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Importance of Control of Cycle Duration and Empty Bed Retention Time on Phosphorus Bio-accumulation in Continuous Alternating Anaerobic/Aerobic Biofilters

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ABSTRACT: Simultaneous removal and recovery of phosphorus (P) from municipal wastewater has been promoted as a global resource strategy. To improve the removal and recovery rate of phosphorus, the integrated role of anaerobic/aerobic cycle duration (T_{CD}) and the empty bed retention time (T_{EBRT}) on phosphorus removal or accumulation was observed for 9 months in a bench-scale continuous alternating anaerobic/aerobic biofilter system (CAABF). The study found that phosphorus accumulation deficiencies frequently occurred in the CAABFs, resulting from the over extension of T_{CD} after net phosphorus accumulation rates were maximized. In addition, the effect of T_{CD} on phosphorus accumulation efficiency was highly dependent on T_{EBRT}. A simplified empirical model was developed to elucidate the interrelationship between T_{CD}, T_{EBRT} and total phosphorus (TP) accumulation in the biomass.

Introduction

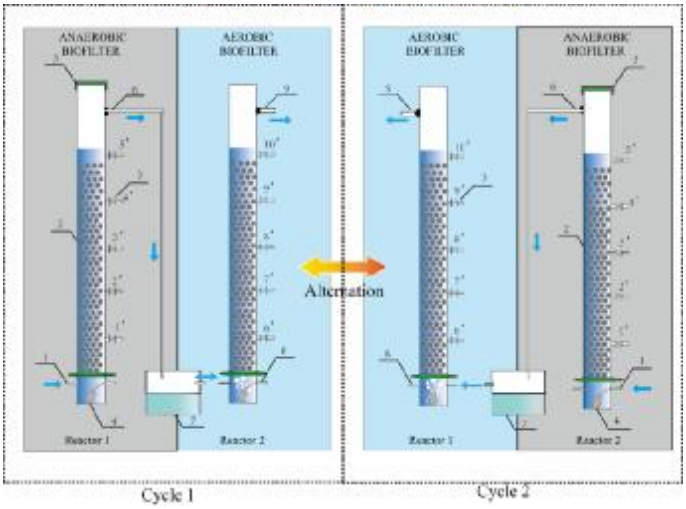
Direct recycling of phosphorus from low-P-containing wastewater is ineffective and expensive [1, 2]. However, research regarding exploiting a continuous P recovery process to accumulate P with a biofilteris still limited [3,4]. Enhanced biological phosphorus removal (EBPR) systems with phosphorus accumulating organisms growing on the packing material can be classified into two configurations: the sequencing batch biofilm phosphorus reactor (SBBR) and the continuous alternating anaerobic/aerobic biofilters system [5]. Phosphorus accumulation is highly dependent on the biomass amount, which is stable in suspended growth enhanced biological phosphorus removal (EBPR) systems but changeable in attached growth enhanced biological phosphorus removal (EBPR) systems. In addition, many of the reported investigations concerning EBPR efficiency in the CAABF were based on a fixed T_{EBRT} and frequent backwashing conditions. Unintentionally, these studies ignored the effect of the rate of phosphorus dynamic cycling between the biomass and the wastewater, which is of crucial importance in deciding the length of the anaerobic/aerobic phase (T_{CD}) in a continuous flow enhanced biological phosphorus removal (EBPR) system. Therefore, to identify the factor responsible for phosphorus accumulation deficiencies in the continuous alternating anaerobic/aerobic biofilter (CAABF), this study employed a CAABF for treating

synthetic municipal wastewater. The statistical method of two-way analysis of variance (ANOVA) was adopted to analyze the factors of T_{CD} and T_{EBRT} on phosphorus accumulation and the link between their controls. The results of the study may provide researchers or engineers a better understanding of CAABF operation, which may be used to improve P accumulation (or removal) in the biomass and also to improve the design or control strategies of the process.

Materials and Methods

Fig.1 shows the schematic diagram of the alternating anaerobic/aerobic biofilter system. Synthetic wastewater was pumped into the anaerobic biofilter(Reactor 1) from the bottom,and the effluent was collected in an intermediate container before it was pumped to the aerobic biofilter (Reactor 2). At the end of a cycle Reactor 2 becomes the leading filter and assumes the anaerobic condition, while Reactor 1 becomes the trailing filter and assumes the aerobic condition. The biofilters were initially inoculated with activated sludge obtained from Songjiang Waste Water Treatment Plant, Shanghai.

Fig. 1. Schematic diagram of the alternating anaerobic/aerobic biofilter system



Water samples were collected from the influent tank and sampling ports along the height of the two biofilters. Temperature, pH, oxidation-reduction potential (Ψ_{ORP}) and dissolved oxygen (ρ_{DO}) were measured with the WTW Multi 3410(Munich, Germany). TP concentration (ρ_{TP}) were measured using standard methods.

Results and Discussion

To understand the release and uptake behavior of TP in the biofilters, effluent TP concentration changes at various times over an anaerobic/aerobic phasetime of T_{CD} = 24 h under different T_{EBRT} *and* the maximum phosphorus release/uptake concentrations are shown in Fig.2. It was found to relate closely with the increase of PAO population and the amount of intracellular poly-P in the biomass [6,7]. Another approach in viewing the data in Fig.2 is that decreasing the T_{EBRT} of the biofilter's loadings of ρ_{SCOD} and TP, which accelerates the phosphorus dynamic cycling rate between the biomass and the wastewater.

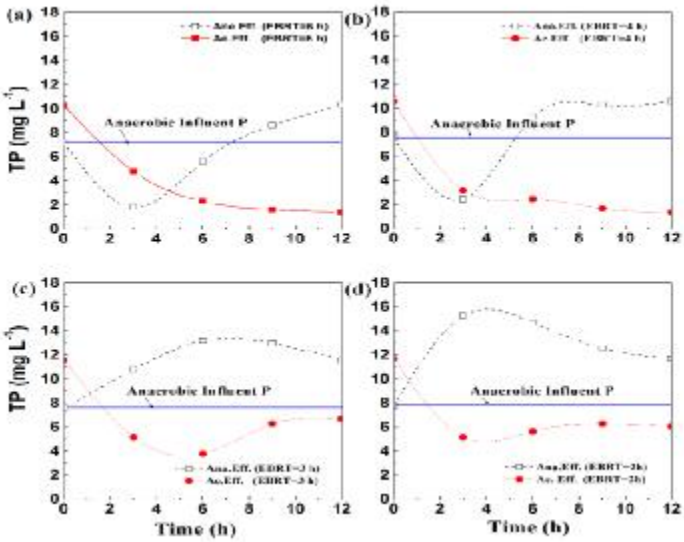


Fig.2. Phosphorus concentrations in anaerobic/aerobic effluent over an anaerobic/aerobic phase time for CD = 24 h after the conditions of the reactors being switched to the anaerobic /the aerobic.

Compared with SBBRs, the anaerobic/aerobic T_{CD} was longer than the T_{EBRT} of the continuous alternating anaerobic/aerobic biofilter (CAABF). Therefore, the volume of wastewater throughput within a T_{CD} would be several folds that of the biofilter available volume (or empty bed volume of the biofilter). From this, the relationship of T_{CD} and T_{EBRT} can be expressed as:

$$q \times T_{CD} = n \times V_{biofiter} = n \times q\ T_{EBRT} \rightarrow T_{CD} = n \times T_{EBRT}. \quad (1)$$

where q, T_{CD}, V and T_{EBRT} are the flow rate of wastewater treated in the system($L \cdot h^{-1}$), cycling duration time(h), empty bed volume of the biofilter(L) and empty bed retention time of the biofilter(h) respectively, and n is the number of bed volumes of wastewater treated in a cycling duration.

The fate of phosphorus distribution in the biofilter system could be described as follows:

(1) total mass of phosphorus (M_{inf}) entering the system with influent in one cycling duration, expressed as:

$$M_{int} = q \times T_{CD} \times \rho_{Pi} = q \times n \times T_{EBRT} \times \rho_{Pi}. \quad (2)$$

where ρ_{Pi} is the influent phosphorus concentration of the anaerobic biofilter($mg \cdot L^{-1}$).

(2) mass of phosphorus that is bio-transformed and stored in the biofilm (M_{bio}) after a complete phosphorus anaerobic release and aerobic uptake cycle (in one cycling duration),expressed as:

$$M_{bio} = (P_0 - P_A) \times \rho_{Mo} \times V. \quad (3)$$

where P_o is average percent phosphorus in the biofilm formed in the aerobic biofilter(%), $P_A$is the average percent phosphorus in the biofilm formed in the anaerobic biofilter(%), ρ_{Mo} is the biomass concentration of the aerobic biofilter($mg \cdot L^{-1}$).

(3) mass of phosphorus that is discharged with the effluent, expressed as:

$$M_{eff} = n \times q \times T_{EBRT} \times \rho_{Pe}. \quad (4)$$

where ρ_{Pe} is the effluent phosphorus concentration of the aerobic biofilter($mg \cdot L^{-1}$).Assuming that the phosphorus contained in the detached biomass in the aerobic effluent is ignored, the phosphorus mass balance within the biofiltersin an anaerobic and aerobic cycle could be expressed as follows:

$$q \times n \times T_{EBRT} \times (\rho_{Pi} - \rho_{Pe}) \times f = (P_0 - P_A) \times \rho_{Mo} \times V \quad (5)$$

where f *is* the phosphorus utilization coefficient.

Therefore, judging from the phosphorus mass balance, a simplified empirical mathematical model explaining the relationship between T_{CD} and T_{EBRT} was established as follows:

$$T_{CD} = \frac{(P_0 - P_A) \times \rho_{Mo} \times V}{(\rho_{Pi} - \rho_{Pe}) \times q \times f} == \frac{(P_0 - P_A) \times \rho_{Mo}}{(\rho_{Pi} - \rho_{Pe}) \times f} \times T_{EBRT} = nT_{EBRT}. \quad (6)$$

$$n = \frac{T_{CD}}{T_{EBRT}} = \frac{(P_0 - P_A) \times \rho_{Mo}}{(\rho_{Pi} - \rho_{Pe}) \times f}. \quad (7)$$

Conclusion

Experimental results showed that the two operating parameters, T_{EBRT} and T_{CD}, in an alternating anaerobic/aerobic biofilter system should be optimized simultaneously to avoid phosphorus accumulation deficiency. Shortening T_{CD} effectively and simultaneously increasing the hydraulic loading will accelerate the cycling of phosphorus uptake/release and the proliferation of PAOs. When the anaerobic phosphorus release decreased rapidly, at the same time aerobic phosphorus uptake also began to decrease leading to high effluent TP. On the other hand, under short T_{CD} and T_{EBRT} conditions, rapid phosphorus accumulation (indicated by phosphorus fraction in the biomass) may be achieved resulting in improved phosphorus accumulation efficiency.

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