0273-2289/00/84–86/1127/$12.25

Effect of Food:Microorganism Ratio in Activated Sludge Foam Control

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Abstract

Foaming is a common operational problem in activated sludge processes that often adversely affects the quality of the treated effluent. Overgrowth of the filamentous *Nocardia* spp. in the microbial ecosystem was previously identified as the cause of foaming. In the present study, the specific growth rate of *Nocardia amarae* was found to be much higher than that of nonfilamentous bacteria under food:microorganism (F:M) ratios lower than 0.5 mg of biological oxygen demand (BOD)/(mg of mixed liquor suspended solids [MLSS]·d). This indicated that filamentous overgrowth may occur in normal activated sludge processes that are continually operated under the usual F:M range of 0.2–0.6 mg of BOD/(mg of MLSS·d). A novel two-component feast-fast operation (FFO) that capitalized on the sensitivity of filamentous bacteria to F:M ratio was designed to prevent and control foaming problems. The F:M ratio in the "feasting" aeration unit was 0.8 mg of BOD/(mg of MLSS·d) whereas that in the "fasting" aeration unit was 0.2 mg of BOD/(mg of MLSS·d). The FFO resulted in an overall process F:M ratio that still remained within the normal range, while avoiding prolonged exposure of the activated sludge ecosystem to an F:M ratio below 0.5 mg of BOD/(mg of MLSS·d). The FFO suppressed the overgrowth of filamentous bacteria without adversely affecting the organic treatment efficiency of the modified process.

Index Entries: Activated sludge; feast-fast operation; filamentous microorganisms; food:microorganism ratio; foam control.

Introduction

For more than 80 yr, the activated sludge process has been widely applied in sewage and wastewater treatment plants. In the past 30 yr, foaming

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problems have become increasingly addressed and investigated for their adverse effects on process operation and the quality of treated effluent *(1,2)*. Level sensors obscured by foams greatly hinder plant operations, especially for sequencing batch reactors. Thick foams often block scum removal systems. Oxygen supply to aeration tanks is significantly reduced when the liquid surface is covered by thick foams. Spillage of foam results in slippery walkways and increases the burden of housekeeping. Dried foam renders pathogens airborne and causes public health problems. Most important, the quality of effluent deteriorates when solids in clarifiers are carried by foam into the treated effluent.

Filamentous microorganisms have been identified and reported as the major cause of thick, persistent, and scumlike foams. The well-being of an activated sludge microbial ecosystem depends on the profound balance among the floc formers, such as *Pseudomonas* spp., *Zoogloea* spp., *Alcaligens* spp., and *Achromobacter* spp., and the filaments, such as *Nocardia* spp. and *Microthrix* spp. Although the floc formers are the major organic degraders, filaments also degrade organics and, at the same time, provide the skeletal matrix for the formation of compact flocs that are essential for good settling properties. However, excessive filaments result in flocs with entrapped air, which in turn result in foaming and bulking problems *(3,4)*. Overgrowth of specific filamentous bacteria of the Actinomycetes group, such as *Nocardia* spp., *Rodococcus* spp., *Micromonospora* spp., *Actinomadura* spp., *Streptomycetes* spp., *Microthrix parvicella*, *Nostocoida limicola*, and Eikelboom type 0041/0675, has been associated with activated sludge foaming in sewage treatment facilities in the United States, Japan, Singapore, Australia, Hong Kong, and South Africa *(1,2,5–11)*.

The specific precursors of filamentous overgrowth are not fully understood and contradicting views remain. Filamentous growth has been associated with a number of physical and chemical factors. Whether or not the hydrophobicity of the filamentous bacterial cells is an important factor in the formation and stability of foam is still being debated *(12)*. Long-chain fatty acids common in sewage promoted the growth of *M. parvicella (13)* and *Nocardia amarae (14)* to different extents. Long solid retention time (SRT), high mixed liquor suspended solids (MLSS), low sludge return rate (RAS), low food:microorganism (F:M) ratio, and low dissolved oxygen favored filamentous growth *(15)*. On the other hand, intermittent aeration was observed to suppress the growth of *N. amarae (1)*. *M. parvicella* grew faster under the lower mesophilic range (18–30°C) whereas *N. amarae* proliferated faster under the higher mesophilic range (25–40°C) *(16–18)*.

Foam control measures that have been developed over the years often lack theoretical bases and are not always effective. Spraying nozzles have often proved ineffective. Effectiveness of classifying selectors, which selectively remove foam by aerating the mixed liquor with fine bubbles at such locations as return sludge and mixed liquor channels, diminished as the mean cell residence time (MCRT) increased, whereas that of anoxic selectors was less affected by MCRT *(19–23)*. Filament control through manipu-

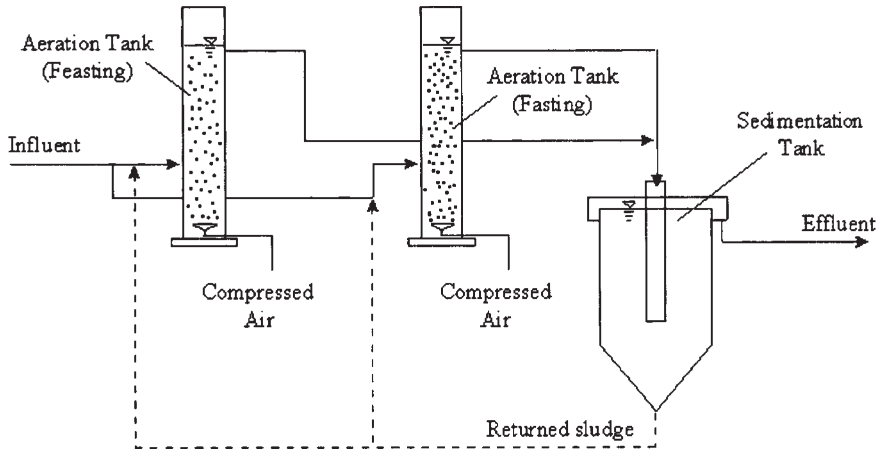

Fig. 1. Activated sludge simulator.

lation of plant operation conditions, namely MLSS, SRT, oxygen supply, and RAS, may lead to other adverse effects *(22)*. For instance, organic loading and effluent residual organics would increase markedly when MLSS and SRT are decreased. Application of chlorination *(24)* and ozonation *(23)* to suppress the filaments occasionally inhibited other nonfilamentous bacteria. Other biochemical methods, such as lysis of filamentous bacteria by synthetic and biological surfactants, polymeric and microbial foam-control agents, are expensive and not universally effective *(9,21)*.

In this article we report on our study of the growth kinetics of *N. amarae* and their use as the theoretical basis to develop an activated sludge operational strategy for foam prevention and control.

Materials and Methods

Synthetic Wastewater

The synthetic wastewater used was prepared with 0.8 g/L of glucose ($C_6H_{12}O_6$), 63 mg/L of ammonium chloride (NH_4Cl), and 26 mg/L of potassium hydrogen phosphate (KH_2PO_4). The equivalent biological oxygen demand (BOD), BOD_5 (5-d BOD), and chemical oxygen demand (COD) were 470 and 800 mg/L, respectively, resulting in a BOD_5:COD ratio of about 0.6.

Activated Sludge Simulator

The two-stage simulator system consists of two 3-L aeration columns and a settling tank (Fig. 1). Both aeration columns received the synthetic wastewater and returned activated sludge at predetermined flow rates. In addition, mixed liquor from the first aeration column entered the second one before liquid-sludge separation (not shown). The system was operated under conventional conditions for 86 d to attain stable operation before it

Table 1
Process Operating Parameters

Parameter	Conventional operation	FFO Feasting unit	FFO Fasting unit
Effective volume (L)	6	3	3
HRT (h)	10.0	8.3	12.5
SRT (d)	15	15	15
pH	6–8	6–8	6–8
Temperature (°C)	26–28	26–28	26–28
Dissolved oxygen (mg/L)	2–4	2–4	2–4
Influent flow rate (L/h)	0.60	0.36	0.24
RAS (L/h)	0.25	0.06	0.21
F:M ratio (g BOD/[g MLSS·d])	0.44	0.75	0.16
Sludge wastage rate (L/d)	0.4	0.2	0.2

was switched to a feast-fast operation (FFO), during which the two aeration columns were operated at different hydraulic retention times (HRTs) and return sludge ratios (R), and hence, F:M ratios. Table 1 summarizes all operating conditions.

Analytical Methods

All mixed liquor and effluent quality parameters were analyzed according to standard methods *(25)*.

Results and Discussion

Development of FFO

In our previous work, we found that the specific growth rate of the filamentous bacteria (*N. amarae*) was higher than that of the nonfilamentous bacteria (*P. aeruginosa*) under F:M ratios lower than 0.5 mg of BOD/(mg of MLSS·d) (Fig. 2) *(14)*. These results showed that filamentous bacteria, represented by *N. amarae*, were "K_s-strategists" that grew slowly but had a strong affinity toward organics at low concentrations. Nonfilamentous bacteria, represented by *P. aeruginosa*, on the other hand, were "U_m-strategists" that grew rapidly but required higher concentrations of organics for growth when compared to the filaments. K_s and U_m are the saturation constant and maximum specific growth rate, respectively, in the Monod growth model for microorganisms. This growth behavior led to the proposition that filamentous overgrowth was inevitable in normal activated sludge processes that were continually exposed to the usual F:M range of 0.2–0.6 mg of BOD/(mg of MLSS·d).

In the FFO that was developed in this work, the first aeration column (feasting unit) was operated with the SRT, influent rate, and return sludge

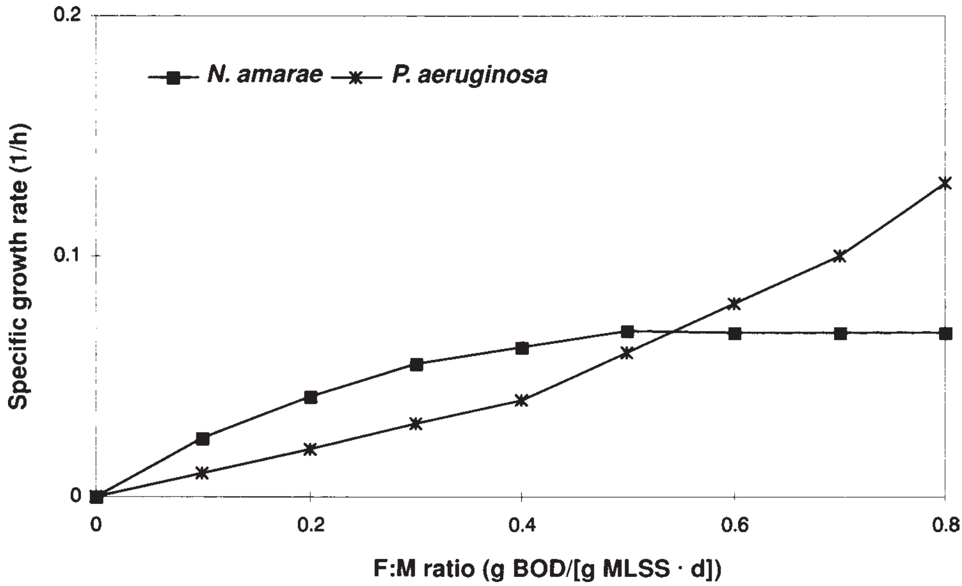

Fig. 2. Specific growth rates of *N. amarae* and *P. aeruginosa*.

ratio (R) at 8.3 d, 0.36 L/h, and 0.867, respectively, giving rise to a high F:M ratio of 0.75 g of BOD/(g of MLSS·d). In the second aeration column (fasting unit), SRT, influent rate, and return sludge ratio (R) were maintained at 12.5 d, 0.24 L/h, and 0.17, respectively, rendering a low F:M ratio of 0.16 g of BOD/(g of MLSS·d). The process conditions of the conventional operation and FFO are summarized in Table 1. The FFO resulted in an overall process F:M ratio that still remained within the normal range while avoiding prolonged exposure of the activated sludge ecosystem in each aeration column to an F:M ratio below 0.5 mg of BOD/(mg of MLSS·d).

Process Performance

Figure 3 shows the variations of the F:M ratio and MLSS of the activated sludge simulator during conventional operation and FFO. The F:M ratio increased from 0.18 g of BOD/(g of MLSS·d) during the process startup to reach a consistent value of 0.45 g of BOD/(g of MLSS·d) during the first 86 d of conventional operation. During this period, the MLSS decreased from the initial seed of 5000 mg/L to a stable level of 2200 mg/L, and the microbial ecosystem was acclimatized to the process conditions. The F:M ratio ascended and the MLSS descended in the two aeration columns in similar trends. From d 87, the system was switched to the FFO. The feasting unit was fed with the synthetic wastewater at 0.36 L/h and the RAS was maintained at 0.062 L/h to result in the relatively low MLSS of 1700 mg/L. In the fasting unit, on the other hand, the MLSS gradually reached a relatively high level of 5000 mg/L by setting the influent flow rate and RAS at

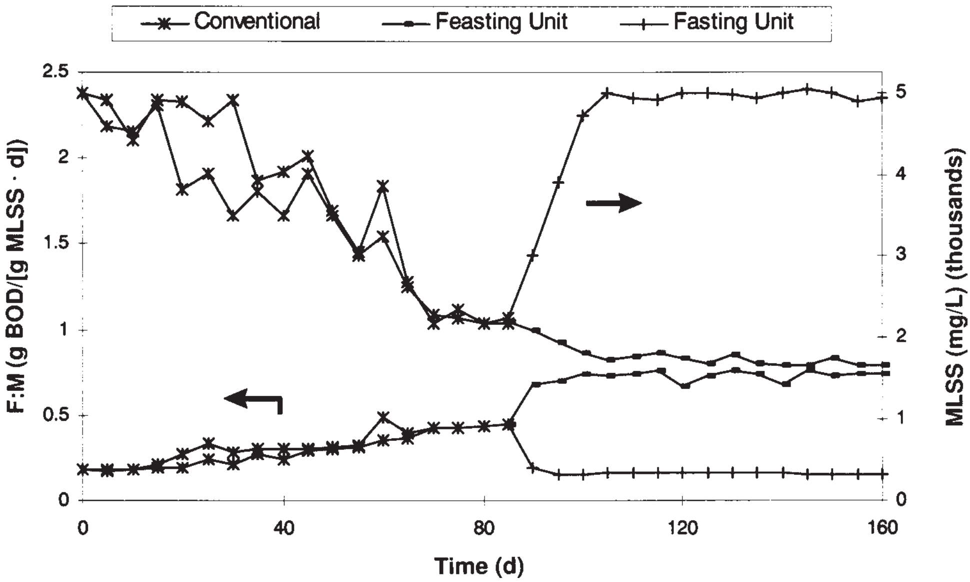

Fig. 3. Variation of F:M ratio and MLSS.

0.24 and 0.205 L/h, respectively. Through the manipulation of these operating parameters, the F:M ratios of the feasting and fasting units maintained at relatively stable values of 0.75 and 0.16 g of BOD/(g of MLSS·d), respectively.

The sludge volume index (SVI) was used as the indicator for sludge settleability and, hence, the degree of dominance of filaments in the microbial ecosystem in the aeration columns of the activated sludge simulator system. Figure 4 shows the variation of activated sludge process performance in terms of SVI and BOD_5 removal efficiency. During the period of conventional operation, the SVI increased from the initial range of 50–70 mL/g to a level as high as 300 mL/g after 86 d of exposure of the activated sludge to an F:M ratio of 0.45 g of BOD/(g of MLSS·d). A sample of the activated sludge at this point showed overgrowth and an overwhelming dominance of filamentous *N. amarae* (Fig. 5).

Within 20 d after the simulator was switched to the FFO, the SVI rapidly returned to a healthy level of 70 mL/g. The values gradually dropped further and stabilized at about 60 mL/g during the next 30 d of operation. SVI values of about 55 and 65 mL/g were observed in the feasting and fasting units, respectively. The lower SVI in the feasting unit compared to that in the fasting unit agreed with previous observations that nonfilamentous bacteria grew better than filamentous bacteria under higher F:M ratios *(14)*. The SVI profiles indicated that the FFO rapidly and effectively suppressed filamentous overgrowth and improved sludge settleability. The process configuration under the FFO enabled the settled activated sludge from the settling tank to be randomly recycled between the feasting and

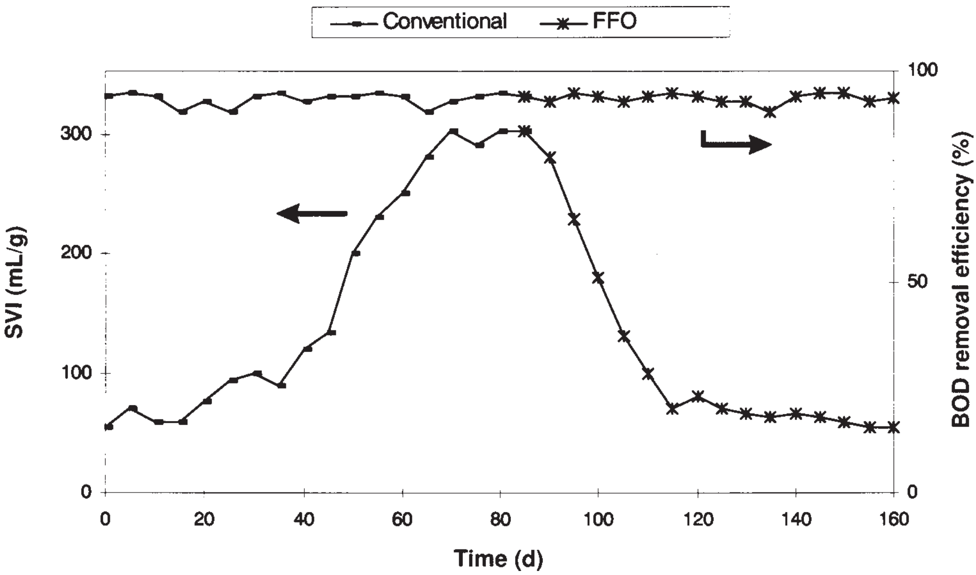

Fig. 4. Variation of SVI and BOD removal efficiency.

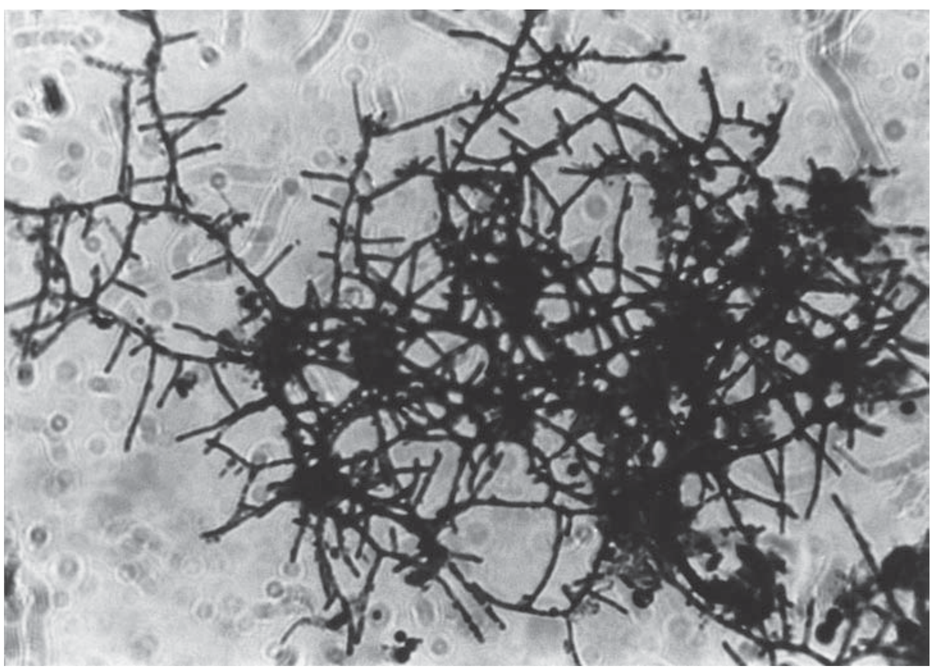

Fig. 5. Filamentous dominance in activated sludge (×1000).

fasting units, thus avoiding prolonged exposure of the sludge to a consistently low F:M ratio. This created a favorable environment for the nonfilamentous bacteria to gain dominance in the ecosystem.

On the other hand, the BOD removal efficiency during the FFO did not significantly differ from that during conventional operation. The residual BOD_5 of the treated effluent BOD_5 maintained at about 26 mg/L, achieving a consistent BOD removal efficiency of 94%. The FFO rendered a relatively high F:M ratio in the feasting unit and a relatively low F:M ratio in the fasting unit that arrested excessive growth of filamentous bacteria. However, the overall process F:M ratio of 0.46 g of BOD/(g of MLSS·d) still fell within the normal working range, and the FFO did not cause any observable adverse effect on BOD removal efficiency and process stability.

Conclusion

The growth kinetics and interspecies interaction in the activated sludge processes provided the theoretical basis for the development of the FFO. The activated sludge process under FFO was shown to be effective in improving the microbial population balance and sludge settleability without any significant adverse effect on the process treatment performance and stability.

Acknowledgments

This work was supported by the Hong Kong Polytechnic University Research Committee under grant YB22 and by the Sewerage Department of the Ministry of the Environment of Singapore.

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