ACTIVATED SLUDGE TREATMENT OF SUGAR MILL/WATTLE BARK MILL EFFLUENTS AT DALTON, NATAL

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Abstract

Operational data, on the running of the Dalton plant between August 1976 and October 1977 have been evaluated. The data are lacking in certain aspects and a number of questions remain unanswered. Good soluble COD and BOD reductions of the feed have been achieved throughout the period proving that the wastes treated are amenable to activated sludge treatment in a full-scale plant. High suspended solids concentrations in the final effluent for most of the period have reduced its quality and consequently must have impaired its usefulness for reuse in the mill. The source of the solids is attributed to the feed so that attention should be given to solving the problem. Bulking of the sludge was experienced when bark mill waste was the only feed but when sugar mill waste was included in the feed the settling quality of the sludge was generally satisfactory. In other words, for the treatment of normal sugar mill wastes, bulking of sludge should not be a problem. The necessity for the addition of the nutrients nitrogen and phosphorus was seen and evaluation of a nutrient budget indicated the level of addition which should be maintained. Some theory concerning the activated sludge process and bulking of sludge has been given so that the reader in the sugar industry may get a better understanding of the complexities of the process. Capital and operational costs of the treatment plant have been summarised. The management of sugar mills should appreciate that activated sludge plants should not be used as dumping grounds for every and any type of waste produced in the mill, since it is a sensitive biological process and that for successful operation careful control and maintenance is necessary.

Introduction

In 1971 the National Institute for Water Research (NIWR) became involved in advising the Darnall sugar mill on the treatment of their dunder water. As a result, laboratory-scale investigations were conducted into the feasibility of using the activated sludge process. This proved successful and showed that the addition of nitrogen and phosphorus to the dunder water was essential to obtain a good quality final effluent and produce a sludge which separated efficiently in the settling tank. The approximate amounts of nutrients required and optimum operational parameters were established and the results published[1]. Unfortunately, a pilot-scale operation at the Darnall sugar mill did not meet with the same success due to lack of control of the plant and an inadequate aerator, so that the process was not proved on a large scale using dunder water, as produced by a sugar mill[2].

A full-scale activated sludge plant, incorporating data from the laboratory investigations, was installed by consultants for the Union Co-operative Bark and Sugar Company Ltd. at Dalton in 1975. This company, which processes 500 000 tons of cane and 30 000 tons of wattle bark per year, produces sugar mill effluent for about 10 months of the year and bark mill effluent for about 8 months, so there is overlap of the two operations. The treated effluent is used as make-up water for the cooling water supply to the sugar mill. In collaboration with the mill laboratory, the NIWR monitored the plant and the performance between August 1976 and October 1977 is assessed.

Basic principles of the activated sludge process

Information given in this section was taken from McKinney[3] and Imhoff *et al*[4]. Activated sludge is developed in a treatment plant when dissolved organic matter is brought into contact with bacteria in the presence of an adequate supply of dissolved oxygen and nutrients. At the onset it takes about 20 days of aeration to develop an activated sludge from domestic sewage or other wastes which contain the necessary micro-organisms. These micro-organisms are plentiful in nature, in the earth and especially in domestic sewage.

Bacteria are the primary agents of purification. They obtain their energy for growth from the oxidation of organic matter; this is not direct addition of oxygen but rather removal of hydrogen and addition of water and the hydrogen acceptor is dissolved oxygen. Therefore the presence of dissolved oxygen is essential for the growth of aerobic bacteria. The energy released during oxidation is used by the bacteria to synthesise protoplasm which consists essentially of proteins, nucleic acids, lipids and carbohydrates. The protoplasm of the average bacteria associated with activated sludge has a definite elemental composition which includes approximately 11% nitrogen and 2,5% phosphorus as the major nutrients and many other elements in much smaller amounts. Without an adequate supply of all the necessary elements in the substrate it would be impossible for the bacteria to form protoplasm and carry out metabolic reactions at their optimum rate.

Bacteria are unicellular plants which reproduce by means of binary fission, in which each cell divides into two new cells so that when food and dissolved oxygen are in unlimited supply, their numbers will increase at an increasing rate. This stage is called the 'log growth phase' which requires a food to micro-organism ratio of at least 2,5:1 so that a plant operating in this phase could not possibly produce a stable effluent, and in any event the growth rate could not be sustained since the supply of dissolved oxygen would soon become a limiting factor.

The normal activated sludge plant is operated such that the supply of food is the limiting factor for further bacterial growth. With active competition for the available food, some bacteria are forced to metabolise their own protoplasm with the result that there is a continual die-off of them and this process is called endogenous respiration. Activated sludge is therefore composed of dead and living microorganisms which have formed a floc. The formation of floc does not occur in the log growth phase since the energy levels in the bacteria are high and they remain in a dispersed state. In the endogenous phase the food level is low and consequently the energy level is also low and therefore the cells lack the energy to overcome the natural forces of attraction once they have collided during mixing, with the result that a floc forms which settles out in the sedimentation tank. Not all the dead bacterial cell is degraded by its neighbours, however, since bacteria have no enzyme capable of degrading the polysaccharide slime layer which makes up part of the cell wall and so an inert solids fraction is continually formed. In normal activated sludge it is estimated that only between 25 and 50% of the combustible fraction of the mixed liquor suspended solids actually consist of living cells.

Although bacteria are the basic purifiers, other larger organisms such as protozoa and rotifers perform essential functions in a healthy activated sludge. Protozoa feed on bacteria, some species such as the stalked ciliates attaching themselves to the sludge flocs while other free-swimming types ingest dispersed bacteria. The rotifers feed on bacteria as well as small organic particles and their presence is usually indicative of a well stabilized sludge. The numerous different population groups of microorganisms present in activated sludge are interdependent and may be described as being a balanced biological system of growth and decay. Most soluble organic materials are amenable to stabilization by the activated sludge process and provided that there is an adequate supply of dissolved oxygen and nutrients, and the pH and biological loading are in the correct ranges, then a healthy activated sludge should develop.

Plant Description

The effluents from the sugar and bark mills are discharged, via drainage channels in the ground, to a series of ponds which are meant to act as sedimentation basins and also provide a large holding capacity. Effluent is pumped from these ponds to a 1 840 m^3 volume cement lined aeration basin. Aeration and mixing is supplied by two 40 kw rotary surface aerators. The overflow is led to an 89 m^3 volume settling tank of conventional design from which there is provision for return of settled sludge to the head of the aeration basin. There are also a number of drying beds for disposal of excess sludge. The designers made provision for automatic dosing of sodium hydroxide for pH control of the feed but nutrient addition is done manually. Flow rate to the basin is estimated by means of either displacement tests to gauge pump capacity or by V-notch reading. No provision was made to estimate sludge return rate.

Results

Variation of Sugar Mill Effluent

In order to assess its variability, the sugar mill effluent was sampled before discharge to the ponds at hourly intervals for one week in July 1976 so as to take into account any changes in quality due to time of the day or day of the week. The samples were serially made up into 4 or 6 hour composite samples and analysed for Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and nutrients. The mean results are given in Table 1, together with standard deviations and some statistical ranges of the parameters. With a mean total COD and BOD of 7581 and 4065 mgℓ^{-1} respectively, this reflects a waste at least 10 times stronger than normal domestic sewage but the results show much lower nutrient concentrations. Soluble nitrogen and phosphorus values for the effluent are a better reflection of nutrients available for growth than are total values and in this case the soluble COD:N:P ratio is 100:0,26:0,07. A ratio of 100:2,0:0,4 was found to be necessary in the laboratory experiment[1], so clearly the sugar mill effluent is nutrient deficient. The COD's and BOD's of the individual samples varied in a random fashion and showed no pattern which could be related to either time of the day or day of the week. Using the upper value of the 90% confidence limits for total COD a load factor of 0,38 g COD g^{-1} MLSS d^{-1} is obtained for a mixed liquor suspended solids concentration of 4000 mgℓ^{-1} in the basin and a feed rate of 340 m^3 d^{-1}. This is below the laboratory optimum load rate of 0,6 g COD g^{-1} MLSS d^{-1} and so well within the design capacity of the plant provided enough oxygen could be supplied by the aerators.

TABLE 1

Mean results of quality of sugar mill effluent, 19-26/7/76, 4-6 hour composites of hourly samples

	mean	Std. deviation	n	90% confidence limits
Sol. COD . . . . mgℓ^{-1}	5803	472	32	5014-6592
Tot. COD . . . . mgℓ^{-1}	7581	354	32	6989-8173
Sol. BOD . . . . mgℓ^{-1}	3498	508	32	2649-4347
Tot. BOD . . . . mgℓ^{-1}	4065	324	32	3524-4606
PO_4 -P . . . . mgℓ^{-1}	4,0	0,7	32	
Tot. Sol. -P . . . . mgℓ^{-1}	4,1	0,6	16	
NH_3 -N . . . . mgℓ^{-1}	1,5	0,5	32	
Sol. Kjel-N . . . . mgℓ^{-1}	15,0	1,1	32	
NO_3 -N . . . . mgℓ^{-1}	Trace			
Tot. P . . . . mgℓ^{-1}	15,0	2,4	20	
Tot. Kjel-N . . . . mgℓ^{-1}	44,4	2,4	16	
Susp. solids . . . . mgℓ^{-1}	693	43	32	621-765

Operational Data

In Figs. 1 and 2 the Solids Volume Index (SVI) of the mixed liquor in the basin, the load factor (L_f), COD's of feed and plant effluent and soluble nutrients in the effluent are graphed for 60 weeks. The results can be divided up into 3 phases of operation according to feed composition, i.e. sugar mill waste only, bark plus sugar mill wastes and bark mill waste only. Mean data for these different phases is given in Table 2. The first 13 weeks of operation represent sugar mill effluent as the only feed to the treatment plant and is discussed first.

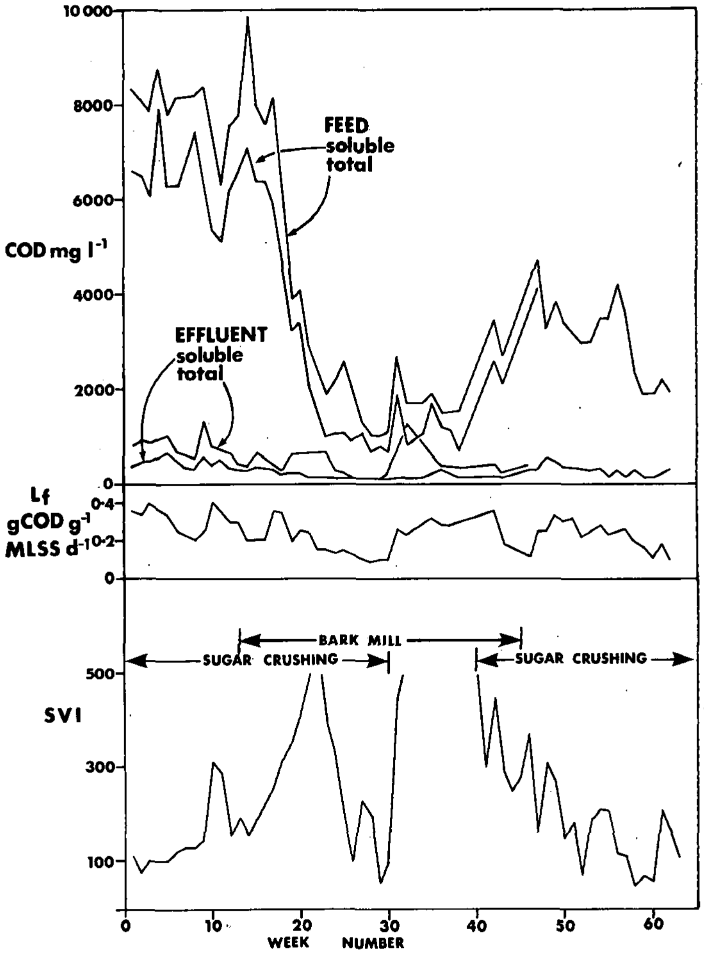

Figure 1: Variation of Sludge Volume Index, Load Factor and C.O.D. of feed and effluent with time. Week No. 1 commencing 2nd August 1976.

Period 2/8 - 25/10/76 (1st - 13th week)

The feed strength in this period fluctuated somewhat (Fig. 1) and was high with mean soluble and total COD values of 6388 and 7864 mgℓ^{-1} respectively (Table 2). For a mean flow rate of 340 m^3 d^{-1} this amounted to a daily load rate of 2700 kg of COD and it is likely that a substantial proportion of the COD was present as sucrose lost in the cane processing. Dissolved oxygen measurements made in the aeration basin showed only trace amounts present but nevertheless a good quality effluent was produced which had low soluble COD and extremely low soluble BOD values so there must have been sufficient dissolved oxygen present for purification. An attempt to improve the reoxygenation capacity of the aerators by increasing the depth of submersion of the rotors resulted in a power failure which put them out of action for 2 days in the 4th week.

Subsequently the ammonia concentration in the final effluent rose to values in excess of 100 mgℓ^{-1} which was the result of the basin contents going anaerobic but sludge separation was unaffected and remained good with SVI values in the region of 120 (Figs. 1 and 2). The definition of SVI is the volume in mls occupied by 1 g of solids after half an hour of settling under the standard conditions of the test.

These events showed that a short period of anaerobic conditions did not adversely affect plant performance and that the aeration equipment was at about its full capacity for the COD and BOD loadings. In the 10th week the supply of phosphorus for nutrient addition ran out and consequently the orthophosphate concentration in the basin which had been ranging about 0,2 mgℓ^{-1} fell to zero (Fig. 2). At the same time the SVI of the mixed liquor rose rapidly to a value in excess of 300 and sludge separation was poor (Fig. 1). Subsequently when phosphorus addition was resumed the SVI recovered, so the conclusion to be drawn is that lack of nutrient caused inefficient separation.

The mean values given in Table 2 for this phase of operation show that 93% of the soluble COD and 99,8% of the soluble BOD was removed. The soluble COD:BOD ratio of the feed was 1,6 and that of the effluent 47, showing that a high proportion of the biologically oxidisable matter in the feed had been removed resulting in a highly stable effluent. The mean suspended solids concentration of the final effluent, however, was almost as high as that of the feed, 394 compared with 434 mgℓ^{-1}, but most of the COD and BOD associated with the suspended material was removed or stabilised in the process. This is clearly shown by the results in Table 2 where the suspended solids in the effluent contained only 0,19 mg BOD mg^{-1} SS whereas the feed contained 1,4 mg BOD mg^{-1} SS. It was noted that the plant effluent contained the same black fibrous material as the feed, probably carbonised bagasse, indicating non-settleable solids passing right through the system. The mean SVI for the period was 155, or 126 if the 2 weeks of sludge bulking is ignored. This represents a sludge with satisfactory settling properties.

Period 1/11/76-28/2/77 (14th - 30th week)

The sugar mill was still operational and the bark mill started up, so the feed to the plant was a mixture of both wastes. Figure 1 shows that the COD of the feed fell rapidly, apparently due to the diluting effect of the weaker bark mill waste, but this was not

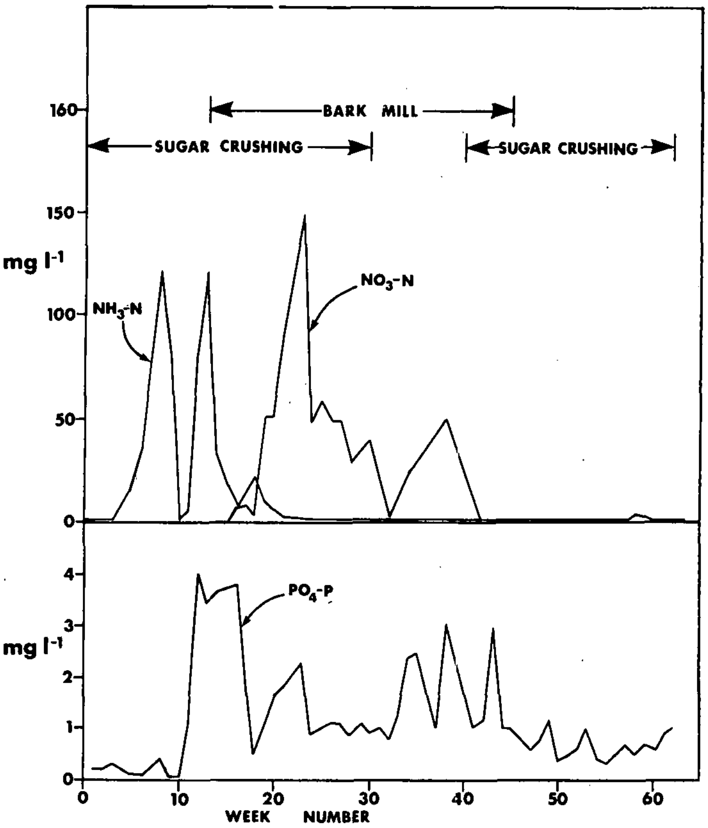

Figure 2: Variation of soluble nutrients in treatment plant effluent. Week No. 1 commencing 2nd August 1976.

TABLE 2

Mean flow rate and concentration of COD and BOD in feed and effluent and % reductions and settling property of sludge for periods when sugar mill and/or bark mill were operational.

	2/8 - 25/10/76	1/11/76 - 28/2/77	7/3 - 9/5/77	16/5 - 20/6/77	27/6 - 10/10/77
Feed to treatment plant	sugar mill effluent	bark + sugar mill effluent	bark mill effluent	bark + sugar mill effluent	sugar mill effluent
Flow rate m^3 d^{-1}	340	302	338	344	440
Feed Sol. COD mg ℓ^{-1}	6388	2800	1229	2381	
Tot. COD mg ℓ^{-1}	7864	3719	1793	2719	3108
Sol. BOD mg ℓ^{-1}	4028	1578			
Tot. BOD mg ℓ^{-1}	4636	1986			
Sol. COD/BOD	1,6	1,8			
Tot. COD/BOD	1,7	1,9			
Susp. solids mg ℓ^{-1}	434	607	489	893	1471
mg susp. BOD mg^{-1} SS	1,4	0,67	—	—	
mg susp. COD mg^{-1} SS	3,4	1,51	1,15	0,38	
Effluent Sol. COD mg ℓ^{-1}	421	179	262	183	279
Tot. COD mg ℓ^{-1}	788	337	663	273	
Sol. BOD mg ℓ^{-1}	9	11			
Tot. BOD mg ℓ^{-1}	85	47			
Sol. COD/BOD	47	16			
Tot. COD/BOD	9	7			
Susp. solids mg ℓ^{-1}	394	238	453	361	453
mg susp. BOD mg^{-1} SS	0,19	0,15	—	—	
mg susp. COD mg^{-1} SS	0,93	0,66	0,89	0,25	
% Reduction Sol. COD	93	94	79	92	
Tot. COD	90	91	63	90	
Sol. BOD	99,8	99,3			
Tot. BOD	98,2	97,6			
Basin SVI mℓ g^{-1}	155	261	817	326	159
MLSS mg ℓ^{-1}	4994	3004	1155	3169	3280

accompanied by a rise in feed volume. Simultaneously the SVI of the mixed liquor rose steadily to values in excess of 500. The reason for the sudden deterioration in sludge quality cannot be attributed to lack of either of the two nutrients since they were present in excess amounts (Fig. 2) or to excessive load rate which was only about 0,2 g COD g^{-1} MLSS^{-1} (Fig. 1); this implies that the deterioration was associated with the change in the nature of the feed. From the purification point of view, however, the plant was still performing well by producing high reductions of soluble COD and BOD (Table 2). This period of sludge bulking did not last for long and the SVI recovered until the sugar mill shut down (Fig. 1). The reason for the inconsistency of the sludge quality in this period is not known. It may be seen in Fig. 2 that the form of inorganic nitrogen changed from ammonia to nitrate when the feed strength fell.This is attributed to higher dissolved oxygen concentrations in the basin due to the lower organic loading thus allowing nitrifying bacteria to operate.

Period 7/3 - 9/5/77 (31st - 40th week)

With essentially only bark mill waste being fed to the plant, although there must have been a residual of sugar mill waste in the ponds from which the feed was drawn, the SVI values throughout were extremely high and the mean value was 817 (Table 2, Fig. 1). There was hardly any sludge separation in the settling tank and such large amounts of suspended solids were lost in the final effluent that the solids concentrations in the basin fell to the region of 1 000 mgℓ^{-1}. Microscopic examination of the sludge showed that a voluminous mat of filamentous organisms had developed and was probably responsible for the lack of sludge separation. The mean soluble COD reduction was lower at 79% than previously and the mean effluent COD higher at 262 mgℓ^{-1}. This does not necessarily reflect lesser purification than before but rather a higher concentration of non-biodegradable but chemically oxidisable material such as lignins in the bark mill waste. The performance of the plant in this period was unsatisfactory since excessive amounts of sludge were being lost from the plant and the effluent was extremely turbid.

Periods 16/5 - 20/6/77 (41st - 45th week) and 27/6 - 10/10/77 (46th-63rd week)

With the start up of the sugar mill there was an immediate improvement in the SVI of the basin samples which continued after the bark mill shut down in the 45th week (Fig. 1). Mean SVI's for the two periods were 326 and 159 respectively. In spite of the greatly improved settling quality of the sludge, suspended solids in the effluent remained at a high level but this may have been due to the nature of the suspended solids in the feed, as discussed previously. In fact, the suspended solids concentration in the feed rose considerably with mean values of 893 and 1 471 mgℓ^{-1} for the two periods respectively. As before, removal of soluble organic matter was good as reflected by mean COD's of 183 and 279 mgℓ^{-1} for the two periods respectively. Clearly the bark mill waste had an adverse effect upon the performance of the plant by causing the sludge to bulk, and this will be discussed in a later section.

Nutrient Budget

Nutrients were added to the basin manually in the form of urea for nitrogen and tri-sodium phosphate or phosphoric acid for phosphorus. Quantities added depended upon the strength of the feed but in general a ratio of COD:N:P of 100:2,0:0,4 was aimed at since this ratio was found to be adequate in the laboratory experiments (1). At times, however, there were large excesses of nutrients present in the basin because changes in feed strength were not always followed by corresponding changes in amounts of nutrients added. Records of nutrients added, nutrients in the feed and in the effluent have been used, together with flow data, to draw up a weekly input-output budget. Only the inorganic nitrogen and phosphorus concentrations have been considered here since these forms of nutrients are readily available for bacterial growth, whereas the availability of the soluble organic and suspended forms of nitrogen and phosphorus is uncertain. A similar treatment has been given to the soluble COD and BOD results giving quantitative data. The mass of COD, BOD, inorganic nitrogen and phosphate removed in certain periods is given in Table 3 where removal of BOD is for a shorter period than COD because of limited data. It can be safely assumed that these amounts went into growth of activated sludge so that the ratios will reflect actual nutrient requirements. The removal ratios were:

COD:N:P = 100:1,50:0,36
BOD:N:P = 100:2,19:0,47

which is in good agreement with those found in the laboratory experiments[1]. If such ratios are maintained in the feed then the nutrient requirement for the process should be satisfied. Nutrients naturally present in the feed supplied on average only 11 and 16% of the nitrogen and phosphorus requirement respectively.

TABLE 3

Mass balance, soluble COD, BOD, inorganic nitrogen and orthophosphate phosphorus removed

2/8/76 - 28/3/77	kg sol. COD removed	280 728
	kg sol. inorganic N removed	4 199
	kg sol. PO$_4$-P removed	1 007
2/8/76 - 13/12/76	kg sol. BOD removed	161 796
	kg sol. inorganic N removed	3 536
	kg sol. PO$_4$-P removed	758
	removal ratio COD:N:P	= 100:1,50:0,36
	BOD:N:P	= 100:2,19:0,47
2/8/76 - 28/3/77	kg sol. inorganic N in feed	469
	kg sol. PO$_4$-P in feed	162
	as % of N requirements	11
	as % of P requirement	16

Discussion

Bulking

A clear final effluent of good quality will only be produced by a plant if the activated sludge flocculates and settles out well in the sedimentation tank. A compact sludge with a low SVI is also necessary because a portion of the settled sludge needs to be returned in order to maintain an adequate level of suspended solids in the aeration basin. Furthermore, the net growth of sludge per day must be discarded and clearly a dense sludge will require less drying bed area and de-water more easily than a bulking sludge. An activated sludge is usually considered to be bulking when its SVI is greater than 200 mℓg^{-1}.

The phenomenon of sludge bulking is not clearly understood by workers in the field, but some ideas have been advanced as to reasons for its development. Fungi,like bacteria,are plants and since they have a common food source there is competition for the available food. Unlike bacteria, fungi are multicellular and generally have filamentous forms so that should conditions be such that they can grow at a faster rate than bacteria the result will be a mat of intertwined filaments, which in activated sludge keep the sludge flocs apart and thus prevent compaction. Between pH 6,5 and 8,5 bacteria predominate over fungi but the position is reversed at pH's between 4 and 5 so that a low pH in the aeration basin could lead to a bulking sludge. High carbohydrate media are also known to favour fungi, and since fungi form normal protoplasm with only half the nitrogen content of that of bacteria, they are able to compete more successfully for food in nitrogen deficient wastes than bacteria, hence the importance of assuring an adequate supply of nutrients when treating an industrial waste.

At very low dissolved oxygen levels, 0 to 0,5 mg ℓ^{-1}, the normal bacteria switch to anaerobic metabolism while the filamentous forms continue with aerobic metabolism, but since the energy balance is by far in favour of the aerobes, the filamentous forms achieve predominance. Should the system go completely anaerobic, however, the bacteria will re-establish because the filamentous forms die off,as they are usually strict aerobes. The tendency of filamentous microorganisms to predominate in extended aeration plants where there is an extremely long solids retention period, is explained by the theory that the filamentous forms are able to utilise the inert polysaccharide material produced by bacterial decomposition and so have a source of food which is not available to the normal bacteria. Another cause of a bulking sludge is a temporary biological overloading of a plant caused by dumping of a strong waste. In this case the sudden increase in available food results in rapid biological growth and the microorganisms remain in a dispersed state with resultant poor floc formation and a turbid final effluent.

A wide variety of remedial measures for the control of a bulking sludge have been reported, some based on scientific reasoning, others from practical experience. These include a temporary cut off of the aeration so that the sludge undergoes an anaerobic period, a reduction in load rate to reduce the growth rate, lengthening the aeration period so that the sludge goes further into the endogenous phase, the addition of coagulants such as ferric chloride or polyelectrolytes to improve settleability, rejection of sludge and reseeding with healthy activated sludge.

In an attempt to identify some of the causes of bulking sludge, the Water Research Centre in England made a survey of 65 plants, both large and small. Their published results make interesting reading in that they only emphasise the lack of knowledge concerning the reasons for sludge bulking [5]. Their statistical evaluation of the findings showed no overall correlation between the occurrence of bulking and any of the parameters which are normally measured such as sludge loading, sludge age, retention time, dissolved oxygen concentration or temperature. One positive aspect to emerge was that plants employing plug-flow design were less prone to bulking than plants employing complete mixing. They showed that theoretical sludge loading, in the first compartment of each tank in the case of plug-flow plants and for the whole tank with complete mixing type plants, was significantly related to SVI, in that high loadings were associated with low SVI's. No reasons for this phenomenon were advanced. This finding suggests that provided the method of aeration permits, baffles could be added to the tank of the complete mixing plant in order to bring about a degree of plug-flow if repeated bulking problems were being experienced. The most common corrective measures reported for improving a bulking sludge were re-seeding and a reduction in sludge concentration. The reader will not be mistaken in concluding that the method of dealing with bulking sludge is more of an art than a science.

The fact that filamentous organisms develop in a sludge does not necessarily mean that the efficiency of purification will be lowered, as judged by the removal of soluble constituents, and provided that the rate of sludge loss in the effluent is not greater than the growth rate, the process will not fail. This was the case at the Dalton plant when only bark mill effluent was fed during the shut-down period of the sugar mill. The reason for excessive growth of filamentous organisms at that time cannot be attributed to any of the common causes such as low pH, low dissolved oxygen, biological overload or lack of nutrients since these parameters were continually monitored at the time. The bulking could only have been caused by something connected with the nature of the feed. The organic strength of the bark mill effluent, as reflected by the COD was low when compared with the sugar mill effluent, but BOD is a better estimate of the biodegradability of a waste than COD. BOD data are not available for the period when bark mill waste only was the feed but previous analyses of bark mill effluent gave a COD of 1929 mg ℓ^{-1} and a BOD of 550 mg ℓ^{-1}. This gives a COD:BOD ratio of 3,5:1 while ratios of less than 2:1 were usually observed in the feed when the sugar mill was working. The conclusion drawn is that a far smaller proportion of the organic matter in the bark mill waste is easily available for biological degradation than in the sugar mill waste. Previously it was suggested that polysaccharide materials may be available as food for filamentous organisms but not to the normal bacteria in activated sludge and this may have been the case at the Dalton plant when bark mill effluent was the only feed. It seems reasonable to assume that effluent from a bark processing mill will contain many lignin and cellulose type compounds which may only be degraded by rather specialised organisms. The fact that the bulking problem disappeared soon after sugar mill effluent was re-introduced suggests that the new food supply allowed the normal bacteria to re-establish predominance.

Solids Concentration in Basin

The mixed liquor suspended solids (MLSS) concentration in an aeration basin is normally considered to be representative of the activated sludge concentration for calculation of the load factor. This is not strictly correct because, as mentioned earlier, inert solids are produced in the process, but there is a definite relationship provided that the feed is low in suspended solids. When settled sewage, which contains only about 20 mg ℓ^{-1} suspended solids is the feed this is a fair assumption but the feed to the Dalton plant contained suspended solids concentrations of the order of 1 000 mgℓ^{-1}, so that the MLSS concentration in the basin gave an over-estimate of the activated sludge mass. The ratio of active to inactive solids in the basin will be related to the ratio of the daily growth of activated sludge to the suspended solids fed per day. Sludge production will be determined by the amount of available COD in the feed, and knowing the suspended solids concentration of the feed, the fraction of MLSS in the basin representative of activated sludge can be calculated.

This relationship is shown in Fig. 3 for different suspended solids concentrations in the feed and for calculation of the curves, a growth rate of 0,2 g sludge g^{-1} COD d^{-1} was assumed while suspended solids in the feed are assumed to be mostly inert. The shapes of the curves in Fig. 3 show that the fraction of MLSS as activated sludge is particularly effected by changes at

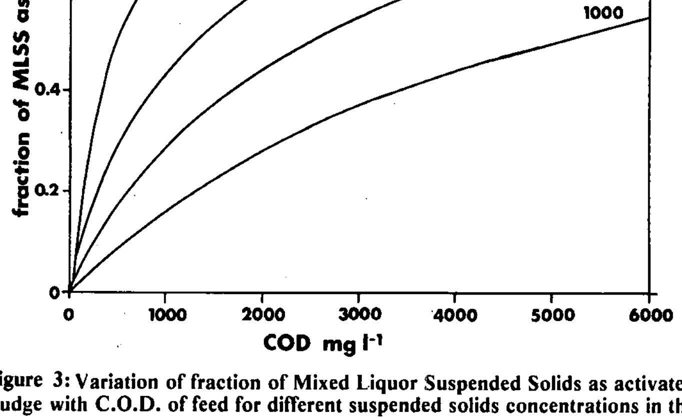

Figure 3: Variation of fraction of Mixed Liquor Suspended Solids as activated sludge with C.O.D. of feed for different suspended solids concentrations in the feed.

low COD concentrations of the feed. For a feed containing 2 000 mg ℓ^{-1} biologically available COD and with suspended solids concentrations ranging from 100 to 1 000 mg ℓ^{-1}, the fraction of the MLSS as activated sludge will range from 0,8 to as low as 0,3 respectively. Therefore in order to maintain a certain biological loading these factors must be taken into account in determining the necessary MLSS concentration to be maintained in the basin.

If the net daily increase in sludge is pumped to waste and the presence of non-settleable solids in the system is ignored then the equilibrium concentration of suspended solids in the basin will be determined by the concentration of suspended solids in the return sludge, and the sludge return to feed rate ratio. For the mass of solids leaving the basin to equal the mass returned via sludge return the following relationship can be derived.

$$\text{MLSS mg } \ell^{-1} = \frac{r}{r+1} \text{ x SS mg } \ell^{-1} \text{ sludge return}$$

$$\text{where } r = \frac{\text{vol. sludge return}}{\text{vol. feed}}$$

Clearly for a fixed value of r the MLSS concentration is dependent on the sludge return concentration which may also be expressed as an SVI, i.e.

$$\text{SS mg } \ell^{-1} = \frac{10^6}{\text{SVI m}\ell \text{ g}^{-1}}$$

and therefore in the above equation the greater the SVI, the lower the MLSS concentration will be. Consequently, when bulking occurs and the SVI rises there will be a loss of MLSS from the system until the equation balances again.

As an example of how the various factors interact, assume a feed COD strength of 3 000mg ℓ^{-1}, suspended solids concentration of 1 000 mg ℓ^{-1} and a daily volume of 500 m^3. For a design loading of 0,4 g COD g^{-1} MLSS d^{-1} on the Dalton plant the MLSS concentration would need to be 2 040 mg ℓ^{-1} but with a suspended solids concentration of 1 000 mg ℓ^{-1} in the feed, reference to Fig. 3 shows that the active fraction of the MLSS would only be 0,38. This means in reality that a MLSS concentration of 2040/0,38 or 5 370 mg ℓ^{-1} would be required. The problem with having to maintain such a high MLSS concentration is that the SVI value of the return sludge would need to be exceptionally good, in this case 93 or less at a recirculation ratio of 1 in order to balance the above equation. Alternatively, if solids were excluded from the feed then a lower MLSS concentration would be required and much higher SVI values could be tolerated without loss of sludge in the effluent. The SVI test as conducted on the basin contents gives a good indication of the condition of the sludge and bears some relation to its separation in the settling tank.

Capital and Operational Costs

The capital cost of the treatment plant was as follows:

Earthworks	R7 000
Mechanics	54 000
Civil	69 000
Total	R130 000

Bruijn[6] gives the capital cost of the biological filtration plant at the Felixton sugar mill as R81 000, but this was based on 1972 costs whereas the above costs were for 1975 so that a direct comparison would not be accurate. The design loading of the Felixton plant was for 1 200 kg BOD d^{-1} and 1 840 kg for the Dalton plant and therefore the plants are of comparable size.

A breakdown of the operational costs of the Dalton plant is given below. Since we are principally interested in the treatment of sugar mill effluent, the cost of running the plant and data when bark mill effluent was the only feed have been excluded from the analysis. During the period of investigation the sugar mill was active for 42 weeks in the year.

mean daily flow	360 m^3
mean daily COD load	1 602 kg
mean daily BOD load	905 kg

unit costs	cents m^{-3}	cents kg^{-1} COD	cents kg^{-1} BOD	cents ton^{-1} cane processed
add. nutrients	4,6	1,0	1,8	1,0
electricity . . .	10,9	2,4	4,3	2,3
Total	15,5	3,5	6,2	3,3

It may be seen that the major cost of running the plant was that of electricity, the unit price of which was 3,2 cents kw h^{-1}. The aerators accounted for 80% of the electricity consumed and this would be a saving in the case of a biological filtration plant which does not rely on mechanical means for re-oxygenation. Nutrient costs of the two processes would most likely be similar since biological filters also require additional nutrients for successful operation[6]. Superficially it appears that installation and operation of a biological filtration plant may be less than that of an activated sludge plant, but one disadvantage of biological filters is that they are not meant to treat feeds containing appreciable amounts of suspended material since the jets of the rotary arms may clog and also "ponding" of the filter may occur, i.e. clogging of the interstices in the filter.

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