Application of small community sewer system for improving the quality of the water resource in Korea

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Abstract An existing SBR plant in a rural area was retrofitted from a conventional fill-and-draw system to an intermittent-aeration system for additional nitrogen removal. This study indicated that organic and nitrogen removal efficiency was improved over that before the retrofitting. But effluent phosphorus concentration was increased gradually with the operating time. In the latter period of investigation, phosphorus concentration in effluent was higher than influent. It was regarded that an excessively accumulated phosphorus was released again under the anaerobic conditions of the sludge storage tank. The application of the electro-coagulation process was investigated as an alternative method in order to prevent phosphorus from re-releasing. A laboratory test for electro-coagulation indicated that T-P removal was more stable than the biological method only. In addition, it was confirmed that T-N and organic materials as well as T-P were removed simultaneously by the electrochemical reaction in the bioreactor combined with electrolysis by more than the bioreactor only.

Keywords Electro-coagulation; intermittent-aeration SBR; nutrient removal; phosphorus re-release; retrofitting; rural community sewage treatment plant

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Introduction

A centralized sewer system has been applied for many years in Korea. However, it has been revealed that a centralized sewer system has many defects, such as decrease of stream flow, inflow and infiltration of groundwater into sewer, low efficiency of sewage treatment and so on. Therefore, it has been changed into a decentralized on-site treatment system in recent years. The Korean government has expanded investments for improving the quality of water resources for the last several years. It is defined that a rural community sewage treatment plant (RCSTP) has a capacity under 500 m^3/day. RCSTP is usually applied to the area with no sewer system, but with high ecological sensitivity. Recently, RCSTP has played an important role in preserving the quality of water resources in Korea. Therefore, this study presents a review of RCSTP in Korea and proposes a suggestion for an appropriate process.

Generally Korean rural areas have a fine natural environment. Therefore, it is important that RCSTP is in harmony with its surroundings. But naturally sound RCSTP is ignored because of unreasonable emphasis only on construction cost. Natural value is so infinite that environmentally sound construction should be in effect.

RCSTP usually has an extreme fluctuation in quantity and quality of influent. This fluctuation has an influence on the effluent quality. But fluctuation control is neglected by lack of knowledge and public misperception. Typical ratio of peak flow to average is 2 to 3 in residential areas, but it is found that some resort areas have a ratio up to 17. Consequently, equalization tanks are essential for RCSTP.

As a general case, RCSTPs are located in the protection area of water sources regulated by Korean laws. But nitrogen and phosphorus are not removed sufficiently by RCSTP, so difficulties of water source management occur. Biological phosphorus removal is not sufficiently effective to protect eutrophication. Among some biological nutrient removal processes, an intermittent-aeration SBR system is suitable because operation is automatic and maintenance is almost free. But the waste activated sludge of RCSTP is left in the thickening-storage tank for a long time until treatment at a nearby municipal wastewater treatment plant. Sometimes effluent phosphorus concentration is higher than influent because the phosphorus releases again under the condition of anaerobic state in the sludge storage tank. Therefore, it is desirable that phosphorus is removed by chemical methods for the purpose of preventing phosphorus re-release. But RCSTP is short of personnel for operating the chemical feeding facilities. Therefore, more effective treatment approaches such as electrochemical methods are anticipated to be applied for easy maintenance as well as effective phosphorus removal below 1 mgT-P/l.

Many researchers have studied that electrochemical methods combined with biological treatment are a technical solution for the simultaneous removal of phosphorus, nitrogen and organic materials (Grfterud and Smoczynski, 1986). Fe ions, which are ionized from iron electrode by electrolysis, react with phosphorus chemically and the removal of nitrogen and organic materials is also enhanced. Phosphorus removal by electrolysis of iron is more effective than other chemical treatments. This method is economical and has no pH drop. Fe^{2+} released from the surface of iron installed as the anode is oxidized to Fe^{3+} in the existence of oxygen. Then phosphorus in wastewater reacts with Fe^{2+} and Fe^{3+} to form an insoluble precipitate (Snoeyink and Jenkins, 1980), and removed with excess activated sludge.

$$Fe(s) \leftrightarrow Fe^{2+} + 2e^- \quad (1)$$

$$Fe^{2+} \leftrightarrow Fe^{3+} + e^- \quad (2)$$

$$3Fe^{2+} + 2PO_4^{3-} \leftrightarrow Fe_3(PO_4)_2 \quad (3)$$

$$Fe^{3+} + PO_4^{3-} \leftrightarrow FePO_4 \quad (4)$$

Electrolysis of iron plates produces oxides and hydroxide such as Fe_3O_4, Fe_2O_3 and $Fe(OH)_2$ under a variety of pH values. Phosphorus is absorbed on the ferric and ferrous salts (James *et al.*, 1992). The amount of released metal is theoretically calculated from Faraday's law of electrolysis.

$$W = ItA/nF \quad (5)$$

where W is amount of released Fe^{2+} (g); I is current (A); t is time (s); A is atomic weight (g); n is number of electrons; F is Faraday constant (96,487A/s).

This study presents a basis for retrofitting real plants under the serious fluctuation of flowrate and low efficiency of nutrient removal. And the applicability of electrolysis as an alternative for phosphorus control has been evaluated in the laboratory.

Methods

Retrofitting of an abnormally operated plant

A real plant was modified to improve performance of RCSTP. This plant is located in a small rural community, Jechon near Chungju lake which provides water sources, recreation and aesthetics for surrounding areas.

This plant with the capacity of 48 m^3/day has a typical fill-and-draw SBR system, and sequence of fill-react-settle-draw and idle (see Figure 1a). But diagnosis of this plant showed an insufficient nutrient removal and malfunction with severe flowrate variation. So operational problems at this plant were surveyed as follows.

- On average, flowrate and quality of inflow were lower than those of the design values. Thus this plant was underloaded.
- Flow equalization was not achieved because a pump with high capacity was operated for a short time until reaching the designed low water level in the equalization tank. Feed flowrate varied with daily flow pattern, so the system was not optimum.
- Sometimes effluent phosphorus concentration was higher than the influent, caused by anaerobic conditions in the sludge storage tank. Supernatant of the sludge storage tank has been transferred into the equalization tank.
- Residents and restaurant business wasted groundwater because of being free of charge for groundwater use. Thus unpolluted water flowed into the sanitary sewer.

Therefore the plant was retrofitted for solving problems as listed in Table 1 through the following steps; (1) analysis of wastewater quantity inflowing into the sewer including unpolluted water (inflow/infiltration); (2) separation of unpolluted water from influent, and in consequence wastewater concentration became higher; (3) review of operating parameters for performance improvement.

The retrofitting was focused on the improvement of nitrogen and BOD removal. The modified plant was operated with 6 h/cycle and 4.8 h/cycle in emergency as shown in Figure 1b,c. Inflow was controlled in the in-line equalization method, and the capacity of the feed pump was lowered to 40 l/min. Waste sludge was stored in the storage tank as it was before.

As shown in Figure 2, inflow into the reactor was adjusted using high and low water level. When water level reaches the high mark during the react or settle period in the 4 cycles/day mode, the draw period starts immediately and the mode is changed into 5 cycles/day (Figure 1c). In the course of the 5 cycles/day (4.8 h/cycle) mode, the secondary pump is operated with a main feed pump simultaneously. The capacities of two pumps are 10.6 m^3/cycle and 53.0 m^3/day and make plant capacity 1.7 times that before. When the feed to the SBR tank lowers below 7.5 m^3, that is, low water level in equalization tank is reached within 1.5 hour from the start of a cycle, the operation mode is changed into 4 cycles/day automatically. The alarm system was equipped against emergencies such as sudden troubles of feed and discharge pump, blower breakdown, unexpected increase of inflow, programmable logic controller failure and so on. When an alarm system is raised, a message is transmitted to personnel in charge of maintenance via mobile phone. And feed water flows into the SBR tank through the emergence inlet. Due to the flow through formed sludge blanket, feed water is purified to some extent. Therefore, minimization of receiving water pollution could be expected.

Table 1 Design and operational parameters before and after retrofitting

Design and operational parameters	Before	After
Capacity (m^3/day)	48	30
Influent concentration (mg/l)		
BOD	200	160
TKN	–	30
Volumetric loading (kgBOD/ m^3.day)	0.35	0.17
Fill volume ratio	0.43	0.26
MLSS (mg/l)	3,000	4,000
Food-to-microbe ratio	0.23	0.12
a-SRT (day)	5.5	43.1
Fraction of aeration time per cycle	0.5	0.33

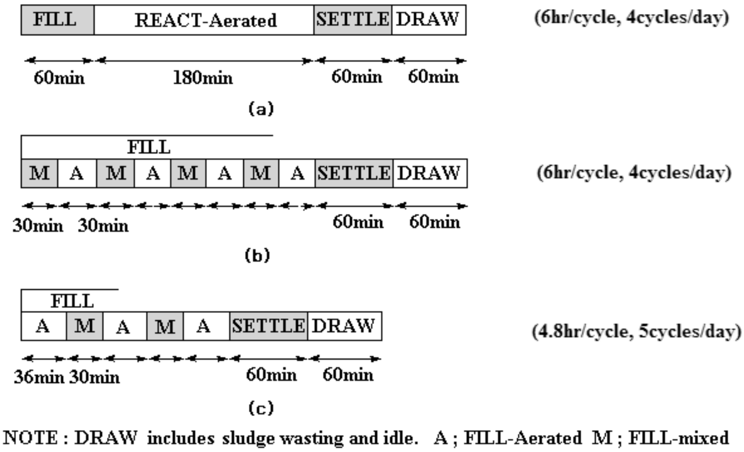

Figure 1 Time schedule mode during a cycle

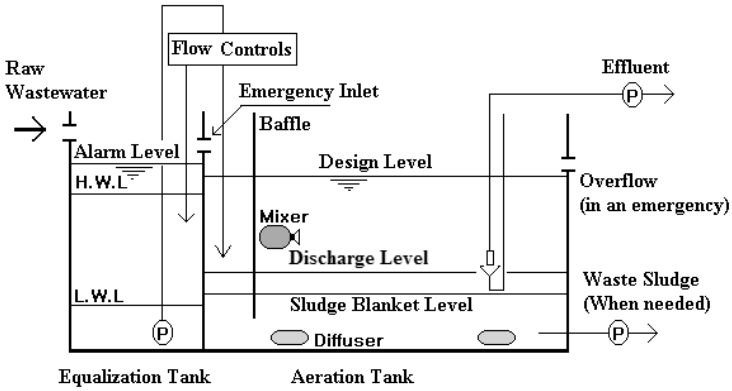

Figure 2 Schematic of retrofitted SBR system

Phosphorus removal using electro-coagulation

The laboratory test was conducted to achieve the optimum phosphorus removal and to ascertain how to operate the plant for its purpose. The laboratory scale SBR used consisted of an acryl vessel with a stirrer for mixing and sludge extraction, and with a working volume of 90 L (250 mm W × 750 mm L × 600 mm H). The required air is supplied through a ceramic diffuser, connected to an air pump with adjustable flow. A peristaltic pump is operated for feed addition, effluent discharge and sludge wasting.

The SBR was operated with 4.8 h/cycle as shown in Figure 1c. Intermittent aeration was performed and aeration time ratio was 0.375. Excess sludge was wasted at the end of the draw period. The SBR was fed with synthetic wastewater composed of glucose, peptone, mineral salts and so on. Required amount of ferrous ion was calculated by Faraday's law, operational Fe-P mol ratio was adjusted to 1.0 and applied current was about 185 mA throughout the test. And the distance between the electrodes of the iron plate was 4 cm. Current is applied only during aeration time to prevent the formation of vivianite precipitate [$Fe_3(PO_4)_2 \cdot 8H_2O$]. Since Fe^{2+} is oxidized to Fe^{3+} under the aerobic condition, vivianite precipitate is not produced, and so current efficiency does not decrease. If current is applied in anaerobic and anoxic conditions, denitrification and P-release are disturbed by the oxygen produced at the cathode.

The experiments were accomplished in two stages. The first stage was the SBR test and the second stage experiment was the SBR bioreactor combined with electrolysis. Both SBR tests were operated with MLSS concentration of 4,300~5,400 mg/l and MLVSS of 2,800~4,300 mg/l. The effective SRT was corrected for the aeration period and it was about 11 days. And F/M ratio based on the aeration was about 0.03 kg BOD/kg MLVSS·day.

Results and discussion

Real plant

By separating unpolluted water from the sewer system, average flowrate of wastewater was decreased from 27.4 to 19.4 m^3/day as shown in Figure 3. The peak decreased to 2.0 from 2.3 times the average flowrate. In addition to that, concentration of influent became higher than before.

Average effluent concentration of the retrofitted plant is shown in Table 2. Organic materials were removed successfully, with average removal rate of above 94%. About 9 mgT-N /l concentration in effluent was obtained in spite of low water temperature. Water temperature range was 9~13°C during the period of operation. But trouble appeared in phosphorus removal although the effluent phosphorus concentration was relatively low. Effluent phosphorus concentration increased gradually with operating time. In the latter period of investigation, effluent phosphorus concentration was higher than influent. It was considered that excessively accumulated phosphorus was released again under the anaerobic conditions of the sludge storage tank. Therefore, it is required to find some solutions for prevention of phosphorus re-release such as chemical methods and frequent wasting of sludge.

Laboratory test

Water temperature and pH were not influenced by electrolysis. Temperature ranged from 15.6 to 18.0°C during operation. Increase of temperature was not observed in stage 2, SBR combined with electrolysis. The pH was decreased in both stages as a result of nitrification. Influent pH was in the range of 6.65 to 7.73 (average 7.19) and effluent was 5.16 to 6.99 (average 6.37).

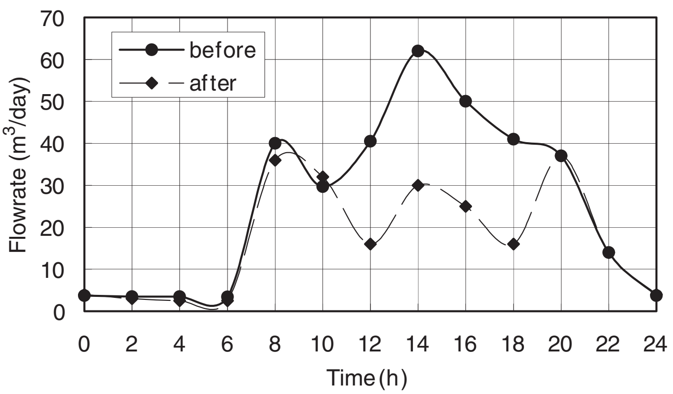

Figure 3 Influent flow of before and after separation of unpolluted water

Table 2 Removal efficiency of pollutants after retrofitting the plant

	Influent (mg/l)	Effluent (mg/l)	Removal efficiency (%)
BOD	129.9	7.7	94.1
COD	285.8	15.9	94.4
SS	55.4	8.0	85.6
T-N*	22.7	9.0	60.4
T-P	2.2	1.3	40.9

* Nitrogen of influent is TKN

Average MLSS concentration was 4,322 mg/l in stage 1 and 5,376 mg/l in stage 2. But average MLVSS concentration was 3,902 mg/l and 3,958 mg/l respectively. And the sludge settleability was improved by the formation of chemical precipitate. Settleability improvement is due to increase of effective density of sludge, and SVI was decreased from 191.4 mL/g in stage 1 to 162.7 mL/g in stage 2. And effluent SS concentration was below 6 mg/l in both stages. But it is expected that MLSS concentration could increase gradually in case of applying electrolysis. So further investigation is required to find operational conditions for phosphorus removal using electrolysis with a viewpoint of MLSS control.

Effluent total Fe concentration, 1.6 mg/l in stage 2 was higher compared with 0.2 mg/l in stage 1. Carter and McKinney (1973) proposed that total iron concentration between 2 mg/l and 10 mg/l would not have any adverse effects on the rate of organic metabolism but rather ensure that the maximum rate of microbial metabolism would occur.

Table 3 summarizes the operation results of stage 1 and stage 2. Organic removal efficiency was very high showing above 92%. Effluent organic concentration was stable during the whole period (see Figure 4). But effluent concentration in stage 2 was lower than stage 1. It is noted that electrolysis in the bioreactor has no adverse effect on organic material oxidation. On the contrary, the removal efficiency of organic material was increased by improvement of both sludge settleability and microorganism activities.

Electrolysis in the bioreactor had no adverse effect on nitrification and denitrification. Nitrogen was removed stably like organic materials in stage 2. It seems that hydrogen gas generated at the cathode surface by the electrolysis of water was utilized efficiently for denitrification, even if excess amount of organic hydrogen donor existed in wastewater, as shown by Kuroda *et al*. (1997). TKN concentration of effluent in stage 2 was lower than stage 1 because the nitrification rate was increased in the latter stage. Microorganism

Table 3 Comparison of performance between stage 1 and stage 2 operation

	Influent (mg/l)	Stage 1		Stage 2	
		Effluent (mg/l)	Removal efficiency (%)	Effluent (mg/l)	Removal efficiency (%)
BOD	248.2	18.0	92.1	14.8	94.3
COD	369.6	28.1	92.5	23.2	93.7
SS	123.0	6.4	94.8	6.5	94.7
TKN	25.3	5.0	80.2	3.2	87.4
NOx-N	1.5	2.2	–	2.2	–
T-N	26.8	6.6	75.4	5.4	79.9
PO_4-P	5.2	0.6	88.5	0.3	94.2
T-P	10.7	1.3	87.9	0.6	94.4

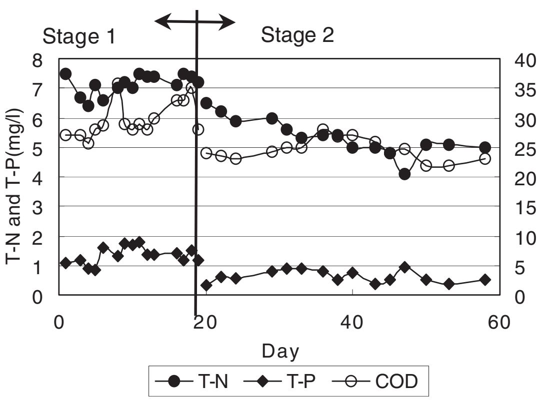

Figure 4 Daily variation of effluent COD, T-N and T-P

activity seems to be increased by electrolysis (Akinlaja and Sachs, 1998), and NH_3-N may have converted into NOx-N through the direct reaction with OH^- released at the anode (Marinĉić and Leitz , 1978).

Effluent T-P concentration was more stable with an average of 0.6 mg/l in stage 2 than stage 1 because of electrolysis. In stage 1, effluent T-P concentration was not accomplished to be lower than 1 mg/l of the goal for this experiment. In stage 2, Fe-P mol ratio was 1.0 although many researchers proposed a ratio of above 1.5. It seems that the phosphorus is removed in various forms through microorganism assimilation, $FePO_4$ precipitation and adsorption by $Fe(OH)_3$, Fe_2O_3 (Kavanaugh *et al.*, 1978; Bowers and Huang, 1987). Effluent T-P concentration as well as T-N in both stages could meet the Korean effluent standards for municipal wastewater treatment plants. This means that the intermittent aeration SBR system performs well for nutrient removal.

The electro-coagulation method is to be applied for phosphorus removal at small plants in rural areas.

Conclusions

The results of this investigation can be summarised as follows.

- Retrofitting an SBR could improve organic material and nutrient removal efficiency: the efficiencies were 94% for BOD, 86% for SS, 61% for T-N and 41% for T-P. However T-P removal efficiency can be impaired by phosphorus re-release resulting from anaerobic conditions in the sludge storage tank.
- The SBR combined with electrolysis is a good solution for effective phosphorus removal as well as prevention of phosphorus re-release. In addition, organic materials and nitrogen are removed more stably in comparison with a bioreactor only. The efficiencies for BOD, T-N and T-P were increased from 92.1%, 75.4% and 87.9% to 94.3%, 79.9% and 94.4% respectively. Furthermore, effluent T-P concentration is stable below 1 mg/l throughout the experiment.
- Because MLSS concentration can be gradually increased in the process of electrolysis, further investigation is needed to maintain the MLSS concentration and VS fraction properly in the aeration tank.

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