Available online at www.sciencedirect.com
ScienceDirect
Journal of Hazardous Materials 143 (2007) 184–191
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

Cause and pre-alarm control of bulking and foaming by *Microthrix parvicella*—A case study in triple oxidation ditch at a wastewater treatment plant

B. Xie *, X.-C. Dai, Y.-T. Xu

Key Laboratory of Urbanization and Ecological Restoration of Shanghai, Department of Environmental Science & Technology, East China Normal University, Shanghai 200062, People's Republic of China

Received 18 December 2005; received in revised form 2 August 2006; accepted 5 September 2006
Available online 9 September 2006

Abstract

The cause and control of foaming and bulking in triple oxidation ditch at a wastewater treatment plant (WWTP) were investigated. The results showed that the foaming and bulking was mainly caused by the excessive propagation of *Microthrix parvicella*, and mostly occurred in the cold winter and spring. Batch and continuous flow experiments indicated that biological techniques such as reducing sludge retention time (SRT) and increasing F/M ratio, chemical methods such as addition of chlorine (NaOCl), quaternary ammonium salt (QAS), or cationic polyacrylamide flocculants (PAM), polyaluminum salt (PAC) could decrease Sludge Volume Index (SVI) and control foaming and bulking at different levels. In practical application, the shorter SRT was effective to control foaming and bulking in initial stage, although it took longer time. Addition of 10 g Cl kg MLSS d^{-1} could gradually change the activated sludge with serious foaming and bulking to normal state within a week. Pre-alert control strategies should be established for the control of filamentous foaming and bulking.

Keywords: *Microthrix parvicella*; Triple oxidation ditch; Foaming and bulking; Filamentous bacteria; Pre-alarm control

1. Introduction

Foaming and bulking are world wide phenomenon in activated sludge treatment plants. One of the most common reasons is the excessive growth of filamentous organisms, which are related to the wastewater properties, such as fats or oils content, and operational aspects such as sludge retention time (sludge ages), low F/M ratio as well as dissolved oxygen. The foaming and bulking occurred seasonally and periodically, which bring serious operating problems and take a relatively long time to restore [1–4].

Microthrix parvicella was one of the most frequently observed filamentous bacteria in foaming at activated sludge treatment plant all over the European countries, Australia and South Africa [5–10]. It is a gram-positive, long-coiled filament with hydrophobic cell walls. The growth of *M. parvicella* was favored by low temperature, lipids and long chain fatty acids (LCFA). The growth of *M. parvicella* could be reduced by specific strategies that address the causes of filament proliferation, or by non-specific control methods, which treat the bulking and foaming symptoms. Specific methods such as reducing sludge retention time (SRT) are preferable but eliminating nitrifying bacteria from activated sludge at same time, while non-specific methods (such as chlorine or hydrogen peroxide) are only temporary solutions, potentially detrimental for all the biomass. Recently it has been reported that the addition of polyaluminium chloride (e.g. PAX-14) is an effective method of controlling *M. parvicella* in WWTPs [11,12], however, the doses of this high-cost chemical and the additional sludge production are unacceptable. No reliable control method specific for *M. parvicella* exists for activated sludge plants, although manipulation of some operating parameters can reduce its abundance [13].

Oxidation ditch plants are especially susceptible to foaming [14–16]. In this research, a 2-year observation of foaming and

Abbreviations: COD, chemical oxygen demand; BOD_5, 5-days biochemical oxygen demand; HRT, hydraulic retention time; SRT, sludge retention time; MLSS, mixed liquor suspended solids; SS, suspended solids; VSS, volatile suspended solids; F/M, ratio of food to microbe; SV_{30}, sludge volume after 30 min settling; SVI, Sludge Volume Index

* Corresponding author. Tel.: +86 21 62233670; fax: +86 21 62233670.
E-mail address: bxie@des.ecnu.edu.cn (B. Xie).

0304-3894/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.jhazmat.2006.09.006

bulking by excessive *M. parvicella* growth in triple oxidation ditch WWTP at northern Tangshan in China was conducted. Since *M. parvicella* foaming and bulking are hard to control, development of pre-alert control strategies is highly recommended. The main objectives of this study are to investigate the biological and chemical control methods for the foaming and bulking caused by excessive *M. parvicella* growth. Based on the laboratory results of batch and simulated experiments as well as the plant practice, pre-alert control strategies to prevent and deal with the excessive foaming and bulking in activated sludge treatment plants will be suggested.

2. Materials and methods

2.1. Batch experiments

Batch experiments were performed in lab. Four different chemicals which most of them are often used in wastewater treatment were tested in batch experiments for controlling the filamentous bacteria. The mixed liquor (MLSS 3500 mg L^{-1}, SVI 200 mL g^{-1}) of activated sludge sampled from the foaming basin in tank C, Tangshan Northern WWPT, were poured into the 1000 mL beakers and stirred at 120 rpm. The chemicals, sodium hypochlorite solution (NaOCl) with 4700 mg Cl L^{-1}, polyquaternary ammonium (QAS) with 45%, polyacrylamide flocculatant (PAM, mw 9×10^6 g mol^{-1}) and polyaluminate (PAC) were introduced to the beakers. The dosage of NaOCl varied from 28 to 560 g Cl kg^{-1} MLSS, polyquaternary ammonium from 16 to 167 g kg MLSS, PAM from 0.5 to 8 mg L^{-1}, and PAC from 50 to 400 mg L^{-1}. The sludge volume after 30 min sedimentation (SV_{30}) in a graduated cylinder and microscopic examinations were conducted after the dosing of each chemical.

2.2. Continuous experiments

Based on the batch test, a pilot simulated reactor of triple oxidation tank (volume is 80 L) was performed in lab to investigate the influence of operation parameters and chemical additions on

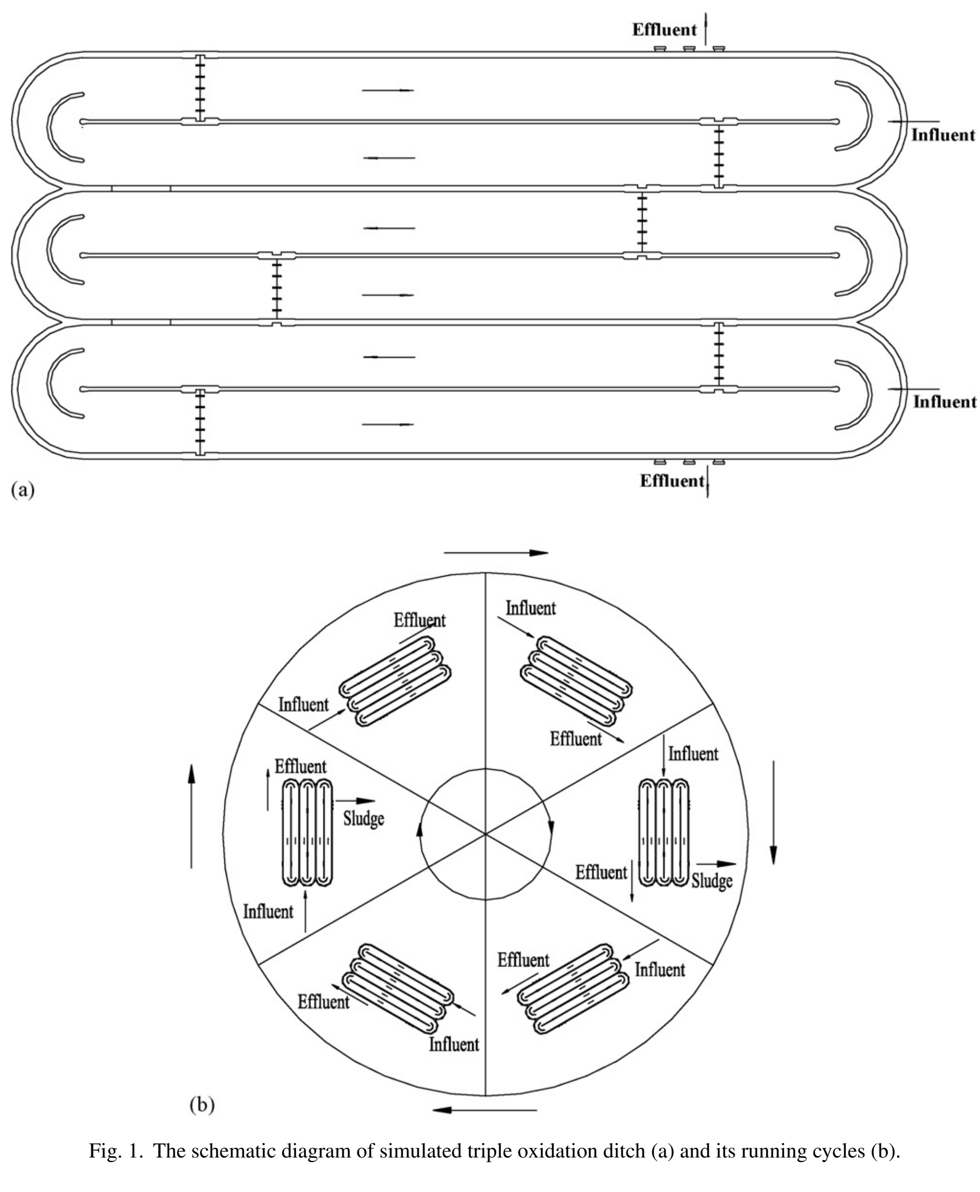

Fig. 1. The schematic diagram of simulated triple oxidation ditch (a) and its running cycles (b).

the control of filamentous bacteria. The scheme and operation cycles of the experiment are shown in Fig. 1. The foaming and bulking activated sludge in the initial stage sampled from the tank C was filled in the simulation reactor, with Sludge Volume Index (SVI) varied in the range of 200–240 mL g^{-1}. Primary effluent of WWTP was used as the influent. The effluent flow is 150 L d^{-1}, hydraulic retention time (HRT) is 16 h, and operational conditions were the same as the actual plant (SRT = 15 d, F/M ratio is 0.15 kgBOD$_5$ (kg MLSS d)$^{-1}$). In order to investigate the effects of SRT, F/M loading and chemical addition, three series of experiments were carried out as following: (i) the sludge age in reactor was reduced to 7 d and maintained 3 weeks by discarding the sludge outside the device; (ii) the F/M ratio increased from 0.15 kgBOD$_5$ (kg MLSS d)$^{-1}$ to 0.3 kgBOD$_5$ (kg MLSS d)$^{-1}$; (iii) the operational conditions of the simulated reactor were same as that in tank C, while the quaternary ammonium salt (QAS) and chlorine were dosed into the influent at 12.5 and 10 g (kg MLSS d)$^{-1}$, respectively, and lasted 5 d.

COD, NH_4-N, MLSS and SVI were measured daily according to the Standard Methods for the Examination of Water and Wastewater [17]. The identification to filamentous organisms in activated sludge or foam were conducted according to the methods described by Jenkins et al. [18]. The filament counting was performed as followings: 50 μL mixed liquor sample was transferred to a glass microscope slide, add a cover slip and examine at 100× magnification. Using an eyepiece ruled with a hairline, count the number of times that any filamentous organism intersects with the hairline for each field. Sum the number of intersection for the entire length of the cover slip and calculate the intersection per VSS.

2.3. Field application

2.3.1. Control of reducing SRT

In field practice, the strategy of reducing sludge retention time was performed in the tank A (tank A was serious than tank C by then) at Tangshan Northern WWTP from 2 December 2004, when the bulking and foaming just happened and SVI, MLSS were 200 mL g^{-1}, 3500 mL g^{-1}, respectively. By sludge discharged, the sludge age in tank A decreased from 15 to 7 d.

2.3.2. Control of chemicals adding

Chlorination on control of foaming and bulking were performed in the tanks A and C on 10 March 2005. Both tanks suffered foaming and bulking for several months and SVI value was nearly 300 mg L^{-1}, which brought serious operation problems. Chlorination dosage on tank A and tank C were about 8–10 and 6.6–8.0 g CL (kg MLSS d)$^{-1}$, respectively. Both additions lasted 1 week. SVI and effluent characteristics were examined in both experiments.

3. Results and discussion

3.1. Plant performance and controls

Tangshan, located in the northeast of China, 150 km east of Beijing, is characterized with relatively cold winter and spring. Tangshan Northern WWPT, which served 40 km^2 area, 364,000 population, located in the North of Tangshan. Industrial wastewater (most of them are from metal manufacturing and food making process) accounts for nearly half of the total influent. The treatment process is triple oxidation ditch, with capacity of 150,000 M^3 per day. The treatment devices were divided into three equal volume tanks (50,000 M^3 d^{-1}) named as tank A, B and C, respectively. The plant was built in 2001, and began to run at the end of the year. From October 2002, the WWTP suffered from foaming and bulking every winter and spring. The foam formed a stable and brown layer, which stayed in the tank for several weeks, and sometimes 90% surface of aeration was covered by foaming. The height of foaming is usually more than 10 cm and SVI value closed to 350 mL g^{-1} (SVI values above 150 mL g^{-1} are typically associated with filamentous growth [19]). Bulking and foaming seldom occurred in summer and autumn, and the SVI was less than 100 mL g^{-1}.

By analyzing the running date of the plant, the significant seasonal pattern was revealed (Fig. 2). The foaming and SVI became intense during winter and spring, while becoming suppressed during the summer and autumn. This phenomenon was observed in some other plants [14,20]. The microscopic examination and physiological experiment revealed that the dominant filamentous microorganism was *M. parvicella* in the foam and sludge. It was also known from Fig. 2a and b that lower F/M and dissolved oxygen (DO) had good correlation with the SVI and foaming coverage rate, indicating that low BOD sludge loading and low DO are the main cause of *M. parvicella* excessive growth in nutrient removal plants. Since *M. parvicella* can use nitrate as a terminal electron acceptor, it is a strongly competitive filamentous microorganism with floc-formers in both anaerobic and aerobic conditions. Therefore it is easily boomed at anoxic/aerobic environment in oxidation ditch [21,22].

The morphology of *M. parvicella* varied at different seasons (Fig. 3). The proliferation of *M. parvicella* in the mixed liquor may be caused by the competitive psychrophilic growth, and the concentrated *M. parvicella* degradable hydrophobic substrates at low temperature. The surface of *M. parvicella* is hydrophobic, which is easily to attach to the hydrophobic substrates such as lipids for growth at low temperature [18]. Cold climate in winter and spring at Tangshan region would be main reason for *M. parvicella* growth. So that, in summer and autumn, filament of *M. parvicella* becomes shorter, less than 100 μm (Fig. 3b) compared with about 500 μm in winter and spring. *M. parvicella* may produce enzymes which could destroy its cell wall in warmer water (more than 20 °C). Shorter *M. parvicella* produced little foaming and bulking [3,23].

In previous research, biological controls including DO, sludge age and F/M ratio and selectors were tested to solve these problems by operational manipulations. However, these methods do not work well when the foaming was disastrous [24,25]. Thus it is important to deal with foaming and bulking in the initial phase. In following batch, model experiments and field application, biological controls were employed to manage the foaming and bulking in the initial stage, while the chemical addition was used as an emergency control method when the foaming and bulking was serious. An effective and economical

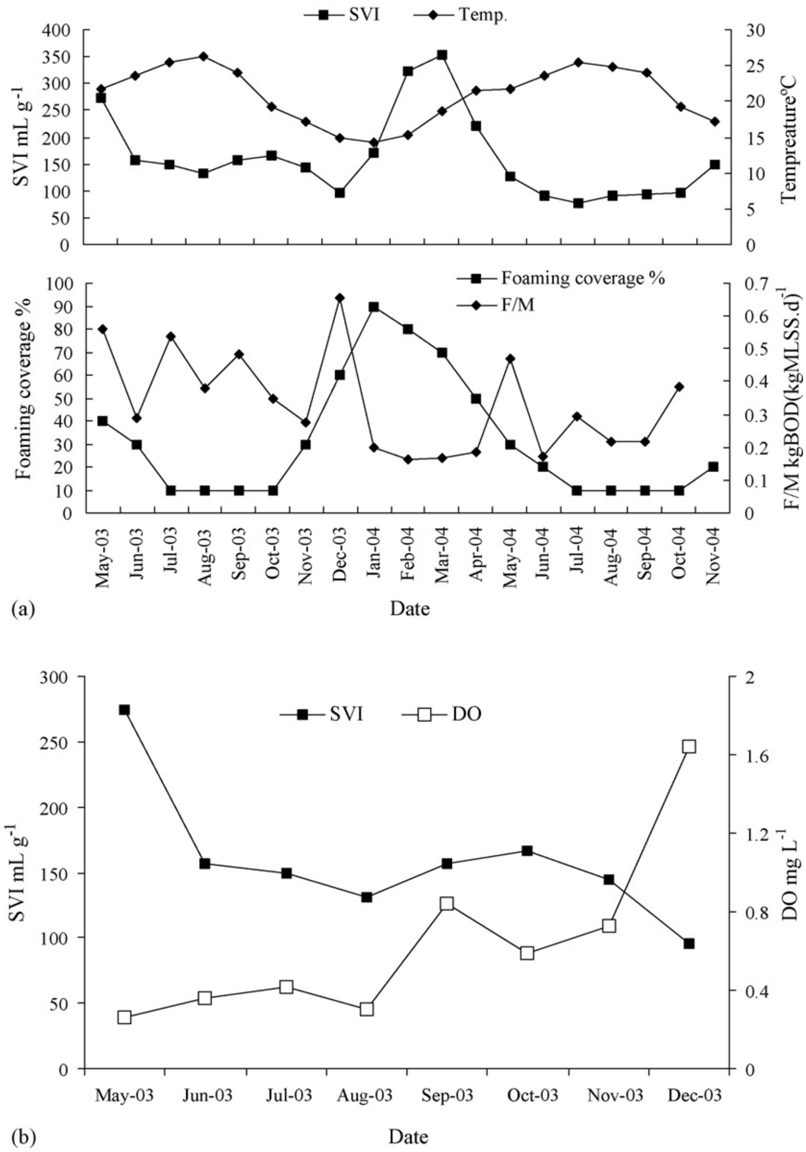

Fig. 2. Monthly variation of foaming and SVI, F/M and temperature (a) and DO (b) at Tangshan Northern WWTP during 2003–2004.

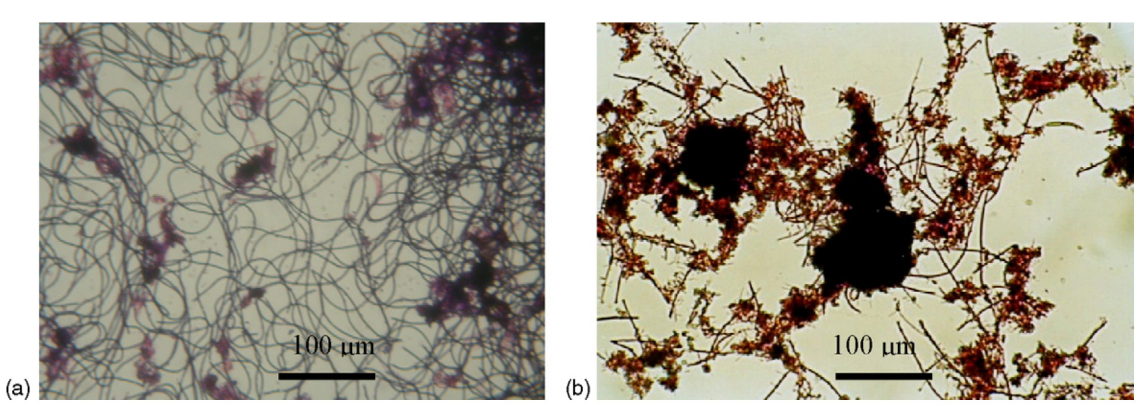

Fig. 3. Morphology of *M. parvicella* at different seasons: (a) April and (b) August. Bar = 100 μm.

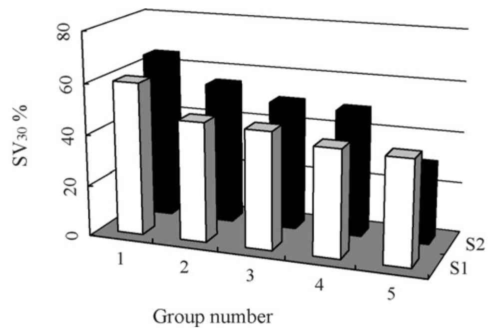

Fig. 4. The variation of SV_{30} value by different dose of bactericide in batch experiments. Group S1, QAS: (1) control, (2) 16.7 g kg^{-1} MLSS, (3) 33.3 g kg^{-1} MLSS, (4) 83.3 g kg^{-1} MLSS and (5) 167.7 g kg^{-1} MLSS; Group S2, NaOCl: (1) control, (2) 28 g kg^{-1} MLSS, (3) 140 g kg^{-1} MLSS, (4) 280 g kg^{-1} MLSS and (5) 560 g kg^{-1} MLSS.

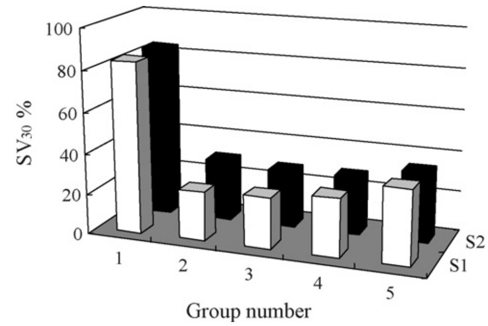

Fig. 6. The variation of SV_{30} value by different dose of flocculants in batch experiments. Group S1, PAM: (1) control, (2) 0.5 g kg^{-1} MLSS, (3) 1 g g kg^{-1} MLSS, (4) 2 g kg^{-1} MLSS and (5) 4 g kg^{-1} MLSS; Group S2, PAC: (1) control, (2) 12.5 g kg^{-1} MLSS, (3) 25 g kg^{-1} MLSS, (4) 50 g kg^{-1} MLSS and (5) 100 g kg^{-1} MLSS.

pre-alert strategy to control *M. parvicella* in oxidation ditch was explored.

3.2. Batch experiments

In order to inhibit *M. parvicella*, several widely used chemicals in wastewater treatment system, NaClO, QAS, PAC, and PAM were selected in batch experiments. NaClO and QAS are bactericide, and PAC and PAM are flocculants.

3.2.1. Bactericide addition experiment

In case of bactericide, the SV_{30} decreased with the amount of NaClO or QAS added (Fig. 4). The breakdown of *M. parvicella* cells was observed by microscopy when NaClO or QAS was added. When the amount of NaClO is more than 140 g Cl kg^{-1} MLSS, the fractured coils were found significantly in places; when QAS was 50 g kg^{-1} MLSS, about half of the coils were broken (Fig. 5). These two chemicals could both cut the *M. parvicella* into short one, and benefit sludge settling. However, chlorination took only several minutes, while QAS took hours (data not shown). Although *M. parvicella* is highly tolerant against chlorination, 10–100 times greater than other filament in activated sludge [14,16], higher concentration of chlorine used in our experiment could kill *M. parvicella*. This results agreed with Hwang and Tanaka [20]. As chlorine is a very toxic chemical for floc bacteria, an improper load condition can lead to a complete failure of biological treatment, for pre-alert control, less dosage of chlorine was recommended to pilot or field scale experiments.

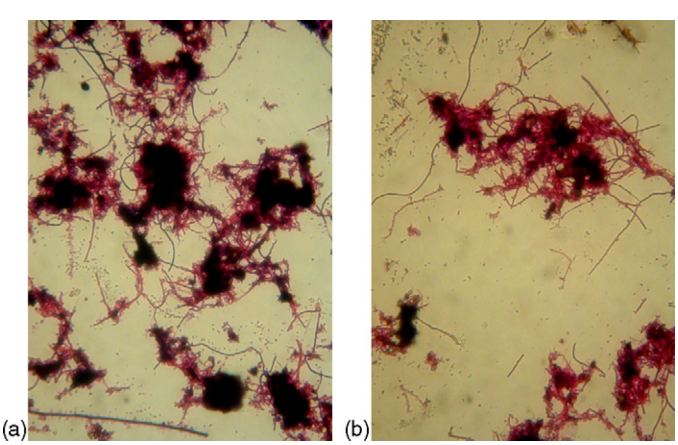

Fig. 5. Morphology change of *M. parvicella* after bactericide addition: (a) chlorine and (b) QAS addition.

3.2.2. Flocculants addition experiment

Fig. 6 shows the effects of two common flocculants and coagulants, PAM and PAC addition on sludge settlement. The SV_{30} value decreased sharply after flocculants addition, both were less than one third of that before addition. PAM exhibited better than PAC. Microscopic examination showed that *M. parvicella* were not broken down in this experiment, which indicated that PAM or PAC have significant effect on thickening sludge but could not kill microorganisms. The mechanism of flocculants influencing activated sludge settling was different to that of bactericide. It is supposed that bulking may happen soon if flocculants stopped. A slight rebound data in Fig. 6 indicates that high dosage of flocculants will increase the SV_{30}. Based on the results of batch experiments, 0.5 g kg^{-1} MLSS of PAM or 12.5 g kg^{-1} MLSS of PAC was recommended for the improvement of sludge settlement in aeration or secondary clarifier.

3.3. Continuous flow experiments

3.3.1. Reducing sludge retention time

SVI value in simulation reactor decreased by reducing sludge retention time to 7 d (Fig. 7), and the SVI decreased with elapse time, to about 100 mL g^{-1} after 2

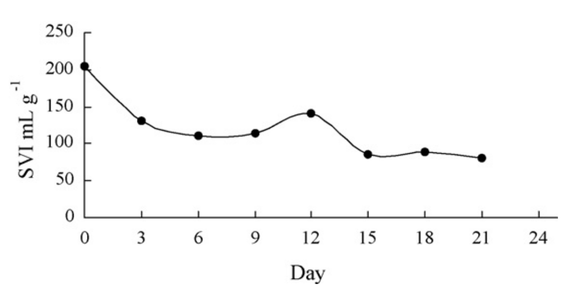

Fig. 7. Changes of SVI value by reducing sludge retention time in simulation reactor.

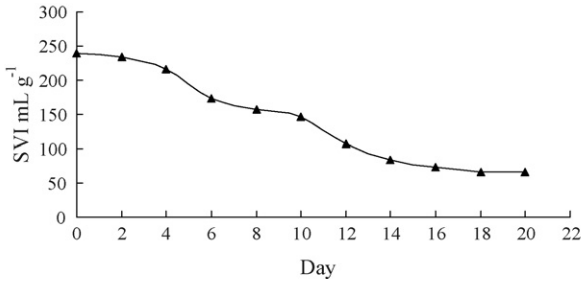

Fig. 8. Changes of SVI value by increasing influent F/M in simulation reactor.

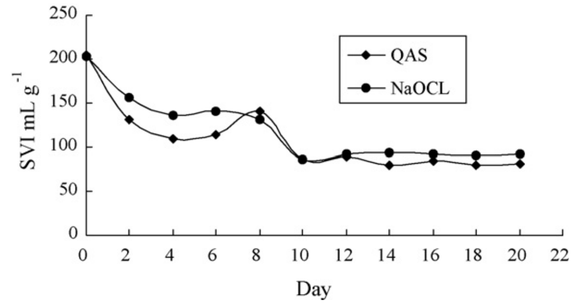

Fig. 9. Changes of SVI value after bactericide addition in simulation reactor.

weeks. The foaming disappeared on the surface of reactor (tank C is almost 50% coverage rate). Filamentous bacteria counting showed that *M. parvicella* decreased from 2.8×10^5 to 1.7×10^5 intersections g^{-1} VSS, while increased from 2.8×10^5 to 3.5×10^5 intersections g^{-1} VSS in tank C. SRT in tank C is 15 d, while it is only 7 d in simulation reactor. The decreasing *M. parvicella* in the simulated reactor is that the generation time of *M. parvicella* is longer than the sludge retention time, and was washed out with the sludge discarding. The reduced filamentous bacteria in activated sludge was accompanied by an SVI decrease to approximately 100 mL g^{-1}. The increasing filamentous organisms in tank C showed *M. parvicella* favored high SRT, it usually existed in high SRT biological nutrient removal (BNR) plants [5,10,25].

3.3.2. Increasing F/M ratio

Increasing influent loading (F/M) from 0.15 kgBOD (kg MLSS d)$^{-1}$ to about 0.3 kgBOD (kg MLSS d)$^{-1}$ in simulation reactor for 3 weeks decreased SVI value gradually to 80 mL g^{-1} (Fig. 8). Increase of F/M ratio supplied more substrates to the floc-forming bacteria, and these bacteria have higher growth rate at high soluble substrate concentration than filamentous bacteria, which are more competitive for substrate utilization at low substrate concentrations. More proportions of non-filamentous provide an activated sludge with better setting and thickening properties.

The results of simulation experiment suggested that biological controls such as reducing SRT or increasing F/M rate could alleviate bulking and foaming at initial stage or not serious conditions.

3.3.3. Chemicals addition

In case of chemicals control experiment, bactericide was selected for the simulation experiment. After QAS addition for 3 d, SVI decreased from 220 to 100 mL g^{-1}, and more than 50% was cut down (Fig. 9), and no foaming was observed on the surface of the lab scale device. Compared with tank C, the SVI maintained above 200 mL g^{-1}, and about 30% foaming covered on the aeration tank. The filamentous bacteria counted in reactor was 2.98×10^5 intersections g^{-1} VSS at the beginning of experiment, and it decreased to 6.3×10^4 intersections g^{-1} VSS after 5 d QAS addition, 78.9% decrease of filamentous bacteria indicated that QAS had suppressed the filament effectively.

Chlorine addition had the same effects as QAS. SVI in the reactor decreased below 100 mL g^{-1} 6 d after chlorine addition shown in same figure. Microscopic observation showed clearly that the filamentous bacteria were killed into segments. The counting of filamentous bacteria also proved the results. It was 2.0×10^5 intersections g^{-1} VSS at the beginning of experiment, and decreased to 1.09×10^5 intersections g^{-1} VSS after chlorine addition, 45.5% filament were killed. Meanwhile in tank C, it changed little.

Chemicals control strategy could kill the filamentous bacteria immediately whenever it occurs, and reduce foaming and bulking in few days. As a cheap and rapid functional chemical, chlorine was selected for field use although it will also kill floc-forming bacteria, and lead to worse effluent, the proper dosage is important.

3.4. Field application

3.4.1. Control of reducing sludge retention time (SRT)

The field SRT experiment started in 2 December at tank A. In winter when water temperature in oxidation ditch dropped to 15 °C around, the bulking and foaming appeared in Tangshan Northern WWTP. The sludge age was about initial 15 d, with MLSS of 3500 mg L^{-1} and SVI of about 200 mL g^{-1}. With the activated sludge discharged during experiment, the sludge age in tank A was reduced to 7 d. SVI value gradually decreased. Twelve days later, SVI dropped below 150 mL g^{-1} (Fig. 10). The foaming on the surface of aeration tank also reduced gradually. These results indicated that sludge age reduction was an effective way on foaming and bulking control. The effluent water quality exhibited somewhat worse trend with the decrease of sludge age (Table 1). This is because the shorter sludge age led to an increasing F/M ratio, which resulted in a decreased substance

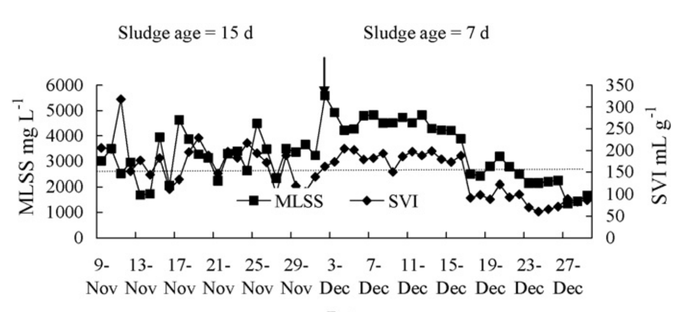

Fig. 10. Changes of SVI value and MLSS before and after SRT adjustment in field experiment (the arrow shows date to adjust SRT).

Table 1
Mean water quality of effluent before and after SRT adjustment

	Before	After
CODcr ($mg L^{-1}$)	37.78 ± 3.46 (25)[a]	47.77 ± 7.60 (25)
BOD_5 ($mg L^{-1}$)	7.93 ± 2.28 (22)	8.45 ± 2.08 (25)
NH_4-N ($mg L^{-1}$)	9.70 ± 2.29 (25)	12.48 ± 3.28 (25)
SS ($mg L^{-1}$)	8.92 ± 3.22 (25)	5.32 ± 1.98 (25)

[a] All data appeared by average value ± standard deviation (number of analyses).

removal rate. Strategy of reducing sludge retention time will take long time to take effect (nearly 2 weeks in this experiment) since the filamentous bacteria must decrease to a certain level that the activated sludge could become better settling. However, it is useful technique to control the foaming and bulking when the bulking and foaming just happened.

Unfortunately this method is not suitable when operating a plant with nitrification or when sludge dewatering capacity is limited.

3.4.2. Control of chlorination

The chlorination experiment was performed in tanks A and C in March 2005. Both tanks suffered foaming and bulking for several months, which brought serious operation problems. The bulking and foaming were getting worse regardless of control strategies of decreasing SRT and flocculating, so that, the chlorination was employed. Chlorine addition lasted from 10 to 16 March.

In the first 4–5 d with chlorine addition, SVI in both tanks changed little (Fig. 11). The reason may be the asymmetry distribution of chlorine in oxidation ditches (it is easy to mix completely with activated sludge in simulation reactor). Until 7th day, the SVI value decreased sharply from 240 to about 130 $mL g^{-1}$. The foaming reduced, and the coverage rate from nearly 80% to less than 20%. Significant segments of *M. parvicella* were found by microscopic examination in samples in following days. SVI value changed a lot and almost maintained to about 100 $mL g^{-1}$ in following one and half month, which indicated that the chlorination of activated sludge was efficient to the filamentous bacteria. The effluent COD was a little bit higher than before, however, it was still below 70 $mg L^{-1}$ and meet national criteria. Some researches showed that normal dosage of chlorine was considered totally ineffective in case of *M. parvicella* foaming [20], which agreed with our pre-experiments. In that experiment, the dosage of chlorine is 10 g Cl kg^{-1} MLSS and lasted only 1–2 d. No good results obtained (date not shown). In this experiment, until the 7th day did SVI change significantly, which indicated that amount of chlorine is important to control *M. parvicella*. Therefore when bulking and foaming severely occurred in practice, addition of chlorine is an effective control strategy. The dosage of chlorine should be high enough, otherwise it would have little effect on *M. parvicella*.

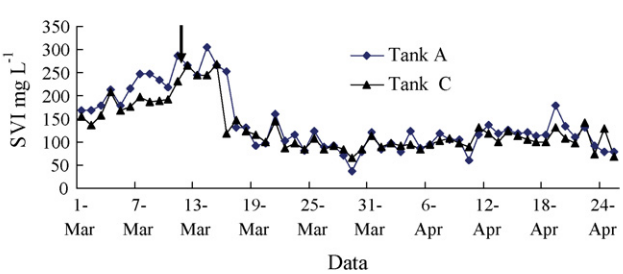

Fig. 11. Changes of SVI value at tanks A and C before and after chlorine addition in field experiment (the arrow shows date to add chlorine).

4. Conclusion

Foaming and bulking in triple oxidation ditch at a wastewater treatment plant in Northern Tangshan China was caused by the excessive growth of *M. parvicella*. A characteristic seasonal pattern was observed, and the intensive growth of *M. parvicella* occurred in the cold winter and spring.

In batch and simulation experiment, biological control such as shorter SRT or higher F/M ratio was proved effectively in decreasing SVI and foaming when they just occurred. Chemicals such as bactericides and flocculants have different mechanisms in improving the sludge settling characteristics and controlling foaming and bulking. In field experiments, strategies of reducing sludge age to 7 d and chlorine addition at 10 g CL (kg MLSS d)$^{-1}$ could inhibit significantly the foaming and bulking in triple oxidation ditch when they happened at different stages, and had little effect on effluent water quality.

Since the foaming and bulking is hard to control when booming, control strategy in its initial stage is important. In order to control and prevent the breakout of foaming and bulking by *M. parvicella*, a pre-alert system should be established, which is to eliminate the foaming and bulking at beginning, and avoid booming period. Biological strategies such as improving DO, F/M ratio or reducing sludge age would be effective. Methods of chemicals precipitation and chlorination could be used as emergent strategies when filamentous bacteria are excessive growth. It is supposed that the pre-alert strategy be an effective and economical strategy for foaming and bulking control.

Acknowledgements

This research was supported by Shanghai Municipal Engineering Institute of Design and Research. The authors thank the supports from Mr. Tian ZH and Ms. Zhang YM of Tangshan Northern WWTP.

References

[1] J.A. Soddel, R.J. Seviour, A review: microbiology of foaming in activated sludge slants, J. Appl. Bacteriol. 69 (1990) 145–176.
[2] R.P. Krishna, J. David, K. Wendell, Nocardia effects in waste activated sludge, Water Sci. Technol. 38 (1998) 49–54.
[3] A. Franz, N. Masche, Investigation of a bacteria-enzyme additive to prevent foaming in activated sludge plants, Water Sci. Technol. V29 (1994) 271–279.
[4] M. Wagner, A. Loy, Bacterial community composition and function in sewage treatment systems, Curr. Opin. Biotechnol. 13 (2002) 218–227.
[5] D.H. Eikelboom, A. Andreadakis, K. Andreasen, Survey of the filamentous populations in nutrient removal plants in four European countries, Water Sci. Technol. 37 (1998) 281–289.

[6] J. Wanner, I. Ruzickova, P. Jetmarova, O. Krhutkova, J. Paraniakova, A national survey of activated sludge separation problems in the Czech Republic: filaments, floc characteristics and activated sludge metabolic properties, Water Sci. Technol. 37 (1998) 271–279.
[7] M. Paola, D. Donatella, G. Giorgia, Survey of filamentous microorganisms from bulking and foaming activated sludge plants in Italy, Water Res. 34 (2000) 1767–1772.
[8] E.M. Seviour, C.J. Williams, R.J. Seviour, J.A. Soddell, K.C. Lindrea, A survey of filamentous bacterial populations from foaming activated sludge plants in eastern states of Australia, Water Res. 24 (1990) 493–498.
[9] L.L. Blackall, A.E. Habers, P.F. Greenfield, A.C. Hayward, Actinomycete scum problems in Australian activated-sludge plants, Water Sci. Technol. 20 (1988) 493–495.
[10] J.R. Blackbeard, G.A. Ekama, G.V.R. Marais, A survey of bulking and foaming in activated sludge plants in South Africa, Water Pollut. Control 85 (1986) 90–100.
[11] D.H. Eikelboom, Control of *Microthrix parvicella* by addition of PAX-14, 35. TNO-MEP-R97/305, TNO Institute of Environmental Science, Energy Research and Process Innovation, Appeldoorn, The Netherlands, 1997.
[12] T. Roels, F. Dauwe, D.S. Van, W.K. De, F. Roelandt, The influence of PAX-14 on activated sludge systems and in particular on *Microthrix parvicella*, Water Sci. Technol. 46 (2002) 487–490.
[13] S. Rossetti, C.T. Maria, P.H. Nielsen, V. Tandoi, "*Microthrix parvicella*", a filamentous bacterium causing bulking and foaming in activated sludge systems: a review of current knowledge, FEMS Microbiol. Rev. 29 (2005) 49–64.
[14] D.H. Eikelboom, The *Microthrix parvicella* puzzle, in: Proceedings of the IAWQ First International Specialized Conference on Microorganisms in Activated Sludge and Biofilm Process, Paris, 1993, pp. 267–275.
[15] D.A. Mamais, C.N. Andreadakis, C. Kalergis, Causes of, and control strategies for *Microthrix parvicella* bulking and foaming in nutrient removal activated sludge systems, Water Res. 34 (1998) 9–17.
[16] P. Miana, L. Grando, G. Caravello, *Microthrix pavicella* foaming at the Fusina WWTP, Water Sci. Technol. 46 (2002) 499–502.
[17] Standard Methods for the Examination of Water and Wastewater, 18th ed., American Public Health Association/American Water Works Association/Water Environment Federation, Washington, DC, USA, 1992.
[18] D. Jenkins, M.G. Richard, G.T. Daigger, Manual on the Causes and Control of Activated Sludge Bulking and Foaming and Other Solids separation problems, CRC Press LLC, Florida, 2004.
[19] D.S. Parker, D.J. Kinnear, E.J. Wahlberg, Review of Folklore in design and operation of secondary clarifiers, J. Environ. Eng. 127 (2001) 476–484.
[20] Y. Hwang, T. Tanaka, Control of *Microthrix parvicella* foaming in activated sludge, Water Res. 32 (1998) 1678–1868;
S. Knoop, S. Kunst, Influence of temperature and sludge loading on activated sludge settling, especially on *Microthrix parvicella*, Water Sci. Technol. 37 (1998) 27–35.
[21] J. Wanner, P. Grau, Filamentous bulking in nutrient removal activated sludge system, Water Sci. Technol. 20 (1988) 1–8.
[22] R.J. Foot, E. Kocianova, C.F. Forster, Variable morphology of *Microthrix parvicella* in activated sludge systems, Water Res. 26 (1992) 875–880.
[23] R.P. Anthony, Bulking and foaming in BNR plants in Johannesburg: problems and solutions, Water Sci. Technol. 34 (1996) 291–298.
[24] D. Davoli, P. Madoni, L. Guglielmi, Testing the effect of selectors in the control of bulking and foaming in full scale activated sludge plants, Water Sci. Technol. V46 (2002) 495–498.
[25] K. Andreasen, Results of the survey in Denmark, Survey of the Filamentous Population in Nutrient Removal Plants in Four European Countries, Report REWA-CT92-0016, TNO-MW, Delft, NL, 1995, pp. 22–39.