The effect of reactor configuration and operational mode on Microthrix parvicella bulking and foaming in nutrient removal activated sludge systems

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Abstract Three bench-scale nutrient removal activated sludge units were used to examine the effect of the reactor configuration and the intermittent aeration mode on the growth of Microthrix parvicella. According to the results, the plug flow configuration seems to achieve satisfactory Microthrix parvicella control. The imposed concentration gradient for both RBCOD and SBCOD creates a selective advantage for the floc forming bacteria throughout the system (both the anoxic and oxic zones) and limits Microthrix parvicella growth. In terms of the operational mode, the intermittent aeration CSTR nutrient removal system promotes the growth of M.parvicella and deteriorates the settling characteristics of the activated sludge.

Keywords Bulking; foaming; intermittent aeration; Microthrix parvicella; nutrient removal; plug flow

Introduction Microthrix parvicella is the most dominant filamentous species causing bulking and foaming problems in nutrient removal systems (Eikelboom et al., 1998). Pure culture and activated sludge studies on the physiology and metabolic activities of M. parvicella indicate that anaerobic and anoxic selectors cannot achieve sufficient Microthrix parvicella control because this bacterium can either use nitrate as electron acceptor and/or polyphosphate as energy source anaerobically at rates comparable to floc formers or can grow on long chain fatty acids that are slowly hydrolyzable and cannot be removed in a selector. On the other hand reactor configuration and operational mode appear to be important factors that influence the growth of Microthrix parvicella. Therefore laboratory-scale activated sludge experiments were conducted to study their effect on the settling characteristics of the activated sludge and specifically to evaluate possible control strategies for suppressing the growth of M. parvicella in nutrient removal systems.

Experimental material and methods
Three continuously fed bench-scale activated sludge systems were set up; one biological nitrogen removal (predenitrification–nitrification) completely mixed system, one biological nitrogen removal (predenitrification–nitrification) plug flow system and one intermittently aerated completely mixed system. All systems were inoculated with bulking sludge from the Metamorphosis Sewage Treatment Works (MSTW) containing low F/M filaments dominated by Microthrix parvicella (FI = 4).

The plug flow conditions were simulated through a cascade of four anoxic and four aerobic completely mixed reactors. The first anoxic reactor of the plug flow system was smaller to promote the selector effect. The intermittently aerated system was set up as a single reactor where both nitrification and denitrification took place by means of an intermittent aeration mode. The air supply was controlled to maintain a dissolved oxygen concentration around 3–4 mg/l to prevent growth of low DO filaments and to ensure that M.parvicella was not DO limited.
All units operated at a constant sludge age of approximately 18 days and a low organic loading around 0.25–0.30 kgCOD/kgSS-day. The performance of the bench scale units was assessed by routine measurements of COD, TSS, VSS, NH₄-N, NO₃-N, P and DSVI as well as microscopic examination of the sludges throughout the experimental period. To quantify the presence of M. parvicella a microscopic counting method was developed (Mamais et al., 1998). Finally, activated sludge samples were periodically taken from the continuous flow systems to conduct aerobic and anoxic substrate uptake batch tests.

Results and discussion

Three BNR systems (predenitrification CSTR, predenitrification plug flow and intermittent aeration CSTR) were operated in parallel for a period of four months and fed with MSTW primary effluent supplemented with 100 mg/l Tween 80 (polyoxyethylene sorbitan mono-oleate) a water soluble carbon source containing 0.22 g of oleic acid/g of Tween 80, to promote the growth of M. parvicella. The ability of long chain fatty acids to stimulate the growth of M. parvicella is well documented for both activated sludge studies (Mamais et al., 1998; Andreasen et al., 1998) and pure cultures (Slijkhuis et al., 1984; Slijkhuis and Deinema, 1988).

All systems demonstrated high total COD removal (73% for the predenitrification CSTR, 78% for the intermittent aeration CSTR and 76% for the predenitrification plug flow system). The desired plug flow pattern was evidenced by the high initial soluble COD removal rates, the presence of significant numbers of typical amorphous zooglea colonies, as well as the fact that the OUR (Oxygen Uptake Rate) obtained for the plug flow system was much higher (almost 2 times) than those of the other two systems. Both the predenitrification–nitrification systems exhibit high soluble COD removal under anoxic conditions (82% for the CSTR and 91% for the plug flow) with similar rates (8.9 mgCOD/gVSS hr for both CSTR and plug flow systems). However it should be noted that almost 74% of the soluble COD removal in the plug flow system was obtained in the first anoxic compartment, which exhibited a high COD removal rate of 38.6 mgCOD/gVSS hr. The high COD removal obtained in the first compartment in conjunction with a much higher than stoichiometry ΔCOD/ΔNO₃-N ratio of more than 13 indicate that a fraction of the soluble COD was removed by sorption to the biological flocs. As more than half of the influent soluble COD was in the form of oleate it can be stated that the above mentioned high initial COD removal rate can be partially attributed to sorption of oleate by the activated sludge flocs and not only to the immediate utilization of COD for denitrification. Similar findings were obtained by Mamais et al. (1998); based on Carbon Uptake Rate (CUR) batch experiments conducted using activated sludge samples and soluble COD in the form of oleate (long chain fatty acid, LCFA) the authors reported that the majority of soluble COD removal by sorption takes place during the first minutes of the experiments.

The two predenitrification–nitrification systems exhibited similar median DSVI values (Figure 1; 210 ml/gSS vs 180 ml/gSS for the CSTR and plug flow system respectively). However incidents of severe bulking occurred more often in the CSTR than in the plug flow system as evidenced by the higher 10% exceedence DSVI values obtained (360 ml/gSS vs 260 ml/gSS for the CSTR and plug flow system respectively). The intermittently aerated system experienced serious bulking problems throughout the period of the experiments, with median and 10% exceedence values of 350ml/gSS and 590 ml/gSS respectively. These results are in accordance with the results from bench-scale experiments reported by Gabb et al. (1996), where two intermittently aerated continuously fed completely mixed reactors developed sludges with DSVI values between 200 and 500 ml/gSS. It should be underlined that both CSTR systems experienced occasionally serious foaming problems, whereas biological foam was completely absent from the plug flow unit. The intermittently
aerated system especially developed a thick foam layer that lasted until the system’s temperature exceeded 20°C.

Figure 2 presents a comparison of the variation of the M. parvicella counts for the three BNR systems for a period of approximately 120 days. According to this figure it appears that the plug flow system developed a sludge with low M. parvicella content. On the other hand M. parvicella appeared to proliferate mostly in the intermittently aerated system. More specifically, M. parvicella counts obtained in the CSTR system ranged between $5.5 - 18.4 \times 10^6$ intersections/gVSS with an average value of $12.1 \times 10^6$ intersections/gVSS. M. parvicella content in the plug flow system ranged between $0.3 - 7.7 \times 10^6$ intersections/gVSS, with an average value of $3.6 \times 10^6$ intersections/gVSS. The intermittently aerated system exhibited higher M. parvicella counts ranging between $7.3 - 19 \times 10^6$ intersections/gVSS, with an average of $13.6 \times 10^6$ intersections/gVSS. Statistical analyses based on the experimental results, showed (at a 99% confidence level) that the plug flow M. parvicella counts were consistently and significantly lower than the values obtained for the other two CSTR systems, as well as that the intermittently aerated CSTR system produced the sludge most enriched with M. parvicella. Therefore it is postulated that satisfactory M. parvicella control may be achieved by the adoption of a continuous plug flow BNR (pre-denitrification–nitrification) system. Such a scheme results in a concentration gradient throughout the system (in the anoxic and aerobic zones) which provides a selective advantage to the floc formers for the removal of the RBCOD (readily biodegradable COD) and
SBCOD (slowly biodegradable COD) as well. Mamais et al. (1998), showed through batch experiments that the removal of long chain fatty acids by sorption was progressively reduced as the M. parvicella content of the activated sludge increased. Therefore by creating a concentration gradient for the SBCOD one can achieve i) utilization of the higher sorption capacity of floc formers to remove greater amounts of SBCOD and ii) avoidance of the dispersion of the soluble COD produced from the hydrolysis of the slowly biodegradable substrate fraction. Thus, both the readily and the slowly biodegradable fraction of COD potentially available for the proliferation of M. parvicella are significantly reduced.

The FI values (Filament Index) obtained in the plug flow system varied between 1.5–2.0 with an average value of 1.8. For the predenitrification–nitrification CSTR system the FI values ranged between 2.5–3.5 with an average value of 2.9, whereas for the intermittently aerated CSTR system the FIs ranged between 3.5–4 and the average value was 3.6. Microscopic observations revealed that M. parvicella was the dominant microorganism in all BNR systems for the period of 120 days. More specifically, the filamentous microorganisms developed in the predenitrification CSTR system in decreasing order of dominance were M. parvicella, Type 0092, Type 0041, Type 0675, H. hydrossis, and N. limicola. The most frequently observed filaments for the intermittently aerated CSTR system were M. parvicella, Type 0041, Type 0092, Type 0675, H. hydrossis, Type 0961, Type 0581 and Type 0914. The microscopic examinations of the plug flow system indicated that the dominant filamentous bacteria were in decreasing order of magnitude M. parvicella, Type 0092, Type 0041, Type 0041, Type 0675 and H. hydrossis.

**Conclusions**

From the lab-scale continuous flow experiments it can be concluded that the plug flow configuration in nitrogen removal systems seems to achieve a satisfactory M. parvicella control. The concentration gradient which is imposed for both RBCOD and SBCOD throughout the system provides a selective advantage to the floc forming bacteria to remove these fractions and thus to limit the growth of M. parvicella whose growth is mainly based on the SBCOD and its hydrolysis products. In terms of the operational mode it is evidenced from the experiments that the intermittent aeration in CSTR nutrient removal systems promotes the growth of M. parvicella and deteriorates the settling characteristics of the activated sludge.

**References**


