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Relationship between Solid Retention Time and Phosphorus Removal in Anaerobic-Intermittent Aeration Process

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Solid retention time (SRT) is one of the most important control parameters in biological phosphorus removal. In this study, lab-scale biological nutrient removal (BNR) reactors using anaerobic-intermittent aeration (AIA) were operated at various SRTs (*i.e.*, 15, 20, and 30 d) to evaluate their phosphorus removal efficiencies. Sludge wasting load decreased as SRT increased; however, the phosphorus content in the biomass increased as SRT increased. The highest phosphorus removal efficiency was 93% at an SRT of 20 d and the phosphorus wasting load was also highest at that SRT, which indicates that the optimal SRT for the highest phosphorus removal is not proportional to the phosphorus content in the biomass. Aerobic digestion experiments were also carried out to determine the number of phosphate-accumulating organisms (PAOs) in the biomass produced in different reactors. All three activated sludges from BNR at SRTs of 15, 20, and 30 d showed a slower volatile suspended solid (VSS) destruction rate and a larger amount of phosphorus released than the conventional activated sludge (CAS), suggesting that the activated sludge from BNR has more PAOs than CAS. Also, the sludge at an SRT of 30 d showed a slower VSS destruction rate and a larger amount of phosphorus released than the sludge at an SRT of 15 d, suggesting that PAOs are more predominant at longer SRTs. Thus, to improve phosphorus removal efficiency, it is recommended that SRT be increased to maximize the number of PAOs in the system and that SRT be determined to maximize phosphorus wasting load.

[**Key words:** aerobic digestion, anaerobic-intermittent aeration, phosphate-accumulating organisms, phosphorus removal, solid retention time]

Solid retention time (SRT) is one of the most important control parameters in advanced biological nutrient removal (BNR). In nitrogen removal, the maintenance of a long SRT is desirable for nitrification because the growth rate of nitrifiers is lower than that of other microorganisms. However, the relationship between SRT and phosphorus removal has not been sufficiently investigated in previous studies of BNR.

SRT is controlled by the amount of wasted sludge in biological wastewater treatment plants, but it is difficult to evaluate the effect of phosphorus removal efficiency on SRT because there are several other factors such as food-to-microorganism (F/M) ratio, mixed liquid suspended solid (MLSS) concentrations, hydraulic retention time (HRT), and biomass yield/decay rate.

The United States Environmental Protection Agency (EPA) (1) reported that phosphorus removal efficiency of decreases, when SRT increases owing to a biomass yield rate decrease. However, Wentzel *et al*. (2) found that phosphate-accumulating organisms (PAOs) are predominant in systems with a long SRT, that phosphorus removal efficiency of increases because the decay rate of PAOs is relatively lower than that of other microorganisms and polyphosphate bacteria can retain more phosphorus than normal bacteria. Also, Randall *et al*. (3) reported that the phosphorus content in biomass increases but phosphorus removal efficiency shows almost no change as SRT increases. On the other hand, Barnard (4) reported that SRT plays a smaller role in phosphorus removal in practice than expected in enhanced biological phosphorus removal (EBPR).

Generally, EBPR requires alternating anaerobic-aerobic or anaerobic-anoxic conditions to enhance the growth of the PAOs responsible for phosphorus removal (5–21). Using intermittent aeration for EBPR, it is possible to easily control aerobic/anoxic phases by only on/off switching using aeration equipment. The advantages of intermittent aeration over conventional biological nutrient processes are as follows: (i) sequentially generated nitrification and denitrification reactions are carried out in a single reactor, (ii) intermittent aeration is easily applied and retrofitted to conventional secondary treatment, (iii) conserves energy for aeration, and (iv)

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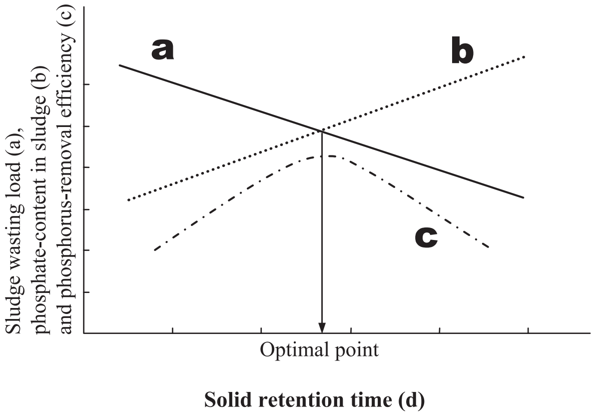

FIG. 1. Relationship between solid retention time (SRT) and phosphorus removal. a, Sludge wasting load; b, phosphate content in sludge; c, phosphorus-removal efficiency or phosphorus removal rate.

has the potential of simultaneously removing phosphorus and nitrogen. Also, intermittent aeration is probably be more effective for selecting biomass that takes up and stores substrates very rapidly because SBR is much more dynamic in terms of chemical oxygen demand (COD) variations than other systems (22).

So far, most studies have been limited to the investigation of optimal operation conditions for developing new processes. Therefore, the purpose of this study is to evaluate the relationship between optimal SRT and phosphorus removal rate with respect to the phosphorus content in biomass, the wastage of surplus sludge, phosphorus removal efficiency, and the number of PAOs. The drawback of general BNR is the optimal control of SRT because SRT for nitrogen removal rate should increase to improve nitrification efficiency but an increase in SRT has an adverse effect on phosphorus removal rate (23, 24). In other words, as SRT increases in the system sludge wasting load decreases whereas phosphorus content increases. We can determine the optimal SRT to increase the phosphorus removal efficiency of the system by controlling sludge waste load and the number of PAOs. It is hypothesized that the relationship between SRT and phosphorus removal efficiency would be the same as that shown in Fig. 1.

MATERIALS AND METHODS

Evaluation of phosphorus removal efficiency in AIA (experiment 1) To estimate phosphorus removal efficiency under the condition of an increasing SRT, an anaerobic-intermittent aerobic tank, shown in Fig. 2, was operated.

Air on/off was cycled at 30/30 min in an intermittent-aeration tank, and dissolved oxygen (DO) concentration was regulated using an aquarium diffuse aerator at 2.0 mg/*l* during the aerobic phase, whereas is was maintained at less than 0.06 mg/*l* during the anoxic phase. A mixed culture obtained from an activated-sludge tank in a livestock wastewater treatment plant in Yongin City, Korea was used as the inoculum.

Hydraulic retention time (HRT) was set at 1 h in an anaerobic tank (1.5 *l*), at 4 h in an intermittent-aeration tank (6 *l*), and at 3 h in a clarifier. Recycle rate was controlled by 100% of the influent flow. Temperature was maintained at 20±2°C. To maintain a suitable MLSS concentration in system and to control SRT, surplus sludge in the intermittent tank was always discarded immediately after aeration stopped. Synthetic wastewater of the following composition was used for reactor operation (in mg/*l*): Bacto-peptone and glucose as COD, 450; K_2HPO_4, 39; $(NH_4)_2SO_4$, 99; $MgSO_4 \cdot 7H_2O$, 50; $FeSO_4 \cdot 7H_2O$, 2; $CaCl_2$, 4; $MnSO_4 \cdot H_2O$, 5; $NaHCO_3$, 600; and KCl, 7. After the concentrated wastewater including the above components was maintained at 4°C, it was diluted and injected into the reactor in which the average concentrations of COD, total nitrogen (TN) and total phosphorus (TP) were 333 mg/*l*, 50 mg/*l*, and 7 mg/*l*, respectively.

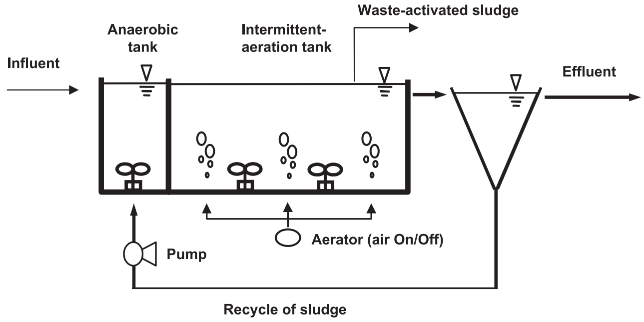

FIG. 2. Schematic diagram of EBPR system.

Phosphorus content in sludge (experiment 2) The phosphorus content in the sludge in the anaerobic and intermittent-aeration tanks was analyzed. The sludge was sampled in the intermittent-aeration tank at the end of the aerobic phase when sufficient phosphorus uptake by PAOs occurred. After the dry weight of the sludge was measured at room temperature, the sludge was digested at 250°C with sulfuric acid. Phosphorus content was then analyzed.

Aerobic digestion (experiment 3) Aerobic digestion was conducted to evaluate the effect of changing the distribution of PAOs with increasing SRT. Two types of suspended solid were used to compare the characteristics of digestion according to the distribution of PAOs in the sludge. Three sludge samples with SRTs of 15, 20, and 30 d were taken from the AIA tank and one sample was taken from an aerobic tank in a public wastewater treatment plant (20,000 m^3/d; Ansan, Korea) using conventional activated sludge. The volume of the batch reactor used was 2 *l*. Temperature was fixed at 23±2°C, and DO concentration was maintained between 5 and 6 mg/*l*. The digestion experiment was conducted for 40 d and the sampling interval was 3 d. The analyzed items were the concentrations of total suspended solid (TSS), volatile suspended solids (VSSs), PO_4^{3-}-P, COD, and the phosphorus content in the sludge.

Sampling and analysis Samples were taken from the reactor at appropriate intervals to analyze the performance of the treatment and immediately filtered through a glass-fiber filter (GF/C; Whatman, Hilsboro, OR, USA) with 1-µm pores. The concentrations of MLSS, mixed liquor volatile suspended solids (MLVSS), TSS, VSS, BOD, COD, and phosphate were analyzed in accordance with Standard Methods for the Examination of Water and Wastewater (25). Ammonia-nitrogen concentration was determined either by a colorimetric method using an indophenol method or ion-chromatography system (IC, Dionex DX-500; Dionex, Chicago, IL, USA). Nitrate concentration was determined using the same IC system equipped with an Ionpac AS11 analytical column and a CD20 conductivity detector. The analysis of phosphate content in the excess sludge was performed by using the ascorbic acid method (25). After the dry weight of the excess sludge was measured, the sludge was digested at 250°C using sulfuric acid for the analysis of phosphate content.