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Effect of an electro phosphorous removal process on phosphorous removal and membrane permeability in a pilot-scale MBR☆

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ABSTRACT

The pilot membrane bioreactor (MBR) was equipped with an electro-coagulation process for phosphorous removal (EPR process). The effect of the EPR process on nutrient removal and membrane permeability was investigated in this study.
Experiments were carried out for about 5 months with the pilot MBR that treated wastewater at a capacity of 50 m^3/day. And the MBR used two different materials of the plate type membrane: polyvinylidene fluoride (PVDF) and polyethersulfone (PES). Phosphorous ion released from the anaerobic settling tank was coagulated by electrochemical reaction with aluminum ion discharged from aluminum plate electrodes in the EPR tank. The phosphate (PO_4^{3-}-P) removal efficiency and the total phosphorous (TP) removal efficiency by electro-coagulation were 89.2% and 79.9%, respectively. Results of particle size distribution (PSD) analysis showed that the particle sizes of flocs were mostly in the range of 50–150 µm, and the membrane resistance decreased significantly in the MBR as the EPR proceeded. Consequently, this study showed that the EPR process was useful for reducing trans-membrane pressure (TMP) and for removal of phosphorous in the MBR, which was operated in long sludge retention time (SRT) conditions.

1. Introduction

Membrane bioreactor (MBR) process is an alternative method using membranes for solid–liquid separation, substituting the conventional biological sedimentation process. Materials bigger than the pore size of the membrane cannot come out of the system and stay in the reactor due to physical characteristics [1].

Generally, MBRs produce an effluent of high sanitary quality by improving the biological treatment efficiency, because MBRs allow high volumetric organic loadings by retaining high concentration of sludge biomass [2–4]. On the other hand, MBRs have disadvantages in that the MBR filtration performance inevitably decreases with filtration time. This is due to the deposition of soluble and particulate materials onto and into the membrane [5]. Also, maintaining long sludge retention time (SRT) and retaining high concentration of sludge lead to difficulty in phosphorous removal [6]. Phosphate can be treated by several physical, chemical, and biological methods.

Biological methods are cost-effective and produce less sludge than physical or chemical methods, but they have disadvantages such as longer treatment time and lower phosphorous removal efficiency. Polyphosphate-accumulating organisms (PAOs) release P during the anaerobic phase and remove it during the aerobic phase by accumulating P as polyphosphate [7]. Fu et al. [8] reported that phosphorus accumulating organisms (PAOs) exist in a modified anoxic/oxic-membrane bioreactor (A/O-MBR) system.

Chemical precipitation is also widely used for phosphate removal [9,10]. The common precipitants used are aluminum sulphate and ferric chloride. Chemical precipitants imply further costs for the purchase and installation of dosing equipment and higher operating costs for power, disposal of additional sludge, manpower, and the chemicals used [11].

Enhanced biological phosphorous removal processes can lower the total phosphorous (TP) concentrations in the effluent to 0.1–0.2 mg/L [12], but, nevertheless, supplemental additions of chemicals such as Al or Fe(III) salts, poly-aluminum chloride (PACl), and/or lime are often required to maintain acceptable effluent TP concentrations [13].

Also, MBRs need high maintenance cost because the membrane must be cleaned periodically or changed to overcome membrane fouling.

Recently, various chemicals have been tested for their filtration and fouling reduction abilities/performance in MBRs through a batch test [14]. Song et al. [15] pointed out that alum injection in the batch tests could be helpful for increasing phosphorus removal and minimizing membrane fouling because small particles can become bigger particles, which have less fouling tendency due to the coagulant. However, besides membrane fouling control, the effects of chemical addition on real MBR systems and on organic and nutrient removal need to be documented by further investigation [16].

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Nomenclature

BOD	biochemical oxygen demand (mg/L)
COD	chemical oxygen demand (mg/L)
DO	dissolved oxygen (mg/L)
EPR	electro-coagulation process for phosphorous removal
HRT	hydraulic retention time (h)
MBR	membrane bioreactor
MLSS	mixed liquor suspended solids (mg/L)
ORP	oxidation-reduction potential (mV)
PAOs	polyphosphate-accumulating organisms
PES	polyethersulfone
PVDF	polyvinylidene fluoride
PSD	particle size distribution
SRT	sludge retention time (day)
TMP	trans-membrane pressure
TN	total nitrogen (mg/L)
TP	total phosphorous (mg/L)

Therefore, electro-coagulation processes for phosphorous removal (EPR processes) have been attempted as an alternative process to overcome these disadvantages, namely, the difficulty of phosphorous removal and membrane fouling.

Phosphorous removal by the EPR process was easily managed under high temperature and pressure. It reduced sludge production and remove phosphorous in a short time [17,18]. Also, it could decrease membrane fouling by increasing sludge particle size, and reduce the footprint for the treatment process [19].

An MBR process with a flat-sheet membrane and the EPR process were studied to improve phosphorous removal efficiency and membrane permeability.

2. Materials and methods

2.1. Experiment setup and operating conditions

The pilot plant with wastewater capacity of 50 m^3/day is located at a municipal wastewater treatment plant in Guri, South Korea (Table 1).

Fig. 1 shows a schematic diagram of the treatment system used in this study.

The system consisted of a buffer tank, an anoxic tank, an anaerobic settling tank, an EPR tank, and an aerobic tank with a submerged membrane separation unit.

Phosphorous was stably removed in the EPR tank by separating the phosphorous from the supernatant, which had high phosphorous concentration because it was imported from the anaerobic separation tank. The EPR tank consisted of an aluminum electrode and a reactor.

Table 2 shows the operation condition of each unit process. The MLSS concentration of the aerobic MBR tank was in the range of 6770–12,150 mg/L.

Table 3 shows the specification of the membranes used in this study. Two different flat-sheet membranes (PVDF, PES) were used. Mean pore sizes of PVDF and PES were 0.08 μm and 0.2 μm, respectively.

Table 1
Operation condition of pilot plant.

Parameter	Value
Capacity	50 m^3/day
HRT[a]	6.7–7 h
SRT	42–69 days
MLSS[b]	6770–12,150 mg/L (MBR)

[a] HRT: hydraulic retention time.
[b] MLSS: mixed liquor suspended solid.

In this study, three different modes according to the type of coagulation designed were implemented, as described in Table 4.

In run #1, the experiment was conducted without coagulation. Alum was induced for run #2. In run #3, the EPR process was used. The experiment for the MBR without coagulation was carried out before running the EPR.

2.2. Analytical methods

To investigate the treatment efficiencies of each unit process, influent and effluent samples were analyzed. Guri municipal wastewater treatment plant treated raw water by microscreen (Mesh: 3 mm) without primary sedimentation, and provided a part (50 m^3/day) of treated water for the MBR pilot system as influent.

All spectrophotometric analyses were performed using a DR 4000 (Hach, USA) with reagent kits according to the manufacturer's instruction. Particle size distribution (PSD) was analyzed using Multisizer II (Beckman Coulter, USA), which measures the particle size distribution by electric resistance. Samples from the mixed suspended liquor were analyzed in advance without coagulation addition and then were analyzed after coagulation with alum and after electro-coagulation were measured in order in this study. The effective measurement range was 22–400 μm.

3. Results and discussion

3.1. Process performance

The biochemical oxygen demand (BOD), chemical oxygen demand (COD_{Cr}), total nitrogen (TN), and total phosphorous (TP) concentration of influent were 70.1, 177.5, 25.1 and 3.1 mg/L, respectively.

Concentrations of BOD, COD_{Cr}, TN, ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3^--N), TP, and phosphate (PO_4^{3-}-P) in each unit process are listed in Table 5. Concentrations of TP and PO_4^{3-}-P in the anoxic tank were 2.4 mg/L and 2.0 mg/L, respectively and in the anaerobic settling tank, 4.0 mg/L and 3.6 mg/L, respectively. This result showed that phosphorous was released from the anaerobic settling tank.

BOD_5 concentrations in the influent and effluent were 70.1 mg/L and 2.2 mg/L, respectively. COD_{Cr} concentration was 45.3 mg/L in the anaerobic settling tank, but this value decreased to 44.4 and 40.1 mg/L in the EPR and the aerobic MBR tanks, respectively. TN concentrations also decreased from 8.6 mg/L in the anaerobic settling tank to 8.0 and 7.5 mg/L in the EPR and the MBR tanks, respectively. These decreases indicate that the EPR and MBR processes had little effect on COD_{Cr} and TN removal.

NH_3-N concentrations in the EPR and the aerobic MBR tanks were 5.7 and 1.4 mg/L, respectively. NO_3^--N concentrations were 1.5 mg/L in the EPR tank and 4.6 mg/L in the MBR tank. This result shows that nitrification was performed successfully in the aerobic MBR tank.

Changes in trans-membrane pressure (TMP) and flux during the operation period are shown in Figs. 2 and 3. PVDF and PES membranes were used in MBR tank simultaneously.

An initial TMP of the PVDF membrane was 7 kPa. The average TMP was about 10 kPa, which was maintained stably for about 5 months without membrane cleaning (Fig. 2).

Fig. 3 shows the changes in TMP and flux of the PES membrane. TMP increased rapidly up to 26.7 kPa from the initial value of 4.0 kPa by the first 30 days of operation, and then decreased to about 15 kPa. The range and average of TMP during the entire operation period were 4.0–26.7 kPa and 16.0 kPa, respectively.

TMP increased in the early period of operation mainly due to the temporary membrane fouling caused by unstable microbial activity during the initial period. After 30 days of operation, TMP gradually decreased and remained stable because microbial activity was recovered and the quality of the treated water was improved