CHAPTER 28

THE FOODSTUFFS INDUSTRY

GENERAL CONSIDERATIONS

The food industry includes several different production processes. The waste water from the various processes varies considerably as the composition of the product will influence the composition of the waste water. However, there are some common features for all types of waste water from the food industry:

1. The waste water contains relatively high concentrations of grease, proteins and/or carbohydrates.
2. Generally the waste water can be treated biologically without complications.
3. In many cases the biological treatment process will be rather costly as the waste water usually has considerably higher concentrations of BOD_5 than municipal waste water. It is often necessary to use a biological treatment process of two or more steps (Hemming, 1968).
4. The BOD_5:nitrogen:phosphorus ratio is often significantly different from the optimum 100:15:1. This means that either the efficiency of the biological treatment will be low or the balance must be adjusted by addition of nutrients. For example, the waste water from the starch industry will have a high concentration of carbohydrates which requires the addition of nitrogen and phosphorus.

The waste water comes from three main sources:

1. Water used for transportation.
2. Water used for cleaning, washing and rinsing the floors, vessels and apparatus.
3. Process water.

The consumption of water in these industries is very high. Table 28.1 gives some characteristic examples of the quantities of water used.

Due to the high water consumption and the relatively high BOD_5 number the total pollution from the food industry is a significant contribution to the overall pollution problem.

TABLE 28.1

Pollution from the food industry in Denmark (Denmark is a country with a highly developed food industry)

Branch	Production tons/ year(round figures)	m^3 waste water/ton of product	Million m^3 waste water/year	BOD_5	10^5 +) person equivalents
Abattoirs	600,000	20	12	1500	7.2
Dairies	5,000,000	1.5	7.5	1800	4.8
Fish filletting plants	100,000	2	0.2	5500	0.4
Potato starch production	25,000	30	0,75	5500	1.6
Breweries	600,000	10	6	1500	3.6

+) 60 g BOD_5/24h per inhabitant

With the increasing cost of water and treatment of waste water these industries have made great efforts to reduce water consumption by recirculation and the introduction of dry methods in place of wet methods. Furthermore, the pollution problems have been reduced by the recovery of valuable proteins from whey in dairies and from blood in abattoirs. These industries include the following branches:

1. The starch and potato products industry.
2. The fermentation industry.
3. The fish industry.
4. Abattoirs and meat packing industry.
5. The sugar industry.
6. The dairy industry.
7. The fruit and vegetable processing industry.

Spray irrigation of waste water

Spraying waste water onto fields and meadows is widely considered to be the best and cheapest way of treating waste water from the foodstuffs industry. The industry favours this solution which ensures maximum utilization of the fertilizing properties of these types of waste water (Sanborn, 1953).

As early as 1942 an outline of the agricultural utilization of waste water from dairies was published.

Raw waste water was stored 5-6 hours in a tank situated on an irrigated area. The irrigation was recommended at a rate of 150-400 mm/year or 75-200 m^3/day of effluent per ha of irrigated fields.

The storage tank should be cleaned continuously, by means of compressed air for example. After irrigation the tanks and pipes should be rinsed with fresh water in an amount equal to 1/3 of the daily discharge of the waste water.

The method is not usually recommended where frosty weather persists or where the soil has a naturally high moisture content or has a high ground water level (see further comments below).

Spraying the waste water on pastures might be a risk as there is a danger of affecting cattle with tuberculosis. It is recommended to have a period of 14 days between irrigation and putting cows out to pasture. The limitation of this process can be summarized as follows (Eckenfelder et al., 1958):

1. Depth of the ground water.
   The quantity of waste water that can be sprayed onto a given area will be proportional to the depth of the soil through which the waste water must travel to the ground water. A certain soil depth must be available if contamination of the ground water is to be avoided.
2. Initial moisture content.
   The capacity of the soil to absorb is dependent on its initial moisture content.
   Sloping sides will increase the run-off and decrease the quantity of water which can be absorbed by a given area.
3. Character of the soil.
   Sandy soil will give a high filtration rate, while clay will pass very little water. A high filtration rate will give too small a biological degradation of the organic material and too low a filtration rate will reduce the amount of water which can be absorbed by a given area.

The capacity is proportional to the coefficient of permeability of the soil and can be calculated by the following equation:

$$Q = K \cdot N \tag{28.1}$$

where Q = the quantity of water (m^3) which can be absorbed per m^2 per 24h; K = the permeability coefficient, expressed as m/24h; N = the saturation of the soil for which a value of 0.8-1.0 can be used in most cases.

If the soil has different characteristics at different depths an overall coefficient can be calculated:

$$K = \frac{H}{H_1/K_1 + H_2/K_2 + \ldots\ldots\ldots H_n/K_n} \tag{28.2}$$

where H = the total depth and H_1, H_2 ..... H_n = the depths of the different types of soil with permeability coefficients K_1, K_2, etc.

Table 28.2 gives the permeability coefficients for different soil types (Eckenfelder et al., 1958).

TABLE 28.2

Permeability coefficients for different soil types

Description	Permeability (m per 24h)
Fine sand	100-500
Trace silt	15-300
Light agricultural soil	1-5
Clay soils 50% and organic soils 50%	0.15-0.40
Dominating clay soil	<0.1

In addition to the properties of the soil several characteristics require consideration in a spray irrigation system. Suspended matter must be removed by screening or by sedimentation before the water is sprayed. Otherwise the solids will clog the spray nozzles and may mat the soil surface rendering it impermeable to further percolation (Canham, 1955). The pH must be adjusted as excess acid or alkali may be harmful to crop.

Also, a high salinity will impair the growth of crops. A maximum salinity of 0.15% has been suggested to eliminate this problem (U.S. Department Agricultural Handbook, 1954).

Spray irrigation has been successfully used for waste water from dairies, pulp and paper industries (Gellman et al., 1959; Wisneiwski, 1956), cannery waste (Luley, 1963; Williamson, 1959) and fruit and vegetable processing plants.

The data from various spray irrigation plants are given in Table 28.3.

TABLE 28.3

Data from spray irrigation plants

Waste water from the manufacture of:	Loading kg BOD_5 per year	Application rate (m/year)
Aspargus and beans	30	5
Tomatoes	600	3
Starch	750	3
Cherries	700	1.6
Paperboard and hardboard	500	1.6

Disposal of industrial waste water by irrigation can be carried out in several ways:

1. Distribution of the water over sloping land with a run-off to a natural water source.
2. Distribution of the water through spray nozzles over relatively flat terrain.
3. Disposal to ridge and furrow irrigation channels.

Example 28.1

Calculate the area necessary for the spray irrigation of 100,000 m^3 waste water per year with a BOD_5 of 1000 mg/l. It has been found that the maximum loading is 20000 kg BOD_5 per ha per year and the maximum application rate is 200-300 cm/year.

Solution

kg BOD_5 per year = 100000 $\cdot$ 1 = 100,000 kg,

which requires 51 ha = $5 \cdot 10^4$ m^3.

Thus:

$$\frac{100,000}{5 \cdot 10^5} = \frac{1}{5} \text{ m per year} = 20 \text{ cm},$$

which is below the application rate indicated.

Reverse osmosis

Reverse osmosis can be used to recover proteins from whey. The results are summarized in Table 28.4.

TABLE 28.4

Reverse osmosis of whey

	Dry matter	Protein	Lactose	Ashes
Whey (%)	6.4	0.8	4.4	0.7
Concentrate (%)	29.0	3.6	23.0	2.2
Permeate (%)	0.15	0.06	-	0.1

The starch and potato products industry

Waste water from starch production is divided into the following groups (Grevemeyer, 1957 and Müller-Mangoldt, 1952):

1. Effluent from the flumes, potato and corn washer.
2. Protein-containing water from the centrifugation of pulp screens, the settling tank in which the starch is extracted and the process for dewatering processes.
3. More diluted water from the washing and refining of the separated starch.
4. Cooling water from vapour condensers and vacuum driers.

Table 28.5 provides analytical data for the waste water from the manufacture of four different types of starch (McCarty, 1964).

TABLE 28.5

Waste water from the manufacture of starch products

	Type of starch			
	Potato+)	Corn	Wheat	Rice
pH	6-8	3.5-5.0	3.5-5.0	3-5-5.0
Suspended matter (mg/l)	200-600	100-500	100-500	100-500
Settleable matter (mg/l)	100-500	80-400	20-200	50-300
$KMnO_4$ value (g/l)	4-10	2-6	5-12	1.5-4.0
BOD_5 (g/l)	3-8	2-5	4-8	1.5-4.0
N (mg/l)	200-400	300-600	200-400	150-350
NH_3 nitrogen (mg/l)	10-100	10-100	20-80	10-60
Total dry matter (g/l)	3-8	2-7	4-12	2-5
Starch (mg/l)	100-500	50-400	20-300	50-200

+) including fruit water

The waste water contains mainly organic compounds such as carbohydrates and albumin (Cerny, 1959). It is very turbid and the waste water coming from the manufacture of corn, wheat and rice starches has an acidic reaction. Due to fermentation the pH will decrease after some time. The fermentation involves the formation of lactic and butyric acids.

Hydrogen sulphide is formed during the decomposition of albumin. The waste water also contains insoluble compounds such as starch grains, parts of cells, small pieces of root fibres, leaves, etc. As seen in Table 28.5, the BOD_5 is very high compared with municipal waste water. This makes the application of biological treatment methods unattractive, although the components of the waste water are easily decomposed by biological treatment (Sproul, 1969) An essential part of the BOD_5 produced can be eliminated by evaporating the waste water having the highest concentration of carbohydrates and proteins.

The residue after evaporation together with other waste products from the production can be used as pig feed. However, evaporation of water with a total matter concentration of 5 g/l is very expensive and the method is only used in a few localities. A combination of chemical precipitation and ion exchange is another possibility. Some parts of the industry also solve their waste water problem by using a partial biological treatment (Buzzel, 1964), f. inst. on plastic filters, which gives a sufficiently low BOD_5 to allow discharge to the municipal sewer system (Hänsler, 1970). The LF value for the use of an activated sludge plant will be relatively high: 0.5-1.0, an average of 0.8 kg BOD_5 per day/kg suspended matter.

In Czechoslovakia and Sweden investigations have been carried out on a method of combined potato processing which consists of reducing the starch extraction from 80% to 50% and processing the potato pulp into yeast or alcohol. These studies have shown that the volume of waste water is reduced and its composition changed. The volume of the protein water particularly decreases, but at the same time new effuents having large concentrations of organic compounds are formed.

A rational method of treating effluents of this type is irrigation, where it is possible. The nutrients taken from the soil by the starch cultures are recycled. According to Szniolis (1952), the field area should be 2500 ha/100,000 tons of raw material processed. Bielicki (1952) quotes 2200 ha.

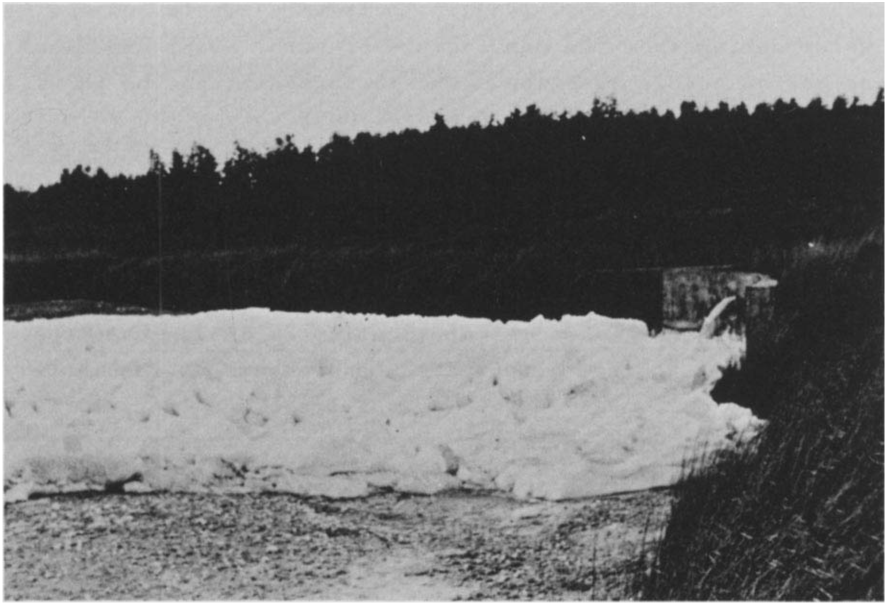

Fig. 28.2. Discharge of waste water from potato starch production. A thick sludge is killing all higher life forms due to the deficiency of oxygen. The foaming is caused by the contents of proteins.

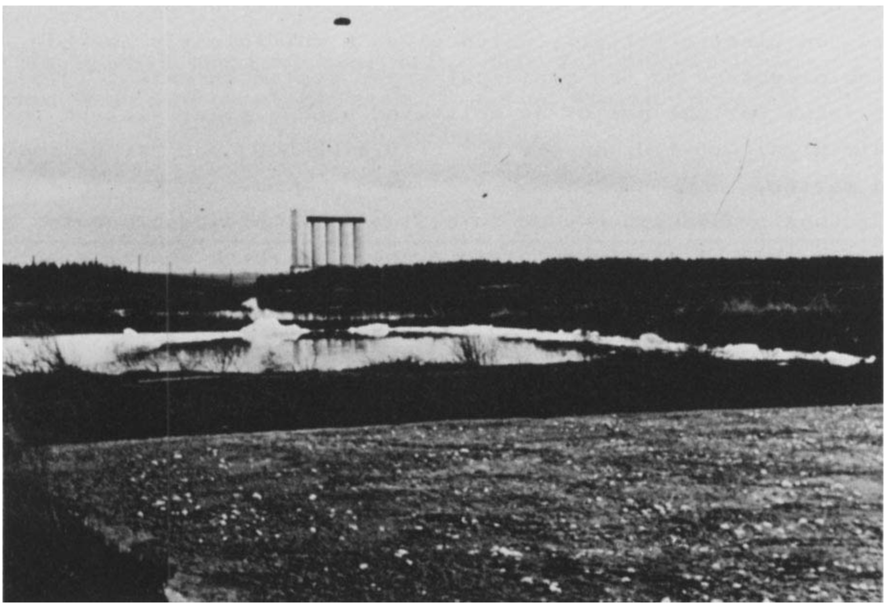

Fig. 28.3. Discharge of waste water from potato starch production. An area of several ha is completely damaged by the high BOD_5 of this waste water.

A number of potato products such as chips and mashed potato are produced in increasing quantities. The waste water from the potato product industry has analytical data, which vary from factory to factory, because there are a number of technical solutions available. However, a BOD_5 value in the range 2000-6000 mg/l is not unusual (Francis, 1962).

The other analytical data are close to those indicated for potato starch (see Table 28.5), but in some instances the waste water is more dilute than corresponding to the figures in the Table.

Fig. 28.1 shows how it is possible, in the manufacture of mashed potato, to treat the waste water and recycle a substantial part of it. This solution substantially reduces the costs for water.

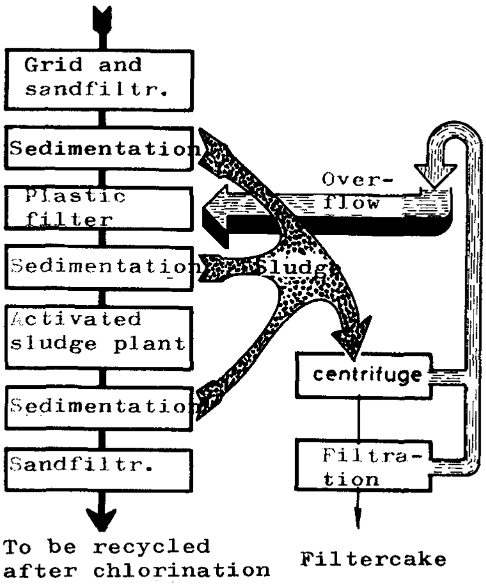

Fig. 28.1. Treatment of waste water from the manufacture of mashed potato and recycling of the water.

Removal of grease prior to clarification may be required for plants producing french fries.

The dewatered sludge from the process water can be fed to cattle. It has been shown to be a valuable feed and can be sold for sufficient to recover the capital cost of primary treatment in two to four years.

Settling in a properly designed clarifier following screening with an overflow rate of 24.5 $m^3/day/m^2$ will reduce the BOD_5 by 60% and the suspended material by 90%. Settling of the flume and wash water in a clarifier with 19 minutes retention time will reduce suspended solids by over 95% (Grames et al., 1969).

Recovery of protein from potato chip processing water by precipitation has been evaluated by Meister et al. (1976). The protein is precipitated by heating the processing water to 80-90°C at pH 4-4.5. 170 kg of dried potato protein could be recovered from processing 31 metric tons of potatoes (150 kg of food containing 30% protein).

Svenska Sockerfabriks A/B has investigated a method which produces a vitamin-B-rich feed based on waste water from a potato processing plant. The method is based on a fermentation process and should, according to information from Svenska Sockerfabriks A/B, be able to balance economically (Gerald, 1970 and Sproul, 1969).

The methods mentioned above for treatment of waste water from the starch industry are also generally applicable to waste water from the potato processing industry.

The fermentation industry

Waste water from the manufacture of yeast is among the more troublesome organic waste water. It is generated during the preparation of the mash, washing of the mash tubes, storage, pipes for the mash, separation, washing and pressing of the yeast and cooling of the mash before and during fermentation. A typical analysis of the waste water from yeast factories is shown in Table 28.6. The volume of yeast waste water/ton of manufactured pressed yeast is approximately 120 m^3.

TABLE 28.6

Analytical data of yeast waste water

Settleable material (l/m^3)	5-7
Suspended solid (mg/l)	1000
Total solid (mg/l)	5000
$KMnO_4$ value of filtered waste water (mg/l)	2000
BOD_5 (mg O_2/l)	3500
Total nitrogen (mg/l)	120

The most important raw material for the fermentation industry is molasses. It contains about 20% water, 50% carbohydrates and $1\frac{1}{2}$% nitrogen in the form of protein and betains.

As the nitrogen and phosphorus concentration is not high enough for the fermentation process, it is necessary to add ammonium dihydrogen phosphate, ammonium sulphate and ammonia.

The waste water from yeast processing has an especially high concentration of the components which are present in molasses; i.e. carbohydrates, proteins and other organic nitrogen compounds.

The molasses itself has a BOD_5 of about 140,000 mg/l, and it is therefore not peculiar that the waste water from yeast factories has a BOD_5 as high as 3000-12000 mg/l (Bode, 1953). Medium size yeast factories have a total BOD_5 contribution of about 1 million kg/year, corresponding to 50000 persons. In more modern plants the concentrated waste water is isolated from the more dilute water and treatment is carried out in two completely different ways. The concentrated waste water can be digested anaerobically, while the more dilute effluent is treated on high-rate trickling filters with recirculation together with the effluent from the anaerobic digestion tanks.

The sludge obtained from treatment of yeast waste water is a very useful fertilizer since the dried sludge contains 2-3% nitrogen, $1\text{-}1\frac{1}{2}$% phosphorus and 8-10% potassium.

The BOD_5 obtained with this waste water solution is 100-200 mg/l, which must be considered satisfactory.

The fermentation gas has a calorific value as high as 6000-6500 kcal/m^3, but before the gas is burned in a boiler furnace the hydrogen sulphide must be removed (Merkel, 1959). This is possible by means of aeration, using 5 m^3 air/m^3 of waste water. 98% of the hydrogen sulphide is then oxidized to elemental sulphur.

Foaming can cause problems in the activated sludge plant. It can be reduced by using a cyclone, by aspirating the foam surface or by the addition of anti-foaming agents.

Loll (1975) has examined the purification of concentrated organic waste water from the food industry by means of an aerobic, thermophillic degradation process.

Aerobic thermophillic waste-water purification is a biological degradation process in which the waste water is purified by means of aerobic micro-organisms at a temperature between 35 and 70°C.

The special characteristics of this procedure are: The process temperature is not obtained by supplying external energy but is reached by direct use of the heat energy developed during the aerobic metabolism. The exothermal and spontaneously starting process will be intensified with higher substrate concentrations since the amount of heat energy increases in proportion to the amount of organic substances biochemically converted. As a result the degradation velocity and thereby also the process temperature reached in each case should increase in proportion to the organic load in the treated water.

In comparison to anaerobic digestion, which in many cases is proposed as a method of treatment for concentrated organic waste water, the gain in energy is considerably larger with aerobic thermophillic degradation since during microbial metabolism of most of the organic compounds to be found in waste water considerably more energy is developed under aerobic conditions than under anaerobic reduction. On the other hand, there is much less energy loss in the direct heat exchange within the bacterial cells than in the separate methane incineration which usually follows the digestion process.

The main application for this method is the purification of concentrated organic waste water and waste water sludge with BOD_5 charges above 5000 mg/l.

The results of the three stages of treatment in accordance with this method are summarized in Table 28.7.

It has been possible to determine the heat energy developed during the metabolism rather precisely at 14.7 kg J/g of COD reduced.

Irrigation or chemical precipitation combined with ion exchange is also a possible solution for the waste water problem of this industry.

Brewery waste water arises during preparation of the malt and in the brewing process. The malt-house waste water is mainly formed from barley washing. The waste substances diffuse into the water. The contaminants include polysaccharides, saccharose, glucose, pectin, minerals and proteins. They constitute 0.5-1.5% by weight of the dried grain.

Approximately 0.6-0.8 m^3 waste water are discharged for every 100 kg of barley processed. The waste water has a yellowish brown colour and has a tendency towards foaming, and acidic digestion (Schneider, 1950).

TABLE 28.7

Results of aerobic thermophilic degradation process

Substrate Retention time	Yeast waste days	Molasses waste 3.stages
Temperature, stage 1	32.2	42.8
" " , stage 2	36	51.3
" " , stage 3	36	50.7
pH, treated water	8.9	9.3
BOD_5, untreated water (g/l)	4.3	18.3
BOD_5, treated water (g/l)	0.4	0.8
COD, untreated water (g/l)	10.3	26.2
COD, treated water (g/l)	4.7	4.7
TOC, untreated water (g/l)	5.3	11.0
TOC, treated water (g/l)	2.8	2.1

The volume of waste water from the brewery itself is 5-15 times larger than the volume of beer produced. The losses arise from the water used for preparing the wort, making ice and from evaporation. In addition, waste water comes from washing the yeast and pressing waste yeast, from washing equipment, fermentation tanks, bottles, barrels and rooms and from laundering filter cloths. The cooling water is almost unpolluted and the volume can count up to two-thirds of the total water demand. It is generally returned to the production process, however. A characteristic analysis of brewery waste water is shown in Table 28.8.

TABLE 28.8

Characteristic analysis of waste water from breweries

Temperature	13-20°C
pH	5.0-7.0
Total nitrogen (mg/l)	25-45
$KMnO_4$ value (mg/l)	800-1400
BOD_5 (mg/l)	1500-3000
Settleable matter ($cm^3/\frac{1}{2}h$)	5-6
Total solid (mg/l)	500-2500
Loss of ignition (mg/l)	500-2200
Total suspended matter (mg/l)	100-500
Combustable suspended solid (mg/l)	50-500
Dissolved material (mg/l)	50-350

As seen, the balance between BOD_5, nitrogen and phosphorus is not very suitable for biological treatment.

This explains the parameter values for the biological treatment of brewery waste water shown in Table 28.9.

TABLE 28.9

Parameters for the biological treatment of brewery waste water

Parameter	Value
OL	0.2-0.7
a	0.52
a_1	0.55
b	0.28
b_1	0.28

Biological treatment can be carried out with a loading of 2-3 kg per m^3 per 24 hours (Lippmann, 1965). A BOD_5 reduction of 95% is common for a correctly designed activated sludge plant (Eckenfelder et al., 1961). A low-rate trickling filter or a two-stage high-rate filter is often employed for the biological treatment of brewery waste water. The volume of waste water obtained from industrial distilleries is relatively small; however, large fluctuations may be observed. The waste water consists chiefly of cooling water, but contains also spent mash water from washing yeast and waste from the washing of rooms and equipments.

The composition of the waste water from a molasses distillery is shown in Table 28.10. The waste water from these distilleries has a brown colour, caused by humus present in the molasses. It is slightly acidic and turbid because of the large concentration of colloids. The content of settleable material is fairly small.

TABLE 28.10

Characteristics of waste water from a molasses distillery

Temperature	35-50°
Settleable matter (cm^3/l-2h)	0.5
$KMnO_4$ value (mg/l)	10000-20000
BOD_5 (mg O_2/l)	4500-6500
Total nitrogen (mg/l)	120-200
Ammonium nitrogen (mg/l)	5-18
Phosphorus (mg/l)	30-40
Total solid (mg/l)	4000-6000

The combined waste water from a molasses distillery, which also contains slops, is treated by anaerobic digestion in a similar way to that of the production of pressed yeast (see above).

A digestion period of 40 days reduces the BOD_5 by 95-98%. The spent mash is often concentrated in multi-stage evaporators and burned.

According to Rau (1972), distillery waste is suitable for anaerobic lagoon treatment with an optimum BOD_5 loading of 0.604 kg BOD_5 per m^3 per day.

The BOD_5 concentration of the lagoon effluent varies from 2500 to 3000 mg/l.

If the anaerobic lagoon treatment is followed by another lagoon, it is possible to reduce the BOD_5 concentration to 600 mg/l with an optimum BOD_5 loading of 0.070 kg BOD_5 per m^3 per day. There seems to be a significant relationship for this effluent between COD and the total volatile solids. The COD concentration is 1.38 times the total volatile solid concentration for the raw water and 1.54 times for anaerobic lagoon effluent of distillery waste.

Another possible solution of the waste water problem of distilleries is irrigation on land for agricultural purposes. The waste water has to be clarified in settling tanks before being pumped to the irrigation fields.

Fish processing industry

Approximately 5-10% of the products from this industry is lost in the waste water during fish filletting or shrimp processing.

As fish and fish blood are rich in proteins, the waste water will have a high concentration of these. As much as 40-80% of the organic matter is protein (Jørgensen, 1968 and 1970a).

Filletting various fish species gives different concentrations of fish oil in the waste water. As much as 50% of the organic matter in waste water from filletting herring is fish oil, while waste water from filletting cod is relatively poor in oil.

The oil content in the waste water varies from season to season. In the autumn and in the first few months of the year, the herring filletting waste water has a relatively high content of oil. The oil concentration in waste water from herring filletting plants is high enough to make separation of the oil by centrifugation profitable. The waste water after the centrifugation still contains fish oil, which makes it advantageous to use flotation instead of settling.

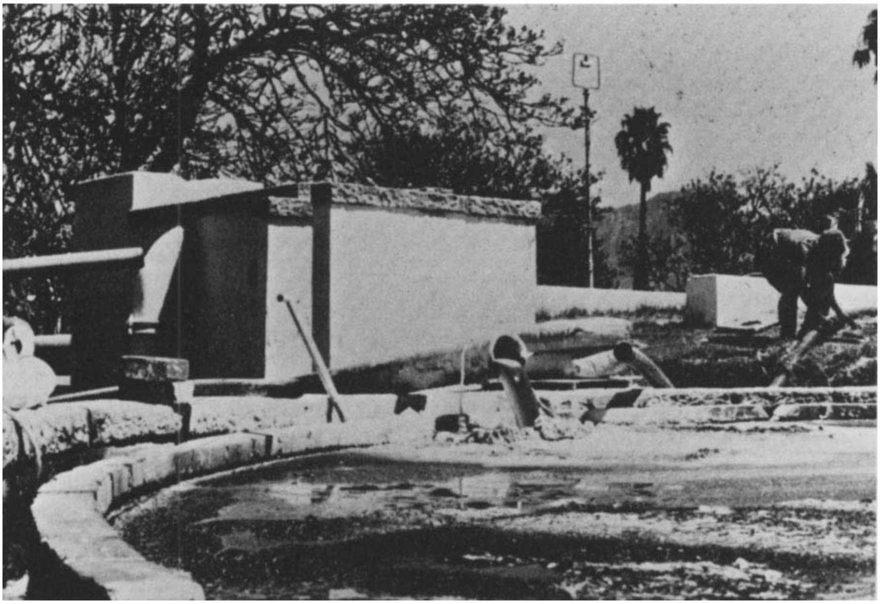

Fig. 28.4. Anaerobic treatment of waste water from a distillery. The retention time in the open tank shown on the figure is approximately 30 days.

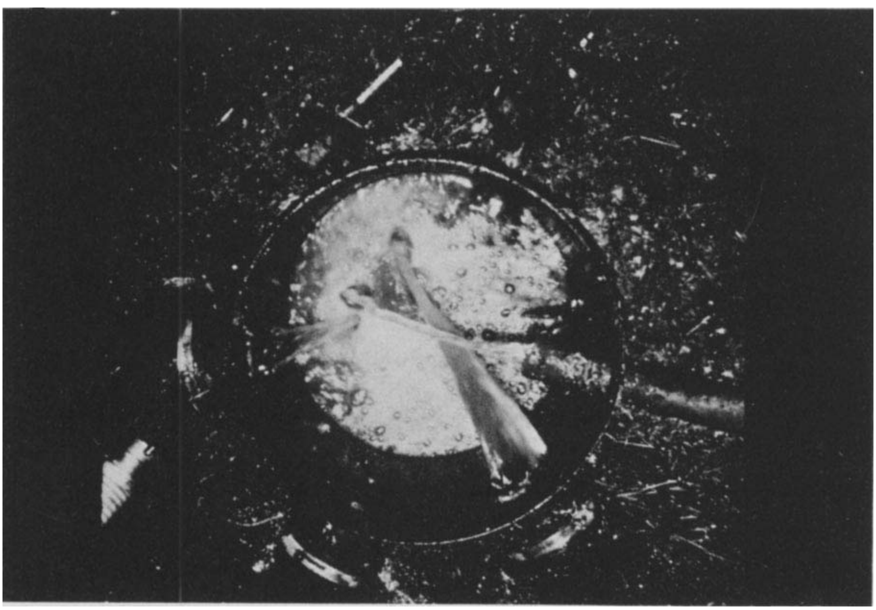

Fig. 28.5. Comparison of untreated and treated waste water from a slaughterhouse. The treatment used is a combination of chemical precipitation (starch sulphate as precipitant) and cellulose ion exchanger.

If the quantity of waste water is a few hundred $m^3/24h$, recovery of proteins is also profitable. It can be carried out by chemical precipitation, see chapter 3, or by heat coagulation. A temperature of 60-80°C is used and the heat is regenerated by heat exchangers. This last mentioned process is developed by Alfa Laval.

Most fish processing industries are situated near the coast and in most cases the waste water does not cause many problems as it can be discharged directly into the sea.

However, the increasing cost of good processing water and the environmental legislation in the industrial countries will probably force the fish processing industry to recover more of the waste products and recirculate the water to a greater extent than it does today.

In Table 28.11 a characteristic analysis of waste water from a herring filletting plant. The data are compared with what can be achieved by a three-step treatment, consisting of centrifugation, protein precipitation with flotation and ion exchange, using a mixed bed cellulose ion exchanger (Jørgensen, 1973 and 1978).

TABLE 28.11

Analytical data of herring filletting waste water

	Raw waste water	After centrifugation 1. step	After chem. precipitation 2. step	After Cellulose ion-exchanger 3. step
BOD_5 (mg/l)	11000	5800	2000	1100
N (mg/l)	180	162	60	23
Suspended matter (mg/l)	400	170	40	2
$KMnO_4$ (mg/l)	8000	4000	1200	600

Very concentrated waste water which comes from the fish meal, the so-called lime water, contains up to 10% dry matter of which more than 50% is fish oil or fish protein. This waste water is almost universally evaporated for the recovery of the valuable waste products.

Abattoirs and the meat packing industry

The major part of waste water from slaughtering has a relatively high concentration of grease and proteins. An essential part of the protein originates from blood, although most of the modern abattoirs try to collect the blood for the production of blood albumin (Meinck, 1960). About 20 l of blood are obtained from a large animal and about 2 l from a small one.

Grease is removed in a grease trap and can be processed into soap, olein, stearine and glycerol.

The content of the alimentary channels is made into compost and yields a high quality fertilizer.

A characteristic analysis of waste water from an abattoir is shown in Table 28.12 (Jørgensen, 1970a and Jørgensen 1970b).

TABLE 28.12

Analysis of waste water from an abattoir (mg/l)

	Raw water	After biological plastic filter	After chem. precipitation (glucose sulphate residue)	After chem. precipitation and ion exchange
BOD_5	1500	400	600	50
$KMnO_4$	950	350	460	60
Total N	140	42	85	15
NH_3-N	20	15	18	2
NO_3^--N	4	5	4	1
P	45	38	39	1.5

Among the methods used to treat waste water from abattoirs are biological plastic filters (Chipperfield, 1967), precipitation of proteins, with sedimentation or flotation, ion exchange as the final step, activated sludge treatment and anaerobic digestion.

Table 28.12 gives the analytical data which are achieved using biological plastic filters, chemical precipitation and in combination with ion exchange.

The waste water from meat processing plants is very similar in composition and properties to the slaughterhouse waste water, but it is generally less polluted. BOD_5 values between 400 and 800 are recorded. For this type of waste water the same methods as mentioned for the treatment of slaughterhouse waste water can be used, but as the water is more dilute the biological method becomes more attractive from an economical point of view and the physical-chemical method correspondingly less attractive (see the discussion chapter 11). However, in this case the use of chemical precipitation should also be considered.

Good results are also obtained by super chlorination of the waste water. The water is allowed to accumulate during the day in a tank fitted with an agitator; then chlorination is carried out to a 50 mg/l excess of chlorine. The quantity required is very high - 700-1000 mg/l. The waste water is again agitated and after some time coagulation begins. The process can be accelerated by the addition of a small amount of iron(III)chloride. The waste water is then allowed to settle overnight without being agitated. However, although this method gives a low BOD_5 (50 mg/l has been recorded) the high chlorine demand makes the process less attractive from an economical point of view than the other methods mentioned above.

Coagulation by iron(III)chloride followed by the addition of high molecular weight, anionic organic polyelectrolytes gave the following results (Larsson et al., 1971): a decrease in the concentration of suspended solid by 100 mg/l, and in the BOD_5 concentration by 140 mg/l, leaving effluent concentrations of 120 mg/l and 550 mg/l, respectively.

Flocculation of the colloidal particles by the iron(III)chloride produces small voluminous flocs that are further increased in size and density by the secondary flocculation of the organic polyelectrolytes which produce a settleable precipitate. Iron(III)chloride alone was unsatisfactory because it produced non-settleable flocs under the prevailing hydraulic conditions.

The quantity of waste water per slaughtered bird in a poultry slaughterhouse is 20-50 l. The waste water contains relatively much blood and is therefore rich of protein. Per animal the BOD_5 loading is 5-30 g - averagely 20 g. The characteristic BOD_5 number for the waste water is 1000-1200 mg/l (Suhran, 1967).

Woodard et al. (1972) have investigated a combination of chemical precipitation and chlorination for the treatment of this waste water. They claim that the treatment will give a BOD_5 removal in the range 74-78%, an 87-99% removal of suspended matter and removal of grease from 97-99%.

The sugar industry

The sugar industry consumes very large quantities of water. A sugar beet factory processing 2000 tons of beet daily has a water demand as high as 30000 m^3/day. This is equivalent to the municipal waste water of a town of 120,000 inhabitants, assuming a daily water consumption of 250 l per head.

The waste water from a sugar factory can be divided into three groups:

1. Water which is only slightly polluted and includes hot water, condensate and cooling water.
2. Waste water containing solid impurities such as beet washing water, and boiler blow-down water.
3. Waste water highly polluted with chemicals such as diffusion battery wash water, pulp press water, gas scrubber water, filter cloth laundry water, overflow from lime sludge settling tanks, and water from beet pulp pitch (Creswell et al., 1965).

Reduction in the volume of waste water is connected to water management. The reduction includes the use of closed series and mixed water recycle systems. The cooling water may sometimes be used successfully as process water in certain sections of the sugar factory.

The degree to which the process waste water can be recycled is related to the reduction of losses during the process of extracting juice from the beet. In order to keep these effluents in circulation, certain safeguards are necessary such as careful separation of suspended solid maintenance of a suitable temperature and maintaining the pH close to 7.0.

Diffusion water can be eliminated by employing continuous diffusion in towers or, more recently, in troughs. If continuous diffusion is not used, it is possible to recirculate condenser water, pulp press water, beet washing water and machinery cooling water. Besides reducing sugar losses recycling of water also improves the heat economy. Good water management in the sugar industry can decrease the amount of waste water by about 50%. If very strict water economy is introduced and appropriate waste-water treatment plants are incorporated, the quantity of waste water discharged can be reduced to almost 1/25 of the figures given above, i.e. the waste water is reduced from 15 m^3/ton of beet processed to about 0.6 m^3.

Table 28.13 shows what the extent of the circulation means for the BOD_5 loading of the waste water from the sugar processing.

TABLE 28.13

Circulation of waste water from the sugar processing

% recirculation	Number of person eqv. ton/beets
0	60
30	30
50	18
75	6.5

The waste water from the sugar industry contains soil, sugar, sugar decomposition products such as organic acids, saponin, and certain quantities of triethylamine, decompostion products of pectin, etc.

The BOD_5 value of the waste water after 75% recirculation is 800-1200 mg/l.

The waste water from the first group (water only slightly polluted), does not usually require any special treatment, although attention must be paid to thermal pollution. This water is usually recirculated in closed cycles.

The waste water from the second group (waste water containing solid impurities) passes through catchers in which floating impurities are removed and then through rotary screens of various types which remove smaller impurities such as roots.

Lagoons are used to separate the finely suspended matter.

The third type of waste water (the highly polluted waste water) is usually treated by a biological or a chemical-biological procedure. The biological procedure can be two-stage digestion by the well-known Nolte-process (Nolte, 1928). The digestion takes place in two ponds. In the first the waste water undergoes acid digestion and as a result the sugar is decomposed. The waste water is afterwards neutralized with lime to an approximate pH of 7.0, which results in precipitation of the colloidal compounds. The second stage of the acid digestion is carried out in the second pond, which completes the digestion and also acts as a second tank.

Nolte has improved the method by increasing the alkalinity of the effluent leaving the first acid digestion pond to a pH of about 9.0. The effluent can be used for irrigation.

The chemical-biological method is used mainly in the U.S.A. The polluted water is coagulated and then passed through a trickling filter. The chemical treatment is usually employed where waste water is recirculated in a closed cycle.

Fungi have been shown to process the ability to rapidly convert soluble and suspended organic material from corn and soil processing waste water to fungal mass (Church et al., 1974).

Hang (1975) has examined the capability of selected fungi to digest the beet waste, especially the pigment that persists in beet processing effluents. He found that food fungus is capable of digesting approximately 93% of the beet waste COD in 72 hours. A considerable reduction in the Kjeldahl nitrogen and total phosphorus was also achieved by this process. In addition, the fungus possessed the ability to degrade up to 96% of the pigments.

The yield of dry mycelium is approximately 52 g/100 g of COD removed. The recovered mycelium may be suitable as animal feed which can be sold to help reduce the treatment costs.

According to a method developed by Wintrelle & Lauritzson the colloidal compounds are coagulated with sulphuric acid. Sulphuric acid in the amount of 0.03-0.05% of the weight of the beet processed is recommended (Skalski, 1956).

Waste water from sugar cane processing can be divided into two groups.

The first group includes cooling and condenser water, while the second group is a more concentrated water from spillage, washing of equipment, production waste water, water from the boiler house and waste water containing lubricants and oil from machinery.

3000 to 4000 m^3/ton of processed cane is a general figure for the quantity of waste water discharged from sugar cane plants.

The BOD_5 for the first group of waste water is fairly low, while it occasionally exceeds 10000 mg/l for the second group. Waste water in the second group may be either acidic or alkaline and contains considerable amounts of carbohydrates.

It is rather difficult to treat cane sugar waste water by conventional methods since volatile organic acids are formed, which again inhibit the activity of micro-organisms retarding the further course of the treatment. It is possible to neutralize these acids with lime and thereby prepare the waste water for anaerobic digestion. An average BOD_5 reduction of 80% for waste water maintained at 29°C for a period of 8 days and a loading of 3.2 g/m^3 of tank capacity recorded.

Two or more oxidation ponds in series can also be used for treating this type of waste water.

The dairy industry

Waste water in the dairy industry can be divided into two groups. The first group includes cooling water and counts for two-thirds or more of the total volume of waste water (Harding, 1952). The second group comprises waste water arising directly from the manufacturing processes and its composition depends very much on the type of plant from which it is discharged.

The BOD_5 found in the waste water from various milk processes is shown in Table 28.14 (Sander, 1957 and 1959).

TABLE 28.14

BOD_5 in the waste water from milk processes

Process	kg BOD_5/m^3 milk processed
Receiving station	0.26
Washing of tanks	0.25
Pasteurization	0.29
Bottling	0.11
Cheese	0.89
Butter	0.46
Cream	1.2
Condensed milk	1.4
Milk powder	0.75
Cooling and other operations	0.25

Many dairy industries are relatively small. This makes treatment of the waste water relatively costly, although it is easily treated by biological treatment methods (Hauner, 1952 and Wheatland, 1960), and in many cases it would be a better economical solution to use small biological plastic filters to reduce the BOD_5 to the same level as municipal waste water, or to use a simple chemical precipitation.

In Fig. 28.2 the removal of BOD_5 is plotted against the loading of a biologcial plastic filter. It is assumed that the BOD_5 of the waste water treated is between 800 and 2000 mg/l.

Precipitation of proteins from the waste water from the dairy industry has been carried out with carboxymethyl cellulose (Cluskey et al., 1970). Improved precipitation can be achieved by the addition of calcium and magnesium. The precipitant is used in a quantity of 10-17% of the precipitated material.

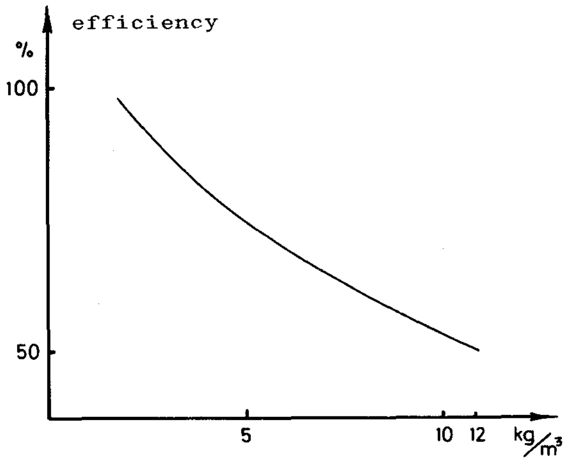

Fig. 28.2. BOD_5 removal plotted against the loading of a biological plastic filter.

As the cost of carboxymethyl cellulose is rather high (0.50 $/kg) and it is doubtful whether the precipitated material can be used as cattle feed, the use of this precipitant is restricted to the treatment of rather concentrated casein solutions.

However, the protein precipitants mentioned in Chapter 3, seem to offer an attractive solution.

It is of importance to discharge the waste water from the dairy industry continuously. The relatively high BOD_5 value will shock the municipal waste water treatment plant if the waste water is discharged intermittently. This is illustrated in Fig. 28.3, where the efficiency of the plastic filters is plotted against time. 3 m^3 of whey are discharged at 08.00 o'clock causing a drastic reduction in the efficiency. As seen in the figure the filter takes several hours to recover.

On page 324 the possibility of recovering protein by reverse osmosis has been mentioned. Another possible recovery method for whey protein has been developed by Alfa-Laval. A flow-sheet is shown in Fig. 28.4. After centrifuging the whey to remove suspended matter, acid is added to precipitate the proteins.

The whey is heated to increase the efficiency of the precipitation. With this method it is possible to recover 90-95% of the whey proteins. After centrifugation of the precipitated proteins the water contains mainly lactose. This operation can be used for the production of lactose.

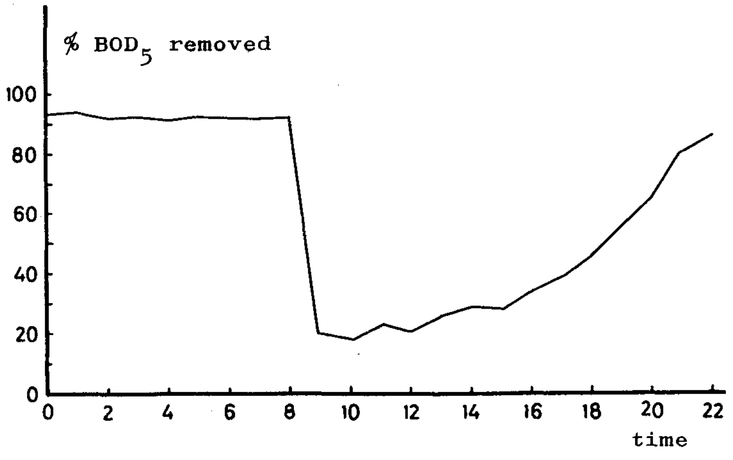

Fig. 28.3. Efficiency of a plastic filter plotted against time. 08.00 3 m^3 of whey are discharged causing a drastic reduction in efficiency.

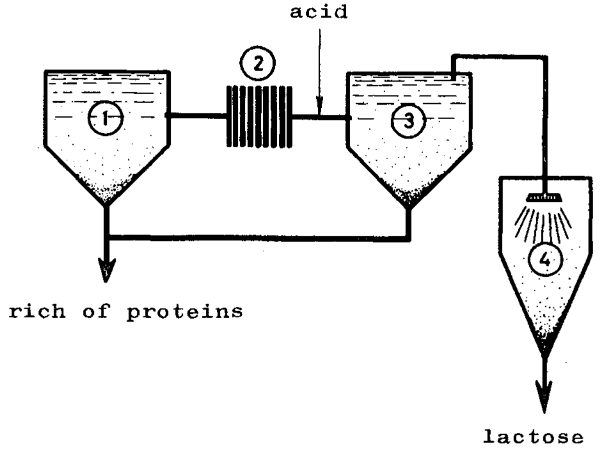

Fig. 28.4. Flow-sheet showing recovery of whey proteins. (1) centrifugation; (2) heat exchanger; (3) sedimentation after the addition of acid; (4) spray drying.

According to Håndström (1975) the condensate from the evaporators can largely replace fresh water in the dairies.

The condensates from the evaporation of skimmed milk and whey can be used.

The permanganate value for the condensate from skimmed milk is 5-10 mg/l and for pasteurized whey 10-20 mg/l.

Values between 20 and 40 mg/l can be expected for condensates for non-pasteurized whey and between 150 and 200 mg/l for the condensate from butter rinse water.

By use of a combination of ion exchange (anionic as well as cationic) and an activated carbon filter, it is possible to reduce the potassium permanganate number for these condensates by about 90%, thus allowing the fresh water to be replaced by the treated condensate.

Fruit and vegetable processing plants

The waste water from fruit and vegetable plants is rather difficult to describe in general ways, since the plants operate seasonally and the processes vary from plant to plant. The height of the processing season is the late summer and autumn. It is possible, however, to classify the waste water into (FWPCA, 1965):

1. Waste water containing solid compounds, mostly organic.
2. Water polluted with organic compounds of various forms.
3. Waste water polluted with sulphur dioxide. These effluents contain 10-20 mg/l SO_2, which is used to stabilize the products.

Table 28.15 gives a survey of the types of waste water which come from this industry (Holdsworth, 1968).

TABLE 28.15

A survey of the types of waste water from the vegetable industry

Product	BOD_5 (mg/l)	Suspended matter(mg/l)	pH	Production +) time
Raspberries	800	50	6.4	July/August
Strawberries	1300	80	6.3	June/July
Rhubarb	1200	40	6.0	June/August
Cherries	400	60	6.0	July/September
Plums	250	70	6.8	August/September
Pears	7000	1600	6.0	September/November
Apples	2500	400	5.8	September/January
Peas	500-4000	400	7.9	June/August
Beans	200-600	50-150	7.5	August/September
Beetroot	1500-4000	700-2000	6.5	September/February
Carrots	300-1400	700	7.1	August/March
Celery	2000	1000	7.2	all year

+) Western Europe

The sources and relative proportions of waste water from the different processes in the fruit and vegetable processing industry are shown in Table 28.16 (Holdsworth, 1968).

TABLE 28.16

Sources and relative proportions of waste water from individual processes

Process	Volume of waste water (l/h)	(l/ton)	% of total effluent
Peeling	4500	180	2
Spray rinsing	41500	1450	17
Sorting, cutting, etc.	11300	450	5
Exhausting the tins	4500	180	2
Processing	2200	90	1
Cooling the tins	90000	3500	37
Plant maintenance	79000	3100	33
Washing boxes	7400	250	3

The water consumption can be reduced by recycling the water used for cooling the tins.

Furthermore, it is possible to reduce the quantity of waste water by use of automatic valves on hoses and pipes, using high pressure instead of low pressure sprays, eliminating overflows and by replacing flumes by conveyors. If the cooling water is not recycled it can be used again for the peeling bath, washing the raw fruits, for lubricating the canning belts on which the raw materials are processed and for washing the rooms.

If the processing plant is situated in a town, the waste water can be discharged into the sewer, provided it constitutes only a small fraction of the total quantity of sewage. It might affect the municipal waste water plant considerably because of the intensity of water consumption from these industries in certain seasons (Ryan, 1940; Zickefoose, 1963).

Fruit and vegetable waste water can be discharged into domestic sewage without upsetting the biological treatment process, provided the peak volume does not exceed the normal maximum fed to the waste water treatment plant by more than 10-20% and the total BOD_5 of the waste water is only about 1.5-2.5 times the average value.

Effluents from these plants are decomposed relatively quickly in the biological plant (Eckenfelder et al., 1958). Before being discharged into the sewer the waste water should be passed through screens to remove solid matter which might clog the pipes.

In most cases, however, it is desirable to treat this waste water separately. This is possible by coagulation, biological treatment or irrigation (Luley, 1963). Irrigation has been mentioned page 320.

According to some investigators coagulation does not proceed satisfactorily in certain qualitative and quantitative combinations of processed raw materials. When coagulation is successful, however, a BOD_5 reduction of 60-70% may be achieved. Either lime, iron(III)chloride, iron(II)sulphate, aluminium sulphate or starch sulphate can be used.

Activated sludge treatment of this waste water can in some instances yield an excess of sludge so nutritious that it can be used as fodder for pigs, poultry or sheep.

According to Sierp (1959) a BOD_5 reduction of about 99.9% is obtained with an aeration time of 60h and an air consumption of 80-90 m^3/kg of BOD_5 removed. The optimum loading of the aeration tank was 2-2.2 kg O_2 per m^3 per day. It was found necessary to add sodium nitrate and sodium phosphate as nutrients to give sufficient concentrations of nitrogen and phosphorus in the waste water.

Activated sludge or contact stabilization treatment of fruit processing waste at a low rate, below 0.4 g BOD_5 removed per day per mg MLVSS, will provide greater than 90% removal of the organic load and removal of solid from the effluent.

The activated sludge process does an adequate job as contact stabilizer and can be recommended because it requires fewer facilities and the costs are therefore lower.

Aerated lagoon treatment can provide BOD_5 removal greater than 70%, but suspended solid will remain in the effluent which is the principal source of effluent BOD_5 and COD. This treatment is considerably less expensive and is recommended if the effluent quality can be tolerated.

Completely mixed aeration basins provide effective buffering to avoid pH fluctuations when of adequate size and equipped with adequate aeration.

Final clarification of the activated sludge or contact stabilization is successful at low surface loading rates less than 16 m^3 per day per m^2. Addition of nutrients is necessary to achieve successful biological treatment as mentioned above.

Saving of nutrients can be made by increasing the amount of biological sludge in the system, thus decreasing the waste loading rate on the sludge thus allowing greater destruction of the sludge by respiration (Esvelt et al., 1970).

Most waste water from food and vegetable processing is easily treated by conventional biological methods. However, lactic acid fermentation of cabbage to produce Sauerkraut regenerates strongly buffered acidic brine. The difficulty in treating this effluent is manifest in its biological oxygen demand, which may reach 41000 mg/l, and its lactic acid content which is in the range 14000-16800 mg/l. Sauerkraut brine represents the extreme condition of refractory food-processing effluent. In addition to its content of organic acid there is also the problem of removing sodium chloride.

However, ozone can be used for treatment of this effluent. By ozonation in 24 hours it is possible to decrease the lactic acid content by 46% and the COD by 48%. In 72 hours these figures can be increased to 70-80%. The ratio of ozone consumed to COD reduced is approximately 2.0 (Walther et al., 1974).

Hang et al. (1975) have sequentially used yeast and a fungus culture to reduce the BOD_5 in Sauerkraut brine. A BOD_5 reduction of over 90% was achieved, and the yield of dried biomass was approximately 60% of the BOD_5 utilized. The protein content of the biomass was as high as 45%.

Another method commonly used in the U.S.A. is to pump the waste water into oxidation ponds. The disagreeable odours involved are alleviated to a certain extent by adding small amounts of sodium nitrate to the waste water. This reduces the anaerobic conditions and prevents unpleasant odours developing. Ammonium nitrate also prevents the formation of gases during the slow flow of waste water into the pond over a distance of about 300 m. The amount of oxygen available from the sodium nitrate should be 25-35% of the BOD_5.

Sulphur dioxide in waste water from vacuum evaporators is removed in cooling ponds. The efficiency can be increased if the plant layout permits passage of the waste water over cascades, where it is cooled and also probably oxygenated.

A cooling pond is shallow with a maximum depth of 0.5 m. The loading of the surface is 0.6-1.2 m^3 per m^2 per day, but depends on the concentration of SO_2 in the waste water.

A typical treatment of waste water from a fruit and vegetable processing plant may include the following stages:

1. Screening.
2. Mixing with municipal waste water to obtain the necessary concentration of nutrients.
3. Quick settling to remove coarser particles.
4. Settling for a period of a few hours to remove all settleable material.
5. Biological treatment on biological plastic filters.
6. Recirculation of part of the treated water.

Spray irrigation is used in England and the U.S.A. 12-18 mm daily or 75-100 mm for 8 hours once every seven days has been recorded. When spraying woodland the rate of irrigation can be increased up to 15 times.

Studies of irrigation using cannery wastes have shown that much of the plant nutrients material that is released during the decomposition of organic matter contained in the waste water is reabsorbed by the soil complex. The capacity of soil to retain large quantities of plant nutrients is a well-established agricultural fact. Nevertheless it is not reasonable to suppose that this storage capacity is infinite. One way of prolonging the plant nutrient storage capacity is to remove the nutrients by harvesting the hay grown on the irrigated soil (Guilde et al., 1971).

Biological and bacteriological studies indicate that the microbial population varies between $500 \cdot 10^6$ and $600 \cdot 10^6$ organisms/g of soil and that on the average about six times as many organisms are present in treated soil than in untreated soil. Of the organisms selected for the evaluation the aerobic heterotrophic bacteria and Streptomyces account for over 90% of the population.

Law et al. (1970) describe a 12 months' study which was conducted to determine the treatment efficiency of a spray run-off treatment system for cannery wastes.

A total of 338 cm of waste water was supplied to each of four experimental areas. Hydrological measurements, removal efficiencies and soil water quality were evaluated. The hydrological measurements showed that 18% of the applied water was lost through evaporation processes, 61% returned to surface streams as run-off and the remaining 21% percolated through the soil.

The quality of the waste water varied regularly according to routine changes in the canning processing operations.

The soil system provided a buffering capacity which eliminated most of the variability from the quality of the stream leaving the farm.

Fig. 28.5 illustrates the effect of temperature on the oxygen consumption and growth of bacteria in water treatment fields. The plot indicates the microlitres of O_2 consumed per hour per g wet soil and is given as a ratio of consumption at a given temperature to consumption at 30^oC. (Vela, 1974).

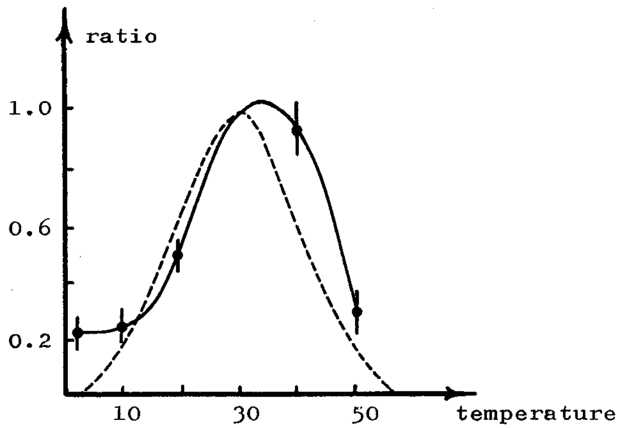

Fig. 28.5. Microlitres of O_2 consumed per hour per g wet soil given as a ratio of consumption at a given temperature to consumption at 30^oC. The dotted line indicates the theoretical relationship.

Waste water from the manufacture of vegetable oil can, according to Folkeson et al. (1976), be treated by a four-step process, consisting of a mechanical step, precipitation with calcium hydroxide, biological treatment and a second chemical step using iron chloride as precipitant.

The results of the last three steps of this four-step process are summarized in Table 28.17.

TABLE 28.17

Results of the last three steps of the four-step process (mg/l)

Sampling point	BOD_7	COD	Total P	Fat & grease	Suspended solid
After mechanical treatment	357	759	23	260	171
After chemical precipitation with calcium hydroxide	121	224	3.9	13	27
After biological treatment	16	67	3.3	2.3	16
After chemical precipitation with iron and filtration	14	48	0.6	0.5	9
Total per cent reduction	96.1	93.7	97.4	99.8	94.7

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