Biological Phosphorus and Nitrogen Removal in Anaerobic-Aerobic Activated Sludge Process

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Simultaneous removal of phosphorus and nitrogen from wastewater was studied by the anaerobic-aerobic system of activated sludge. In the anaerobic stage, most of the influent glucose was removed and orthophosphate was released, when the nitrate and/or nitrite concentration in the wastewater was almost zero. The amount of the released phosphorus was found to be directly proportional to the amount of the removed glucose. When the ratio of phosphorus to glucose in the influent was less than 0.04, the phosphorus in the wastewater was almost completely removed during the aerobic state. Under the anaerobic condition, activated sludge released phosphate and excess removal of phosphate occurred during the aerobic condition. Namely, the stress received in anaerobic period stimulated the uptake of phosphorus in aerobic period.

The amounts of phosphorus release in the anaerobic and uptake in the aerobic stage were less in proportional to the concentration of NO_X-N. Further, if the initial ratio of NO_2-N/glucose was less than 0.37, the inorganic nitrogen in the influent could be completely removed.

Introduction

The lakes or estuaries are polluted by phosphorus and/or inorganic nitrogen, which leads to the eutrofication to result in undesirable water quality for human's use of the water supplies. The phosphorus is involved in synthetic detergents and fertilizers, and on the other hand, nitrogen in wastewater results from human's excreta, ground garbage and from food processing waste, particularly.

Phosphorus in the form of orthophosphate in excessive amount promotes abundant growth of aquatic flora. Algal blooms in particular leads to the deterioration of water quality (Marais *et al.*, 1983). This problem is one of the main concerns of wastewater treatment. The treatment of wastewater goes into three major processes. In primary treatment, the wastewater containing debris or large particle solids that can be easily removed is eliminated by physical means. Secondary treatment removes inorganic compound and/or phosphorus by biological growth. In this process, however, a maximum of only 20~30% of the phosphorus content in the wastewater is removed because the ratio of phosphorus to inorganic compound in domestic wastewater is much more than that required for growth by the microorganisms in the activated sludge. Consequently, chemical precipitation using aluminum and iron coagulants or lime has been used for phosphorus removal. This is tertiary treatment. The use of coagulants, however, presents some problems such as accumulation of excess inorganic compound and the availability of the coagulants itself.

Recently, the enhanced phosphorus uptake by the alternating anaerobic/aerobic activated sludge system has been developed. The operational condition and the exact mechanism for the biological uptake in this system, however, have not yet been elucidated.

The proposed model for the biological phosphorus uptake in activated sludge is shown in Fig. 1.

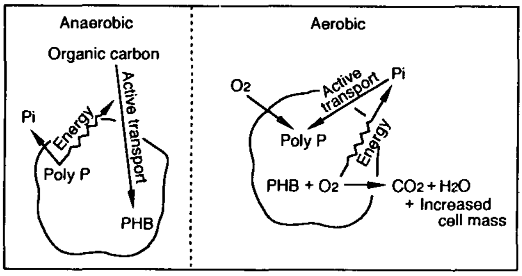

Fig. 1. The postulated model for the biological phosphorus release and uptake in activated sludge.

In the absence of oxygen, the carbon source is stored in the form as poly-β-hydroxybutyrate (PHB) while the stored polyphosphate in the cell is degraded, releasing phosphate into the solution (Nicholls *et al.*, 1979). During this process, energy produced by degradation of polyphosphate is used for the storage of organc carbon as PHB.

Under aerobic condition, as external carbon source in the wastewater is consumed by the biomass, bacteria accumulating phosphate are expected to oxidize their own PHB to produce energy. The stored PHB provides energy for the phosphate uptake process.

The purpose of this study is to investigate the operational condition to achieve phosphorus removal by the biological treatment process based on the proposed biochemical model for phosphorusremoval.

Materials and Methods

Fill and draw system

The flow charts of the fill and draw system and the experimental facility were shown in Fig. 2. A 10*l* fermentor(MD-500, Marubishi Bioeng. Co. Ltd., Tokyo, working volume: 4*l*) was used for reactor. The phosphorus uptake in the cells after the anaerobic state was high at 120*min* (Faculty of Engineering Osaka University, 1986). Thus the system consists of feeding of wastewater up to 4*l*(about 10 *min*), 120*min* of anaerobic process, 120*min* of aerobic process, 20*min* of sludge sedimentation, and withdraw of treated wastewater(about 10*min*). And the activated sludge was acclimatized in this fill and draw system. The conditions for the reactor were as follows: temperature, 25℃; agitation speed, 300*rpm*, N_2 gas flow rate for anaerobic condition, 0.5*vvm*; air flow rate for aerobic condition, 1*vvm*. The artificial wastewater was composed of peptone 1.4*g*, meat extract 0.92*g*, NaCl 2.36*g*, KCl 0.06*g*, $CaCl_2 \cdot 2H_2O$ 0.06*g*, $MgSO_4 \cdot 7H_2O$ 0.05*g*, and $NaHCO_3$ 2.0*g* in 1*l*.

Batch experiment system

Activated sludge for the batch experiment (Fig. 2) was taken from the fill and draw fermentor and centrifuged at 5,000*rpm*, 4℃ for 10*min*. Then, the activated sludge was suspended into 500*ml* of tap water and the artificial wastewater was added with 500*ml* of tap water (total volume of 1*l*). The com-

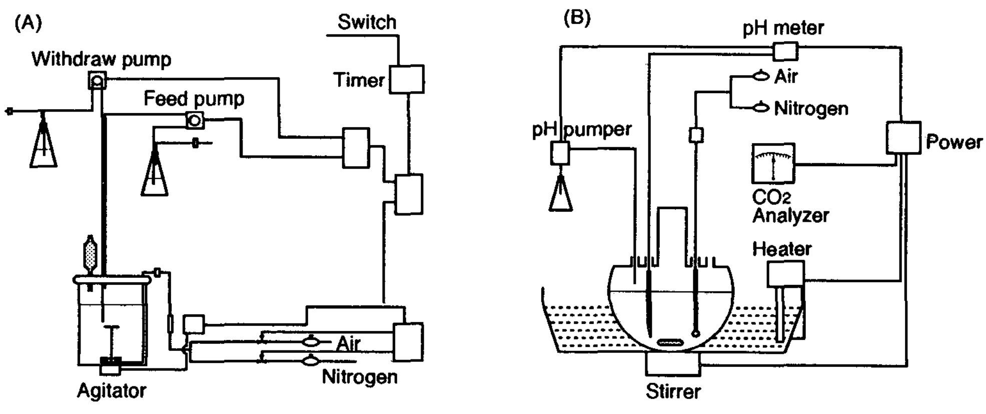

Fig. 2. Schematic diagram of fill and draw system (A) and batch experiment system (B).

position of artificial wastewater for this batch experiment was same as that of the artificial wastewater of fill and draw system, except that of glucose 0.2*g*, of NH_4Cl 0.1*g* and of KH_2PO_4 0.03*g* were added instead of peptone, meat extract. In this experiment, to investigation the effect of NO_3^- on phosphorus removal, 0.05*g* or 0.10*g* of KNO_3 was added. Operation conditions were as follows: temperature 25℃, agitation speed 100*rpm*, pH was automatically controlled to 7.0, N_2 gas flow rate during anaerobic period 0.5*vvm*, air flow rate during aerobic period 1 *vvm*, and the anaerobic and the subsequent aerobic period was set for 2*hr*, respectively.

Measurement

In every 20*min*, the sample was taken and centrifuged at 4℃, 15,000 *rpm* for 10 *min*. The supernatant was used for analysis of phosphate, ammonia, nitrate, nitrite and glucose, and the precipitate was used for MLSS (mixed liquor suspended solid) measurment on the basis of dry weight. The concentration of orthophosphate was analyzed by scorbic acid method. Glucose concentration in treated wastewater was analyzed (Gaudy, 1962) by glucose autoanalyzer, and ammonia was analyzed by indophenol method, while, sulfanil acid method was applied for nitrate and nitrite measurement (APHA *et al.,* 1975).

Results and Discussion

Fig. 3 shows the typical time course of PO_4-P, NH_3-N, NO_X-N, MLSS, glucose and CO_2 during 2*hr* anaerobic and subsequent 2*hr* aerobic process. During anaerobic condition, phosphorus was released by using the energy bound of polyphosphate to accumulate carbon sources into the cell(Comeau *et al.,* 1986), therefore, glucose in the wastewater decreases and also CO_2 was produced. Comeau *et al.* (1987) reported that the key factor to the success of phosphorus removal processes is proposed to be the maximization of anaerobic carbon storage. Also the conversion of nitrate to nitrogen gas, the so called denitrification should be accompanied with glucose consumption. NH_3-N was used for the growth of activated sludge, but the change was negligible.

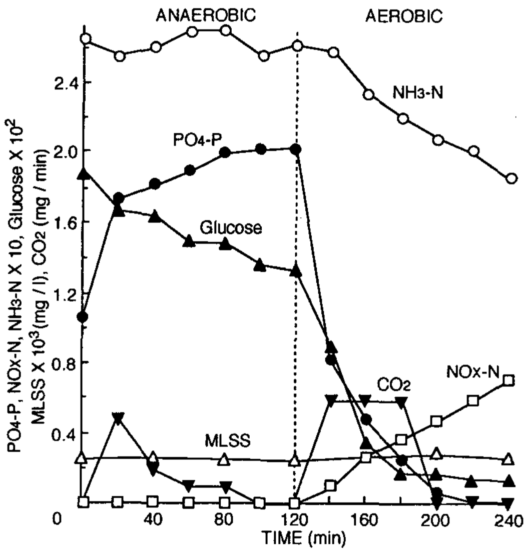

Fig. 3. Time courses of PO_4-P, NH_3-N, NO_X-N, MLSS, glucose and CO_2 during 2 *hr* anaerobic and 2 *hr* aerobic process.

The concentration of MLSS was not shown significant variation during even all processes. While, during aerobic condition, microorganism oxidized their own carbon reserves and the residual carbon sources in the wastewater to produce energy resulting in phosphorus uptake. Ammonia was converted to nitrite and nitrate. Comeau *et al.*(1987) also reported that phosphorus uptake could take place in the presence of nitrate. It should be pointed that the reactions converting ammonia to nitrite and nitrate required the carbon source consumption. Then the ratio of phosphorus/glucose or nitrogen/glucose at initial stage of anaerobic and aerobic period should be significant for this operation.

As described above, phosphorus was released and simultaneously carbon sources were accumulated. The relationship between the released phosphorus and glucose consumed in the wastewater was shown to be linear in anaerobic condition and

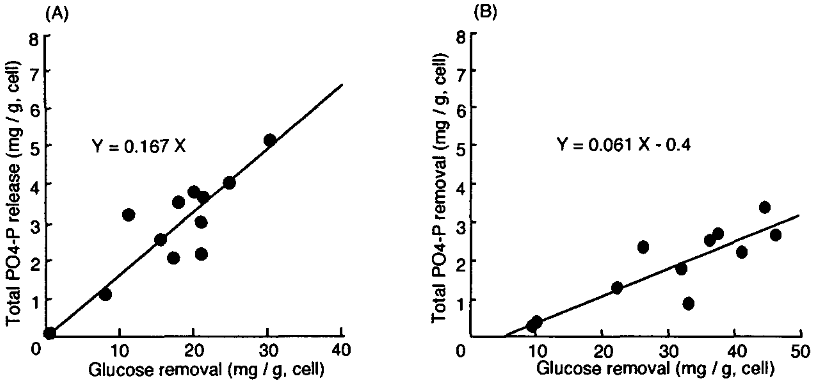

Fig. 4. Effect of glucose on the PO_4-P release and removal. (A), 2 *hr anaerobic stage;* (*B*), 2 *hr* anaeroic and 2 *hr* aerobic stage.

in whole period (Fig. 4). Where total phosphorus removal meant the difference between total phosphorus uptake and total phosphorus released. From this figure, it was seen that glucose was needed for phosphorus removal.

Fig. 5 shows the effect of initial NO_3-N on the relationship between phosphorus released and glucose removal during anaerobic process. Most of the influent glucose was removed and orthophosphate was released, when the nitrate and/or nitrite concentration in the wastewater was almost zero. As shown in the previous result, during the anaerobic condition, high concentration of glucose caused high phosphorus release, however at each concentration of NO_3-N, phosphorus release was repressed because glucose in the wastewater was used for denitrification. As mentioned before, glucose is necessary for phosphorus removal.

Fig. 6 shows the effect of initial phosphorus/glucose ratio on the phosphorus removal. From this figure, when phosphorus/glucose ratio in the wastewater was more than 0.04, the phosphrus could not be removed completely by this anaerobic-acrobic system.

Effect of initial NO_2-N/glucose ratio on the denitrification process in the anaerobic condition was also shown in Fig. 6. It is shown that complete denitrification could be achieved if the ratio of NO_2-N/glucose in the wastewater was not more than 0.37. These results can be used for determination of allowable initial condition of input to the fill and draw system.

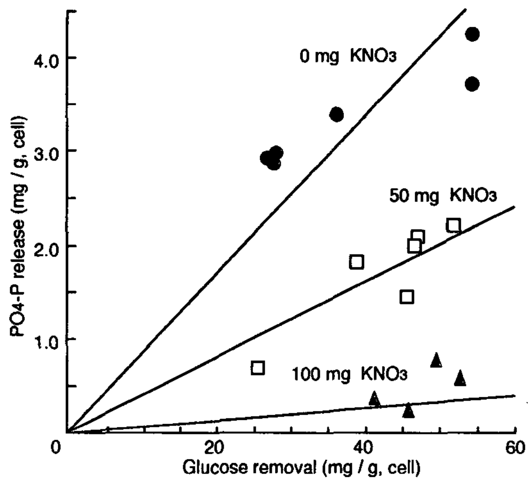

Fig. 5. Effect of NO_3-N on the relationship between PO_4-P release and glucose removal during anaerobic process.

In conclusion, until now many experiments were conducted with the condition of aerobic or anaerobic. But in this experiment we know that if the activated sludge receives the stress in anaerobic stage, more phosphorus uptake could be achieved in the subsequent aerobic stage. If the initial concentration of nitrate and/or nitrite was almost zero and the initial concentration of glucose was high,

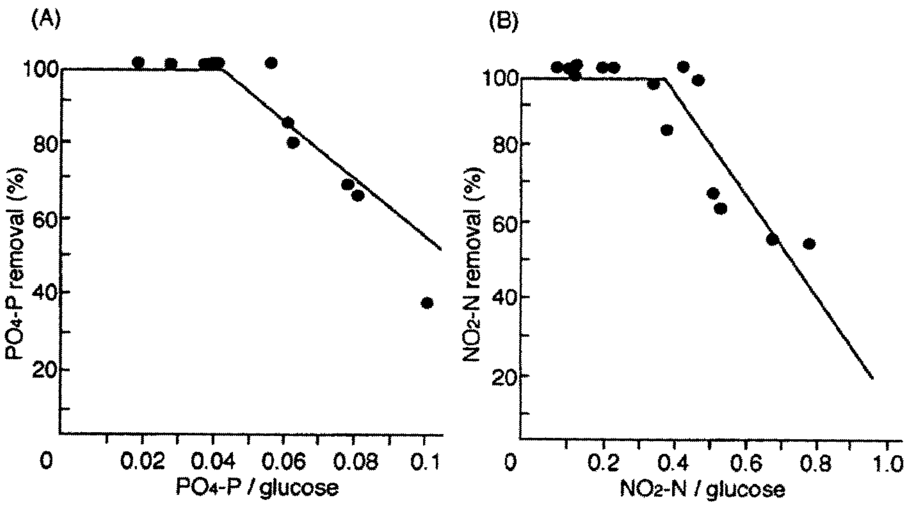

Fig. 6. Effect of initial ratio of PO_4-P to glucose on the PO_4-P removal (A) and initial NO_2-N/glucose on the NO_2-N removal (B).

most phosphorus in wastewater could be removed during the aerobic state. When the initial ratio of NO_2-N/glucose in the wastewater was less than 0.37, complete denitrification could be achieved.

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활성오니를 이용한 인 및 질소의 생물학적 제거

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혐기-호기 체계의 활성오니를 이용하여 폐수로부터 인과 질소를 동시에 제거하는 연구를 행하였다. 혐기적인 조건에서 nitrate 혹은 nitrite의 농도가 거의 0일 때, 제거된 glucose의 양은 orthophosphate의 방출과 직선적인 관계를 나타내었으며, 유입수에서 인과 glucose의 비율이 0.04 이하일 때, 폐수 중의 인은 호기적인 단계에서 거의 제거되었다. 이는 혐기적 단계에서 받은 stress로 인해 호기적 단계에서 받은 stress로 인해 호기적 단계에서 훨씬 많은 양의 인을 흡수한 것으로 생각된다.

혐기적 단계에서의 인의 방출양과 호기적 단계에서의 인의 흡수양은 NO_x-N의 농도와는 비례적인 관계가 아니었으며, 더우기, glucose에 대한 NO_2-N의 비가 0.37보다 낮을 때, 유입수 중의 무기질소는 완전히 제거되었다.