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BIOLOGICAL NUTRIENT REMOVAL CHARACTERISTICS OF LOW STRENGTH MUNICIPAL WASTEWATER

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Abstract – Most Korean community represents the primary effluent of 180 mg/L COD, 80 mg/L BOD, 25 mg/L TKN and 4 mg/L TP. A/O, A^2/O and MUCT (Modified University of Cape Town) systems were applied to laboratory scale reactor with a temperature of 10 to 20°C. A total of 6 hour hydraulic retention time including anaerobic, anoxic and aerobic zones was used with a maximum 3,000 mg/L MLSS to simulate the existing municipal plants. All BNR systems represented effluent BOD less than 10 mg/L. MUCT produced better quality; 0.5 mg/L SP (soluble phosphorus) with 10 mg/L TN vs 1.8 mg/L SP with 12 mg/L TN for A^2/O with the same internal recycle ratio. Performance of BNR systems would suggest the primary effluent used for this study represents a nature of slowly biodegradable COD. As that result, anaerobic fraction must be increased to attain lower effluent P concentrations. However, prefermentation to increase P removal was not necessary since P was also limited. Microbial mass fractions computed from COD and nitrogen mass balances suggested that poly-P microbes were about 33% in A/O and MUCT, denitrifier fractions were about 30% in A^2/O and MUCT. Nitrifier fractions were about 2%.

Key words: Biological Nutrient Removal, Low Strength Municipal Wastewater, A/O, A^2/O, MUCT, Population Dynamics

INTRODUCTION

Biological nutrient removal (BNR) systems have known to be sensitive to the wastewater characteristics varied with sewer systems used, types of detergent used, temperature and others. Generally, BNR systems have applied to BOD concentrations of more than 100 mg/L.

Most Korean community represents the primary effluent concentrations of 180 mg/L COD, 80 mg/L BOD, 25 mg/L TKN and 4 mg/L TP. Pitman et al. [1983] reported failure of 5-stage Bardenpho for low strength waste at Northern Works Plant in South Africa. However, successful operation of MUCT at Henrico County, Virginia in USA was reported by Wallis-Lage et al. [1992]. This study was conducted to compare basic performance characteristics of BNR systems for low strength waste expected from large municipalities in Korea.

MATERIALS AND METHODS

A/O, A^2/O, and MUCT systems were applied to laboratory reactor with a temperature of 10 to 20°C. A total of 6 h hydraulic retention time (HRT) including anaerobic (An), anoxic (Ax) and aerobic (Ox) zones was used with a maximum 3,000 mg/L MLSS (or 2,000 mg/L MLVSS=Mv) to simulate the existing municipal plants. The operating retention times were varied by zones; 1 to 2 h for the anaerobic, 1 h for the anoxic and 3 to 5 h for the aerobic. Table 1 shows the characteristics of primary effluent used for this study; 180 mg/L COD, 25 mg/L TKN and 4 mg/L TP.

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RESULTS AND DISCUSSION

1. Phosphorus Removal

Table 2 shows the summary of operating results and Fig. 1 represents phosphorus removal characteristics with various operating systems. Generally speaking, nitrate concentrations in return sludge greatly affected the effluent phosphorus concentrations as reported by Pitman et al. [1983] and Wallis-Lage et al. [1992]. This could be noticed during 20°C operations from 1 to 51 days (low NH_3N) in A/O and 41 to 70 days in A^2/O (low NH_3N) systems. However, MUCT system showed little nitrate effect during 20°C operation from 27 to 50 days.

Table 1. Characteristics of primary effluent, mg/L

Constituents	Range	Average
pH	6.5-7.5	7.1
COD		
Total	74-228	180
Sol	45-131	80
BOD		
Total	60-112	80
Sol	14-91	35
SS		
Total	47-260	120
Volatile	16-131	80
Nitrogen		
TKN	17-31	25
NH_3N	10-25	17
Phosphorus		
Total	1.2-6.7	4.0
Sol	0.8-4.4	3.0
Alkalinity	90-180	150

Table 2. Operating conditions and effluent concentrations

Items	A/O	A^2/O	MUCT
Operating HRT, h			
An	1-3	1	1-2
Ax	-	1	1
Ox	3-5	4	3-4
Temp. °C	10-20	10-20	15-20
Return activated sludge ratio, %	30-50	30-50	30-50
Internal recycle ratio, %	-	100	100
No. of operating days	120	70	50
Effluent BOD, mg/L	6.6(3.0)	9.6(5.3)	4.0(1.9)
COD, mg/L	18.4(4.8)	21.3(4.1)	19.7(3.4)
SS, mg/L	5.8(4.9)	6.3(3.5)	3.3(1.9)
SP, mg/L	1.1(0.7)	1.4(0.6)	0.3(0.2)
NH_3N, mg/L	9.2(4.6)	4.4(4.1)	2.3(1.1)
NO_3N, mg/L	8.8(3.7)	5.3(3.8)	3.2(2.8)
P/Mv, %	6.5(2.4)	4.4(1.9)	6.8(2.7)
NO_3N to An, mg/L	8.0(3.5)	4.5(4.2)	1.9(2.8)

( ) denotes standard deviation.

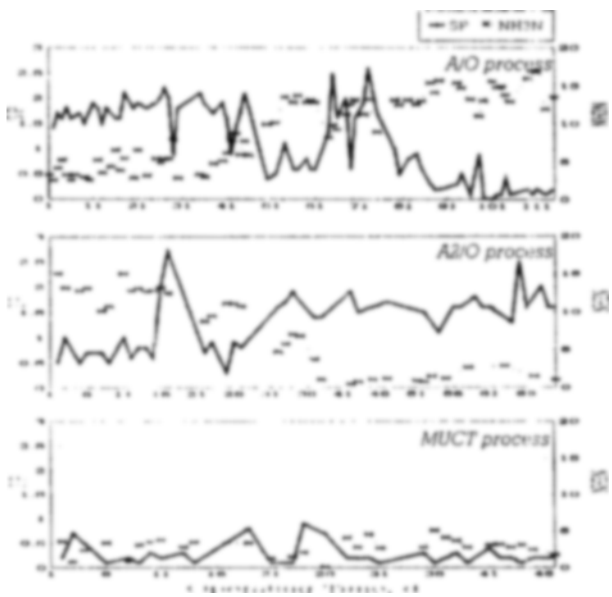

Fig. 1. Operating time vs effluent SP and NH_3N concentrations, mg/L.

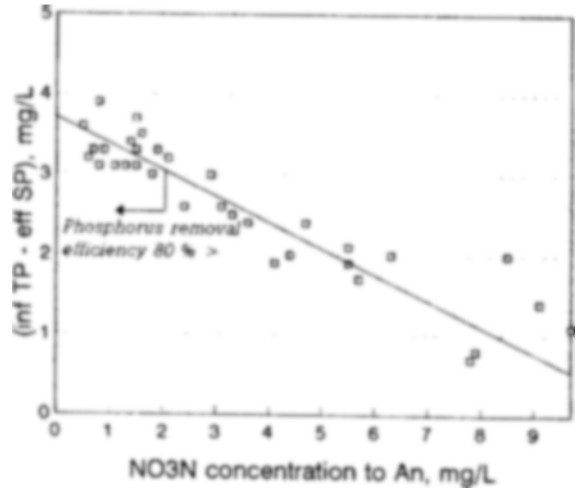

Fig. 2. NO_3N to An vs P removed.

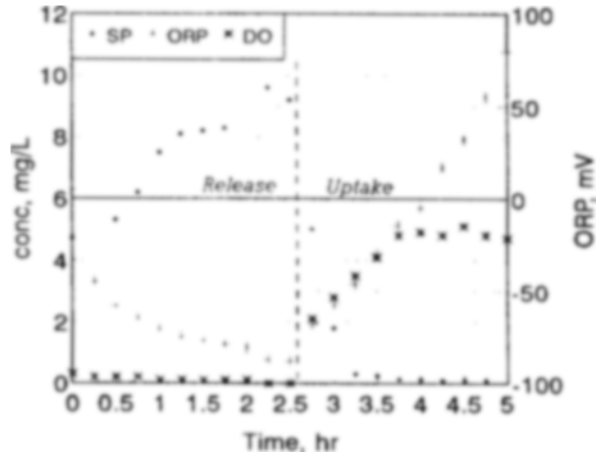

Fig. 3. Phosphorus release and uptake (MUCT system).

This suggests nitrate was removed more successfully in anoxic reactors in MUCT than in A^2/O. Both systems employed 100% internal recycle and nitrate concentrations to anaerobic reactor are shown in Table 2. Among the 3 systems, MUCT represents less nitrate input to anaerobic reactor and produced a better effluent water quality in terms of organics, phosphorus and nitrogen concentrations. In Fig. 1, the reasons for the peaks observed during 65 to 75 days in A/O, 16 to 20 days in A^2/O and 18 to 25 days in MUCT could not be found to explain. In addition, Fig. 2 denotes the effects of nitrate in RAS on P removal; The nitrate concentration in RAS must be less than 2 mg/L in order to keep the effluent SP less than 1 mg/L.

Fig. 3 represents P release and uptake characteristics. P release was quite rapid during the first 1 hour and P uptake was finished in about 1.5 hours. DO concentration was nearly zero with ORP of −50 to −100 mV in anaerobic zone, while DO and ORP were increased to 5 mg/L and +50 mv, respectively in aerobic zone.

2. COD Utilized and Phosphorus Released

Fig. 4 shows average COD and phosphorus concentrations in different zones. Phosphorus was released and COD was utilized at anaerobic zone, and released phosphorus was removed at anoxic and aerobic zones. The measured SPreleased/SCODutilized ratios were respectively 0.14 for A/O, 0.24 for A^2/O and 0.15 for MUCT. Wentzel et al. [1987] reported SPreleased/SCODutilized ratios were 0.5 to 0.9 with acetate, but the ratios were varied with different volatile fatty acid [Abu-ghararah and Randall, 1991]. Assuming SPuptaked/SPreleased is 1.13 [Randall, 1988], the effluent phosphorus concentrations could be computed to be 1.3 for A/O, 1.7 for A^2/O and 0.5 for MUCT which are close to those measured values as shown in Table 2. SPRR were 2.17 to 2.54 mgSP/gMv/hr for A/O and MUCT, and 1.62 mgSP/gMv/hr for A^2/O. Specific phosphorus uptake rate was measured to be 1.5 to 2.2 mgSP/gMv/hr.

3. Effect of Acetic Acid and Phosphorus Additions

To evaluate prefermentation requirement, acetic acid was add-

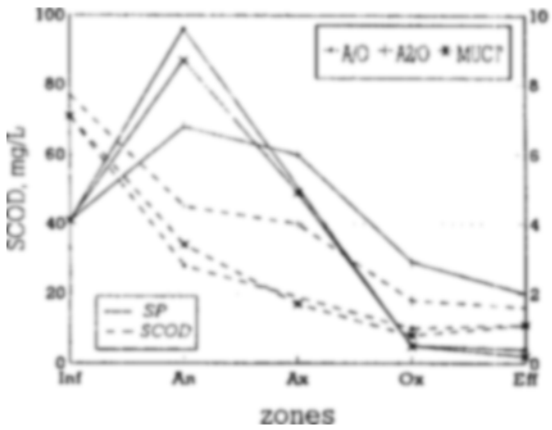

Fig. 4. SCOD and SP concentrations in different zones (average with 5 measurements at 15-20°C).

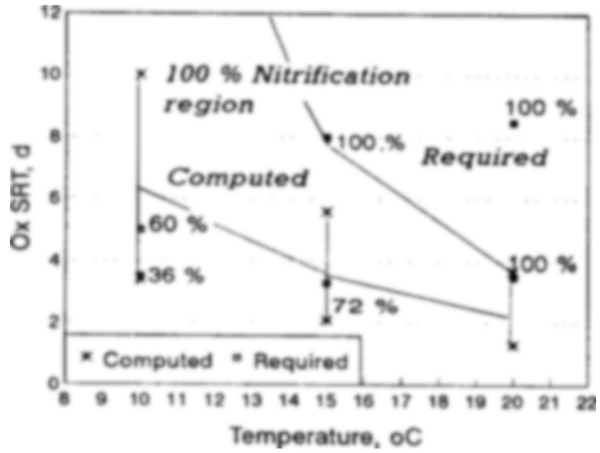

Fig. 6. Proposed complete nitrification region.

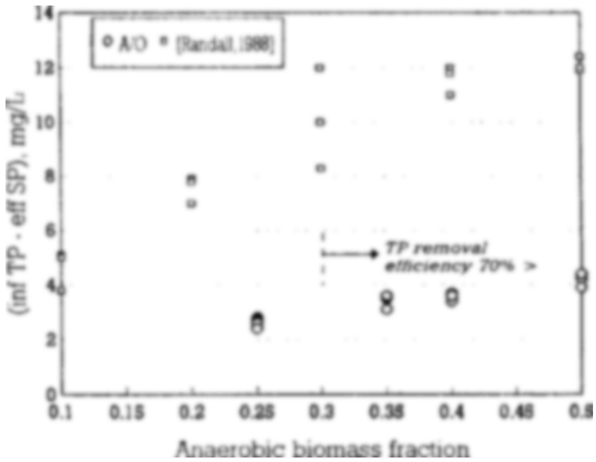

Fig. 5. Anaerobic biomass fraction vs P removed.

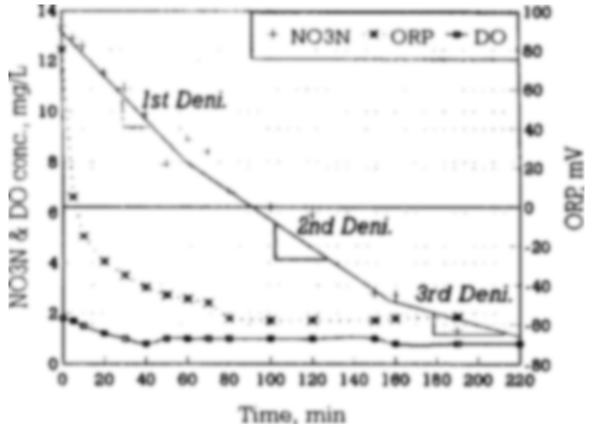

Fig. 7. Batch denitrification study with influent (MUCT system, at 20°C).

ed into primary effluent to make 130 mg/L SCOD. Phosphorus release rate was doubled with the same anaerobic time, but the total amount released was not changed.

In addition, SP concentration was increased to 6 mg/L from 3 mg/L without COD increase, the effluent SP concentration remained as the same without SP increase. This would suggest phosphorus was limiting and carbon available was slowly degradable.

4. Effect of Anaerobic Biomass Fraction

Fig. 5 represents phosphorus removed vs anaerobic biomass fraction in comparison with data obtained from York River Plant [Randall, 1988] which operated with 180 mg/L BOD and 10 mg/L TP (average concentration). It seems the anaerobic biomass fraction requirement would vary with the waste characteristics. For 70% TP removal, York River Plant [Randall, 1988] required to operate with a biomass fraction 0.2, while this study would require a higher biomass fraction like 0.3. Effluent SP/TP ratio was about 0.85.

5. Nitrogen Removal

Nitrification rate has known as temperature dependent. Fig. 6 illustrates Ox SRT requirements at different temperatures. Assuming $\mu_{n,max}$ is 0.10 to 0.77/d at 10°C to 20°C [EPA, 1993], min Ox SRT could be computed to be 6.7 days at 10°C, 3.9 days at 15°C and 2.5 days at 20°C, respectively. However actual Ox SRT for complete nitrification required more than 8 days and SNR was 2.8 to 3.4 mgN/gMv/h at 15 to 20°C. The required SRT were relatively longer than those computed. This would suggest $\mu_{n,max}$ for this waste be 0.06 to 0.45/d at 10 to 20°C.

Denitrification rates could be break down into 3 different rates depending on the substrate available [Ekama et al., 1984]. The SDNR were measured to be 3.6 with readily biodegradable COD, 3.0 with slowly biodegradable COD and 1.1 $mgNO_3N/gMv/h$ with endogenous respiration, respectively at 20°C [Fig. 7]. The measured SDNR were relatively smaller those reported rates [Ekama et al., 1984; Eckenfelder et al., 1991] due to the low influent COD concentration.

Fig. 8 represents nitrate reduction in A^2/O system by varying the internal recycle ratio 50% to 300% along with the computed values by the methods of EPA [1993] and Eckenfelder et al. [1991]. Denitrification rate increases as internal recycle ratio increases, but the actual rate did not increased after 100% recycle. Therefore, 100% recycle ratio was used in this study.

6. Population Dynamics

Fig. 9 shows microbial population fractions computed from COD and nitrogen mass balances for A/O, A^2/O and MUCT

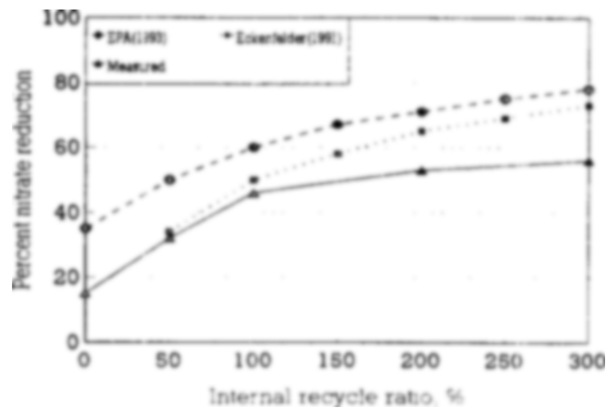

Fig. 8. Effect of internal recycle ratio on nitrate reduction (A^2/O system, at 20°C).

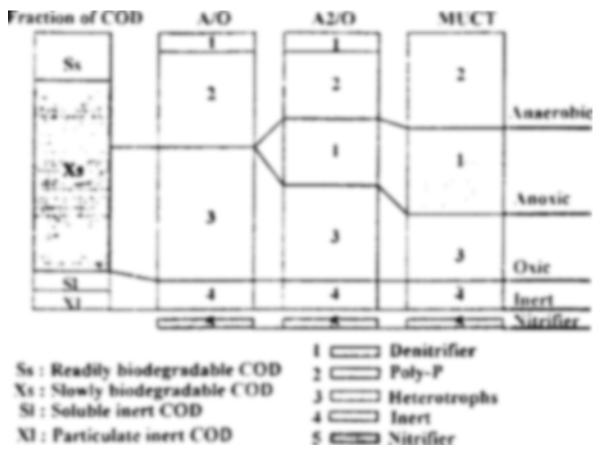

Fig. 9. COD and biomass fractions.

systems. In A/O and A^2/O, denitrifier could present in anaerobic zones (about 7%) since return sludge contained higher nitrate. Poly-P microbes were about 33% in A/O and MUCT on a basis of SPreleased/SCODutilized. Denitrifier fractions were 23 to 29%, while aerobic heterotrophs were 33 to 43% for A/O and A^2/O. Nitrifier population were 1.5 to 2.4% on a basis of yield coefficient of Y_A (as nitrifier)=0.2 gVSS/gNH_3N [EPA, 1993]. G-bacteria [Cech and Hartman, 1993] were observed in all systems, but its fractions could not be quantified. Also, denitrifying ability of poly-P microbes [Henze, 1992] was not included in computation. Inert mass fractions were about 10% of total VSS in all systems. Since P/VSS content of MUCT was 9.5%, the net content of poly-P microbes ignoring G-bacteria population could be increased to approximately 29% which is somewhat lower than the reported content of 38% [Wentzel et al., 1991].

SUMMARY AND CONCLUSIONS

Performance of BNR systems would suggest the primary effluent used for this study represents a nature of slowly biodegradable COD. As that result, anaerobic fraction must be increased to attain lower effluent P concentrations. However, prefermentation to increase P removal was not necessary since P was limited. SPRR were 2.17 to 2.54 mgSP/gMv/hr for A/O and MUCT, and 1.62 mgSP/gMv/hr for A^2/O. Specific phosphorus uptake rate was measured to be 1.5 to 2.2 mgSP/gMv/hr and the measured SPreleased/SCODutilized ratios were 0.14 to 0.24.

In addition, denitrification rate were also smaller because available carbon was limited. The SNR were 2.8 to 3.4 mgN/gMv/h and SDNR were about 3.0 mgNO_3N/gMv/h at 15 to 20°C.

Microbial mass fractions computed from COD and nitrogen mass balances suggested that poly-P microbes were about 33% in A/O and MUCT, denitrifier fractions were about 30% in A^2/O and MUCT. Nitrifier fractions were about 2%.

ACKNOWLEDGEMENTS

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NOMENCLATURE

$\mu_{n,max}$: maximum specific growth rate values for nitrification
SNR : specific nitrification rate
SDNR : specific denitrification rate
Mv : mixed liquor volatile suspended solid
SPRR : specific phosphorus release rate
A/O : anaerobic aerobic
A^2/O : anaerobic anoxic aerobic
SP : soluble phosphorus
TN : total nitrogen
TP : total phosphorus
Y_A : yield coefficient for nitrification

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