Characteristics and Control of *Microthrix Parvicella* Bulking in Biological Nutrient Removal Plant

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생물학적 영양소제거공정에서 *Microthrix Parvicella*에 의한 Bulking 특성 및 제어

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Abstract

Many BNR (Biological Nutrient Removal) plants have experienced a bulking problem, mainly due to the growth of filamentous organisms, particularly during the winter months. This study investigated the problem of bulking due to the growth of *M. parvicella* both at a full-scale municipal wastewater treatment plant and a pilot scale plant located in the C city. The full-scale facility was operated at a flow rate of 51,000 m^3/d, an F/M (Food-to-Microorganism) ratio of 0.12 kgBOD/kgMLVSS/d and an SRT (Solids Retention Time) higher than 25 days, respectively. This plant experienced bulking and foaming problems at low temperatures below 15 °C since it was retrofitted with the BNR system in 2003. The pilot plant employed had an identical process configuration as the full scale one and used the same wastewater source. It was operated at a flow rate of 3.8 m^3/d, temperatures between 10 to 25 °C and SRTs between 10 and 25 days. At full scale, the *M. parvicella* growth and SVI (Sludge Volume Index) patterns were studied in conjunction with temperature variations. At pilot scale, DO and SRT variations were also explored, in addition to the filamentous bacteria growth and SVI patterns. During the full-scale investigation, over a 3 year period, it was noted that the SVI was maintained within acceptable operational values (i.e. under 160) during the summer months. Moreover settling in the secondary clarifiers was good and was not affected by the presence of *M. parvicella*. In contrast, at low mean temperatures during winter, the SVI increased to over 300. Overall, as the temperature decreased, the predominance of *M. parvicella* became apparent. According to this study, *M. parvicella* growth could be controlled and SVI could drop under 160 by a change in operational conditions which involved an increase in DO concentration between 2 and 4 mg/L and a decrease in SRT to less than 20 days.

keywords : Biological nutrient removal, Bulking and foaming, Dissolved oxygen, Filamentous growth, Solids retention time, Temperature

1. Introduction

In the last two decades many municipal wastewater treatment plants in Korea have been upgraded from conventional activated sludge facilities to BNR systems. Many BNR plants however have experienced a bulking problem, particularly during the winter months. The bulking, foaming and settling problems observed in BNR facilities have been largely associated with the presence of filamentous microorganisms such as *Microthrix parvicella* (*M. parvicella*) and *Nocardia*. These microorganisms possess poorly wettable cell surfaces (i.e. hydrophobic surfaces). When they grow in sufficient numbers in BNR systems they render the flocs hydrophobic and amenable to attachment onto air bubbles. The aggregate formed (i.e. air bubble-flocs) is less dense than water and therefore floats to the surface. Since it is hydrophobic, once at the surface, it tends to stay there. Eventually it accumulates to form a thick, chocolate-brown coloured float or scum (Jenkins et al., 1993).

Some nutrient removal plants usually operate at low (DO) concentrations (e.g. less than 2 mg/L), high SRTs (e.g. greater than 18 days) and/or intermittent aeration patterns. These operating conditions tend to promote the growth of *M. parvicella*(the most commonly identified filamentous species) which causes serious settling problems

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in the secondary clarifier(s) of a treatment plant (Ministry of Environment of Korea, 2005). Similar problems have been observed in BNR facilities in other researches. For example, in South Africa, filamentous organisms were frequently observed in BNR-activated sludge plants with initial anaerobic and/or anoxic zones (Ekama et al., 1986). A survey of more than 200 BNR plants in the European Union including Denmark, Germany, Greece and the Netherlands has revealed that BNR systems favour filamentous organisms in their competition with floc-forming organisms (Eikelhoom et al., 1998). This survey also confirmed that *M. parvicella* was the most predominant filamentous species observed. Furthermore, a study by Noutsopoulos et al. (2002) reported that BNR plants in Greece operating on an intermittent aeration mode experienced a thick layer of scum at temperatures below 20°C. Mamais et al. (1998) has also observed that the growth of *M. parvicella* can be related to the bioreactor's temperature; at 29°C, *M. parvicella* was completely eliminated from BNR systems. The proliferation of *M. parvicella* at low ambient temperatures (i.e. below 15°C) can be attributed to the reduced solubility of lipids and fats. At low temperatures these substrates tend to accumulate on the surface of the activated sludge aeration basin and therefore become available to organisms that possess hydrophobic surfaces such as *M. parvicella*. The effect of temperature on *M. parvicella* growth well documented (Eikelboom et al., 1998; Mamais et al., 1998). Based on their results, it appears that high temperatures not only influence the availability of lipids and fats but also create a competitive advantage to other bacteria that causes a change in the activated sludge microbial population.

Although definite control methods for filamentous organisms, such as *M. parvicella*, have not been firmly established several general operational techniques and chemical control method such as chlorination have been suggested that may lead to an improvement. For instance, if fluctuations in the DO concentration in the aerobic zone of a BNR system are minimized *M. parvicella* can be eliminated. In addition, at a low F/M ratio, an increase in the sludge wasting rate can lead to eliminating *M. parvicella* with the system returning to a non-bulking condition (Jenkins et al., 1993). Moreover, it has been reported that recycling patterns can affect the levels of *M. parvicella* in BNR systems (Jenkins et al., 1993). If filamentous organisms are recycled to the influent or the aeration basin of the bioreactor(s), they tend to increase in quantity. Although successful control of the proliferation of *M. parvicella* has usually occurred in aerobic environments (Mamais et al., 1998), there is evidence in the literature that effective minimization of filamentous growth can also occur under anaerobic conditions (Pujol et al., 1994). It has been suggested that the best control strategy for suppressing the growth of *M. parvicella* can be achieved by adopting a plug flow reactor configuration (Mamais et al., 1998). The concentration gradient which is imposed throughout a plug flow reactor for both RBCOD (Readily Biodegradable Chemical Oxygen Demand) and SBCOD (Slowly Biodegradable COD) provides a selective advantage to the floc-forming bacteria which are capable of assimilating both COD fractions. This can limit the growth of *M. parvicella* which is based principally on SBCOD and its hydrolysis products (Noutsopoulos et al., 2002). This study investigated the causes and characteristics of the bulking problem due to the growth of *M. parvicella* both at a full-scale municipal wastewater treatment plant and a pilot scale plant in C city. This research has also focused on finding strategies for controlling *M. parvicella* growth in nutrient removal activated sludge plants.

2. Materials and Methods

2.1. Full-Scale Experiments

The full-scale plant experiments had focused on investigating the bulking phenomena caused by *M. parvicella* through microscopic examination of the sludge and SVI analysis. During the full-scale study over 3 years, none of the operating conditions changed except for the temperature. The full-scale plant operated under the fixed operating conditions of F/M ratio, SRT and DO. The full-scale plant in C city was retrofitted with the BNR system from the conventional activated sludge system in 2003. In order to simultaneously remove nitrogen and phosphorus using *Bacillus*, the DO concentration has to be maintained around 1.0 mg/L in the bioreactor. The bioreactor was divided into 4 zones. The DO concentration of the first zone was maintained below 1.0 mg/L. The internal recycle of 150% and RAS (Returned Activated Sludge) of 100% based on influent flow rate was recycled to the first zone. The other zone was operated by the tapered aeration system as an aerobic condition with DO concentration around 0.5 mg/L. The first zone's HRT was 2.0 hours and the other zone's HRT was 4.5 hours. The MLSS concentration in the bioreactor was maintained at 2,500 mg/L. Also, the MLVSS/MLSS ratio was about 0.7. A schematic diagram of the full-scale plant is depicted in Fig. 1, while a summary of the operating conditions is shown in Table 1. It should be noted that of the facility was designed for a F/M ratio of 0.25 kgBOD/kgMLVSS/d and a SRT of approximately 15 days. However, as illustrated in Table 1, the plant was operated at a much lower F/M ratio and higher SRT (i.e. 0.12 kgBOD/kgMLVSS/d and 26 days, respectively). It is not unusual for municipal wastewater treatment plants in Korea to operate at lower loading conditions than they have been designed for, mostly due to low strength of the wastewater source and the use of combined sewerage systems (Lee, 1995). Typical characteristics of the influent wastewater have been included in Table 2. As it can be observed, the influent wastewater was characterized by a low Biochemical Oxygen Demand (BOD) and Total Suspended Solids (TSS) content, but a high Total Nitrogen (TN) content, as compared to other typical municipal wastewater (Metcalf & Eddy, 2005). The full-scale set of experiments was conducted over a period of 3 years. The focus was to investigate the bulking phenomena caused by filamentous organisms through microscopic examination of the sludge and SVI measurements.

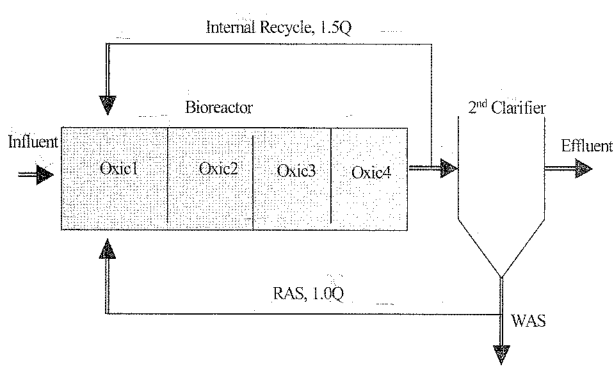

Fig. 1. A schematic of the full-scale plant.

2.2. Pilot-Scale Plant Experiments

The pilot-scale study was initiated to create control strategies regarding bulking and the growth of filamentous microorganisms such as *M. parvicella*, in a BNR environment. The pilot-scale plant had an identical process configuration as the full-scale plant (Fig. 1). As indicated in Table 1, this part of the investigation was divided into three stages, with experimental variables being the SRT value and the DO concentration in the bioreactor. Simultaneously, the result of each operation condition was compared with the full-scale plant result. The pilot-scale plant experiments were divided into three separate operating stages. In the first stage, DO concentration in the bioreactor increased to 2.5 mg/L which was significantly higher than the full-scale plant. In 2nd and 3rd stages, the SRT were decreased to 10 and 20 days, respectively, which were less than that of the full-scale plant. The pilot-scale plant used the same wastewater source. It was operated at a flow rate of 3.8 m^3/d with temperatures between 10 to 25°C and F/M ratio 0.12 kgBOD/kgMLVSS/d. The pilot-scale plant study was conducted over 110 days.

Table 2. Bioreactor influent characteristics

Parameter	Average	Range		Standard Deviation
		Min	Max	
pH	7.4	7.0	7.7	0.2
BOD, mg/L	120	99	135	12
TSS, mg/L	97	61	119	20
TN, mg/L	42	34	48	5.2
TP, mg/L	3.1	2.3	3.7	0.5

2.3. Sampling and Analysis

The performance of the pilot-scale and the full-scale plants was assessed by routine measurements of BOD, TSS, TN and Total Phosphorous (TP) throughout the study. In addition, SVI analysis and microscopic examinations of the filamentous organisms were carried out several times a week. All chemical analyses were conducted in accordance with the Standard Methods (1995). SVI values were determined using 1L unstirred cylinders. Soluble fractions were obtained by 0.45 ㎛ membrane filtration for MLVSS. Microscopic examinations of filamentous organisms were performed according to the Gram

Table 1. All operating conditions and design parameters of pilot-scale and full-scale plants

Parameter		Full-scale	Pilot-scale		
			1st stage	2nd stage	3rd stage
SRT, day		26	25	10	20
DO, mg/L	Oxic1	1.0	0.5	1.0	1.0
	Oxic2-4	0.5	2.5	0.5	0.5
F/M, kgBOD/kgMLVSS		0.12	0.12		
HRT, hour	Oxic1	2.0	2.0		
	Oxic2-4	4.5	4.5		
Flow rate, m^3/d		51,000	3.8		
Internal Recycle, %		150	150		
RAS, %		100	100		
MLSS, mg/L		2,500	2,500		
MLVSS/MLSS		0.7	0.7		

staining method. *M. parvicella* findings in the activated sludge samples were confirmed in terms of the Gram-positive colour (Mamais et al., 1998). Further details are available elsewhere (Ahn, 2005).

3. Results and Discussion

3.1. Observations and Performance at the Full-Scale Plant

Microbiological examinations at the full-scale plant during the winter months only (over a three-year period) revealed that filamentous microorganisms were present at low temperatures. The predominant filamentous species identified was *M. parvicella*. In general, *M. parvicella* is a Gram-positive microorganism, with an irregular-coiled filament shape, 0.6 to 0.8 ㎛ in diameter and 50 to 200 ㎛ in length, and occurs in tangles in the floc (Jenkins et al., 1993). Visual observations of the filamentous growth and its effect on the performance of the facility (i.e. foaming of the bioreactor) have been depicted in Fig. 2. Although the proliferation of *M. parvicella* has been associated mostly with BNR systems, it has been observed that conventional activated sludge municipal treatment plants tend to favour the growth of *M. parvicella* as well, when operated at an F/M ratio from 0.05 to 0.2 kgBOD/kgMLVSS/d and temperatures below 15°C (Mamais et al., 1998). In addition, lipid-rich wastewater have been found to promote filamentous growth (Andreasen et al., 1998). It was observed at the full scale plant that as winter approached and the temperature dropped, *M. parvicella* growth in the bioreactor became predominant, which resulted in a large quantity of foam and scum formation that covered the surface of the oxic zones and in reduced settling efficiency in the secondary clarifier. Furthermore, as filamentous organisms entered the anaerobic digesters of the plant through the secondary sludge feeding line, the foam caused a spillage and eventually a serious performance deterioration. It is well known that the cause of digester foam and spillage is related to the presence of *M. parvicella* in the WAS (Westlund et al., 1998). It has been suggested that this type of process disturbance may be attributed to a combination of alkalinity deficiency, low mixing efficiency, low pH in the digester as well as the abnormal increase of filamentous microorganisms in the activated sludge system (Choi, 2003). It should be noted that the full-scale plant experienced these problems, despite adequate alkalinity, neutral pH and proper mixing conditions occurring in the digesters.

Fig. 3 illustrates the temperature and SVI profiles over the 3 year period of this investigation. It is evident that there is an inverse relationship between SVI and temperature values. As indicated, the foaming of the aerobic bioreactor and the spilling of the digester occurred when SVI values were about the 300 level, at temperatures below 15°C. This phenomenon was observed on an annual basis. It should be also mentioned that following the spillage, the digesters were emptied and cleaned properly and then returned to operation.

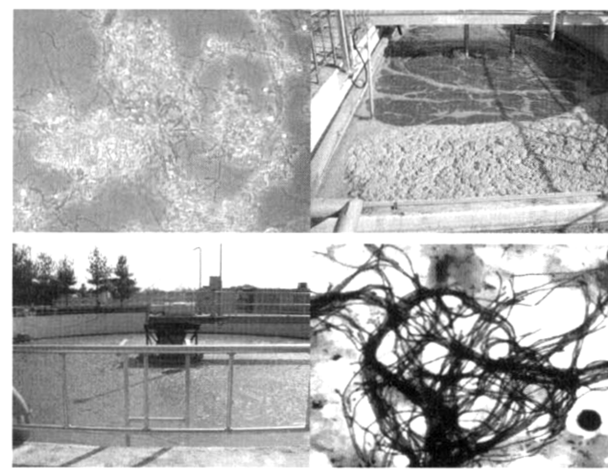

Fig. 2. Visual observations of filamentous microorganisms and foaming conditions at the full-scale plant.

As mentioned previously, low ambient temperature is one of the most important factors promoting the growth of *M. parvicella* in an BNR system. Considering the effect of temperature as a single factor, it has been reported that at 29°C, *M. parvicella* was completely eliminated from BNR systems (Mamais et al., 1998). Although detailed microscopic examinations were not conducted at the full-scale plant during the summer months, frequent visual observations indicated that there was practically no filamentous growth occurring at an average temperature of 25°C.

The BNR plant performance in terms of BOD, TSS, TN and TP along with the SVI values have been summarized in Fig. 4. It is apparent that at SVI values higher than 300, corresponding to the winter months in Korea, the percent removal values of all parameters shown are at

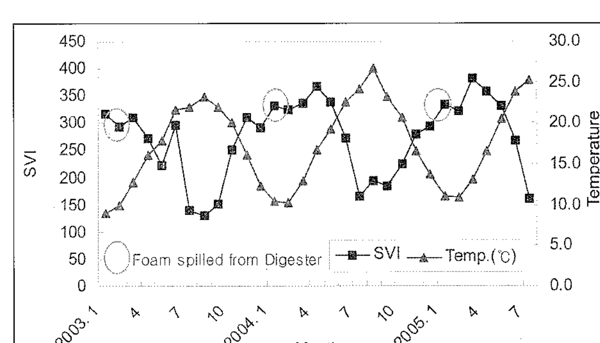

Fig. 3. Temperature and SVI profiles at the full-scale plant over a 3 year period.

their lowest as a result of the foaming and bulking problems experienced at the plant. However, the efficiency of the bioreactor improved slowly as the temperature increased manifested by a decrease in SVI and the gradual elimination of filamentous microorganisms. Based on the results of this investigation, it can be concluded that temperature has a significant influence on the growth of *M. parvicella*. Temperature control in a full-scale plant is difficult to achieve due to high operational costs and other practical limitations. It would therefore be preferable to control the growth of *M. parvicella* by alternative means, including the manipulation of operational parameters such as DO, SRT, or F/M ratio, as discussed below.

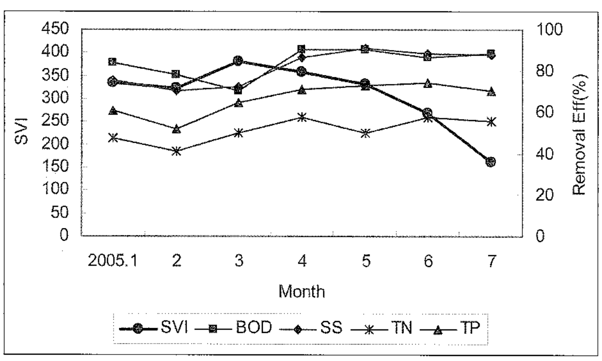

Fig. 4. Percent BOD, TP, TN and TSS removal efficiency and SVI profiles at the full-scale plant.

3.2. Effect of Do and Srt on M. Parvicella Growth

The 1st stage of the pilot-scale study was initiated to investigate the effect of DO concentration in the oxic zones of a BNR system on the growth of *M. parvicella* at temperatures around the 15°C mark. As indicated earlier (Table 1), this stage was performed at an oxic DO concentration of 2.5 mg/L. The pilot plant operated at a mode identical to that of the full-scale facility. As shown in Fig. 5, the SVI values obtained during the 1st stage of the pilot study were much lower (i.e. averaging 160) than those at the full-scale plant. In addition, no filamentous growth or any bulking problems were observed during this stage. This implies that the DO concentration in the oxic zone has a major effect on the growth of *M. parvicella* and therefore, DO can be a useful control parameter. The findings from this study are in agreement with those reported in the literature with respect to the role of DO on filamentous species (Jenkins et al., 1993).

The last two stages of the pilot-scale study were conducted to explore the effect of SRT on filamentous growth and plant performance at an oxic DO concentration below 1.0 mg/L. The two SRTs investigated were 10 days (2nd stage) and 20 days (3rd stage). Data depicted in Fig. 5 suggest that during the 2nd stage the SVI index at the pilot plant was approximately 170 with minimal fluctuation. Moreover, as in the 1st stage, no filamentous growth or any operational or settling problems were detected. However, an increase in SRT from 10 to 20 days (3rd stage) resulted in a substantial increase in SVI (ranging from 200 to 300) with much greater fluctuations and also initiated the onset of filamentous organisms. According to Jenkins et al. (1993), *M. parvicella* grows actively at SRTs longer than 20 days. Results from this investigation clearly indicate that higher SRTs may promote the growth of filamentous organisms at a given DO concentration and therefore SRT could be used as a control parameter.

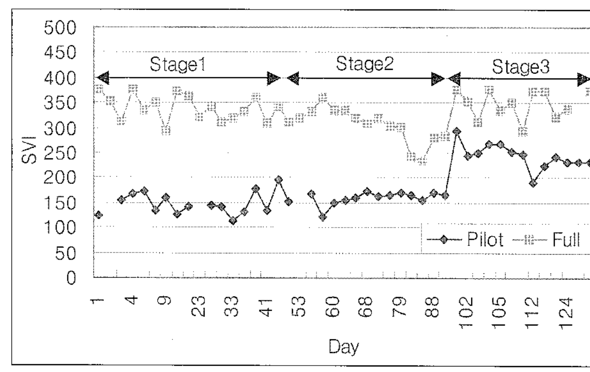

Fig. 5. SVI profiles of the pilot-scale plant and the full-scale plant.

4. Conclusions

Several conclusions can be made from this investigation. With respect to the full-scale BNR facility, it was found that filamentous growth (e.g. *M. parvicella*) during the winter months created significant bulking and foaming problems not only in aerobic bioreactor, but also in the secondary clarifiers and the anaerobic digesters of the plant. It was also evident that temperature played a critical role on the growth of filamentous organisms, as they were practically absent during the summer months. The pilot-scale study however revealed that both DO and SRT can be used as operational parameters to control the growth of *M. parvicella* year round.

국문요약

생물학적 영양소 제거공정의 하수처리장에서 운전온도가 낮은 겨울철 기간중 사상성 미생물에 의한 Bulking 문제가 발생하고 있다. 본 연구는 사상성 세균의 한 종류인 *M. parvicella*의 성장에 의한 Bulking 문제를 C시 하수처리장과 파일럿 시설을 이용하여 검토하였다. Full-scale 시설은 1일 처리용량이 51,000 m^3/d이고 F/M비는 0.12 kgBOD/kgMLVSS/d이며 SRT는 25일 이상으로 운전되고 있었다.

본 시설은 2003년 생물학적 영양소 제거공정으로 전환된 이후 운전온도가 15°C 이하의 저온으로 운전될 때 Bulking과 그로 인해 반응조내 거품현상이 주기적으로 발생되어 왔다. 파일럿 플랜트는 Full-scale과 동일한 시스템 및 폐수를 이용하였으며 1일 처리용량은 3.8 톤이고 운전온도는 10°C에서 25°C이었으며 SRT는 10일에서 25일 사이로 운전되었다. Full-scale에서는 온도변화에 따른 *M. parvicella* 성장과 SVI 변화 양상이 검토되었다. 아울러 파일럿 시설에서는 DO와 SRT를 변화시키면서 그에 따른 Bulking 미생물의 성장과 SVI 변화 형태를 분석하였다. 3년간 Full-scale의 운전결과를 분석한 결과 여름철 기간은 SVI가 160 이하의 양호한 분포를 나타내는 가운데 *M. parvicella*에 의해 더 이상 침전효율이 저조한 결과를 나타내지 않고 있었다. 반면 낮은 운전온도에서는 SVI가 300 이상의 높은 값을 나타내었다. 본 연구결과 DO 농도를 2-4 mg/L로 운전하거나 SRT를 20일 이내로 유지하였을 경우 *M. parvicella*에 의한 Bulking 문제가 효과적으로 제어되었다.

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