TREATMENT OF SUGAR FACTORY EFFLUENT IN BIOLOGICAL TRICKLING FILTERS

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Abstract

The biological degradation of sugar factory effluent by trickling filters was investigated in a pilot plant. The process was found to be suitable provided additional nitrogen and phosphorus were added. The cost of trickling filters and other biological oxidation processes were compared.

Introduction

Factory effluents contain mainly organic waste, small amounts of salts and no toxic substances. This type of effluent can be treated by anaerobic or aerobic biological treatment, or a combination of both.

Although anaerobic degradation greatly reduces oxygen demand the effluent of this treatment will not meet the required standard in South Africa (COD < 75 mg/ℓ) and the process will invariably lead to odour problems, which would only be tolerable at some distance from a factory or housing scheme.

Various aerobic processes are applied for organic waste degradation: activated sludge, biological filtration and aeration in fermentation tanks. The aerobic activated sludge process for sugar factory effluent has been described in Australia[1]. The importance of the addition of nitrogen and phosphorus in this process has been stated by various authors[2,3,4]. Aeration of waste water in a pilot plant fermenter was described by Revuz[5]. The mixed liquid suspended solids content was kept very high in this fermenter (40 000 mg/ℓ) and no solids were discharged. The BOD dropped from 4 600 mg/ℓ to 300 mg/ℓ after 4 hours retention.

A modification of the activated sludge process in the form of a ditch, and applied to sugar factory effluent, was described by Ashe [6,7]. This type of activated sludge plant is used by many small municipalities in Europe for the treatment of domestic effluent.[8]

Biological trickling filters for purification of sugar factory effluent have been used by Rennie. An experimental biological trickling filter at Darnall operated successfully at a load of 1 kg COD/m³ per day. The main advantages of a trickling filter over an activated sludge process are the insensitivity to overloading and easier operation.

In order to obtain more data on the operation of trickling filters for the treatment of sugar factory effluent a pilot plant was constructed at the SMRI.

Construction of the pilot plant

Factory effluent has a COD between 1 500 and 15 000 mg/ℓ and the industrial average is 3 000 mg/ℓ. The COD : BOD ratio for untreated factory effluent is approximately 2 : 1.

Effluent having a higher COD content than 500 mg/ℓ cannot be treated in a single stage filtration plant and two stages are usually employed. The first unit is operated as a high rate filter, removing 50-60% of the oxygen demand and the second unit is operated as a low rate filter, which has to provide an effluent conforming to the standards laid down for sugar factory effluent.

In a high rate filter rapid production of biological film takes place and if the void spaces in the packing are insufficiently large blockage of the filter will occur. In conventional filters 75-150 mm stones or other media are used for this reason. For secondary filters smaller packing material is adequate as the lower loading of these filters results in less bio-mass accumulation.

For small scale filters the depth should be identical to the full scale depth which for gravel filters is normally 2 metres[9]. For plastic media towers having a depth up to 8 m can be used. However, greater depth is usually specified to save floor space and filters of different depth normally show similar efficiencies at similar loads of BOD per unit volume[10].

As alternatives to conventional filter media various pre-fabricated plastic media are available. These materials are designed to provide a high specific surface and large void spaces to reduce blockages. Table 1 shows the properties of these media.

TABLE I
Packing media for biological filters

Medium	Specific Surface		Void Space
	ft²/ft³	m²/m³	%
Blast furnace slag	13,4	40	50
Flocor	26	85	98
Surf pac (crinkle-close)	56	187	94
Surf pac (standard)	25	82	94
Cloisonyle	66	220	94
Smooth rock	13,4	40	53

To avoid too much influence on the process from wall effects the ratio of the diameter of the packing medium to the diameter of the filter should be at least 1 : 8[11]. Thus for example in a low rate filter, 25 mm diameter medium can be used in a cylinder of 200-300 mm diameter.

A conventional medium for a high rate filter would require a cylinder with a diameter of 800-1 200 mm, which would be inconveniently large for laboratory experiments and would require large quantities of effluent. For this reason a plastic medium was used for the high rate filters and of the 3 packing media listed in Table 1 Cloisonyle was considered the most suitable for small scale experiments.

Cloisonyle has one of the highest specific surfaces of all packing media and the efficiency of a trickling filter is proportionate to the specific surface[12]. The suppliers of Cloisonyle claim a possible load of 3,4 kg/m³ per day for domestic sewage as compared to a load of 0,3-0,5 kg BOD/m³ per day for conventional media. Cloisonyle medium could therefore be expected to accept about 8 times higher loading than a filter using conventional stone media.

It has been shown by Gameson *et al*[13] that considerable differences can occur in the performance of apparently identical filter units. Because of this variation 3 replicate filters were used in parallel to obtain a measure of the variation in operational efficiency and to get meaningful results.

A flow diagram of the pilot plant is shown in Fig. 1. The plant consisted of 2 identical units having 3 high rate filters followed by 3 low rate filters with a settling tank after each filtration step.

One unit operated on synthetic effluent to which nitrogen and phosphorus had been added, the other unit on synthetic effluent without additional nutrients. Synthetic effluent was used for easier operation and was made up by mixing molasses, sugar and water. The capacity of the feed tanks was such that a new mixture was prepared twice a week.

The effluent was evenly distributed over the filters by acrylic plastic pipes with holes rotating at 9 rpm. (See Fig. 2). The surface area of the high rate filters was 0,039 m^2, that of the low rate filters was 0,031 m^2. The latter were packed with stone of 25 mm diameter. The height of all filters was 2 m.

To prevent the possibility of inhibition of bacterial growth, metals were avoided in the construction of the plant. The effluent storage tanks were made of galvanised steel, painted inside with epoxy paint. Further construction materials and piping were plastic and asbestos cement. A picture of the plant is shown in Fig. 3.

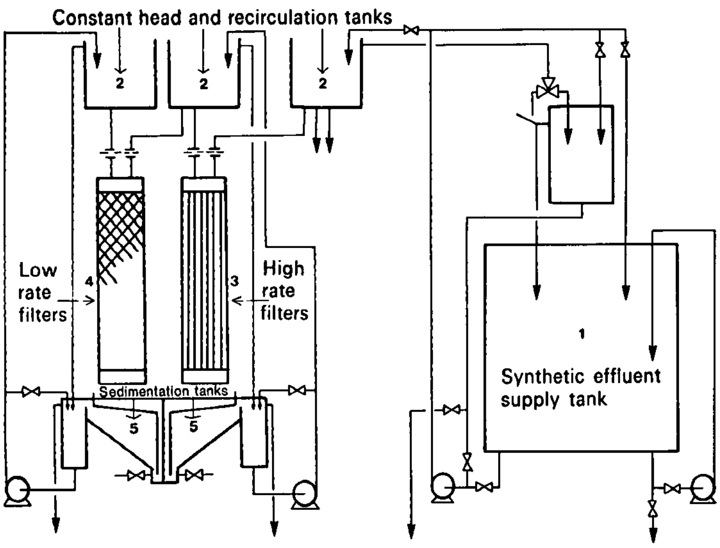

FIGURE 1 Flow diagram of pilot plant.
1. Synthetic effluent supply tank.
2. Constant head and recirculation tanks.
3. High rate filters.
4. Low rate filters.
5. Sedimentation tanks.

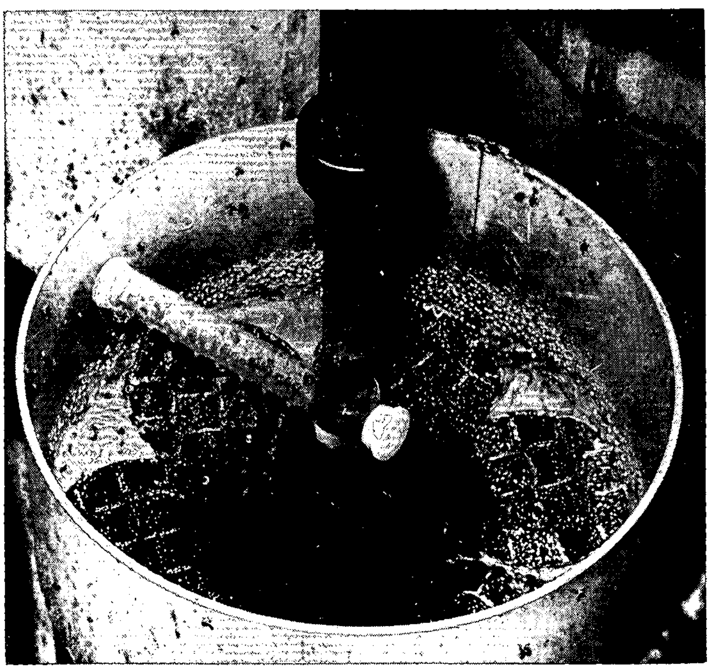

FIGURE 2 Distributor.

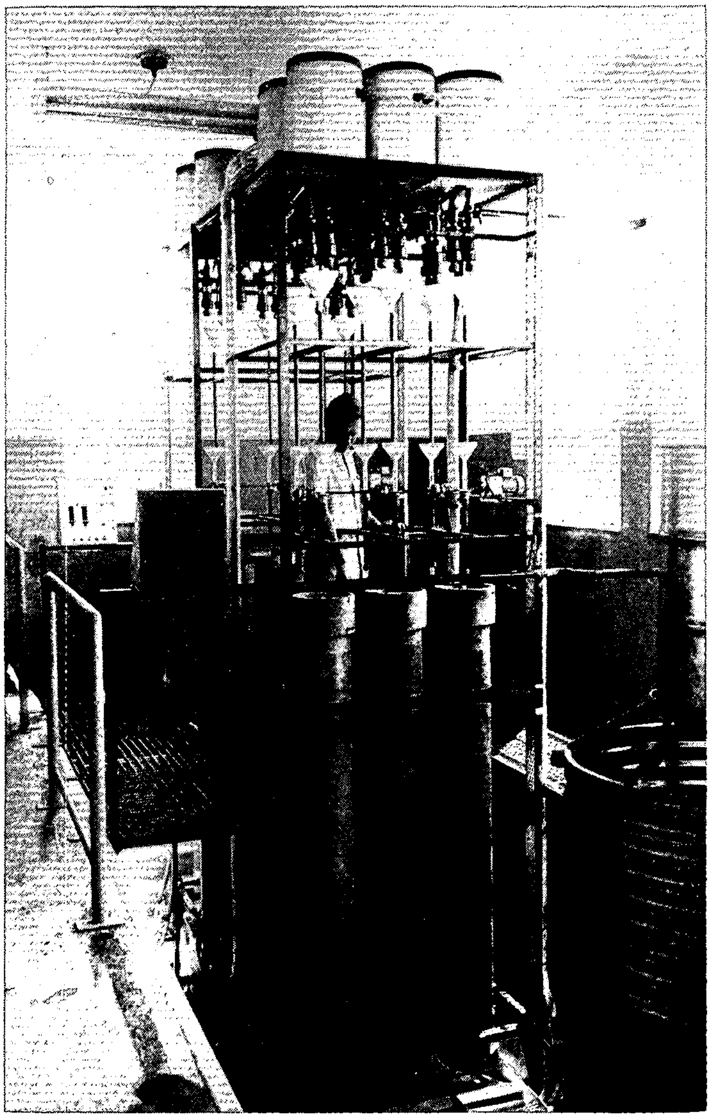

FIGURE 3 Pilot plant.

Synthetic effluent was prepared as shown in Table 2.

TABLE 2
Composition of synthetic effluent

Molasses	6 000 g
Sucrose	3 000 g
Nitrogen (as urea, 46% N)	128 g
Phosphorus (as super phosphate 8,3%)	27 g
Water	2 300 ℓ
COD mg/ℓ	3 500 – 4 000
BOD mg/ℓ	2 000 – 2 300

During the experiments the load on the filters was varied in some cases by changing the flow rate to the filter. In a number of cases the molasses and sucrose concentration was changed while the flow was kept identical. This was done to avoid the manufacture of new orifice plates to control the flow every time a change in filter loading was carried out.

The ratio of molasses to sucrose was always kept at 2 : 1, N and P were added in such a way that COD : N : P was 100 : 2 : 0,4 during the earlier experiments. The last experiments were carried out doubling the concentration of N and P.

Results

The experiments were carried out in 7 different phases. All results during one phase were averaged and are listed in Table 3.

After the filters had been operating under the conditions of Phase 1, it was evident from visual observation that the low rate filters were not properly wetted, and both the forward flow rate and recirculation rate were increased. At the same time the COD of the feed was increased to study conditions at higher loading during phase 2.

The nitrate and nitrite concentrations as well as the free and saline ammonia in the effluent leaving the secondary filters were low and in all the subsequent experiments the nitrogen content in the feed was increased to a rate of COD : N, 100 : 4. At the same time the phosphate concentration was doubled but it is likely that optimum plant performance can be obtained with lower phosphate concentration in the feed. Phase 3, however, does not show improved COD values for HR and LR filtration as compared with phase 2. During phase 4 the flow rate to the high rate filters was slightly increased and a much larger recirculation rate was applied. The load on the low rate filters was slightly decreased. The high rate filtration efficiency increased under these conditions. The high rate filters operated during phase 3 and 4 under anaerobic condition and produced a bad odour. The load was reduced substantially during phase 5.

During phase 5 the same hydraulic load was applied as before but the COD of the feed was reduced. During this period no odours were produced and dissolved oxygen was found in the effluent from the high rate and the low rate filters. The final effluent from the filters operating with nutrient addition was only slightly higher than the acceptable standard. Efficiency of the low rate filters, however, was low.

Higher hydraulic load during phase 6 improved the efficiency, probably due to better wetting, and the final effluent was within the required standards for sugar factory effluent.

During phase 7 the COD concentration was increased from approximately 1 000 ppm to 1 500 ppm, while operating on the same hydraulic load as before. The low rate filters operated

TABLE 3

Performance of pilot plant

(all values in mg/ℓ)

Phase	Flow rate ℓ/hr	Recycling ℓ/hr	COD	BOD	pH	N Kjeldahl	NH_3 Free & Saline	NO_2 NO_3	Total N	PO_4 as T	Diss. O_2
Feed	—	—	3 650	—	5,1	13	0,2	0,7	15	10	—
HR filter	9	9	2 750	—	4,4	13	0,5	0,4	11	5	—
LR filter	1,8	1,8	1 270	—	7,1	8	0,3	0,2	9,6	6	—
1 Feed+N+P	—	—	3 700	—	4,8	69	7,6	4,1	75	35	—
HR filter	9	9	1 620	—	6,0	39	3,1	1,4	40	26	—
LR filter	1,8	1,8	296	—	7,8	8,5	0,6	0,6	9	12	—
Feed	—	—	5 580	—	4,6	23	0,1	0,1	—	7	—
HR filter	9	9	3 420	—	4,3	17	0,2	0,5	—	4	—
LR filter	4	8	1 800	—	6,3	9,4	0,4	0,3	—	1,9	—
2 Feed+N+P	—	—	5 450	—	4,7	112	9	7,7	—	56	—
HR filter	9	9	2 250	—	6,4	63	6	0,9	—	27	—
LR filter	4	8	296	—	7,7	12	0,9	0,3	—	16	—
Feed	—	—	5 200	2 300	—	22	0,2	0,1	—	7	0
HR filter	9	9	3 970	1 900	—	18	0,8	0,8	—	4,5	0
LR filter	4	8	1 670	860	—	11	0,7	0,4	—	1,7	0
3 Feed+N+P	—	—	4 900	2 500	—	188	17	10	—	60	0
HR filter	9	9	2 370	1 130	—	133	54	12	—	21	0
LR filter	4	8	370	53	—	26	4,3	11	—	18	1,8
Feed	—	—	4 875	2 325	—	19	—	—	—	7	0
HR filter	10	30	3 575	1 650	—	18	—	—	—	3,8	0
LR filter	3	12	1 500	825	—	16	—	—	—	2,8	0
4 Feed+N+P	—	—	4 500	2 475	—	173	—	—	—	38	0
HR filter	10	30	1 430	700	—	102	—	—	—	10	0
LR filter	3	12	572	30	—	82	—	—	—	19	0,2
Feed	—	—	1 074	690	—	6,6	—	—	—	1,3	0,1
HR filter	10	30	686	331	—	50	—	—	—	0,5	2,2
LR filter	3	12	367	129	—	4,2	—	—	—	0,8	4,3
5 Feed+N+P	—	—	970	622	—	38	—	—	—	8,4	0,1
HR filter	10	30	217	68	—	18	—	—	—	1,6	0,6
LR filter	3	12	147	9,6	—	12	—	—	—	5,7	5,9
Feed	—	—	965	333	4,5	1,5	—	—	—	0,7	0,3
HR filter	10	30	609	293	6,1	3,0	—	—	—	0,4	3,4
LR filter	5	12,5	407	153	6,8	1,6	—	—	—	0,3	4,4
6 Feed+N+P	—	—	1 011	498	5,0	34	—	—	—	5,1	0
HR filter	10	30	219	62	7,1	20	—	—	—	2,4	1,7
LR filter	5	12,5	118	3,7	6,2	7,2	—	—	—	2,6	6,2
Feed	—	—	1 462	767	4,3	5,7	9	—	—	0,3	0
HR filter	10	30	1 257	516	5,4	6,9	7,5	—	—	0,5	1,4
LR filter	5	12,5	898	345	7,0	4,9	21,2	—	—	0,4	1,6
7 Feed+N+P	—	—	1 365	633	4,2	32	17,8	—	—	4,2	0
HR filter	10	30	444	111	6,6	20	29	—	—	2,0	0
LR filter	5	12,5	147	5,8	7,0	6,8	21,6	—	—	3,2	3,9

All analysis on filtered samples, except Diss. O_2 and pH more efficiently than during the previous phase and the quality of the final effluent was only slightly higher than the official standard.

Discussion

From the data obtained on the high rate filters the BOD load in kg/day per m³ of filter volume was calculated. For the first two periods BOD values were not determined, but the average COD/BOD values for the other periods were calculated. These values were found to be 1,96 for the ingoing feed to the filters and for the outgoing effluent 2,09. Applying these factors the BOD values for the first two periods were calculated from the COD values.

In Table 4 the combined loads and percentage decreases in BOD for the primary filters are listed.

The results of the performance of the high rate filters are shown in a graph in Fig. 4. The curves obtained are compared with the data published for "FLOCOR" operating on municipal sewage.

From this data it is evident that provided nitrogen and phosphorus are added and a recirculation rate of at least 1 : 3 is applied the removal of oxygen demand from sugar factory effluent is similar to that claimed by the manufacturers, when plastic filter media is used for the treatment of municipal sewage, although the hydraulic load with the latter would be some ten times greater.

During the experiments it was observed that the biological film in the filters without nitrogen and phosphorus was more slimy and filamentous. Also, the low rate filters of the control group showed a higher tendency to ponding than did the group with N and P addition. Adult filter flies (*Psychoda* sp.) were abundant at all times around the filters which received the enriched effluent, but almost absent on the control filters. It has been claimed in literature that the larvae of *Psychoda* sp. are an important factor in the control of ponding due to their scouring action on accumulated biological film.

Values for the efficiency of the low rate filters in removing oxygen demand are shown in Table 5.

The data obtained again show the marked improvement in performance that results from N and P addition. No relationship between BOD load and % of BOD removed is evident from the data in Table 5. Within the range of the filter operation the efficiency remained rather constant between 94 and 97% of BOD removed and at very reduced load the efficiency even decreased.

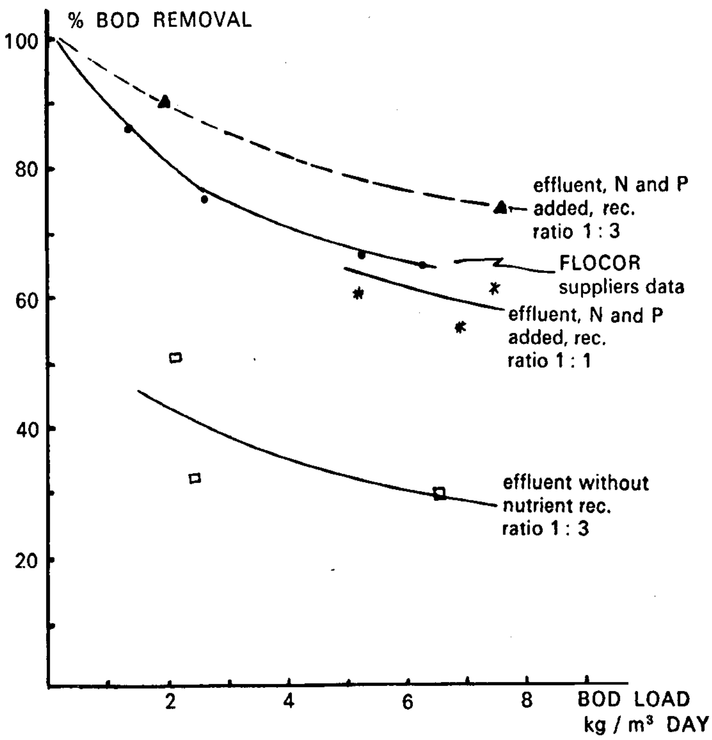

FIGURE 4 Plot of BOD load versus BOD removal.

TABLE 4

% Decrease and BOD load of high rate filters

Phase	Filters + N + P			Filters without addition		
	BOD load kg/m³/day	BOD removed kg/m³/day	% BOD decrease	BOD load kg/m³/day	BOD removed kg/m³/day	% BOD decrease
1	5,2	3,1	60	5,0	1,8	35
2	7,7	4,3	61	7,4	2,9	39
3	6,9	3,8	55	6,5	1,2	18,5
4	7,6	5,5	72	6,5	1,9	29
5	1,9	1,7	89	2,1	1,1	52
6	1,5	1,3	88	1,0	0,1	11,7
7	2,0	1,7	82,5	2,4	0,8	32

TABLE 5

% Decrease, BOD load and COD of effluent of low rate filters

Phase	Filters + N + P			Filters without addition		
	BOD load kg/m³/day	% BOD decrease	COD effluent	BOD load kg/m³/day	% BOD decrease	COD effluent
1	0,5	94	230–350	0,8	43	600–1 600
2	1,7	96	270–320	2,5	42	1 700–2 000
3	1,7	95	250–530	2,9	54	900–2 300
4	0,8	96	530–650	1,9	50	1 200–2 000
5	0,08	86	124–156	0,4	61	195– 590
6	0,12	94	97–119	0,6	48	300– 570
7	0,26	97	139–151	1,0	37	835– 977

A reduced load on the low rate filters occurred when the high rate filters removed more BOD, leaving the more difficult oxidisable material for the low rate filters. This is shown by the COD/BOD ratio's.

The ratio for untreated synthetic effluent was about 2,0. At low loading of the high rate filters the discharge of these filters showed a COD/BOD ratio of 3,5. This shift became larger the more the effluent was treated as is illustrated in Table 5, where COD/BOD ratio's of the final effluent are listed.

TABLE 6
COD / BOD ratio's of final effluent from the low rate filters operating with N and P addition

Phase	COD / BOD ratio
3	7,0
4	20,4
5	15,3
6	31,9
7	31,2

It should be noted that the final effluent obtained in the experiments of Hemens and Simpson[3] showed a COD/BOD ratio of 11. Their laboratory plant operated on real factory effluent. It is possible that due to the molasses in the synthetic effluent more bio undegradable material occurred in the final effluent of the present experiments.

An effluent having such a low BOD content as discharged by the low rate filters should present little load on a public stream. Standards however are laid down in COD values and the secondary filters can only operate in such a way that a final effluent having a COD value < 120 mg/ℓ is obtained.

The influence of recirculation rate on low rate filtration is not very evident from these experiments. Comparing the results of the first 3 phases there is some indication that a recirculation ratio of 1 : 1 is too low and that a ratio of 1 : 2 or 1 : 3 results in a better efficiency.

The mud resulting from the high and low rate filtration under nutrient addition settled well. No information is yet available on the dewatering characteristics of the sludge and on whether further sludge treatment is required.

Conclusions

Sugar factory effluent can be treated adequately by biological filtration in a two stage system. The addition of nitrogen and phosphorus is essential for satisfactory performance. A suitable ratio of nitrogen and phosphorus in relation to COD was found to be COD : N : P = 100 : 4 : 0,8.

A plastic filter medium is very suitable for the first stage of treatment of sugar effluent. At no stage was any filter blockage observed and with proper recirculation ratio and nutrient addition the same efficiency for sugar factory effluent was obtained as specified for plastic media operating on domestic effluent. The highest filter loading under aerobic condition was about 2kg BOD/m^3/day. The filters, however, removed large quantities of BOD under anaerobic conditions and gave no operating difficulties at much larger loadings, but produced odours.

In the appendix the cost of 3 industrial treatment plants are compared. The sizes of these units are all of the same order of magnitude. The BOD load/day and the total installed capital cost are as follows:

Factory	BOD load/day	Capital cost	Cost/kg BOD load*
Felixton	1 200	R81 000	R68
Umfolozi	800	R49 000	R61
Union Bark & Sugar Co.. .	1 840	R105 125	R57

* This price gives only approximate comparison. Cost price is not in linear relationship to size of the plant.

Felixton costs are based on 1972 prices. The costs for Umfolozi have been recalculated to today's prices and the Union Bark & Sugar Co. costs are based on a recent tender. The plant performance of the latter factory is unknown as the plant is still under construction.

Felixton and Umfolozi constructed their own plants, while Dalton's treatment plant is being constructed by an outside contractor.

From the combined information it appears that an activated sludge process is cheaper than bio filtration and if the construction of the plant is carried out by the factory a Pasveer ditch is probably the easiest to construct.

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Appendix A

Comparison of the installation costs of some effluent treatment plants in the sugar industry

The installation costs and rated capacities of a few effluent treatment plants are given. As prices change quickly a true comparison is difficult. Most of the quoted costs are one to two years old.

1. *Biological filtration plant at Felixton Sugar Factory* (costs based on values in October 1973).

The plant consists of a two stage bio filtration preceeded by an anaerobic dam which decreases the original COD of the factory effluent and acts as buffer. The two identical filters are packed with gravel.

The designed capacity is	2 400 m³/day
Reflux ratio	1 : 1
Capacity anaerobic pond	5 000 m³
Diameter filters	25 m
Height bed	2 m
Surface area	500 m²
Capacity	1 000 m³
Settling tanks (8)	25 m²
Average COD of effluent from anaerobic dam	1 000 mg/ℓ
Average BOD of effluent from anaerobic dam	500 mg/ℓ
Average COD of final effiuent	100 mg/ℓ
BOD load	1 200 kg/day
BOD load on first filter	1,2 kg/m³/day

Installation costs

		R
Civil	Site preparation	2 700
	Anaerobic pond	7 500
	Filters	24 000
	Settling tanks	14 000
	Stone media (2 000 m³)	10 000
	Sludge beds	3 000
	Pump house	1 000
	Distribution box	1 000
		R63 200
		R
Mechanical	Pumps & Motors	8 700
	Pipes, valves, fittings	5 700
		R14 400
		R
Electrical	Cables, switchgear	2 500
	Instrumentation	900
		R3 400
	Total	R81 000

Prices of alternative bed packing material/m³ (cost based on values at 1-4-75).

(*a*) *Filterpak*

Type	*Specific surface*	
YTH 1127	120 m²/m³	R115
YTH 1130	190 m²/m³	R130

With these materials the supporting structure can be made lighter than in the case of gravel packing. The cost of YTH 1127, including the cost of the supporting tower, amounts to R150.

(*b*) *Cloisonyle*
Specific surface 220 m²/m³ . . . . ± R140

(*c*) *Flocor* . . . . ± R110

For comparison between gravel and plastic media the figures of the Felixton plant and Filterpak are taken.

	Specific sugar m²/m³	Price/m³ incl. tower
Gravel	40	R17
Filterpak	120	R150

Assuming that the load which can be applied to a filter is directly proportional, Filterpak could be loaded at 3 × 1,2 kg BOD = 3,6 kg BOD/m³/day, and Cloisonyle to 5 × 1,2 kg BOD = 6 kg BOD/m³/day.

Present experiments show that at the latter load these filters do operate although under anaerobic condition. Even at this load the installed cost of a gravel filter appears to be lower and the major advantage is space saving.

2. *Activated sludge plant at Union Bark & Sugar Milling Company* (at present under construction)

The plant consists of an aerated tank followed by a sedimentation tank provided with sludge return. The aeration tank is concrete lined and provided with 2 Simplex turbine aerators. The plant is preceded by a pond for storing and buffering the effluent flow. The plant is designed on the assumption that no appreciable reduction of BOD content of the effluent will take place. However experience at other factories has shown that lagooning of sugar factory effluent often reduces the BOD content considerably, depending on temperature and retention time. For this reason it can be expected that the activated sludge plant will have ample capacity. The plant was designed to the following specifications:

Average effluent flow	460 m³/day
Peak effluent flow	685 m³/day
BOD load (4 000 mg/ℓ)	1 840 kg/day
Volume aeration tank	1 840 m³
Retention time	97 h
Aerators: 2 Simplex turbine aerators each of.	40 kW
Total oxygen production about	3 600 kg/day
kg oxygen produced/BOD load	(2 kg 0_2/m³day)
Settling tank volume	130 m³

Cost

Civil	R 55 000
Mechanical	R 50 125
	R105 125

3. *Pasveer ditch at Umfolozi Sugar Factory*

The plant consists of an oval ditch, with gunite walls and bottom. As part of the system are 2 parallel ditches 33 m long which in turn act as sedimentation tanks. Along the length of the ditch 10 surface aerators are installed of which 8 can run simultaneously, the other 2 being stationary during the sedimentation period. Under normal operation 6 aerators are sufficient to provide the necessary oxygen. No chemicals have been added as yet but in the coming season the plant will treat a mixture of domestic and factory effluent. The plant has not discharged any sludge during its 2 years of operation.

Evidently all organic material is oxidised completely.

The oxidation ditch is preceeded by a large anaerobic pond, which reduces the BOD content of the factory effluent considerably.

The plant operates under the following conditions:

Average effluent flow (estimated)	2 250 m³/day
Average COD content of effluent from dam	700 mg/ℓ
Average BOD content (estimated)	350 mg/ℓ
Average COD of final effluent	110 mg/ℓ
BOD load of plant	800 kg/day
Volume of ditch	1 600m³
Number of aerators	8
Installed hp per aerator	7,5
Absorbed hp per aerator	6,5
Total absorbed hp per aerator	52,0
Total oxygen production	2 500 kg/day
kg oxygen produced/BOD load in kg (1,6 kg/m³/day)	3
Settling part of ditch length —	33 m
volume —	225 m³
Cost in 1972	
Mechanical and Civil	R46 000
Present cost	
Civil: excavating and guniting	R130/m
total for 270 m	R35 000

Mechanical: Aerators

	R
Rotor	300
Motor	120
Gearbox	385
	R 805
Price for 10 units	R 8 000
Switch gear and instrumentation	R 4 000
Installation aerators	R 1 000
Housing for switch gear	R 1 000
Total	R49 000

According to the original data for a Pasveer ditch the total volume should be 100 m³ per 20 kg BOD load/day. At Umfolozi this figure is 100 m³ per 50 kg BOD load per day. In Europe, however, plants have to operate at a water temperature in winter time between 0 and 5°C. The installed aerator capacity is more than required, for this reason only 6 aerators are normally operating.