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Nocardia foaming control in activated sludge process treating domestic wastewater

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Abstract

In this study, filamentous bacteria (*Nocardia amarae*) were identified as the major causal microorganism in foaming sludge. The results of growth kinetics study indicated that *N. amarae* had a relatively strong affinity for non-readily biodegradable fatty acids. *N. amarae* was able to consume various fatty acids at a constant growth yield from 0.413 to 0.487 g/gCOD. Under common *F*/*M* ratio (less than 0.5 gBOD/gMLSS/d) used in activated sludge processes, specific growth rate of *N. amarae* was found to be more significant than that of non-filamentous bacteria. Based on this feature, a novel technique feast–fast operation (FFO) was developed for the foaming control. The sludge volume index (SVI) rapidly decreased from 300 to 80 mL/g and further stabilized at about 70 mL/g and the system was free from stable foam, while the BOD removal efficiency was maintained above 95%. This control technology effectively suppressed the overgrowth of filaments and improved the settleability of activated sludge without adverse effects on the treatment performance and the process stability.

Keywords: Foaming control; Wastewater treatment; Filamentous bacteria; Long-chain fatty acids

1. Introduction

In recent decades, activated sludge process is accredited to be the most widespread technology for treating various types of wastewater such as domestic sewage and industrial effluent (Martins et al., 2004). However, since its development in 1914, operation problems and deterioration of treatment efficiency due to bulking sludge have been cited as common problems in activated sludge processes around the world (Graveleau et al., 2005; Krhutkova et al., 2002).

Activated sludge process is a biological process which depends on the profound balance ecosystem among the floc-formers, such as *Pseudomonas* spp., *Zoogloea* spp., *Alcaligens* spp., and *Achrombacte*r spp., and the filaments, such as *Nocardia* spp., *Rhodococcus* spp., Type 1863 and *Microthrix* spp. (Martins et al., 2004; Rossetti et al., 2005; Wagner et al., 2002). They are the key organic degraders and offer the skeletal matrix for the formation of compact flocs. However, the overgrowth of filamentous microorganisms is generally identified as the main origin of foaming, which deteriorates sludge settleability, and results in decreased sludge settling rate and incompact sludge blanket (Jenkins et al., 2004; Jolis et al., 2006; Tsang et al., 2007).

Physical factors such as process design parameters (e.g. aeration basin configuration and feeding regime) and operating conditions (e.g. high mixed liquor suspended solids (MLSS), low sludge return rate and low dissolved oxygen) are contributed to the growth of filamentous bacteria (Martins et al., 2003, 2004; Metcalf and Eddy, 2003). Chemical factors such as nutrient balance and substrate composition also play an important role in governing the filamentous overgrowth (Liu and Liu, 2006; Tsai et al., 2003). The nonionic and self-producing surfactants also significantly boosted the foam generation and stability (Iwahori et al., 2001; Pagilla et al., 2002; Theander and Pugh, 2003).

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Nomenclature

Biochemical oxygen demand (BOD) (mg/L)	Mixed liquor suspended solid (MLSS) (mg/L)
Chemical oxygen demand (COD) (mg/L)	Saturation constant (K_s) (gCOD/L)
Dry cell mass (g/L)	Sludge volume index (SVI) (mL/g)
F/M ratio (gBOD/gMLSS/d)	Specific growth rate (μ_m) (1/h)
Growth yield ($Y_{x/s}$) (g/gCOD)	

Bulking and foaming problems have been alleviated by addition of toxic chemicals such as chlorine or hydrogen peroxide to the aeration tank or the return sludge line (Chang et al., 2004; Ramothokang et al., 2003). Metal ions such as calcium, magnesium, iron (Philips et al., 2003; Thompson and Forster, 2003; Agridiotis et al., 2007), synthetic polymer (Juang, 2005), and multi-component additive (Seka et al., 2001) are observed to control bulking effectively. However, these chemical treatment methods are costly and, most importantly, they only offer short-term solution as bulking and foaming will resume when chemical additions are stopped. Kinetic selection is an alternative to control filamentous overgrowth specifically under low F/M condition, it was first published by Chudoba et al. (1973). The theory stated that substrate concentration gradient favors the growth of floc-formers, instead of filamentous bacteria, among the activated sludge microbes.

Although many studies have been carried out, the root causes of filamentous overgrowth are still not fully understood and contradicting views remain (Martins et al., 2004), and not much detailed comparison of the growth characteristics is done between floc-formers and filaments. The effects of the amount and the types of substrates on growth kinetics of floc-formers and filaments are also not clearly identified. Therefore, a comprehensive understanding of filamentous growth is essential for more effective control. In addition, universal filamentous control strategy is still unavailable; a cost-effective method should be developed to solve this problem, which commonly occurrs in the activated sludge process treating domestic wastewater with high concentration of fatty acids, without affecting the treatment performance.

In this study, the predominant microorganisms in the foaming sludge collected from Shatin and Tai Po Sewage Treatment Works in Hong Kong were identified. The effects of common fatty acids on the filamentous bacteria and the foaming mechanism were investigated. Studies and comparisons of growth kinetics of filamentous and non-filamentous bacteria in activated sludge were also carried out. By the use of growth kinetic of *N. amarae* as a theoretical basis, a new activated sludge operation strategy was interpreted for foaming control.

2. Methods

This study was divided into three parts. In Part A, the cell culture was prepared from the activated sludge processes in Shatin and Tai Po Sewage Treatment Works for the determination of the predominated filamentous microorganism. The growth of filaments under various chain lengths and concentrations of the carbon source was also investigated. In Part B, the pure cultures of *N. amarae* and *Pseudomonas aeruginosa* were sourced and examined in order to monitor their growth rates under different fatty acids as sole carbon source. In Part C, according to the results obtained from Parts A and B, a novel activated sludge system was designed and studied by altering the process operation parameters to investigate the effectiveness for foaming control.

2.1. Part A

2.1.1. Cell cultures

The microorganisms in sludge samples collected from local wastewater treatment plants were isolated by plated culture with Czapek's agar supplemented with 0.4% yeast extract, and incubated at 28 °C for 3 weeks. The bacteria were identified according to the criteria adopted by Blackbeard et al. (1988) and Jenkins et al. (2004). The isolated bacteria were cultured in 500 mL shake flasks with 100 mL sterilized LB on an orbital shaker at 28 °C and 200 rpm for 5 days. The pure cultures were then separately inoculated in shake-flasks with (i) minimum salt medium (MSM) added with various general sewage fatty acids as sole carbon source, and (ii) autoclaved raw sewage added with different fatty acids.

2.1.2. Foaming stability test

Fatty acid solutions (0.5 g/L) were solubilized by 1 N NaOH, 20 mL of acid solution was added into 980 mL of activated sludge with MLSS of 3400 mg/L. Five-hundred millilitre of the mixture was placed in a 1 L graduated cylinder and aerated with an air flow rate of 2 L/min through a sintered-sand diffuser for 60 s. The foam height was recorded at 15 s intervals during aeration and stationary periods (Tsang et al., 2006). This procedure was repeated for the concentrations of fatty acids of 1.0 g/L and 1.5 g/L.

N. amarae in shake-flask cultures were yielded by centrifugation, then washed twice and re-suspended in distilled water to give a 20 g/L suspension. 5, 10, and 15 mL of the suspension were added to 500 mL of activated sludge with MLSS of 3400 mg/L, respectively. The same test procedures as described above were carried out.