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для здобувачів вищої освіти першого (бакалаврського) рівня
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ECOLOGY OF FOOD TECHNOLOGIES

GUIDELINES FOR PRACTICES
FOR STUDENTS OF THE SPECIALTY
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Abbreviations

BOD – Biochemical oxygen demand: the quantity of dissolved oxygen required by micro-organisms in order to decompose organic matter. The unit of measurement is mg O_2/l. In Europe, BOD is usually measured after 3 (BOD_3), 5 (BOD_5) or 7 (BOD_7) days.

CIP – Cleaning-in-place.

COD – Chemical oxygen demand: the amount of potassium dichromate, expressed as oxygen, required to chemically oxidise at approximately 150°C substances contained in waste water.

DAF – Dissolved air flotation.

EC – European Commission.

EU – European Union

F/M – Food to microorganism ratio.

FDM – Food, drink and milk.

FOG – Fats, oils and greases.

HACCP – Hazard Analysis Critical Control Points.

HRT – Hydraulic retention time.

HTST – High temperature short time (pasteurisation).

MLSS – Mixed liquid suspended solids.

MWWTP – Municipal waste water treatment plant.

PE – Polyethylene.

RO – Reverse osmosis.

SRT – Sludge retention time.

SS – Suspended solids.

TS – Total solids.

TSS – Total suspended solids.

UHT – Ultra-high temperature (sterilization).

VLR – Volumetric loading rate.

WWTP – Waste water treatment plant.

Introduction

Environmental problems require immediate solutions. Climate change, depletion of the ozone layer, pollution of the biosphere, reduction of biological diversity are the most significant of them. Industrial enterprises, transport, agriculture and the domestic sector are the main cause of these environmental problems. Pollution of atmospheric air, water, soil causes diseases of people and degradation of ecosystems. An increase in the average temperature of the planet leads to a reduction in fresh water supplies and threatens food security for many countries, especially for low-income ones. In this regard, industrial ecology is important for reducing the anthropogenic negative impact.

The Food Industry is a source of a large volume of organic waste and wastewater. The Dairy Industry, the production of meat and fish products, the Fruit and Vegetable Sector are characterized by one of the most significant levels of environmental impact. Therefore, the use of technologies for environmental protection in the enterprises of the FDM sector is an important step for cleaner production.

Each sector of the Food Industry has its own characteristics regarding the impact on the environment. Therefore, for each of them there is a certain complex of strategies and technologies for environmental protection. An ecologist must know these features in order to make environmental technologies as efficient as possible.

In addition, industrial enterprises of the FDM sector differ in the volume of production, type of products, financial capabilities, location. The task of an ecologist is to choose the right complex of environmental technologies taking into account all factors both internal and external.

First of all, the experience of the European Union countries and The United States of America as leaders in the use of environmental technologies should be taken into account.

Tasks for individual work

I Describe the environmental issues in some individual FDM sectors (on the example of an enterprise):

1. Meat and poultry;
2. Fish and shellfish;

3 Fruit and vegetables;

4 Vegetable oils and fats;

5 Bread;

6 Sugar.

7. Dairy products.

When describing the consumption and emission levels in some individual FDM sectors, try to follow the plan:

1.1 General information.

- A description of the company's processes should answer the following questions:
- What does the company produce?
- What is the history of the company?
- How is the company organized?
- What are the main processes?
- What are the most important inputs and outputs?

1.2 Water consumption.

1.3 Waste water (Quantity of waste water, Composition of waste water).

1.4 Air emissions.

1.5 Solid output.

1.6 Energy.

1.7 Consumption of chemicals.

1.8 Noise.

When looking for answers to these questions you should first try to find already existing operational data such as production reports, audit reports and site plans. This checklist would make this step more comprehensive.

II Describe existing techniques for minimizing emissions, which are used in this enterprise.

III Based on the presented data, compare strategies and technologies for environmental protection used in the analyzed enterprise with those used in European Union and other countries.

IV Suggest own solution for environmental protection for this enterprise.

PRACTICE 1
Environmental issues in the Dairy Industry

1.1 Water consumption

Water consumption is mainly associated with cleaning operations. The factors affecting water consumption in European dairies are:

- availability of surface and groundwater for cooling;
- time and amount of water used for rinsing;
- characteristics of CIP programmes;
- maintenance, e.g. reparation of leaks.

A reasonably efficient consumption of water is reported to be around 1–5 l/kg milk, however, it is reported that a water consumption of 0.8–1.0 l/kg milk can be achieved by using advanced equipment and a good operation. According to a German survey, 132 dairies used, on average in 1999, 2.06 l/kg of milk. Table 1.1 shows water consumption in European dairies. Table 1.2 shows water consumption for some Nordic dairies.

Table 1.1 – Water consumption in European dairies

Product	**Water consumption* (l/kg processed milk)**	
	Min	**Max**
Market milk and yoghurt	0.8	25
Cheese and whey	1.0	60
Milk powder, cheese and/or liquid products	1.2	60
*Cooling water is included		

Table 1.2 – Water consumption for some Nordic dairies

Product	**Water consumption (l/l processed milk)**			
	Sweden	**Denmark**	**Finland**	**Norway**
Market milk and yoghurt	0.96–2.8 (8)	0.60–0.97 (3)	1.2–2.9 (8)	4.1 (1)
Cheese and whey	2.0–2.5 (4)	1.2–1.7 (5)	2.0–3.1 (2)	2.5–3.8 (2)
Milk powder, cheese and/or liquid products	1.7–4.0 (7)	0.69–1.9 (3)	1.4–4.6 (2)	4.6–6.3 (2)
Figures in brackets show the number of dairy installations in each category				

In the UK Dairy Industry, there is a wide variation in the water consumption/amount of milk processed ratio, compared to the volume of the milk received for processing per installation, as shown in Figure 1.1.

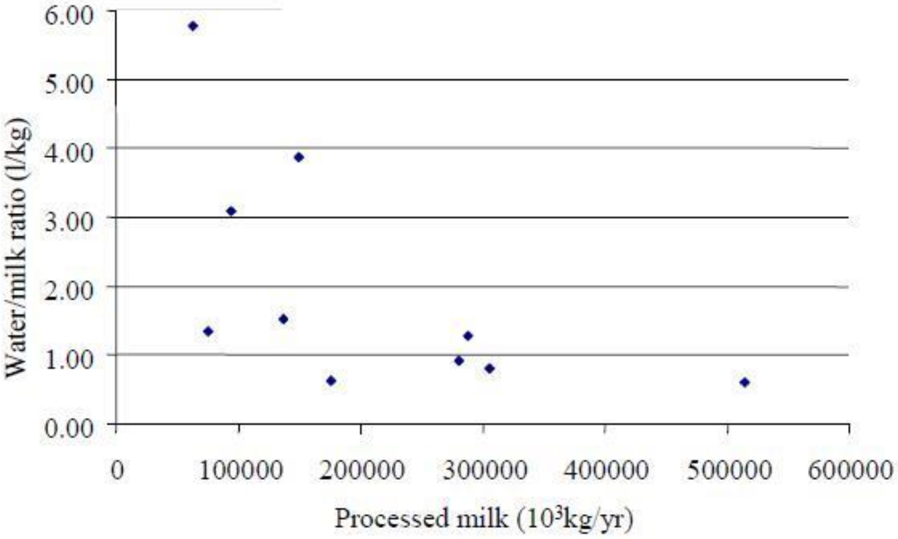


Figure 1.1 – Water consumption/processed milk ratio as a function of the quantity of processed milk

Seven ice-cream installations in Nordic countries have reported a water consumption in the range 3.6–10.3 l/kg of produced ice-cream. For ice-cream installations where no water recycling is applied in the cooling system, a water consumption of 10–325 l/kg of product has been reported.

1.2 Waste water

Waste water is the main environmental issue in the dairy sector. The sector uses a vast amount of water, and generates a huge amount of waste water in maintaining the required level of hygiene and cleanliness. Data reported for specific waste water discharge for dairy activities in Austria are shown in Table 1.3. Waste water volume in a well-managed installation is reported to be about 1–2 l/kg of milk processed.

Table 1.3 – Approximate volumes of waste water in dairy activities

Type of product	**Waste water volume (l/kg of milk processed)**
“White” products, e.g. milk, cream and yoghurt	3
“Yellow” products, e.g. butter and cheese	4
“Special” products, e.g. concentrates of milk or whey and dried milk products	5

In the UK, around 14 million m^3 of milk is produced for processing each year. It is reported that a new dairy in the UK is achieving a 1:1 volume of milk processed: waste water volume ratio, i.e. one litre of waste water for each litre of milk litre processed and that a 1.5:1 ratio is achievable in existing dairies. A comparison is reported between a dairy generating 2 liters of waste water per litre of milk processed. This would produce around 28 million m^3/year of waste water for disposal to a WWTP. If this waste water is considered to have an average COD strength of 3000 mg/l, then the total loading would be around 84000 t COD/yr, equivalent to the waste of more than two million people. Also, if 1 m^3 of milk is released into a watercourse, its oxygen depleting potential, in terms of BOD_5 load, is equivalent to the daily raw sewage of 1500–2000 people.

Untreated dairy waste waters have an average BOD load ranging from 0.8 to 2.5 kg BOD/t milk. Other significant pollutants present in the waste water are phosphorus, nitrogen and chloride. Individual waste water streams of a wide pH range are produced. The temperature of the waste water streams may also need to be considered. The waste water may contain pathogens from contaminated materials or production processes. Table 1.4 gives data on the typical untreated waste water from dairy processing.

Table 1.4 – Reported untreated dairy waste water contamination levels

Component	**Range**
SS	24–5700 mg/l
TSS	135–8500 mg/l
COD	500–4500 mg/l
BOD_5	450–4790 mg/l
Protein	210–560 mg/l
Fat	35–500 mg/l
Carbohydrate	252–931 mg/l
Ammonia -N	10–100 mg/l**
Nitrogen	15–180 mg/l
Phosphorus	20–250 mg/l
Sodium	60–807 mg/l
Chloride	48–469 (up to 2000) mg/l
Calcium	57–112 mg/l
Magnesium	22–49 mg/l
Potassium	11–160 mg/l
pH	5.3–9.4 (6–10)
Temperature	12–40°C
Actual levels will depend on the use of in-process techniques to prevent water contamination reported	

Volume and pollution levels of dairy waste water in Europe are shown in Table 1.5. The typical BOD of various milk products is shown in Table 1.6.

Table 1.5 – Volume and pollution levels of dairy waste water in Europe

Product	**Waste water volume (l/kg)**	**Parameters (mg/kg of processed milk)**		
		COD	**Total N**	**Total P**
Market milk and yoghurt	0.9–25	2.0–10	0.05–0.14	0.01–0.02
Cheese	0.7–60	0.8–13	0.08–0.2	0.01–0.05
Milk and whey powder	0.4–60	0.5–6	0.03–0.3	0.01–0.2
Ice-cream	2.7–7.8			

Table 1.6 – Typical BOD levels of various milk products

Product	**BOD_5 (mg/kg of product)**
Whole milk	104000

Table 1.6 (continued)

Skimmed milk	67000
Double cream	399000
Yoghurt	91000
Ice-cream	292000
Whey	34000

The largest proportion of waste water is cleaning water. This is used for equipment cleaning, e.g. line purging at product change-over, start-up, shut-down and change-over of HTST pasteurisation units as well as some product washing. Product loss during milk manufacture can be as high as 3–4 %, with normally 0.5–1.5 % of product being wasted. These milk losses can occur during cleaning; the run-off during the start-up, shut-down or change-over of an HTST unit; or from accidental spills. Product losses to waste water can contribute greatly to the COD, nitrogen and phosphorous content. Typical milk losses are shown in Figure 1.2.

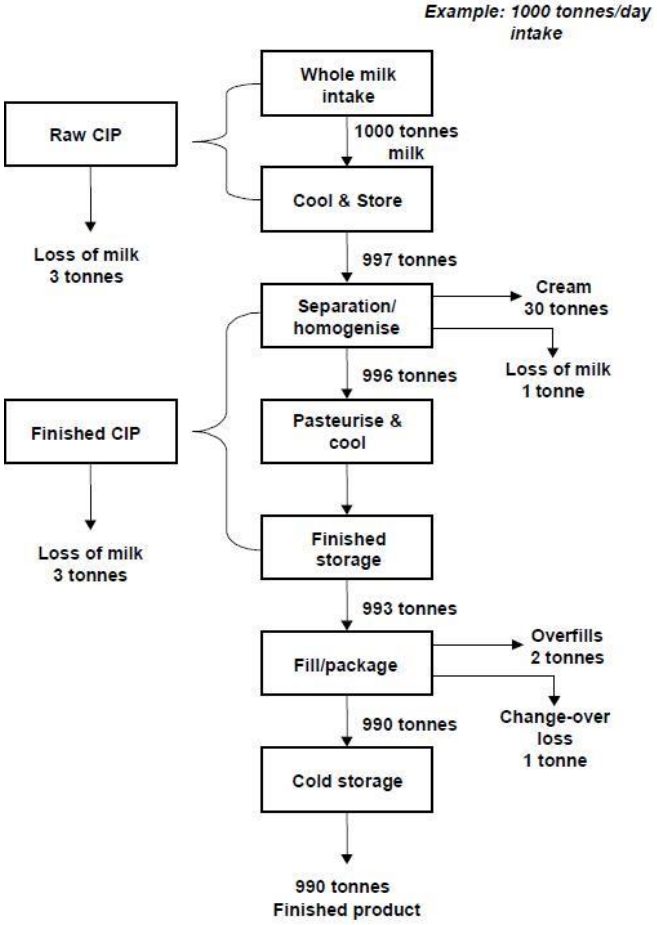


Figure 1.2 – Typical losses of milk in the Dairy Industry

Although CIP operations contribute to saving water, energy and chemicals, they still generate large volumes of waste water, which may have a high or low pH due to the use of acid and alkaline cleaning solutions. The use of phosphoric and nitric acids will increase the phosphate and nitrate content of the waste water. Badly designed CIP systems and inadequate product removal prior to the start of the CIP cycle cause large quantities of product to enter the cleaning water. Some UK dairy sites have achieved a reduction of 40–65 % in their waste water COD as a result of improvements in this area. Waste water with high concentrations of dissolved solids is produced by the regeneration of ion exchange resins and from membrane backwashing.

Large evaporators are used in the production of milk concentrate, which is the first stage in the production of milk powder, and dried whey. The evaporated water is condensed, giving rise to large quantities of condensate. Normally this is clean, but vacuum leaks on the condensers can lead to contamination with product. Condensate may be used in other processes, such as preheating incoming milk or as cleaning water after suitable treatment, e.g. RO followed by disinfection.

There are smaller contributions to the waste water from the non-dairy ingredients used in some of the products and from lubricants. SS are associated with coagulated milk, particles of cheese curd and non-dairy ingredients.

For cheese manufacturing, about 90 % of the milk used ends up as whey. Sweet whey is often recovered and used as a food grade additive. Salt whey, produced after salt has been added to the curd to remove additional liquid, is not suitable for this application unless the salt is removed by RO. The RO permeate is highly saline. Unless whey is processed quickly it becomes acidic due to lactic acid formation. If acid whey is discharged to a WWTP, it may cause low pH levels.

This waste water has an extremely variable composition, depending on the technology applied and whether whey is segregated. The characteristics of a typical waste water from cheese manufacturing are shown in Table 1.7.

Table 1.7 – Composition of cheese manufacturing waste water

Parameter	**Installation with whey recovery**	**Installation without whey recovery**
	mg/l	
BOD_5	2397	5312
COD	5312	20559
Fats	96	463
N total	90	159
P total	26	21

1.3 Air emissions

Many dairies produce thermal energy on site. Emissions of carbon dioxide, sulphur dioxide and nitrogen oxides derive from the energy production in the boiler plants and are not discussed here. Many dairies still use halogenated compounds in their cooling systems, mostly HCFCs, but small amounts of CFCs are still used in some countries. The interaction of halogen refrigerants with ozone in the air has resulted in the progressive prohibition of the placing on the market and use of ozone depleting substances and of products and equipment containing those substances. There is currently a proposal for a Regulation of the European Parliament and of the Council on certain fluorinated greenhouse gases.

Ammonia used in cooling systems may leak or accidental releases may occur which also result in odour complaints. Odour problems are usually related to waste water treatment operations. Dairy installations situated in urban areas usually receive complaints regarding noise, e.g. associated with vehicle movements, refrigeration and UHT installations.

Bag filters can be used to reduce dust emissions to < 5 mg/Nm^3. Filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones allowing huge energy savings and noise reductions to be achieved. The filter powder of food quality can be used for other purposes.

1.4 Solid output

Packaging waste such as paper, wooden pallets, big bags and plastic films, and other wastes need to be re-used or disposed of. Wastes are also produced in fat traps, and in flotation and biological WWTPs. As well as these wastes, major solid or liquid wastes and by-products are also produced, e.g. whey residues, non-conforming products, sludge from separation during milk clarification and filtration, product loss on the heat transfer surface and discharged in the waste water during the cleaning of the equipment, curd waste, and small pieces of cheese. Whey may be segregated and processed to make further useful products. The non-conforming products are used as animal feed or sent for landfill and the sludge produced in the WWTP is sent for landfill.

Product losses in the Dairy Industry, expressed as a percentage of the volume of milk or fat or whey processed, are summarized in Table 1.8.

Table 1.8 – Product losses in some processes in the Dairy Industry

Type of processing	**Product losses (%)**		
	Milk	**Fat**	**Whey**
Butter/transport of skimmed milk	0.17	0.14	–
Butter and skimmed milk powder	0.60	0.20	–
Cheese	0.20	0.10	1.6
Cheese and whey evaporation	0.20	0.10	2.2
Cheese and whey powder	0.20	0.10	2.3
Consumer milk	1.9	0.7	–
Full-cream milk powder	0.64	0.22	–

Reported solid outputs per tonne of processed milk are shown in Table 1.9.

Table 1.9 – Solid output per tonne of processed milk

Products	**Solid output (kg)**	**WWTP sludges**
Liquid milk and yoghurt	1.7–45.0	0.2–18.0
Cheese	1–20	0.2–24
Milk and whey powder	0.5–16	3–30

Table 1.10 gives the reported total amounts of waste produced in Nordic dairy installations and their disposal. The figures do not include waste that is intended for animal feed. Non-conforming products sent for landfilling are included.

Table 1.10 – Production and disposal of solid wastes from some Nordic dairies

Products	Total solid waste (kg/1000 l)	Of which			
		Recycled	**Incinerated**	**Composted**	**Sent for landfilling**
Market milk, cultured products	1.7–14 (13)	5–41 %	0–48 %	0–14 %	14–95 %
Cheese, whey, powder	0.5–10 (17)	1–91 %	0–80 %	0–2 %	9–88 %
Ice-cream (kg/1000 kg)	35–48 (4)	4–33 %	0–6 %	0 %	67–95 %
*The figures in brackets show the number of dairy installations in each category					

The overall solid output for ice cream manufacturing reported for Europe is in a wider range, i.e. 30–150 kg/t product.

1.5 Energy

Dairies have a significant energy consumption. Around 80 % of the energy is consumed as thermal energy from the combustion of fossil fuels to generate steam and hot water. It is used for heating operations and cleaning. The remaining 20 % is consumed as electricity to drive machinery, refrigeration, ventilation, and lighting. The most energy consuming operations are the evaporation and drying of milk. In pasteurisation, e.g. significant energy is also needed for the heating and cooling steps. Recovery of heat by heat-exchangers can be applied. Evaporation is normally combined with vapour recompression. A wide range of energy consumption data has been reported for the European dairy industry. Figures are included in Table 1.11.

Table 1.11 – Energy consumption in European dairies

Products	Energy consumption (GJ/t processed milk)		
	Electricity	**Fuel**	**Remarks**
Market milk and yoghurt	0.15–2.5	0.18–1.5	Minimum for liquid milk, maximum for specialities
	0.09–1.11*		
Cheese	0.08–2.9	0.15–4.6	Depends on the type of cheese and production run. Maximum fuel for whey evaporation
	0.06–2.08*		
Milk and whey powder	0.06–3.3	3–20	Maximum fuel for whey products
	0.85–6.47*		
*Approximate kWh/l (assuming milk has a density of 1 kg/l)			

More energy is used in dairies where butter, as well as drinking milk, is produced and where the production of powdered milk is greater. Four installations of the Ice-cream Industry in Nordic countries have reported to have a total energy consumption in the range 0.75–1.6 kWh/kg of ice-cream produced. Other reports show an energy consumption of 2–10 GJ/t ice-cream produced.

1.6 Consumption of chemicals

Most of the chemicals are used for the cleaning and disinfection of process machinery and pipelines. Fresh product dairies mainly use caustic and nitric acid and some disinfectants, such as hydrogen peroxide, peracetic acid and sodium hypochlorite. Disinfection agents are also used in a range of 0.01–0.34 kg/t processed milk. Table 1.12 shows the consumption of cleaning agents used in European dairies. Of the total chemical consumption in Nordic dairies, 55 % is caustic and 30 % nitric acid.

Table 1.12 – Consumption of cleaning agents used in European dairies

Products	**Consumption of cleaning agents (kg/t processed milk)**		
	NaOH, 100 %	**HNO_3, 100 %**	**Detergents**
Market milk and yoghurt	0.2–10	0.2–5.0	*
Cheese	0.4–5.4	0.6–3.8	0.1–1.5
Milk and whey powder	0.4–5.4	0.8–2. 5	*
Values vary with the length and capacity of production runs; *Not applicable			

Whey processing involving electrodialysis, ion exchange, ultra and nanofiltration, requires large amounts of phosphoric, sulphuric and hydrochloride acid as well as potassium hydroxide and sodium hypochlorite. Chelating agents are widely used in dairy cleaning operations.

1.7 Noise

Noise is caused by the movement of milk tankers and distribution lorries; evaporators, spray driers, and cooling condensers. Bag filters use significantly less energy than cyclones and produce less noise. If filtering installations suitable for CIP are used for outgoing air, it is not necessary to use cyclones allowing huge energy savings and noise reductions to be achieved.

1.8 Waste water treatment

Dairy processing typically consumes large quantities of water and energy and discharges significant loads of organic matter in the effluent stream. For this reason, Cleaner Production opportunities focus on reducing the consumption of resources (water and energy), increasing production yields and reducing the volume and organic load of effluent discharges.

There are also opportunities in the areas of housekeeping, work procedures, maintenance regimes and resource handling.

Water is used extensively in dairy processing, so water saving measures are very common Cleaner Production opportunities in this industry. The first step is to analyze water use patterns carefully, by installing water meters and regularly recording water consumption. Water consumption data should be collected during production hours, especially during periods of cleaning. Some data should also be collected outside normal working hours to identify leaks and other areas of unnecessary wastage.

The next step is to undertake a survey of all process area and ancillary operations to identify wasteful practices. Examples might be hoses left running when not in use, CIP cleaning processes using more water than necessary, etc. Installing automatic shut-off equipment and restricters could prevent such wasteful practices. Automatic control of water use is preferable to relying on operators to manually turn water off.

Once wasteful practices have been addressed, water use for essential process functions can be investigated. It can be difficult to establish the minimum consumption rate necessary to maintain process operations and food hygiene standards. The optimum rate can be determined only by investigating each process in detail and undertaking trials. Such investigations should be carried out collaboratively by production managers, food quality and safety representatives and operations staff.

When an optimum usage rate been agreed upon, measures should be taken to set the supply at the specified rate and remove manual control. Once water use for essential operations has been optimized, water reuse can be considered. Waste-waters that are only slightly contaminated could be used in other areas. For example, final rinse waters could be used as the initial rinses for subsequent cleaning activities, or evaporator condensate could be reused as cooling water or as boiler feed water. Wastewater reuse should not compromise product quality and hygiene, and reuse systems should be carefully installed so that reused wastewater lines cannot be mistaken for fresh water lines, and each case should be approved by the food safety officer.

A checklist of water saving ideas follows:

- Use continuous rather than batch processes to reduce the frequency of cleaning;
- Use automated cleaning-in-place (CIP) systems for cleaning to control and optimize water use;
- Install fixtures that restrict or control the flow of water for manual cleaning processes;
- Use high pressure rather than high volume for cleaning surfaces;
- Reuse relatively clean wastewaters (such as those from final rinses) for other cleaning steps or in non-critical applications;
- Recirculate water used in non-critical applications;
- Install meters on high-use equipment to monitor consumption;
- Pre-soak floors and equipment to loosen dirt before the final clean;
- Use compressed air instead of water where appropriate;
- Report and fix leaks promptly.

Exp., reduction of Water Consumption for Cleaning at an Estonian Dairy Processing Plant:

At an Estonian dairy processing plant, open-ended rubber hoses were used to clean delivery trucks. Operators used their fingers at the discharge end of the hose to produce a spray, resulting in ineffective use of water. Furthermore, the hoses were not equipped with any shut-off valve, and the water was often left running.

The operators found that they could reduce water consumption by installing high-pressure systems for cleaning the trucks, the production area and other equipment. Open-ended hoses were also equipped with trigger nozzles. The cost of this equipment was USD 6,450 and the saving in water charges was USD 10,400 per year; a payback period of less than 8 months. Water consumption has been reduced by 30,000 m^3/year.

Some important characteristics of dairy waste water for the purposes of treatment are:

- large daily variation in flowrate;
- variable pH;
- waste water may be nitrogen deficient, unless the raw water has a high nitrate content or nitric acid is used;
- waste water may be high in phosphorus if phosphoric acid is used for clean-up. Milk also has a high phosphorus content, e.g. 93 mg P/100 g whole milk;
- the treatment of dairy waste water results in lower surplus sludge than domestic waste water treatment, owing to, e.g. the lower content of suspended solids, the lower F/M ratio used and the higher waste water temperatures;
- despiteutilising preceding equalisation basins, it is still prudent to allow for peak loads when designing the oxygen supply.

Effluent Cleaner Production efforts in relation to effluent generation should focus on reducing the pollutant load of the effluent. The volume of effluent generated is also an important issue. However, this aspect is linked closely to water consumption. Therefore, efforts to reduce water consumption will also result in reduced effluent generation.

Opportunities for reducing the pollutant load of dairy plant effluent focus on avoiding the loss of raw materials and products to the effluent stream. This means avoiding spills, capturing materials before they enter drains and limiting the extent to which water comes into contact with product residue. Improvements to cleaning practices are therefore an area where the most gains can be made.

A checklist of ideas for reducing pollutant loads in effluents:

- Ensure that vessels and pipes are drained completely and using pigs and plugs to remove product residue before cleaning;
- Use level controls and automatic shut-off systems to avoid spills from vessels and tanker emptying;
- Collect spills of solid materials (cheese curd and powders) for reprocessing or use as stock feed;
- Fit drains with screens and/or traps to prevent solid materials entering the effluent system;
- Install in-line optical sensors and diverters to distinguish between product and water and minimize losses of both;
- Install and maintain level controls and automatic shut-off systems on tanks to avoid overfilling;
- Use dry cleaning techniques where possible, by scraping vessels before cleaning or pre-cleaning with air guns;

- Use starch plugs or pigs to recover product from pipes before internally cleaning tanks.

In the dairy sector, solids from washing water from vehicle washing units are generally removed at source. This may be carried out by using sand or grit traps, or the rainwater from the sealed surfaces is generally passed into the on-site waste water treatment system. Next, segregation of waste water is generally applied, by high solids content, very high BOD and high salinity. After segregation, primary treatment is required and the following techniques can be used: screening; flow and load equalization; neutralization; sedimentation; DAF; centrifugation; precipitation.

Following primary treatment, secondary treatment may be required. For waste water with a BOD concentration greater than 1000–1500 mg/l, anaerobic treatment processes are used. Anaerobic techniques are widespread across Europe for dairy waste water when BOD is greater than 3000 mg/l. Following surface aeration, the resultant final waste water from the anaerobic process can be discharged directly to a MWWTP. Nevertheless, there may be a risk of phosphorus release in the final waste water if anaerobic processes are used. For lower strength waste water streams, aerobic treatment is applied. Figure 1.3 shows a typical waste water treatment flow sheet applied to dairy waste waters.

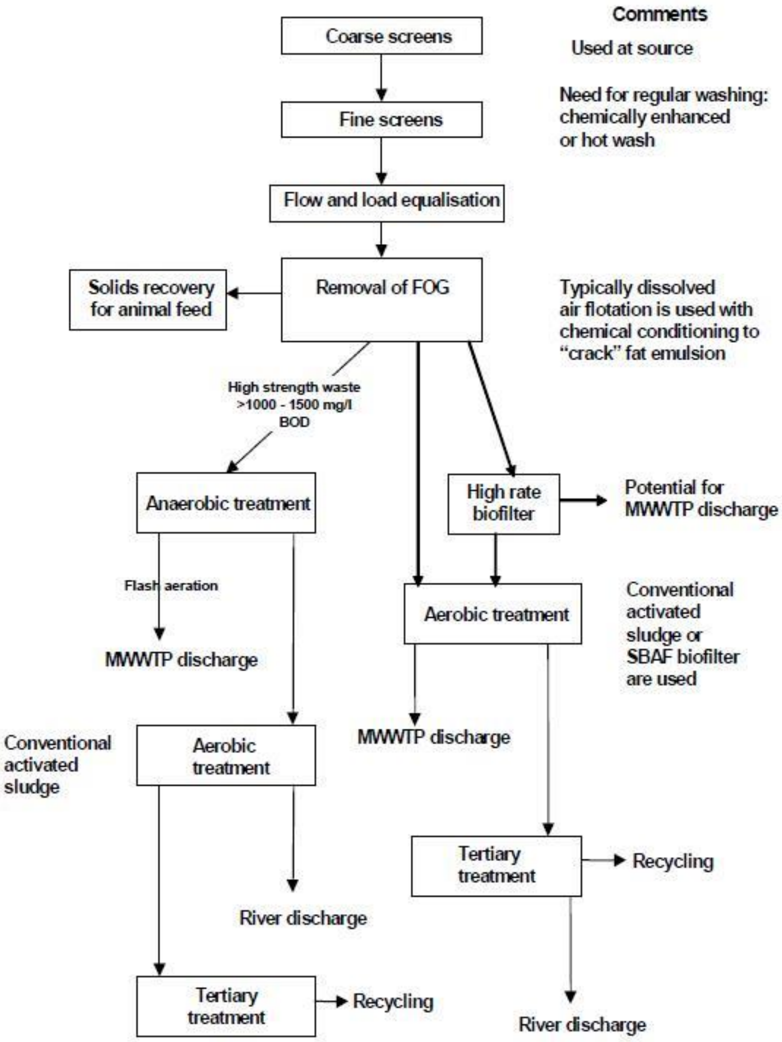


Figure 1.3 – Typical waste water treatment applicable to a dairy

1.9 Receipt and Storage of Milk

Raw milk is generally received at processing plants in milk tankers. Some smaller plants may also receive milk in 25–50 L aluminium or steel cans or, in some less developed countries, in plastic barrels. Depending on the structure and traditions of the primary production sector, milk may be collected directly from the farms or from central collection facilities. Farmers producing only small amounts of milk normally deliver their milk to central collection facilities.

At the central collection facilities, operators measure the quantity of milk and the fat content. The milk is then filtered and/or clarified using centrifuges to remove dirt particles as well as udder and blood cells. The milk is then cooled using a plate cooler and pumped to insulated or chilled storage vessels, where it is stored until required for production.

Empty tankers are cleaned in a wash bay ready for the next trip. They are first rinsed internally with cold water and then cleaned with the aid of detergents or a caustic solution. To avoid build-up of milk scale, it is then necessary to rinse the inside of the tank with a nitric acid wash. Tankers may also be washed on the outside with a cold water spray. Until required for processing, milk is stored in bulk milk vats or in insulated vessels or vessels fitted with water jackets. Figure 1.4 is a flow diagram showing the inputs and outputs for this process.

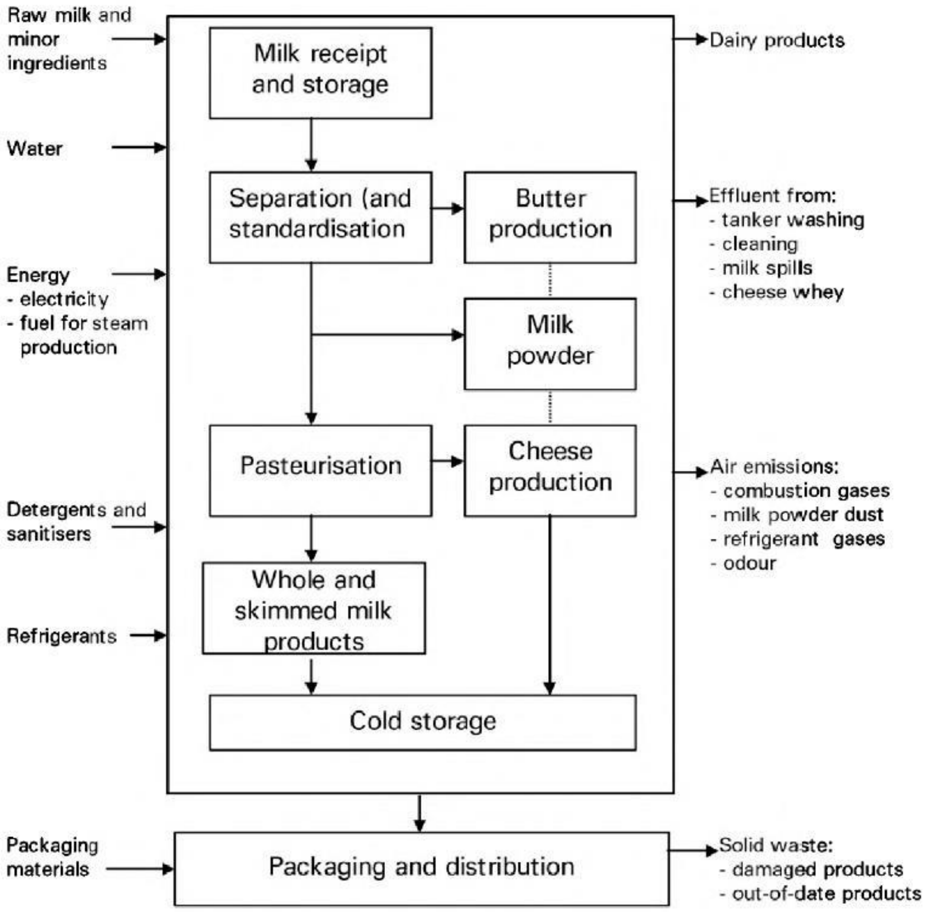


Figure 1.4 – Inputs and outputs from milk receipt and storage vessels

Water is consumed for rinsing the tanker and cleaning and sanitising the transfer lines and storage vessels. The resulting effluent from rinsing and cleaning can contain milk spilt when tanker hoses are disconnected. This would contribute to the organic load of the effluent stream.

Table 1.13 provides indicative figures for the pollution loads generated from the receipt of milk at a number of plants.

Table 1.13 – Indicative pollution loads from the milk receival area

Main product	**Wastewater (m^3/tonne milk)**	**COD (kg/tonne milk)**	**Fat (kg/tonne milk)**
Butter plant	0.07–0.10	0.1–0.3	0.01–0.02
Market milk plant	0.03–0.09	0.1–0.4	0.01–0.04
Cheese plant	0.16–0.23	0.4–0.7	0.006–0.03
Havarti cheese plant	0.60–1.00	1.4–2.1	0.2–0.3

Table 1.14 provides indicative figures for the pollution loads generated from the washing of tankers. Solid waste is generated from milk clarification and consists mostly of dirt, cells from the cows' udders, blood corpuscles and bacteria. If this is discharged into the effluent stream, high organic loads and associated downstream problems can result.

Table 1.14 – Indicative pollution loads from the washing of tankers

Main product	**Wastewater (m^3/tonne milk)**	**COD (kg/tonne milk)**	**Fat (kg/tonne milk)**
Market milk plant	0.08–0.14	0.2–0.3	0.04–0.08
Havarti cheese plant	0.09–0.14	0.15–0.40	0.08–0.24

Cleaner Production opportunities in this area focus on reducing the amount of milk that is lost to the effluent stream and reducing the amount of water used for cleaning. Ways of achieving this include:

- Avoiding milk spillage when disconnecting pipes and hoses;
- Ensuring that vessels and hoses are drained before disconnection;
- Providing appropriate facilities to collect spills;
- Identifying and marking all pipeline to avoid wrong connections that would result in unwanted mixing of products;
- Installing pipes with a slight gradient to make them self-draining;
- Equipping tanks with level controls to prevent overflow;
- Making certain that solid discharges from the centrifugal separator are collected for proper disposal and not discharged to the sewer;
- Using 'cleaning-in-place' (CIP) systems for internal cleaning of tankers and milk storage vessels, thus improving the effectiveness of cleaning and sterilisation and reducing detergent consumption;
- Improving cleaning regimes and training staff;
- Installing trigger nozzles on hoses for cleaning;
- Reusing final rinse waters for the initial rinses in CIP operations;
- Collecting wastewaters from initial rinses and returning them to the dairy farm for watering cattle.

PRACTICE 2
Environmental issues in the Bakery Industry

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.

Almost every operation unit can produce wastes and wastewaters. In addition, other types of pollution resulting from production are noise pollution and air pollution.

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.

2.2 Air Pollution

The air pollution is due to emission of volatile organic compounds (VOC), odour, 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 odour, avoidance of using the refrigerants forbidden by laws, and cyclic use of the refrigerants.

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.

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 from the Bakery Industry are shown in Table 2.1.

Table 2.1 – 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	–	–

Different products can lead to different amounts of wastewater produced. As shown in Table 2.1, pastry production can result in much more wastewater than the others.

The values of each item can vary significantly as demonstrated in Table 2.2.

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 has low strength and mainly contains flour and grease (Table 2.2).

Table 2.2 – Wastewater Characteristics in the Bakery Industry

Type of bakery	**pH**	**BOD_5 (mg/L)**	**SS (suspended solids) (mg/L)**	**TS (total solids) (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

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 2.2, 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. 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.

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.

2.5 Bakery waste treatment

Generally, the 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.

2.5.1 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 2.1.

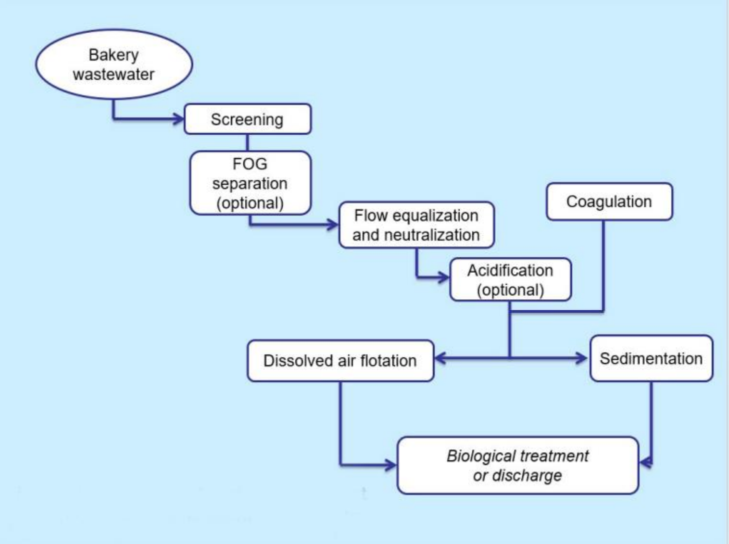


Figure 2.1 – Bakery wastewater pretreatment system process flow diagram

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.

Flow Equalization and Neutralization. In bakery plants, the wastewater flow rate and loading vary significantly with the time as illustrated in Table 2.3. 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 odours are common problems during the operations.

Table 2.3 – 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

Screening. Screening is used to remove coarse particles in the influent. There are different screen openings ranging from a few mm (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.

FOG Separation. As wastewater may contain high amount of FOG, a FOG separator is thus recommended for installation. The FOG can be separated and recovered for possible reuse, as well as reduce difficulties in the subsequent biological treatment.

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. A treatment system can be designed by 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 ft3 and detention time of 87 hours. The nitric acid also furnished nitrogen for proper nutrient balance for the biodegradation.

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. During experiments it was observed that 90–100 mg/L of alum and ferric chloride can be 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.

It was also found that $FeCl_3$ was relatively more effective than alum. Coagulation-flocculation can be used to treat a wastewater with much higher waste strength. Table 4 gives the treatment results of some corresponding experiments.

Owing to the higher organic content, SS, and FOG, coagulants with high dosage of 1300 mg/L were applied. 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.

Table 2.4 – Comparison of Different Bakery Waste Pretreatment Method

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

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 down. Rectangular tanks, circular tanks, combination flocculator-clarifiers, and stacked multilevel clarifiers can be used.

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.

In one experiment DAF was used 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. In other experiment DAF was used 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.

2.5.2 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.

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 odour problems.

Comprehensive considerations must be taken into account when selecting a suitable system.

Aerobic treatment. 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.

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 2.5.

Table 2.5 – 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

Owing to the high organic content, it is not recommended that bakery wastewater be directly treated by aerobic treatment processes.

The bakery wastewater treatment can be more cost-effective if the waste is first treated by an anaerobic process and then an aerobic process.

Trickling Filter Process. Aerobic attached-growth processes include tricking filters (biotower) (Figure 2.2) 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.

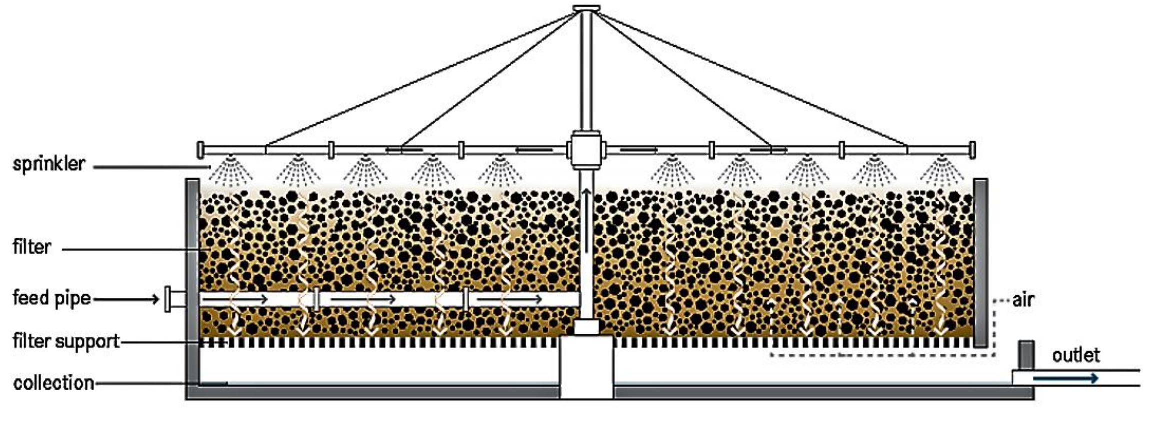


Figure 2.2 – Tricking filter

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. 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 2.6.

Table 2.6 – Design and Performance of Trickling Filter

Type of filte	**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

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 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 2.3 illustrates a typical anaerobic treatment process for bakery wastewater.

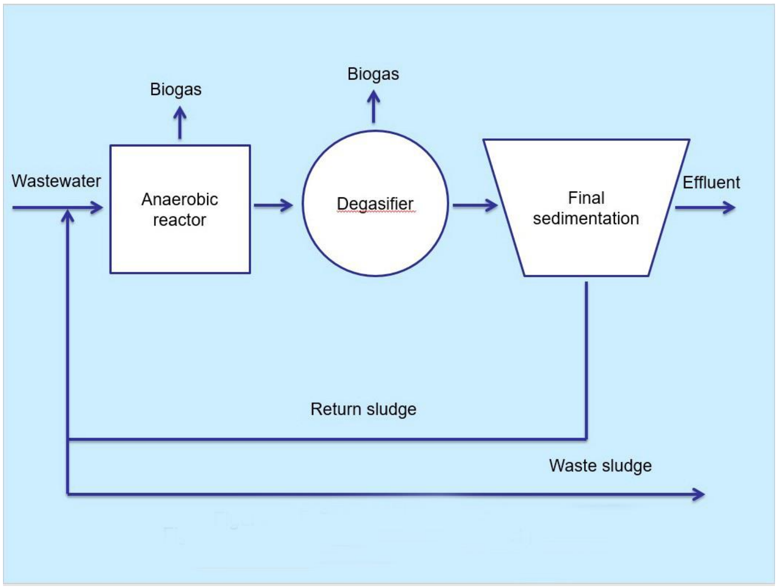


Figure 2.3 – Schematic of anaerobic contact process

In addition to accommodating organic waste treatment, anaerobic treatment can produce methane, which can be used for production of electricity (Figure 2.3). The disadvantages, however, include complexity in operation, sensitivity to temperature and toxicity, time-consuming in startup, and susceptibility to process upset. Table 2.7 gives a summary of design and performance of typical anaerobic treatment processes.

Table 2.7 – 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

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. The waste strength was extremely high as demonstrated in Table 2.8. The BOD_5 to COD ratio of the raw wastewater was 0.44. An anaerobic contact reactor was used, similar to that in Figure 3, except that two bioreactors were operated in series. As shown in Table 8, 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.

Table 2.8 – 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

Table 2.8 (continued)

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

2.6 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.

2.6.1 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.

2.6.2 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.

2.6.3 VOC

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

2.7 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.

2.8 Cleaner production in the Bakery Industry

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.

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.

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.

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.

PRACTICE 3
Manufacture of olive oil: main environmental aspects and pressures

3.1 Introduction

Average olive oil production in the EU in recent years has been 2.2 million tonnes, representing around 73 % of world production. Spain, Italy and Greece account for about 97 % of EU olive oil production, with Spain producing approximately 62 % of this amount.

In terms of oil quality, in 2009 Spain produced 35 % extra virgin oil, 32 % virgin oil and 33 % lampante oil. The respective figures for Italy in relation to these three categories of oil are 59 %, 18 % and 24 %. These percentages change year on year, notably because of climate conditions.

The EU is the world's biggest consumer (66 % share). Spain, Italy and Greece account for around 80 % of EU consumption, i.e. 1900 kt. Consumption seems to be stable in the producer countries, whereas it is increasing in the non-producer Member States.

Consumption models differ in the EU's three main producer countries. In Italy and Greece, the majority of oil consumed is extra virgin, whereas in Spain this category represents less than half of consumption. The general trend is towards the consumption of extra virgin oils.

Trade within the EU is considerable and continues to rise steadily. In 2010/11 it was around 1,000 kt, i.e. 45 % of EU production. Spain is the biggest supplier with 655 kt, while Italy is the biggest buyer with 533 kt.

EU exports represent approximately 66 % of world exports. In 2010/11, exports to third countries amounted to 447 kt, of which Spain sold 225 kt and Italy 160 kt. The biggest markets are the USA, Brazil, Japan, Australia and China.

In 2010/11, EU imports accounted for 115 kt, of which the majority is traditionally under inward processing rules and the remainder within the framework of tariff-free quotas with the Mediterranean countries, primarily Tunisia. The new agreement with Morocco has fully liberalised imports from this country.

The degree of organisation of the Olive Industry differs greatly from one Member State to another. According to an ongoing study on cooperatives in the European Union, the level of organisation is 70 % in Spain, 60 % in Greece, 30 % in Portugal and only 5 % in Italy. Nonetheless, in general these producer organisations are too small to have any weight in the face of industry concentration and the retail chains.

In Spain, a few big groups control the majority of the olive oil market. Upstream there are 740 processing businesses (mills), including some 950 cooperatives, that produce olive oil, although the majority do not bottle or market oils.

In Italy, there are some 5,000 mills, whereas downstream the industry is very concentrated with the major bottlers controlling almost half the virgin olive oil market (80% of domestic consumption). In Greece there are approximately 2,200 mills. The majority of the oil put on the market is owned by a few large companies. In Italy and Greece, the producer customarily retains ownership of the oil after its extraction in the mill, placing some of the production on the market via short distribution channels.

In view of this, producers and primary processors lack the means to adapt supply to demand and consequently to properly benefit from the full value of their production.

The oils produced from olives are classified (under the Council Regulation No 865/2004 and Commission Regulation No 2568/91) as shown in Table 3.1.

Table 3.1 – Types of olive oil

Types of olive oil	**Description/ Main characteristics**
Virgin olive oil	Oils obtained from the fruit of the olive tree solely by mechanical or other physical means under conditions that do not lead to alterations in the oil, which have not undergone any treatment other than washing, decantation, centrifugation or filtration, to the exclusion of oils obtained using solvents or using adjuvants having a chemical or biochemical action, or by re-esterification process and any mixture with oils of other kinds. Virgin olive oils are exclusively classified and described as follows. (a) Extra virgin olive oil Virgin olive oil having a maximum free acidity, in terms of oleic acid, of 0.8 g per 100 g, the other characteristics of which comply with those laid down for this category. (b) Virgin olive oil Virgin olive oil having a maximum free acidity, in terms of oleic acid, of 2 g per 100 g, the other characteristics of which comply with those laid down for this category. (c) Lampante olive oil Virgin olive oil having a free acidity, in terms of oleic acid, of more than 2 g per 100 g, and/or the other characteristics of which comply with those laid down for this category.
Refined olive oil	Olive oil obtained by refining virgin olive oil, having a free acidity content expressed as oleic acid, of not more than 0.3 g per 100 g, and the other characteristics of which comply with those laid down for this category.
Olive oil – composed of refined olive oils and virgin olive oils	Olive oil obtained by blending refined olive oil and virgin olive oil other than lampante olive oil, having a free acidity content, expressed as oleic acid, of not more than 1 g per 100 g, and the other characteristics of which comply with those laid down for this category.
Crude olive – pomace oil	Oil obtained from olive pomace by treatment with solvents or by physical means or oil

Table 3.1 (continued)

	corresponding to lampante olive oil, except for certain specified characteristics, excluding oil obtained by means of re-esterification and mixtures with other types of oils, and the other characteristics of which comply with those laid down for this category.
Refined olive – pomace oil	Oil obtained by refining crude olive pomace oil, having a free acidity content expressed as oleic acid, of not more than 0.3 g per 100 g, and the other characteristics of which comply with those laid down for this category.
Olive – pomace oil	Oil obtained by blending refined olive pomace oil and virgin olive oil other than lampante olive oil, having a free acidity content, expressed as oleic acid, of not more than 1 g per 100 g, and the other characteristics of which comply with those laid down for this category.

3.2 Main environmental aspects and pressures

The environmental aspects of the production of olive oil can be classified as direct or indirect.

Direct aspects. Table 3.2 illustrates the main direct environmental aspects and related environmental pressures of each phase of virgin olive oil production.

Table 3.2 – Main environmental aspects and pressures of virgin olive oil production

Main environmental aspects	**Main environmental pressures**	
	Inputs	**Outputs**
Fruit cleaning and washing	Energy consumption (electricity) Water consumption	Solid wastes generation (stones, leaves, soil, etc.) Waste water generation
Milling	Energy consumption (electricity)	Waste water generation (in some cases)
	Water consumption (in some cases)	
Malaxing	Energy consumption (electricity and fuel)	Air emissions
	Water consumption	-
Extraction	Energy consumption (electricity)	Solid waste generation (spent olives or moist spent olives, depending on the system used)
	Water consumption (depending on the system used)	Waste water generation (depending on the system used)
Separation	Water consumption	Waste water generation
	Energy consumption (electricity)	–
Packaging	Energy consumption (electricity) Use of materials (packaging)	–
Cleaning of equipment and installations	Water consumption Energy consumption (heat) Use of chemicals (acid, alkali, detergents and disinfectants)	–

Table 3.2 (continued)

Energy supply	Energy consumption (fuel and electricity)	Air emissions (SO_x, NO_x, etc.) GHG emissions (CO_2)

Overall, the most relevant environmental aspects are:

- Water consumption and waste water generation in the fruit washing stage.
- Water consumption and waste water generation in the olive oil cleaning stage (separation).
- Water consumption and waste water generation in the extraction stage when a three-phase extraction system is used.
- By-products; spent olives and moist spent olives.
- Energy consumption.

The water consumption in olive oil mills varies widely, both because of equipment requirements (for example, the three – phase system mill needs substantially greater quantities of water) and local operational conditions and practices. Water consumption in olive oil mills ranges as shown in Table 3.3. Likewise, the amount of wastewater generated varies (Table 3.4) depending on the extraction system and management practices (water added and segregation of the effluents).

Table 3.3 – Water consumption in oil mills

Water consumption (l/kg olives processed)	**Traditional system**	**3-phase system**	**2-phase system**
	0.27–0.35	0.75-1	0.25–0.33

Table 3.4 – Average volumes of waste water generated in the different steps of the 3- and 2-phase olive oil extraction processes

Effluent (l/kg olives processed)	**Traditional system**	**3-phase system**	**2-phase system**
Washing of olives	0.05–0.12	0.05–0.12	0.05–0.12
Extraction	–	0.9	–
Separation/Cleaning of olive oil (vertical fuge)	0.62–0.69	0.20	0.15
General cleaning	–	0.05	0.05
Total effluents	0.63–0.81	1.24	0.25

Olive oil wastewater from oil mills is characterised in general by high BOD_5 and phenolic compound content as well as a high COD/BOD ratio. However, wastewater streams present different characteristics, depending on the variety and maturity of the olives, the climate and soil conditions and the oil extraction method and habits.

The main by-product/solid residue generated in olive oil production is the spent olives and moist spent olives. Both contain a certain quantity of residual oil which is not possible to extract by physical means and which is extracted in the extracting plants of olive oil mills.

The energy demand in olive oil mills ranges as shown in table 3.5.

Table 3.5 – Energy consumption in oil mills

Energy consumption (kWh/tonne olives processed)	**Traditional system**	**3-phase system**	**2-phase system**
	40–60	90–117	< 90–117

However, the electrical energy consumption in an olive oil mill is distributed in the production phases as presented in Table 3.6.

Table 3.6 – Electrical energy balance

Production stages	**Consumption (%)**
Reception, cleaning and washing	7.46
Milling	20.60
Malaxing	11.76
Centrifugation	41.39
Storage	4.15
Packaging	1.5
Others	13.15
TOTAL	100

Likewise, the main thermal energy is consumed in order to heat the water which is used in the following stages:

- malaxing;
- extraction, when the three-phase system is used;
- separation (vertical centrifugation).

Indirect aspects. Indirect aspects are related to the upstream and downstream activities of olive oil production. Agriculture and production of packaging are the most relevant in the supply chain. In addition, transport and logistics (both upstream and downstream), retail and food preparation by consumers are the other indirect environmental aspects.

3.3 Best environmental management practices

Olive oil is the oil obtained solely from the fruit of the olive tree. It is a key ingredient in the Mediterranean diet, renowned for being healthy, although its popularity has now expanded beyond its area of origin: the Mediterranean basin.

Olive-growing and olive oil production are very important within the EU’s agricultural and food sectors. The European Union is the largest olive oil producer; in the year 2011/12 Spain, Italy and Greece alone accounted for 70 % of global olive oil production. In terms of area, in 2012 olive farming (for both olive oil and table olives) covered 23 % of agricultural land in Greece, 7 % in Italy and 11 % in Spain 48 %.

Due to the growing popularity of this product over the last two decades, olive growing has become more intensive, using an increasing amount of land and resources. Olive oil production also requires large amounts of water. This is particularly problematic given that it is concentrated in countries and areas where water resources are scarce.

The large volumes of water used for processing result in a significant amount of contaminated waste water. Its management is regulated in European olive oil-producing countries given that uncontrolled disposal of such liquids causes phytotoxicity, water and soil pollution. Although the waste water from different types and stages of processing varies, it can be described with the following general characteristics:

- strong foul odour;
- high degree of organic pollution, with COD values up to 220 g/L;
- slightly acidic pH (between 3 and 5.9);
- high content of non-easily biodegradable polyphenols which are toxic to most microorganisms.

This BEMP focuses on the final stage of olive oil processing: separation (also known as clarification or polishing). The outline of a continuous process for olive oil production is shown in Figure 3.1; the traditional press can also be used for primary extraction. Olives are picked by hand or by automatic means, contaminants such as leaves, stones and soil must be removed through the de-leafing and cleaning stages. The olives must then be crushed to liberate the oil from the fruit’s cells. The malaxation stage, which results in liberating more oil from the flesh, is necessary to increase the yield of extraction. The olive oil is firstly extracted from the paste by mechanical means; pressure, centrifugation and percolation technologies are available. Horizontal decanters are the most common choice of extraction machinery in Europe.

The final processing stage, as mentioned above, is the separation of the olive oil from remaining fine particles and water. This is required to “clean” the oil of remaining impurities in order to produce higher quality oil. This is usually done through centrifugation; a vertical centrifuge with a rotatory speed of 6,500–7,000 rpm is used for this process.

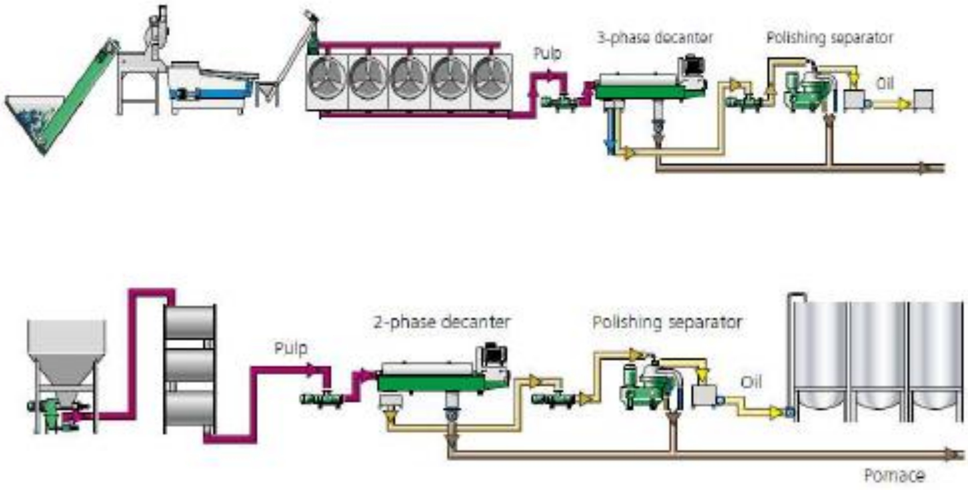


Figure 3.1 – Continous olive oil extraction process (3-phase system, above, 2-phase system below)

In the centrifuge, substances with different densities separate along the radial direction. The heavier substances, in this case the fine particles, move away from the centre and are collected in a container, as shown in Figure 3.2. Water, which has a medium density, forms the middle stratum and drains from the centrifuge. The oil, which is the lightest substance, stays in the centre from where it is pumped out.

Warm water is generally added to the previously extracted oil. The water improves the separation of the fine particles from the oil by creating a larger phase separation within the centrifuge. The amount of water required is a fine balance between better removal of the fine particles and preservation of polyphenols within the oil. Polyphenol content is very important for oil quality. Polyphenols are water-soluble; therefore, the addition of water for centrifugation results in reduced content following this process. However, the water improves the removal of fine solids.

The centrifuge must be cleaned periodically to remove the accumulated solids. Machinery with either automatic or manual cleaning is available. If cleaned manually, the centrifuge has to be stopped and cleaned with water; this takes approximately one hour. Modern technology automatically discharges the accumulated solids whilst in operation (in just few seconds) by automatically opening peripheral holes in the drum. Some oil can be lost during this operation; however, this is limited in the presence of water which acts as a phase separator between the soil and oil phases.

The literature gives varying data with regards to the amount of water used during this separation stage. This will depend on the quality of the oil after extraction, the amounts of impurities present and the centrifuging machinery. In the 1990s, 300 litres of water were added per 1000 litres of olive oil produced. More recent literature provides the following figures:

- between 15 % and 50 % of the oil volume.
- an industry source reported that the typical amount of water used in 2014 was 200 litres of water added per 1000 litres of oil (20 %).

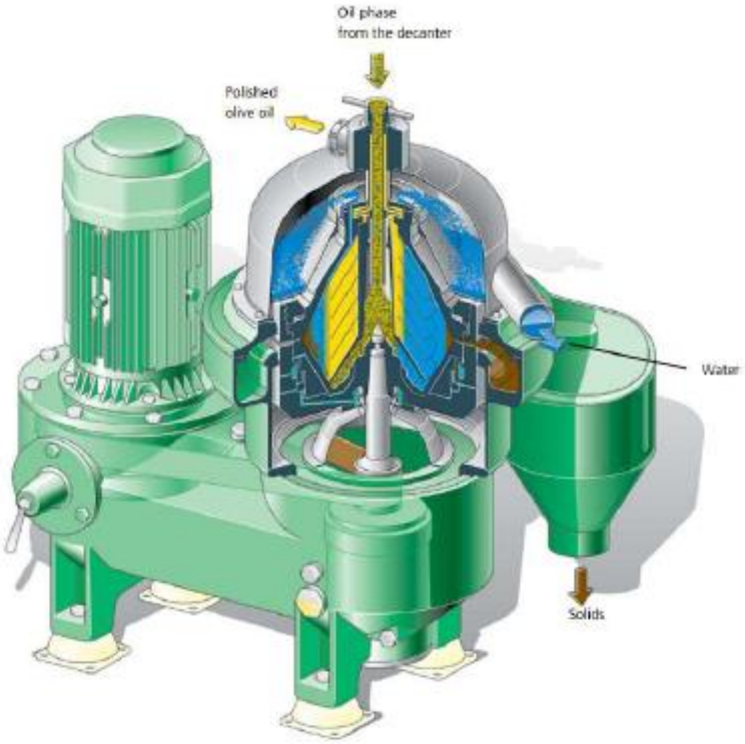


Figure 3.2. – Oil separation through a vertical centrifuge

Minimisation of added water has been identified as best practice for this stage of olive oil production. This must be done mindful of the final quality of the olive oil and the efficiency of fine solids removal. This is particularly important given the increasing demand for high quality olive oil. Improved technology and research have resulted in lower quantities of water being needed for effective impurity removal. According to different sources, the use of water can be reduced down to between 100 litres and 50 litres of water per 1000 litres of oil (10 % to 5 %) all the way to using no water. This will depend on the quality of the oil following extraction.

The water is used to aid the removal of impurities in the oil and does not form part of the end product but instead generates waste water. Consequently, the lower the amount of water used, the lower the amount of generated waste water requiring treatment. Several methods to manage such wastes exist, depending on the country of production and the size of the olive oil producer. In Spain it is considered best practice to treat this water from the separator by mixing it in the "repasso" phase with the pomace waste arising from two-phase decanters used in the first extraction, and then dry it in evaporating lagoons. In other countries the solids from the used olive wash water are removed through natural sedimentation and the cleaned water can then be recycled in the initial olive washing process.

Achieved environmental benefits. This BEMP focuses on the reduction in water used during the separation phase of olive oil production. Therefore, the obvious environmental benefit is that of reduced water consumption. By looking at the data above, the reduction in water use specifically related to the vertical centrifugation of oil will vary according to the initial amounts of water used and the quality of the incoming oil, which dictates the minimum water requirement so as not to compromise the quality of the product. The highest water use cited in the literature is 50 % (500 litres of water per 1000 litres of oil). If this is reduced to 5 % of the oil quantity, it will result in a 90 % reduction in the vertical centrifugation step. However, it was reported that the typical amount of water used in 2014 was of 200 litres per 1000 litres of oil. Therefore, reducing this to 5 % will result in water savings in this stage of olive oil production of 75 %.

This aspect is particularly important as water in the major oil-producing countries is scarce. For example, Andalucia and Puglia, the largest olive oil-producing regions in Spain and Italy respectively, are both shown as “over-exploited”. Major producing countries, including Greece, Italy, Spain, and Portugal, but also Morocco, Syria, Tunisia and Turkey outside of Europe have large areas classed as “highly exploited” or “over-exploited”.

Reduced water use also results in a reduction in waste generation from the separation process and therefore lower waste water treatment needs. Water added to the oil for centrifugation is used as a means to improve the removal of water (1 % to 10 % water content) and fine particle impurities still present in the oil following extraction. Therefore, this water plus the removed impurities all result in waste water which must be treated.

Appropriate environmental indicators. The most appropriate environmental indicator for this BEMP is: water used in olive oil separation (litres) per weight (tonnes) of olives processed or per unit volume (litres) of olive oil manufactured.

Cross-media effects. The waste water from vertical centrifugation can be recycled in the olive washing or added into the “repasso” (the solids exit phase of the two phase decanter) before the pomace is centrifuged again or dried. When lower amounts of water are used, lower amounts of waste water will be generated meaning less of this will be available for recycling. Hence, other water sources must be found for this purpose.

Operational data. Table 3.7 shows the composition of the waste water generated during vertical centrifugation at six Spanish olive oil processing plants. As can be seen, there is some variation in the characterisation of these effluents, particularly regarding COD values and the phenolic content. The latter depends on the degree of ripening of the olives used during processing and on the volume of water used during the first separation process. As mentioned above, the lower the amount of water added for separation, the lower the amounts of waste water requiring such treatment.

Table 3.7 – Composition and features of the waste water generated during the separation of virgin olive oil at different Spanish olive oil factories located in Cordoba (Co) and Jaen (J) provinces

Factory	**pH**	**Total solids (%)**	**Ash (%)**	**Organic matter (%)**	**BOD_5 (mg/L)**	**COD (mg/L)**	**Phenolic content (ppm)**
1 (Co)	5.69	0.18	0.04	0.14	790	2,874	373
2 (Co)	5.40	0.15	0.05	0.1	520	5,935	86
3 (Co)	5.67	0.24	0.04	0.2	465	3,805	NA
4 (Co)	5.73	0.33	0.07	0.26	690	4,230	NA
5 (J)	5.11	1.47	0.05	1.42	915	12,087	157
6 (Co)	5.16	0.59	0.1	0.49	790	10,931	NA

Applicability. It is reported that the majority of olive oil producers make use of vertical centrifugation technology for clarification purposes. The amount of water used will depend on the quality of the oil coming from the decanter. This can depend on a number of factors, including the amount of oil processed and the quality of the olives. The amount of water can be minimised when the oil contains a low concentration of water and fine particles, thus not affecting the final product quality. In all cases, the quantity of water used should be kept to the minimum amount required to achieve the desired final composition.

Economics. The aim of this BEMP is to minimise the amount of water used during the final clarification in olive oil processing. A clear economic saving is that of water costs. In terms of machinery, no costs will be incurred as different technologies are not required; vertical centrifuges are already owned and used by most olive oil processors.

Reducing water inputs also results in reduced waste water outputs. Therefore, in mills where these are treated chemically or biologically, the cost of such treatments will be lowered given that the amount of waste is also reduced.

Driving force for implementation. Water scarcity is an increasingly important issue in major olive oil-producing countries. In these regions, the major environmental problems associated with olive oil mills are related to water consumed during the production process. For this reason, reducing the stress on the water resources and consequently the environmental impact of olive oil production should be seen as a major driver.

Within Europe, around 4.6 million tonnes of olive mill waste water are produced each year, including the waste produced during the final separation of olive oil. This water is highly polluted and is expensive and difficult to treat, causing environmental concern. A reduction in the generation of such waste and its environmental impacts should be considered a major driver to minimise the use of water during olive oil separation.

Historically, the treated waste water reuse in Greece, Italy and Spain has been very low. A study in 2007 stated that “The treated waste water reuse rate is high in Cyprus (100 %) and Malta (just under 60 %), whereas in Greece, Italy and Spain treated waste water reuse is only between 5 % and 12 % of their effluents”. Consequently, water reduction and the associated reduction in waste water generation should be seen as a major driver in these three countries.

PRACTICE 4
Environmental issues and solutions in the Sugar Industry

4.1 Water consumption

The water requirement for fluming is about 500–800 % of the amount of beet. For washing, 150–200 % is needed, and for a single stone catcher 70–100 % water is needed based on the amount of beet. The mechanically clarified water is re-used for fluming and washing, thus only 25–30 % beet based industrial water needs to be added during the last rinsing of the beets after washing.

Smaller losses are caused by evaporation of the cooling water and by discharging by-products and wastes containing water. However, the root body consists of about 75–78 % water, therefore, the beets carry sufficient water into the processing, which accumulates as condensate. Thus, an installation producing sugar is a net water producer, because the water contained initially in the beet becomes available as surplus cooling water.

While the overall water used is about 15 m^3/t sugar beet processed, the consumption of fresh water is 0.25–0.4 m^3/t sugar beet processed, or even less in modern sugar factories. Water consumption depends on the activities of each installation, e.g. more water is consumed in an installation that extracts and refines sugar beet, than one that does only one of those activities. In Austria, the consumption of water is of 1.5 m^3/t of sugar beet processed, equivalent to 9 m^3/t produced sugar, was reported. Table 4.1 shows the water consumption in Danish sugar factories.

Table 4.1 – Water consumption in Danish sugar factories

Parameter	**Specific value per tonne of beet processed**		**Specific value per tonne of sugar produced**	
	Average	Range	Average	Range
Water (m^3)	0.37	$0.23^a – 0.50^b$	2.39	$1.56^a – 3.21^b$
[a]Excluding cooling water (two factories); [b]Including cooling water (two factories)				

4.2 Waste water

Sugar beet is 75 % water, and the extraction process, by definiton, aims to release a high proportion of water contained in the beets. Approximately half of this water is lost due to evaporation or inclusion in various product streams. The remainder is, after usage for washing and fluming, a source of high strength waste water.

The beets are floated through the cleaning stage where stones, weeds and other gross contaminants are removed. The transport water pumped off with the soil sludge can be up to 70 % of the beet. It has a high organic contamination due to the soil and sugar from damaged beets. Its COD is 5000–20000 mg/l.

The beets then enter the installation, where they are washed before being sliced into cossettes to maximise the surface area for the extraction process. The condensate from the evaporation and crystallisation stages is partly used as process water in several process stages, including beet washing. Process waste water is deemed to be the excess condensate from the concentration and crystallisation stages. This surplus condensate is high in ammonia and relatively low in COD content. Waste water with high BOD levels is produced in large volumes and is cleaned in a WWTP.

4.3 Solid output

During the reception and fluming of the sugar beet, soil, stones, sand and vegetable matter, e.g. seeds, beet tails and leaves, are removed. The amount of the earth adhering to the beet may vary greatly depending on, e.g. the weather conditions during harvesting and the design and operation of the harvester. In the annual processing of 500000 tonnes of beets, an average of 60000 tonnes of soil accumulates. The soil arriving at the installation is removed in settling ponds. The sediment may be re-applied to arable land or may be used for other purposes, such as horticulture or civil engineering works. The vegetable matter is separated from the fluming water for sale as animal feed or fertiliser.

The sugar content of the beets does not vary greatly, e.g. 18.4 % in Austria and 13.9 % in Greece. The efficiency of sugar extraction is about 90 %. There are other substances either in the wastes or by-products, such as beet pulp. After sugar is taken out, the extracted beet pulp is pressed. The wet pulp may then be dried. Beet pulp is normally sold as sweet feed for cattle. Another by-product is carbonatation lime. Juice purification is done using lime. It may be pressed and sold to de-acidify or balance the pH of soil.

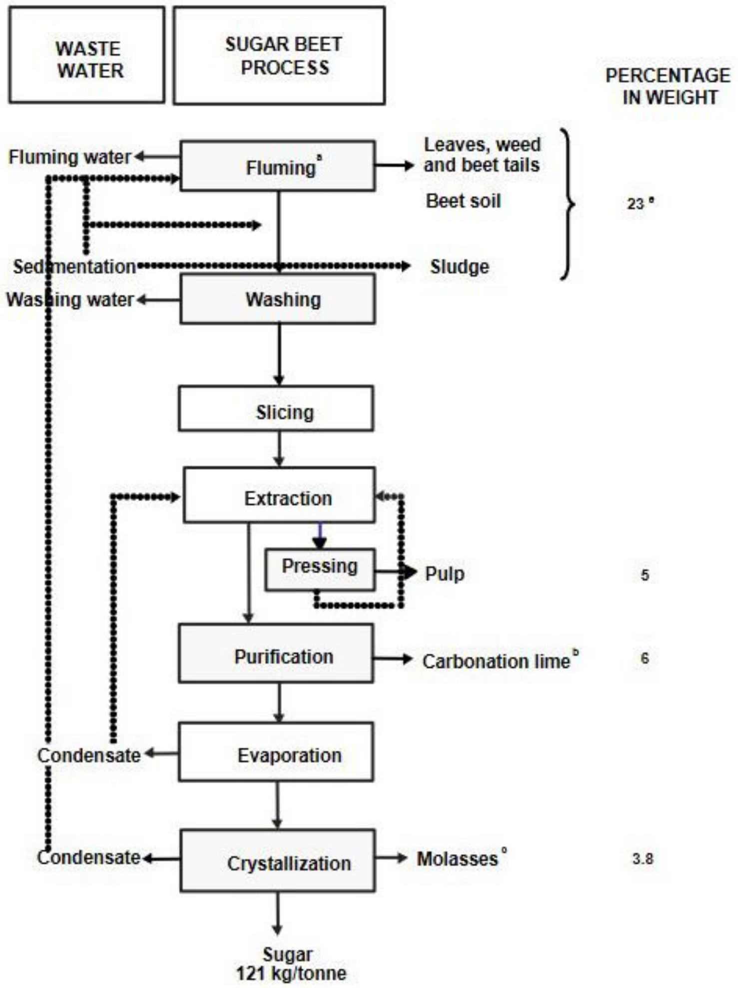
Sugar beets contain some soluble non-sugar substances, 30–40 % of which are eliminated during purification of the juice with Ca^{2+} precipitable anions, pectins and proteins. The remainder is left in the juice and prevents the complete crystallisation of the sugar, leaving a final syrup, called molasses. This is the major single loss of sugar in the process. 10–18 % of the sugar content of the beet is in molasses. About 38 kg molasses per tonne of sugar beet is generated. Molasses is about 80 % solid material and 20 % water.

In a study of Danish sugar factories, approximately 49 % of the total production was reported to be primary products such as sugar, molasses and feed pills. While the remaining by-products such as lime, beet pulp and weeds were sold or re-used.

Figure 4.1 shows a typical process flow diagram for a sugar beet processing installation and the production of waste water, wastes and by-products.

4.4 Energy

Significant thermal energy is consumed for the evaporation and beet pulp drying. Electrical energy is needed for the pumps and for driving the centrifuges. According to CEFS, specific energy consumption was 31.49 kWh/100 kg beet in 1998. Table 4.2 shows the energy consumption in Danish sugar factories.



[a] Integrated with primary treatment of fluming water by screening and sedimentation
[b] Water content down to 30 % if separated in filter press. It is estimated that 60 kg lime are generated per tonne of beet processed
[c] Liquid by-product with established market
[e] It is estimated that on average 230 kg of soil and green waste are collected per tonne of sugar beet processed
One tonne of sugar beet yields 121 kg sugar, 38 kg molasses and 50 kg pulp. The high water content is used as recycled process water, in cooling operations and as discharge to the WWTP

Figure 4.1 – Type and amount of waste water, wastes and by-products from sugar beet processing

Table 4.2 – Energy consumption in Danish sugar factories

Total energy (kWh) consumed			
Specific value per tonne of beet processed		**Specific value per tonne of sugar produced**	
Average	Range	Average	Range
307	232–367	1987	1554–2379

In a Greek study, a figure of 280 kWh/t is given for the electrical part of the energy consumption in sugar manufacturing.

4.5 Cane sugar refining

The starting point is not sugar cane, but raw sugar, therefore less water is required than in sugar beet processing. The regeneration every 40–50 hours of the ion exchange resin cells used in the decolourisation process generates a difficult waste water as caustic brine is used as the regenerant. There may be excess condensate and sweet water although these can be eliminated. Waste water is generated from the steam cleaning of the bulk road tankers used to transport liquid sugar products.

4.6 Waste water treatment

It is reported that depending on the configuration of the WWTP, waste water segregation is sometimes carried out at sugar beet processing installations, before waste water treatment. The process water, i.e. the surplus condensate from the concentration, which is high in ammonia and the water from crystallisation; the fluming water and the wash-water are reportedly kept separate from the high strength fluming water. In some installations the condensate is used to wash beets.

Example 1. The soil is settled out from the transport water in sedimentation ponds. The decanted water is treated using both anaerobic and aerobic lagoons. The use of lagoons can make it possible to use the water to irrigate the land during dry weather, which also reduces the need for extracting water from the rivers or from the ground. For the treatment of process waters in southern Europe, it may be possible to use lagoons for natural water evaporation due to the high average temperatures.

Further treatment is needed if there is a risk of offensive odour or should the needs of the environment dictate a more stringent level of treatment. In this case, the previous treatment can be enhanced by surface aeration, possibly preceded by aerobic treatment.

Example 2. Should the environmental needs dictate that further levels of treatment are required, sedimentation, anaerobic treatment followed by oxygenation and/or aerobic digestion with a final sludge sedimentation process can be used.

The high strength supernatant passing from the sedimentation ponds is ideally suited for treatment using anaerobic techniques. Moreover, the betaines from the sugar beet, composed of organic nitrogen compounds, can only be degraded anaerobically. Consequently, about half of the sugar factories in Germany are currently equipped with anaerobic systems.

The organic material in the fluming water breaks down into shorter chain organic acids. Historically, pH correction was made using additives such as lime in a neutralisation process. However, this “acidification” of the waste water stream is ideally suited for anaerobic treatment. “Acidogenesis” is an essential reaction that takes place in anaerobic conditions to break the longer chain organic material into more treatable organic acids. A number of anaerobic installations require an acidification tank upstream of the anaerobic reactor to initiate the acidogenesis stage. Hence pH correction of the fluming water is no longer required.

The biomethanation is undertaken at higher temperatures, e.g. 37ºC, although a lower rate of digestion can take place at 20ºC or less. Operating problems may occur as a result of changes in the composition of the organic constituents of the waste water and also its high calcium content.

In the methane reactor, the presence of calcium from the carbonation process which is present in the waste water in combination with the carbon dioxide formed in the reactor, leads to the precipitation of calcium carbonate. Experience shows that regardless of the concentration of the incoming waste water and regardless of the process used, the calcium content is reduced to around 0.3–0.7 kg/m^3. This means annual calcium carbonate loads of 300–1000 tonnes remain in the reactor. This gives rise to problems with mixing in the system, and also to additional work and cost to keep the relevant pumps, heat-exchangers and pipes in good working order.

A portion of the anaerobically treated waste water can be recycled as fluming water.

Furthermore, the methane produced as part of the anaerobic process can be used for drying beet pulp intended for use as animal feed. Low grade heat can be used to preheat the waste water entering the anaerobic reactor.

Sugar processing excess condensate is considered to be high in ammonia content, yet low in COD. The recommended process for reducing the ammonia levels is to use aerobic techniques configured to allow for the nitrification of the ammonia. For this to take place, the waste water stream needs to be dosed with an external carbon source.

For those installations using anaerobic techniques for treating the fluming water, combining the waste water from the anaerobic process with the excess process water is usually sufficient to provide a feed of adequate balance onto the aerobic treatment stage.

Some factories use hydrocyclones to remove lime-laden bacterial sludge from the system. In nearly all factories it is necessary, during the off-season period, to mechanically remove the lime that has formed in the reactors. This is carried out at regular intervals, every 2–5 years. The lime concentrations on removal are around 800–1000 kg/m^3 of carrier material.

Since such operations are seasonal, the aerobic system downstream of the anaerobic system must be activated accordingly at the start of the season. This is not necessarily the case with fluidised beds. Lime is precipitated almost entirely on the carrier material, which can then be drawn off during operation.

The final waste water from this stage may be of a high enough quality to be discharged to a watercourse. Alternatively, discharge would be to WWTP. For potential recycling of final waste water, tertiary treatment techniques can be employed on some of the waste water.

Example 3. For those circumstances which demand additional control of nitrogen and its compounds, it is necessary to install suitably designed nitrification and denitrification systems. There are several biological and non-biological techniques, e.g. ammonia stripping and biological nitrification/denitrification.

Example 4. First an anaerobic process is applied and the biogas produced is used as fuel. Later, an aerobic process is applied degrading nitrogen and phosphorus.

After waste water treatment, the water is either re-used in the factory or discharged into rivers or the open sea.

Example 5. Figure 4.2 shows a typical process flow diagram of the waste water treatment for a sugar beet processing installation.

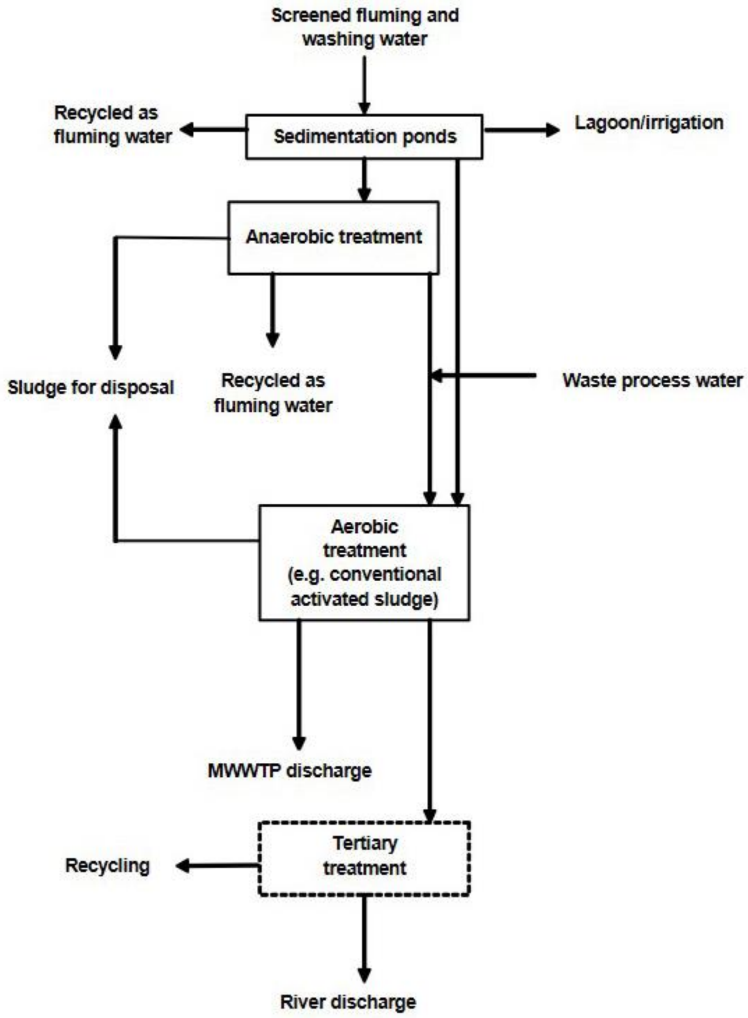


Figure 4.2 – Typical options for treating sugar beet waste water

Emission levels achieved. The performance of waste water treatment in the Sugar Industry of the Nordic countries is shown in Table 4.3.

Table 4.3 – Performance of waste water treatment in the Sugar Industry of the Nordic countries

Treatment	**BOD (mg/l)**	**Total N (mg/l)**	**Total P (mg/l)**
Before treatment	3300	120	10
After anaerobic treatment	100	80	8
After anaerobic and aerobic treatment	2	10	0.4

Figures per tonne of sugar beet processed in Danish sugar installations are given in Table 4.4.

Table 4.4 – Waste water production and main characteristics in Danish sugar installations

Parameter	**Total Average (range)**	**No treatment Average (range)**	**After anaerobic/ aerobic treatment**
Waste water m^3/t beets processed	0.79 (0.53–1.10)		

Table 4.4 (continued)

Waste water m^3/t sugar produced	5.13 (3.73–6.98)	5.59 (3.76–6.98)	
BOD kg/t sugar produced	10.3 (0.01–24.4)	14.6 (10.7–24.4)	0.01
Suspended solids kg/t sugar produced	1.25 (0.76–1.62)	1.16 (0.76–1.42)	n/a
Nitrogen kg/t sugar produced	0.27 (0.01–0.56)	0.33 (0.19–0.56)	0.03
Phosphate g/t sugar produced	31.3 (0.81–83.2)	40.4 (27.5–83.2)	1.22

Specific loads for waste water contaminants after biological waste water treatment are shown in Table 4.5.

Table 4.5 – Waste water loads after biological treatment during a sugar beet processing campaign

Parameter	**Sugar produced (kg/t)**
BOD_5	0.24
COD	2.4
TOC	0.9
Nitrogen_{total}	0.35

It is reported that waste water from sugar installations is sometimes not subject to waste water treatment, but is sent off-site for landspreading.

PRACTICE 5
Environmental technologies in the Fruit and Vegetable Sector

5.1 Water consumption

Water is used mainly during washing. It is also used during peeling and blanching. The fruit and vegetable canning industry in Greece consumes 7–15 m^3 water per tonne of product. Table 5.1 shows water consumption levels reported by, and achieved in, fruit and vegetable installations. Water consumption levels reported for some processes in the fruit and vegetable sector are shown in Table 5.2.

Table 5.1 – Water consumption levels achieved in fruit and vegetable installations

Product category	**Water consumption (m^3/t product)**
Canned fruit	2.5–4.0
Canned vegetables	3.5–6.0
Frozen vegetables	5.0–8.5
Fruit juices	6.5
Jams	6.0
Baby food	6.0–9.0

Table 5.2 – Water consumption for some processes in the fruit and vegetable sector

Type of processing	**Water consumption (m^3/t finished product)**
Deep frozen vegetables	2.5–5.0
non-peeled products, e.g. leeks, onions, aubergines, cabbage, blanched celery, rhubarb and courgettes	2.6
beans, peas, cauliflower, sprouts and flageolets	3.0
blanched leaf vegetables, e.g. spinach	5.1
peeled products, e.g. carrots, celery and potatoes	3.8
Preserved vegetables (range)	7–11
well managed	5.9
Potato processing (range)	4.5–9.0
well managed	5.1
Potato peeling company (well managed)	2.4

Tomatoes are one of the most processed raw materials. Italy is the second largest producer in the world after the US, and the largest exporter of tomato products. Reported figures for water and energy consumption together with waste water and solid waste production in the different processing steps for canned peeled tomatoes and tomato juice are summarised in Table 5.3 and Table 5.4.

Table 5.3 – Consumption and emission levels for canning tomatoes

Canned peeled tomatoes (whole and cut)						
Unit operation		**Water consumption (m^3/t)**	**Waste water load (kg COD/t)**	**By products/ solid wastes (kg/t)**	**Electrical energy (kWh/t)**	**Thermal energy (kg steam/t)**
No.	Description					
A.1	Materials handling and	0.2	1.5	10–15	1	

Table 5.3 (continued)

	storage					
A.2	Sorting screening, grading, dehulling, destemming/ destalking and trimming	1	0.1	0.2	1.5	
A.3	Peeling (refining)	0.5–2	3–5	25–30	2.5	100
A.4	Washing	2	2	0.2	0.5	
B.1	Cutting, slicing, chopping, mincing, pulping and pressing		1			
B.2	Mixing blending, homogenisation and couching					
C.5	Filtration		1			
E.2	Blanching		0.5		4–5	60
E.8	Pasteurisation, sterilisation and UHT	15–25(1)			2	450–500
	Cans and bottles					200–300
F.1	Evaporation (for juice)	10–12(1)			7–8	150–200
H.1	Packing and filling			0.5	1.5	
U.1	Cleaning and disinfection	1.5	1	0.2–1		
U.4	Vacuum generation	0.5			1–2	
	Overall totals of typical installations (all unit operations are not undertaken at each installation, so the totals are not the sum of the levels for each umt operation)	35–40	7–10	25–35	19–24	750–850
			6–8(2)			

(1)Not discharged, but recycled
(2)Waste water – m^3/t

Table 5.4 – Consumption and emission levels for manufacturing of tomato juice, puree and paste

Tomato juice, puree and paste (28–30 °Brix puree(1))						
Unit operation		**Water consumption (m^3/t)**	**Waste water load (kg COD/t)**	**By products/ solid wastes (kg/t)**	**Electrical energy (kWh/t)**	**Thermal energy (kg steam t)**
No.	**Description**					
A.1	Materials handling and storage	5	6	12	0.4	
A.2	Sorting[1] screening, grading, dehulling, destemming/ destalking and trimming	10	2		1.5	
A.3	Peeling (refining)			150–200	8–12	
A.4	Washing	15	5			

Table 5.4 (continued)

B.1	Cutting, slicing, chopping, mincing, pulping and pressing				2.5	
B.2	Mixing blending, homogenisation and conchins					
E.2	Blanching				15–25	700–900
E.8	Pasteurisation, sterilisation and UHT				0.5	60–80
F.1	Evaporation (liquid to liquid)	100–150(2)			60–80	1500–1800
F.2	Drying (liquid to solid)					
H.1	Packing and filling			1.5	3.5	10
U.1	Cleaning and disinfection		1			
U.4	Vacuum generation	1			4–5	
	Overall totals of typical installations (all unit operations are not undertaken at each installation, so the totals are not the sum of the levels for each unit operation)	**130–180(2)**	**10–12**	**160–210**	**90–125**	**2300–2800**
			60–80(2)			

(1)All figures are referred to 11 of 28–30 °Brix tomato puree. Conversion coefficients for other final products: 7–12 °Brix puree - multiply by 0.3; 20–22 °Brix puree - multiply by 0.7, 36–40 °Brix puree – multiply by 1.3;
(2)Without cooling towers

5.2 Waste water

Waste water characteristics are affected by various factors. These include the raw material being processed, seasonal and source variations, unit operations, production patterns and operator practice. Table 5.5 shows data reported for canning fruits and vegetables in the US.

Table 5.5 – Average waste water and water pollution generated in the US canning industry

Parameter	**Fruit**	**Vegetables**
Waste water volume (m^3/t raw material)	10.86	22.91
BOD_5 (kg/t raw material)	11.8	13.0
TSS (kg/t raw material)	2.2	6.6

Typically, waste water is high in SS, sugars and starches. Residual pesticides that are difficult to degrade during waste water treatment may be a concern, especially with produce from countries with less stringent controls on pesticide use. Reported levels of BOD and TSS in the waste water arising from the processing of various fruits and vegetables, are shown in Table 5.6 and Table 5.7.

Table 5.6 – BOD and TSS concentrations in waste water from fruit and vegetable processing

BOD <500 mg/l		BOD 500–1000 mg/l		BOD 1000–2000 mg/l	
Product	**TSS mg/l**	**Product**	**TSS mg/l**	**Product**	**TSS mg/l**
Citrus	130	Apple juice	104	Frozen potatoes	1716
Asparagus	43–114	Strawberries	96–210	Dried potatoes	981
Broccoli	100-455	Baby foods	101–533	Apricots	33–387
Brussel sprouts	29–1680	Peeled tomatoes	280–1280	Mushrooms	33–467
Cauliflowers	18–113	Tomato products	512–1180	Peaches	164–1020
Dehydrated vegetables	168–778			Plums	60–187
Leafy greens	19–419				
BOD 2000-3000 mg/l		**BOD 3000 - 5000 mg/l**		**BOD >5000 mg/l**	
Product	**TSS mg/l**	**Product**	**TSS mg/l**	**Product**	**TSS mg/l**
Carrots	262–1540	Dried fruit	8–568	Beetroots	367–4330
Grape juice	216-228	Jams, jellies, preserves	404–711	Whole potatoes	1660–24300
Peas	79–673	Pears	84–702	Sweetcom	131–2440
Potato crisps	1450–3910				

Table 5.7 – Waste water characteristics from some fruit and vegetable processing

Type of operation	SS (mg/l)	COD (mg/l)	BOD5 (mg/l)	N_{tot} (mg/l)	P_{tot} (mg/l)
Vegetables, frozen vegetables, preserves, fruit and vegetable juices	700	5000	3000	150	30
Potato processing	700	10000	3000	150	200
Potato peeling	1100	6000	2500	200	30
Fruit and vegetable juices(1) Apples Apples (without pressing)	33^{2} 16.5^{2}	5500 5100	2500 2500	26.5 27	21 23
Sour cherries	9^{2}	4000	2300	15	
Blackcurrants	24^{2}	4900	2600	13.5	12.5
Blackcurrants without pressing	21^{2}	4600	2100	–	9
Carrots	24^{2}	8600	2700		
(1)Rounded average figures; (2)Settleable solids after two hours, ml/l					

Specific waste water generation and pollution loads are presented in the next two tables. Table 5.8 shows reported loads per unit production that can be achieved by implementing pollution reduction measures, such as procuring clean raw fruit and vegetables, and the use of countercurrent systems for washing and recycling process water, although the specific techniques used for each example and the unit of product are not identified. Table 5.9 shows the waste water volume and water pollution per unit of product generated in the processing of some fruit.

Table 5.8 – Waste water volume and water pollution per unit of product generated in the processing of some vegetables

Product	**Waste water volume (m^3/U)**	**BOD$_5$ (kg/U)**	**TSS (kg/U)**
Asparagus	69.0	2.1	3.4
Broccoli	11.0	9.8	5.6
Brussels sprouts	36.0	3.4	11.0
Carrots	12.0	20.0	12.0
Cauliflowers	89.0	5.2	2.7
Maize			
Canned	4.5	14.0	6.7
Frozen	13.0	20.0	5.6
Dehydrated onions and garlic	20.0	6.5	5.9
Dehydrated vegetables	22.0	7.9	5.6
Dry beans	18.0	15.0	4.4
Lima beans	27.0	14.0	10.0
Mushrooms	22.0	8.7	4.8
Onions, canned	23.0	23.0	9.3
Peas			
Canned	20.0	22.0	5.4
Frozen	15.0	1S.0	4.9
Pickles			
Fresh packed	8.5	9.5	1.9
Process packed	9.6	18.0	3.3
Salting stations	1.1	8.0	0.4
Pimentos	29.0	27.0	2.9
Potatoes			
All products	10.0	18.0	16.0
Frozen products	11.0	23.0	19.0
Dehydrated products	8.8	11.0	8.6
Cabbage			
Canned	3.5	3.5	0.6
Cut	0.4	1.2	0.2
Snap beans			
Canned	15.0	3.1	2.0
Frozen	20.0	6.0	3.0
Spinach			
Canned	38.0	8.2	6.5
Frozen	29.0	4.8	2.0
Squash	5.6	17.0	2.3
Sweet potatoes	4.1	30.0	12.0
Tomatoes			
Peeled	8.9	4.1	6.1
Products	4.7	1.3	2.7
Unit of production (U) is not defined			

Table 5.9 – Waste water volume and water pollution per unit of product generated in the processing of some fruit

Product	Waste volume (m^3/U)	BOD_5 (kg/U)	TSS (kg/U)
Apricots	29.0	15.0	4.3
Apples All products	3.7	5.0	0.5
All except juice	5.4	6.4	0.8
Juice	2.9	2.0	0.3
Cranberries	5.8	2.8	0.6
Citrus	10.0	3.2	1.3
Sweet cherries	7.8	9.6	0.6
Sour cherries	12.0	17.0	1.0
Bing cherries	20.0	22.0	1.4
Cranberries	12.0	10.0	1.4
Dried fruit	13.0	12.0	1.9
Grapefruit Canned	72.0	11.0	1.2
Pressed	1.6	1.9	0.4
Peaches Canned	13.0	14.0	2.3
Frozen	5.4	12.0	1.8
Pears	12.0	21.0	3.2
Pineapples	13.0	10.0	2.7
Plums	5.0	4.1	0.3
Raisins	2.8	6.0	1.6
Strawberries	13.0	5.3	1.4

A reported typical process is shown in Figure 5.1.

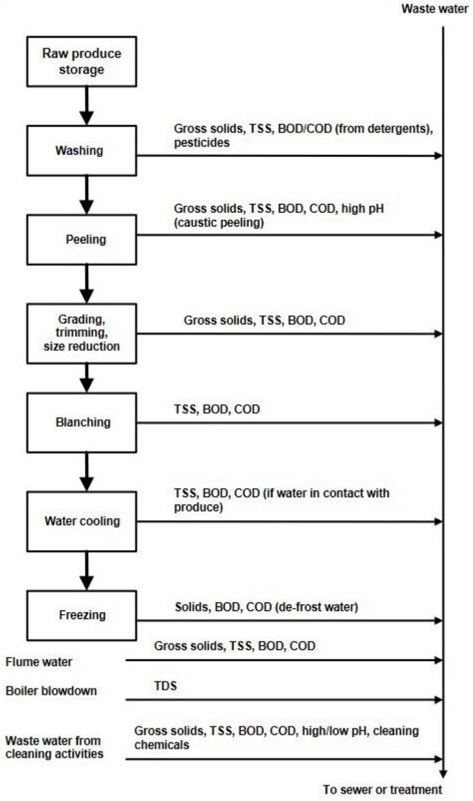


Figure 5.1 – Waste water produced in fruit and vegetable processing

The incoming produce is washed in chlorinated water to remove residual soil, stones and other debris and to reduce the microbial population. Large volumes of chlorinated water are required, especially for root vegetables which carry a lot of earth, and leafy vegetables which have a large surface area. Mechanical or air flotation techniques are used to aid soil removal and reduce the quantity of water used.

Some recirculation or re-use of water from other operations is common. Waste water from pre-washing mainly contains field debris and soil particles with small fragments of the fruit or vegetables. If detergents are used to increase cleaning efficiency, they contribute to the COD of the waste water.

Most processes involve some type of grading, trimming and size reduction. Sometimes density graders containing brines of different strength are used. Discharge of significant quantities of brine can adversely affect any biological WWTP. Washing of the produce after these operations creates waste water containing soluble starch, sugars and acids.

The use of water fluming to convey both the product and waste material causes additional leaching of these substances. Waste water from citrus fruit processing also contains pectic substances that can interfere with the sedimentation of SS. All lines, equipment and process areas that are not in designated dry areas require wet cleaning, which generates waste water contaminated with raw material, product and cleaning chemicals.

There are generally fewer requirements for aggressive chemicals in this sector than in others, unless oil or fat is used in processing.

5.3 Solid output

Large amounts of solid wastes are produced. These are organic materials, including fruit and vegetables discarded during selection, and those from processes such as peeling or coring. These typically have a high nutritional value and can be used as animal feed.

Undesired materials discarded from the first processing steps include soil and extraneous plant material, spoiled food stocks, and some trimmings, peels, pits, seeds and pulp.

When caustic agents are used for peeling fruit and soft vegetables, a highly alkaline or salty solid waste is produced. High moisture content solid wastes can be generated by wet cleaning and re-use operations in which the dissolved solids or SS are concentrated and separated from the waste water. Up to 50 % of fruit and typically 10 to 30 % of raw vegetable materials are wasted during processing.

Part of the waste goes to the waste water and significant amounts of solid wastes are also generated. Some reported figures are shown in Table 5.10.

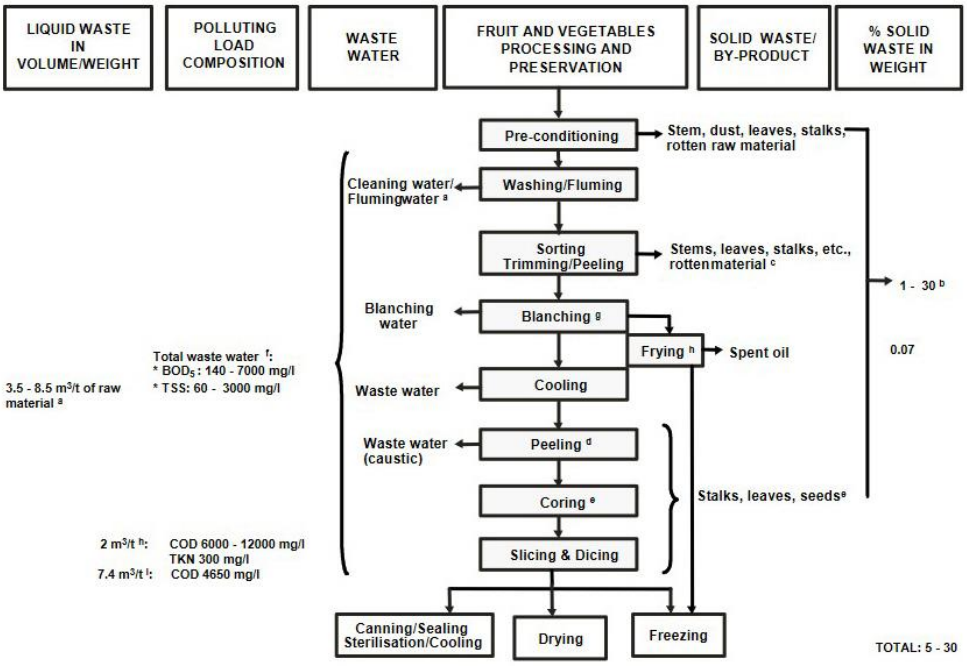
Table 5.10 – Solid waste produced during fruit and vegetable processing

Raw material processed	Solid waste produced per tonne of product (kg)
Maize	40
Peas	40
Potatoes	40

Table 5.10 (continued)

Strawberries	60
Apples	90
All vegetables	130
Peaches	180
Broccoli	200
Carrots	200
Frozen peaches*	200
*Product	

The reported types and amount of wastes produced in processing and preservation of fruit and vegetables are shown in Figure 5.2.



[a] Large quantities of water are used for processing fruit and vegetables, specially in cleaning operations. Very variable depending on the raw material and the type of process.

[b] There is a large difference of solid waste percentage depending on the type of vegetable or fruit, from 1 % in cranberries to 20 % in broccoli or carrots.

[c] Removal of rotten and injured fruits and vegetables by mechanical methods such as sieves and perforated plates. For the removal of very rotten fruits, salty solutions are used (brine density graders).

[d] Removal of peel. Different methods are used depending on the peel thickness, toughness and final's product demand: mechanical, thermal (steam) and chemical (NaOH) in case of potatoes it is steam peeling and takes place before blanching.

[e] Sometimes is necessary to do it mechanically (cherries) for seeds and kernels removal.

[f] Average total wastewater is around 3.7 m^3/U (unit of production), with average values of BOD_5 of 5 kg/U and TSS 0.5 kg/U.

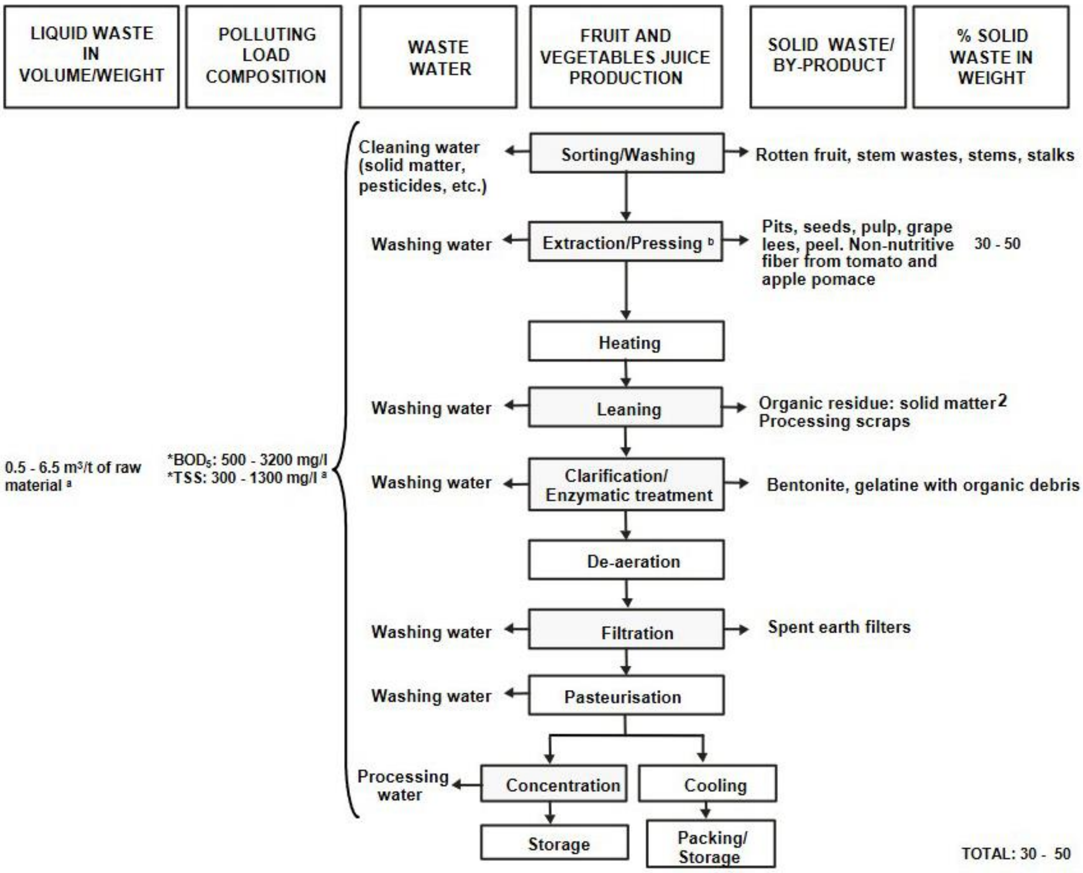
[g] Some products are not blanched such as preserved onions.

[h] For fried potatoes production. The wastewater from washing, steam peeling and blanching are sent to the WWTP and 5 l/t of anaerobic sludge is generated and incinerated.

[i] For the production of preserved potatoes and carrots (data from Finnish companies).

Figure 5.2 – Type and amount of wastes produced in fruit and vegetable processing and preservation

Some reported figures for producing fruit and vegetable juices are shown in Figure 5.3.



[a] Pollution load and water consumption are variable depending on the fruit or vegetable.
[b] For tomato juice production, grinding takes place before pressing.
[c] Membrane is also applied when treating leaning water.

Figure 5.3 – Type and amount of wastes produced in fruit and vegetable juice manufacturing

If fruit and vegetables are treated with enzymes during juice manufacturing, less waste is produced. Table 5.11 shows the effects of apple and tomato processing in Hungary.

Table 5.11 – Fruit and vegetable wastes in juice manufacturing in Hungary

Raw materials	**Type of pretreatment**	**Amount of waste (%)**
Apple	With enzyme Without enzyme	8–18 10–25
Tomato	With enzyme Without enzyme	2–6 4–8

Solid wastes are normally used for the production of animal feed and organic fertilisers. They may also be used for producing food or other marketable products, or disposed of in waste water or to land. Possible re-use and disposal routes for the different solid wastes produced are as follows:

- non-nutritive fibre from apple pomace, dried citrus peel and lecithin from soybeans, may be used for the production of foods such as fermented foods, drinks, oils and proteins, or for the development of biopolymers for elaboration of biodegradable packing and construction material. Pectin is extracted from apples. Citrus is extracted during juice production;

- citrus wastes, grape lees, grapes and potato processing wastes, may be used for biosynthesis of natural chemicals such as furfural, xylitol, alcohol, organic acids and polysaccharides, and pharmaceuticals such as hycogenin, antibiotics and vitamins. This option is growing as more opportunities are identified;
- production of animal feed from sugar beet pulp, apple and tomato pomace and citrus pulp pellets, without or after treatment (physical, chemical, microbial, ensilage, production of microbial biomass). This use is limited by several factors, including shipping, putrefaction during storage and transport, and the presence of undesirable constituents such as alkalis or salt. Water content is the major contributor to shipping costs and to some extent to the putrefaction rates. Putrefaction reduces the shelf-life and value of the solid wastes and limits its use as animal feed;
- peach and olive pits, rice hulls and straw, may be burnt directly, or converted to produce biogas or alcohol. Incineration is a viable option for solid wastes with a relatively low (< 10 %) water content. Catalytic gasification or pyrolysis may also be applied;
- composting and land application of organic waste is limited because of odour and possible soil contamination by leaching organics and salts.

Within the unit operations used in the fruit and vegetables sector, peeling is one of the major solid output and waste water producers. Steam peeling is generally used for large quantities of potatoes, carrots and other tubers. Pre-processing includes the washing and the separation of mud and stones. This solid waste has no value for bioconversion. The waste produced in peeling has solids, mainly peel, which are separated by sedimentation from the aqueous phase, dried and may be composted. They may be further treated to recover minerals, fibre and phenolics. The aqueous phase goes for waste water treatment together with waste water from other processes. Its pollution, before discharge to MWWTP, expressed in COD is about 4000 mg/l. Soluble vitamins, starch, fibre and tissue fluid may be recovered from this waste water. Mechanical peeling is used for small quantities of potatoes, carrots, apples, pears, etc. or when vegetables are used for catering or in institutional kitchens. The peeling is often performed outside the main processor. There are numerous peeling companies with varying capacity and equipment. The unit operations are basically the same as in steam peeling. The processing starts with the separation of mud and stones similar to the step for the steam peeling process. The peeling consists of three consecutive steps: mechanical pre-peeling, using, e.g. carborundum; knife peeling and then washing. Waste water is produced in all three steps. After sedimentation, the aqueous phase goes for waste water treatment. Its pollution expressed in COD is about 5000 mg/l. The separated solid phase is normally composted. Vitamins, starch, fibre and minerals may be recovered. Knife peeling produces a similar output as steam peeling and it can be used similarly, either directly as animal feed or for recovery of its components. About 60 % of the total organic solid waste produced comes from pre-peeling, by abrasion peeling and the rest is from knife peeling. After cutting, defective pieces which are, e.g. too dark or too small, are separated and used as animal feed. However, especially in carrot processing, several valuable substances such as vitamin C, fibre, phenolic compounds and carotenoids, can be recovered from this by-product. The next step is rinsing, and in the case of potato processing, this is usually combined with the addition of browning inhibitors or sulphites before transporting the peeled product to the main processing facility.

5.4 Energy

Processes involving heating, cooling, drying, evaporation, sterilisation, pasteurisation and blanching consume significant energy. Almost every process step requires electricity. For steam production, natural gas boilers can be used. The frozen vegetable sector is a large consumer of electricity and natural gas. Deep freezing is the process which uses the most electricity.

During deep freezing, cooling to a very low temperature level, i.e. -30 to -40ºC, is necessary. During this process, energy is consumed at a rate of 80 to 280 kWh$_e$/t of frozen vegetables. Other processes, e.g. washing, require less electrical energy, a maximum of 28 kWh$_e$/t of frozen product. Deep freezing carrots consumes ± 8 kWhe/t and freezing salsifies consumes ±20kWh$_e$/t and these require a lot of electrical energy for sorting. Washing spinach for deep freezing consumes ± 4 kWhe/t and is electricity intensive. The mechanical processing of frozen beans and salsifies consumes ± 6 kWh$_e$/t and ± 9 kWh/t respectively, i.e. much more electricity compared with other vegetables. The electricity consumption of the belt blancher with air cooling, which produces 7 to 30 kWh$_e$/t of frozen product, is significantly higher than that of the belt blancher with water cooling, which produces 2 to 9 kWh$_e$/t of frozen product, or the drum blancher with countercurrent water cooling, which produces 1 to 2.6 kWh$_e$/t of frozen product. Spinach requires most electricity for intermediate processes such as packing or making of portions Steam is used for peeling and blanching. Steam peeling uses approximately five times more steam than caustic peeling. Belt blanching with water cooling consumes approximately half the energy of belt blanching with air cooling or drum blanching with countercurrent water cooling. For storage, electricity consumption is between 20 and 65 kWh$_e$/m^3 of storage space/year.

Data for some fruit and vegetable products. Fresh-pack. Fresh-pack fruit and vegetables require minimal processing. Water consumption is mainly for produce washing, transport flumes and line cleaning. Processing installations are often close to growing areas, creating opportunities for the use of waste water in irrigation. Some fresh-pack vegetables require peeling.

Preserved fruit and vegetables. Fruit and vegetables that are to be preserved undergo further processing. The most common types are discussed below. Many vegetables and some fruits require peeling, which can be a major source of BOD and TSS and represent a substantial proportion of the total waste water volume. Peeling is usually followed by washing. Conventional steam peeling uses large quantities of water and produces waste water with high levels of product residue. At potato processing installations, the peelings can contribute up to 80 % of the total BOD. In fruit processing, peeling waste water can account for as much as 10 % of the total waste water flow and 60 % of the BOD. Water cooling in steam peeling increases water consumption. Caustic peeling causes higher solubilisation of material and consequently a higher COD, BOD and SS load than mechanical peeling, which is a combination of knife and abrasion peeling. Furthermore, the use of caustic in peeling may lead to pH fluctuations in the waste water. Dry caustic peeling tends to have a lower caustic consumption than wet methods and can greatly reduce the volume and strength of the waste water from this operation and allows for the collection of peel as a pumpable slurry. Blanching is used in most vegetables destined for canning, freezing or drying. Typically, it is carried out using hot water or steam. If the produce is to be frozen, blanching is followed by water or air cooling.

Both water and steam blanching produce waste water high in BOD; in some cases, over half of the total BOD load. The volume of waste water is less with steam blanching than with water blanching. The quantity of waste water from steam blanching can be reduced by steam recycling, effective steam seals and equipment designs that minimise steam consumption. Waste water can be completely eliminated by microwave blanching, which is used in Europe and Japan.

For fruit and vegetable products which can be microbiologically sterilised at temperatures not higher than 100ºC, sterilising, which, in this case, is generally named pasteurisation, can be carried out in installations using hot water or steam at atmospheric pressure. The most traditionally used low temperature process is the open bath. These are metallic cylindrical or parallel piped baths, containing water heated by direct steam injection with a nozzle placed on the bottom. These baths are not generally equipped with automatic thermostats. The operating temperature is the boiling point of water at atmospheric pressure with a continuous flow of excess steam. The packs to be sterilised are loaded into large baskets; the baskets, by means of pulleys, are immersed in the baths and treated by boiling water for the required time. Cooling does not generally take place in the sterilising bath itself, which is thus ready to receive a new load, but in another bath containing cold running water.

For products packaged in glass containers, linear tunnels are used, including the phases of feeding, preheating, heating, precooling, cooling and drying. Heating is by means of saturated dry steam or hot water coming down on the packs from the top from a series of nozzles or by simple percolation from a perforated ceiling. The water is then recovered in recycling baths equipped with direct or indirect steam heating. Cooling is also carried out by sprinkling with water. Precooling water is partially recycled, thus keeping it at around 60ºC. The drying step is indispensable for the prevention of marks on the cap and above all to enable labelling and secondary online packaging. It is carried out by means of hot or cold air blowers. To sterilise low acidity products, which require temperatures greater than 100ºC, various means of heating can be used, although autoclaves are predominantly used. All high temperature sterilisers operate at pressure higher than atmospheric.

Single-phase acid products or products with small pieces, such as fruit juices, vegetable juices and purees, tomato purees, jams, marmalades and jellies, can be hot-filled. Heat sterilisation may be carried out before packaging because of the low pH and/or awof these products. The hot product itself sterilises the metal or glass container, so that only the caps and necks of bottles, and lids of small containers, need to be sterilised separately. Filling and hermetic closure of the container need to be carried out before the product cools down. The filling temperatures must be kept between 85–92ºC. In all cases, the subsequent cooling is undertaken with sterilised chlorinated water.

Finally, aseptic packaging is undertaken. It is a combination of sterilising plants for the product and for the containers of various types, with an isolated system of filling and sealing.

The aseptic packaging of liquid products involves the following sequence of operations: heating at pre-fixed temperatures; transfer to a holding section; cooling at a temperature of around 35ºC; filling of the pre-sterilised pack, opening and kept in conditions of perfect asepsis; and closure of the pack. The type of heat-exchanger is selected according to the rheological properties of the fluid.

Pickling is also an important operation for the preservation of fruit and vegetables. The following process phases produce brine; fresh brine after slashing and salting (100–150 kg/t of white cabbage) and sour brine in the course of lactic fermentation (150–180 kg/t of white cabbage). The blanching process is carried out in sour brine, which produces blanching brine.

Table 5.12 shows the waste water values of brine during the production of cabbage.

Table 5.12 – Waste water values of brine during the production of Sauerkraut

Brine	**PH**	**Concentration in waste water**		
		BOD_5 (mg/l)	**COD (mg/l)**	**Chloride (mg/l)**
Fresh brine	6.0–6.2	10000–30000	15000–40000	12000–15000
Fermentation brine	3.8–4.2	17000–50000	25000–75000	2500–20000
Blanching brine	3.8–4.0	40000–55000	65000–85000	–

Frozen vegetables. Materials handling and storage (A.1). In manufacturing frozen vegetables, transportation and storage operations require energyas follows:

• the transportation of frozen vegetables requires 2–14 kWh_e/t frozen vegetables. For most production lines, the electrical rating of the belts is between 5–30 $kW_{e;}$

• the storage of vegetables needs 20–65 kWh_e/m^3 storage/year electricity and about 26.389 kWh/m^2 (95 MJ/m^2) storage/year is needed in the form of hot water. Data from the literature show that the average energy balance is made up as follows:

•11 % for the evaporator fans;

•5 % for the condenser fans;

•7 % for peripheral equipment;

•77 % for compressors, of which 21 % is used for heat input via doors/hatches, 48 % used due to losses via the building shell, and 8 % through the product. Sorting/screening, grading, dehulling, destemming/destalking and trimming (A.2).

The sorting operation has an electrical energy consumption of 0–20 kWh_e/t frozen vegetables. Table 5.13 shows the electricity consumption during the sorting of vegetables.

Table 5.13 – Electricity consumption during the sorting of vegetables

Product	Electricity consumption (kWh$_e$/t frozen vegetables)
Spinach	0
Cauliflowers	1
Peas	4
Sprouts	4
Beans	5
Carrots	8

Peeling (A.3). In frozen vegetable processing, salsifies and carrots are peeled before being mechanically processed. Caustic peeling and steam peeling are two methods used. Caustic peeling needs less energy, both in terms of electricity consumption and steam consumption, than steam peeling, but creates more load for the WWTP. Table 5.14 shows the energy carrier and consumption for the caustic peeling of vegetables and Table 5.15 shows the energy carrier and consumption for the steam peeling of vegetables.

Table 5.14 – Energy carrier and consumption for the caustic peeling of vegetables

Energy carrier	Approximate consumption
Hot water (kWh t frozen vegetables)	0
Steam (t/t frozen vegetables)	0.16
Steam pressure (bar)	7
Electricity (kWh t frozen vegetables)	2

Table 5.15 – Energy carrier and consumption for the steam peeling of vegetables

Energy carrier	Approximate consumption
Hot water (kWh/t frozen vegetables)	0
Steam (t/t frozen vegetables)	0.9
Steam pressure (bar)	4–15
Electricity (kWh/t frozen vegetables)	3.5

Washing (A.4). Washing, as used in the production of frozen vegetables, needs 0–5 kWh$_e$/t frozen vegetables. Certain vegetables, e.g. sprouts and cauliflowers, do not require any washing and thus do not consume energy. Table 5.16 shows the electricity consumption for the washing of vegetables.

Table 5.16 – Electricity consumption for the washing of vegetables

Product	Electricity- consumption (kWh$_e$/t frozen vegetables)
Sprouts	0
Cauliflowers	0
Beans	0.5
Carrots	2.5
Salsifies	3
Peas	3
Spinach	5

Cutting, slicing, chopping, mincing, pulping and pressing (B.1). Some vegetables are cut before deep freezing. The electrical energy consumption is up to 9 kWh/t frozen vegetables. Table 5.17 shows the electricity consumption of mechanical processing of vegetables before freezing.

Table 5.17 – Electricity consumption of mechanical processing of vegetables before freezing

Product	**Electricity consumption (kWh_e/t frozen vegetables)**
Peas	0
Sprouts	0
Spinach	0
Carrots (sliced)	1
Carrots (diced)	2.5
Salsifies	6
Beans	9
Peas	0

Carrots, salsifies and beans require a reasonable amount of electrical energy for mechanical processing. Other vegetables examined do not require any electricity at all.

Blanching (E.2). Drum and belt blanchers are used in manufacturing deep frozen vegetables. Energy consumption depends on, not only the type of blanching device, but also the type of subsequent cooling step. Typical energy consumption levels are shown in Table 5.18 and Table 5.19.

Table 5.18 – Energy source and consumption for drum blanching in the deep freezing of vegetables

Energy carrier	**Approximate consumption**
Hot water (kWh_e/t frozen vegetables)	0
Steam (t/t frozen vegetables)	0.16
Steam pressure (bar)	7
Electricity (kWh_e/t frozen vegetables)	0.5–1.3

Table 5.19 – Energy source and consumption for countercurrent water cooling of vegetables processing

Energy carrier	**Approximate consumption**
Hot water (kWh/t frozen vegetables)	0
Steam (t/t frozen vegetables)	0
Steam pressure (bar)	0
Electricity (kWh_e/t frozen vegetables)	0.5–1.3

Furthermore, the electricity consumption for the production of ice-water is included in the electricity consumption shown for deep freezing. For example, in terms of energy consumption, the belt blancher with water cooling has the lowest total consumption. The heat released by the cooling of the product in the cooling zone is used to preheat the vegetables. In this way, less steam is necessary for blanching. Table 5.20 shows the energy carrier and consumption for belt blancher with water cooling in vegetable processing and Table 5.21 shows the energy carrier and order of magnitude indicators of the belt blancher with air cooling in vegetable processing.

Table 5.20 – Energy carrier and consumption for a belt blancher with water cooling in vegetable processing

Energy carrier	Approximate consumption
Hot water (kWh/t frozen vegetables)	0
Steam (t/t frozen vegetables)	0.09
Steam pressure (bar)	7
Electricity (kWh_e/t frozen vegetables)	2–9

Table 5.21 – Energy carrier and order of magnitude indicators of a belt blancher with air cooling in vegetable processing

Energy carrier	Order of magnitude indicators
Hot water (kWh/t frozen vegetables)	0
Steam (t/t frozen vegetables)	0.16
Steam pressure (bar)	7
Electricity (kWh_e/t frozen vegetables)	7–30

With regard to electricity consumption, the drum blancher for countercurrent water cooling has the lowest consumption. The water consumption for such an installation is rather high. The use of heavy duty fans (60 kW_e) in the belt blancher with air cooling, make the electricity consumption high for this type of operation.

Juices. Energy is consumed when the juice is concentrated by evaporation and during pasteurisation. Waste water is produced from the condensate during evaporation and during start-up, product change-over and cleaning of pasteurisers. Solid wastes are produced during the pressing of fruit and vegetables. For example, 2 % of tomatoes and 30 % of citrus fruits may be lost as solid wastes during pressing.

Other products. Jams, jellies and preserves are based on the production of fruit gels, that come from extracted juices, purees or the whole fruit respectively. Fruit gels are composed of pectin, acid, sugar and water. The use of sugar and additional cooking tends to increase the BOD of waste water compared with most other fruit processing. The presence of natural or added pectin in the waste water may have an adverse effect on solids settling.

5.5 Waste water characteristics

The processing of fruit and vegetables produces a large volume of waste water, which generally contains high organic loads, e.g. from peeling and blanching; cleaning agents, e.g. disinfectants such as chloride, soil particles, SS such as fibres, dissolved solids, salts, nutrients and plant pathogens. It may also contain pesticide and fungicide residues from the washing of the raw materials. Other parameters to be considered for waste water treatment are pH, temperature, salts. The characteristics of the waste water depend on various factors, such as:

- quality of the influent water and the rate of consumption;
- the type of raw materials processed and the type of processing carried out, e.g. peeling, blanching and canning;

- the condition of the raw material, e.g. damage, ripeness;
- seasonal variations;
- type of equipment used;
- wet or dry transportation of the products;
- cleaning operations and the type of cleaning agents used.

The most important pollutants in the fruit and vegetable sector are BOD and SS. It may be necessary to measure pesticide levels, to comply with local legislation. In the US if levels exceed 0.05 mg/l, corrective action must be taken.

5.6 Waste water treatment

The following treatment options are not necessarily applicable to potato processing. Before waste water treatment, segregation of water streams is typically applied in the fruit and vegetable sector. After segregation, primary treatment is applied and the following techniques are used:

- screening;
- flow and load equalization;
- neutralisation;
- sedimentation;
- DAF;
- centrifugation;
- precipitation.

SS and soil are better separated using sedimentation than DAF. However, if the waste water contains appreciable levels of FOG, then a combination of sedimentation and DAF is typically applied.

For the waste water of peeling operations, the use of chemicals may restrict the nutritional exploitation of the separated peel mass. In fact, if peel mass is used for nutrition, separate waste water treatment is needed. Steam peeling plants may have separate units. In some instances, waste water after primary treatment can be discharged into the MWWTP. For discharges to watercourses, or for treating waste water to a quality suitable for re-use, secondary treatment is required. Due to the seasonal operation, biological treatment of waste water from the fruit and vegetable sector may represent a problem for the operators. For waste water with a BOD concentration greater than 1000–1500 mg/l, anaerobic treatment processes can be used. After this treatment, waste water may be discharged to a MWWTP following surface aeration, but not to water bodies. For lower strength waste water streams, aerobic treatment can be used. The waste water from fruit and vegetable processing is often deficient in nitrogen and phosphorus and may require supplements of these nutrients to support adequate biological activity. Nitrification and dephosphatation processes can be stimulated by controlling aeration. A two-stage biological system, anaerobic followed by aerobic, may achieve a quality of waste water suitable for discharge to a watercourse.

If stricter permit conditions are in place due to the receiving water, or if the water is to be recycled in the process, then tertiary treatment is needed. If the recycled water is to be used in processing areas as drinking water, tertiary treatment, including disinfection and sterilisation, is essential.

Figure 5.4 illustrates a flow sheet of typical waste water treatment techniques used in the fruit and vegetable sector.

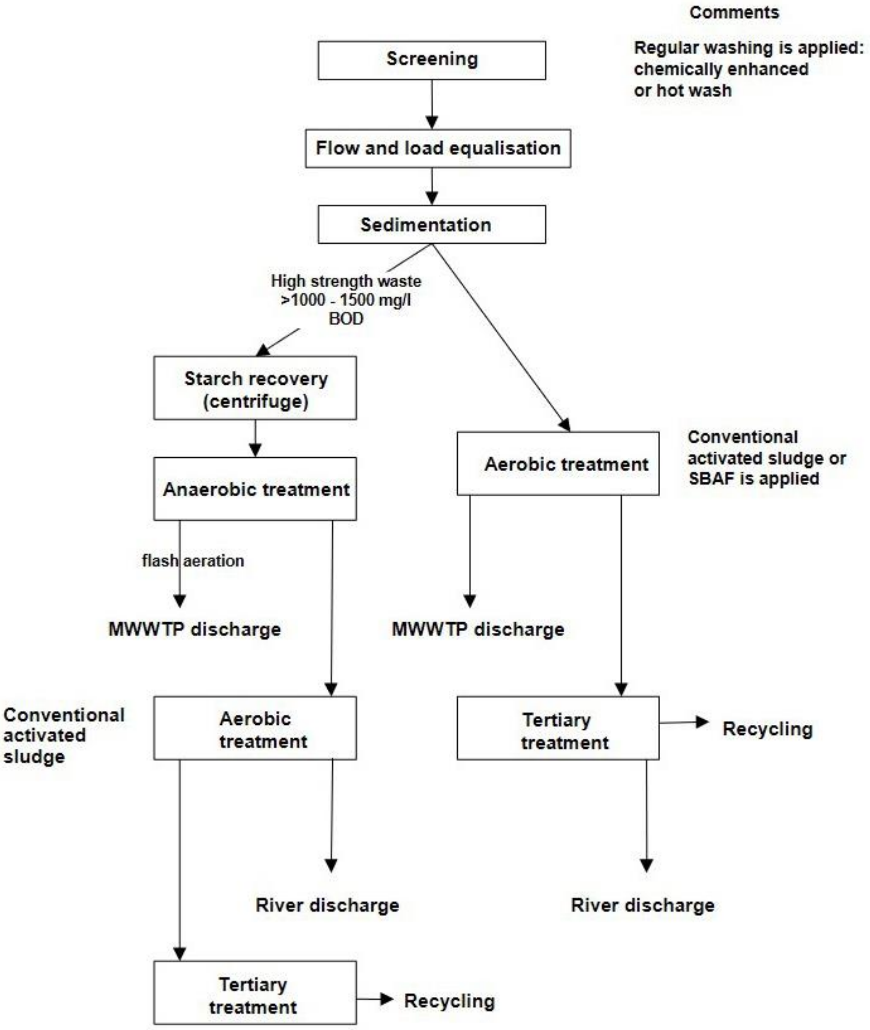


Figure 5.4 – Flow sheet of typical waste water treatment in the fruit and vegetable sector

Table 5.22 shows some waste water treatment combinations reported for the fruit and vegetable sector.

Table 5.22 – Some waste water treatment combinations reported for the fruit and vegetable sector

No	Combination of techniques
1	Primary treatments
2	Primary treatments + Aerobic processes
3	Primary treatments + Anaerobic processes + Aerobic processes
4	Primary treatments + Anaerobic processes + Aerobic processes + Biological nitrification/denitrification + Phosphorus removal by biological methods
5	Primary treatments + Anaerobic processes + Aerobic processes + Biological nitrification/denitrification + Phosphorus removal by biological methods + Precipitation + Filtration
6	Primary treatments + Anaerobic processes + Aerobic processes + Biological nitrification/denitrification + Phosphorus removal by biological methods + Precipitation + Filtration + Carbon adsorption

Table 5.22 (continued)

7	Primary treatments + Anaerobic processes + Aerobic processes + Biological nitrification/denitrification + Phosphorus removal by biological methods + Precipitation + Filtration + Carbon adsorption + Membrane separation, i.e. CMF
8	Primary treatments + Anaerobic processes + Aerobic processes + Biological nitrification/denitrification + Phosphorus removal by biological methods + Precipitation + Filtration + Carbon adsoiption + Membrane separation, i.e. RO

PRACTICE 6
Treatment of Meat Wastes

6.1 Processing facilities and wastes generated

Waste Characteristics and Quantities Generated. Wastewater Flow. Water is used in the slaughterhouse for carcass washing after hide removal from cattle, calves, and sheep and after hair removal from hogs. It is also used to clean the inside of the carcass after evisceration, and for cleaning and sanitizing equipment and facilities both during and after the killing operation. Associated facilities such as stockyards animal pens, the steam plant, refrigeration equipment, compressed air, boiler rooms, and vacuum equipment will also produce some wastewater, as will sanitary and service facilities for staff employed on site: these may include toilets, shower rooms, cafeteria kitchens, and laboratory facilities.

Meat plant waste water can be classified into four major categories, defined as manure-laden; manure-free, high grease; manure-free, low grease; and clear water (Table 6.1).

Table 6.1 – Examples of Wastewater Types and Arisings from Slaughtering and Processing

Wastewater	Examples
Manure-laden	Holding pens, gut room washwaters, scald tanks, dehairing and hairwashing, hide preparation, bleed area cleanup, laundry, casing preparation, catch basins
Manure-free, high grease water	Drainage and washwater from slaughter floor area (except bleeding and dehairing), carcass washers, rendering operations
Manure-free, low grease water (slaughterhouse)	Washwater from nonproduction areas, finished product chill showers, coolers and freezers, edible and inedible grease, settling and storage tank area, casing stripper water (catch basin effluent), chitterling washwater (catch basin effluent), tripe washers, tripe and tongue scalders
Manure-free, low grease water (cutting rooms, processing and packing)	Washwater from nonproduction areas, green meat boning areas, finished product packaging, sausage manufacture, can filling area, loaf cook water, spice preparation area
Clear water	Storm water, roof drains, cooling water (from compressors, vacuum pumps, air conditioning) steam condenser water (if cooling tower is not used or condensate not returned to boiler feed), ice manufacture, canned product chill water

The quantity of wastewater will depend very much on the slaughterhouse design, operational practise, and the cleaning methods employed. Wastewater generation rates are usually expressed as a volume per unit of product or per animal slaughtered and there is a reasonable degree of consistency between some of the values reported from reliable sources for different animal types.

Wastewater Characteristics. Effluents from slaughterhouses and packing houses are usually heavily loaded with solids, floatable matter (fat), blood, manure, and a variety of organic compounds originating from proteins.

The composition of effluents depends very much on the type of production and facilities. The main sources of water contamination are from lairage, slaughtering, hide or hair removal, paunch handling, carcass washing, rendering, trimming, and cleanup operations. These contain a variety of readily biodegradable organic compounds, primarily fats and proteins, present in both particulate and dissolved forms.

The wastewater has a high strength, in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), nitrogen and phosphorus, compared to domestic wastewaters. The actual concentration will depend on in-plant control of water use, byproducts recovery, waste separation source and plant management.

In general, blood and intestinal contents arising from the killing floor and the gut room, together with manure from stockyard and holding pens, are separated, as best as possible, from the aqueous stream and treated as solid wastes.

The wastewater contains a high density of total coliform, fecal coliform, and fecal streptococcus groups of bacteria due to the presence of manure material and gut contents. Numbers are usually in the range of several million colony forming units (CFU) per 100 ml. It is also likely that the wastewater will contain bacterial pathogens of enteric origin such as *Salmonella* sp. and *Campylobacter jejuni*, gastrointestinal parasites including *Ascaris* sp., *Giardia lamblia,* and *Cryptosporidium parvum,* and enteric viruses. It is therefore essential that slaughterhouse design ensures the complete segregation of process washwater and strict hygiene procedures to prevent cross-contamination.

The mineral chemistry of the wastewater is influenced by the chemical composition of the slaughterhouse's treated water supply, waste additions such as blood and manure, which can contribute to the heavy metal load in the form of copper, iron, manganese, arsenic, and zinc, and process plant and pipework, which can contribute to the load of copper, chromium, molybdenum, nickel, titanium, and vanadium.

Wastewater minimization. Water use minimization methods include:

- the use of directional spray nozzles in carcass washing, which can reduce water consumption by as much as 20 %;
- use of steam condensation systems in place of scald tanks for hair and nail removal;
- fitting washdown hoses with trigger grips;
- appropriate choice of cleaning agents;
- reuse of clear water (e.g., chiller water) for the primary washdown of holding pens.

6.2 Wastewater treatment processes

6.2.1 Primary Treatment

Grease removal is a common first stage in slaughterhouse wastewater treatment, with grease traps in some situations being an integral part of the drainage system from the processing areas. A typical grease trap has a minimum detention period of about 30 minutes, but the period need not to be greater than 1 hour.

Dissolved air flotation has become a well-established unit operation in the treatment of abattoir wastes, primarily as it is effective at removing fats from the aqueous stream within a short retention time (20–30 minutes), thus preventing the development of acidity. Operated efficiently the DAF unit can remove 15–30 % COD/BOD, 30–60 % SS, and 60–90 % of the oil and grease without chemical addition.

Chemical treatment can improve the pollution removal efficiency of a DAF unit, and typically ferric chloride is used to precipitate proteins and polymers used to aid coagulation. The adjustment of pH using sulfuric acid is also used in some slaughterhouses to aid the precipitation of protein.

It must be borne in mind that although chemical treatment can be used successfully to reduce pollution load, especially of soluble proteinaceous material, it results in much larger quantities of readily putrescible sludge. It will, however, significantly reduce the nutrient load onto subsequent biological processes. In many existing plants a conventional train of unit operations is used, in which solids are removed from the wastewater using a combination of screens and settlement. Screening is usually carried out on a fine-mesh screen (1/8 to 1/4 inch aperture, or 0.3–0.6 cm), which can be of vibrating, rotating, or mechanically cleaned type. The screen is designed to catch coarse materials such as hair, flesh, paunch manure, and floating solids. Removals of 9 % of the suspended solids on a 20-mesh screen and 19 % on a 30-mesh screen have been reported. The coarser 20-mesh screen gives fewer problems of clogging, but even so the screen must be provided with some type of mechanism to clean it. In practice mechanically cleaned screens using a brush type of cleaner give the best results. Finer settle able solids are removed in a sedimentation tank, which can be of either a rectangular or circular type.

The nature of operations within a slaughterhouse means that the wastewater characteristics vary considerably throughout the course of a working day or shift. It is therefore usually necessary to include a balancing tank to make efficient use of any treatment plant and to avoid operational problems. The balancing tank should be large enough to even out the flow of wastewater over a 24 hour-period.

6.2.2 Secondary Treatment

Physico-Chemical Secondary Treatment. Chemical treatment of meat-plant wastes is not a common practise due to the high chemical costs involved and difficulties in disposing of the large volumes of sludge produced. There are, however, instances where it has been used successfully. For example, using chlorine and alumin sufficient quantities could significantly reduce the BOD and color of the wastes.

Biological Secondary Treatment. Using biological treatment, more than 90 % efficiency can be achieved in pollutant removal from slaughterhouse wastes. Commonly used systems include lagoons (aerobic and anaerobic), conventional activated sludge, extended aeration, oxidation ditches, sequencing batch reactors, and anaerobic digestion. A series of anaerobic biological processes followed by aerobic biological processes is often useful for sequential reduction of the BOD load in the most economic manner, although either process can be used separately.

Anaerobic Treatment. Anaerobic digestion is a popular method for treating meat industry wastes. In the United States anaerobic systems using simple lagoons are by far the most common method of treating abattoir wastewater. These are not particularly suitable for use in the heavily populated regions of western Europe due to the land area required and also because of the difficulties of controlling odours in the urban areas where abattoirs are usually located. The extensive use of anaerobic lagoons demonstrates the amenability of abattoir wastewaters to anaerobic stabilization, however, with significant reductions in the BOD at a minimal cost. The anaerobic lagoon consists of an excavation in the ground, giving a water depth of between 3–5 m, with a retention time of 5–15 days. The BOD reductions vary widely, although excellent performance has been reported in some cases, with reductions of up to 97 % in BOD, up to 95% in SS, and up to 96 % in COD from the influent values. Table 6.2 summarizes some of the literature data on the performance of anaerobic lagoons for the treatment of slaughterhouse wastes.

Table 6.2 – Treatment of Meat Industry Wastes by Anaerobic Lagoon

Loading rate (kgBOD/m^3 day)	**Retention time (days)**	**Depth (m)**	**BOD removal (%)**
–	16	2.1	80
0,13	7–8	4,6	60
0,19	5	4,3	80
0,20	–	3,2	86
0,41	3,5	4,6	87
0,21	1,2	4,6	58
0,15	11	2,7	92
0,16	–	4,6	65

Anaerobic filters have also been applied to the treatment of slaughterhouse wastewaters. These maintain a long SRT by providing the microorganisms with a medium that they can colonize as a biofilm. Unlike conventional aerobic filters, the anaerobic filter is operated with the support medium submerged in an upflow mode of operation. Because anaerobic filters contain a support medium, there is potential for the interstitial spaces within the medium to become blocked, and effective pretreatment is essential to remove suspended solids as well as solidifiable oils, fats, and grease.

The third type of high-rate anaerobic system that can be applied to slaughterhouse wastewaters is the upflow anaerobic sludge blanket reactor (UASB). This is basically anexpanded-bed reactor in which the bed comprises anaerobic microorganisms, including methanogens, which have formed dense granules. The mechanisms by which these granules form are still poorly understood, but they are intrinsic to the proper operation of the process. The influent wastewater flows upward through a sludge blanket of these granules, which remain within the reactor as their settling velocity is greater than the upflow velocity of the wastewater.

Aerobic Treatment. Aerobic biological treatment for the treatment of biodegradable wastes has been established for over a hundred years and is accepted as producing a good-quality effluent, reliably reducing influent BOD by 95 % or more. Aerobic processes can roughly be divided into two basic types: those that maintain the biomass in suspension (activated sludge and its variants), and those that retain the biomass on a support medium (biological filters and its variants). There is no doubt that either basic type is suitable for the treatment of slaughterhouse wastewater.

Waste Stabilization Ponds. A waste stabilization pond (WSP) is the simplest method of aerobic biological treatment and can be regarded as bringing about the natural purification processes occurring in a river in a more restricted time and space. They are often used in countries where plenty of land is available and weather conditions are favorable.

Biological Filters. Biological filters can also be used for treating meat industry wastes. In this process the aerobic microorganisms grow as a slime or film that is supported on the surface of the filter medium. The wastewater is applied to the surface and trickles down while air percolates upwards through the medium and supplies the oxygen required for purification.

However, biological filters have not been widely adopted for the treatment of slaughterhouse wastewaters despite the lower operating costs compared with activated sludge systems. Obtaining an effluent with a low BOD and ammonia in a single-reactor system can provide conditions suitable for the proliferation of secondary grazing macro-invertebrate species such as fly larvae, and this may be unacceptable in the vicinity of a slaughterhouse. There is also the need for very good fat removal from the influent wastewater flow, as this will otherwise tend to coat the surface of the biofilm support medium.

Rotating Biological Contactors. Rotating biological contactors (RBCs) are also fixed biofilm reactors, which consist of a series of closely spaced circular discs mounted on a longitudinal shaft. The discs are rotated, exposing the attached microbial mass alternately to air and to the wastewater being treated, and allowing the adsorption of organic matter, nutrients, and oxygen.

Aerated Filters. These comprise of an open tank containing a submerged biofilm support medium, which can be either static or moving. The tank is supplied with air to satisfy the requirements of the biooxidation process.

Activated Sludge. The activated sludge process has been successfully used for the treatment of wastewaters from the Meat Industry for many decades. It generally has a lower capital cost than standard-rate percolating filters and occupies substantially less space than lagoon or pond systems.

6.3 Solid wastes

If good operational practise is followed in the slaughterhouse, the solids and organic loading entering the aqueous phase can be minimized. The separated solids still require treatment prior to disposal, however, and traditional rendering of some of these fractions is uneconomic because of the high water and low fat content. These fractions are the gut manures, the manure and bedding material from holding pens, material from the wastewater screens and traps on surface drains, sedimentation or DAF sludge, and possibly hair where no market exists for this material. Other high-protein and fat-containing residues such as trimmings, nonedible offal, and skeletal material can be rendered to extract tallow and then dried to produce meat and bone meal.

Land Disposal. The EU Animal By-products Regulations now prohibit land disposal of all animal wastes with the exception of manures and digestive tract contents, and these only when “the competent authority does not consider them to present a risk of spreading any serious transmissible disease.” The blood will need to be treated in an approved rendering, biogas, or composting plant before it can be land-spread.

Anaerobic Digestion. Anaerobic digestion of abattoir solid wastes is not common in the United States, UK, or elsewhere, despite the potential for stabilization of the solid residues with the added bonus of fuel gas production. One successful operation is the Kristianstad biogas plant in Sweden, which co-processes organic household waste, animal manure, gastrointestinal waste from two slaughterhouses, biosludge from a distillery, and some vegetable processing waste. The slaughterhouse waste fraction is 24,600 tonnes per annum of a total throughput of 71,200 tonnes which is treated in the 4500 m^3 digester.

PRACTICE 7
Environmental issues in the Fish and Seafood Sector

Major environmental impacts associated with fish processing operations are the high consumption of water, consumption of energy and the discharge of a waste water with a high organic concentration due to the presence of oils, proteins and SS. Waste water can also contain high levels of phosphates, nitrates and chloride.

Noise, odour and solid wastes may also be concerns for some installations. In addition to this, due to its highly perishable nature when compared to other FDM products, if not properly refrigerated, product yield decreases and product losses contribute to the solid and liquid waste loads. These solids may be used in fish-meal production.

In seafood-processing industries, odour is caused by the decomposition of the organic matter, which emits volatile amines, diamines, and sometimes ammonia. In wastewater that has become septic, the characteristic odour of hydrogen sulfide may also develop. Odour is a very important issue in relation to public perception and acceptance of any wastewater treatment plant. Although relatively harmless, it may affect general public life by inducing stress and sickness.

7.1 Water consumption

To meet quality and hygiene standards, the fish sector uses high quantities of water. It is mainly consumed for cleaning operations and washing, cooling, and transportation of fish. Fish canning and fish filleting consume large quantities of water, e.g. to clean and lubricate the filleting machinery. Typical figures for fresh water consumption are for thawing, about 1 m^3/t fish; for filleting 5 to 11 m^3/t fish, and for canning, 15 m^3/t fish. Water is used for transporting fish and viscera, for cleaning the installation and the equipment, for washing raw materials and products, and for thawing.

Reported water consumption and specific COD loads for traditional fish processing are summarised in Table 7.1.

Table 7.1 – Specific water consumption and organic load in Nordic countries

Production	Water consumption (m^3/t raw fish)	COD (kg/t raw fish)
Herring filleting	3.3–10	Up to 95
Mackerel		
Cleaning and head cut	20	270
Thawing included	26–32	
White fish processing		
Fresh fish	4.8	5–36
Thawing included	9.8	
Shrimp processing	23–32	100–130

7.2 Waste water

In general, the wastewater of seafood-processing wastewater can be characterized by its physico-chemical parameters, organics, nitrogen, and phosphorus contents. Important pollutant parameters of the wastewater are five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), fats, oil and grease (FOG), and water usage. As in most industrial wastewaters, the contaminants present in seafood-processing wastewaters are an undefined mixture of substances, mostly organic in nature. It is useless or practically impossible to have a detailed analysis for each component present; therefore, an overall measurement of the degree of contamination is satisfactory.

pH serves as one of the important parameters because it may reveal contamination of a wastewater or indicate the need for pH adjustment for biological treatment of the wastewater. Effluent pH from seafood processing plants is usually close to neutral. For example, a study found that the average pH of effluents from blue crab processing industries was 7.63, with a standard deviation of 0.54; for non-Alaska bottom fish, it was about 6.89 with a standard deviation of 0.69. The pH levels generally reflect the decomposition of proteinaceous matter and emission of ammonia compounds.

Most of the water consumed during fish processing becomes waste water. The process related waste water is produced in different processing steps, e.g. thawing, washing, head cutting, filleting, skinning and trimming, and in cleaning the equipment and the installation.

When frozen fish is used as a raw material, a thawing step is needed. The organic pollution of the waste water is relatively small. Scaling normally takes place in rotating perforated drums. Scales are flushed away using large amounts of water – 10 to 15 m^3/t fish. Large volumes of waste water and organic pollution are generated. If the fillets are to be skinned, scaling is not necessary. In automated filleting and eviscerating processes, water is used to lubricate fish while passing through the machine. For some species such as mackerel, a warm caustic bath is necessary to remove the skin and the waste water needs to be neutralised before it is discharged.

Water is used for washing and rinsing the fish, giving rise to waste water carrying fish scraps and viscera. Viscera from oily fish contain high levels of oil and soluble matter, thus waste waters from their filleting normally have higher COD levels (3000–60000 mg/l) than those from white fish filleting (2000–6000 mg/l). The highly polluted waste water is generated due to the time that solid wastes are in contact with the water which contains blood and fat. In automated skinning, the fillet is pulled over a freezing drum. Water is used to clean and lubricate the machine. The skinning of fatty fish releases large quantities of oil to the waste water. The skinning process contributes about one third of the overall organic pollution in the waste water of filleting installations.

As the evisceration of fatty fish takes place at the processing installation, and white fish are eviscerated at sea, this also adds to the reason for the waste water having higher COD and TSS levels. Table 7.2 shows the reported waste water characteristics from fish filleting.

Table 7.2 – Waste water from fish filleting

Parameter	**Filleting of herring**		**Filleting of cod**	
	Average (kg/m^3)	**Range (kg/m^3)**	**Concentration (kg/m^3)**	**Load (kg/t fish)**
BOD_7	10000	500–20000	600–1300	8–19
Fat	12000	2500–16000	50–70	0.3–1.4
Dry matter	20000	5000–28000		
Protein	6000			
Total nitrogen			100–600	0.3–3.1
Suspended solids				1.6–11.3
Water consumption (m^3/t)		5		

In precooking, water is re-used several times and recovery can be made. About 3–4 g oil/kg fatty fish, protein and pieces of fish are released into the water with oil forming a layer on the surface. If the fish is made in brine, there is a high salt concentration in the waste water. Skin is removed from some species, such as mackerel, with the help of a warm caustic bath. Waste water is consequently alkaline and is treated by neutralisation.

The waste water contains blood, flesh, guts, soluble protein and waste material and is high in BOD, COD, TSS, FOG, and phosphates, as well as detergents and other cleaning agents.

Waste water production rates and characteristics depend highly on the production lines. Data for Germany are presented in Table 7.3.

Table 7.3 – Typical waste water production rates and characteristics for fish processing in Germany

Production	**Waste water production (m^3/t)**	**SS (mg/l)**	**BOD_5 (mg/l)**	**Fats* (mg/l)**
Herring	17–40	220–1520	2300–4000	190–450
Fresh fish	About 8	170–3650	1000–6250	46–2500
Smoking of fish	About 8	14–845	1000–1700	24–180
Salting of salmon	About 35			
Deep frozen fish	2–15			
Thawing		0–70	30–1800	4–46
*expressed as petrolether extract				

Nitrogen and phosphorus are nutrients that are of environmental concern. They may cause proliferation of algae and affect the aquatic life in a water body if they are present in excess. However, their concentration in the seafood processing wastewater is minimal in most cases. It is recommended that a ratio of N to P of 5:1 be achieved for proper growth of the biomass in the biological treatment. Sometime the concentration of nitrogen may also be high in seafood-processing wastewaters. One study shows that high nitrogen levels are likely due to the high protein content (15–20 % of wet weight) of fish and marine invertebrates.

7.3 Solid output

The solid wastes generated during fish processing range between 20–60 % of the catch, comprising skin, guts, bones, heads, cephalopods, feathers and shells. For example, when the fish quality is poor, soft fillets can get caught in the skinning knife. This decreases the yield and increases the production of by-products and waste. Part of the waste water and almost all of the solid output may be used for different purposes. Fatty acids and flavours may be recovered from cooking water. Rejected fish are used in animal feed or for production of fish-meal and fish-oil and used afterwards in foodstuff, animal feed and coatings.

By-products from the filleting, skinning, cutting and canning steps are used for: production of foodstuffs, e.g. fish-meal, ingredients, surimi, polyunsaturated fatty acids, gelatine and collagen; production of animal feed, e.g. fish protein, fish silage, fish protein hydrolysate, petfood, fish-oil and solubles; production of fertilisers such as fish solubles and fish protein hydrosylate; production of pharmaceuticals such as gelatine and collagen; production of coatings, e.g. fish-oil and pearl essence, and adhesives such as fish glue; production of leather. Fluid lost from the fish may be treated anaerobically to produce biogas. Heads, shells, intestines and scraps have different applications, such as: production of animal feed, e.g. fish-meal, crustacean meal for cats and antaxanthin for aquaculture; production of foodstuff, e.g. fish-meal, chitin and chitosan; production of flocculants for waste water treatment, e.g. chitin and chitosan; production of pharmaceuticals, e.g. chitin and chitosan. Figure 7.1 shows consumption and emission levels of the process steps in fish canning.

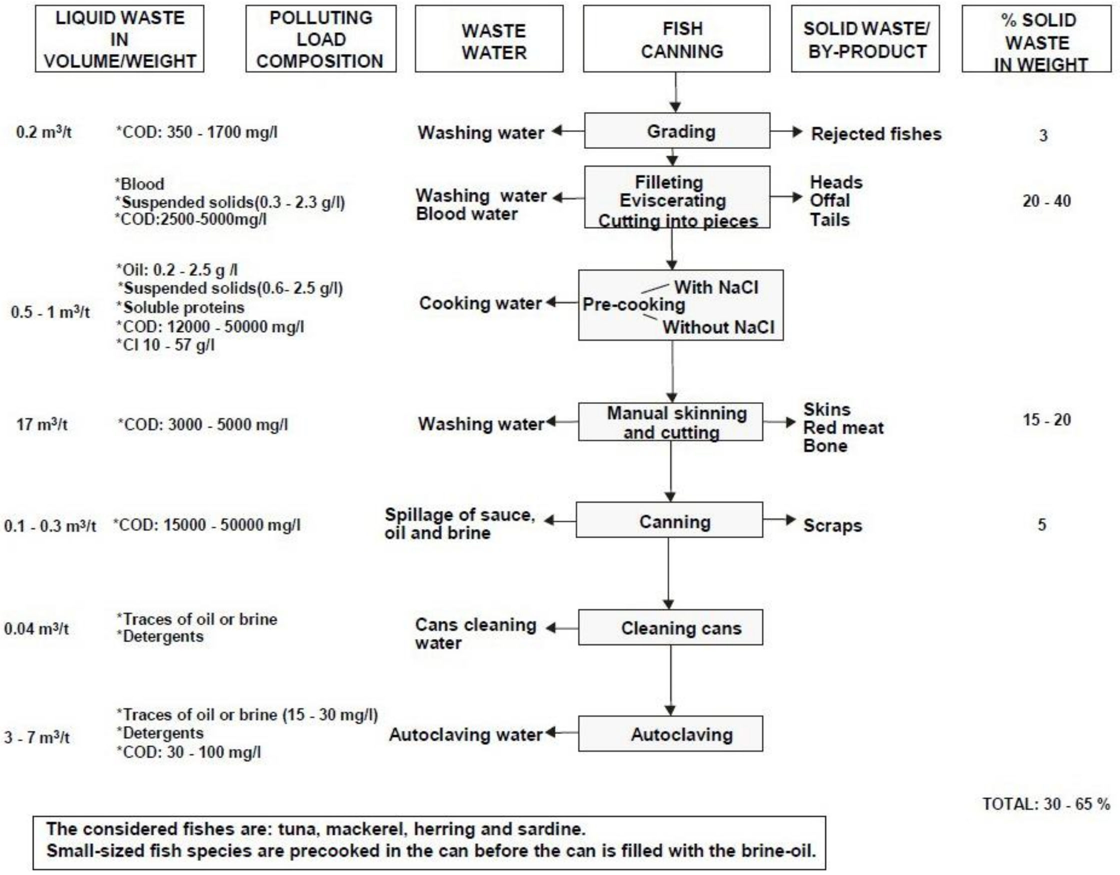
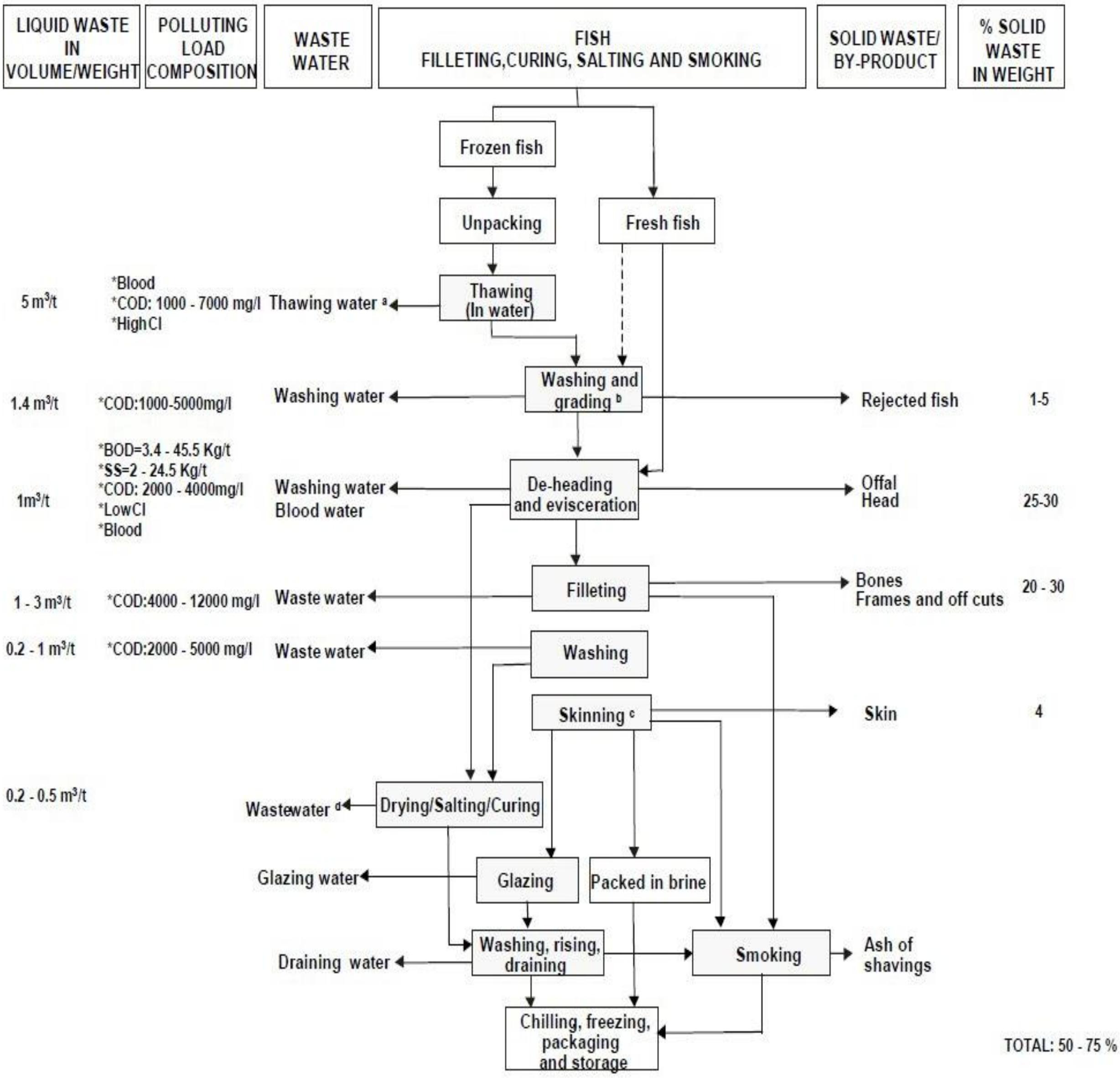


Figure 7.1 – Consumption and emission levels of the process steps in fish canning

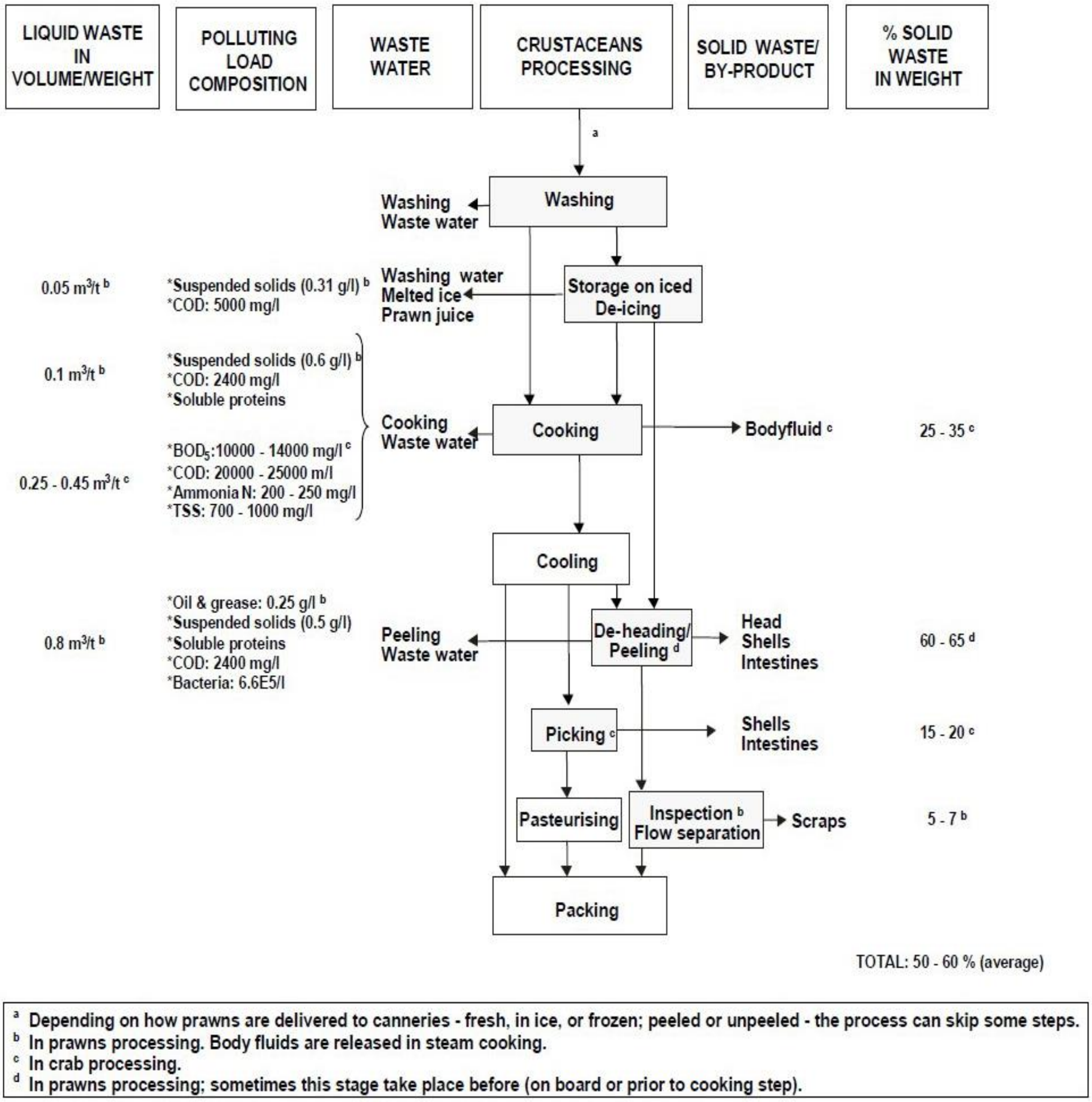
Solid by-products of the filleting, curing, salting and the smoking of fish have similar uses as mentioned above for the canning of fish. Ash from shavings is generally disposed of with municipal solid waste. Figure 7.2 shows the consumption and emission levels of the process steps in filleting and preserving fish.



- For pelagic fish the filleting solid waste 44 %.
[a] Water consumed during thawing is around 50 % of the total water consumed during filleting.
[b] In some cases in this step the fish can be scaled.
[c] Skinning can take place before or after filleting.
[d] In case of liquid salting, the brine is included in the waste water.

Figure 7.2 – Consumption and emission levels of the process steps in filleting and preserving fish

The main crustaceans processed and consumed in Europe comprise shrimps, prawns, lobsters, crayfish crabs and crabs. The main processing steps together with consumption and emission levels are presented in Figure7.3.



[a] Depending on how prawns are delivered to canneries - fresh, in ice, or frozen; peeled or unpeeled - the process can skip some steps.
[b] In prawns processing. Body fluids are released in steam cooking.
[c] In crab processing.
[d] In prawns processing; sometimes this stage take place before (on board or prior to cooking step).

Figure 7.3 – Consumption and emission levels of the process steps in crustaceans processing

Sand and shell particles generated during the shell removal and washing steps of mollusc processing are used in the production of chemicals such as plastics and paints, construction materials and fertilisers. Fluid lost from the fish, e.g. clam juice, may be used in foodstuffs. Figure 7.4 shows the consumption and emission levels of the process steps in mollusc processing.

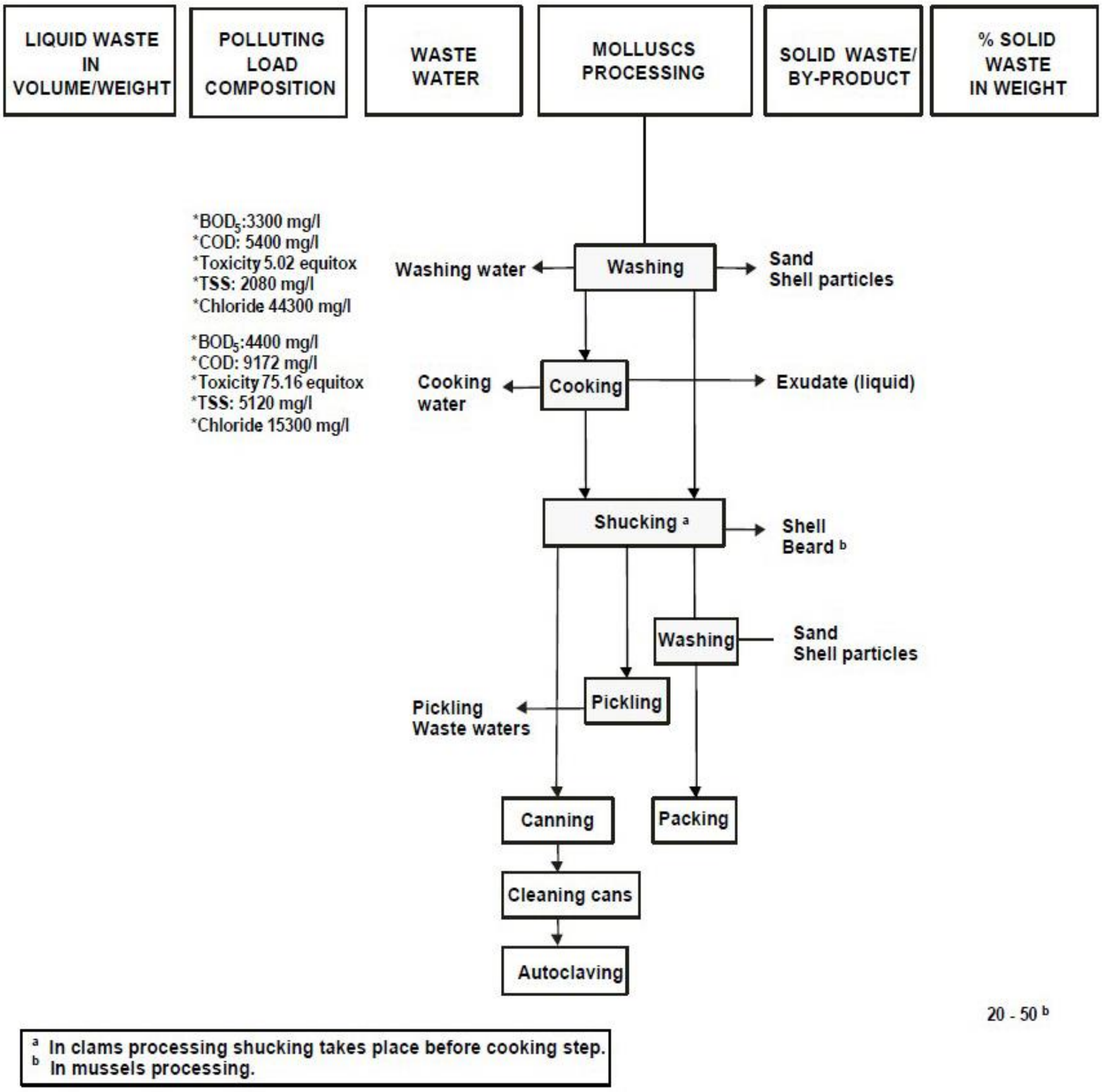


Figure 7.4 – Consumption and emission levels of the process steps in mollusc processing

7.4 Energy

The consumption of energy depends on the installation, the equipment and the fish manufacturing processes that take place. Processes, e.g. canning, that involve heating, cooling, production of ice, drying, evaporation and oil production consume more energy than those that do not, e.g. filleting, where energy consumption is low. On average, filleting consumes 65–87 kWh/t of fish and canning consumes 150–190 kWh/t of fish.

7.5 Waste water treatment

Fish processing waste water primary treatment applies to the following techniques:

- screening;
- sedimentation;
- DAF;

- centrifugation;
- precipitation.

Screening. Generally, tangential screening and rotary drum screening are the two types of screening methods used for seafood-processing wastewaters. Tangential screens are static but less prone to clogging due to their flow characteristics. The solids removal rates may vary from 40 to 75 %.

Fish solids dissolve in water with time; therefore, immediate screening of the waste streams is highly recommended. In small-scale fish- processing plants, screening is often used with simple settling tanks.

Sedimentation. The primary advantages of using sedimentation basins to remove suspended solids from effluents from seafood- processing plants are: the relative low cost of designing, constructing, and operating sedimentation basins; the low technology requirements for the operators; and the demonstrated effectiveness of their use in treating similar effluents.

Flow Equalization. A flow equalization step follows the screening and sedimentation processes and precedes the dissolved air flotation (DAF) unit. Flow equalization is important in reducing hydraulic loading in the waste stream. Equalization facilities consist of a holding tank and pumping equipment designed to reduce the fluctuations of the waste streams.

The equalizing tank will store excessive hydraulic flow surges and stabilize the flow rate to a uniform discharge rate over a 24 hour-day. The tank is characterized by a varying flow into the tank and a constant flow out.

Separation of Oil and Grease. Seafood-processing wastewaters contain variable amounts of oil and grease, which depend on the process used, the species processed, and the operational procedure.

Gravitational separation may be used to remove oil and grease, provided that the oil particles are large enough to float towards the surface and are not emulsified; otherwise, the emulsion must be first broken by pH adjustment.

Flotation. Flotation is one of the most effective removal systems for suspensions that contain oil and grease.

In one case, oil removal was reported to be 90 %. In tuna processing wastewaters, the DAF removed 80 % of oil and grease and 74.8 % of suspended solids in one case, and a second case showed removal efficiencies of 64.3 % for oil and grease and 48.2 % of Seafood processing wastewater treatment of suspended solids.

The main difference between these last two effluents was the usually lower solids content of the second. However, although DAF systems are considered very effective, they are probably not suitable for small-scale seafood- processing facilities due to the relatively high cost.

Table 7.4 shows the characteristics of untreated waste water from the fish sector and its primary treatment efficiencies.

Table 7.4 – Characteristics of untreated fish industry waste water and primary treatment efficiencies

Treatment method	**BOD (mg/l)**	**Total N (mg/l)**	**Total P (mg/l)**	**FOG (mg/l)**
Untreated	2000–28000	400–1000	80–150	500–25000
Centrifugation	1500–5000	–	–	500–2000
DAF	1500–6000	200–600	40–90	400–2000
Precipitation (H_2SO_4) and DAF	800–3000	150–300	30–50	100–500
Precipitation (Fe/Mo) and polyelectrolyte	600–3000	150–300	5–10	100–500
Two step DAF with precipitation (Fe/Mo) and polyelectrolyte)	500–1500	100–200	5–10	50–300

After primary treatment, if the waste water quality is not suitable for discharge to a MWWTP, secondary treatment is needed. Removal efficiency using aerobic treatment is high for waste water with BOD/COD < 3000 mg/l. For highly polluted waste water, e.g. BOD/COD > 3000 mg/l, anaerobic treatment is used.

The population active in a biological wastewater treatment is mixed, complex, and interrelated. In a single aerobic system, members of the genera *Pseudomonas*, *Nocardia*, *Flavobacterium*, *Achromobacter*, and *Zooglea* may be present, together with filamentous organisms. In a well- functioning system, protozoas and rotifers are usually present and are useful in consuming dispersed bacteria or nonsettling particles.

Aerobic Process. In seafood processing wastewaters, the need for adding nutrients (the most common being nitrogen and phosphorus) seldom occurs, but an adequate provision of oxygen is essential for successful operation. The most common aerobic processes are activated sludge systems, lagoons, trickling filters and rotating biological contactors.

Digestion Systems. Anaerobic processes are applied in seafood- processing wastewaters, obtaining high removal efficiencies (75–80 %) with loads of 3 or 4 kg of COD/m^{3}day. In total, 60–70 % of the gas produced by a balanced and well-functioning system consists of methane, with the rest being mostly carbon dioxide and minor amounts of nitrogen and hydrogen. This biogas is an ideal source of fuel, resulting in low-cost electricity and providing steam for use in the stirring and heating of digestion tanks.

Tertiary treatment in the fish sector includes, e.g. coagulation/flocculation membrane separation and disinfection and sterilisation.

Coagulation/Flocculation. In seafood processing wastewaters, the colloids present are of an organic nature and are stabilized by layers of ions that result in particles with the same surface charge, thereby increasing their mutual repulsion and stabilization of the colloidal suspension. This kind of wastewater may contain appreciable amounts of proteins and microorganisms, which become charged due to the ionization of carboxyl and amino groups or their constituent amino acids.

In seafood-processing wastewaters there are several reports on the use (at both pilot plant and working scale) of inorganic coagulants such as aluminum sulfate, ferric chloride, ferric sulfate, or organic coagulants. On the other hand, fish scales are reported to be used effectively as an organic wastewater coagulant. These are dried and ground before being added as coagulant in powder form. Another marine byproduct that can be used as coagulant is a natural polymer derived from chitin, a main constituent of the exoskeletons of crustaceans, which is also known as chitosan.

Disinfection. Most disinfection systems work in one of the following four ways: damage to the cell wall, alteration of cell permeability, alteration of the colloidal nature of protoplasm, or inhibition of enzyme activity. Disinfection is often accomplished using bactericidal agents. The most common agents are chlorine, ozone (O_3), and ultraviolet (UV) radiation.

7.6 Land disposal of wastewater

Land application of wastewater is a low capital and operating cost method for treating seafood-processing wastes, provided that sufficient land with suitable characteristics is available. The ultimate disposal of wastewater applied to land is by one of the following methods:

- percolation to groundwater;
- overland runoff to surface streams;
- evaporation and evapo-transpiration to the atmosphere.

Generally, several methods are used for land application, including irrigation, surface ponding, groundwater recharge by injection wells, and subsurface percolation. Although each of these methods may be used in particular circumstances for specific seafood- processing waste streams, the irrigation method is most frequently used. Irrigation processes may be further divided into four subcategories according to the rates of application and ultimate disposal of liquid. These are overland flow, normal irrigation, high-rate irrigation, and infiltration- percolation.

Two types of land application techniques seem to be most efficient, namely infiltration and overland flow. As these land application techniques are used, the processor must be cognizant of potential harmful effects of the pollutants on the vegetation, soil, surface and groundwaters. On the other hand, in selecting a land application technique one must be aware of several factors such as wastewater quality, climate, soil, geography, topography, land availability, and return flow quality.

The treatability of seafood-processing wastewater by land application has been shown to be excellent for both infiltration and overland flow systems. With respect to organic carbon removal, both systems have achieved pollutant removal efficiencies of approximately 98 and 84 %, respectively. The advantage of higher efficiency obtained with the infiltration system is offset somewhat by the more expensive and complicated distribution system involved. Moreover, the overland flow system is less likely to pollute potable water supplies.

Recommended sources

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