Chemical Engineering Journal 287 (2016) 38–46

Contents lists available at ScienceDirect

Chemical Engineering Journal

journal homepage: www.elsevier.com/locate/cej

Free nitrous acid inhibition of biological phosphorus removal in integrated fixed-film activated sludge (IFAS) system

P. Jabari [a,*], G. Munz [b], Q. Yuan [a], J.A. Oleszkiewicz [a]

[a] Dept. of Civil Engineering, University of Manitoba, 15 Gillson St., EITC Bldg E1-368, Winnipeg, MB R3T 5V6, Canada
[b] Dept. of Civil and Environmental Engineering, University of Florence, Via Santa Marta 3, 50139 Florence, Italy

HIGHLIGHTS

- DPAO/PAO were selected in IFAS system with different FNA levels during anoxic stage.
- DPAO in att. and sus. biomass adapted to higher FNA level, aerobic P uptake did not.
- NA inhibition threshold for DPAO was four times higher than the adapted conc.
- FNA inhibition of aerobic P uptake in biofilm was 20% of that in suspended biomass.
- The attached biomass could moderate the FNA inhibition of P removal in IFAS system.

ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form 19 October 2015
Accepted 27 October 2015
Available online 14 November 2015

Keywords:
Phosphorous removal
Integrated fixed film activated sludge (IFAS)
Free nitrous acid (FNA)
Attached biomass
Anoxic
Aerobic

ABSTRACT

Free nitrous acid (FNA) inhibition of anoxic and aerobic phosphorous removal in an integrated fixed-film activated sludge (IFAS) system with different FNA adaptation was investigated. A bench scale sequencing batch reactor (SBR) with plastic media was operated in an anaerobic/anoxic/aerobic sequence. During the anoxic period, nitrite was fed into the reactor at different concentrations to select for biomass adapted to 0.06 and 0.4 μg HNO_2-N L^{-1} of FNA during anoxic stage in Phase I and II, respectively. Long term anoxic/aerobic phosphorus removal was achieved in the IFAS reactor in both phases. In Phase I, aerobic phosphorous uptake was inhibited at higher level compared with anoxic phosphorus uptake. In Phase II, DPAO in both suspended and attached forms could adapt and were not inhibited at FNA level four times higher than the adapted concentration. The PAO's aerobic activity in Phase II, did not show significant adaptation and was inhibited at slightly lower level compared with that in Phase I. The FNA inhibition of aerobic phosphorous uptake rate in attached biomass was 20% of that in suspended forms. In batch testes with the FNA level was raised to three times the adapted concentration, the contribution of attached biomass to overall anoxic and aerobic phosphorus uptake increased by 20% and 39%, respectively. The attached biomass could allow an IFAS system to be less inhibited and better maintain phosphorous removal at sudden FNA inhibition events.

1. Introduction

Integrated fixed film activated sludge (IFAS) system allows the co-existence of attached and suspended sludge in one bioreactor. This facilitates higher biomass concentration and diverse solids retention times (SRT) that provides higher volumetric treatment capacity [1]. The advantages of IFAS technology have been demonstrated widely for nitrogen removal from wastewater [2,3]. Recent pilot and full-scale tests have shown that IFAS systems could sustain enhanced biological phosphorous removal (EBPR). Sriwiriyarat and Randall [4] reported that EBPR and nitrification in an IFAS reactor was achieved; however, its performance was affected by biomass distribution between media and suspended biomass and by the availability of carbon source in the anaerobic zone. In another study, Kim et al. [5] compared the nutrient removal performance of an IFAS system (media in the aerobic zone) with a conventional activated sludge process. In both systems, high COD and phosphorous removal were obtained at SRT of the suspended biomass ($SRT_{suspended}$) of 8 d. In all these studies phosphorous removal was carried out by suspended biomass of the systems.

The attached biomass in IFAS system could also contribute to biological phosphorous removal. Kodera et al. [6] successfully used

* Corresponding author.
E-mail addresses: umjabari@cc.umanitoba.ca (P. Jabari), giulio@dipolo.dicea.unifi.it (G. Munz), qiuyan.yuan@umanitoba.ca (Q. Yuan), jan.oleszkiewicz@umanitoba.ca (J.A. Oleszkiewicz).

http://dx.doi.org/10.1016/j.cej.2015.10.117
1385-8947/

the attached biomass in a trickling filter to recover phosphorus as a concentrated phosphate solution from the effluent of a non-bio P removal process. Phosphorous removal is conducted by selecting polyphosphate accumulating organisms (PAO) through consecutive anaerobic and aerobic/anoxic conditions. For activated sludge processes with suspended biomass these alternative conditions could be achieved in different tank of zone; while, for attached biomass, could be introduced in to the system in time sequences, as practiced in sequencing batch reactors (SBRs) [7]. The biological phosphorous removal has been mainly achieved through aerobic phosphorus uptake by PAO. A group of PAO, namely denitrifying PAO (DPAO), are able to uptake phosphorous using nitrite or nitrate as electron acceptor during anoxic condition [8]. The anoxic phosphorous uptake by DPAO is of interest because it allows a reduction of carbon and aeration demand and sludge production. The DPAO activity over nitrite in particular, bypasses the pathways of full nitrification and denitrification in conventional nitrogen removal, leading to considerable economic benefits [9].

The presence of nitrite could affect both anoxic and aerobic phosphorous uptake. Studies showed that inhibition of anoxic/aerobic phosphorous uptake rate is correlated with the concentration of free nitrous acid (FNA), the protonated form of nitrite [10,11]. Thus the concentration of FNA should be considered when the phosphorous removal inhibition at the presence of nitrite is investigated. The FNA concentration (HNO_2-N) is estimated using the equation $FNA = \frac{NO_2^-\text{-N}}{K_a \times 10^{pH}}$ where $K_a = e^{-2300/(T+273)}$ and T is temperature (°C) [12]. Meinhold et al. [13] observed that FNA at different concentration of 1.3–2.1 μg HNO_2-N L^{-1} (assuming tests were conducted at 20 °C) inhibited the anoxic phosphorous uptake rate. They postulated that different FNA thresholds could be caused by the variable condition of the activated sludge used in the kinetic tests. In their experiment activated sludge was taken at different days from an anoxic/aerobic reactor of Biodenipho™ pilot plant treating real wastewater. Saito et al. [14] used PAO/DPAO enriched sludge not adapted to FNA and found complete inhibition of aerobic phosphorus uptake rate and 64% inhibition of anoxic phosphorous uptake rate at FNA concentration of 1.5 and 3 μg HNO_2-N L^{-1}, respectively. Sin et al. [15] reported 75% and 37% inhibition of aerobic phosphorous uptake rate at 3 μg HNO_2-N L^{-1} of FNA in an activated sludge of a SBR and membrane bioreactor (MBR), respectively; the biomass in both reactors were intermittently exposed to nitrite, but the adapted FNA concentration was not determined. The studies by Yoshida et al. [16] and Saito et al. [17] showed that biomass adaptation should be considered when FNA inhibition of aerobic and anoxic phosphorous uptake activity are investigated.

So far, the inhibitory effect of FNA on aerobic and anoxic phosphorous removal have been studied mainly in suspended activated sludge systems. Zhou et al. [10] reported that anoxic phosphorous uptake rate in granular activated sludge were inhibited at slightly lower level compared with floccular biomass and proposed that attached biomass may have higher resistance to FNA inhibition compared with suspended biomass. In that study the granular and floccular biomass were selected in different bioreactors with different level of nitrite accumulation; while, the level of FNA adaptation was not reported. Yayi et al. [18] also observed a lower inhibition of DPAO activity in granular activated sludge compared with floccular biomass. In that study, DPAO were acclimated to nitrate as electron acceptor during anoxic condition. The fact that adaptation and other environmental factor could affect the FNA inhibition [19] requires that experiments comparing FNA inhibition in suspended and attached biomass is conducted with biomass ideally selected in the same reactor with known FNA adaptation.

The objective of this study was to assess the FNA inhibition of anoxic and aerobic phosphorous removal in an IFAS system in which, both suspended and attached biomass performs biological phosphorous removal. To characterize the effect of FNA adaptation, experiments were conducted in two phases with relatively low and high levels of FNA during anoxic conditions. Furthermore, the FNA inhibition of anoxic and aerobic phosphorous uptake in suspended and attached biomass were compared through kinetic tests using DPAO/PAO selected in the IFAS reactor with relatively high FNA adaptation.

2. Materials and methods

2.1. Experimental set up

IFAS system was set-up in a 3 L sequencing batch reactor (SBR). The SBR was seeded with sludge (both suspended and attached biomass) from a lab-scale IFAS system with alternating anaerobic/anoxic/aerobic cycle described by Jabari et al. [20]. The reactor was filled with media to 30% of the working volume. The media had a specific surface area of 500 m^2 m^{-3} (Anox Kaldnes, K1). Each cycle of operation consisted of 20 min filling period; 70 min anaerobic period, 225 min anoxic and 90 min aerobic period followed by 50 min settling and 25 min decanting period. HRT was 12 h and SRT of the suspended sludge was 10 d. Synthetic wastewater was used as feed with the following composition (all in mg L^{-1}): 240 CH_2COONa, 57.5 NH_4Cl, 51 K_2HPO_4, 83 $MgSO_4$, 13 $CaCl_2$, 65 yeast extract and 65 beef extract. The feed had 300 mg COD L^{-1}, 30 mg TN L^{-1} and 9 mg TP L^{-1}. During anaerobic and anoxic conditions nitrogen was purged in the reactor to prevent oxygen transfer from the air to the bulk. In aerobic condition, dissolved oxygen (DO) was controlled at 4.5 mg L^{-1}. The pH was controlled at 7.8 ± 0.1 using 0.1 M HCl and NaOH solutions. Reactor was operated at room temperature (22 ± 1 °C).

The study was run for 5 months and IFAS reactor was operated in two phases. In Phase I during anoxic stage, total NO_2^--N of 60 mg (20 mg NO_2^--N per litre of the reactor) were dosed in eight steps with an interval of 20 min. This manner of nitrite addition was performed to select for DPAO in low nitrite conditions. After one month steady state was achieved and reactor was operated for another month in this condition. In Phase II, total NO_2^--N of 105 mg (35 mg NO_2^--N per litre of the reactor) were dosed during anoxic stage in three steps to grow DPAO at elevated concentration of nitrite. Dosing was performed at minute 90, minute 150 with 15 mg NO_2^-–N L^{-1} each time, and at minute 240 with 5 mg NO_2^-–N L^{-1}. Steady state was achieved in three weeks and reactor was operated for two month under this condition.

2.2. Kinetic study

In both phases when steady state was achieved the inhibitory effect of FNA on DPAO and PAO were assessed through different kinetic tests. In Phase I nitrite of 20, 40 or 60 mg NO_2^-–N L^{-1} was dosed to the reactor (in total of 60, 120 and 180 mg NO_2^--N, respectively). Dosing was conducted in one step (spike dosing) at the beginning of anoxic condition. In Phase II, suspended and attached biomass were separated using a 1 mm pore size sieve. The size of activated sludge flocs are typically much less than 1 mm [21]. After first screening, separated media were mixed with the reactor effluent to separate the potential suspended biomass attached to media. The screening was conducted again and the liquid was added to suspend biomass medium. The concentration of mixed liquor suspended solids (MLSS) in batch reactors containing media (attached biomass testes) in all cases was below 60 mg L^{-1}. The suspended biomass were settled and collected as well. The screening was conducted slowly to avoid detachment of attached biomass from media. Each biomass was then divided into four batch reactors. The new batch reactors were assessed for one cycle with