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Nutrient Release during the Aerobic and Alternant Aerobic Sludge Digestion

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도시하수슬러지의 호기성 소화시 영양염류 용출에 관한 연구

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ABSTRACT

Batch digestion experiments of the biological sludge by full aeration and alternant aeration were carried out to find the release characteristics of nitrogen and phosphorus in this study. Nitrogen content of the sludge increased for the endogenous respiration period but the content gradually decreased to the same content of raw sludge. Nitrogen removal efficiency was up to 42.5% for 34 days by the alternant aerobic digestion of which aeration ratio was 0.5 and the efficiency was dependent on aeration ratio. Phosphorus released as the sludge digested and phosphorus content of the digested sludge increased because phosphorus release rate was much lower than VSS reduction rate. A new empirical equation was made based on this study. Phosphorus release rate can be estimated using this equation dependent on the VSS reduction rate and initial phosphorus content of the sludge.

Keywords : Aerobic digestion; alternant aerobic digestion; nutrient release, sludge

요 약

생물학적 슬러지를 대상으로 간헐포기 소화와 호기성 소화의 회분실험을 실시하였다. 생물학적 슬러지의 간헐포기 및 호기성 소화 초기단계에서 미생물의 감량은 주로 내생 호흡에 의해 이루어졌다. 이 단계에서 질소는 곧바로 용출되지 않고 슬러지내에 잔존함으로서 슬러지의 질소함량은 일시적으로 증가한다. 그러나 소화후반에서는 최초의 질소함량수준으로 다시 감소하였다. 34일간의 회분식 소화에서 호기성 소화의 총질소 제거효율은 0.1%로서 거의 제거가 안된 반면, 포기 비율 0.25, 0.5 및 0.75인 간헐포기 소화에서는 각각 42.7%, 42.5% 및 17.6%로 나타나 간헐포기 소화가 호기성 소화보다 질소 제거측면에서 우수하였다. VSS의 감소에 따라 슬러지내의 인도 수중으로 용출하였으나, 인 용출율은 VSS 감소율 보다 훨씬 낮았고 그 결과 소화슬러지의 인 함량은 지속적으로 증가하였다. 호기성 소화와 간헐포기 소화는 소화슬러지의 인 함량이 증가하는 공정이므로 반송수의 인 부하는 상대적으로 낮아지게 되고 이는 하수의 영양염류 제거측면에서 긍정적인 효과를 미칠 것으로 기대된다.

I. Introduction

Wastewater sludge from the wastewater treatment plant contains nutrients like nitrogen and phosphorus. Nitrogen and phosphorus release again to supernatant in the digestion process which is carried out for reduction and stabilization of the sludge. Compared to aerobic digestion, alternant aerobic digestion has many advantages like less-energy consumption, no need to add of neutralization chemical. Compared to anaerobic digestion, alternant aerobic digestion is a relatively inoffensive process and low capital cost process. The purpose of this study is to

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find nitrogen release, oxidation/reduction property of nitrogen and release characteristics of phosphorus from the sludge in the digestion process for the prediction of nutrient load of the supernatant.

Wastewater sludge contains nitrogen and phosphorus as well as organics. Primary sludge contains about 2.5% nitrogen and about 0.9% phosphorus while waste sludge contains about 7.5% nitrogen and about 2.5% phosphorus (Bishop and Farmer, 1978). The content of nitrogen or phosphorus is not always constant and dependent on biological process, wastewater characteristics, sludge age etc. Therefore, there is no general molecular formula of the biological sludge. For example, $C_{60}H_{87}O_{23}N_{12}P$ was proposed for the molecular formula of the biological sludge(Sherrard, 1976). At the sludge digestion processes, released organic nitrogen transformed into ammonia nitrogen by ammonification reaction. It was reported that soluble organic nitrogen concentration filtered by 0.45 μm filter was ranged 11~17 mg/*l* which was much far less than ammonia nitrogen concentration, 113~230 mg/*l*(Hao and Kim, 1990). Therefore It is regarded that released organic nitrogen is easily converted into ammonia nitrogen. Sludge destruction under the aerobic condition can be written as Eq.(1) if sludge structure equation is shortly expressed as $C_5H_7O_2N$(Mavinic and Koers, 1982). It is an alkalinity generation reaction and stoichiometrically 1 mole of alkalinity generated as 1 mole of ammonia nitrogen production.

$$C_5H_7O_2N + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_4^+ + OH^- \quad (1)$$

Under the aerobic condition, ammonia nitrogen oxidized to nitrate nitrogen by autotrophic nitrobacteria. In this case, 1.98 mole of alkalinity consumed as 1 mole of ammonia nitrogen oxidized to nitrate nitrogen along the Eq.(2). The reason of pH drop in the aerobic digestion process is that the amount of alkalinity consumption is greater than the amount of alkalinity generation mentioned above. Ammonia nitrogen is also accumulated in the reactor after the depletion of alkalinity because of nitrification inhibition.

$$NH_4^+ + 1.86O_2 + 1.98HCO_3^- \rightarrow 0.02C_5H_7O_2N + 0.98NO_3^- + 1.04H_2O + 1.88H_2CO_3 \quad (2)$$

Under the anoxic condition, sludge digestion is possible too because of nitrate nitrogen. Most heterotrophic organisms can use nitrate nitrogen as an electron acceptor. Nitrate nitrogen be reduced to nitrogen gas in this reaction therefore this reaction is often called denitrification reaction. When the oxygen and carbon source are not sufficient, microorganisms sustain their life by endogenous respiration consuming nitrate nitrogen. So it would be called endogenous nitrate respiration(ENR) by some researchers(Kim and Hao, 1990).

Most organics which can be utilized in the reaction of the oxygen as an electron acceptor are also utilizable in the reaction of denitrification. But denitrification rate is different(Henze, 1991). ENR is an alkalinity production reaction. The amount of alkalinity production in the ENR reaction is 4.46 mg as $CaCO_3$/mg N denitrified as described in Eq.(3) and it is greater than general denitrification reaction using methanol or glucose, 3.57 mg as $CaCO_3$/mgN denitrified.

$$C_5H_7O_2N + 4NO_3^- + H_2O \rightarrow 5CO_2 + 5OH^- + NH_4^+ + 2N_2 \quad (3)$$

Most phosphorus of biomass cell are within nucleo acid, coenzyme, polyphosphate, phosphatide(Bishop and Farmer, 1978). The amount of total phosphorus does not vary throughout the wastewater or sludge treatment system because phosphorus is not volatile material. But it is possible that solution state phosphorus is transformed to solid state phosphorus or reverse. Bishop and Farmer (1978) concluded that phosphorus content of sludge would not changed during aerobic digestion because the content was 1.6~1.7% before digestion and 1.9~2.0% after digestion respectively. Matsuda *et al.*(1988) reported that phosphorus content of sludge for the raw wastewater sludge was 1.7% and it increased to 2.0% after 5 days aerobic digestion and finally it decreased to 1.2~1.5%. Jenkins and Mavinic(1989) conducted aerobic digestion of sludge from the biological phosphorus removal process. They reported that phosphorus release rate was slower than VSS reduction rate so phosphorus content of the digested sludge was higher than that of raw sludge based on their experimental study.

At the present, phosphorus content seems to increase at the aerobic digestion but there are no rational reasons. Therefore some researchers suppose that lower phosphorus content biomass destroyed earlier than higher phosphorus content biomass and other researchers

Table 1. Characteristics of the viological sludege

Constituent	Concentration(mg/l)
pH	7.4
Alkalinity	500 as $CaCO_3$
TCOD	6,790
SCOD	3.4
TS	5,140
TVS	4,370
SS	4,820
VSS	4,340
TKN	260
NH_4^+-N	Not detected
NO_2^--N	Not detected
NO_3^--N	0.1
TP	62
PO_4^{3-}-P	0.3

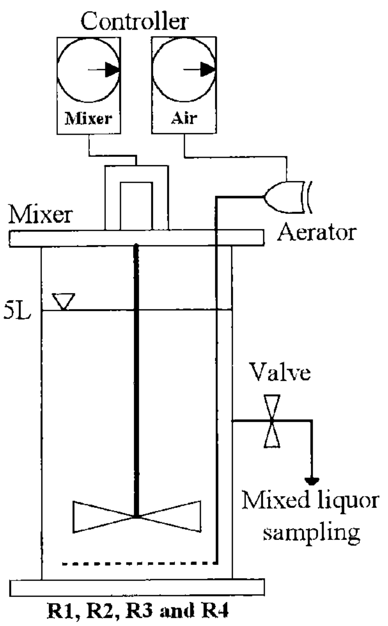

Fig. 1. Schematic diagram of the batch digestion system.

Table 2. Operational conditions of this study

Reactor	Aeration time	Non-aeration time	Aeration ratio(φ)	Remarks
R 1	3 hrs	9 hrs	0.25	Alterant aeration
R 2	6 hrs	6 hrs	0.5	Alterant aeration
R 3	9 hrs	3 hrs	0.75	Alterant aeration
R 4	12 hrs	0 hr	1.0	Continuous aeration

suppose that alive microorganisms would possess phosphorus in their cell under the endogenous condition because phosphorus is an essential compound for energy metabolism. Phosphorus release from the sludge can be described as Eq.(4) for the sludge digestion process.

$$\frac{dP_S}{dt} = -i_{PBM}\frac{dX}{dt} \qquad (4)$$

where Ps = dissolved phosphorus, (mgP/L); i_{PBM} = phosphorus content of biomass(mgP/mgVSS)

II. Materials and Methods

Biological sludge was aerobically risen in the laboratory using synthetic wastewater for this study. Synthetic wastewater was composed of powdered milk, yeast extract and sodium bicarbonate as a pH buffer. Biological sludge was directly used for batch digestion experiment without any other treatment. Characteristics of biological sludge at the digestion start-up are shown in Table 1. Experimental apparatus was shown in Fig. 1. Mixing device, aerator and diffuser controlled by electric timer were equipped to each reactor.

Four sets of reactor were used in this study and the operation method was shown in Table 2. R1 and R3 were

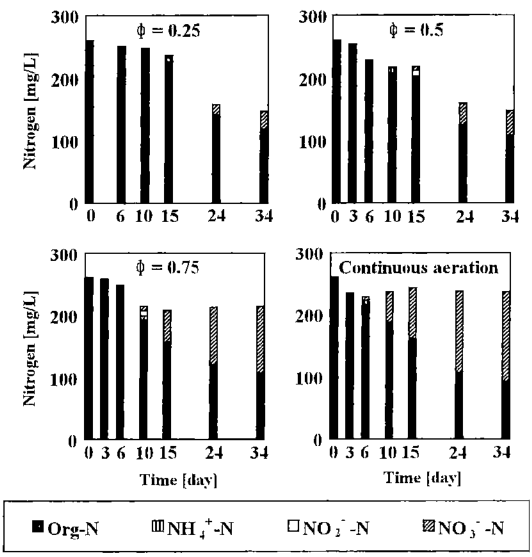

Fig. 3. Changes in composition of nitrogen during the batch digestion (φ=aeration ratio).

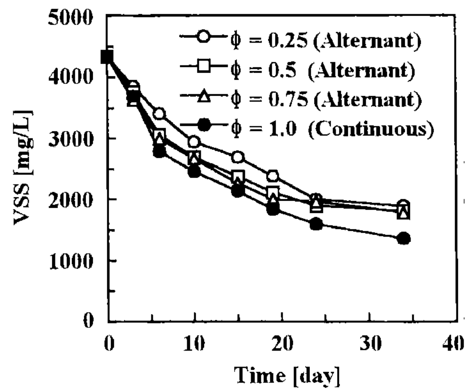

Fig. 3. Changes in VSS reduction during the batch digestion (φ=aeration ratio).

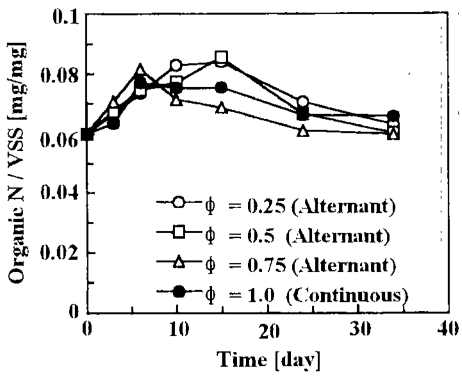

Fig. 4. Changes in nitrogen content in the sludge during the batch digestion (φ=aeration ratio).

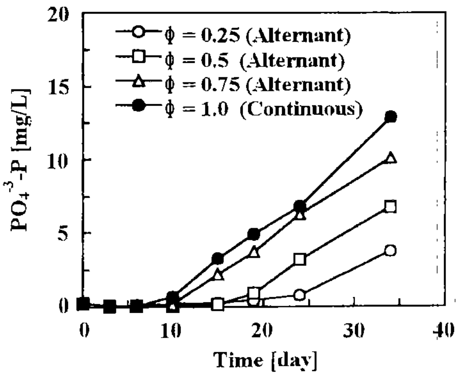

Fig. 5. Changes in phosphorus content during the batch digestion (φ=aeration ratio).

alternant aerobic digestion and R4 was fully aerobic digestion. The batch digestion experiments were continued for 34 days. pH, alkalinity, TCOD(total chemical oxygen demand), SCOD(soluble chemical oxygen demand), SS(suspended solids), VSS(volatile suspended solids), TKN(total kjeldahl nitrogen), NH_4^+-N, NO_2-N, NO_3-N, TP(total phosphorus), PO_4^{3-}-P were checked according as Standard Methods(APHA, 1992). Deionized water was added daily to preset level for the compensation of evaporation loss and all the data were adjusted for the sampling.

III. Results and Discussions

1. Nitrogen release and transformation

Nitrogen composition changes were shown in Fig. 2. For the first 36 days, VSS reduced rapidly(Fig. 3) but the decrease of organic nitrogen did not almost shown. It was reported that nitrogen content of the digested sludge increased slightly than that of raw sludge by Eikum *et al*(1974). Otherwise, nitrogen content of the sludge was 0.08gN/gVSS and the content was not changed during the aerobic digestion experimented by Mavinic and Koers (1982). Nitrogen content of the digested sludge was 7.0~8.5gN/gVSS and it was not so different from that of raw sludge(Bishop and Farmer, 1978). This result is supported by the reports of Jenkins and Mavinic(1989) and Hao and Kim(1990). Activated sludge model of IAWQ(International Association of Water Quality) adopt this opinion that nitrogen content of biomass is constant during synthesis or lysis of biomass. So, it was possible that

$$\frac{dN_s}{dt} = -i_{NBM}\frac{dX}{dt} \quad (5)$$

and i_{NBM} is always constant where N_S = soluble nitrogen, (mgN/L);

i_{NBM} = nitrogen content of biomass, (mgN/mgVSS);
X = concentration of biomass, (mgVSS/L).

Under the starvation condition, organisms consumed their own protoplasm for the sustenance of life and relatively weaker organisms died and destructed gradually. In the Death-Regeneration Model, It is considered that destruction fragments produced as the heterotrophic organisms died and these nutrients could be used again for the other heterotrophic organisms(Dold *et al*, 1980). As

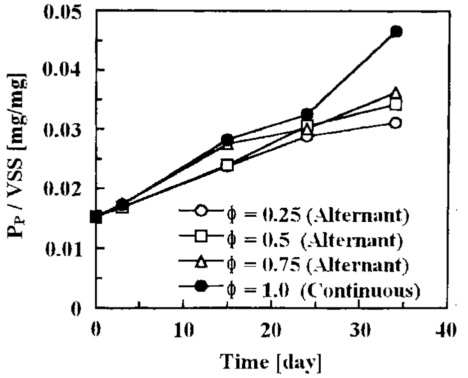

Fig. 6. Changes in total phosphorus content during the batch digestion (φ=aeration ratio).

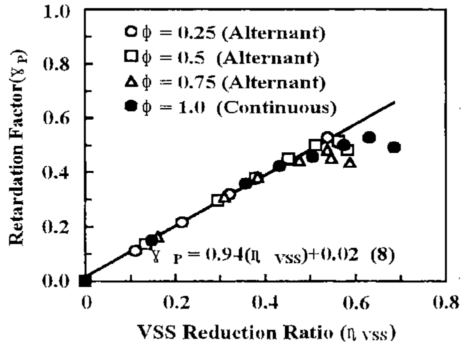

Fig. 7. Phosphorus retardation factor versus VSS reduction (φ=aeration ratio).

the result of this experiment, VSS reduction for the first few days is absolutely endogenous reduction. In this stage, nitrogen is not released rapidly from the biomass and nitrogen content of biomass is not constant. Fig. 4 shows that nitrogen content increases from 6% to 8% for the endogenous period and gradually decreases to the content of TN reduction was only 0.1% for the 34 days batch aerobic digestion since it had not a anoxic condition in the aerobic digestion. But TN reduction was 42.7%, 42.5%, 17.6% for the alternant aerobic digestion when the aeration ratio was 0.25, 0.5 and 0.75, respectively. The reason of lower TN reduction at =0.75 than =0.5 or 0.25 is relatively short anoxic period.

2. Phosphorus release

Phosphorus would be released from the cell as the death and lysis of microorganisms. TP maintained the start-up concentration but soluble phosphorus (phosphate) concentration increased gradually because of cell destruction as shown in Fig. 5. But the increasing rate of the soluble phosphorus concentration was not directly proportional to the VSS decreasing rate. VSS reduced to 68%, 62%, 62% and 57% at the aeration ratio of 0.25, 0.5, 0.75 and 1.0 for the 10 days digestion, but soluble phosphorus release was so low that its concentration was only 0.2 mg/*l*, 0.0 mg/*l*, 0.2 mg/*l* and 0.6 mg/*l*, respectively.

Variations of the phosphorus content of the sludge are shown in Fig. 6. This value was 1.5% at the start-up, but the value continuously increased and reached to the 3.1~4.7% after the 34 days digestion. Phosphorus content of the sludge was increasing for the alternant aerobic digestion and this increasing was also shown at the full aerobic digestion. It represents that this phosphorus storage phenomenon is not caused by phosphorus accumulating organisms(PAO's) activity. Therefore, it can be concluded that phosphorus content of the sludge is increasing under the aerobic digestion or alternant aerobic digestion. It assumes that phosphorus release rate is directly proportional to the VSS reduction rate in the activated sludge modeling(Dold *et al.*, 1980; Henze *et al.*, 1995). This assumption can not be applied to aerobic or alternant aerobic digestion, so one modification for the sludge digestion process was carried out in this study as follows.

The released phosphorus concentration from the biomass can be expressed as Eq.(6) and original activated sludge model adopts this equation. In this study, it assumes that phosphorus release is retarded proportional to VSS reduction(retardation factor is γP). Because phosphorus retardation factor is directly proportional to VSS reduction when VSS reduction ratio is less than 50% as shown in Fig. 7. After the rearrange and application of the Eq.(6) to Eq.(7) then Eq.(8) is obtained. Eq.(8) is an empirical equation which can estimate the amount of phosphorus release dependent on initial phosphorus content of the sludge and VSS reduction rate. For example, if VSS reduction ratio is 50% then γP is 0.49 and these mean that only 1% of phosphorus will be released.

$$P_R = i_{PBM} \cdot VSS_0 \cdot \eta_{VSS} \quad (6)$$

$$P_{R'} = i_{PBM} \cdot VSS_0 \cdot \eta_{VSS} - i_{PBM} \cdot VSS_0 \cdot \gamma_P \quad (7)$$

$$P_{R'} = i_{PBM} \cdot VSS_0 \cdot (0.06\eta_{VSS} - 0.02) \quad (8)$$

where i_{PBM} = phosphorus content of biomass, (mgP/mgVSS);
VSS_0 = initial VSS concentration, (mgVSS/L];
η_{VSS} = VSS reduction ratio, (-);
P_R = released phosphorus, (mgP/*l*);
$P_{R'}$ = released phosphorus(modified), (mgP/*l*);
γ_P = (phosphorus release) retardation factor (= retarded PP/initial PP), [-];
P_P = particulate phosphorus, (mgP/*l*)

IV. Conclusions

After the experimental study of the biological sludge digestion by aeration and alternant aeration, some conclusions are obtained as follows;

Earlier stage of aerobic or alternant aerobic digestion, biomass reduction is caused by endogenous respiration. Nitrogen content of the sludge increases temporary in this stage because nitrogen does not released from the biomass. But under the long time digestion, this content is recovered to the initial content. Alternant aerobic digestion is a nitrogen removal process compared with aerobic digestion. For the 34 days digestion, 17.6~42.7% of total nitrogen could be removed by the alternant aerobic digestion but only 0.1% of total nitrogen was removed by the aerobic digestion.

Phosphorus releases as the sludge digests. But phosphorus release rate is much slower than VSS reduction rate so that phosphorus content of the sludge increases continuously. A new empirical equation was made based on this study. Phosphorus release rate can be estimated using this equation dependent on the VSS reduction rate and initial phosphorus content of the sludge. Aerobic digestion and alternant aerobic digestion are phosphorus accumulating process and this affect good to wastewater treatment stream.

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