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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Keywords: phosphorus accumulation & recovery; empty bed retention time; cycle duration; biofilter

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 (TCD) and the empty bed retention time (TEBRT) 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 TCD after net phosphorus accumulation rates were maximized. In addition, the effect of TCD on phosphorus accumulation efficiency was highly dependent on TEBRT. A simplified empirical model was developed to elucidate the interrelationship between TCD, TEBRT 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 biofilter is 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 TEBRT 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 (TCD) 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 would increase 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/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:

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

where $q$, $T_{CD}$, $V$, and $T_{EBRT}$ are the flow rate of wastewater treated in the system (L·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. **(1)** total mass of phosphorus ($M_{int}$) entering the system with influent in one cycling duration, expressed as:

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

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

2. **(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 $P_0$ 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 (%), $\rho_{Mo}$ is the biomass concentration of the aerobic biofilter (mg·L$^{-1}$).

3. **(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 $\rho_{Pe}$ is the effluent phosphorus concentration of the aerobic biofilter (mg·L$^{-1}$). Assuming that the phosphorus contained in the detached biomass in the aerobic effluent is ignored, the phosphorus mass balance within the biofilters in 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:
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.

Acknowledgements

This work was financially supported by the Natural Science Foundation of Shanghai (16ZR1402000) and the National Natural Science Foundation of China (51478099).

References


