Wat. Sci. Tech. Vol. 22, No. 9, pp. 101–111, 1990.

0273–1223/90 $0·00 + ·50

CONTROL OF BULKING SLUDGE IN AGRO-INDUSTRIAL TREATMENT PLANTS

J. R. Rensink and H. J. G. W. Donker

Department of Water Pollution Control, Agricultural University, Biotechnion, Bomenweg 2, P.O.B. 8129, 6700 EV Wageningen, The Netherlands

ABSTRACT

Bulking sludge has been studied on laboratory, pilot plant and large scale circumstances. Special attention has been paid to different kinds of agro-industrial waste waters and domestic sewage. It has been clearly shown that besides a deficiency of nutrients and oxygen, the feed pattern of the plant plays a very important role in the field of bulking sludge control. Different experiments have obviously demonstrated that a completely mixed activated sludge system leads much more to bulking sludge than a plug-flow system. Also a contact tank (selector ahead of the plant) is positive for depressing bulking sludge in completely mixed systems.

KEYWORDS

Bulking sludge; settleability; plug-flow system; completely mixed system; nutrients; oxygen.

INTRODUCTION

Bulking sludge is one of the biggest problems of the activated sludge process. Bulking sludge is characterised by poor settling properties, which are usually associated with excessive growth of filamentous bacteria. Although the insight in the control of bulking sludge has been improved dramatically, many plant operators have to contend with poor settling sludge. A variety of causes of bulking sludge have been implicated including low oxygen concentration, nutrient deficiency, high sulphide concentration (septic wastewater) and last but not least the feed pattern of the plant.

In the late sixties and the beginning of the seventies a breakthrough in the control of bulking sludge was caused by Chudoba (1973, 1974) and Rensink (1966, 1974). They both clearly proved that the feed pattern of the plant plays a predominant role in the occurrence or in the absence of bulking sludge. It was pointed out that a completely mixed activated sludge system leads much more to bulking sludge than a plug-flow or fill-and-draw system. The last mentioned system is an ideal plug-flow system.

The difference in feed pattern - and also the process operation - has to deal with the initial organic loading of the sludge flocs. In a completely mixed system the organic material of the wastewater is totally mixed with the whole biomass of the aeration tank, which leads to a low loading of the sludge floc. The COD of the filtered sludge mixture corresponds roughly with the COD of the effluent. This low loading of the sludge mass promotes the growth of filamentous bacteria owing to a higher growth rate than the flow system where the organic material of the wastewater meets the return sludge at the head end of the aeration tank; a high loading of the sludge takes place at the spot. In this area the sludge floc is highly penetrated with organic material. The COD of the filtered sludge mixture is much higher at the head end of the tank than further along the aeration tank and effluent. A substrate gradient along the aeration tank can be observed. The high substrate concentration at the head end stimulates the growth of the floc-forming bacteria.

The different kinetic behaviour of filamentous and floc-forming bacteria is given in Figure 1.

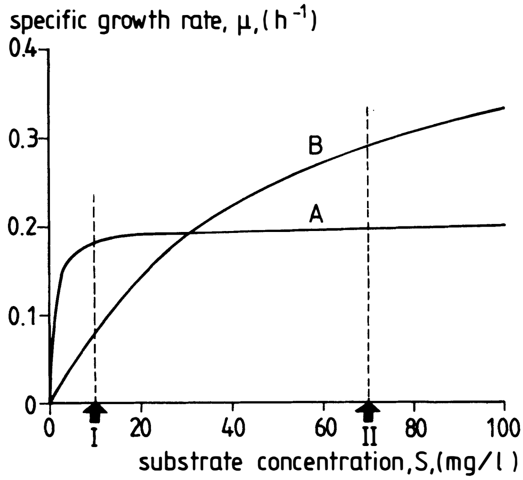

Fig. 1. Graphical presentation of the relation between growth rate (μ) and substrate concentration (S) for two hypothetical organisms. A (K_s = 1 mg/l, μ_m = 0.2 hr^{-1}) and B (K_s = 50 mg/l, μ_m = 0.5 hr^{-1}) (From Chudoba et al.).

The influence of the feed pattern can be simply and clearly demonstrated by the following laboratory experiment. Two aerated sludge vessels from e.g. 1 litre, filled with activated sludge, are fed differently in time. The first vessel - after effluent drain-off - is fed with a quantity of waste water at once (per day), the second vessel- also after effluent drain-off - receives the same quantity of the waste water in about 20 - 24 hours per day. During the dosing time the vessel is aerated. Figure 2 demonstrates the result of this experiment, using skim milkpowder as substrate. By changing the feed pattern of the vessels the sludge characteristics alter also, which has been read out from the SVI in Figure 2.

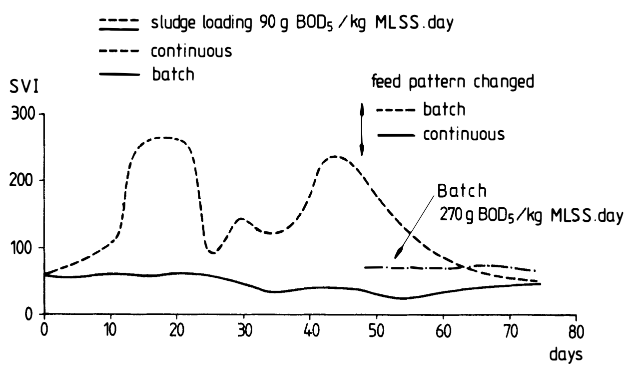

Fig. 2. Relationship between feed pattern and SVI.

Existing completely mixed activated sludge plants as e.g. oxidation and carousel ditches, which have bulking sludge, can be controlled by placing a small contact tank (selector) ahead of the plant. The waste water and the return sludge passes the contact tank in a short time before entering a completely mixed aeration ditch. In the contact tank the waste water and the return sludge are mixed, which results in a heavy loading of the sludge flocs. The detention time of the sludge water mixture amounts circa 10 - 30 minutes. The principal of the process taking place in the contact tank simulates the process which occurs at the head end of the plug flow system.

This paper deals with research especially based on the feed pattern of the plant. It includes pilot plant studies with agro-industrial and settled domestic waste water in completely mixed and plug-flow systems as well as the use of a contact tank.

Research - Agro-industrial waste water.

1. Potato-chip waste water

In practice it has become clear that the treatment of chip waste water presents no problem. The only difficulties occur in the separation of the sludge from the treated effluent in the settling tank. Only low loaded completely mixed activated sludge systems were used. This hopeless situation of bulking sludge led to the investigations whether the settleability of the sludge is improved by treating chip waste water in a longitudinal aeration tank and in an oxidation ditch with a small contact tank (Rensink, 1977).

Experimental plant (Figure 3). For the tests two oxidation ditches, with a capacity of 240 litres each, were used, which were available in the pilot plant hall. One ditch was converted to obtain a longitudinal tank. It was divided into seven interconnected chambers, the brush was removed and a compressed air pipe was installed at the bottom of the ditch for the aeration of the activated sludge. The other oxidation was unaltered, except for a contact tank which was inserted at the beginning of the ditch.

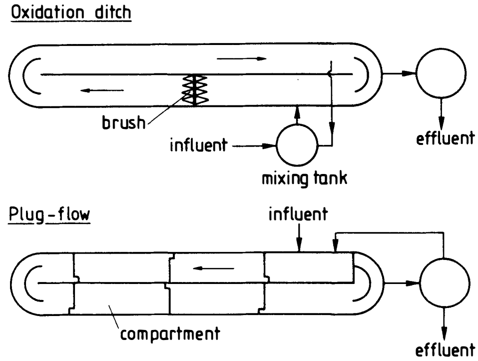

Fig. 3. The pilot plants.

Characteristics of the waste water. The prepared waste water from potatoes is given in table 1.

TABLE 1. Composition of potato waste water

COD	1530	mg/l
BOD_5	920	mg/l
$N_{Kjeldahl}$	60	mg/l
P_{total}	7	mg/l
pH-value	7.6	mg/l
$BOD_5 : N : P$ = 100 : 6.5 : 0.76		

Tests in the longitudinal tank. As already mentioned, the longitudinal tank consisted of seven chambers. At the beginning of the test we investigated the extent to which there was blockage of the flow. For this purpose a salt solution was introduced into the tank and forced out with tap water. The quantity of tap was 14 l/h. This represented a flow of 6.2 l waste water and 7.8 l returned sludge. It was also established that the tank is comparable to three completely mixed vessels, i.e. that only slight longitudinal mixing occurs. Fifty litres of waste water were supplied per 8-hour day. The average period for which waste water remained in the tank was approximately 5 days. The sludge loading was 160 g COD/kg MLSS.day, or 96 g BOD_5/kg MLSS.day. In the ditch we attempted to obtain a sludge concentration of approximately 2 - 2.5 g/l. Oxygen was never the limiting factor. Excess sludge was removed once a day by hand. The pilot plant was injected with sludge, which was fed batchwise. The temperature during the tests was 16 to 18 °C.

Test results. The most important parameter of this investigation was the Sludge Volume Index (SVI), which was regularly obtained. The course of the SVI has been illustrated in Figure 4. Figure 4 clearly shows that, under the conditions existing, the SVI of the activated sludge remains very low and stable. After the starting period it varies around an average value of approximately 70 ml/g MLSS. Throughout the test the sludge flocs were compact in form; no filamentous bacteria appeared during the research. Protozoa as ciliates and rotifers were always present.

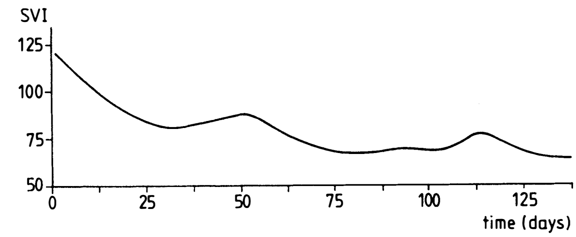

Fig. 4. The course of the SVI during the experiment.

Degree of treatment. On the basis of the COD and BOD_5 it was established that a treatment efficiency of 97% to 99% was achieved. Even in the first chamber a pollution load of 93% - on the basis of the COD - was eliminated. In the second chamber the elimination was only 2.5%. On the basis of these analyses it can be established that the removal of the substrate occurs mainly in the first chamber. Figure 5 illustrates the curve of the COD in the longitudinal tank. Since we were dealing with a low phosphate content in the waste water, the phosphate was extensively used for the synthesis of new cell material. The nitrogen compounds ammonia and nitrite amounted to less than 1 mg N/l. For nitrate the content varied between 16 - 18.5 mg N/l. The pH was approximately 8.0. In this test a high oxygen content was required to achieve satisfactory mixing of the activated sludge.

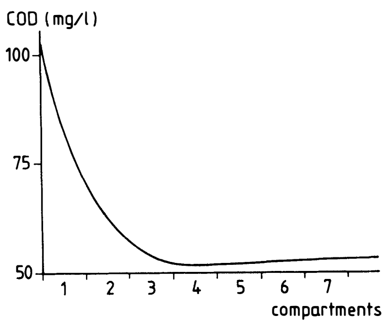

Fig. 5. The course of COD along the compartments.

Denitrification. To reduce still further the nitrate content of the treated waste water the aerator was removed from the sixth chamber and replaced by two stirrers. Since there is no longer any substrate for denitrification present in chamber 6, a sixth of the waste water was channelled into chamber 6. Figure 6 shows that after a few days denitrification sets in, and the nitrate content falls to 6 mg N/l thus circa two thirds of the original nitrate content is eliminated. This alteration of the procedure did not affect the SVI and the degree of treatment. Under these conditions it proved quite simple to build in a denitrification stage.

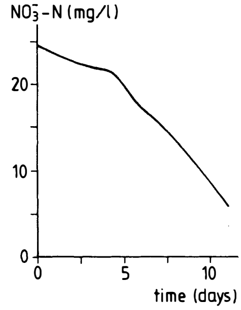

Fig. 6. The course of nitrate during a denitrification period.

Tests in oxidation ditch. For these tests the oxidation ditch was supplied with 50 l/d of waste water during a period of eight hours. The sludge loading was 160 g COD/kg MLSS.day, or 96 g BOD_5/kg MLSS.day. Three tests were carried out in the oxidation ditch; namely a load level of approximately 60 g COD/kg sludge, a load level of 30 g COD/kg sludge and a level of O, i.e. without a contact tank. For the load level of 60 g COD/kg sludge, the contact tank had an effective volume of 10 l. The waste waster supply of 6.2 l/h was mixed with 60 l/h activated sludge, direct from the oxidation ditch in order to garantee a constant sludge concentration. The temperature in the ditch was 17 - 19 °C. The average time in the contact tank was approximately 9 minutes. After the contact tank, the waste water/sludge mixture was led continuously into the oxidation ditch.

The load level of 30 g COD/kg sludge was achieved by 6.2 l/h waste water with 150 l/h activated sludge mixture. The average time in this case was also approximately 10 minutes. For the load level of 0 g COD/kg sludge the contact tank was disconnected and 6.2 l/h waste water fed directly into the ditch.

Test results. The course of the SVI and load level is shown in Figure 7. For a load level of 60 g COD/kg sludge the SVI fell initially from 118 to 89 ml/g, then stabilised at an average of approximately 85 ml/g. The test was ended after 40 days. Under the microscope ciliates, rotifers and flagellates were regularly observed during the investigation. Filamentous bacteria did not appear. The sludge flocs were fairly large and compact throughout the whole period. With a load level of 30 g COD/kg sludge the flocs gradually became smaller and looser. Moreover filamentous bacteria developed, but without dominating. The activated sludge contained relatively large numbers of

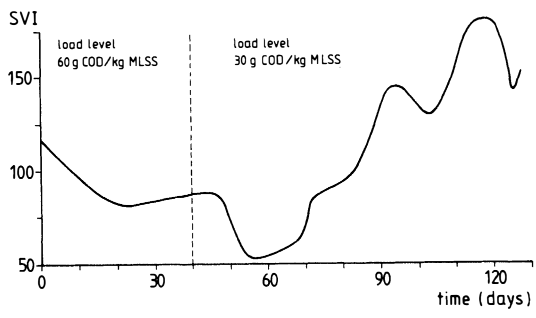

Fig. 7. The course of SVI during different loading levels in contact tank.

flagellates and ciliates. The SVI was still stable and low at first, but gradually rose, with fluctuations, to a maximum of 180 ml/g. In the third test, without a contact tank, the settleability rapidly declined, as a result of which the SVI rose after 20 days from 56 to 130 ml/g (See figure 7a). In tests by Jellema and Rensink (1974) under the same condition the SVI rose within six days from 110 to 320 ml/g. Have and Müller (1972) have also reported on this matter.

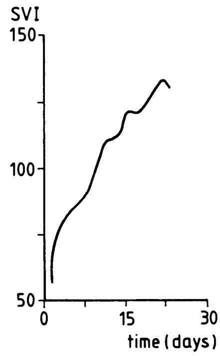

Fig. 7a. The course of SVI without contact tank.

Treatment efficiency. At all load levels the waste water was extensively purified. The COD and BOD_5 of the effluent were 45 and 8 mg/l. Phosphate removal was 87%. Where there was a contact tank, 82% of the phosphate was already eliminated before the waste water reached the ditch. In the case of nitrogen compounds it was established that in all three cases the ammonia and nitrite content of the effluent was less than 1 mg N/l. The nitrate content had an average value of approximately 23 mg N/l. The pH-value varied between 7.5 and 7.7. The oxygen content fluctuated in all three cases between 6 and 7 mg O_2/l. For technical reasons it was not possible to employ a lower oxygen content. Within the general scheme of the investigations it was also desirable that oxygen content should not be a limiting factor. There was always sufficient oxygen present in the contact tank. During loading with waste water the oxygen content in the contact tank dropped by a few mg/l.

Supplementary experiments. In order to obtain further information on the removal of organic substances in the contact tank, experiments were carried out in a settling cylinder with discontinuous supply of waste water (1 per day). The cylinder had an effective volume of 11 l. Ten litres of activated sludge mixture with a concentration of 2.5 g/l were placed in the settling cylinder. The liquid was mechanically stirred. Thereafter the settling cylinder was supplied with 1 l chip waste water with a COD of 1570 mg/l; the load level amounted to 63 g COD/kg sludge and the track of the filtered COD in the activated sludge mixture was established. The result is shown in Figure 8.

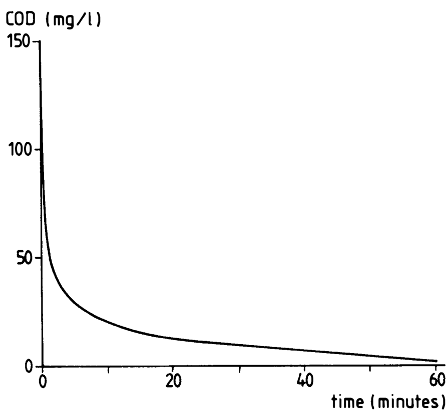

Fig. 8. The course of COD in batch experiment.

The graph shows that after 9 to 10 minutes, 80% of the COD had been removed, mainly by adsorption, before it reached the oxidation ditch, which agrees with the time in the contact tank.

CONCLUSIONS

In these long-term tests it has been shown that the treatment of chip waste water in a longitudinal tank permits a low and stable SVI. In a long-term test of 20 weeks, the SVI was 70 ml/g.

The test with a contact tank inserted before the oxidation ditch showed that with a load level of 60 g COD/kg sludge a lower SVI appeared after stabilisation. During the long-term test of 40 days, the SVI was 85 ml/g. Load levels of 30 and 0 g COD/kg sludge scored high SVI values with large fluctuations.

2. Dairy waste water

Initially the introduction of a contact tank on large scale was not always successful. A completely mixed contact tank leads fewer times to an improvement of the sludge settleability than a rectangular contact tank. Therefore experiments were performed with both types of contact tank, which were fed with synthetic dairy waste water (Rensink, 1981).

A rectangular and a completely mixed tank were tested. Each was placed ahead of an oxidation ditch with a capacity of 240 litres. The contact tanks each had a volume of 12 l. This volume is 5% of the volume of the oxidation ditch. The lay-out of the pilot plants is given in Figure 9.

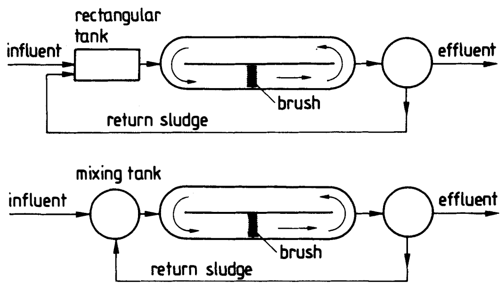

Fig. 9. The pilot plants.

Characteristics of dairy waste water. According to practice the pilot plants were fed 10 hours per day with synthetic dairy waste water. This waste water was daily prepared by mixing whey powder and milk powder in a ratio 3:1. This waste water can be compared with waste water of a cheese-butter factory in The Netherlands.

The synthetic dairy waste water is given in Table 2.

TABLE 2: Characteristics of dairy waste water

COD	1250	mg/l
BOD_5	750	mg/l
$N_{Kjeldahl}$	35	mg/l
P_{total}	7	mg/l
pH	7.6	mg/l
$BOD_5 : N : P$ =	100 : 5 : 1	

Each plant was fed with 80 litres of waste water for ten hours only each day. The sludge loading of the oxidation ditches amounted 120 g BOD_5/kg MLSS.day. The MLSS concentration was maintained at 2 g/l, excess sludge was removed daily, and the oxygen concentration was never the limiting factor. The following process operations were carried out:

1. Operation of the pilot plants without contact tanks. The experiment was started with a sludge with good settling properties, adapted to the synthetic dairy waste water.
2. Operation of the oxidation ditches with the contact tanks. The experiment was started with bulking sludge, the result of experiment 1.
3. Operation of the plants with contact tanks. The experiment was started with a sludge with good settling properties, adapted to synthetic dairy waste water.
4. Continuation of experiment 3, but now without contact tanks.

In experiments 1 and 2 the "loading level" of the contact tank amounted to 60 g COD/kg MLSS. The detention time of the mixed-liquor in the contact tank was 8 minutes. In Figures 10 and 11 the variation of the SVI is given during the four experiments. Without contact tanks in experiment 1 the sludge soon began to bulk. In both oxidation ditches the filamentous bacteria *Sphaerotilus natans* occurred. In experiment 2 only the rectangular tank was capable of improving the settleability of the sludge. *Sphaerotilus* disappeared from this system. However the sludge from the oxidation ditch with the complete-mixing contact tank remained unchanged and *Sphaerotilus natans* predominated.

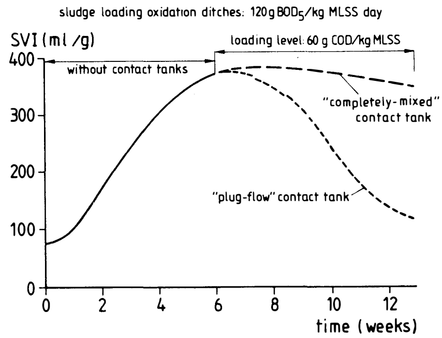

Fig. 10. The course of SVI during experiments with and without contact tanks.

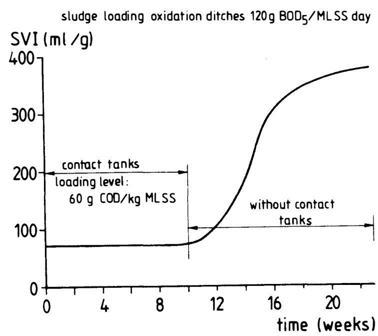

Fig. 11. The course of SVI during experiments with and without contact tanks.

In experiment 3 the plants were started with sludges with good settling characteristics. Both contact tanks were able to maintain the sludge in a good position. As soon as the contact tanks were removed (experiment 4) the sludge in the oxidation ditches bulked due to massive growth of *Sphaerotilus natans*.

During the experiment with a contact tank the substrate gradient along the rectangular tank and the completely mixed tank had been measured. The average results have been presented in Figure 12.

CONCLUSIONS

It has been proved that in an activated sludge plant, starting with good settling sludge, the type of contact does not matter. Both types investigated prevented the formation of bulking sludge. However the configuration of the contact tank is important in curing bulking sludge. In this case a contact tank with a rectangular configuration is necessary. Although both contact tanks need the same residence time for the mixed liquor, the rectangular tank exhibited a low degree of dispersion. Therefore the latter provided a high substrate concentration at its inlet and a low concentration at its outlet.

Domestic Waste Water. Pilot plant studies (Rensink, 1981). The occurrence of bulking sludge has been studied extensively in a plug-flow and completely mixed system at different sludge loadings, see Figure 13. The settled domestic waste water is given in Table 3.

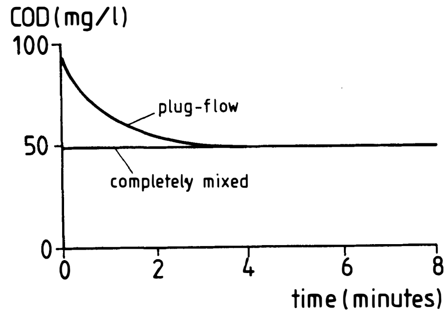

Fig. 12. The course of COD along the rectangular contact tank.

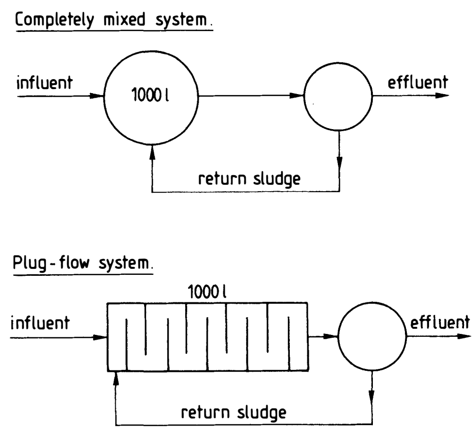

Fig. 13. The pilot plants.

TABLE 3: The composition of the settled domestic waste water

COD	500	mg/l
BOD_5	300	mg/l
$N_{kjeldahl}$	70	mg/l
P_{total}	18	mg/l
Alkalinity	7	mg/l
Ca	50	mg/l
Mg	2.5	mg/l
Hardness	125	mg $CaCO_3$/l

BOD_5 : N : P = 100 : 23 : 6

During the experiments the MLSS concentration was maintained at 2 g/l. Excess sludge was wasted continuously and the dissolved oxygen was never limiting.

RESULTS

In Figure 14 the SVI is given as a function of the loading for the completely mixed system (CM) and the plug flow system (PF). At loading in the range of 100 - 600 g BOD_5/kg MLSS.day the CM-system induced bulking sludge. In the filamentous sludge *Sphaerotilus natans* prevailed. Below a loading of 100 g BOD_5/kg MLSS.day the SVI was mostly low. In some cases bulking occurred and the filamentous bacteria responsible was *Microthrix* *parvicella* or *Haliscomenobacter hydrossis*. At loadings between 600 and 700 g BOD_5/kg MLSS.day the SVI decreased and *Sphaerotilus natans* and zoogloeal bacteria were predominant in the sludge. Loadings higher than 700 kg BOD_5/kg MLSS.day resulted in smaller flocs, dispersed bacteria and increasingly turbid effluent. The sludge settles well.

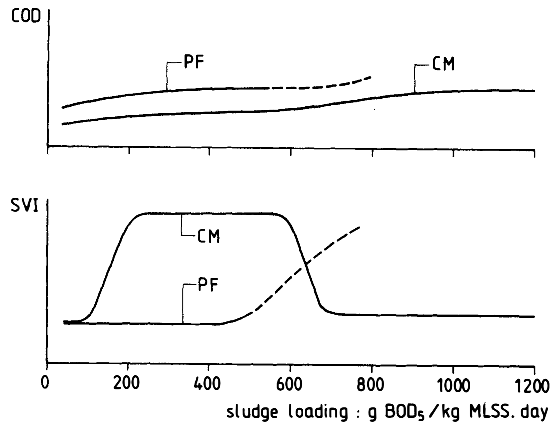

Fig. 14. Relationship between SVI and sludge loading.

The plug-flow system (PF) had a low and stable SVI below a loading of 500 g BOD_5/kg MLSS.day. The floc was compact and few or no filamentous micro-organisms were present. Slightly above a loading of 500 g BOD_5/kg MLSS.day the sludge became bulky and *Sphaerotilus natans* and zoogloeal bacteria occurred massively. Higher loadings have not been investigated.

In Figure 14 the relationship is given between the COD of the filtered mixed liquor from the CM-system and from the first compartment of the PF-system. The COD of the CM-system and first compartment of the PF-system differ approximately 40 mg/l. At the end of the plug-flow system the COD is equal to the COD of the CM-system.

CONCLUSIONS

This experiment clearly showed the significance of the feed pattern of the plant. Below a loading of 500 g BOD_5/kg MLSS.day a low SVI can be expected in an activated sludge plant of the plug flow type. The lower SVI at higher loadings (>600) can be attributed to the higher sludge waste rate than the growth rate of filamentous bacteria. The situation is comparable with the nitrifying bacteria at a low sludge age and a higher waste rate.

GENERAL DISCUSSION

The above described experiments show clearly that the method of waste water supply to an activated sludge plant plays a decisive role in the prevention of bulking sludge. Bulking occurs in systems where the sludge was only in contact with a low concentration of soluble COD. This was the case in the completely mixed systems as oxidation ditches and mixed aeration tanks. Slow growers such as filamentous bacteria occur with the result: bulking sludge. Sludges with good settling properties were produced by systems where part of the sludge was in temporary contact with a high concentration of soluble COD. This situation existed in the plug-flow fed system and in contact tanks ahead of the oxidation ditches. In both cases a part of the sludge is highly penetrated with organic material. More than 70-80% of the organic material in this area is removed from the waste water. This high substrate concentration promotes the growth of floc forming bacteria. Very important is the high removal degree of the organic material in order to prevent mixing of a high rest-COD with the total biomass. When the adsorption is too low, the system works as a completely mixed system and as a consequence bulking sludge.

For existing completely mixed systems with bulking sludge, the introduction of a contact tank is useful. It has been clearly proved that a rectangular tank with a plug-flow character guarantees a better control of bulking sludge than a mixing contact tank. For practice it is better to increase the detention time of 20-30 minutes of the sludge-liquor owing to the strong fluctuation of the strength and flow of the waste water.

Experiments on pilot level showed that aeration or stirring of the contact tank makes no difference in sludge control. In both cases the high adsorption degree may be the main process. The use of an anoxic zone at the head end of a plug-flow system as described by Chambers (1981), and therefore suppressing of bulking sludge, may probably be attributed to the forming of low fatty acids in the anoxic zone which stimulates the growth of the floc-forming bacteria *Acinetobacter* responsible for the luxury P-uptake.

The sludge loading is also important in the field of bulking. To ascertain the range of sludge loading where no bulking sludge occurs, laboratory batch experiments at different sludge loadings can be easily carried out. These experiments can also be used to fix the detention time of the sludge-liquor in the contact tank. Therefore the course of the filtered COD must be determined .

Besides the feed pattern and sludge loading, care must be taken of sufficient oxygen and nutrients. A deficiency can lead to bulking sludge. Pure oxygen as aeration guarantees a better sludge settleability than air aeration.

Plants on large scale which have problems with bulking sludge can be tackled by the following steps:

1. Nutrient control
2. Oxygen housekeeping
3. Feed pattern
4. Sludge loading

If nutrient and oxygen deficiency is not limited, batch experiments must be carried out to get information on the best sludge loading trajectory or detention time of the sludge-liquor in the contact tank on the basis of COD-removal.

REFERENCES

Chambers, B. (1981). Effect of longitudinal mixing and anoxic zones on settleability of activated sludge. In Bulking of Activated Sludge: Preventive and Remedial Methods, 166-183. (Edited by Chambers B. and Tomlinson E.J.). Ellis Horwood-Publishers.

Chudoba, J., Ottová, V. and Madëra, V. (1973). Control of activated sludge filamentous bulking. I Effect of the hydraulic regime or degree of mixing in an aeration tank. Water Research, 7, 1163-1182.

Chudoba, J., Grau, P. and Ottová, V. (1973). Control of activated sludge filamentous bulking - II Selection of micro-organisms by means of a selector. Water Research 7, 1389-1406.

Chudoba, J., Bláha, J. and Madëra, V. (1974). Control of activated sludge filamentous bulking - III Effect of sludge loading. Water Research 8, 231-237.

Have, P.J.W., und Müller, F.M. (1972). Treatment of potatochip wastewater by the Activated Sludge process (in Dutch). Rapport 48 van Instituut voor Bewaring en Verwerking van Landbouwprodukten I.B.V.L., Wageningen, The Netherlands.

Jellema, J., und Rensink, J.H. (1974). Development and control of Bulking sludge (in Dutch); Doctoral Studium, Landbouwhogeschool, Afd. Waterzuivering, Wageningen, The Netherlands.

Rensink, J.H. (1966). Report pilot plant studies with dairy waste water during 1965-1966. Dairy Institute for waste water consulting Arnhem, The Netherlands, in Dutch.

Rensink, J.H. (1974). New approach to preventing bulking sludge. Journal of the Water Pollution Control Federation, 46, 1888-1894.

Rensink, J.H., H.J.G.W. Donker and IJwema, T.S.J. (1981). The influence of feed pattern on sludge bulking. In Bulking of Activated Sludge: Preventive and Remedial Methods, 147-163. (Edited by Chambers B. and Tomlinson E.J.). Ellis Horwood-Publishers.

Rensink, J.H., Voetberg, J.W. and IJwema, T.S.J. (1977). Die Verhinderung der Eintwicklung von Blahschlamm bei der Vollbiologischen Reinigung von Abwasser der Pommesfritesindustrie. GWF-Wasser/Abwasser, 118, 75-79.