Effect of chlorination bulking control on water quality and phosphate release/uptake in an anaerobic-oxic activated sludge system

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Abstract This study evaluates the effect of chlorination bulking control on water quality and phosphate release/uptake in an anaerobic-oxic activated sludge system. A series of batch experiments with different specific NaOCl mass dose were conducted to determine the sludge settling properties, supernatant water quality and phosphate metabolism behavior of filamentous bulking sludge. The harvested sludge was from a continuous-flow anaerobic-oxic (A/O) activated sludge pilot-plant, i.e., enhanced biological phosphorus removal (EBPR) system, operated with 15 days of sludge retention time. The filamentous bacteria in the A/O pilot plant were identified to be *Thiothrix* according to Eikelboom's classification techniques, which was in accordance with the high influent sulfate concentration of this study (50 mg/L sulfate). Increasing NaOCl concentration, as revealed by experimental results, obviously decreased the sludge settling properties (SVI values and zone settling velocities) and meanwhile significantly reduced supernatant water quality (COD, SS, TP) mainly due to higher suspended solids caused by floc disruption. Moreover, the nine-hour batch experiments indicated that high NaOCl dosage (40 mg/gMLSS) completely deteriorated phosphate metabolism of EBPR sludge. Such a high dosage of chlorination further confirmed overdosing through disappearance of intracellular PHB and death of protozoa by microscopic investigation. Still, phosphate release/uptake behavior of EBPR sludge properly functions at low NaOCl dosage (5 mg/g MLSS). Besides, phosphate metabolism worsens rapidly before the SVI value reaches its lowest level. These findings imply that determining NaOCl requirement with merely SVI values can readily result in chlorination overdosing. Proper NaOCl dosage requires a delicately balanced consideration between sludge settling improvement, water quality demand and phosphate metabolism. Batch test of phosphate release/uptake is apparently a prerequisite to conclude an appropriate NaOCl dosage for bulking control.

Keywords Anaerobic-oxic activated sludge process; bulking control; chlorination; phosphate release; phosphate uptake

Introduction

Anaerobic/oxic (A/O) activated sludge system has found extensive application in sludge bulking control, for which the anaerobic zone is called the anaerobic selector (Wanner *et al*., 1987), and phosphorus removal is called an enhanced biological phosphorus removal (EBPR) process (Bowker and Stensel, 1990). Nevertheless, the excess growth of filamentous microorganisms in the biological nutrient removal process has been reported (Wanner and Grau, 1988; Ramadori, 1987). High sulfate influent concentration was experimentally proved to be one of the main reasons accounting for filamentous bulking due to the anaerobic sulfate reduction and the following oxic sulfur oxidation in an EBPR process (Yamamoto *et al*., 1991, 1994, 1996; Wanner, 1994).

Sulfate reducing bacteria convert influent sulfate in the anaerobic zone of EBPR process into sulfide; filamentous sulfur bacteria thereby oxidize sulfide in the oxic zone so as to obtain energy for growth. While this sulfur cycle is taking place, filamentous sulfur bacteria lead to serious bulking phenomena. Especially when the utilization of fermentation products in the anaerobic zone of EBPR process is incomplete, the mixotroph *Thiothrix* will be expected to abundantly develop (Wanner, 1994; Sevior and Blackall, 1999). That is, providing an anaerobic zone in front of a traditional aeration tank for bulking control can just establish symbiosis between sulfate reducing bacteria and filamentous sulfur bacteria and therefore cause a bulking problem in an anaerobic-oxic system. Non-specific methods such as chlorination are generally adopted to control this kind of filamentous bulking problem.

Chlorination is indicated to be the most effective of the three oxidants (chlorine, ozone, hydrogen peroxide) for bulking control in a full-scale biological nutrient removal process. A lower dosage of chlorine less affected nutrient removal functions; however, higher dosage significantly worsened effluent quality (Saayman *et al*., 1996; Jenkins *et al*., 1993). Still, little research is found to evaluate the simultaneous response and correlation of sludge settling properties, supernatant water quality and phosphorus metabolism of EBPR sludge over a broader range of chlorination dosage.

The objective of this research was to investigate the effect of chlorination on sludge settling properties and supernatant water quality of bulking sludge from the EBPR process. Emphasis is placed on conducting a phosphate release/uptake batch test that would give an appropriate appraisal of optimum chlorination dosage.

Materials and methods

Continuous-flow anaerobic-oxic activated sludge pilot plant

The continuous-flow BNR pilot plant shown schematically in Figure 1 was installed in a 20°C constant-temperature laboratory. Synthetic wastewater at a constant flowrate of 100 ml/min was continuously fed with a pump to a reactor in which the anaerobic:oxic volume ratio is 1:2.3. Settling sludge in the clarifier was continuously pumped back to the anaerobic zone of the reactor using a peristaltic pump at a rate of 50% of influent flow. Excess sludge was wasted by discharging mixed liquor from the oxic zone of the reactor to correspond to 15 days of sludge retention time. The characteristics of the wastewater are listed in Table 1. Operating parameters of the laboratory scale activated sludge pilot-plant are summarized in Table 2.

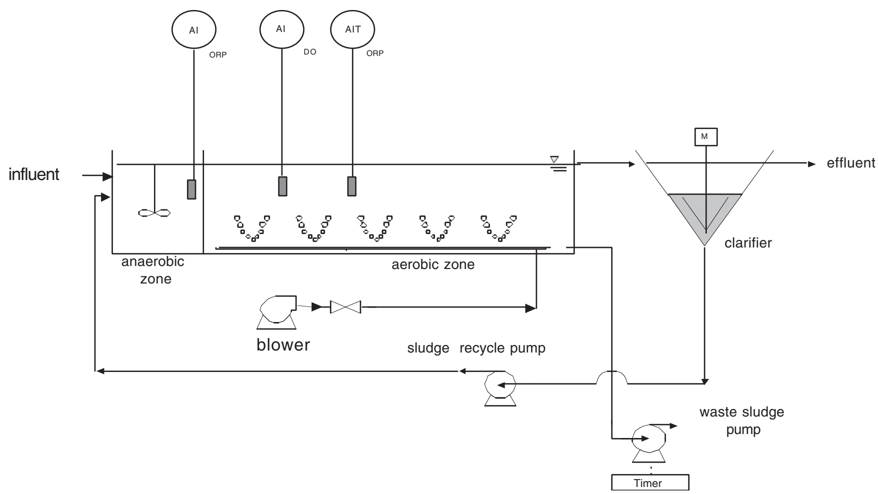


Figure 1 Schematic diagram of A/O pilot plant

Table 1 The characteristics of synthetic wastewater

Characteristics	Concentration(mg)
Total COD (TCOD)	300
Soluble COD (SCOD)	215
Total BOD (TBOD)	210
Soluble BOD (SBOD)	160
Total Nitrogen (TN)	15
Total Phosphorus (TP)	5
Sulfate	50
Suspended Solid (SS)	50

Table 2 Operating parameters and average values for the bench-scale activated sludge systems

Parameter	Value
Influent flowrate (ml/min)	100
Ratio of return sludge (r)	0.5
SRT (day)	15
F/M (g COD/g MLSS*day)	0.228
HRT of anaerobic basin	2.4
HRT of oxic basin	5.6
Total HRT	8
Oxic basin pH	6.8~7.2
MLSS (mg/L)	1,900
MLVSS/MLSS	0.86

Batch test

Chlorination batch test. The chlorination batch tests were conducted by using a 500 mL mixed liquor taken from the oxic zone of the continuous-flow anaerobic-oxic activated sludge pilot plant. The obtained mixed liquor was then put into 500 mL beakers and mixed with NaOCl by magnetic stirrer so as to have a 20-minute chlorination contact time. A series of batch tests with different NaOCl dosages (0, 5, 25, 40, 50, 65, 75, 100 mg NaOCl/gMLSS) were repeated. Sludge settling properties (in terms of sludge volume index, SVI, and zone settling velocity, ZSV) and supernatant water quality (SS, TCOD, soluble COD, TP, soluble P) after 30 min settling were analyzed.

Phosphate release/uptake test. Anerobic/oxic batch experiments were conducted to assess the inhibitory effect on phosphate release/uptake of EBPR sludge after chlorination. After performing the same chlorination batch test, the chlorinated mixed liquor was then centrifuged to separate the unreated NaOCl and residual COD and phosphate from the biomass. Acetate solution is then added to the biomass to serve as a volatile fatty acid for providing an initial COD concentration of 200 mg/L. The entire nine-hour testing period includes two stages, i.e., five hours for anaerobic stage and four hours for oxic stage. Figure 2 schematically illustrates the experimental procedure of phosphate release/uptake batch tests. Standard Method (APHA, 1995) techniques were used for all water quality analyses.

Results and discussion

Operational results of the continuous-flow A/O pilot plant indicated high COD removal (96%). However, the effluent phosphate, as was suggested in previous research (Yamamoto *et al*., 1991), seemed to be hindered by sulfate to maintain at 2.2 mgP/L.

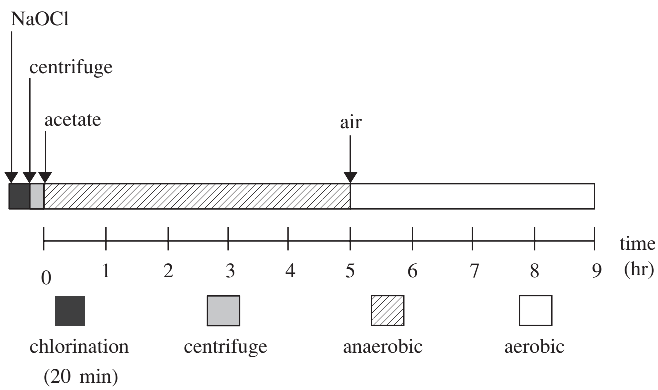


Figure 2 The experimental procedure of chlorination batch tests

Besides, filamentous bulking seriously interfered with sludge settling. The filamentous bacteria in the A/O pilot plant were identified to be *Thiothrix* according to Eikelboom's classification techniques (Eikelboom, 2000), which was in accordance with the high influent sulfate concentration of this study (50 mg/L sulfate). The SVI value of the bulking sludge before chlorination treatment was as high as 490 mL/g.

Effect of chlorination dosage on sludge settling properties

Figure 3 depicted the responses of EBPR sludge settling properties to different chlorination dosages. As indicated in this figure, increasing chlorination dosages from 5 to 40 steadily improves the SVI values. Further increases in chlorination dosages gradually reduce the sludge settling properties (SVI values) owing to deterioration of larger flocs into smaller ones. Such a case strongly implied overdosing of NaOCl. Besides, similar trends in experimental results were obtained when zone settling velocity (ZSV) was utilized as an alternative sludge settling indicator for evaluating the response of the bulking sludge to chlorination, as was also shown in Figure 3. Still, diminishing marginal benefit effect in terms of ΔSVI/mg NaOCl was observed, i.e., lower chlorination dosages were more beneficial.

Effect of chlorination dosage on supernatant water quality

Soluble matter. Figure 4 illustrates the soluble phosphate and COD concentrations of 20-minute-reaction batch experiments under different NaOCl concentrations. Chlorination methods, aiming at selectively killing the filaments protruding from the flocs, can also destroy the floc-forming microorganisms and thus raised the soluble COD and phosphate concentrations. As depicted in Figure 4, the soluble COD concentration was strongly correlated with NaOCl dose, whereas soluble phosphate concentration in the bulk liquid remains relatively constant over this NaOCl dosing range.

Suspended matter. Experimental results of chlorination dosage on supernatant suspended water quality is indicated in Figure 5. Apparently, the suspended solids were closely related

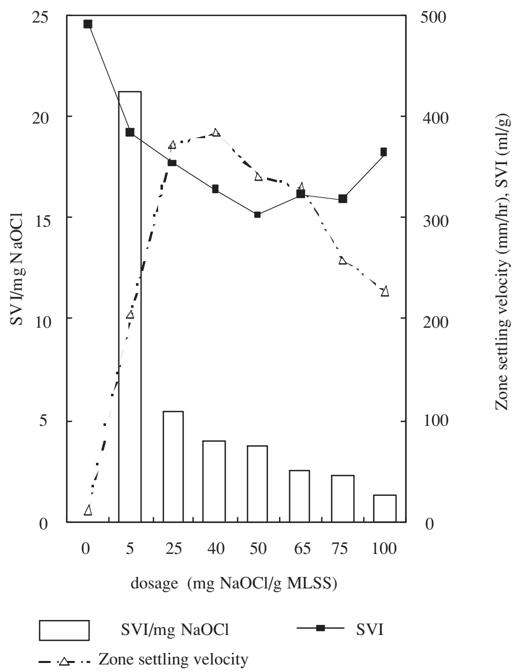


Figure 3 Effect of chlorination dosage on sludge settling properties

to the NaOCl dosages, because chlorination broke biological flocs into smaller ones and therefore results in a turbid supernatant. Moreover, the phosphorus and COD contained in suspended solids were observed from a comparison with Figure 4 to be noticeably larger than those contributed from soluble matter, so that the optimum dosage usually should concern more on suspended matter in the supernatant. These findings strongly suggested that improving sludge settling by chlorination should be carefully examined not to upset the

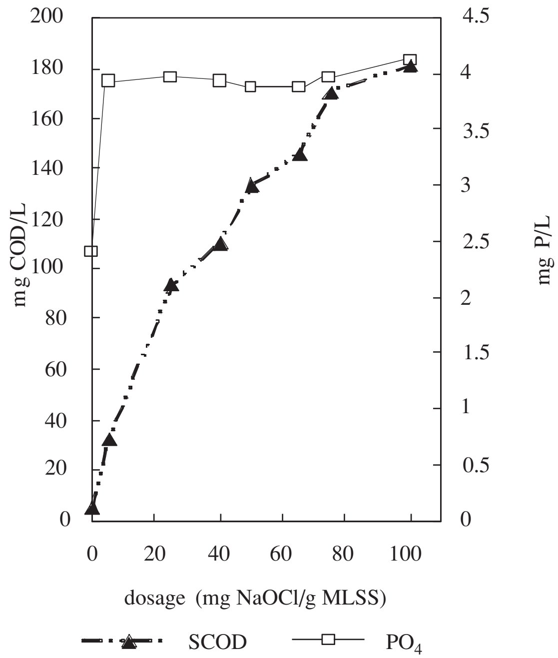


Figure 4 Effect of chlorination dosage on soluble water quality

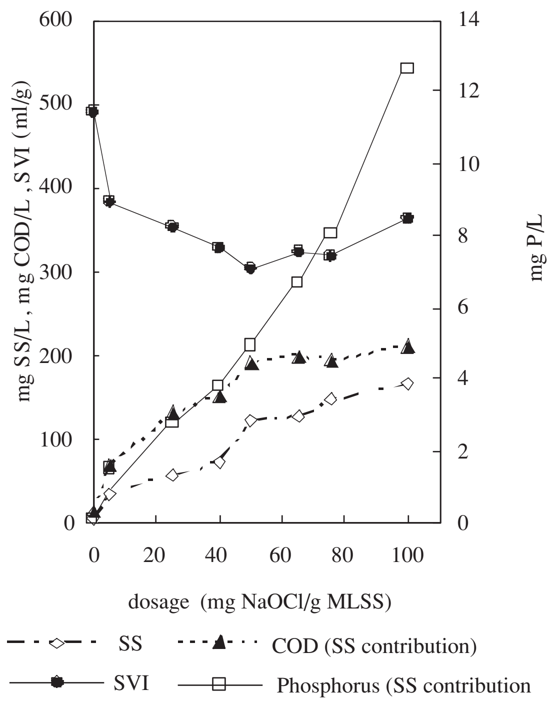


Figure 5 Effect of chlorination dosage on supernatant suspended matter

supernatant water quality, which were in agreement with those suggested by Saayman *et al.* (1996).

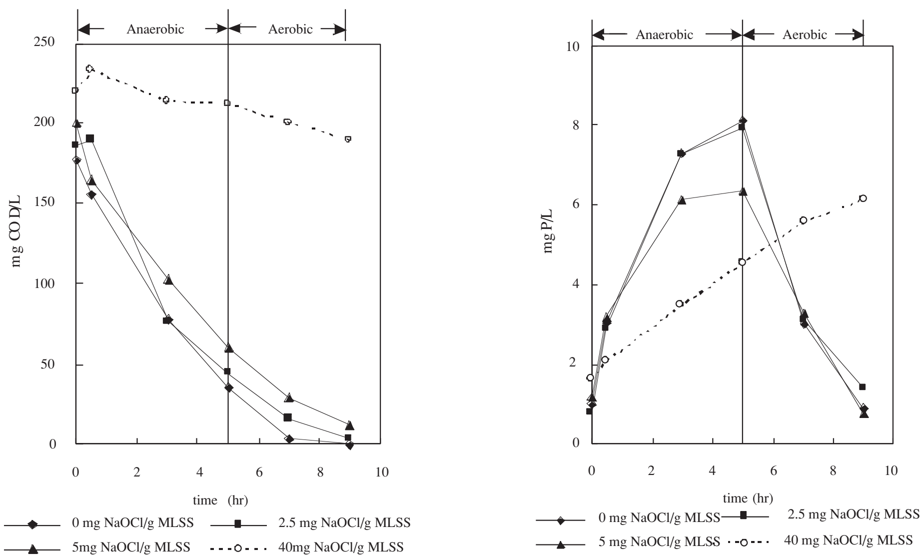
Effect of chlorination dosage on phosphorus metabolism of EBPR sludge

Damaging filamentous microorganisms by chlorination can only be successful when the phosphorus metabolism of phosphate-accumulating microorganisms (PAO) is not seriously reduced. Effects on this phosphorus metabolic function by chlorination were therefore investigated by the phosphate release/uptake batch test. Figure 6 displays the experimental results of chlorination dosage effect on phosphorus metabolism of EBPR sludge. This figure indicates that increasing the specific mass dose from 2.5 mg NaOCl /g MLSS to 5 mg NaOCl /g MLSS apparently reduces the rates of COD uptake and phosphate release/uptake behavior of EBPR sludge; still, the phosphorus metabolism functions properly at 5 mg NaOCl/g MLSS of dosage. However, the same nine-hour batch experiment indicated that high NaOCl dosage (40 mg/g MLSS) significantly obstructed phosphate metabolism of EBPR sludge, although this high NaOCl dose was demonstrated in Figure 3 to achieve better sludge settling properties. Meanwhile, overdosing was further confirmed through the disappearance of intracellular PHB and death of protozoa by microscopic investigation.

As stated above (Figure 3), increasing chlorination dosages from 5 mg NaOCl /g MLSS to 40 mg NaOCl/g MLSS steadily improve the SVI values. Nevertheless, phosphate metabolism worsens rapidly before the SVI value reaches its lowest level, as is indicated from a comparison of Figure 6 and Figure 3. That is, determining the NaOCl requirement using merely SVI values can readily result in an overdosing condition. These results imply that proper NaOCl dosage requires a delicately balanced consideration between sludge settling improvement, water quality demand and phosphate metabolism. The batch test of phosphate release/uptake is apparently a prerequisite to determine an appropriate NaOCl dosage for bulking control.

Conclusion

Increasing NaOCl concentration noticeably decreases the sludge settling properties in



(a) COD variation (b) phosphate variation

Figure 6 Effect of chlorination dosage on phosphate metabolism of EBPR sludge terms of SVI values and zone settling velocities. However, elevated NaOCl dosage can also significantly reduce supernatant water quality (COD, SS, TP) mainly due to higher suspended solids caused by floc disruption. For such a high NaOCl dosage as 40 mg/g MLSS phosphate metabolism of EBPR sludge was completely deteriorated, while the phosphate release/uptake behavior of EBPR sludge still properly functions at low NaOCl dosage (5 mg/g MLSS). Moreover, phosphate metabolism worsens rapidly before the SVI value reaches its lowest level. That is, determining the NaOCl requirement using merely SVI values can readily result in an overdosing condition. These results imply that proper NaOCl dosage requires a delicately balanced consideration between sludge settling improvement, water quality demand and phosphate metabolism. The batch test of phosphate release/uptake is apparently a prerequisite to determine an appropriate NaOCl dosage for bulking control.

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