INDUSTRY WASTE SOURCES

The bakery industry is one of the largest water users in Europe and the United States. The daily water consumption in the bakery industry ranges from 10,000 to 300,000 gal/day. More than half of the water is discharged as wastewater. Facing increasing stringent wastewater discharge regulations and cost of pretreatment, more bakery manufacturers have turned to water conservation, clean technology, and pollution prevention in their production processes.

As shown in Figure 8.1, almost every operation unit can produce wastes and wastewaters. In addition, other types of pollution resulting from production are noise pollution and air pollution.

8.2.1 Noise

Noise usually comes from the compressed air and the running machines. It not only disturbs nearby residents, but can harm bakery workers' hearing. It is reported that sound more than 5 dB(A) above background can be offensive to people. A survey of bakery workers' exposure showed that the average range is 78–85 dB(A), with an average value of 82 dB(A). Ear plugs can help to effectively reduce the suffering. Other noise control measures include the reduction of source noise, use of noise enclosures, reduction of reverberation, and reduction of exposure time [2,7].

8.2.2 Air Pollution

The air pollution is due to emission of volatile organic compounds (VOC), odor, milling dust, and refrigerant agent. The VOC can be released in many operational processes including yeast fermentation, drying processes, combustion processes, waste treatment systems, and packaging manufacture. The milling dust comes from the leakage of flour powder. The refrigerant comes from the emissions leakage of the cooling or refrigeration systems. All of these can cause serious environmental problems. The controlling methods may include treatment of VOC and odor, avoidance of using the refrigerants forbidden by laws, and cyclic use of the refrigerants.

8.2.3 Wastewater

Wastewater in bakeries is primarily generated from cleaning operations including equipment cleaning and floor washing. It can be characterized as high loading, fluctuating flow and contains rich oil and grease. Flour, sugar, oil, grease, and yeast are the major components in the waste.

The ratio of water consumed to products is about 10 in common food industry, much higher than that of 5 in the chemical industry and 2 in the paper and textiles industry [3,6]. Normally, half of the water is used in the process, while the remainder is used for washing purposes (e.g., of equipment, floor, and containers).

Typical values for wastewater production are summarized in Tables 8.2–8.4 [3,8,9]. Different products can lead to different amounts of wastewater produced. As shown in Table 8.2, pastry production can result in much more wastewater than the others. The values of each item can vary significantly as demonstrated in Table 8.3. The wastewater from cake plants has higher strength than that from bread plants. The pH is in acidic to neutral ranges, while the 5-day biochemical oxygen demand (BOD_5) is from a few hundred to a few thousand mg/L, which is much higher than that from the domestic wastewater. The suspended solids (SS) from cake plants is very high. Grease from the bakery industry is generally high, which results from the production operations. The waste strength and flow rate are very much dependent on the operations, the size of the plants, and the number of workers. Generally speaking, in the plants with products of bread, bun, and roll, which are termed as dry baking, production equipment (e.g., mixing vats and baking pans) are cleaned dry and floors are swept before washing down. The wastewater from cleanup

Table 8.2 Summary of Waste Production from the Bakery Industry

Manufacturer	Products	Wastewater production (L/tonne-production)	COD (kg/tonne-production)	Contribution to total COD loading (%)
Bread and bread roll	Bread and bread roll	230	1.5	63
Pastry	Pies and sausage rolls	6000	18	29
Specialty	Cake, biscuits, donuts, and Persian breads	74	–	–

Source: Ref. 3.

has low strength and mainly contains flour and grease (Table 8.3). On the other hand, cake production generates higher strength waste, which contains grease, sugar, flour, filling ingredients, and detergents.

Due to the nature of the operation, the wastewater strength changes at different operational times. As demonstrated in Table 8.3, higher BOD_5, SS, total solids (TS), and grease are observed from 1 to 3 AM, which results from lower wastewater flow rate after midnight.

Bakery wastewater lacks nutrients; the low nutrient value gives $BOD_5 : N : P$ of 284 : 1 : 2 [8,9]. This indicates that to obtain better biological treatment results, extra nutrients must be added to the system. The existence of oil and grease also retards the mass transfer of oxygen. The toxicity of excess detergent used in cleaning operations can decrease the biological treatment efficiency. Therefore, the pretreatment of wastewater is always needed.

8.2.4 Solid Waste

Solid wastes generated from bakery industries are principally waste dough and out-of-specified products and package waste. Solid waste is the loss of raw materials, which may be recovered by cooking waste dough to produce breadcrumbs and by passing cooked product onto pig farmers for fodder.

8.3 BAKERY WASTE TREATMENT

Generally, bakery industry waste is nontoxic. It can be divided into liquid waste, solid waste, and gaseous waste. In the liquid phase, there are high contents of organic pollutants including chemical oxygen demand (COD), BOD_5, as well as fats, oils, and greases (FOG), and SS. Wastewater is normally treated by physical and chemical, biological processes.

Table 8.3 Wastewater Characteristics in the Bakery Industry

Type of bakery	pH	BOD_5 (mg/L)	SS (mg/L)	TS (mg/L)	Grease (mg/L)
Bread plant	6.9–7.8	155–620	130–150	708	60–68
Cake plant	4.7–8.4	2,240–8,500	963–5,700	4,238–5,700	400–1,200
Variety plant	5.6	1,600	1,700	–	630
Unspecified	4.7–5.1	1,160–8,200	650–13,430	–	1,070–4,490

Source: Refs. 8 and 9.

Table 8.4 Average Waste Characteristics at Specified Time Interval in a Cake Plant

Time interval	pH	BOD_5 (mg/L)	SS (mg/L)	TS (mg/L)	Grease (mg/L)
3 am–8 am	7.9	1480	834	3610	428
9 am–12 am	8.6	2710	1080	5310	457
1 pm–6 pm	8.1	2520	795	4970	486
7 pm–12 pm	8.6	2020	953	3920	739
1 am–3 am	8.9	2520	1170	4520	991

Source: Ref. 9.

8.4 PRETREATMENT SYSTEMS

Pretreatment or primary treatment is a series of physical and chemical operations, which precondition the wastewater as well as remove some of the wastes. The treatment is normally arranged in the following order: screening, flow equalization and neutralization, optional FOG separation, optional acidification, coagulation–sedimentation, and dissolved air flotation. The pretreatment of bakery wastewater is presented in Figure 8.2.

In the bakery industry, pretreatment is always required because the waste contains high SS and floatable FOG. Pretreatment can reduce the pollutant loading in the subsequent biological and/or chemical treatment processes; it can also protect process equipment. In addition, pretreatment is economically preferable in the total process view as compared to biological and chemical treatment.

8.4.1 Flow Equalization and Neutralization

In bakery plants, the wastewater flow rate and loading vary significantly with the time as illustrated in Table 8.4 [8,9]. It is usually economical to use a flow equalization tank to meet the peak discharge demand. However, too long a retention time may result in an anaerobic environment. A decrease in pH and bad odors are common problems during the operations.

8.4.2 Screening

Screening is used to remove coarse particles in the influent. There are different screen openings ranging from a few μm (termed as microscreen) to more than 100 mm (termed as coarse screen). Coarse screen openings range from 6–150 mm; fine screen openings are less than 6 mm. Smaller opening can have a better removal efficiency; however, operational problems such as clogging and higher head lost are always observed.

Fine screens made of stainless material are often used. The main design parameters include velocity, selection of screen openings, and head loss through the screens. Clean operations and waste disposal must be considered. Design capacity of fine screens can be as high as 0.13 m^3/sec; the head loss ranges from 0.8–1.4 m. Depending on the design and operation, BOD_5 and SS removal efficiencies are 5–50% and 5–45%, respectively [8,9].

8.4.3 FOG Separation

As wastewater may contain high amount of FOG, a FOG separator is thus recommended for installation. Figure 8.3 gives an example of FOG separation and recovery systems [4]. The FOG

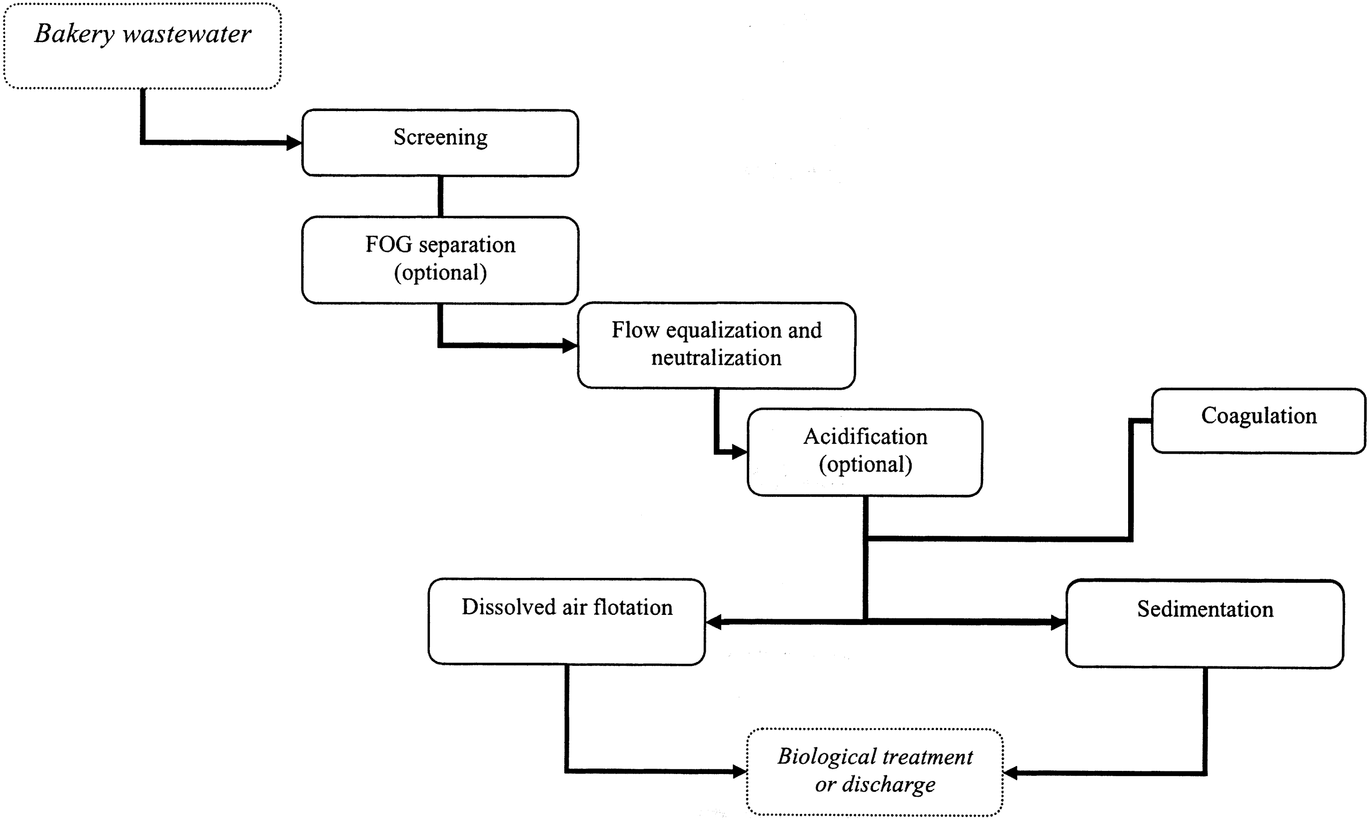

Figure 8.2 Bakery wastewater pretreatment system process flow diagram.

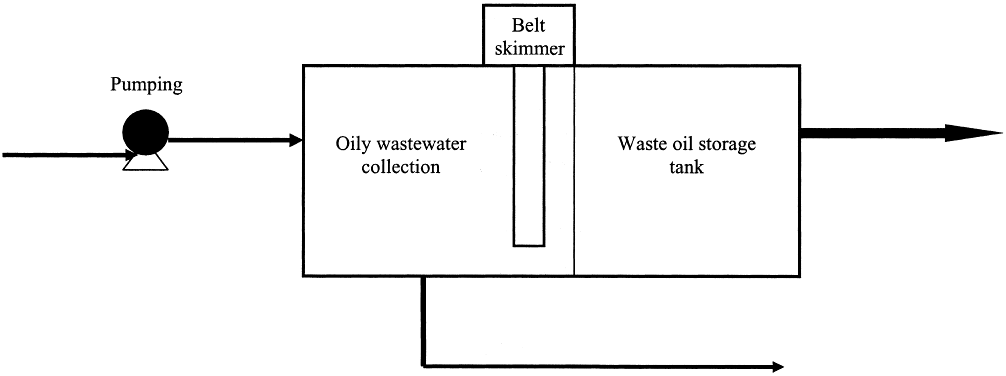

Figure 8.3 Fats, oils, and grease (FOG) separation unit.

can be separated and recovered for possible reuse, as well as reduce difficulties in the subsequent biological treatment.

8.4.4 Acidification

Acidification is optional, depending on the characteristics of the waste. Owing to the presence of FOG, acid (e.g., concentrated H_2SO_4) is added into the acidification tank; hydrolysis of organics can occur, which enhances the biotreatability. Grove et al. [10] designed a treatment system using nitric acid to break the grease emulsions followed by an activated sludge process. A BOD_5 reduction of 99% and an effluent BOD_5 of less than 12 mg/L were obtained at a loading of 40 lb $BOD_5/1000\ ft^3$ and detention time of 87 hour. The nitric acid also furnished nitrogen for proper nutrient balance for the biodegradation.

8.4.5 Coagulation–Flocculation

Coagulation is used to destabilize the stable fine SS, while flocculation is used to grow the destabilized SS, so that the SS become heavier and larger enough to settle down. The Coagulation–flocculation process can be used to remove fine SS from bakery wastewater. It normally acts as a preconditioning process for sedimentation and/or dissolved air flotation.

The wastewater is preconditioned by coagulants such as alum. The pH and coagulant dosage are important in the treatment results. Liu and Lien [11] reported that 90–100 mg/L of alum and ferric chloride were used to treat wastewater from a bakery that produced bread, cake, and other desserts. The wastewater had pH of 4.5, SS of 240 mg/L, and COD of 1307 mg/L. Values of 55% and 95–100% for removal of COD and SS, respectively, were achieved. The optimum pH for removal of SS was 6.0, while that for removal of COD was 6.0–8.0. It was also found that $FeCl_3$ was relatively more effective than alum. Yim *et al.* [8] used coagulation–flocculation to treat a wastewater with much higher waste strength. Table 8.5 gives the treatment results. Owing to the higher organic content, SS, and FOG, coagulants with high dosage of 1300 mg/L were applied [8,9]. The optimal pH was 8.0. As shown, removal for the above three items was fairly high, suggesting that the process can also be used for high-strength bakery waste. However, the balance between the cost of chemical dosage and treatment efficiency should be justified.

8.4.6 Sedimentation

Sedimentation, also called clarification, has a working mechanism based on the density difference between SS and the water, allowing SS with larger particle sizes to more easily settle

Table 8.5 Comparison of Different Bakery Waste Pretreatment Methods

Coagulant	BOD_5 Influent (mg/L)	BOD_5 Removal (%)	SS Influent (mg/L)	SS Removal (%)	FOG Influent (mg/L)	FOG Removal (%)
Ferric sulfate	2780	71	2310	94	1450	93
Alum	2780	69	2310	97	1450	96

Source: Ref. 9.

down. Rectangular tanks, circular tanks, combination flocculator–clarifiers, and stacked multilevel clarifiers can be used[6].

8.4.7 Dissolved Air Flotation (DAF)

Dissolved air flotation (DAF) is usually implemented by pumping compressed air bubbles to remove fine SS and FOG in the bakery wastewater. The wastewater is first stored in an air pressured, closed tank. Through the pressure-reduction valves, it enters the flotation tank. Due to the sudden reduction in pressure, air bubbles form and rise to the surface in the tank. The SS and FOG adhere to the fine air bubbles and are carried upwards. Dosages of coagulant and control of pH are important in the removal of BOD_5, COD, FOG, and SS. Other influential factors include the solids content and air/solids ratio. Optimal operation conditions should be determined through the pilot-scale experiments. Liu and Lien [11] used a DAF to treat a wastewater from a large-scale bakery. The wastewater was preconditioned by alum and ferric chloride. With the DAF treatment, 48.6% of COD and 69.8% of SS were removed in 10 min at a pressure of 4 kg/cm^2, and pH 6.0. Mulligan [12] used DAF as a pretreatment approach for bakery waste. At operating pressures of 40–60 psi, grease reductions of 90–97% were achieved. The BOD_5 and SS removal efficiencies were 33–62% and 59–90%, respectively.

8.5 BIOLOGICAL TREATMENT

The objective of biological treatment is to remove the dissolved and particulate biodegradable components in the wastewater. It is a core part of the secondary biological treatment system. Microorganisms are used to decompose the organic wastes [6,8–15].

With regard to different growth types, biological systems can be classified as suspended growth or attached growth systems. Biological treatment can also be classified by oxygen utilization: aerobic, anaerobic, and facultative. In an aerobic system, the organic matter is decomposed to carbon dioxide, water, and a series of simple compounds. If the system is anaerobic, the final products are carbon dioxide and methane.

Compared to anaerobic treatment, the aerobic biological process has better quality effluent, easies operation, shorter solid retention time, but higher cost for aeration and more excess sludge. When treating high-load influent (COD $>$ 4000 mg/L), the aerobic biological treatment becomes less economic than the anaerobic system. To maintain good system performance, the anaerobic biological system requires more complex operations. In most cases, the anaerobic system is used as a pretreatment process.

Suspended growth systems (e.g., activated sludge process) and attached growth systems (e.g., trickling filter) are two of the main biological wastewater treatment processes. The activated sludge process is most commonly used in treatment of wastewater. The trickling filter is easy to control, and has less excess sludge. It has higher resistance loading and low energy cost. However, high operational cost is its major disadvantage. In addition, it is more sensitive to temperature and has odor problems. Comprehensive considerations must be taken into account when selecting a suitable system.

8.6 AEROBIC TREATMENT

8.6.1 Activated Sludge Process

In the activated sludge process, suspended growth microorganisms are employed. A typical activated sludge process consists of a pretreatment process (mainly screening and clarification), aeration tank (bioreactor), final sedimentation, and excess sludge treatment (anaerobic treatment and dewatering process). The final sedimentation separates microorganisms from the water solution. In order to enhance the performance result, most of the sludge from the sedimentation is recycled back to the aeration tank(s), while the remaining is sent to anaerobic sludge treatment. A recommended complete activated sludge process is given in Figure 8.4.

The activated sludge process can be a plug-flow reactor (PFR), completely stirred tank reactor (CSTR), or sequencing batch reactor (SBR). For a typical PFR, length–width ration should be above 10 to ensure the plug flow. The CSTR has higher buffer capacity due to its nature of complete mixing, which is a critical benefit when treating toxic influent from industries. Compared to the CSTR, the PFR needs a smaller volume to gain the same quality of effluent. Most large activated sludge sewage treatment plants use a few CSTRs operated in series. Such configurations can have the advantages of both CSTR and PFR.

The SBR is suitable for treating noncontinuous and small-flow wastewater. It can save space, because all five primary steps of fill, react, settle, draw, and idle are completed in one tank. Its operation is more complex than the CSTR and PFR; in most cases, auto operation is adopted.

The performance of activated sludge processes is affected by influent characteristics, bioreactor configuration, and operational parameters. The influent characteristics are wastewater flow rate, organic concentration (BOD_5 and COD), nutrient compositions (nitrogen and phosphorus), FOG, alkalinity, heavy metals, toxins, pH, and temperature. Configurations of the bioreactor include PFR, CSTR, SBR, membrane bioreactor (MBR), and so on. Operational parameters in the treatment are biomass concentration [mixed liquor volatile suspended solids concentration (MLVSS) and volatile suspended solids (VSS)], organic load, food to microorganisms (F/M), dissolved oxygen (DO), sludge retention time (SRT), hydraulic retention time (HRT), sludge return ratio, and surface hydraulic flow load. Among them, SRT and DO are the most important control parameters and can significantly affect the treatment results. A suitable SRT can be achieved by judicious sludge wasting from the final clarifier. The DO in the aeration tank should be maintained at a level slightly above 2 mg/L. The typical design parameters and operational results are listed in Table 8.6.

Owing to the high organic content, it is not recommended that bakery wastewater be directly treated by aerobic treatment processes. However, there are a few cases of this reported in the literature, including a study from Keebler Company [4]. The company produces crackers and cookies in Macon, Georgia. The FOG and pH of the wastewater from the manufacturing facility were observed as higher than the regulated values. Wastewater was treated by an aerobic activated sludge process, which included a bar screen, nutrient feed system, aeration tank, clarifier, and sludge storage tank. Because of the large quantities of oil in the water (Table 8.7), two FOG separators as shown in Figure 8.3 (discussed previously) were installed in the oleo/lard

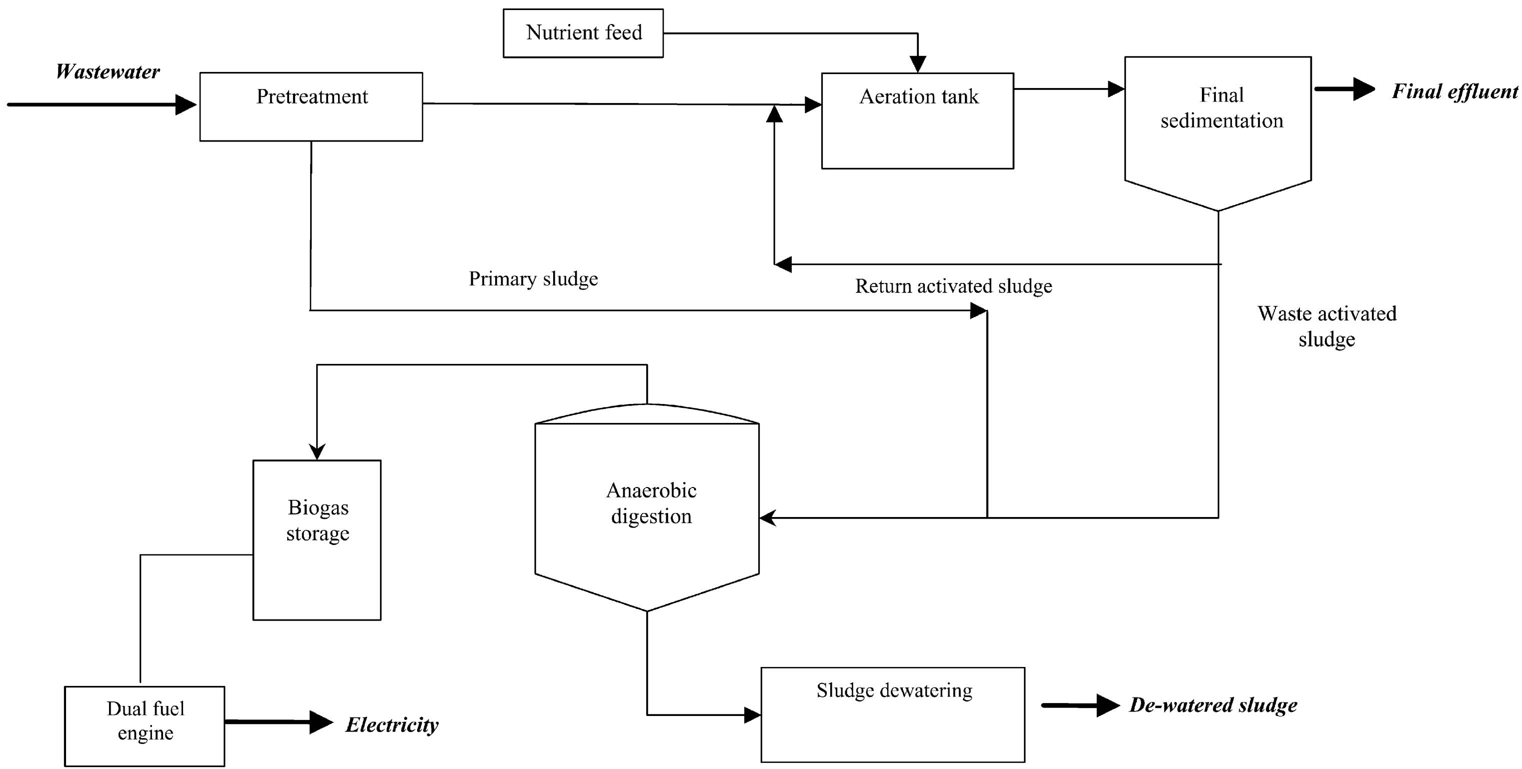

Figure 8.4 Process flow diagram of activated sludge treatment of bakery wastewater.

Table 8.6 Design and Performance of Activated Sludge Processes

Activated sludge processes	Extended	Conventional	High rate
F/M (kg BOD_5/kg MLSS · day)	0.06–0.2	0.3–0.6	0.5–1.9
MLSS (g/L)	4–7.5	1.9–4	5–12
HRT (hour)	18–36	4–10	2–4
SRT (day)	20–30	5–15	3–8
BOD_5 removal (%)	> 95	95	70–75
VLR (kg BOD_5/m^3 · day)	0.2–0.4	0.4–1.0	2–16

Note: F/M, food to microorganisms ratio; MLSS, mixed liquid suspended solids; SRT, sludge retention time; HRT, hydraulic retention time; BOD_5, five-day biochemical oxygen demand; VLR, volumetric loading rate.

storage area and the coconut oil spray machines. Characteristics of influent and effluent as well as design parameters are given in Table 8.7. As shown, the company had favorable treatment results; the effluent was good enough for direct discharge to a nearby watercourse. Owing to the poor nutrient content in the influent, nutrient was fed directly into the aeration tank. Not all the added nitrogen was consumed in the treatment, thus the total Kjedahl nitrogen (TKN) concentration in the effluent was higher than that in the influent. The high HRT in Table 8.7 shows that the process was not in fact economical. The bakery wastewater treatment can be more cost-effective if the waste is first treated by an anaerobic process and then an aerobic process.

8.6.2 Trickling Filter Process

Aerobic attached-growth processes include tricking filters (biotower) and rotating biological contactors (RBC). In these processes, microorganisms are attached onto solid media and form a layer of biofilm. The organic pollutants are first adsorbed to the biofilm surface, oxidation reactions then occur, which break the complex organics into a group of simple compounds, such as water, carbon dioxide, and nitrate. In addition, the energy released from the oxidation together with the organics in the waste is used for maintenance of microorganisms as well as synthesis of new microorganisms.

Table 8.7 Summary of Wastewater Treatment in the Keebler Company

Parameter	Influent: Design basis[a]	Influent: Operation[b]	Effluent[b]
Flow rate (gpd)	51,200	37,000	–
PH	5.6	6.0	6.8
TCOD (mg/L)	1620	830	65
SCOD (mg/L)	–	290	40
$TBOD_5$ (mg/L)	891	500	39
$SBOD_5$ (mg/L)	–	175	24
TS (mg/L)	756	–	11[b]
FOG (mg/L)	285	–	3[b]
TKN (mg/L)	–	2	5
PO_4-P (mg/L)	–	3	3

[a]Based on historical pretreatment program monitoring data.[b]Based on operation in August 1988. Operational parameters: HRT = 2.8 day; MLSS = 3300 mg/L; VSS = 2600 mg/L; DO = 2.2 mg/L; F/M = 0.07 1b BOD/1b VSS/day. Yield = 0.32; clarifier overflow rate = 118 gpd/ft^2; clarifier solids loading rate = 5 1b/ft^2/day.
Source: Ref. 4.

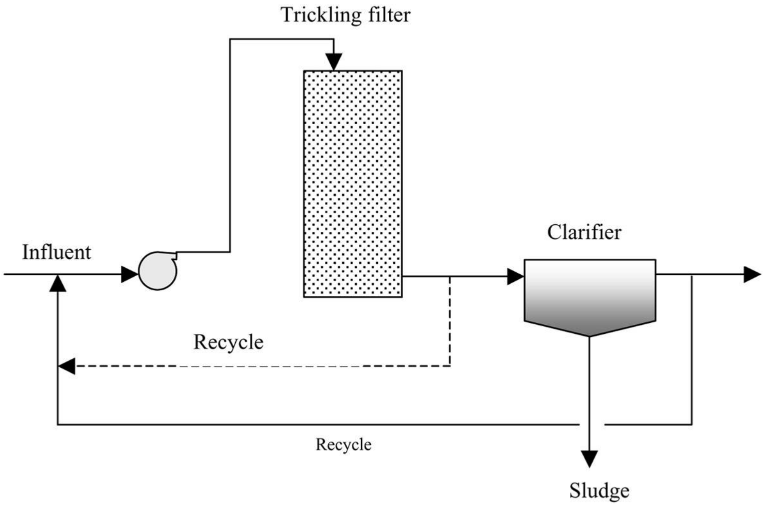

Figure 8.5 Flow diagram of trickling filter for bakery wastewater treatment.

The tricking filter can be used to treat bakery wastewater. Solid media such as crushed rock and stone, wood, and chemical-resistant plastic media are randomly packed in the reactor. Figure 8.5 shows a typical trickling filter, which can be used for the bakery wastewater treatment. Surface area and porosity are two important parameters of filter media. A large surface area can cause accumulation of a large amount of biomass and result in high treatment efficiency; large porosity would lead to higher oxygen transfer rate and less blockage. A common problem in trickling filter systems is the excess growth of microorganisms, which can cause serious blockage in the medium and reduce the porosity. Typical design parameters and performance data for aerobic trickling filters are listed in Table 8.8. Keenan and Sabelnikov [14] demonstrated that a biological system containing a mixing-aeration tank and biological filter (trickling filter) was able to eliminate grease and oil in bakery waste. A dramatic reduction of FOG content from 1500 mg/L to less than 30 mg/L was achieved. This system was fairly stable during 20 months of continuous operation.

8.7 ANAEROBIC BIOLOGICAL TREATMENT

Bakery waste contains high levels of organics, FOG, and SS, which are treated using the preferred method of anaerobic treatment processes. There are different types of anaerobic

Table 8.8 Design and Performance of Trickling Filter

Type of filter	BOD_5 loading (kg/m^3/day)	Hydraulic loading (m^3/m^2/day)	Depth (m)	BOD_5 removal (%)	Medium
Low rate	0.07–0.4	1–3	1.8–2.4	95	Rock, slag
Mid-range rate	0.2–0.45	3–7	1.8–2.4	–	Rock, slag
High rate	0.5–1	6–20	1–1.8	50–70	Rock

processes available on the market, such as CSTR, AF, UASB, AFBR, AC, and ABR. The most obvious operational parameters are high SRT, HRT, and biomass concentration. Anaerobic processes have been widely used in treatment of a variety of food processing and other wastes since they were first developed in the early 1950s. Figure 8.6 illustrates a typical anaerobic treatment process for bakery wastewater.

In addition to accommodating organic waste treatment, anaerobic treatment can produce methane, which can be used for production of electricity (Fig. 8.6). The disadvantages, however, include complexity in operation, sensitivity to temperature and toxicity, time-consuming in startup, and susceptibility to process upset. Table 8.9 gives a summary of design and performance of typical anaerobic treatment processes.

Anaerobic processes are suitable for a variety of bakery wastewater. For example, an anaerobic contactor was successfully used to treat wastewater from a production facility of snack cake items [13]. The waste strength was extremely high as demonstrated in Table 8.10. The BOD_5 to COD ratio of the raw wastewater was 0.44. An anaerobic contact reactor was used, similar to that in Figure 8.6, except that two bioreactors were operated in series. As shown in Table 8.10, the system provides good treatment results. The removal efficiencies for BOD_5, COD, TSS, and FOD were above 96%. The treated stream can be directly discharged to the domestic sewage systems. Alternatively, a subsequent aerobic treatment can be used to further reduce the waste strength and the effluent can then be discharged to a watercourse.

8.8 AIR POLLUTION CONTROL

While air pollution in the bakery industry may be not serious, it can become a concern if not properly handled. Dust, VOC, and refrigerant are three main types of air pollutants.

8.8.1 Dust

Flour production workers are usually harmed by dust pollution. Lengthy exposure time at a high exposure level can cause serious skin and respiration diseases. The control approaches include prevention of the leakage of flour power, provision of labor protection instruments, and post treatment. Filters and scrubbers are commonly used.

8.8.2 Refrigerant

In the chilling, freezing storage or transport of bakery products, a large amount of refrigerant is used. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are the common refrigerants and can damage the ozone layer. They can be retained in the air for approximately 100 years. Owing to the significantly negative environmental effects, replacement chemicals such as hydrofluorocarbons (HFC) have been developed and used. Another measure is the prevention of the refrigerant leakage.

8.8.3 VOC

Several measures can be used to control VOC pollution, including biological filters and scrubbers.

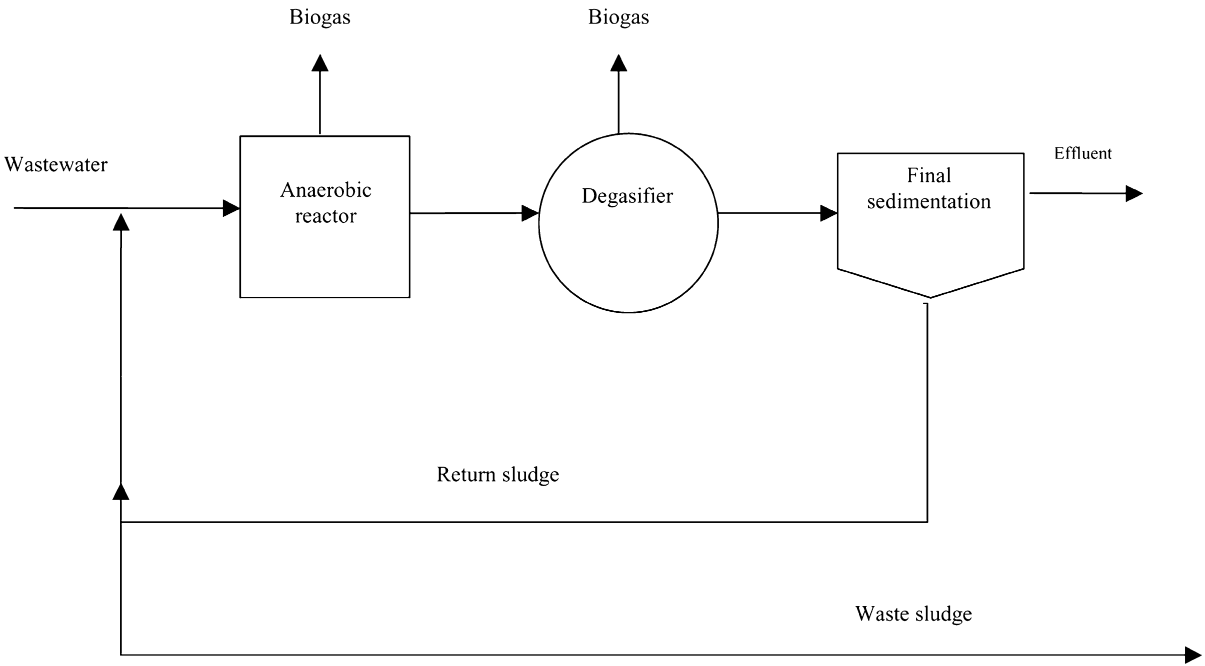

Figure 8.6 Schematic of anaerobic contact process.

Table 8.9 Design and Performance of Anaerobic Treatment Processes

Reactor	Influent COD (g/L)	HRT (day)	VLR (kg COD/m^3/day)	Removal (%)
AF	3–40	0.5–13	4–15	60–90
AC	3–10	1–5	1–3	40–90
AFBR	1–20	0.5–2	8–20	80–99
UASB	5–15	2–3	4–14	85–92

8.9 SOLID WASTE MANAGEMENT

Bakery solid waste includes stale bakery products, dropped raw materials (e.g., dough), and packages. The most simple and common way is to directly transport these to landfill or incineration. Landfill can cause the waste to decompose, which eventually leads to production of methane (a greenhouse gas) and groundwater pollution (organic compounds and heavy metals). Incineration of bakery waste can also release nitrogen oxide gases.

Reclamation of the bakery waste can play an important role in its management. The waste consists primarily of stale bread, bread rolls, and cookies – all of which contain high energy and can be fed directly to animals, such as swine and cattle. Another application is to use the waste for production of valuable products. For example, Oda *et al.* [15] successfully used bakery waste to produce lactic acid with a good conversion efficiency of 47.2%.

8.10 CLEANER PRODUCTION IN THE BAKERY INDUSTRY

8.10.1 Concepts

The production of bakery products involves many operation units that may cause a variety of wastes. Most bakery industries are of small or medium size, and are often located in densely populated areas, which makes environmental problems more critical. Nevertheless, the conventional "end-of-pipe" treatment philosophy has its restrictions in dealing with these problems. It only addresses the result of inefficient and wasteful production processes, and should be considered only as a final option.

Table 8.10 Performance of Anaerobic Contact Process

Parameter	Raw water (mg/L)		Clarifier effluent (mg/L)		Average removal (%)
	Range	Average	Range	Average	
BOD_5	906–24,000	9,873	65–267	145	98.5
COD	2,910–50,400	23,730	315–1,340	642	97.3
TS	848–36,700	15,127	267–1,260	502	96.7
FOG	429–10,000	5,778	9–113	41	99.3

Operational parameters: Bioreactor: HRT = 7.8 day; SRT = 50 day; volumetric BOD_5 loading = 1.3 kg BOD_5/m^3/day, volumetric COD loading = 3.0 kg COD/m^3/day. Clarifier: Overflow rate = 3.7 m^3/m^2/day; HRT = 16 hour, solids loading = 20.5 m^3/m^2/day, clarification efficiency = 91%.
Source: Ref. 13.

Manufacturing will always cause direct or indirect pollution of the environment. It is hard to realize "zero discharge," and waste treatment is always expensive. Cleaner production (CP) has two key components: maximization of waste reduction and minimization of raw material usage and energy consumption. The United Nations Environment Program (UNEP) defines CP as [7]:

> The continuous application of an integrated preventive environmental strategy to processes, products, and services to increase overall efficiency, and reduce risks to humans and the environment. Cleaner Production can be applied to the processes used in any industry, to products themselves and to various services provided in society.

Cleaner production results from one or a combination of conserving raw materials, water, and energy; eliminating toxic and dangerous raw materials; and reducing the quantity and toxicity of all emissions and wastes at source during the production process. It aims to reduce the environmental, health, and safety impacts of products over their entire life-cycles, from raw materials extraction, through manufacturing and use, to the "ultimate" disposal of the product. It implies the incorporation of environmental concerns into designing and delivering services [3,7].

In the CP process, raw materials, water, and energy should be conserved, their emission or wastage should be reduced, and application of toxic raw materials must be avoided. It is also important to reduce the negative impacts during the whole production life-cycle, from the design of the production to the final waste disposal. The main steps of a CP assessment are outlined in Figure 8.7. The CP can be illustrated by the following example.

8.10.2 A Case Study in Country Bake Pty. Ltd.

Country Bake Pty. Ltd. [3] is a well-known bakery in Queensland, Australia, that produces mainly bread and bread rolls, as well as pastry products and cakes. Production is highly automated, and CP was carried out at the bakery to improve its operational efficiency.

Staff Awareness and Management Expectation

An initial brief survey showed that general awareness of CP at the manufacturing facility was fairly low before its implementation. The staff felt that changes were most likely to be in the areas of general housekeeping and minor process improvements. However, workers were keen on voluntary improvements to their operations as CP could lead to reduction of environmental and health risk liability, less operating costs through better waste and energy management, and reduction of environmental impact. In addition, both management and labor believed that higher business profitability as well as improvement of the company's public image could be achieved through exercising CP.

Assessment of Waste

Areas of waste generation were identified and characterized. It was found that water usage was 719,000 L/week, with about 59% used in production, while the remainder was ultimately discharged as wastewater from cleaning and other ancillary uses. The pastry area and bread and bread rolls area contributed 35 and 36% of wastewater volume, respectively. Other wastewater arose from the boiler, the crate wash, and the staff amenities. In terms of COD loading, the pastry area, bread and bread rolls area, and night cleaning contributed 29, 25, and 38%, respectively. The characterization of wastes can be found in Table 8.2.

Approximately 1.7 tons of dough per week was lost in the waste stream, leading to a loss of 0.5% of the total mass of ingredients (or a loss of $4000/month). Pancoat oil and white oil

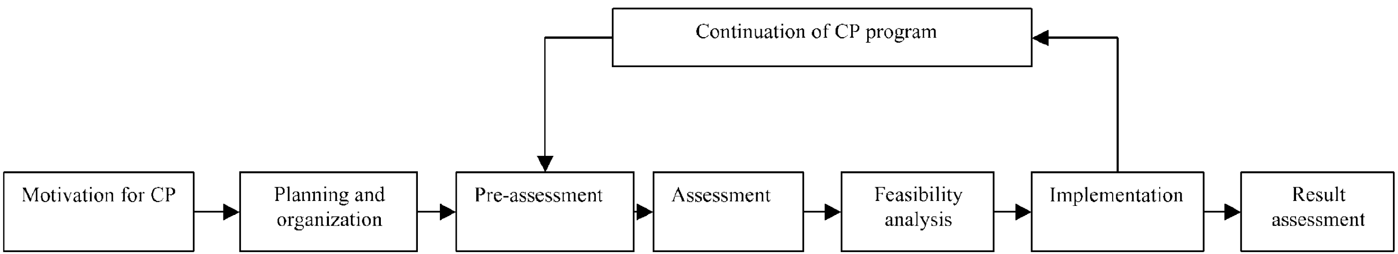

Figure 8.7 Outline of CP assessment process.

were used in production, most of which were lost and became the main contributors to the FOG in the waste stream. Monthly cost for their purchase was $13,140. Prevention of oil loss therefore could lead to significant savings for the bakery.

CP Strategies

Three CP strategies were proposed. The first was to reduce the COD load of wastewater discharged from the bread/bread roll area. Some dough material still fell on the floor and ultimately found its way to the drains. The following approaches were used for reclaiming and recycling the material: relocation of drains for easier collection of dough and installation of screens at drain points to capture fallen dough. A second strategy was to reduce the volumes of wastewater discharged from the pastry area by modification of cleaning practices, elimination or reuse of water discharges from the vacuum pump, and reuse of water discharges from the blast chiller. The last strategy was to reduce the loss of oil by modifications of equipment.

Staff Involvement

Cleaner production cannot be implemented well without great enthusiasm and commitment of the staff to CP, as they are the first to fulfill the CP. The company developed 12 work teams made up of individuals from the major functional work areas. These teams met regularly to discuss issues relevant to their specific work areas. These teams assumed responsibility for driving CP in the workplaces. Team leaders who were trained by the UNEP Working Group conducted a series of training programs for the remaining staff. Finally, the staff was rewarded for their implementation of CP.

Cost-Saving Benefits

Through implementation of CP in production, it was estimated that a total monthly saving of $27,700 could be achieved.

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