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Phosphorus Release from Sediment in Lake Sihwa and its Control

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Abstract

In this study the effects of initial pH, temperature, dissolved oxygen concentration, and sediment depth on the release of phosphorus from sediment in Lake Sihwa were investigated. No phosphorus release occurred at 10 ℃ for all pH values. DO concentrations were decreased and equilibrium was obtained 4-8 days after phosphorus release started. The DO concentrations were less than 1 mg/L. Sediment depth had little effect on phosphorus release rate. In order to control the released phosphorus, raw sludge and chalk were used. Results showed that a portion of phosphorus was removed by adsorption to chalk and raw sludge. About 90 % phosphorus removal was observed using sludge and calcinated chalk from the water sample in Lake Sihwa.

Keywords : phosphorus, release, sediment, DO concentration, adsorption

1. Introduction

Due to the rapid industrialization and development, water quality in lakes and rivers deteriorates by overusing chemicals including detergent and fertilizer which cause eutrophication. Nutrients release from sediment can be an important source of eutrophication as well as input to water body from outside of water bodies. Among nutrients, phosphorus is known to be limiting factor of eutrophication in most fresh water(Lambert, et al.,1992). Especially SRP (Soluble Reactive Phosphorus) which exists as soluble state is known to be direct nutrition source of phytoplankton(Boers, et al., 1991). In order to lessen eutrophication phenomena, phosphorus control is more effective and easier because nitrogen is relatively more abundant and is generated spontaneously(Kim, et al., 1997, Kim, et al., 1998). Moreover, nitrogen control is more complicated due to its diverse incoming paths. Major factors affecting the phosphorus release from sediment include pH, temperature, oxidation reduction potential, dissolved oxygen concentration. Active phosphorus release was observed under anaerobic and high pH condition(Istvanovics, 1994). Phosphorus movement in sediment is also greatly influenced by the interaction with the compound containing iron.

In this study the phosphorus release characteristics from sediment was investigated by varying water temperature, initial pH, and the amounts of sediment. Also the phosphorus release rate was predicted by using a mathematical model. Based on these data, phosphorus concentration in water body can be calculated by considering phosphorus released from sediment. This can be used to control the eutrophication in the lake or river.

Recently many efforts have been made to remove phosphorus in water by using various abandoned materials such as slag from smelting furnace and ground clam shell etc.. In this study, raw sludge from water treatment plant and chalk from schools and institutes were used

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to remove phosphorus in water body. Both material were usually abandoned and filled up as wastes. Therefore, the use of raw sludge and chalk has an advantage in an economical aspect.

This paper consists largely of two parts. The first part is focused on the study of phosphorus release movement from the sediment in the lake and the second part deals with the control of phosphorus in the water body.

2. Methods and Materials

The sediment in Lake Sihwa in GyeongGi Province in Korea was used. Sediment in 15-20 cm depth from boundary layer between sediment and water was collected by grab sampler. The pH of the sediment was 7.6. Particle size analysis showed that the composition of the sediment was as follows : 0 % of sand, 67 % of silt, and 33 % of clay. Sediment sample was air-dried in the shade and ground. The portion which passed through No. 200 sieve (0.75 m) was collected as homogeneous sample. As experimental apparatus, a series of glass column with 2.5 cm diameter and 24.5 cm length were prepared and analyzed with time elapsed. Each glass column was tightly closed with rubber stopper and sealed with silicon to keep anaerobic conditions. In order to prevent photosynthesis by phytoplankton during experiment, each column was wrapped with aluminum foil.

It was known that the nutrient release in the lake was most greatly influenced by the conditions of boundary layer between water body and sediment. 20 mL of sample water was precautiously taken from the upper part of the boundary layer without disturbance during sampling to measure DO concentration and pH. To measure phosphorus concentration full water sample was poured, filtered with 0.45 m membrane filter paper, and mixed thoroughly. SRP (Soluble Reactive Phosphorus) was measured according to stannous chloride method(APHA, et al., 1995). Measurements were taken in triplicate to take average value. DO concentration, pH, and SRP concentration were measured by YSI Model 58 DO Meter, Jenway 3020 pH Meter, and Spectrophotometer (Shimadzu Co., UV-1201), respectively.

The parameters involved were water temperature, pH, and the amount of sediment. The experiment to investigate the relation between DO concentration and phosphorus concentration released from sediment was conducted for 20-23 days. 10 g of sediment and 100 mL of distilled water were slowly poured into each column, sealed, and measured every day for DO and SRP concentrations. To investigate the effect of temperature on the phosphorus release from sediment, three different temperatures were fixed: 10 ℃, 25 ℃, and 35 ℃. In this experiment, the amount of sediment was 10 g and pH was set at 7 respectively. To study the relationship between initial pH and SRP concentrations, three different pH values were used: pH 4, 7, and 10. In this experiment temperature was fixed at 25 ℃ and the amount of sediment was 10 g. Also, different amounts of sediment (5, 10, and 15 g)were poured into glass columns and SRP concentrations were measured respectively to investigate the effects of the amount of sediment on the phosphorus release at 25 ℃ and pH 7.

To control the phosphorus in water body, waste chalk and raw sludge were used. Chalk which was abandoned after use was collected from schools and institutes. Collected chalk was ground and the portion which pass through sieve No. 35 was used. Dewatered raw sludge was air-dried in the shade and the portion which pass through sieve No. 10 was used. Water sample was taken from Lake Sihwa. The phosphorus concentration of water sample in Lake Sihwa was 0.173 ppm and the pH was about 7. Previous study(Kim, et al., 1998) showed that CaO was much more effective in removing phosphorus in water than $CaCO_3$. Since the major component of chalk is $CaCO_3$,

calcination of chalk using 550 ℃ muffle furnace was conducted. Under constant conditions (25 ℃, 160 rpm), batch shaking experiments were conducted with chalk, calcinated chalk, and raw sludge. 1 g of each material and 100 mL of water sample were poured into 250 mL Erlenmeyer flask. Shaking time was 12 hours. After 12 hours shaking, phosphorus removal efficiencies were compared.

3. Results and Discussion

3.1. PHOSPHORUS RELEASE CHARACTERISTIC RELATED WITH DO CONCENTRATION CHANGE

The relationship between SRP concentration and DO concentration was investigated. At 10 ℃, no phosphorus release was observed at all for all pHs. It means that water temperature is an important factor in phosphorus release and that no phosphorus release from sediment occurs under 10 ℃ regardless of pH. For other conditions (i.e. combination of pH = 4, 7, 10 and water temperature = 25 ℃, 35 ℃), the following similar trends were observed. That is, in early stage of experiment, the inside of columns was in aerobic conditions and no phosphorus release occurred. After the oxygen in columns was depleted, DO concentration decreased. When DO concentration approached 1 mg/L, phosphorus release started and increased with time. Among these common trends, typical one for 25 ℃ and pH 7 was shown in Fig. 1. Fig. 1 clearly shows the reverse relationship between DO and SRP concentration. This could be explained as follows: As time elapsed, sediment oxygen demand increased and oxygen in column was depleted. As condition became anaerobic, oxidation-reduction potential decreased. The multivalent metal ions which had had stable structure with PO_4^{-3} in aerobic condition in the sediment were reduced due to depletion of oxygen. Then the bonding with phosphorus was broken and phosphorus release occurred.

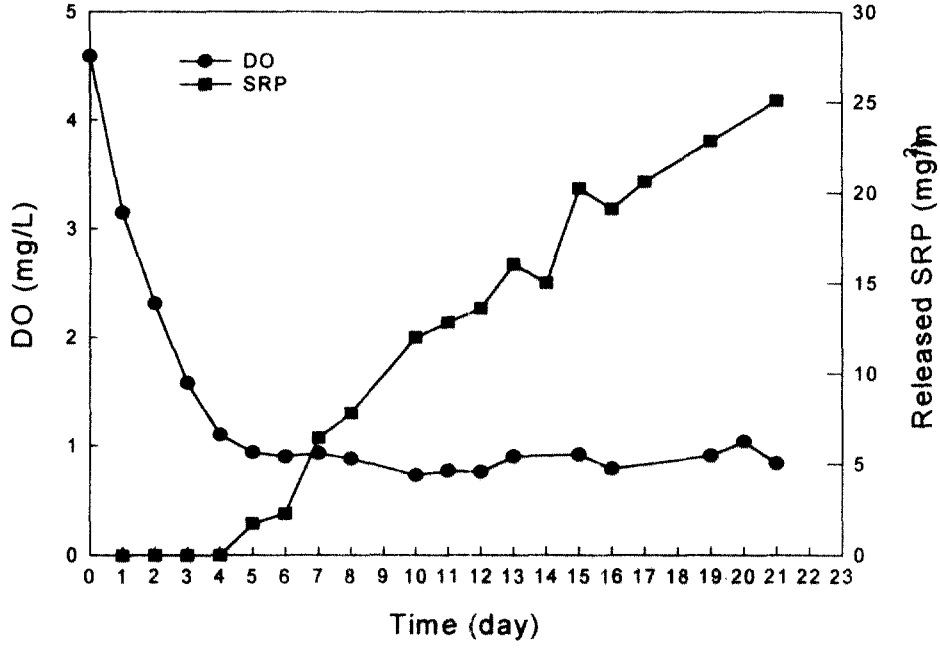

Fig.1. Relationship between DO and SRP concentrations at 25 ℃ , pH 7

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3.2. Phosphorus release characteristic related with the amount of sediment

Previous study showed that the phosphorus release characteristics depended on the depth of sediment7). According to Hilerods research (Hilerod, et al., 1972), phosphorus present in 2 cm-depths sediment was actively released from the boundary layer between water and sediment to water body. As depth increased, phosphorus release rate decreased. And beyond 10 cm, phosphorus release was not observed. In our study, we changed the amounts of sediment (5, 10, and 15 g), and the result was shown in Fig. 2. Fig. 2 showed that phosphorus was released in the same manner even though the amount of sediment added was different. And the amount of SRP released was almost same. According to the models on release or volatilization from sediment or soil, mass transfer starts from the top of soil or sediment down and mass transfer rate decrease as time elapses and depth increases to bottom(McDabe, et al., 1978, Kang, et al., 1996, Mayer, et al., 1974).

The general material release curve can be drawn as in Fig. 3. Section I indicates the upper part of sediment in which phosphorus release rate is fast because the moving distant to boundary layer is too short to be hindered by porous media or particles in sediment. As time elapses, phosphorus path length to boundary layer increases and phosphorus release rate decreases (section II). When it approaches equilibrium, no further phosphorus release occurs (section III). Considering these phosphorus release stages, the first stage phosphorus release (section I) occurred in our study because the amount of phosphorus released was almost same even though the amount of sediment (so the path length of phosphorus) was changed.

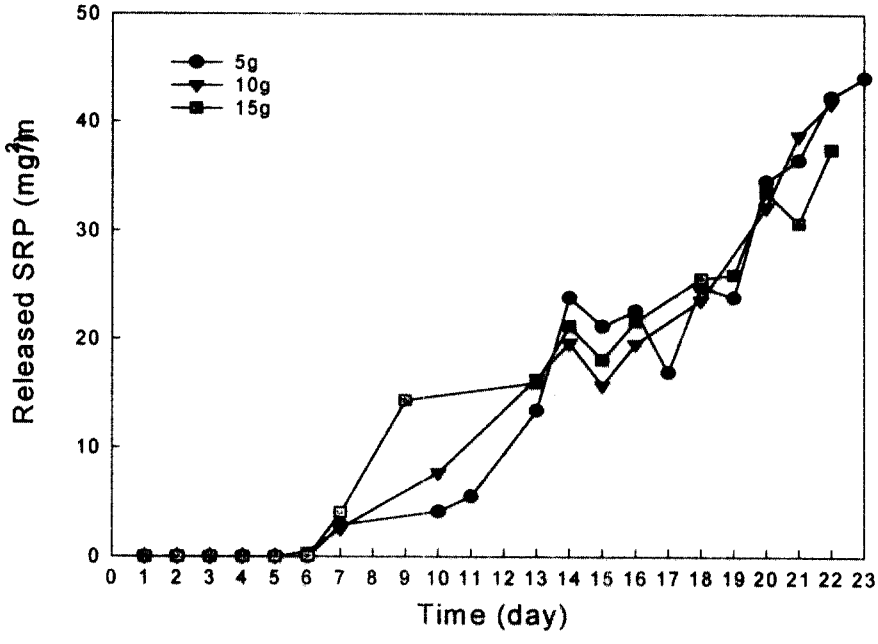

Fig. 2. SRP release amounts as a function of sediment quantity

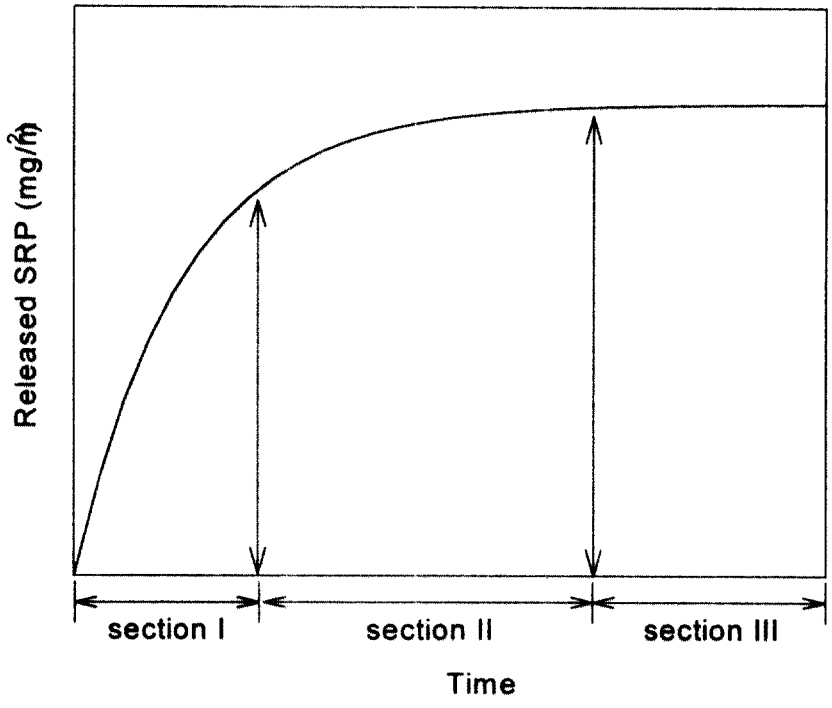

Fig. 3. General release curve from sediment

3.3. Development of model for phosphorus release from sediment

According to the above result, phosphorus release in this study was in the first stage(section I) in which phosphorus release was not hindered by the release path. Therefore, SRP concentration change with time was assumed as zero order reaction. That is,

$$dC/dt = k \quad \text{---------- (1)}$$

where C = SRP concentration (mg/L)
t = time (day)
k = reaction rate constant (mg/L/day)

Based on zero order reaction assumption, linear regression technique was applied to the SRP concentration with time. For all conditions (i.e. combination of pH = 4, 7, 10 and water temperature = 25 ℃, 35 ℃), high linearity was observed. Typical result was shown in Fig. 4, which is the SRP concentration at 25 ℃ and pH 7. According to Fig. 4, phosphorus was not released for the first three days due to aerobic condition. Slope in linear regression line represents the reaction rate constant, k. These values were summarized in Table 1. By comparing these k values, the relation between temperature and SRP concentration could be figured out at each pH. Results (Table 1) showed that k25 was greater than k35 at pH 4 and reverse trends were observed at pH 7 and 10. Therefore phosphorus release was more active at 25 ℃ than 35 ℃ under acidic condition according to Table 1. Under neutral or alkaline conditions, more phosphorus was released at 35 ℃ than 25 ℃. In a natural condition, the pH of lake is usually near neutrality due to its buffering capacity. Therefore it could be predicted that the amount of SRP released

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Table 1. Comparison of reaction rate constant values at each pH and temperature

Temp(℃) \ PH	4	7	10
25	0.01489	0.00967	0.01101
35	0.01072	0.01016	0.01345

(unit of k : mg/L/day)

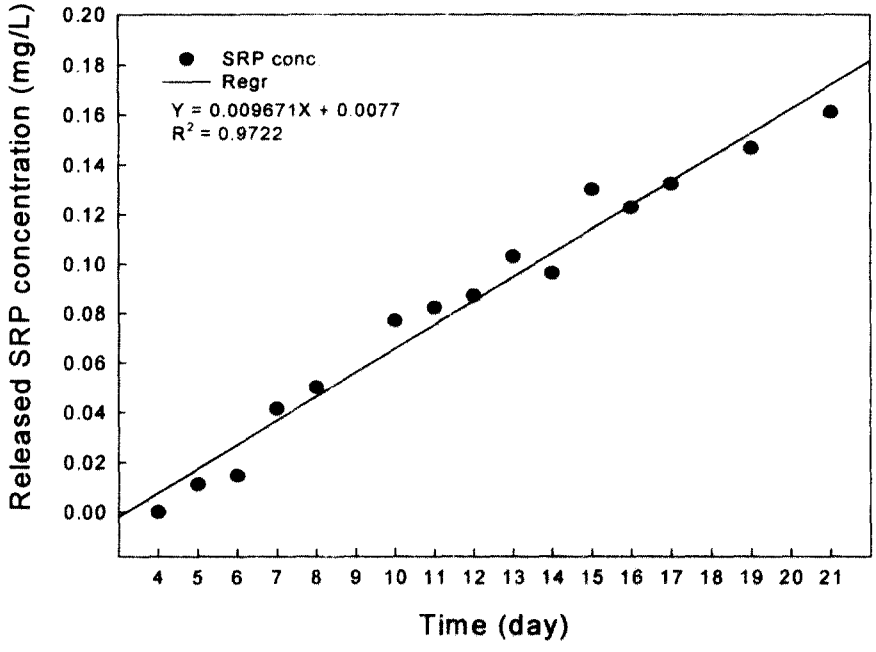

Fig. 4. Relation between released SRP concentration and time at 25 ℃ , pH 7

increases with temperature. The SRP concentration and the amount of phosphorus released from sediment can be calculated because the reaction rate constant, k, can be determined.

3.4. Control of phosphorus in water

Phosphorus removal efficiencies were compared in Fig. 5. Fig. 5 showed the phosphorus removal percentage using 1 g of chalk, calcinated chalk, and raw sludge, respectively. Water sample was taken from Lake Sihwa. Chalk showed about 20 % of phosphorus removal efficiency. Phosphorus removal efficiencies of both of calcinated chalk and raw sludge were about 90 %. When the same amount of calcinated chalk and raw sludge were used, calcinated chalk showed better phosphorus removal efficiency. $CaCO_3$ in chalk was converted to CaO during calcination in the 550 ℃ furnace. Due to this conversion, calcinated chalk had much higher phosphorus removal efficiency than normal chalk.

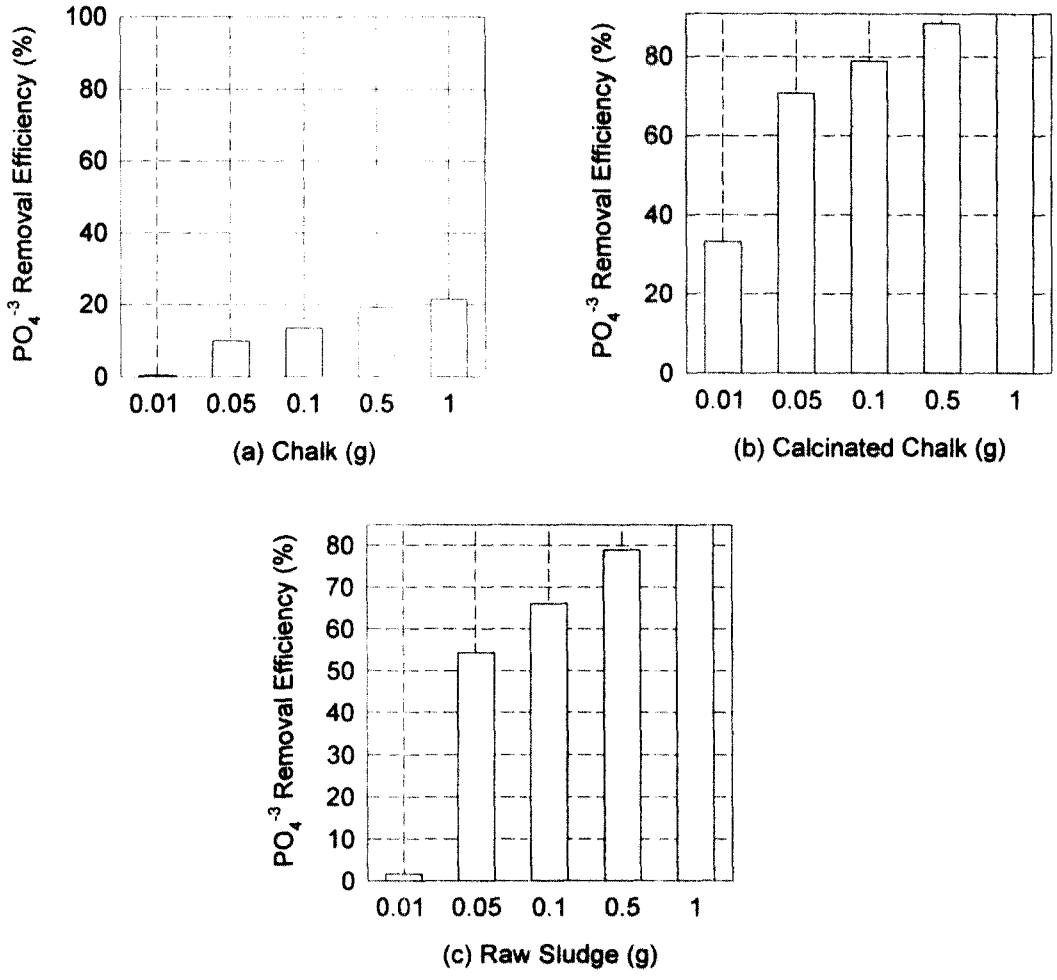

Fig. 5. Phosphorus removal efficiencies in Lake Sihwa using various materials

4. CONCLUSIONS

In this study, phosphorus release characteristics and control strategy were investigated. Temperature effect on phosphorus release showed that water temperature was an important factor in phosphorus release and that no phosphorus release from sediment occurred under 10 ℃ regardless of pH. DO concentration and phosphorus release had reverse relationship. That is, in early stage of experiment, the inside of columns was in aerobic conditions and no phosphorus release occurred. When DO concentration decreased to 1 mg/L, phosphorus release started and increased with time.

To investigate the effect of the amount of sediment on phosphorus release, the amount of sediment was varied. Results showed that phosphorus was released in the same manner even though the amount of sediment added was different. And the amount of SRP released was almost the same. This means that phosphorus release in this study was in the first stage in which phosphorus release was not hindered by the release path. Therefore, SRP concentration change with time can be considered as zero

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order reaction.

Based on zero order reaction assumption, linear regression technique was applied to the SRP concentration with time. For all conditions, high linearity was observed. By comparing these reaction rate constant (k) values, the relation between temperature and SRP concentration could be figured out at each pH. Moreover, SRP concentration and the amount of phosphorus released from sediment can be calculated because the reaction rate constant, k, can be determined.

Phosphorus removal efficiencies were compared using chalk, calcinated chalk, and raw sludge, respectively. Chalk showed about 20 % of phosphorus removal efficiency. Phosphorus removal efficiencies of both of calcinated chalk and raw sludge were about 90 %. When the same amount of calcinated chalk and raw sludge were used, calcinated chalk showed better phosphorus removal efficiency. $CaCO_3$ in chalk was converted to CaO during calcination in the 550 ℃ furnace. Due to this conversion, calcinated chalk had much higher phosphorus removal efficiency than normal chalk.

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