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WASTE WATER TREATMENT IN THE BEET-SUGAR INDUSTRY

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I. INTRODUCTION

It has often been said that water is the essential element of the world upon which we live. Yet we have needed a great number of centuries to realize this and to reach the conclusions implied by this statement. Even a few years ago there were few industries concerned with problems relating to water sources and pollution control. Today, we believe that there are at least four factors which bring us to close consideration of these problems. These are:

(1) The increase of pollution in surface waters;

(2) The continuous increase of water needs which sometimes cannot be supplied by natural sources;

(3) The progressive strengthening of laws in the highly-industrialized countries which regulate with increasing severity both the quality of the discharged waters and the amounts of natural waters used;

(4) Finally, the cost of the water, which may reach very high values due to the above-cited factors.

The sugar industry thus has a field which deserves close consideration. The sugar industry has long been considered as a consumer of large amounts of water and as a highly-polluting industry. On the contrary, we will show in this review that the process of beet-sugar extraction actually produces water rather than consuming it, and that its pollution charge may be greatly reduced.

In the solution of these waste water problems, the imperative industrial and economic considerations must be kept in mind. The solving of the waste waters problems of a sugar factory will always involve a compromise between uncontrolled discharge, which should be forbidden, and the absolute prohibition of the introduction of any effluent into a river, which, from an economic point of view, is unrealistic. Practically, it means that the sugar industry will have to make great efforts to reach economic solutions which satisfy the authorities, industry, agriculture and nature. Although it is possible for a beet-sugar factory to discharge only water of good quality into natural water bodies, this causes difficult problems in settling, recycling and purification of the various waters.

Before considering these problems in detail we will briefly describe the quantities and the compositions of the sugar-factory waters, which have been fully described in the literature.

II. WASTE WATERS BALANCE IN A SUGAR FACTORY: THEIR GENERAL CHARACTERISTICS, THEIR RELATIVE VOLUMES AND POLLUTION CHARGES[1-104]

A. *Preliminary remarks*

(1) When making a literature search on the water requirements of a sugar factory, the importance of the volumes and pollution charges is a constant source of surprise. These figures, of course, vary, depending on local conditions, such as soil composition, climatic conditions, and processing schemes. The amount of water necessary for transporting and washing the beets will be quite different if the beet tare amounts to 3–10%, as in warm and dry countries, or 20–50% as in wet countries. The volumes of water necessary to condense the vapors from the evaporators and from the vacuum pans also depend very strongly upon the processing scheme of the sugar factory, upon whether it is a raw or a white sugar factory, and upon the availability of a cooling tower. The presence in the factory of certain specific installations, such as deliming, demineralization, a saccharate process, or a Quentin installation, may also highly influence the amounts of waste water.

It is therefore practically impossible to give absolute figures, and we can present only orders of magnitude for the volumes and the pollution charges. It must always be kept in mind that each factory is an individual case, and differences from the average figures given here may be relatively large.

(2) It may be recalled that the pollution charge of a waste water is generally measured by the BOD_5, from which one may calculate the "specific loading" B, which is defined as follows (Schneider *et al.*[9]):

$$B = \frac{\text{g BOD}_5\text{/ton of processed beets}}{E \text{ (population equivalent)}}$$

According to Imhoff[2], the population equivalent, E, is defined as 54 g BOD_5 per inhabitant per day.

Since the equation takes into account the amount of beets processed, the specific charge for B permits direct comparison between the waste waters of different sugar factories.

B. *Production of waste waters and processing in closed circuits*

In order to save water, the sugar industry has been led to the recovery of a maximum amount of water, so as to limit the effluent only to that water which cannot be re-used.

This principle has been largely applied throughout the European sugar industry and has strongly reduced the consumption of fresh water, and the absolute pollution charge of the waste waters, expressed as g BOD_5 per ton of beets. On the other hand, it has led to an increase of the relative loading, expressed as g BOD_5 per m^3 of waste water.

Table 1 gives the types and average amounts of the most important waters used in a sugar factory.

TABLE 1

	Liters % kg beets
Beet transport water	400–800
Beet wash water	100–200
Barometric condenser water	400–800
Refrigeration water	20–100
Total:	920–1900

Thus about 15 m^3 of water have been required for processing 1 ton of beets. Formerly, these 15 m^3 were produced as more or less polluted waste waters, and were discharged into a river, often without purification. We will see later that at the present time many sugar factories, for working this same amount of beets, introduce only from 0.5 to 1 m^3 of polluted waste waters into the purification process, and sometimes even less.

This great reduction of waste waters has been obtained only by appropriate innovations in the factory: by reduction and even elimination of the use of fresh water taken from natural sources; by complete separation of clean, weakly-polluted, from highly-polluted waters. The first two are rationally recycled while the latter are introduced into a separate circuit.

Figure 1 (see Schneider *et al.*[9]) represents the water circuits in a white-sugar factory and the amounts of waste waters, expressed in liters per 100 kg beets, excluding the beet-flume and wash-water circuits.

We believe this flow scheme to be an important step in the reduction of both fresh-water consumption and river pollution.

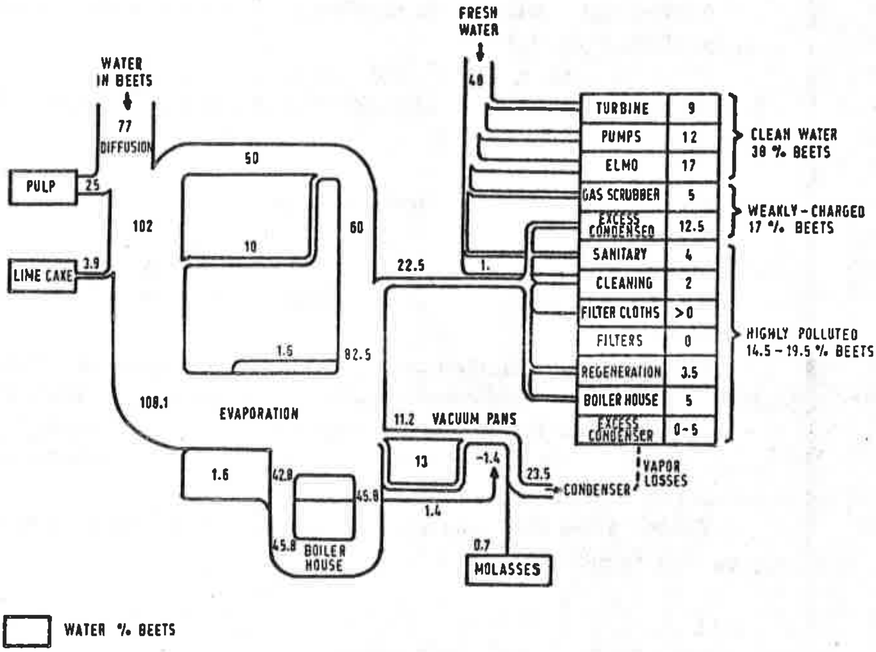

Fig. 1. Water balance in a white-sugar factory[9].

It may be seen that only 48 liters % kg beets of clean water is introduced, of which 38 liters % kg beets is eliminated as cooling, *i.e.* clean water. The weakly-polluted waters, gas washer and excess condensed waters still represent 17.5 liters % kg beets.

The highly-polluted waste waters, excepting those of the flume and wash circuit, represent only 14.5–19.5 liters % kg beets. This applies to a factory in which there is no wash water for filter cloths or filters.

The figures in Table 2 give average values for the amounts and specific charges, *B*, of the other waste waters. These values closely approach the actual figures in a white-sugar factory.

In Table 2 these figures are compared with values which we believe can be reached in ideal cases described later.

Years ago, when there was no recirculation or purification of waste waters, a sugar factory with a daily capacity of 4000 tons of beets was considered to have a pollution identical to that of a city of 500,000–2,000,000 inhabitants ($B =$ 128–500). When this same sugar factory uses a partial recycling of flume and wash waters, with total recycling of press waters and barometric condenser waters, together with dry storage of its limecake, its pollution charge amounts only to that of a city of 92,000 inhabitants ($B = 23$).

If this same 4000-ton sugar factory applied our ideal scheme, without purification, its pollution loading would be further decreased to that of a city of

TABLE 2
VOLUMES AND SPECIFIC CHARGES "B" IN A WHITE-SUGAR FACTORY

	Hoffmann-Walbeck[11]			Ideal scheme		
	Liters % kg beets	BoD_5 mg/l	B	Liters % kg beets	BOD_5 mg/l	B
Non-polluted waters						
Cooling {Turbo, Machines, Pumps}	30–50	12	0.07–0.14	[45–70][a]	10	[0.10]
Weakly-polluted waters						
Gas scrubber	5	26	0.02			
Cooling of pumps and of bearings of beet washer	—	—	—	[10][b]	50	[0.09]
Excess condensed water	3–15	25–35	0.02–0.10	10	35–45	0.05–0.07
Total weakly-polluted waters	8–20	—	0.04–0.12	10	—	0.06
Highly-polluted waters						
Beet-flume and wash-water	20–(150)[d]	3000–6000	11–(167)	1–5	5500–6500	1.1–5.5
Factory cleaning water	2–3	3500	1.3–2	2	4000	1.5
Filter-cloth wash water	2–3	5500	2–3.1	2.5	5500	2.5
Laboratory control	0.5	5000	0.46	0.5	5000	0.46
Boiler purge water	5.0	473	0.44	2	500	0.18
Excess barometric condenser	0–5	400	0–0.4	0–5	250	0–0.23
Ion exchange regeneration	3–5	4000	2.2–3.7	—[c]	—	—
Total highly-polluted waters	32–42	—	17.4–21.1	8–17	—	5.7–10.4
General total:	70–112	—	17.5–21.3	17–24	—	6–10

(a) The cooling waters from the turbogenerator, from the machines and the pumps are circulated in closed circuit via aerorefrigerators.
(b) The waters from the gas scrubber and those from the pump bearings and the other machines are re-used in the beet washer. From there, they join the circuit of the flume waters to the ponds to compensate for the losses of water occurring by the occlusion of water in the muds or by percolation into the soil.
(c) The great majority of Belgian sugar factories do not have ion-exchange installations, and thus resin-regeneration waters are not included in the ideal scheme. The literature[11] gives a few values of the specific charge, *B*, of such waste waters:

	B
for juice deliming	1.17
for Quentin process	2.94
for total demineralization	25.00

(d) The volumes and pollution charges cited for the beet-flume and wash-waters are all for normal processing conditions, and do not include unusual situations such as the processing of frozen beets or beets with very high tare.
(e) We have not taken into account sanitary waters, because they are not polluted by materials from processing and are usually disposed of to the public sewers.

24,000–40,000 inhabitants ($B = 6–10$). If, moreover, waste-water purification were installed, lowering the residual BOD_5 to 500 mg/l, the pollution charge would be further decreased to pollution equivalent to a city of 1000–2000 inhabitants ($B = 0.25–0.50$).

The British sugar factories[18–20] have been forced to maximum water economy, since the laws forbid discharge of water with a BOD_5 above 20 to rivers. They therefore recycle a maximum amount of water and do not use any fresh water. The excess waters are stored in ponds, and are purified after the campaign to lower their pollution to below the legal limits.

If we express the pollution charge of sugar-factory waste waters by the specific charge, B, we observe that the value of 17–21 population-equivalents per ton of beets, as given by Hoffmann-Walbeck[11], constitutes a very significant improvement over past conditions.

The literature gives the following values for B:

1950	Wagner[1]	700	(+ limecake)
1958	Imhoff[2]	120–400	
1959	Kramer[3]	40–180	
1960	Phipps[18]	83	
1961	Schneider *et al.*[9]	26	
1970	Hoffmann-Walbeck[11]	17–21	
1973	Following our ideal scheme	6–10	(without purification)
		0.25–0.50	(with purification)

The water balance of a sugar factory is complex, both because of the large volumes of water to be handled and because of the many different kinds of waters used. For each, a suitable treatment will enable re-use. The discharge into the river can in this way be reduced to a minimum of nonpolluting water which will consist of cooled and aerated condensate water.

In the next section we will describe such an ideal scheme of water circuits in a sugar factory, and the equipment necessary to reduce sugar-factory pollution to a minimum.

C. *Description of an ideal scheme of water circuits in a sugar factory*[24]

In most of the European countries, the legislation for protection of surface waters is continually being strengthened. The industries are charged not only for discharging used waters into the rivers but also for taking clean waters either from a well or from the river. It is clear that the sugar industry has strong economic reasons to reduce the amount of used and discharged waters to a minimum.

It is pertinent to determine how much fresh water is needed to run a sugar factory. Our industry has always been considered as a large consumer of fresh water, which explains the need for a factory to be situated beside a river. From a theoretical point of view, a sugar factory has no need of any fresh feed water, since it produces an amount of water which exceeds the amount it uses. This is shown by the following balance of the flows of water into and out of a sugar factory:

Water into the process for 100 kg of beets at 23% d.s.	77 kg of water
Water loss in finished products	
in white sugar after drying	0.0 kg
in molasses (4 kg at 80 Bx.)	0.8 kg
in dried pulp (5.5 kg of pellets at 90% d.s.)	0.5 kg
in limecake (6 kg limecake at 65% d.s.)	2.0 kg
Total:	3.3 kg
Losses of water to the atmosphere	
in pulp dryers	17.5 kg
in sugar dryers	0.2 kg
through the carbonation station	2.0 kg
through the noncondensable gases	1.0 kg
losses by evaporation and in droplets at the condenser-water cooling tower	25.0 kg
Total:	45.7 kg

Thus there is a loss, either in the finished products or as vapor, amounting to $3.3 + 45.7 = 49$ kg. This leaves an excess production of about 28 kg water % kg beets.

So whatever the water savings are, and without any water intake from outside, a sugar factory always produces an extra amount of water, as condensates leaving the juice in the evaporators.

If this excess water is intelligently used, there will be more clean water to be discharged into the river after cooling and oxygenating, and there will be less water to be ponded.

The ideal solution is to discharge into the river a maximum amount of excess water as clean water, of such quality that there is no payment required.

This necessitates a maximum savings of water by increased recycling and rational re-use of the water for successive purposes. The waters of different quality must be separated, so as to discharge clean waters without taxation, and to pond a minimum of highly-polluted water.

A study of Huberlant *et al.*[24] shows how it is theoretically possible to combine the different water circuits in a sugar factory without the necessity for fresh water intake from the outside.

Figure 2 summarizes this ideal scheme of water use in a sugar factory.

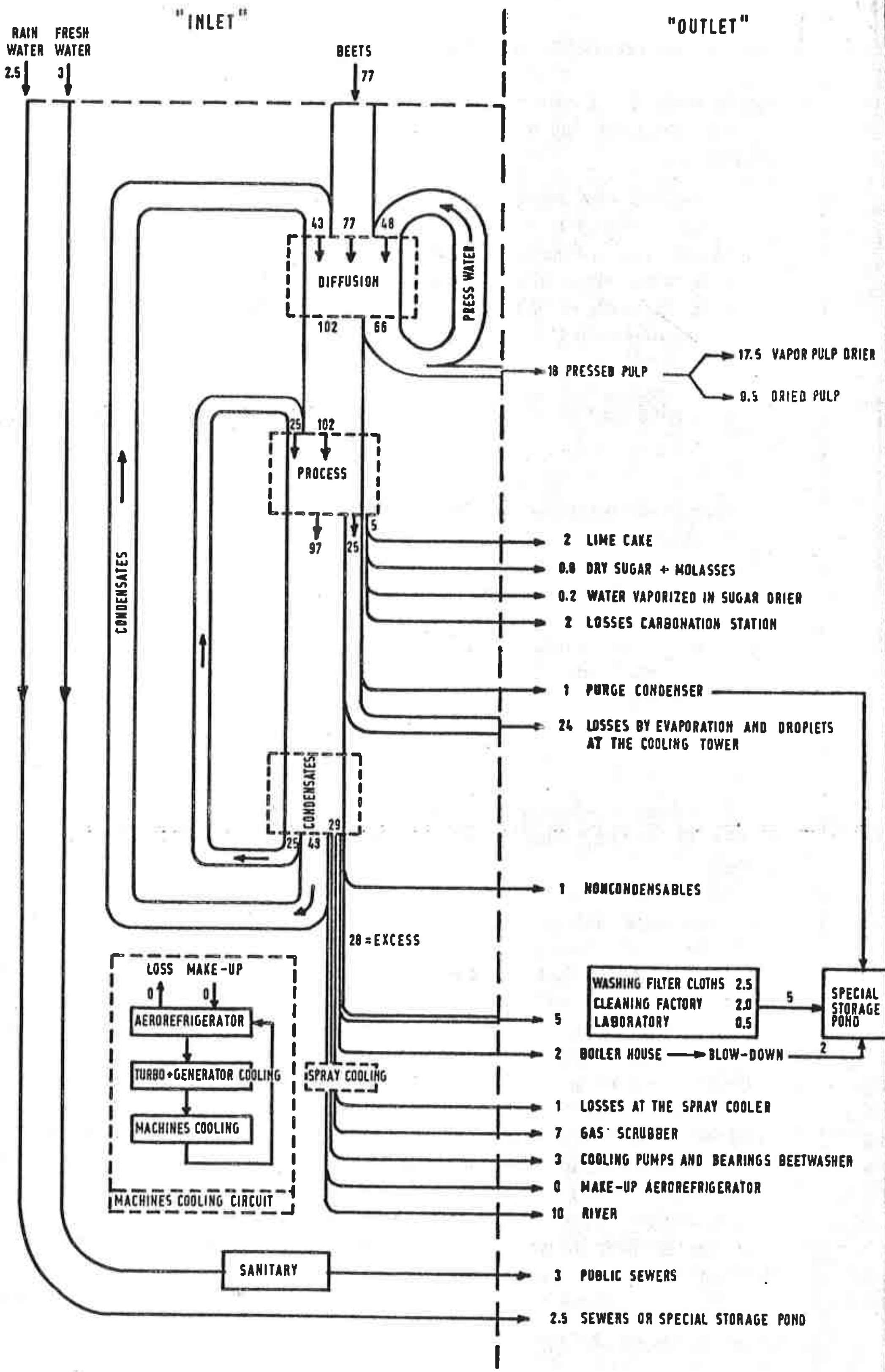

Fig. 2. Water balance in a sugar factory of 4000 tons of beets per day (water % beets).

There are four main water circuits which may eventually be interconnected. These are:

(i) The actual processing water circuit, starting from the beets through to the condensates from the evaporators;

(ii) The barometric condenser circuit;

(iii) The mechanical cooling water circuit;

(iv) The beet-flume and wash-water circuit.

All subsequent figures are flows, in liters % kg beets.

1. *The actual processing waters, from the beets through to the condensates from the evaporators*

(*a*) *The diffuser* (*see Fig.* 3). With a draft of 120 kg and with pulp pressed to about 22% d.s., we have to dispose of 43 liters fresh water % kg beets besides the 48% of pulp-press water. In order not to use fresh water, the most radical solution is to take this water from the surplus of condensed waters. Before re-use, however, these waters must be partly cooled; *e.g.* with an aerorefrigerator, and they must be acidified with sulfuric or hydrochloric acid, or with sulfur dioxide.

It is also recommended to add calcium chloride to this water to improve its buffering power and to improve the pressability of the pulp[79].

It may be noted that the press waters are wholly recycled to the diffuser, representing about 50% of the water necessary for the diffusion. There are separate storage ponds for highly polluted purges. This recycling means additional costs, because, to avoid an increase of diffuser fermentations, the press waters must be pasteurized and disinfected with formalin (1/10,000) before re-use. However, these extra expenses are compensated for by the diminution of

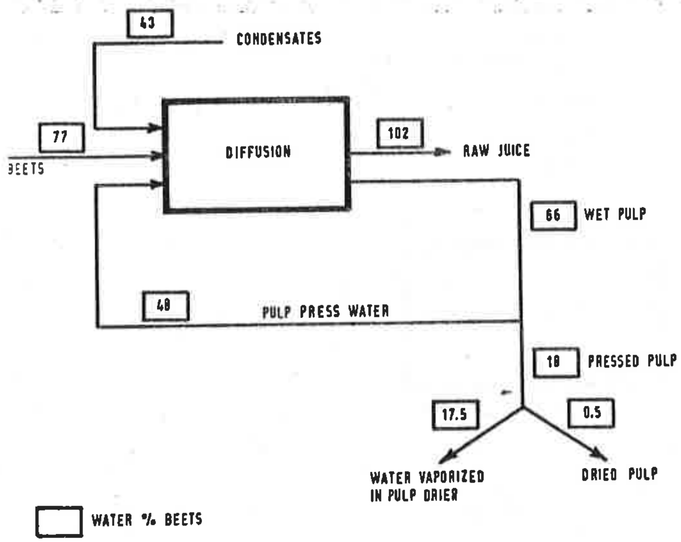

Fig. 3. Water balance in the beet diffusion circuit.

the sugar losses in the diffusion. This recycling slightly lowers the purity of the diffusion juice; this is the ransom which the sugar factory has to pay for the reduction of environmental pollution.

(*b*) *Juice purification* (*see Fig. 4*). For sweetening-off the sludges, we use 1 kg of water per kg of sludge at 50% d.s. This water will afterwards be used for preparing the milk of lime. Hot condensed waters are quite suitable for this purpose.

The amount of sludge produced will be a function of the total amount of lime. For a liming of 1.6 kg CaO % kg beets, about 5.8 kg limecake % kg beets (65% d.s.) will be produced and will contain about 2 kg of water.

In some factories the situation is still such that the limecake from the press filters (50–55% d.s.) is diluted in order to pump it to the lime pond. The supernatant liquid is then very highly polluted.

The volume of this polluted water, as well as the area for storing the limecake, have been significantly reduced by pneumatically pumping the cake to the ponds, or by using transport belts for this purpose[80–83].

At the present time modern filters, such as G.P., combined with Choquenet filters or Putsch pressure-filters, deliver very dry limecake (±65% d.s.), which may be taken directly for use on the fields. Such a solution completely solves the problem of the highly-polluted waste waters from the limecake.

In many cases, according to the nature of the soil and to the climate, these limecakes may be advantageously used for the neutralization of acid soils and as a mineral fertilizer. They also contribute to improving greatly the micro-structure and the agrochemical properties of the soil, which will improve the yield of sugar beet or of other rotating crops.

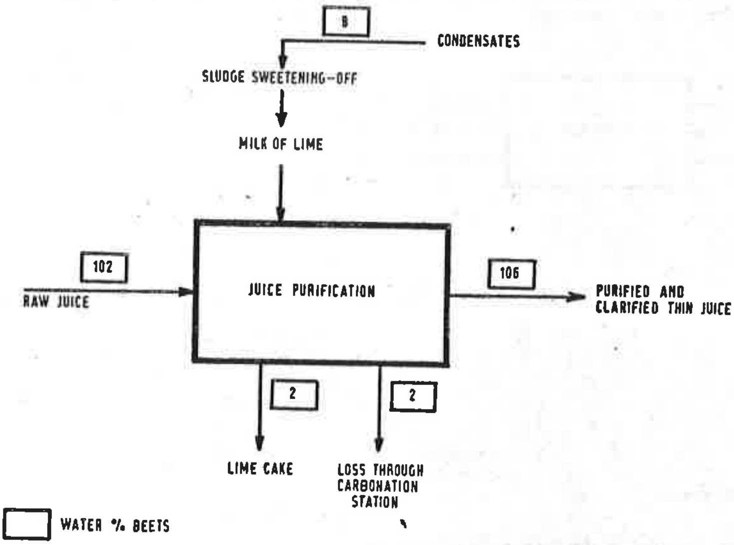

Fig. 4. Water balance in the juice purification circuit.

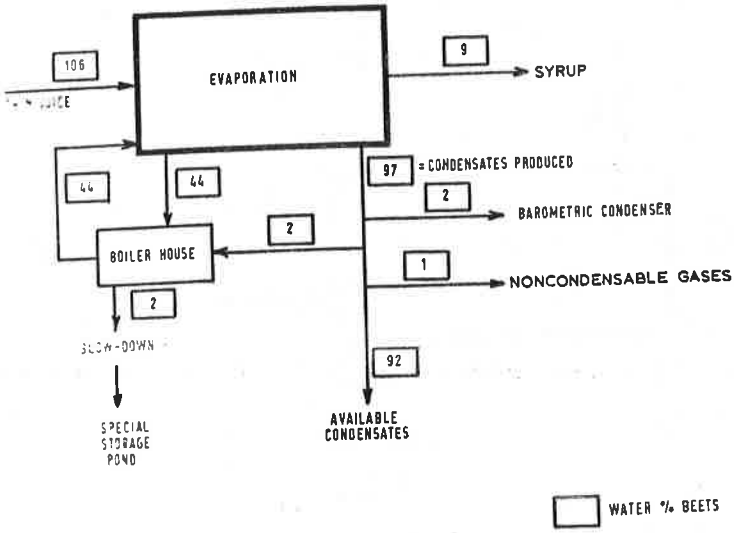

Fig. 5. Water balance in the evaporation circuit.

(*c*) *Evaporation* (*see Fig. 5*). The amount of hot condensate produced by the factory is nearly equal to the amount of water extracted from the juices when increasing the Brix of the thin juice of 13.7 to thick juice of 65.0 Brix: the thin juice loses thus 97 kg water % kg beets in the form of vapor during the evaporation.

The waters of the boiler-house are circulated in a closed circuit; to compensate for the purges and other water losses makeup water is used, composed of condensates which come preferably from first-effect vapors.

The vapors from the last effect, under vacuum, are condensed in a vacuum heat exchanger and then introduced into the barometric condenser circuit.

For losses in noncondensable vapors we use a figure of 1 kg water % kg beets. This may seem a high value; it is, however, a figure which is not readily measured.

The rest of the vapors from the evaporation, after being used either for heating the following effects or in the heaters or vacuum pans, will constitute 92 kg condensate % kg beets, which may be disposed of in various ways, detailed later.

(*d*) *Crystallization* (*see Fig. 6*). An accurate water balance for this station requires setting up a detailed flow scheme, including the numerous variants which are met within different factories. We have chosen a factory using a three-boiling system. This enables us to estimate the amount of vapors coming from the vacuum pans. Taking into account the water contained in the molasses produced and in the wet sugar going to the dryer, we can, by difference, estimate the requirements of water for the remelting of sugars, the washing in the centrifugals and the cleaning of the vacuum pans.

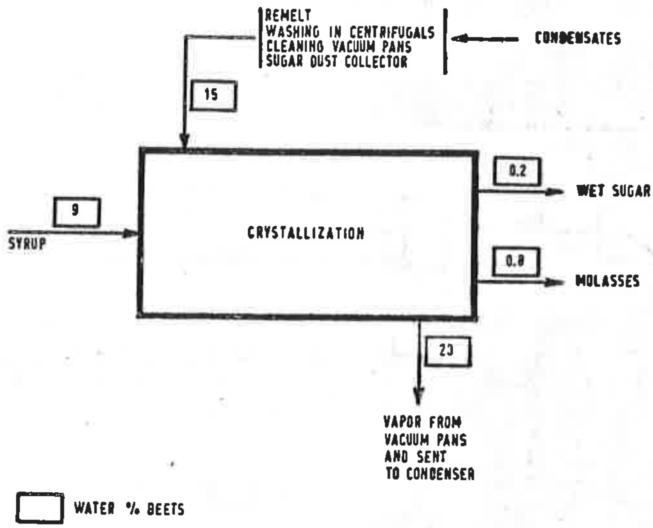

Fig. 6. Water balance in the crystallization circuit.

(*e*) *Condensed waters* (*see Fig.* 7). In the evaporators, we have produced 97 kg water % kg beets.

We have recycled:

	Water % kg beets
to the diffuser sugar-free makeup water	43 kg
to juice purification (sweetening-off the sludges and milk of lime)	8 kg
to crystallization	15 kg
We have accepted as losses:	
in noncondensables	1 kg
as makeup water for the condensers	2 kg
Total:	69 kg

This leaves 97 − 69 = 28 kg % kg beets of excess hot condensate. Of this amount, we already used 2 kg as makeup water in the boiler house. The other 26 kg will have uses for which there are many options according to the needs of the individual factory.

We may reasonably assume the following type of distribution:

(1) Utilizations of hot water which cannot be recovered after use

washing filter cloths
factory cleaning
in the control laboratory

a total of 5 kg % kg beets

All these uses will highly pollute the waters. Thus it may seem desirable to send them to a special storage pond which also receives accidental spills or other

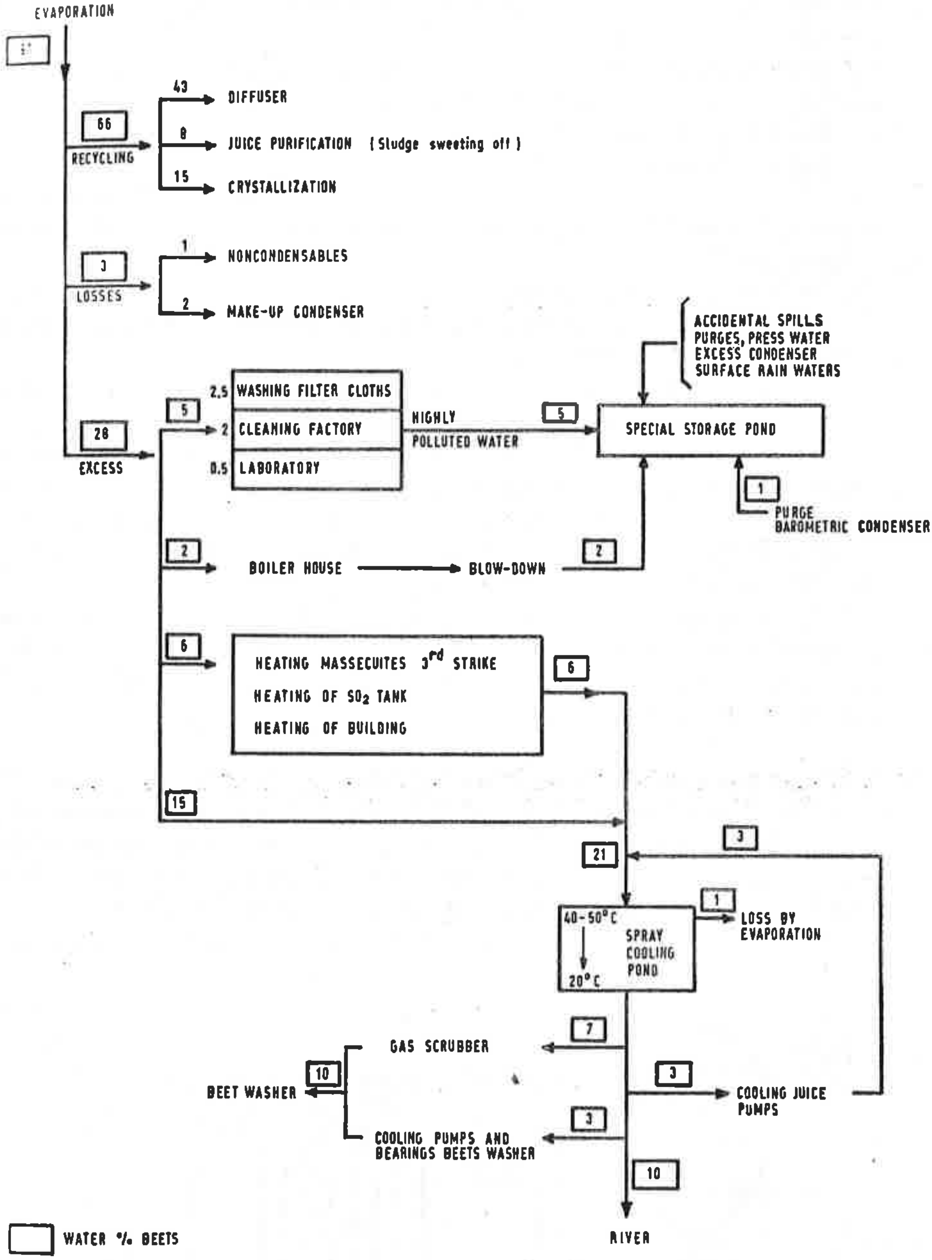

Fig. 7. Balance of the condensates produced.

polluted waters, so as not to increase the pollution charge of the flume-water circuit.

(2) Heating usages with possible recovery of the partly cooled water
heating of the 3rd strike massecuites
heating of the sulfur dioxide tanks
building heating

a total of *ca* 6 kg beets

After having recovered these calories, the waters are routed to the excess hot condensates.

(3) Uses for clean, cold water
with possibility of recovery; *e.g.* the cooling waters from juice pumps, *ca.* 3 kg
without possibility of recovery; *e.g.* gas-scrubber waters (7 kg) and waters for cooling the pumps and washer bearings (3 kg)

In all these uses we dispose of 21 kg % kg beets of condensate water, which is still warm after having given up part of its heat. This has to be cooled to about 20°C, *e.g.* by spraying in a pond[69]. This pond feeds the factory with clean, cold water. Its overflow, about 10 kg % kg beets, may be discharged into the river after final oxygenation to meet legal requirements.

The recoverable waters are recycled ahead of the spraying pond. The non-recoverable waters will be introduced in the flume-water circuit; *i.e.* into the beet washer, to compensate for the losses from occlusion of water in the muds and from soil percolation.

2. Barometric condenser circuit (see Fig. 8)

The vapors from the last evaporator effect and from the vacuum pans are condensed in the barometric condenser. This is a very large volume of weakly-polluted water. The pollution is mainly due to the temperatures of 40–50°C, the lack of oxygen and the presence of dissolved sugar and gases.

Formerly, these waters were discharged into a river after cooling and aera-

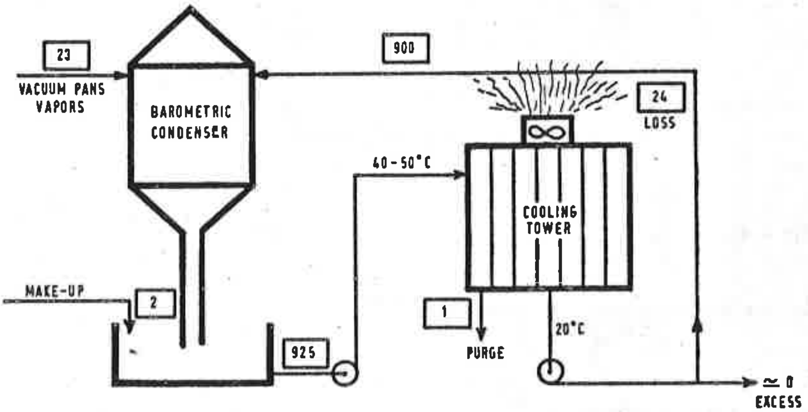

Fig. 8. Water balance in the barometric condenser circuit.

tion. However, in order to avoid pollution, it is highly desirable to keep these waters free of sugar, which means a close surveillance of the vacuum circuits.

At the present time it is generally customary to recycle these waters, after cooling in cooling towers.

Condensed vapors coming from the vacuum pans, amounting to 23 kg % kg beets, enter the barometric condenser circuit, as well as 2 kg of condensed vapors from the last evaporator effect, after having passed through a heat exchanger.

There also are important losses into the atmosphere: *i.e.* losses by evaporation, and material losses as droplets.

It is difficult to calculate accurately the amount of evaporation losses in the circuit. According to some simplified formulas[84] those losses by evaporation, for a temperature decrease of 15°C, would amount to 2–3% of the total volume of water. The losses as droplets would be about 0.2%. This would give a total theoretical loss of about 24 kg water % kg beets, which is very close to the equilibrium.

For simplicity, we assume that equilibrium is reached. Practically, and according to the type of cooling tower used, there may be slight positive or negative differences.

In any case, the following possibilities must be provided for: making up an eventual shortage of water by adding excess condensates; handling excesses by routing them to a special storage pond.

3. Mechanical cooling water circuit (see Fig. 9)

In certain machines the heat produced must be continuously removed. This cooling normally is done with heat exchangers, and with cold water. This solution not only necessitates having the required amount of cooling water available, but it is also not an ideal solution with regard to the protection of the

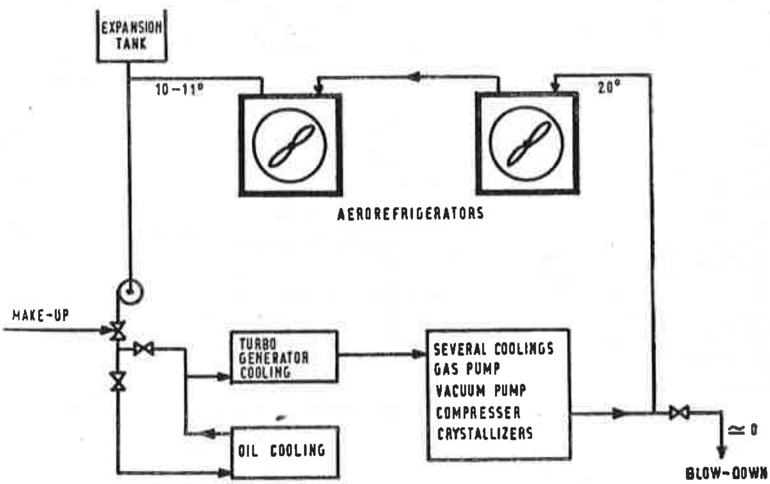

Fig. 9. The circuits of cooling water for the machines.

environment against thermal pollution: an important volume of relatively warm water will be sent to the excess condensate waters.

In our opinion the best solution for this problem is to maintain the cooling system in a closed circuit, *e.g.* by means of aerorefrigerators (see Fig. 9).

The excess calories are dispersed into the atmosphere by sending the waters to be cooled through closed heat exchangers, similar to car radiators cooled by large fans. The capacity of these aerorefrigerators may be as high as 180,000 kcal/h with a flow of 20 m^3/h of water. They achieve a decrease of the water temperature of 9°C. The electrical power requirement for the fan is 10–15 kW.

4. *Flume and wash waters circuit (see Fig. 10)*

The legislation protecting surface waters has imposed on the sugar industries a closed-circuit process, without any discharge during the beet campaign.

The schemes shown in Fig. 10 for the flume and wash waters prove that it

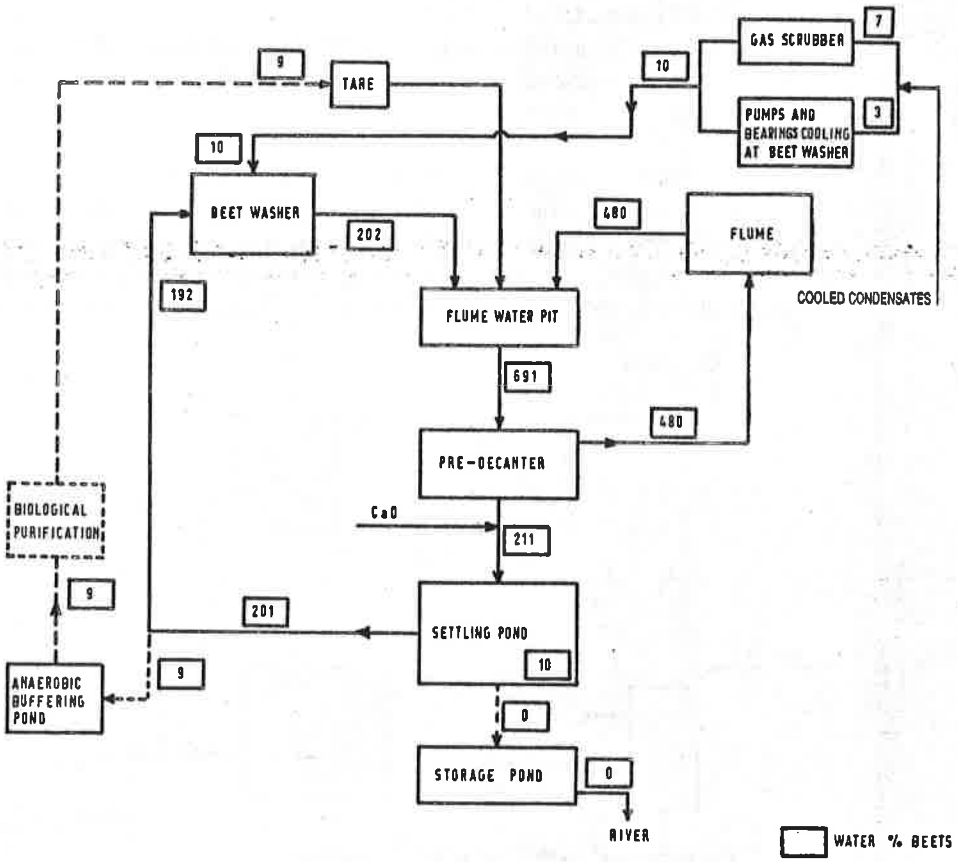

Fig. 10. Water balance in the beets-flume and wash-waters circuit.

is possible to eliminate the storage of water, together with the use of a minimal amount of makeup water.

The beet-flume and wash-waters, together with the waters from the tare laboratory, in case the beets received are sampled and analyzed for tare and percent sugar, are collected in the flume water pit and sent to the predecanter, a cylindro-conical tank. The overflow is used again as beet-flume water. The underflow from the predecanter, whose concentration of sedimentable solids will be of the order of 50 g d.s. per liter, is pumped to the settling ponds. An addition of CaO, either as milk of lime or as residue collected from the mechanical purification of the milk of lime, improves settling and ensures a sufficient pH value (6–7) in the settling ponds. After settling, the clear effluents are generally sufficiently clean to recycle to the factory for washing the beets.

Such a scheme enables the sugar factory to limit the use of clean water only to compensate for water losses in the circuit. We will neglect the water losses by evaporation and by percolation, which may be compensated by the rain water. We must, however, consider the water which is retained by the soil particles deposited in the settling ponds. By assuming: that there are 20 kg mud % kg clean beets, which means a tare value of 16.7%; that this mud, adhering to the beets, contains 25% moisture; and that this mud, when settling in the settling pond, retains 50% moisture; it is seen that 20 kg of wet soil, or 15 kg of dry soil, corresponds to 30 kg of settled sludge, which means that it retains 10 kg water % kg beets.

Thus a continual makeup of fresh water is necessary. This makeup water may originate from the 10 kg water coming from the gas scrubber or being used for cooling the pumps and beet washer bearings.

It should be pointed out that some authors estimate that the settling ponds circuit will be practically balanced in its water needs, because the deficit calculated will be mostly compensated for by rain water.

These data should always be considered with much caution because both the actual composition of the tare and the moisture content of the soils and muds may vary over large limits, according to the weather and the region.

The volume of makeup water required in this circuit has thus been greatly reduced. The pollution charge, however, is highly concentrated and amounts to 6000–9000 mg BOD_5/l. Therefore the installation of a unit which, during the beet campaign, ensures biological purification of a part of the waters returning from the settling pond (as indicated at Fig. 10), would permit holding the pollution of those waters down to an acceptable level so as to permit processing without troubles, both at the beet washer and in the tare laboratory.

After the beet campaign, this purification unit can be used to reduce the pollution charge of the waste waters remaining in the settling pond. It can also handle the highly-polluted waters stored in a special pond during the manufacturing period, reducing the pollution to values meeting the requirements of the river authorities.

Although different techniques of biological purification are known in the world, we might draw attention to the interest attracted by the new activated-sludge process, "Lefrançois-R.T.", developed by the S.S.E.C. (Société Sucrière d'Etudes et de Recherches, Tienen—Belgium), and specially designed for the purification of highly-polluted waters. This new technique is described in detail later.

(a) A few practical points in significantly reducing the pollution charge of the waters in this circuit

(1) In the first place it is important to reduce the abrading of the beets during their handling in mechanical harvesting, and in loading and unloading. Beet breakage is most undesirable for satisfactory beet storage, for good cossette quality, and for the microbiological state of the diffuser. These lacerations also lead to washing-out of the sugar from the opened beet cells, resulting in sugar losses and in useless and costly increase of the BOD_5 of the flume and wash waters (see II.C.4 (b): "the losses of sugar in the flume and wash water circuit").

(2) It must also be emphasized that it is most important to leave a maximum of tare and of leaves on the field. Presently there are dirt scrapers which remove about half of the soil attached to the beets. Certain sugar factories also practice tare removal at beet unloading. Others believe it is economically justifiable to recover the beet tails in the tare material. This may be of less importance in countries where beets have low tare content; however, it deserves particular attention in those regions where the tare percent is very high, because of its economic implications: decrease of freight costs, reduction of investment in settling ponds, and reduction of the pollution charge brought with the dirt.

(3) The first treatment of the flume waters will be to remove all leaves, tails and small pieces of beets; the leaves may be recovered and added to the beet pulp after an efficient washing, followed by crushing and milling, or they can be used for preparing fertilizer. The removal of the tails and other pieces of beets is done to recover the sugar they contain.

(4) Care should be taken to avoid bringing into the flume water circuit other highly-polluted waters, or any other product from the sugar factory, during the time they are stored in the special pond for after-campaign purification. Among those other products can be the solid or liquid wastes from the tare laboratory. It is also highly undesirable to discharge limecake into the flume waters.

(5) Before pumping the waters to the settling ponds, they should be screened; either the flume waters leaving the predecanter, *e.g.* on a curved screen with automatic removal of the solid matter, or the transport waters, as is done in the new R.T. beet washers[104]. This will allow the removal of the small tails, leaves and other vegetable wastes. This operation eliminates a source of potential pollution from the settling ponds: the diffusion of sugar from the tails cannot proceed in the ponds; the fermentation of the tails and other organic wastes will not solubilize the vegetable tissue and thus slowly increase the pollution charge of the waters. Such fermentation can also give rise to gas bubbles which can interfere with the settling of the muds.

(b) The sugar losses during the transport and washing of beets

It was stated that it is important to avoid damaging the beets during mechanical harvesting, or the loading and the unloading. All these skin abrasions destroy the beet cells, whose contents of sugar and organic substances enters the flume water.

Previous to 1960 only a few research workers have tried to estimate the sugar losses in flume waters. In 1937, Radbruch[85] and Bielitzer[86] considered this subject. Reference was made to three papers published between 1890 and 1900[87-89] and to a paper of Kryz[90], who estimated the losses per cm^2 of abraded area.

In 1960, Leclerc and Edeline[91] of Cebedeau (Centre Belge d'Etude des Eaux) studied the sugar losses occurring during hydraulic transport and washing of the beets. They came to the conclusion that the increase of organic charge during the transport was small compared with the increase occurring in the beet washer (0.05% beets). Edeline[92] also has shown that it is possible to predict changes of concentration of dissolved matter from certain parameters of the circuit. The knowledge of these changes enables us to forecast the BOD_5 which will be obtained at the end of the campaign, as well as the length of time needed for the circuit to reach its equilibrium. The parameter which is most suitable for this purpose is the concentration of sugar, which, according to the author, is responsible for 60–90% of the BOD_5 in the waters coming from the sugar factory settling ponds.

Aleksandrovich[93] cites a loss of 0.07% beets in the flume-water circuit, while Popov and Nagornova[94] estimate that the loss of sugar originating only from the washing of the beets amounts to about 0.04% beets. Grinfel'd[95] has proposed a new plan in which the time of both the transport and the washing of the beets is reduced to a minimum, leading to decrease of sugar losses.

Becker[96] and Ignatov[97] made a close examination of the structural changes in the tissue of frozen beets and of the influence of these changes on the sugar losses into the flume water. These losses amounted to 0.1–1% of sugar on beets.

Swietlicka[98] has followed with microscopic techniques the changes in the cell structure of beets which were damaged, either mechanically or by frost. More recent work of Stiemerling[99] also calls attention to this important subject.

In 1962 Schneider[100] estimated the sugar losses in the flume and wash waters of the German sugar factories. He cited a figure of 0.17–0.37% on beets. The same author[101] mentions a loss of 0.11% sugar in the flume waters of a factory where the temperature of the waters was 35°C; in another factory, where this temperature was only 15°C, the loss was reduced to 0.06% beets.

Oldfield *et al.*[102] have compared five different methods for measuring the variation of the sugar content in the flume and wash waters. They recommend the resorcinol method as being the most suitable. In their study they reached the following conclusions: in several factories, it was found that between 50 and 400 ppm of sugar diffused into the water during hydraulic transport; the increase in sugar content of the water was estimated for two beet washers and it was found that this increase amounted to 100–300 ppm, which loss corresponds to about 0.03% on beets of sugar dissolved, per minute of retention time in the washer; laboratory trials have shown that in fluming and washing only minor losses occurred through the cut faces from the topping of the beets; the major loss was shown to occur by the continuous abrasion and bruising of the beets.

Uhlenbrock[103] has studied in laboratory and in factory the influence of the quality of the beets on the sugar losses occurring during fluming: the losses were shown to increase with the extent of the abrasions: for healthy beets 0.08% on beets of sugar was lost during a retention time of 18 minutes in the water. This figure rose to 0.25% with abraded beets. The losses for stored beets (0.016–0.162) were significantly less than those observed for fresh beets (0.029–0.27). Enzymatic sugar determination was shown to be the best method.

De Vletter *et al.*[46] also studied the sugar losses in fluming and washing beets in Dutch sugar factories: as to the loss of sugar in the flume water it was shown that, except when the beets are heavily damaged by frost or severe mechanical handling, the velocity of sugar extraction slows down rapidly and is very slow after 5 minutes. The figures mentioned (0.01–0.025% on beets), correspond with the measurements made 40 years ago by Radbruch[85]. The loss of sugar in the beet washer is proportional to the retention time. Figures are mentioned of 0.06–0.095%. The sugar loss through a cut face amounts to 2–3 mg of sugar/cm^2. This figure corresponds to a retention time of 4 minutes in water of 10–20°C. The sugar loss in drum beet washers is less than in paddle-type washers. Hydraulic transport was compared with dry transport of beets. The following figures were obtained:

	Loss in fluming	*Loss in washer*	*Total loss*
Factory A: Hydraulic transport	0.06	0.07	0.13
Factory B: Dry transport	—	0.095	0.095

Thus dry transport tends to increase the sugar loss in the beet washer. However, in this case the total loss remains lower than with hydraulic transport. The measured losses of 0.1–0.2% beets correspond to the sugar leached into the water. To this figure one should add the sugar remaining in the beet tails, which is estimated to be 0.2% on beets.

These different observations confirm that to reduce sugar loss in flume waters, one should reduce to a minimum the length of the hydraulic transport, or even replace this by dry transport. It is also shown to be very important to avoid any abrasion of the beets during the washing and to reduce the length of this operation.

In this regard the new R.T. beet washer[104] is interesting, since it permits efficient washing even of soils which cling to the beets. For tare contents of 12.6–26.5%, figures after washing are mentioned of the order of 0.06–0.17%. This beet washer may be used either after fluming or after dry transport of the beets.

The very low sugar losses of 0.006% on beets are essentially due to the very short retention time of the beets in the washer, of 15–20 seconds. Pollution of the water circuits and fresh water requirements are reduced to a minimum.

III. PURIFICATION OF WASTE WATERS BEFORE DISCHARGE INTO A RIVER OR RE-USE IN THE PROCESS

The treatment of the waste waters of a sugar factory, particularly the flume and wash waters, for purifying them before their discharge into a river or to enable their re-use in the process, is a complex and a costly operation. Settling, with or without settling aids, precipitates the largest part of the suspended matter and clarifies the waters. The organic substances, in particular sugar, however, remain dissolved and cannot be eliminated by physical or chemical means. For doing so a treatment by biological purification is required.

We will review the classical processes used for waste waters treatment:

A. Settling
B. Irrigation: (1) with flume water
(2) with water clarified by settling
Injection underground
C. Biological purification: (1) Lagooning
(2) Biological filters
(3) Activated-sludge process

A. *Settling*

We have seen above that the total volume of the beet flume and wash waters may vary from 5 to 10 m^3 per ton of processed beets. These waters contain mainly suspended mineral matter such as soil, clay, and sand, in varying proportions depending on the climatic conditions and the nature of the soil. They also contain suspended organic matter, such as tails, leaves, and weeds, and relatively little dissolved organic substances.

To enable their partial or total recycling, one must remove the suspended matter from these waters by settling. By means of a curved screen or any other device one first separates the larger-sized mineral and organic substances: stones, tails, and leaves.

We drew attention above to the need to provide efficient dirt removal from the beets, first on the field, and later at the factory receiving station. Some authors recommend that the concentrated flume waters be used to irrigate fields, or for filling up boggy valleys or improving chalky soils. Generally speaking, however, the most-practised solution is to store the muds in lagoons from where, eventually, they may be taken away by farmers.

Recycling of these waters brings several problems, with respect to the settling and to their biological pollution.

1. Settling equipment

The separation of the suspended matter by settling may be done with different types of equipment:

(*a*) *Hydrocyclones*[16,26,27,36,64,69,105–113]. The hydrocyclone is the simplest of the apparatus. With a diameter of 0.5–2 m, its efficiency is maximal since its own volume is very small compared with the volume of recycled waters. Generally, however, these units have not completely met expectations. They enable a more or less satisfactory removal of the large particles, but the retention time is too short to ensure good removal of the fine clay particles.

According to the results of settling trials made in Germany[113], a first hydrocyclone removes 50–70% of the sedimentable particles, of which 90% have diameters > 0.02 mm, and a second hydrocyclone retains 10–25% of the remaining solids, in which 40–70% of the particles have diameters of 0.02–0.0002 mm.

It must also be said that when this apparatus is not well protected, it is very susceptible to erosion.

(*b*) *Settling ponds*[11,14,18,21,26,27,69,72,114–125]. Settling may be done in large ponds, where results are practically perfect, due to the long retention times. It is a cheap technique which, however, needs large areas and piping and pumps. We believe that it will remain the most-used process for a long time.

Characteristics of ponds

The shapes and the dimensions of the settling ponds have been examined by many authors[114,116–119]. The main problem is the storage of the enormous quantities of soil brought to the factory on the beets, and the disposal of these soils is very costly. Some specialists recommend the coupling of two ponds, the first one being used for a presettling where the largest particles settle, and the second pond for the final sedimentation.

Edeline and Leclerc[120] estimated that a presettling is desirable when the initial waters contain more than 25 ml/l of sedimentable particles, measured after two hours. When this figure reaches 50 ml/l, they consider presettling as unavoidable, and they propose a series of successive ponds.

According to Phipps[18], the ideal form of a settling pond is a rectangle with length 5–6 times its width. The circulation rate of the water through the pond should be maintained above 25 cm/minute. Some sugar technologists prefer long ponds of canal-shape; others prefer ponds of U-form. Some prefer a single pond of large dimensions; others prefer separate small ponds with which there are fewer difficulties in case of breakage of the retaining walls. It seems that no ideal solution exists, and that local conditions will dictate the solution.

Problems of settling in ponds

Correct settling of the suspended matter in the ponds requires a minimum depth and a low flow rate. These conditions unfortunately favor the development of anaerobic fermentations which give rise to small gas bubbles. These

The dimensions of such settlers will depend on the volume of water to be treated and on the characteristics of the suspended matter to be removed. In any case, the concentrated sludge, of 250–350 g/l d.s., taken from the mechanical settler, must still be sent to a lagoon. We should note here that for factory water economy, the drainage water from the lagoon must be pumped back to the transport and wash-water system; *e.g.* into the clarified overflow of the mechanical settler. There is no doubt as to the efficiency of these installations and they are used in many European sugar factories. They are, however, very expensive.

2. Flocculation agents or settling aids

Whatever settling technique is used, it has often been recommended that the settling be accelerated and completed by using flocculating agents. The choice of these reagents will depend on the particular quality of the water and on local conditions. Among the numerous products proposed, we may cite aluminum and iron salts, but especially lime or certain polyelectrolytes.

(a) Lime[9,11,14,20,21,26,27,44,131–145]. The agent mostly used is lime, which is generally made from the residue from the mechanical purification of the milk of lime. We believe it to be the most economical solution. The use of carbonation sludge, although sometimes proposed, seems a wrong solution to us, because it increases the pollution loading of the transport water very highly. This charge may even be doubled.

The majority of authors recommend that, from the start of the beet-sugar campaign, between 0.01 and 0.1% CaO be added, so as to reach the optimal pH value of 11–12 (> 10.5).

This technique has many advantages: it increases the settling rates from 1 cm/min to values between 5 and 15 cm/min; it improves the natural ultimate settling, of which the original value of 80–85% rises to an average of 97–98%; the BOD_5 is reduced by 40%[131], 53%[174], 75%[142], or even 85%[138]. This reduction is due to a better removal of the suspended organic substances. Personally we have observed an average reduction of pollution charge of about 25% for a mean liming up to 10.5–11 pH; the number of microorganisms in the water is reduced from 5×10^8–10^9/cm³, to about 10^4–10^5/cm³. This will also automatically decrease the number of microorganisms in the diffuser; the risk of odorous anaerobic fermentation will also be strongly reduced.

However, the addition of lime may present some inconveniences. If the pH value of the water is between 8.5 and 10.5, strong foam formation may be observed, due to the beet saponins in the flume waters; although by maintaining the pH value of the water between 11 and 12 the microbiological activity is significantly slowed or even stopped, the quality of the water may deteriorate as a result of the progressive increase of the sugar content and of the concentration of other organic substances. In such situations important volumes of fresh makeup water may be needed and this may lead to a significant increase in consumption of anti-foam agents; when the water must be purified by a not only inhibit the sedimentation of the particles, but they also redisperse the mud on the bottom of the pond. Moreover, anaerobic fermentations increase the water color and evolve hydrogen sulfide, the unpleasant odor of which makes working conditions unpleasant, and may even be toxic to workers. To avoid such fermentations, specialists have suggested rules for operating settling ponds. These rules are not always applied, and they are listed briefly as follows:

Flume waters should not be mixed with highly-polluted waters, which are rich in sugar or in nitrogen, such as sweet waters, transport waters from carbonation sludge or limecake itself. Makeup with hot condensates is not recommended, as they may introduce ammonia and heat, both of which further fermentations and solubilize the vegetable organic matter.

It is essential that the circulation rate of the water in the ponds is not too slow. The flow rate will be dictated by the rate of sedimentation of the suspended particles. The circulation must be as homogeneous as possible. Especially to be avoided is stagnant water in dead corners and particularly in the channel created when raising the levels. The water overflows, both at the entry and the outlet, must be intelligently located. The ponds must be free of weeds, because they not only interfere with water circulation, but they also form soluble matter by their decomposition. For this reason tails, leaves and other vegetable fragments are undesirable in the flume water.

Good settling needs only a few hours. For economic reasons, however, it is usually justifiable to construct relatively large ponds, because small ones are rapidly filled with settled soil which requires the building of higher retaining walls, or new ponds. The ponds generally are designed to have maximum retention time without fermentation. This retention time should be under 24 hours. It will of course be a function of the temperature, induced either by the season or by such factors as the introduction of hot condensates as makeup water.

(*c*) *Mechanical settlers*[11,14,18,20,21,26,27,39,52,56,64,68,69,126–130]. At the present time there is a tendency in modern sugar factories to replace settling ponds with mechanical settlers. These are generally made of concrete and are provided with automatic systems for the removal of the concentrated solids. These are usually circular, but are occasionally rectangular in plan. Practically all work on the same principle.

Among the circular settlers, certain types are divided radially into a number of compartments through which the water flows in series, such as "Hirschfelder tanks"[39], or in parallel, such as "Borsig tanks"[52]; the other types, "Dorr tanks"[56,68,69] or "Bruckner tanks"[14,17,126] have no compartments but a mechanical scraper which sweeps the settled mud to the center of the tank from where it is pumped.

These mechanical settlers have certain advantages over settling ponds: for a high settling yield they need less space; the retention time is small, 2–3 hours; and the continuous scraping of the inclined or conical bottom avoids mud stagnation, and thus the risk of fermentation is considerably reduced.

biological process, the high pH value may lead to considerable difficulties in orienting the fermentation in the desired direction.

We believe it to be sufficient to lime the flume waters before pumping them into the settling ponds, so as to keep a pH value of about 6.5–7 in the settled waters returning from the ponds. Such a value eliminates any danger of corrosion.

This limited liming maintains a microbial flora with sufficient activity to degrade part of the carbohydrates and in this way to limit the pollution loading in the flume-water circuit. On the other hand, a later biological purification plant can then be fed with water of pH 6–7, which is a favorable range.

(*b*) *Polyelectrolytes*[21,26,27,144,146–149]. The polyelectrolytes most often used in sugar factories are polyacrylamides. They do not present the inconvenience of lime, but they are very expensive. By using them, a static settling is transformed into an orthokinetic settling; *i.e.* a settling in which the particles will no longer settle individually at different rates according to their dimensions, but in which they stick together to build a film which during the settling carries along all the particles, regardless of their size. This calls attention to the advantage of having a water in ponds which is free of suspended fine particles.

Devillers *et al.*[148] have made laboratory tests of the efficiency of different settling aids in improving the settling rates in flume waters taken from four French sugar factories.

The natural settling rate of the suspended particles increased from 1.66 cm/min to between 4 and 30 cm/min, depending on the flocculant used. These tests were done at a constant solids concentration of 1 ppm. With 2.5 ppm, certain flocculants enabled settling rates of as high as 48 cm/min to be reached. These tests show the great efficiency of these products and the possibility of obtaining, within a short time, overflow waters which are extremely clear. These tests have also shown the difference in efficiency of these products with different types of soil. It is therefore necessary to make preliminary tests to find the most suitable flocculant for local conditions. It is, of course, assumed that the rating for the products obtained by laboratory tests can be carried over to the industrial scale.

Roche[149] has compared the performance of a few settling aids on suspensions of clay, and also their rheological properties. The results show that with an addition of 1 ppm and more, the differences in settling rates between the products are not very significant. The settling rate does not significantly increase with higher amounts. The settling rate is indeed such that the particles reach the state of compaction with 1 ppm. Between 0.2 and 0.5 ppm, the results show differences. Certain products permit a very good flocculation with doses as low as 0.22 ppm, while others need significantly higher concentrations. The settled muds have also been sent to a biological purification process to find the eventual effect of the settling aids on the settled mud. Although the permeability of the mud layer did not seem to be modified, the settling aid had, however, a disturbing effect on the biological purification.

3. *Chlorination*[21,26,27,150–155]

When attempting total recycling of the settled water, disinfection of the water by chlorination must be scheduled, to avoid unpleasant anaerobic odors. The amount of added chlorine varies generally between 10 and 100 g Cl_2/m^3. In principle, the dose will be chosen to leave not more than 1 g Cl_2/m^3 in the settled water at the point of use, such as the beet washer or tare house, in order to avoid annoyance to workers. Such chlorination should also only be done on waters which are perfectly clear. The addition of small amounts of sodium nitrate may help to reduce the rate of development of hydrogen sulfide. Again it should be underlined that chlorine or nitrate additions should not interfere with a later biological water purification.

B. *Irrigation*[6,7,26,28,43,156–165]

The exact composition of the waste waters from a sugar factory is not well known. The COD of the dissolved substances varies between 500 and 5000 mg/l[165]. This corresponds to about 80% BOD_5, 10–120 mg total nitrogen, 2–10 mg total phosphorus and 25–300 mg potassium, per liter.

These waters also contain Ca, Mg and Na. The suspended matter, clay and sand, amount to 300 g per liter. Eventually they may contain carbonation sludges which are interesting because of their high calcium carbonate, phosphorus, and organic matter content. These sludges may also help to correct the N/P inbalance of the waste waters.

The agricultural utilization of the organic and inorganic constituents of beet-sugar factory waste waters has been long known. This technique has been studied in detail by Kramer[156–158]. He first points out that the purification possibilities of the soil are related to its mechanical characteristics (filtration), as well as to its adsorptive properties (fixation of the mineral and organic substances) and to its content of microorganisms, which play an essential part. According to Catroux and Betremieux[165], one hectare of land may contain 1–3 tons of microorganisms in the soil, *i.e.* an amount equivalent to an activated sludge pond of 200–600 m^3 volume. Having cited the conditions of a soil which favor good water purification, the author proves that the degree of purification depends on the concentration of wastes and on the depth of soil, so that generally in more highly concentrated wastes a larger decrease of organic substances will occur, and the amount of purification will decrease with increasing soil depth. For Kramer, the temporary increase of the soil water content, which occurs when irrigating with wastes, will increase the degree of purification.

The author proves that the decomposition of the organic substances of the wastes in soils is a logarithmic function, which is denoted as the "decomposition law", given by the following equation:

$$A_T = A_0/10^{T/C}$$

in which A_0 = mg BOD_5/l in irrigated water

A_T = mg BOD_5/l remaining in the water at a depth T
T = depth in cm
C = a coefficient varying with the type of soil, the temperature, and other experimental conditions.

This result is interesting because it corresponds to one of the mathematical models commonly used in the calculations of biological filters.

The irrigation techniques do not, apparently, present major difficulties for agriculture, taking into account the following.

The choice of the soil is critical: it must be a permeable, thick layer of clay, rich in humus, to ensure good purification. The amount of flooded water is calculated as a function of the permeability of the soil and of the amount of fertilizing substances contained in the water, so as to avoid any complications in cultivation: less than 500 mm of water per campaign according to Kramer[158]; Devillers[26] and Mariani[43] cite a figure of 10 m^3/h per hectare; Parkhomenko[164] describes trials of irrigation made in the Ukraine in which 15 m^3/day per hectare were used. Since the water purification takes place in the upper part of the soil, samples must be taken regularly by drilling in order to check if the underground acquifers have been contaminated. The waste water brings nutritive elements into the soil. Mazur[162] estimated that, during one campaign in Poland, each sprayed hectare received 167 kg of N, 63 kg of P_2O_5 and 457 kg of K_2O. Parkhomenko[164] estimated that irrigation of fields increases the harvest capacity by 65–70% and replaces 40–70% of mineral fertilizers. According to Kramer[158], soil analyses show that there is a reduction in available phosphate, an increase in potash and nitrogen, and no change in calcium content, or in the pH value after the irrigation. Arable land, with or without additional fertilization, gives increased production of wheat, potatoes or beets, but the land requires fresh water irrigation during the vegetative period. Mühlpforte[6] considered that irrigation fields are frequently overloaded or exhausted so that they no longer perform their function.

Two types of irrigation are used[26,28,160,162–164]:

1. Irrigation with settled flume waters

This type of irrigation may be used with existing crops and particularly on grass lands, either by spraying or by flooding. Devillers[26] and Bidan and Heitz[28] have obtained satisfactory results at French sugar factories by the utilization of this system: for an average BOD_5 of the irrigating water of 600 mg/l, the BOD_5 of the water, sampled from borings, increased by 20 mg/l during the time of irrigation; it decreased again to zero in 2 or 3 months after the end of the campaign. Only the potassium content of the water increased progressively. The quantity of potassium brought with the water amounted to 5 tons per hectare per campaign. The quantity of retained nitrogen amounted to about 450 kg/hectare.

This method, although involving small amount of labor and relatively small areas, may, however, present the disadvantage of progressively clogging the soil, and of impeding normal culture, since many plants may be damaged by such enormous doses of potassium. It also has the inconvenience of requiring settling ponds for eliminating the suspended matter before irrigation.

2. Irrigation with unsettled flume waters

With this process the sugar factory can dispose of its waste water and its tare entirely. It also permits the elimination of weeds, tails and even carbonation sludges.

Irrigation with unsettled waters may be done by:

(*a*) *Spray irrigation.* This long-used technique has the following disadvantages: the flow of water is limited by the diameter of the conduits, which are also heavily corroded; a preliminary screening of the flume waters is necessary; one must have a flat plot of land; and, due to the spraying, the soil will rapidly lose its permeability.

(*b*) *Flood irrigation.* Wherever possible, flood irrigation is used rather than spray irrigation. However, this technique requires good land preparation: the land must have a slight slope, contour lines must be traced, and channels should be opened at distances of 50 cm on these contour lines. The muddy water should be brought to the highest level and then circulated by overflow from channel to channel. The suspended matter progressively fills up the channel and the water flows further down. There is only slight classification of the soil from this technique. A good mixture is easily obtained by plowing the land perpendicular to the contour lines. A particular area can only be flood-irrigated once every three years.

After having tested different systems for control of irrigation, Catroux and Betremieux[165] cite results obtained in a French sugar factory: with irrigating water containing 1800 mg COD/l, 43 mg total nitrogen/l and 1.3 total phosphorus/l, the authors obtained the following average analysis for the water collected in the lysometers: 346 mg COD/l and 7.3 mg total nitrogen/l. The phosphorus content was practically zero.

After having examined the lands before and after irrigation, Betremieux estimates that one should not overvalue the advantages of this technique, either for agriculture, or for purification. Water spraying must be as regular as possible because one often observes large fluctuations in the sprayed materials, both in composition and in amount. This cannot be neglected from the agricultural point of view. The possibilities of purification and of water absorption by the soil limit the amounts of water flooded on specific land.

Summarizing, one may conclude that flood irrigation seems to certain authors the best solution because it disposes of the water by returning the soil to its agricultural use. However it must also be underlined that this technique includes some important risks and disadvantages.

A few words should be added on the technique of underground injection of waste waters[166–168].

In this technique, the polluted water is injected through a drilling into a water layer at great depth. This water layer is generally saline. It supposes favorable geological conditions and compatibility between the injected water and the acquifers.

This recent method is at the present time in some use in the U.S.A., and it has also been studied in France by some industries, including the beet-sugar industry.

C. *Biological purification*[169–223]

Biological purification of the waste waters from sugar factories has been solved in different ways depending on the selected type of discharge. These solutions also depend on the legal requirements, the environmental conditions, geographical features, and technical or economic constraints. Therefore each sugar factory should be considered as an individual case.

1. *Lagooning or natural autopurification*[7,10,11,13–15,18,20,26–28,42–44,59,60,68–74,76,169–223]

(*a*) *Principle.* While storing waste waters in a pond, a more or less rapid, natural autopurification takes place, from December to August–September. In this degradation of the pollution charge, three stages may be recognized:

(1) In the beginning, the content of organic substances is so high that intense anaerobic fermentation takes place. This changes the carbohydrates, mainly sucrose, into organic acids. The fermentation leads to acidification, to foam formation and to the development of acid odors. This degradation, which is very slow, generally takes place during the cold winter months.

(2) The next stage is also anaerobic and it includes degradation of the nitrogen-containing organic substances, *e.g.* albumins and amino acids. This phase is characterized by increase of pH up to neutrality or low alkalinity; it is also accompanied by a darkening of the water colors, due to sulfurous compounds, and by the development of malodorous hydrogen sulfide.

One observes what is essentially competition between the anaerobic fermentation and putrefaction. Each bacterial phase can only occur alone, and one must succeed the other. The length of time between the two degradation phenomena is longer in cold weather.

(3) When the anaerobic bacteria have transformed all susceptible materials, *i.e.* 90% of the organic substances, their development slows down. When this stage coincides with the warm months, aerobic fermentation starts and progressively spreads into the whole depth of the pond. The surface of the water is gradually re-oxygenated, allowing for development of the aerobic bacteria.

The increase of the temperature, to 15–18°C, as well as the greater amount of sunlight, starts the development of red algae. This condition goes on for about a month, when the green algae take over. As this growth increases, a definite rise in pH (7.5–8.0) is noted, and provided the BOD_5 has already decreased to about 100 mg/l, supersaturation of the dissolved oxygen to the extent of 10 or 20 mg/l is likely to occur. As pointed out by Edeline and Lambert[204], the development rate of the algae is not constant. An alternation is observed between periods of abundant algae and periods during which they are present in much smaller amounts.

Starting from July, when the purification is practically terminated, an important invasion of predators, such as daphnia, ciliates, rotifers, cyclops and other types, is observed in the pond[219–224]. Thus there is a transformation of organic substances contained in the waters into living matter via succeeding degradations and syntheses, and through the action of more and more evolved bacteria. For terminating the cycles, one may use, as in Poland, grass carp which, by the ingestion of excess aquatic vegetation, contribute to the purification of the waste waters contained in the ponds.

When the aerobic phase is reached, the water in the pond might also be handled by activated-sludge processes, which are discussed later.

The natural autopurification phenomenon seems to be a low-cost process since no energy is needed. Its industrial application may be made difficult by the requirement of ponds with large surfaces and because many sugar factories are situated close to cities. The production of unpleasant odors may not be underestimated, nor can the dangers of seepage of water into the deep acquifers, accidents to the embankments, and the importance and difficulty of maintenance while the ponds are filled with water during a large fraction of the year.

(*b*) *Applications.* The numerous data from the recent literature show on one hand the importance of the autopurification of factory waste waters by natural lagooning, and on the other hand the evolution of its basic principle as a function of sanitary and economic considerations.

Carruthers *et al.*[172] cite interesting results of the autopurification of flume and wash waters. In Great Britain the BOD_5 decreases progressively from 1239 mg/l in March to 38 mg/l in October. The last figure indicates a well-purified water, which then has multiple use at the beginning of the campaign.

Chekurda and Parkhometz[193] report results obtained in the Ukraine with purification in ponds. In this region the average yearly temperature is 7°C. Stored at the end of August in ponds with an average depth of 1 meter, the pollution charge of the water decreases from 2000 to 900 mg BOD_5/l during the months of September, October and November. During the next three winter months the BOD_5 increases somewhat. After the thaw the autopurification restarts rapidly, ending up in August with a very well-purified water, with a residual BOD_5 of 12 mg/l.

Edeline and Lambert[204] have studied in a Belgian sugar factory the autopurification of waste waters in ponds with depths varying from 80 cm to 1.80 m. The main results of their work may be summarized as follows: no significant purification occurred in any of the ponds before June, probably because the temperature remained below 15°C that particular year; from June onwards, the degree of pollution decreased slowly from anaerobic processes; only in shallow ponds of 80 cm was a combination of bacteria and algae found, which is characteristic of aerobic ponds.

Purification was much more rapid and the purification effect was four times as great in the 80 cm-pond, where algae were present, than in the others.

The authors also describe in detail their study of the development of chlorophyllic algae in these ponds.

According to Baltjes[44], trials made in the Netherlands in ponds of 1–1.20 m depth were very decisive. The author, however, calls attention to the difficulty of finding the large areas required for lagooning in this country.

Devillers *et al.*[209,210,212,214] have made autopurification tests on waste waters in several French sugar factories. The treatment was done in ponds with large surfaces and small depths of about 1 m. The BOD_5 value could be reduced by 96–98%, from 850 to 5000 mg BOD_5/l in January to 16–160 mg BOD_5/l in August. They observed a faster and more complete purification for the less polluted water. When the thickness of the water layer is increased, they also note a slowing down of the purification. These same authors indicate a favorable effect from mechanical aeration of the pond surface. Within the two months of January and February the pollution charge in an aerated pond was reduced to a quarter of its initial value, while no autopurification was observed during the same period in the control pond.

Lescure[214] also studied at another sugar factory autopurification in ponds with depths of 1, 1.5, 2 and 5 m. In contrast to certain preceding observations, the results show that: the autopurification rate is not reduced when the pollution charge of the flume and wash waters is increased by strong recirculation; the autopurification rate is not strongly influenced by depth of water varying between 0 and 3 meters.

Klapper[206] reports trials of artificial aeration, by means of surface aerators, made in Germany in storage ponds where the depth (above 1 meter) did not allow sufficient natural purification. Within two months in the aerated pond the BOD_5 value was reduced from 1200 to 30 mg/l, *i.e.* a reduction of 97%. A fortnight later, this value only amounted to 11 mg/l. In the nonaerated test pond, the residual BOD_5 was still 160 mg/l at the beginning of the following campaign.

Natural autopurification generally gives satisfactory results when the depth of the storage pond does not exceed 1 meter. There are, however, problems with unpleasant odors, and large surface areas are required. Sugar factories are often obliged to store their waste waters in deep ponds where the degradation does not produce the desired purification if the aerobic stage is not sufficiently intensified.

Schneider, Hoffmann-Walbeck, Kollatsch *et al.*[177,178,195,199] have made very extensive tests on this problem and have also shown that, for ensuring the most favorable degradation conditions, ponds with 1–1.20 m of depth are required. They particularly underlined the absolute necessity of settling the flume waters as fast as possible and of storing the excess of settled waters in a separate pond. When turbid flume waters are stored, a latent putrefaction may take place between the sludge and the lowest water level. This putrefaction will slow down the aerobic degradation phenomena in the upper layer of the water. One-stage processes have not given entirely satisfactory results. Therefore, and with regard to the process slowly proceeding in the storage ponds, the authors developed a process in three stages, permitting speeding up these phenomena so as to terminate the degradation within a few days. The temperature is maintained at 20°C in the three stages; water from the storage pond is subjected to an anaerobic fermentation lasting 2 days. This stage is followed by a putrefaction which also lasts for 2 days. The water is finally highly aerated during 18 hours. This process enables the reduction within 5 days of the BOD_5 by 97–98% of its initial value. It should be pointed out that at the end of the putrefaction stage, 85% of the degradable substances have been removed.

In practice, acid fermentation and alkaline putrefaction may simultaneously take place in one single installation, catalyzed by an anaerobic flora. The pH value becomes 6.5–7.2. The optimum temperature is between 23 and 30°C. During the aerobic fermentation stage the waters are mechanically aerated, as with surface aerators. It is also recommended that activated sludge be introduced into the system. This combined process, used on a water with a pollution charge of 3–4 kg BOD_5/m^3/day, enables a reduction of the BOD_5 typically from 1500 to 30 mg/l or from 3000–5000 to 50–100 mg/l.

The U.S.A. literature also describes many experiences with lagooning[68–71,73,74,76,174,191,205,207,210].

Barr[174] reports on lagoon systems consisting of three areas with, respectively, 5, 3 and 1.8 m of depth. For eliminating odor problems and to obtain as much bioactivity as possible during the warm months of campaign and the spring months, he suggests the use of commercial enzyme material.

Tsugita *et al.*[205,210] have studied the treatment of sugar-beet flume waste waters by lagooning. Their overall objective was to demonstrate on a pilot scale the possibility of reducing and eliminating pollution and odor problems by application of an anaerobic–facultative–aerobic pond system operated continuously in series, in which the ponds were respectively 4.5, 2 and 0.3–1 m deep. The BOD_5 and COD loadings in the system were varied respectively from 0.05 to 0.25 and from 0.09 to 0.5 kg/m^2 per day. With a total retention time of 28 days, the treatment removed 94–99% of the incoming BOD_5, 84–98% of the COD and 75% of the total nitrogen, mostly during the anaerobic stage. The BOD_5 removal in the anaerobic pond increased in direct proportion to the amount of loading. Odor problems were significant only in the anaerobic pond and increased with the BOD_5 loading. A mixing system in the aerobic pond, and either recirculation of aerobic pond effluent to the anaerobic pond effluent, or mechanical aeration in the anaerobic pond, had a beneficial effect in maintaining algae growth and in preventing excessive odor formation.

The specific purpose of the second study was to explore mechanisms of aeration, and to improve pond design and operation to increase the rate of BOD_5 and odor removal and to explore further methods of decreasing land requirements. The facultative pond used in earlier trials was not used. Satisfactory effluent treatment was achieved using a 4-meter deep anaerobic pond provided with surface aeration, followed by a 1-meter deep aerobic pond with supplementary mixing or surface aeration. Nutrients were added between the first and second pond and a portion of the second pond effluent was recirculated to the first.

Investigations of the treatment of fresh waste waters from sugar factories have been made in several pilot installations and in a few industrial ones. Starting from a BOD_5 value of 5000 mg/l and higher, and from a charge of over 2–3 kg BOD_5/m^3/day, degradations could be obtained of 90–95%. Generally, however, one observes after a short time the building of "puffed" sludges, which slow down the settling of the sludge[199]. The reasons for the building of such sludges must be found in massive multiplication of encapsulating and fibrous bacteria (*Sphaerotilus natans*)[11,215,217,218]. Since the mucous membranes of the bacteria are mainly polysaccharides, particularly levan and dextran, it is understandable why the building of these capsules mostly takes place in fresh waste waters and less often in stored waste waters, in which the carbohydrates are already degraded in large part. Therefore, whatever technique may be utilized, most specialists agree that a purification of sugar-factory waste waters may only be easy and total if it is done in two stages: anaerobic fermentation for five days in deep ponds (2–3 m), followed by aerobic fermentation. The anaerobic degradation may also be done in tanks where the temperature is maintained at 23–30°C. Aerobic degradation may be effected, either by natural means in ponds which may or may not be aerated, or by more elaborate techniques, such as bacterial filters or activated-sludge processes.

2. *Bacterial filters*[10,20,43,172,173,175,182,199]

In this process, the water to be purified is brought into close contact with bacterial flora fixed on a support which is generally made of inert material such as coke, granite, chalky rock, or lava, piled to a height of 1–3 m, through which the waste trickles. One must generally recirculate some of the purified water to dilute the water to be treated. Sometimes an aeration is provided, either by natural draft, or by mechanical ventilation. The so-called "fast" filters may degrade up to 1 kg BOD_5/m^3 of filtering material per day with a yield which varies according to the recirculation and to the height of the filter, and for which figures of 70% are cited. These filters may be installed in parallel, but more often they are provided in series. In the last case the yield may reach about 90%. This means that for obtaining at the outlet a BOD_5 below 30, one should not exceed a BOD_5 of 300 mg/l at the entry.

Bacterial filters are only rarely used in sugar factories, excepting in Great Britain[20,172], where they are rather often used as a final stage. The main purification is then done in ponds where the treatment is spread over 12 months, with satisfactory results.

Crane[20] reports an installation of bacterial filters in an English sugar factory. Normal average charges for the primary and secondary filters were, respectively, 300 and 60 g BOD_5 per m^3 material per day. Between 90 and 99% of the pollution charge could be removed.

This technique needs the long induction period of two months before the filter reaches its maximum yield. This is a major inconvenience for a seasonal industry. The use of bacterial filters, moreover, is relatively delicate because of their tendency to clog and because maintenance operations require much time.

3. *Activated-sludge processes*[10,11,14,15,17,20,26–28,42,43,170–172,175,176,179–181,183,184,188,190,194,196–203,211]

The activated-sludge process constitutes without doubt the most perfected biological waste-water treatment. Its use in the sugar industry is, however, still relatively infrequent.

In this process the microbial colonies are developed directly in the medium which must be purified[196]. A supply of oxygen is provided, which is necessary for the proliferation of the aerobic microorganisms.

The aerated-water–sludge mixture passes to a clarifier from which the sludge, after reactivation, is pumped back to the aeration tank.

In all cases it is suggested that preliminary storage of the waste water in a lagoon for anaerobic fermentation is essential for efficient operation of the activated-sludge process.

The aerators may be constructed in different ways, but they do not affect the purification yield, as long as a sufficient amount of oxygen is furnished. For an identical amount of furnished and dissolved oxygen, one may distinguish between the main aerators by the two following factors: the cost of the entire installation, and the power requirements related to the amount of supplied oxygen.

Among the aerators a distinction can be made between:

(a) The air-suppliers forcing the air through; either plunging tubes producing large bubbles, vibrating valves producing average-sized bubbles, or porous tubes or plates producing small-sized bubbles.

(b) Surface brushes, as utilized in the technique of "Oxidation channels Pasveer or Passavant"[215]. This technique is based upon the development of activated sludges in an elliptical or circular channel on which rotating brushes with horizontal axes are placed. They ensure both the aeration and the circulation of the water in the channel. This process consumes about 1 kWh/kg BOD_5 removed, and has a yield varying between 80 and 90%. Originally it was developed for the purification of city waste waters.

(c) Surface-aeration turbines mounted on floats or on bridges installed over the activated-sludge ponds[171,179,180,183,196–198]. Such equipment was installed in a German sugar factory[180,196,198] and gave a yield of 92%. For a retention time of 24 hours the BOD_5 value decreased from 1000 to 70 mg/l. Another type of purification equipment using activated sludge, and in which the aeration is done by surface turbines, works perfectly in a Swiss sugar factory[197]; the yield varies between 96 and 98%. For a retention time varying between 6 and 10 days the COD value is reduced from 12000–15000 mg/l to 300–500 mg/l. Power requirements amount to about 1–1.2 kWh/kg of COD removed. The effluent, which is still weakly polluted, is further treated in the city purification plant.

Although they give satisfactory results, these activated-sludge processes originally were not conceived to handle highly-polluted waste waters such as those from sugar factories. Actually these processes only accept weakly-charged waters. Moreover, they are slow and have only limited yields. Indeed, the concentration of activated sludge is relatively slow, the biomass is made up of large agglomerates with surfaces of low activity, and the oxygen necessary for the biological activity is often irregularly distributed in the mass.

We may mention here a purification system which was developed to cope with the main inconveniences of the traditional purification systems, and which may offer good possibilities for solving certain problems. The principle of the Lefrancois-R.T. fermenter[211], indeed, meets perfectly the fundamental criteria for a continuous development of microorganisms: homogeneity of the medium, permanent and systematic circulation, agitation and aeration, and high exchange rates.

A pilot-scale plant, using a Lefrancois-R.T. fermenter with activated sludge, was tested to develop a new process for the purification of beet-flume and wash-waters.

Having obtained favorable results, full-scale equipment of 60 m^3/h capacity was set up and tried out in a Belgian sugar factory. Polluted water was taken from the settling ponds, stored for 4 to 8 days in a stabilisation pond, screened, heated and fed into the fermenter, where small quantities of urea and diammonium phosphate were added. Mud leaving the fermenter was settled and returned to the fermenter.

The following are the most important characteristics of this new process. The process permits the treatment, without dilution, of highly-polluted waters of BOD$_5$ varying between 4000 and 6000 mg per liter; the activated sludge concentration in the fermenter is very high, *i.e.* 15–20 g/l expressed as organic matter; during 4–6 hours treatment of the water in the fermenter, the COD decreased from 5500–7000 mg/l to 600–700 mg/l, and the BOD$_5$ decreased from 4000–5000 mg/l to 200–300 mg/l. Expressed in percentage of BOD$_5$ removed, the yield of the process reaches 92–95%. The purified and settled effluent was of a sufficiently good quality to replace fresh water previously used at the tare house; the power requirements amounted to 0.6–0.75 kWh/kg BOD$_5$ removed; the other advantages of this new process are reduced space and reduced investment and working costs.

Concluding, it may be said that, among all the biological purification processes used in the sugar industry, autopurification in storage ponds is probably the most practised. Bacterial filters and activated-sludge processes are still rarely used because of, on the one hand, the seasonal character of the sugar industry, and, on the other hand, the large volumes and charges which have to be handled. They are mainly used as purification finishers.

Geographical, economic and environmental imperatives will without doubt prompt the sugar factories to adopt more elaborate purification techniques.

In the preceding pages we have summarized the numerous problems and difficulties met in the water policy planning at the sugar factories. We have also underlined the important improvements made during recent years for reducing the amounts of waste waters and for their treatment.

Many of the ideas described may seem evident. Although we are aware of many omissions, we hope that this review may be useful in guiding choice. It must be kept in mind that fighting pollution is synonymous with helping to ensure the future of our nations, of our populations and of our economy.

SUMMARY

The increase of pollution in surface waters, the continuous increase in water needs and the progressive strengthening of laws in the highly industrialized countries are three aspects which lead us to consider closely the waste-water problem in the sugar industry.

Before considering the problems involved in settling, recycling and purification of the various waters, the author describes briefly the quantities and the compositions of the sugar-factory waters and describes an ideal scheme of water circuits without fresh water intake from the outside and with discharge into the river of a maximum amount of excess water as clean water of such quality that no payment is required.

The classical methods of treating waste waters, particularly flume and wash water, in order to purify them before their discharge into a river or to enable their re-use in the process, are reviewed; these are the settling, irrigation and biological purification processes.

Each sugar factory encounters its own particular problems in processing its waste waters; it is of interest to study the various solutions in order to make the best use of the one appropriate to the particular circumstances of each factory.

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SUMARIO

Tratamiento de las aguas residuales en la industria de la remolacha azucarera. El aumento de la contaminación de las aguas superficiales, el continuo aumento de las necesidades de agua y la intensificación progresiva de las leyes en los países altamente industrializados, son tres aspectos que nos llevan a considerar cuidadosamente el problema de las aguas residuales en la industria azucarera.

Antes de considerar los problemas relacionados con el asentamiento, recirculación y purificación de las diferentes aguas, el autor escribe brevemente las cantidades y la composición de las aguas de la fábrica de azúcar y también un esquema ideal de circuitos de agua sin introducir agua fresca del exterior y descargando al río una cantidad máxima de exceso de agua como agua limpia de tal calidad que no se requiera un pago extra.

Se describen los métodos clásicos para el tratamiento de las aguas residuales, particularmente las de los canales y las aguas de lavado, con objeto depurificarlas antes de arrojarlas a un río o permitir volver a usarlas en el processo, y estos métodos son: el asentamiento, el riego y la purificación biológica.

Cada fábrica de azucar reconoce sus propios problemas en el tratamiento de sus aguas residuales y fué interesante estudiar las diferentes soluciones con objeto de hacer el mejor uso de la apropiada para las circunstancias particulares de cada fábrica.