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COMPARISON OF COD, NITROGEN AND PHOSPHORUS REMOVAL BETWEEN ANAEROBIC/ANOXIC/AEROBIC AND ANOXIC/AEROBIC FIXED BIOFILM REACTOR USING SAC (SYNTHETIC ACTIVATED CERAMIC) MEDIA

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Abstract – In order to remove nitrogen and phosphorus simultaneously and to develop a compact process for retrofitting a conventional activated sludge system, a new fixed-biofilm reactor was designed and tested employing an operation strategy with three and two reaction phases: anaerobic/anoxic/aerobic (Run-1) and anoxic/aerobic (Run-2). Four kinds of HRT (4, 6, 8 and 10 h) were varied to investigate the effect of nitrification and denitrification in each reactor. The results of the experiments are summarized as follows. All removal rates of COD, T-N and T-P in the water treated in Run-1 were higher than those of Run-2. The average values of COD, T-N and T-P in the treated water were reduced to 5.0 mg/L, 5.6 mg/L and 3.1 mg/L in case of Run-1. The COD and T-N removal efficiencies of Run-1 were higher than that of Run-2, but the difference between Run 1 and Run 2 was almost negligible. More than 60 % T-P removal efficiency could be achieved when the HRT was above 8 hour, but the efficiency was sharply decreased to 36 % as the HRT was decreased to 4 hour in case of Run-1. Although the removal efficiency of T-P in Run-2 decreased by 56 % compared with that of Run-1, the fixed biofilm reactor using SAC media reduced the volume of reactor, and high-level COD and T-N removal from domestic wastewater was performed; stable effluent quality was thereby achieved. The performance of Run 2 with no anaerobic reactor was mostly similar to that of Run 1 with an anaerobic reactor, except for T-P removal. Hence, according to these results, anoxic and aerobic processes using SAC media could be possible for removing organics and nutrients from municipal wastewater, in case phosphorus removal is not considered for municipal wastewater with low concentration of phosphorus.

Key words : Fixed-film Reactor, Nitrification, Denitrification, Phosphorus Uptake, SAC Media, Anoxic Condition, COD/NO_x-N Ratio

INTRODUCTION

Adopting various process configurations may perform biological nutrient removal (BNR) from sewage and wastewater [Munch, 1996]. It is well known that nitrogen removal can be accomplished by nitrification, followed by denitrification in a BNR process [Liu, 1996]. One of the BNR processes was the AAO system using anaerobic, anoxic and aerobic reactors in series [EPA, 1993], and another was the A/O process using anoxic and aerobic reactors for removing nutrient laid emphasis on nitrogen [Chiu-Yang Chen, 1997]. Biological phosphorus removal can be obtained through a selection of bacteria capable of storing polyphosphate. The selection of these phosphorus-accumulating bacteria to anaerobic conditions alternating with oxidizing conditions [Kerm-Jesperson, 1994]. One process, which has recently demonstrated significant potential for BNR, is the biofilm process. This process differs from the activated sludge process in that the latter operates with the activated biomass suspended in the system, while it attaches to the carriers in the biofilm process, which means biomass grow and adhere to the surface of the carriers [Wang, 1991].

Barnard [1974] adopted a single sludge system to remove both nitrogen and phosphorus without adding chemicals. Anaerobic, anoxic and aerobic conditions are typical of those used in nutrient removal processes. Many systems have been developed in recent years to rearrange the layout of anaerobic, anoxic and aerobic reactors. However, some conflicts arise when employing such a single sludge system to remove nitrogen and phosphorus simultaneously. First, growth of nitrifiers is slower than that of heterotrophic bacteria. Therefore, operation using a long SRT should be adopted if improved nitrification is required. On the other hand, the system must be operated using a short SRT if phosphorus removal must be enhanced. Second, the carbon sources are generally not rich enough for denitrification since (a) the anoxic reactor is typically placed behind the anaerobic reactor and (b) the short-chain fatty acids (SCFA) are utilized primarily for phosphate release in the anaerobic reactor. Biofilm has a long sludge age attached bed, a high biomass concentration and stability in operation. Biofilm can be used to resolve the above-mentioned conflicts, that is, addition of a fully submerged fixed-film process to provide attached beds for bacteria

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[Su, 1996].

To remove organics, nitrogen and phosphorus simultaneously from sewage and wastewater, the modification of a conventional activated sludge system to an advanced treatment process requires additional space and cost. It becomes necessary to develop a new compact BNR process without any expansion of the space. In this study, two compact processes (anaerobic/anoxic/aerobic and anoxic/aerobic process) were compared. The fixed-film reactor by addition of SAC media could reduce HRT and accelerate the overall treatment since it combines the advantages of both activated sludge and attached biomass.

MATERIALS AND METHODS

1. Experimental Conditions

Two units of laboratory scale reactors capable of performing continuous experiments for nutrient removal were used; one unit (Run 1) included anaerobic/anoxic/aerobic reactors and the other (Run 2) was composed of anoxic/aerobic reactors in series.

A diagram of the Run 1 and Run 2 processes is provided in Fig. 1. The net volumes of the anoxic and aerobic reactors were each 15.0 L, anaerobic reactor 7.5 L, and the total net volume of all reactors was 37.5 L (Run 1) and 30.0 L (Run 2). All of reactors were filled with SAC (synthetic activated ceramic) media having a porosity of 66.5 %, a packing ratio of 15 % based on the volume of each reactor, and a specific surface area of 5.5 m^2/g. An agitator for mixing was installed in each of anaerobic and anoxic reactors. Air was supplied through two fine-bubble bar-type diffusers at the bottom of the aerobic reactors by a blower with a capacity of 150 L/min. Air flow rate in the aerobic reactor was kept constant at 16 L/min (20 °C, 1 atm) over a wide range of HRT (hydraulic retention time). Temperature of the anaerobic reactor in Run 1 was controlled at 37±2 °C using a temperature controller and the anaerobic reactor was made airtight on the top in Run 1.

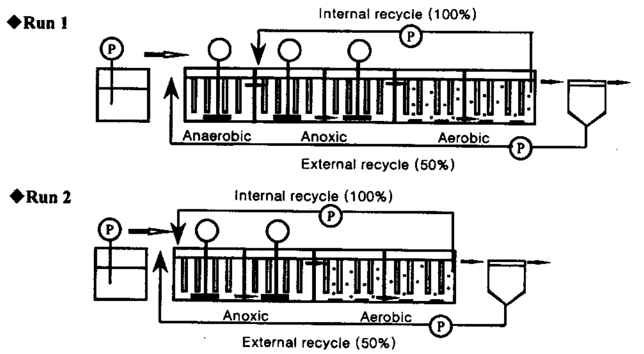

Fig. 1. Schematic configurations of the fixed-film biological

Table 1 shows experimental conditions used in this study. The influent was fed with synthetic wastewater of COD 200 ±20 mg/L, NH_4-N 20±2 mg/L and T-P, 8±0.5 mg/L. These are similar to typical raw influent values of a domestic wastewater treatment plant in Korea. Sodium bicarbonate buffer was added to prevent pH drop mostly caused by nitrification, and alkalinity in synthetic municipal wastewater was maintained at 200 mg $CaCO_3$/L.

2. Analysis of Samples

Influent samples were collected twice a week and effluent samples every 2 days. Samples for the determination of soluble components were immediately filtered using 0.45 μm filter paper and cooled in order to prevent further reaction after sampling. All the samples, except NO_x-N measured by HPLC (Waters, USA), were performed according to Standard Methods [19th, 1995].

RESULTS AND DISCUSSIONS

The performance characteristics between the control and the units were compared in terms of organic carbon, nitrogen and phosphorus. During the operation period, pH fluctuations were rarely observed in the biofilm reactor, reflecting the variation of pH values in the synthetic municipal wastewater. The pH was observed as 6.8-7.2 and 6.7-7.5 in the influent and effluent, respectively.

1. Removal of Organic Compounds

The COD removal rate in each reactor of two units (Run 1 and Run 2) is shown in Fig. 2. The results with these tests indicated that the COD removal rate slightly decreased as the HRT decreased. In two cases, COD removal efficiencies of 90.5-97.5 % in the Run 1 and 89.0-97.0 % in the Run 2 were achieved and COD removal efficiencies in the Run 1 were slightly higher than those of Run 2. In Run 1, the differences of COD removal efficiency in the anaerobic, anoxic and aerobic reactors resulted from the recycle flow (internal and external recycle) and microbial function of each reactor. COD concentrations removed in anaerobic reactor of Run 1 were caused by the dilution with the 50 % external sludge recycle flow and fermentation of anaerobic bacteria on the an-

Table. 1. Experimental conditions

Operating condition	Reactor arrangement	Media packing ratio (%)	Influent concentration (mg/L) COD	T-N	T-P	HRT variation (hr)
Run 1	Anaerobic (7.5 L)	15	200±20	20±2	8±0.5	10, 8, 6, 4
	Anoxic (15 L)	15				
	Aerobic (15 L)	15				
Run 2	Anoxic (15 L)	15	200±20	20±2	8±0.5	10, 8, 6, 4
	Aerobic (15 L)	15				

- Internal recycle (nitrified liquor): 100 %
- External recycle (settled sludge): 50 %

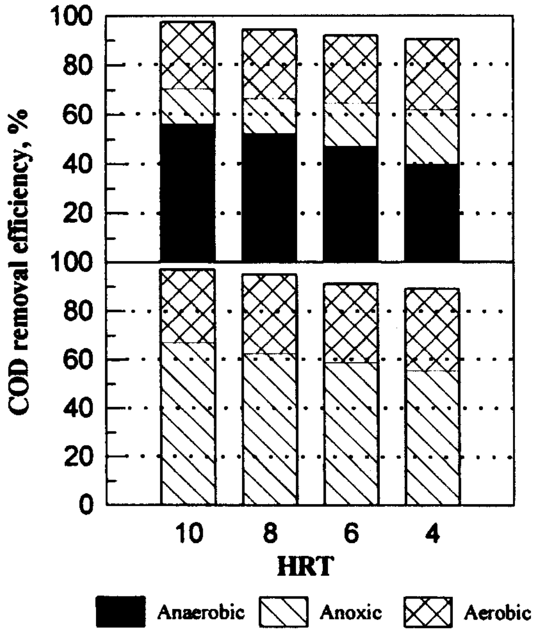

Fig. 2. COD removal efficiency vs. HRT.

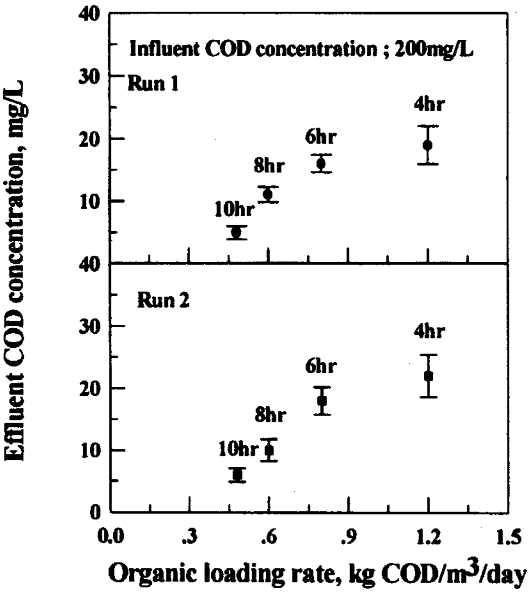

Fig. 3. COD concentration profiles vs. organic loading rate.

aerobic reactor. COD reductions of 14.0-22.4 % occurred in the anoxic reactor of Run 1. On the other hand, 55.5-67.2 % of the influent COD concentration was removed in the anoxic reactor of Run 2, which removal efficiencies were similar to the removal amounts in anaerobic and anoxic reactors of Run 1. This was caused by the dilution with 50 % external sludge recycle flow and 100 % internal nitrified liquor recycle flow and the COD reduction by the electron donor for denitrification on the anoxic reactor. And a major part of the COD reduction in the aerobic reactor was also observed. In the aerobic reactor, COD removal efficiencies were 26.9-28.3 % in Run 1 and 29.8-33.5 % in Run 2, respectively. These COD removals resulted from organic consumption of heterotrophic bacteria for the growth, and the removed COD was capable of helping phosphorus-accumulating bacteria to uptake phosphorus in the aerobic reactor. The COD reduction of Run 2 is slightly larger than that of Run 1 in the aerobic reactor.

These results are similar to Su and Ouyang's [1996] results that organic compound reduction was large in order of anaerobic>anoxic>aerobic reactor.

The COD concentration profiles in the effluent of two units (Run 1 and Run 2) are shown in Fig. 3. Fig. 3 presents the results obtained from two units in which different organic loading rates ranging from 0.48 to 1.20 kg COD/m^3/day were applied using synthetic wastewater of the 200 mg COD/L. Both cases indicated that the effluent COD concentrations increased as the flow rates increased. This trend was mostly similar to Run 1 with anaerobic/anoxic/aerobic reactors and Run 2 with anoxic/ aerobic reactors. A better COD removal efficiency in Run 1 was achieved than that of Run 2, but the differences of the two units were very slight. It is significant that Run 2 with no anaerobic reactor is capable of taking COD efficiency as high as that of Run 1 with an anaerobic reactor. As the HRT increased, the variation of effluent COD increased. The difference in the effluent COD concentration was 3.0 mg/L in HRT 4 hr while in other HRT conditions (6-10 hr) varied 0.9-1.1 mg/L. Despite organic loading the rate of HRT 4 hr was increased about three times higher than the condition of HRT 10 hr, only 14 mg/L of effluent COD concentration was increased.

It was represented that the effective removal of organic compounds could be achieved up to 1.20 kg COD/m^3/day in two units. It was found that COD removal efficiencies ranging between 90.5-97.5 % were appreciable to the 79.4-83.0 % obtained from the extended aeration submerged biofilm process at HRT 0.5-5 days [Wang et al., 1991] and the 89.7-91.3 % obtained from a combined process with activated sludge and fixed biofilm reactor at HRT 8-12 hr [Su and Ouyang, 1996].

2. Nitrogen Removal: Nitrification and Denitrification

Fig. 4 shows the concentrations of T-N, NH_4^+-N and NO_x-N in each stage of Run 1 and Run 2. The sum of NH_4^+-N and NO_x-N could be regarded as T-N, since there was no organic nitrogen in the influent of synthetic municipal wastewater. The differences of NH_4^+-N concentration in influent and anaerobic effluent were 5.14-6.88 mg/L on the HRT range of 4-10 hr in Run 1. NH_4^+-N concentrations removed in anaerobic reactor were caused by the dilution of external recycle and adsorption by anaerobic bacteria and SAC media on the anaerobic reactor [Lee et al., 1996]. It was supposed that NH_4^+-N reductions of 4.93-5.62 mg/L in Run 1 and 8.25-11.69 mg/L in Run 2 occurred by the effects of dilution of internal and external recycle and cell synthesis, partly in the anoxic reactor. NH_4^+-N reductions of 3.30-6.56 mg/L in Run 1 and 4.68-6.96 mg/L in Run 2 occurred in the aerobic reactors on the HRT range of 4-10 hr. The major part of the NH_4^+-N removal of two units was in the aerobic reactor and the fraction of NH_4-N removed was caused by nitrification of nitrifiers and assimilation by carboneous bacteria and nitrifiers in aerobic reactor.

Also, Fig. 4 indicates that as the HRT decreased from 10

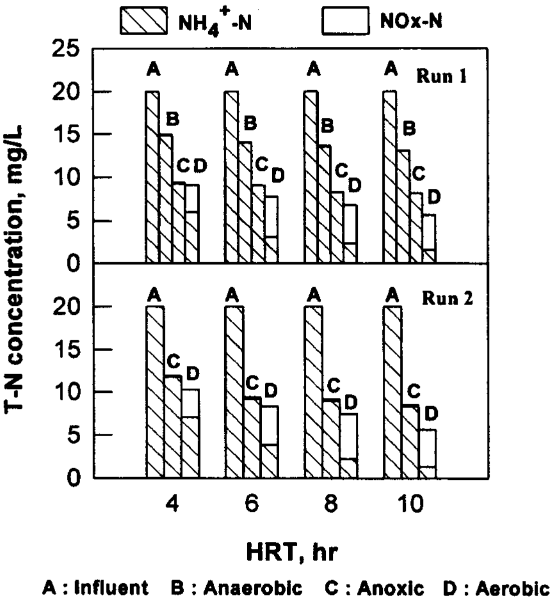

Fig. 4. Variations of T-N concentration vs. HRT.

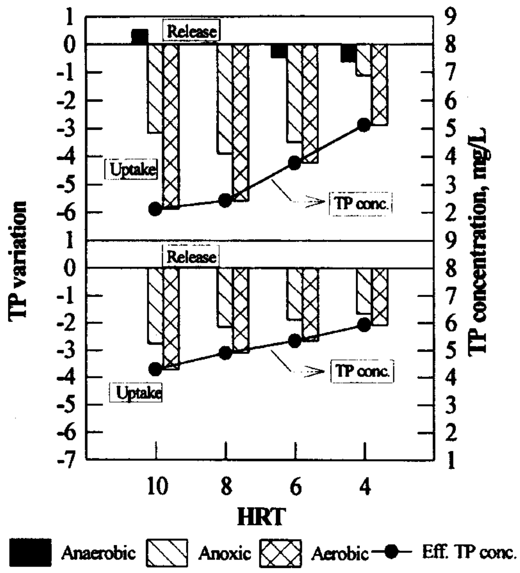

Fig. 6. Changes of the T-P concentration in each stage.

hr to 4 hr, NH_4^+-N concentration of aerobic effluent increased and NO_x-N concentration of aerobic effluent decreased. It was found that 56.4-73.7 % and 48.6-71.7 % of T-N removal efficiencies in Run 1 and Run 2 process are comparable with 59.0-74.4 % from extended aeration submerged biofilm process at HRT 0.5-5.0 days [Wang et al., 1991].

Fig. 5 shows the effects of C/NO_x-N ratio on denitrification in the Run 1 and Run 2 process. In anoxic conditions, the C/NO_x-N ratio is a very important parameter for the denitrification process and C/NO_x-N ratio also plays a significant role for the design and operation of the wastewater treatment plant. In the case of a lake of organic carbon in the anoxic reactor, the denitrification process could cause incomplete NO_x-N removal in the anoxic reactor and NO_x-N accumulation in following aerobic reactor; total nitrogen removal efficiency could decrease. In 1968, Barth et al. estimated that the BOD/NO_3-N ratio required to reduce nitrate nitrogen was 4.0. And the C/NO_x-N ratio was developed by considering that the COD used can be accounted for by cell synthesis and COD oxidation by NO_x-N reduction to produce energy for the cell [Sedlak, 1989]. In this study NO_x-N concentrations in the final effluent of the Run 1 and Run 2 were increased just a little during the operation period, as HRT was decreased from 10 hr to 4 hr. Because of the abundant carbon source and low NO_x-N loading rate in the anoxic reactor of the two units, the denitrification rate was nearly 100 % during operating days.

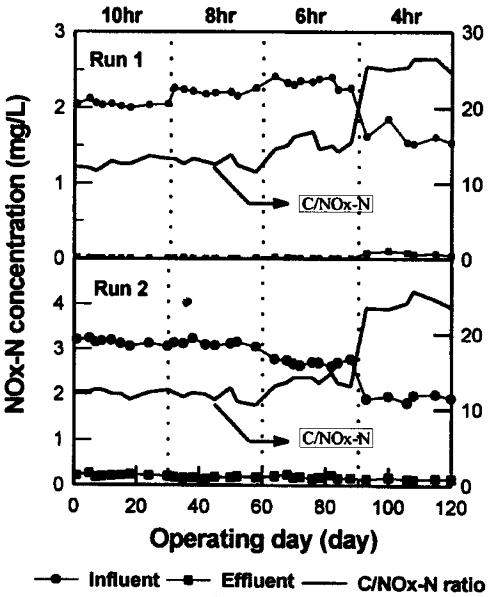

Fig. 5. Effect of C/NO_x-N ratio on denitrification.

3. Phosphorus Removal: P Release and P Uptake

Fig. 6 indicates the changes of the T-P concentration in each stage of Run 1 and Run 2. In Run 1, the varied amount of T-P concentration in the anaerobic reactor was −0.62-0.53, and T-P concentrations varied in the anaerobic reactor were the effects by the dilution of the external recycle and phosphorus release. There was some phosphorus release by phosphorus-accumulating bacteria like the *Acinetobactor ssp.* etc. [Kerm-Jesperson et al., 1994]. Nicholls and Osborn [1978] suggested that the anaerobic stage was necessary to allow the *Acinetobactor ssp.* to selectively take up acetates into the cells, using stored polyphosphates as the energy source and releasing phosphates to the liquid phase. The final effluent concentrations of the Run 1 and Run 2 process was 2.11-5.12 mg/L and 4.28-5.92 mg/L, respectively, as the HRT was decreased from 10 hr to 4 hr. And T-P reduction of 3.69-0.49 mg/L and 2.76-1.66 mg/L occurred in the anoxic reactors of Run 1 and Run 2 as the HRT was decreased. T-P removal efficiency of HRT 4 hr in Run 1 was only 36.00 %, but T-P removal efficiencies of HRT 6-10 hrs in Run 1 were 52.86-61.11 %, while T-P removal efficiencies of HRT 4-10 hr in Run 2 were 26.00-46.50 %. It was supposed that the anaerobic reactor needed to improve T-P removal efficiency in this study.

Fig. 7 indicates the relationship between the effluent SS con-

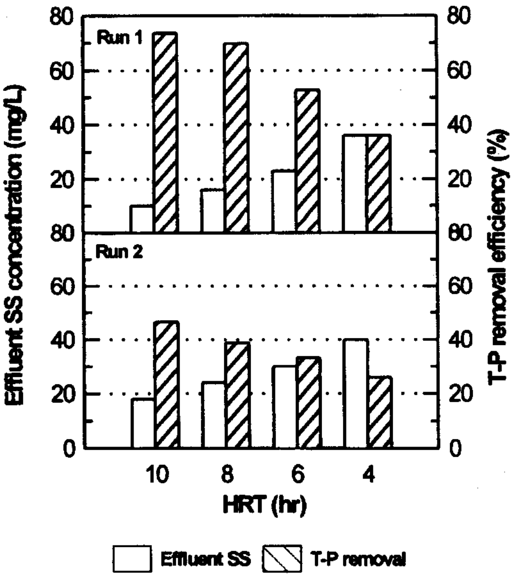

Fig. 7. Relationship between effluent SS conc. and T-P removal efficiency.

centration and T-P removal efficiency. The range of the effluent SS concentrations in the Run 1 and Run 2 process was increased 10-36 mg/L and 18-40 mg/L in final effluents, respectively, as the HRT was decreased from 10 hr to 4 hr. But T-P removal efficiency was decreased as the HRT was decreased. It was estimated that the decrease of T-P removal efficiency resulted from increasing SS concentration contained phosphorus with increasing the detachment of biofilm in each reactor by increasing substrate-loading rate. And it was also considered that the SS concentration is a parameter for controlling T-P concentration in fixed-film reactors due to a characteristic of fixed-film reactors of maintaining low suspended growth in each reactor.

CONCLUSIONS

1. The fixed biofilm reactor using SAC media performed with the COD removal efficiencies of 90.5-97.5, 89.0-97.0 % in Run 1 (anaerobic/anoxic/aerobic process) and Run 2 (anoxic/aerobic) at the organic loading rate of 0.48-1.20 kg COD/m^3/day. The COD removal efficiency of Run 1 was larger than that of Run 2, but the difference between Run 1 and Run 2 was almost negligible.

2. T-N removal efficiencies of 56.47-73.7, 61.3-72.5 % were obtained in HRT 4-10 hours of Run 1 and Run 2. T-N removal efficiency of Run 1 was larger than that of Run 2 since the nitrification and denitrification rate was slightly higher than that of Run 2. In other words, no significant difference can be found between the two cases.

3. T-P removal efficiency of HRT 4-10 hrs in Run 1 was 36.00-61.11 %, and T-P removal efficiency of HRT 4-10 hrs in Run 2 was 26.00-46.50 % because of the existing anaerobic reactor.

4. The performance of Run 2 with no anaerobic reactor was mostly similar to that of Run 1 with an anaerobic reactor, except for T-P removal. Hence, according to these results, an anoxic and aerobic process using SAC media could be possible for removing organics and nutrients from municipal wastewater, in case phosphorus removal is not considered for municipal wastewater with low concentration of phosphorus.

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