Monitoring and troubleshooting of non-filamentous settling and dewatering problems in an industrial activated sludge treatment plant

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Abstract A large industrial activated sludge wastewater treatment plant had temporary problems with settling and dewatering of the sludge. Microscopical investigations revealed that the poor settling properties were not due to presence of filamentous bacteria, but poor floc properties. In order to characterise the changes in floc properties that led to settling and dewatering problems and to find reasons for this taking place, a comprehensive monitoring program was conducted during more than one year. The monitoring program included various measurements of floc settleability, floc strength and sludge dewaterability. The monitoring program revealed that a deterioration of the floc strength and the settling properties in the process tanks was closely connected to downstream dewatering problems and poor effluent quality. Particularly severe problems were observed a few weeks after the production at the factory had started after summer closedown. Possible reasons for the changes in floc properties in the process tanks were found by a) analysing change in wastewater composition by evaluating the different production lines in the industrial plant, b) evaluating the operation of the plant, and c) performing short-term laboratory experiments testing factors that could potentially affect floc properties (absence of oxygen, presence of sulphide, detergents, etc). Among several measured parameters, the use of floc strength measurements in particular proved useful to monitor the activated sludge floc properties at this industrial plant. The described strategy can be useful in general to find and solve many solid/liquid separation problems in activated sludge wastewater treatment plants.

Keywords Activated sludge; deflocculation; dewatering; floc strength; industrial wastewater treatment; monitoring program

Introduction

Industrial activated sludge wastewater treatment plants often have problems with the solid/liquid separation due to problems with settling, clarification and effluent quality, and with the dewatering (Eckenfelder and Musterman, 1995). Problems with the settling (bulking) are often due to presence of filamentous microorganisms, but can sometimes also be caused by poor floc formation (Novak *et al.*, 1993; Wanner, 1994). Depending on type of poor flocs, it can be pin-point flocs or viscous sludge. These flocs usually give a poor clarification and thus a poor effluent quality. The dewatering is hampered mainly by many small, weak activated sludge flocs, leading to high polymer consumption, low dry matter content and long dewatering time (Mikkelsen *et al.*, 1996).

The problems with the solid/liquid separation can arise because of "difficult" wastewater, inadequate design of the plant or because of poor operation of the plant. A well-known example of inadequate design is when filamentous microorganisms cause bulking due to lack of a selector. Installation of a proper selector can in most cases solve the problem by preventing growth of the filaments. However, troubleshooting of poor floc properties in particular and a deteriorated dewatering can be very difficult. The factors leading to these problems are not as well described as for filamentous bulking, so detailed surveillance of the treatment plant is often necessary to find and solve the problems.

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Methods most widespread used for monitoring settling properties of the activated sludge include SVI or DSVI and initial zone settling time. Clarification can be estimated by turbidity in the water after settling, while microscopy (e.g. Eikelboom and van Buijsen, 1983) can be very useful to assess presence of filamentous microorganisms and special floc morphologies. Dewatering is usually measured by the use of filtration methods as specific resistance to filtration (SRF) or capillary suction time (CST) (Christensen, 1992). The floc strength, also known as the sensitivity to shear, is a relatively new method. It is used for the characterisation of physical stability of the sludge and measured by the number of fine particles (turbidity) developed after a defined shear treatment (Eriksson *et al.*, 1992; Mikkelsen and Keiding, 1999).

In the work presented here we show how conventional and new methods can be combined in a strategy to monitor and troubleshoot a chemical industrial treatment plant with temporary severe settling and dewatering problems.

Methods

The industrial treatment plant

The activated sludge treatment plant is situated at a large chemical industry in Denmark. The plant is treating wastewater from about 15 different production plants, laboratories and offices, water from surface areas, etc. It is designed for biological removal of organic substances and for removal of phosphorus by precipitation by lime. The plant is operated at 33°C with a MLSS content of 30–40 g SS/l and a sludge age of 8–12 days.

The quantity of the wastewater is 2,500–5,000 m^3/d, and the load of organic substances is 25,000–60,000 kg/d consisting of organic phosphorus compounds, different types of alcohol and other substances used in the production. About 20–30% of the average load consists of methanol and ethanol (measured as COD). The load of phosphorus is high (2,000–5,000 kg/d). The nitrogen load is low, approximately 500 kg/d, so ammonium is added in the process tanks to ensure that nitrogen is not limiting during the removal of organic substances. The conductivity is high (30–60 mS/cm), almost like seawater.

Monitoring program

A monitoring program was established at the wastewater treatment plant with focus on the floc settling and dewatering properties (Table 1).

The floc strength measurements were performed once a week on fresh (collected within 2 hours) activated sludge from process tanks and in some periods from storage tanks for excess sludge. The temperature was kept at 33°C as in the treatment plant. The concentration of suspended solids was kept at 35 g SS/l and was obtained either by dilution with effluent or by thickening, depending on the actual values in the plant. The floc strength measurement is in this case used in a simplified version, where turbidity is measured (Mikkelsen and Nielsen, 2000). Turbidity is in this case proportional with the floc strength because all conditions are kept unchanged during the measurements. 1 litre of sludge was added to a reaction chamber equipped with paddle and stirred at 750 rpm (Mikkelsen and Keiding, 1999) for 2–3 hours. Every 10 minutes, the turbidity of the sludge was measured

Table 1 Parameters in the monitoring program

Locality	Parameters
Process tanks	Floc strength, SVI, microscopy, conductivity, pH
Effluent from settling tanks	Total phosphorus, ortho-phosphate, suspended solids
Effluent to recipient	Total phosphorus, ortho-phosphate, suspended solids
Dewatering part	Floc strength, SVI, microscopy, pH, SRF, content of solids in the filter cake, type of polymer used

after centrifugation (5 ml sample for 2 minutes at 500 G) as the absorbency of the supernatant at 650 nm on a spectrophotometer. The turbidity increased during the first 1–2 hours and was then stabilised at a state of equilibrium. A low level of turbidity at this state indicates high floc strength with a low concentration of fine particles in the sample. The results presented here are all turbidities measured at the state of equilibrium after 2–3 hours of stirring.

Sludge volume index (SVI), specific resistance to filtration (SRF), and content of dried solids in the filter cakes were measured according to *Standard Methods* (1995). The type and quantity of polymer used for filtration of excess sludge were read daily. Fractions of phosphorus (total phosphorus, orthophosphate), suspended solids, pH and conductivity were measured daily in the effluent from settling tanks and in the effluent to the recipient. The analyses were performed according to *Standard Methods* (1995). The floc morphology (size, structure, free cells, etc.), presence and identification of filamentous bacteria and higher animals were determined by the use of light microscopy (Eikelboom and van Buijsen, 1983).

Short-term experiments

The measurements of floc strength were then used in laboratory experiments to examine parameters that could affect the floc strength in short-term experiments. The conditions and agents examined are listed below (Table 2).

To ensure that anaerobic conditions were present in some experiments, the sludge was stirred for 45 minutes at 200 rpm in a closed chamber with a flow of nitrogen gas. A nitrate stick was used to ensure that all nitrate was removed from the sludge. Methanol and ethanol were added in concentrations of 100 and 200 mg/l, respectively. Tests of the influence of sulphide were performed as described by Nielsen and Keiding (1998). The chemical agents and wastewater were added to 1 litre of sludge and stirred at 200 rpm for 10 minutes to keep the solids suspended and to ensure total mixing. If addition of the agents had an effect on pH, it was regulated by addition of NaOH or HCl. The experiments started when the stirring after 10 minutes was increased to 750 rpm. pH was measured during all experiments to ensure it was constant.

Results and discussion

For several years the industrial treatment plant has had temporary severe problems with settling of the activated sludge in the process tanks, effluent quality, and with the dewatering. The reasons for these problems were not known, and it was not clear whether there was a direct relation between the different problems. After an evaluation of design, loading, and general operation of the treatment plant, a monitoring program and a troubleshooting procedure were established in order to find and solve the problems. 1) A monitoring programme was established to describe "normal" conditions, clarify when the problems

Table 2 Conditions and agents examined in the short-term experiments

Condition	Addition/concentration
Anaerobic conditions	Methanol/ethanol: 0–100/200 mg/l
Anaerobic conditions	Sulphide: 0.2.7 mM
Aerobic conditions	Detergent no. 1: 0–20 ml/l
Aerobic conditions	Detergent no. 2: 0–20 ml/l
Aerobic conditions	Emulsifying agent no. 1: 0–5 ml/l
Aerobic conditions	Emulsifying agent no. 2: 0–5 ml/l
Aerobic conditions	Alkaline wastewater with high COD conc.: 0.1–1.2 g COD/l
Aerobic conditions	Acid wastewater no. 1 with high COD conc.: 0.1–1.2 g COD/l
Aerobic conditions	Acid wastewater no. 2 with high COD conc.: 0.1–1.2 g COD/l

appeared, and to find suitable parameters that were able to detect the problems. 2) Possible correlation between the different problems in the different parts of the treatment plant was established. 3) The daily operation of the plant was evaluated. 4) Analyses of possible change in wastewater composition by investigation of type and amount of waste from the different production lines in the industrial plant were conducted. 5) Short-term laboratory experiments testing factors that could potentially affect floc properties (absence of oxygen, presence of sulphide, cleaning chemical, etc.) were performed. 6) Suggestions for actions that could solve the problem and for future surveillance procedures were prepared.

Monitoring program

The settling properties of the activated sludge were usually very good with a SVI in the process tanks in the range of 4–8 ml/g (Figure 1). The very low value was due to a high content of inorganic substances (75–85%). In the period investigated with poor settling properties, SVI increased in less than 1 week to 15–36 ml/g, causing trouble with retention of sludge in the plant. Use of microscopy revealed that there were not many filamentous bacteria present in the sludge (filament index of 1 in a scale of 0–4), so filamentous bacteria were not responsible for the increased SVI. Instead, microscopy showed a change from normal strong spherical flocs (average diameter ca. 40 µm) to more diffuse small flocs and many free bacteria.

The floc strength measurements (Figure 2) for this particular type of sludge showed that it usually formed strong flocs with the maximum turbidity typically being in the range of 0.04–0.08 abs. The values show that the sludge was stable, and deflocculation was not very easily initiated. In the period before SVI changed, a decrease in turbidity was found indicating temporary formation of stronger flocs. However, the floc strength clearly became much weaker when the SVI began to increase and the turbidity rose to around 0.10 abs.

The effluent concentration of total phosphate (Figure 3) was normally in the range of 7–10 mg/l with very few fluctuations. The concentration in the effluent increased to a range of 20–60 mg/l, when the decreased floc strength and the high SVI were observed in the process tanks.

The dewatering of the sludge usually takes place without any problems, producing a very high dry matter content (55–65%), but in the situation described, the dry matter content was reduced to less than 30% in a week (Figure 4). The filtration cloths became greasy and had to be cleaned more often than normally and the charges of the filterpress became smaller. Furthermore, the dewatered sludge could not pass the drying unit because the sludge was too greasy. Because of these handling problems the excess sludge could not be spread on fields and had to be stored, causing huge problems. At the same time, measurements of SRF also revealed that the dewaterability was reduced, and the type of polymer was changed from the cationic Zetag 87 to the anionic Magnafloc.

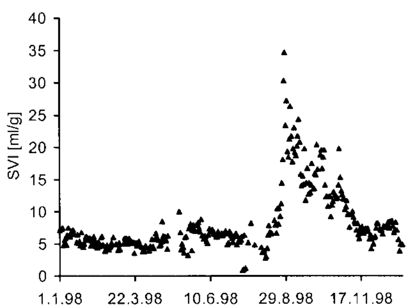

Figure 1 Sludge volume index during the monitoring period

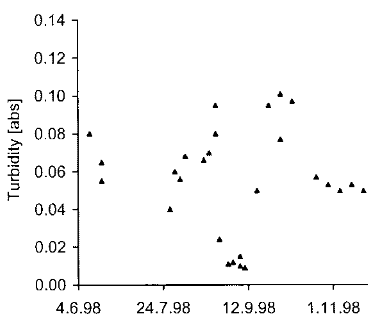

Figure 2 Floc strength measurements during the monitoring period

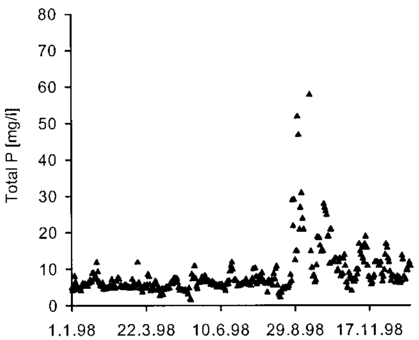

Figure 3 Concentration of total phosphorus in the effluent during the monitoring period

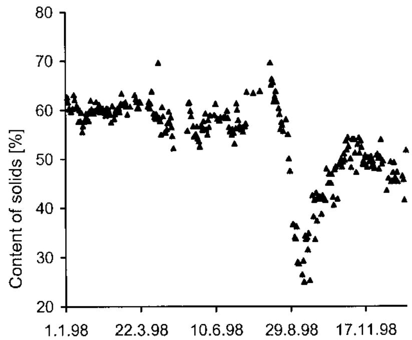

Figure 4 Content of solids in the filter cakes from the filter press during the monitoring period

Correlation between different problems

By comparing the time course of the different parameters measured, it was found that within a few days (starting around 29th of August 1998) all measured parameters were affected (see Figure 1–4): SVI, floc strength, effluent phosphorus, SRF and cake dry matter in the dewatered sludge. This observation suggested that the cause(s) for the development of the problems should be found in the aerobic process tanks and not in the separation or dewatering unit (settling, storage, mixing, polymers, etc.). Furthermore, the deterioration in floc strength leading to small, weak flocs correlated well with the poor dewatering or reduction in effluent quality, as is already well described (Mikkelsen *et al.*, 1996). Thus, a close correlation between the different problems in the plant was present. An important observation was that, by analysing only one of the monitoring parameters, it took at least one week to be sure something was going wrong, but by analysing all parameters and comparing the development, it was possible to register the changes faster. All parameters measured were found to be important for detection of the problem (microscopy, SVI, floc strength, effluent phosphate and dewatering capability).

Evaluation of the daily operation of the plant

The problem period investigated was found to take place during a period 2–3 weeks after a summer close-down, where the treatment plant was exposed to a reduced load of wastewater (around 20–40% of normal load). Many factors related to operation of the plant and wastewater composition varied during re-start after summer close-down and could therefore potentially cause the problems with the flocs. Focus in the investigations was on two factors: changes in plant operation (internal conditions) and changes in wastewater composition (external conditions). The internal conditions related to oxygen concentration, ammonium supply, change in pH, etc. were investigated in detail to describe the condition under which the poor floc properties were developed. During the close-down, some changes were found due to limited amount of wastewater coming into the plant: slight increase of pH (from ~7.5 to ~8.5), lowering of salinity (from 60 to ~15 mS/cm) and increase of sludge retention time (from 8–12 days to around 30 days). During the following 3–4 weeks, all plant operational parameters were normalised again.

Change in wastewater composition

The different production lines of the factory were analysed to examine if possible changes of the wastewater composition could occur during close-down and re-start. The focus was on lines with high concentrations of COD and high salinity. Furthermore, lines where surface-active agents were used for production purposes were included. The risk of having sudden loads of detergents due to spillage or cleaning of some production plants was evaluated. It was found that there could be a risk of spillage of surface-active agents from several production lines, and the agents were therefore tested in the short-term experiments to examine if they had a negative impact on the floc strength (see below). Furthermore, it was found that the load of COD from especially one production plant was varying considerably (from 0% to 30% of the total load of COD) and thereby might cause a situation of anaerobic conditions in the plant, which could induce reduced floc strength (see below).

Short-term floc strength experiments

In order to evaluate whether specific operational conditions, specific compounds in the wastewater or specific wastewater lines could be problematic for the floc properties, several short-term experiments were run to describe the effect of these factors on the floc strength. Among the parameters tested in relation to plant operation, anaerobic conditions were particularly critical and could cause strong deflocculation (Figure 5, Table 3). This is in agreement with other investigations showing that aerobic conditions are critical for maintaining strong flocs (Wilén *et al.*, 2000). Sulphide could also cause deflocculation as we have seen for other sludge types (Nielsen and Keiding, 1998). However, deflocculation was only problematic at high sulphide concentrations like 2.7 mM, which were never found in the wastewater.

From these and other experiments it was concluded that anaerobic conditions could be critical during the re-start phase after summer close-down. The load of COD was high (60,000 kg/d) during some periods and could cause oxygen depletion.

Among the chemical agents and different types of wastewater that could potentially be present in the wastewater during the period investigated, surface-active agents (detergents and emulsifying agents) and some distinct lines of wastewater (Table 3) were tested. One detergent and one emulsifying agent could deteriorate the flocs. The results were used as the basis of a further survey concerning the quantity and risk of spillage from the use of detergents and emulsifying agents in the production lines. The conclusion was that spillage of a quantity that could seriously destroy the flocs could take place, but that it would most likely be discovered in the equalisation tanks before it was led to the process tanks, so precautions could be taken.

These short-term floc strength experiments provided very useful information about critical parameters for this particular activated sludge. It was useful for troubleshooting and for the decisions about future actions to be taken to prevent/control similar problems.

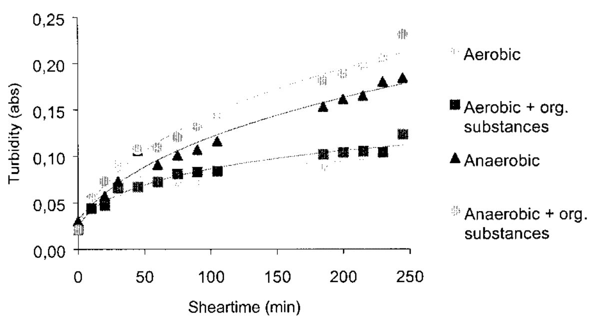

Figure 5 Effect of anaerobic conditions on floc strength. Aerobic/Anaerobic: Respectively, aerobic and anaerobic conditions during experiments. Org. substances: Addition of external methanol and ethanol to the sludge in the start of the experiments

Table 3 Results from short-term floc strength experiments

Effect	Addition	Deflocculation
Anaerobic conditions	Anaerobic	Yes
	Anaerobic & Org. Substances	Yes
Sulphide	0.5–2.0 mM Sulphide	No
	2.7 mM Sulphide	Yes
Detergents	1–20 ml/l Detergent no. 1	Yes
	1–20 ml/l Detergent no. 2	No
Emulsifying agents	1–20 ml/l EA no. 1	Some
	1–20 ml/l EA no. 2	Yes
Wastewater types	0.1–1.2 mg COD/l alkaline WW	Some
	0.1–1.2 mg COD/l acid WW type 1	No
	0.1–1.2 mg COD/l acid WW type 2	Some

Future actions and surveillance

The monitoring program was shown to be very effective and should be maintained in future. It is possible to find out if dewatering problems originate from reduced floc strength in the process tanks due to one of the critical parameters mentioned, or if they originate from storage and handling problems of excess sludge. The measurement of floc strength in particular was shown to be a useful tool, both in the monitoring program and in the short-term experiments.

Future short-term experiments could be used as a test before wastewater from a new production line or a changed composition of wastewater from existing lines were discharged to the treatment plant to examine the impact on floc strength and dewaterability. Other methods as for instance oxygen uptake rate (OUR) could be used in the short-term to evaluate the organic composition of new types or changes in composition of wastewater. Thus, the risk of anaerobic conditions caused by high oxygen consumption due to a high content of easily degradable organic substances could be evaluated.

Conclusion

A combination of conventional methods such as sludge volume index (SVI), specific resistance to filtration (SRF) and newer methods such as floc strength measurements was used effectively in a strategy for monitoring and troubleshooting an industrial activated sludge treatment plant with settling, dewatering and effluent quality problems. By using this combination it was possible to show a correlation between deterioration of the floc strength, increased sludge volume index, reduced effluent quality and poor dewatering of sludge. The origin of the problems were shown on this basis to be floc formation in the aerobic process tanks.

The floc strength measurements proved to be a successful method to investigate the sensitivity of activated sludge towards critical parameters such as anaerobic conditions, presence of detergents, etc. in short-term experiments. For this particular type of sludge anaerobic conditions, presence of detergents and emulsifying agents and high concentrations of sulphide constituted a potential risk to deteriorate the floc strength.

The analysis of the production lines revealed a set of possible critical parameters to the activated sludge. These were compared with the potential risks found in the short-term experiments to evaluate whether they constituted a problem during production and close-down. This strategy for finding possible critical parameters can be transferred to any industrial treatment plant.

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