

## Removal of Nitrogen and Phosphorus Using a New Biofilm Process -INRS (Innovative Nutrient Removal System)

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**Abstract-** Adopting various process configurations may perform biological nutrient removal (BNR) from sewage. To get a compact BNR process, biofilm reactors were chosen for nitrification and denitrification. Enhanced biological nitrogen and phosphorus removal in a new fixed biofilm reactor was investigated in operation strategies with two reaction phases: anaerobic/anoxic/aerobic process with post-anoxic/aerobic biofilm process (Run 2A) and Run 2A with exogenous carbon sources for denitrifying and removing phosphorus (Run 2B). The influent used was "J" WWTP influent that consisted of wastewater from nearby a factory district area, leachate, and sewage. Therefore, the influent contained a great deal of refractory organic compound. The mean concentrations of COD,  $\text{NH}_4^+\text{-N}$  and T-P in the influent were about 297.0 mg/L, 64.92 mg/L and 2.63 mg/L, respectively. The C : N : P ratio of influent was 113 : 25 : 1 and it was not suitable for growth of microorganism compared with 100 : 5 : 1 of proper growth C:N:P ratio. But, at a total HRT of the system of 16 hours in Run 2, the system worked successfully obtaining removal of COD, T-N and T-P of the case of Run 2A, 80.1 %, 74.9 %, and 50.8 %, respectively, and Run 2B(c) with exogenous carbon source (Na-acetate) obtained 86.2 % T-N removal efficiency. The results of this research showed that an innovative nutrient removal system (INRS) process packed with SAC media could be applicable for treatment of nutrients from municipal wastewater.

Key words : Fixed-Film Reactor, Nitrification, Denitrification, Exogenous Carbon Source, Anoxic Condition, COD/ $\text{NO}_3\text{-N}$  Ratio

### INTRODUCTION

The topic of upgrading sewage treatment plants is particularly important in Korea at this time because of the large number of old facilities and the increasingly stricter discharge requirements imposed on wastewater treatment facilities.

The biofilm process differs from the activated sludge process in that the latter is operated with the activated biomass suspended in the system, while the former is operated with biomass both the attached biomass in the biofilms which grow and adhere to the surface of the carriers and the suspended biomass in the system. The system has many characteristics and advantages [Park et al., 1995, 1996a, b]. Nowadays, due to increasingly restrictive effluent nitrogen standards, attention is paid to create and improve denitrification capacity.

In the historical development of nitrogen removal processes, a move has been made from the use of an external carbon source as feedstock for the denitrifying bacteria in order to improve BNR process. It has been known wastewater with low COD/TKN ratio produces higher effluent  $\text{NO}_3\text{-N}$  and adversely affects poly-P microbes returning it to an anaerobic stage in BNR systems. The satisfactory operation of processes employing the wastewater's carbon content for denitrification presupposes a proper balance of carbon source to nitrogen in the incoming water.

Nitrogen removal from sewage using the fixed-biofilm reactors was investigated in lab scale over a 2-year period. This paper focuses on denitrification and phosphorus removal with the fixed-biofilm reactors operated by four different conditions.

### MATERIALS AND METHODS

#### 1. Experimental Conditions

Enhanced biological nitrogen and phosphorus removal in a new fixed biofilm reactor was investigated in operation strategies with three reaction phases: anaerobic/anoxic/aerobic process (Run 1A) and anoxic/aerobic process (Run 1B) [Park et al., 1998], anaerobic/anoxic/aerobic process with post-anoxic/aerobic biofilm process (Run 2A) and Run 2A with exogenous carbon sources for denitrifying and removing phosphorus (Run 2B). In the system, synthetic activated ceramic (SAC) media was packed in each tank for the attached growth of bio-

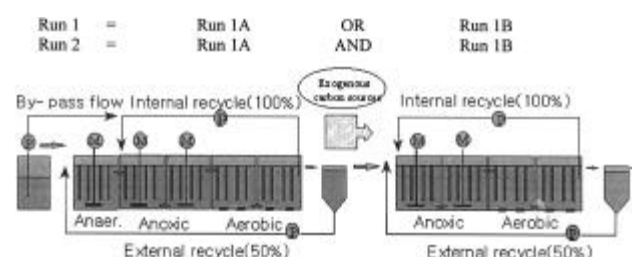


Fig. 1. Schematic diagram of fixed biofilm process in Run 1 and Run 2.

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**Table 1. Operating conditions in the fixed biofilm process at each stage**

Operating condition	Arrangement		Packing ratio (%)		HRT		Operating days (day)	Etc.
	1 <sup>st</sup>	2nd	1st	2nd	1st	2nd		
Run 1A	Anaerobic		15					
	Anoxic	-	15	-	8	-	120	Reactor vol : 37.5 L
	Aerobic		15					
Run 1B	Anoxic	-	15	-	8	-	120	Reactor vol : 30.0 L
	Aerobic		15					
Run 2A	Anaerobic		15					
	Anoxic	Anoxic	15	15	8	8	60	Reactor vol : 37.5 L (1st)+30.0 L
	Aerobic	Aerobic	15	15				
Run 2B	Anaerobic		15					
	Anoxic	Anoxic	15	15	8	8	50	Run 2A process+ *Addition of exogenous carbon sources
	Aerobic	Aerobic	15	15				

•\*Run 2B(a) : Glucose, Run 2B(b) : Methanol, Run 2B(c) : Na-acetate

•Run 1A : I. R. R. (Internal recycle ratio)=100 %, E. R. R. (External recycle ratio)=50 %, Bypass flow =40 %

•R-2A & R-2B : 1st stage : I. R. R.=100 %, E. R. R.=50 %, Bypass flow =40 %  
2nd stage : I. R. R.=100 %, E. R. R.=50 %

mass. A diagram of the fixed biofilm reactor is provided in Fig. 1.

The internal and external recycle ratios were 1.0 and 0.5, respectively, on the basis of the influent flow rate. The net volumes of Run 1A, Run 1B and Run 2 were 37.5 L, 30 L and 67.5 L, respectively. All of these reactors were filled with granular type SAC media having a porosity of 66.5 %; packing ratio of 15 % based on the volume of each reactor and a specific surface area of 5.5 m<sup>2</sup>/g. Operating conditions are provided in Table 1. The influent used was "J" WWTP ("Janglim" Wastewater Treatment Plant) influent that consisted of wastewater obtained from nearby a factory district area, leachate, and sewage. Therefore, the influent contained many refractory organic compounds. The mean concentrations of COD, NH<sub>4</sub><sup>+</sup>-N and T-P in the influent were about 297.0 mg/L, 64.92 mg/L and 2.63 mg/L, respectively.

## 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  $\mu$ m filter paper and cooled up to 0 °C in order to prevent further reaction after sampling.

All the samples, except NO<sub>3</sub>-N measured by HPLC (Waters, USA), were analyzed according to Standard Methods (19th,

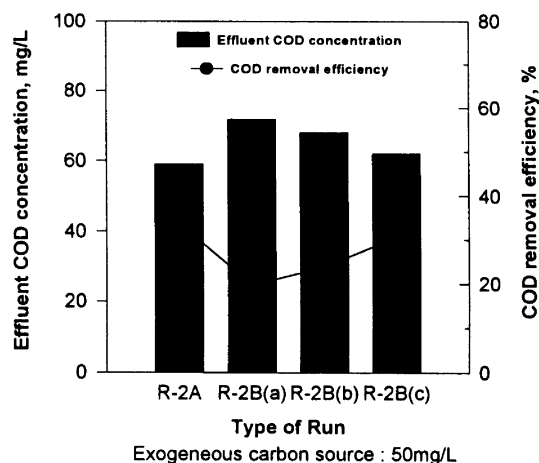
1995). The methods for sampling analysis are given in Table 2.

## 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 "J" WWTP influent. The pH was observed as 7.4-7.6 and 6.7-7.5 in the influent and effluent, respectively.

### 1. Removal of Organic Compounds

Fig. 2 shows COD removal efficiencies and effluent COD concentration obtained from Run 2A and Run 2B with exogenous carbon sources in second stage anoxic reactor. The results with these tests indicated that the effluent COD concentrations in the Run 2A and Run 2B were insignificantly different in



**Fig. 2. COD removal efficiencies and effluent COD concentration in Run 2A and Run 2B.**

**Table 2. Sample analysis methods**

Parameter	Method
DO	DO meter, model 58 (YSI Inc., USA)
PH	pH meter, HM-14P (TOA Electronics, Japan)
COD <sub>Cr</sub>	Open reflux methods (Standard Method 19th edition)
NH <sub>4</sub> <sup>+</sup> -N	Nesslerization method (Standard Method 19th edition)
NO <sub>3</sub> <sup>-</sup> -N	HPLC (Waters, USA)
T-P	Stannous chloride method (Standard Method 19th edition)
Alkalinity	Titration method (Standard Method 19th edition)

spite of addition of exogenous carbon sources at the anoxic reactor of second stage. In these cases, COD removal efficiencies of 33.9 % in Run 2A, 19.7 % in Run 2B(a), 23.9 % in Run 2B(b) and 30.7 % in Run 2B(c) were achieved and the effluent COD concentrations in Run 2A were lower than those of the Run 2B. But, the difference of effluent COD concentrations of each process fell into insignificance. Among the processes of Run 2B, differently from the other exogenous carbon sources, sodium acetate directly enters the pathways without any preliminary process while glucose and methanol must undergo a condensation process to form C-3 or C-4 intermediates before entering the TCA cycle [Ekama et al., 1984]. On the basis of the above catabolic pathway, it was found out that sodium acetate was the most effective exogenous carbon source in this study.

## 2. Nitrogen Removal : Nitrification and Denitrification

Fig. 3 shows the effect of exogenous carbon sources on  $\text{NO}_x\text{-N}$  removal efficiency in the Run 2B. Gerber et al. [1987] found that substrates such as acetate, propionate, butyrate and lactate consistently produce higher denitrification rates than substrates such as glucose, methanol and citrate. Carley and Mavinic [1991] also reported that acetate was the most efficient substrate for complete denitrification of a high ammonium land-fill leachate, followed by methanol and glucose. In this study, glucose, methanol and sodium acetate were used as exogenous carbon sources because three substrates were the most commonly used exogenous carbon sources, based on cost and availability on the denitrification study.  $\text{NO}_x\text{-N}$  removal efficiency in the Run 2B increased by addition of 50 mg/L of exogenous carbon sources. And, SCOD (Soluble COD)/ $\text{NO}_x\text{-N}$  ratio was controlled at 5.0 due to comparison of denitrification efficiency in the second stage of anoxic reactor. SCOD/ $\text{NO}_x\text{-N}$  ratio of 5.0 was chosen for achieving complete denitrification rate and 50 mg/L of each exogenous carbon source was added for attainment of SCOD/ $\text{NO}_x\text{-N}$  ratio of 5.0. Run 2B with addition of sodium acetate showed 95 % of  $\text{NO}_x\text{-N}$  removal efficiency in the second stage of anoxic reactor and this efficiency was higher than that of Run 2B(a) with glucose and Run 2B(b) with methanol. Sodium acetate was the most effective exogenous carbon source for deni-

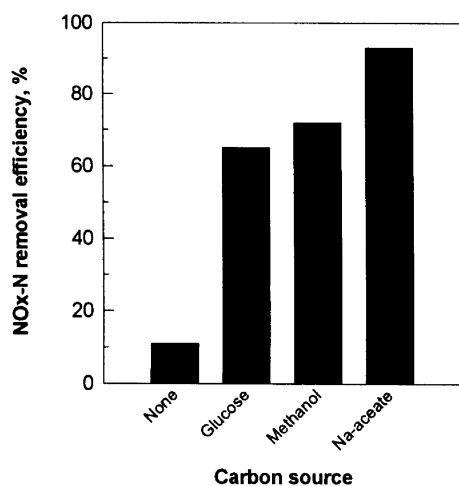


Fig. 3.  $\text{NO}_x\text{-N}$  removal efficiency vs. exogenous carbon sources.

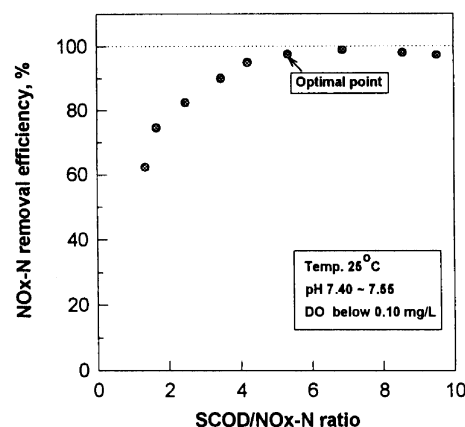


Fig. 4. Relationship between  $\text{NO}_x\text{-N}$  removal efficiency & SCOD/ $\text{NO}_x\text{-N}$  ratio.

trification. These results caused that sodium acetate directly enters the pathways without any preliminary processes such as EMP and PR pathway, while glucose and methanol must undergo a condensation process (glycolytic pathway) to form C-3 or C-4 intermediates before entering the TCA cycle. Recent research works demonstrated that glucose was a less reliable carbon source which often resulted in an inconsistent denitrification performance with nitrate removal efficiency fluctuating between 10 and 100 % [Manoharan et al., 1989; Carley and Mavinic, 1991].

Fig. 4 shows the effect of C/ $\text{NO}_x\text{-N}$  ratio on denitrification in the Run 2B. In anoxic condition, the C/ $\text{NO}_x\text{-N}$  ratio is a very important parameter for the denitrification process. C/ $\text{NO}_x\text{-N}$  ratio also plays a significant role for the design and operation of the wastewater treatment plant. In case of a lack of organic carbon in the anoxic reactor, the denitrification process could cause incomplete  $\text{NO}_x\text{-N}$  removal in anoxic reactor and  $\text{NO}_x\text{-N}$  accumulation in following aerobic reactor, and total nitrogen removal efficiency could decrease. Barth et al. [1968] estimated that the BOD/ $\text{NO}_3\text{-N}$  ratio required for reduction of nitrate nitrogen was 4.0. And the C/ $\text{NO}_x\text{-N}$  ratio was considered that the COD used can be accounted by cell synthesis and COD oxidation by  $\text{NO}_x\text{-N}$  reduction to produce energy for the cell [Sedlak, 1989]. In this study, the SCOD/ $\text{NO}_x\text{-N}$  ratio required for reduction of nitrate nitrogen was over 3.46. The denitrification rate was over 90 % at SCOD/ $\text{NO}_x\text{-N}$  ratio of 3.46, due to the abundant carbon source and low  $\text{NO}_x\text{-N}$  loading rate in the anoxic reactor; and complete denitrification rate was achieved over 5.0 of SCOD/ $\text{NO}_x\text{-N}$  ratio.

Fig. 5 shows the concentrations and removal efficiency of T-N,  $\text{NH}_4\text{-N}$  and  $\text{NO}_x\text{-N}$  in each process. The sum of organic-N,  $\text{NH}_4\text{-N}$  and  $\text{NO}_x\text{-N}$  could be regarded as T-N.  $\text{NH}_4\text{-N}$  removal of each process was mainly achieved in the aerobic reactor and this fact was caused by nitrification of nitrifiers and assimilation by carbonaceous bacteria and nitrifiers in the aerobic reactor. On the other hand, the denitrification of each process was mainly achieved in the anoxic reactor and fraction of  $\text{NO}_x\text{-N}$  removed was caused by denitrification of heterotrophic bacteria. In Fig. 5, as the HRT increased from 8 hr to 16 hr by transforming single stage to double stage,  $\text{NH}_4\text{-N}$  and organic-N concentration of effluent decreased. And as Run 2B(c) with addition of sodium acetate was increased  $\text{NO}_x\text{-N}$  removal

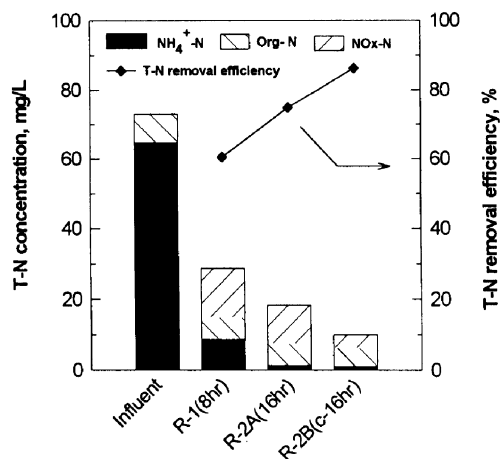


Fig. 5. Variation of T-N conc. in each process.

efficiency, total-nitrogen removal efficiency was increased from 74.9 % in Run 2A to 86.2 % in Run 2(c). According to these results, it is found out that Run 2B(c) process of 86.2 % T-N removal efficiencies with sodium acetate was the most effective process for T-N removal.

### 3. Phosphorus Removal : P Release and P Uptake

Fig. 6 shows the changes of the T-P removal efficiency in each exogenous carbon source used in Run 2B(a), Run 2B(b) and Run 2B(c). Kerrn-Jespersen et al. [1994] reported there was some phosphorus release by phosphorus-accumulating bacteria like the *Acinetobacter* sp. etc. Nicholls and Osborn [1978] suggested that the anaerobic stage was necessary to allow the *Acinetobacter* sp. to selectively take up acetates into the cells, using stored polyphosphates as the energy source and releasing phosphates to the liquid phase. In Run 2B(b) with methanol, the T-P removal efficiency was 50.0 % in the second stage anoxic reactor. In comparison with T-P removal of no exogenous carbon source and the other carbon sources, methanol of Run 2B(b) was the most effective carbon source for T-P removal. It generally showed that more phosphorus uptake and assimilation by carbaceous bacteria took place in

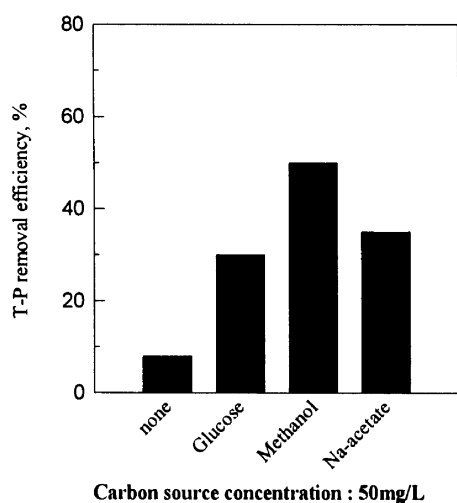


Fig. 6. Variation of T-P removal efficiency in each exogenous carbon source.

Run 2B with carbon source. The T-P removal efficiency of Run 2B(c) with sodium acetate was lower than that of Run 2B(b) with methanol. This seemed to be as a result of the competition between uptake of substrate (Na-acetate) by anaerobic bacteria in the anaerobic reactor and assimilation of substrate (Na-acetate) by heterotrophic bacteria in the anoxic reactor.

## CONCLUSIONS

In this study, the effect of nutrient removal in fixed biofilm processes with "J" WWTP influent was studied when four conditions were operated. Because "J" WWTP influent contained amount of NBDCOD fraction, we consider an advanced fixed biofilm process compared to an existing AS system. At the total HRT of the system of 16 hours in Run 2, the system worked successfully obtaining removal of COD, T-N and T-P of the case of Run 2A, 80.1, 74.9, and 50.8 %, respectively, and Run 2B(c) with exogenous carbon source (Na-acetate) obtained 86.2 % T-N removal efficiency. The results of this research showed that an innovative nutrient removal system (INRS) process packed with SAC media could be applicable for treatment of nutrients from municipal wastewater.

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