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Effect of influent flowrate on the performance of biological wastewater treatment processes

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ABSTRACT

The organic and nutrient removal efficiency of municipal wastewater treatment plant (WWTP) can be affected by various environmental factors including sewage influent flowrate, pH, and water temperature. In this study, we investigated the effect of sewage influent flowrate on the organic and nutrient removal efficiency. Three biological wastewater treatment processes (membrane bioreactor [MBR], sequencing batch reactor [SBR], anoxic/anaerobic/oxic [A_2O]) were operated with a designed sewage flow rate of 1.5 m^3/d. The organic and nutrient removal efficiency were investigated when the sewage influent flowrate gradually decreased from 100% to 70%, 40%, and 10% of the design flowrate. The organic removal efficiencies deteriorated slightly as the sewage influent flowrate decreased from 100% to 10% for all the three processes. At 10% of flowrate condition, MBR process showed highest soluble chemical oxygen demand (SCOD) removal efficiency (89%), with slightly lower SCOD removal obtained with A_2O (74%) and SBR (70%) processes. Total nitrogen (T-N) and total phosphorus (T-P) removal efficiency decreased significantly with decreasing influent flowrate. In particular, the T-N removal rate of the SBR process decreased to 31% at 10% of flowrate condition. It can be concluded that at least 10%–40% of design flowrate should be maintained for the efficient treatment in biological WWTPs.

Keywords: Biological wastewater treatment; Sewage influent flowrate; Membrane bioreactor; Sequencing batch reactor

1. Introduction

Wastewater treatment system may consist of the application of number of physical, chemical, and biological processes. Primary treatment removes suspended solid waste that will either float or readily settle out. It includes the physical processes of screening, comminution, grit removal, and sedimentation. For secondary treatment, biological treatment is most widely used because it is more cost-effective than other types of treatment processes, such as chemical oxidation or thermal oxidation [1,2]. The performance of biological processes is affected by various environmental and operational factors including pH, hydraulic retention time (HRT), water temperature, and food to microorganism (F/M) ratio [3–5]. For example, nitrogen removal can be decreased at shorter solid retention time condition as autotrophic microorganisms usually grow slower than heterotrophic ones [6,7]. The sewage influent flowrate is one of the important operational factors that can greatly affect the performance of the biological wastewater treatment process.

It is very important to estimate the sewage flowrate properly in designing the wastewater treatment facilities including sewers, pumping stations, and treatment plants [8]. The influent flowrate markedly affects the performance of unit process and overall system of biological wastewater treatment plant (WWTP). The equalization tanks are generally used for storing sewage to equalize the influent quantity and quality. However, it is quite difficult to control the sewage flowrate at

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the initial operation (start-up) stage. Especially for the facilities built in the newly planned and constructed cities and area, the actual inflow flowrate at the beginning of operation is less than the design flowrate because the population influx is made step by step. When the actual sewage influent flow is smaller than design value, the physicochemical and biological unit processes can be significantly affected. Generally, the sludge retention time decreases when the inflow sewage amount decreases. It is reported that the oxygen uptake rate and nitrification rate decreases as the sludge retention time increase in membrane bioreactor (MBR) process [9].

In this study, we investigated the effect of actual sewage influent flowrate (compared with the designed flowrate) on the performance of biological wastewater treatment process. Three representative wastewater treatment processes (anoxic/anaerobic/oxic [A_2O], MBR, sequencing batch reactor [SBR]) were operated on pilot scale with a design influent flowrate of 1.5 m^3/day. The sewage influent flowrate was reduced from 100% to 70%, 40%, and 10% of the design value (1.5 m^3/day), and the performance of treatment process was evaluated and compared.

2. Material and methods

2.1. Reactor configuration and operation

Three representative biological treatment processes were designed and installed in S WWTP, Korea. The design sewage influent flowrates were 1.5 m^3/d for all three reactors. A flow equalization tank was installed in the raw wastewater inlet to keep the influent quality entering the three reactors the same.

The SBR cycle consisted of 30 min for fill phase, 60 min for anoxic phase, 180 min for aerobic phase, 40 min for settle phase, 40 min for decant phase, and 10 min for idle phase. The HRT of A_2O process was 1.2 h for anaerobic reactor, 2.4 h for anoxic reactor, 4 h for oxic reactor, and 6 h for settling tank. The internal recycle from oxic reactor to anoxic reactor was 200%. The MBR systems consist of anoxic tank and aerobic MBR. Hollow fiber polyvinylidene fluoride membranes with nominal pore size of 0.4 μm have been used. The submerged MBR was operated at a constant flux less than 10 LMH to minimize the biofouling during the experimental period. The internal recycle from aerobic MBR to anoxic tank was 300%.

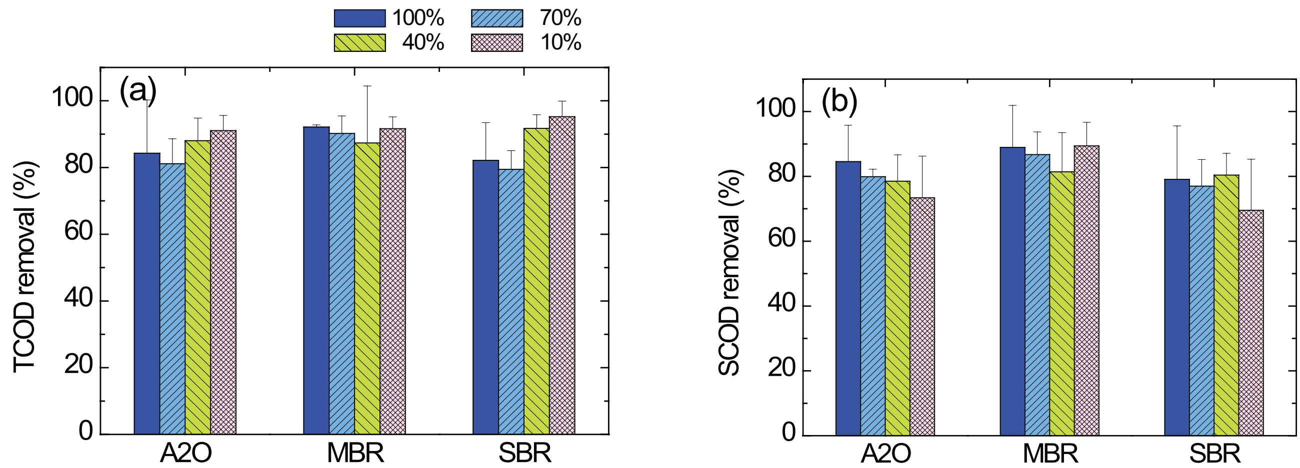

Fig. 1. (a) TCOD removal and (b) SCOD removal at different influent flowrate conditions.

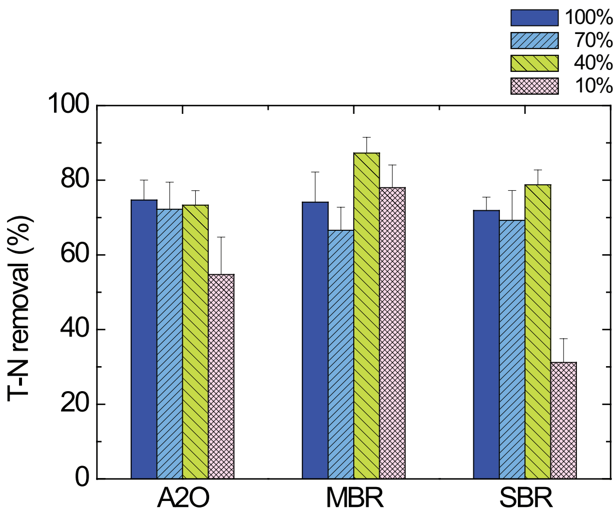

Fig. 2. T-N removal at different influent flowrate conditions.

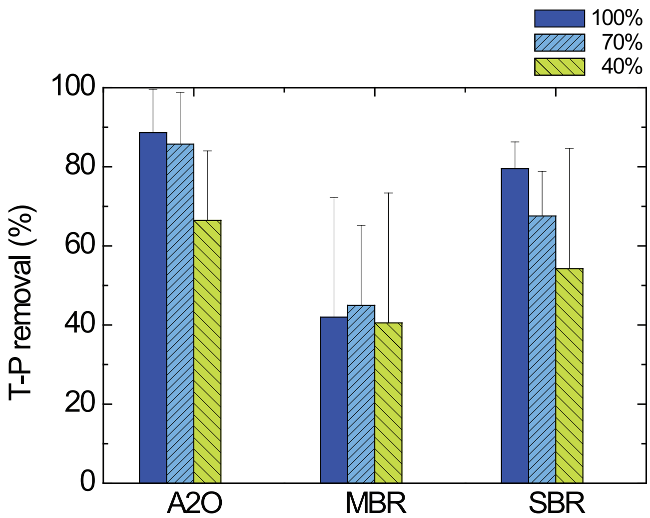

Fig. 3. T-P removal at different influent flowrate conditions.

All reactors were inoculated with the sludge taken from anoxic and aerobic tank in S WWTP, Korea. The influent flowrate was decreased from 100% to 70%, 30%, and 10% of design flow rate. The reactor was operated at least 30 d at each flowrate conditions. The influent soluble chemical oxygen demand (SCOD) concentration was 99 ± 10 mg/L. Influent total nitrogen (T-N) concentration ranged from 35 to 44 mg/L and total phosphorus (T-P) concentration ranged from 3.7 to 4.9 mg/L.

2.2. Analytical methods

Samples were taken from each reactor at least twice a week and kept in refrigerator at 4°C until analysis. The chemical oxygen demand (COD) concentration was determined according to Standard Method 5220 [10]. T-N and T-P concentrations were measured using a spectrophotometer (DR-5000, HACH, Germany). The dissolved oxygen (DO) concentration was measured using a DO meter (ORION STAR A223, Thermo, USA) and the pH was measured using a pH meter (ORION STAR A121, Thermo, USA).

3. Results and discussion

3.1. Organic removal efficiency

All three treatment processes showed high total chemical oxygen demand (TCOD) removal rates (>80%) (Fig. 1). MBR process showed the highest removal rate (92%), with slightly lower TCOD removal obtained with A_2O (82%) and SBR (84%) processes. High COD removal for MBR process is due to the excellent solids removal efficiency of the membrane separation process [11,12]. SCOD removal also showed similar tendency to TCOD removal. MBR process showed 89% highest SCOD removal rate (89%) and A_2O and SBR process showed 85% and 79% removal rates, respectively.

When the influent flowrate was gradually decreased from 100% to 70% and 40%, no significant trend was observed in the case of TCOD removal. However, the MBR process showed a relatively constant TCOD removal rate (86%–90%) irrespective of fluctuations in inflow flowrate. The SCOD removal rate tended to decrease as the influent flowrate decreased, even though there were values that did not fit the trend were observed. At the lowest influent flowrate condition (10%), the SCOD removal rate was 89% for the MBR, 74% for the A_2O, and 70% for the SBR. Both of TCOD and SCOD removal rates decreased with decreasing influent flowrate, but all processes showed relatively stable and high treatment efficiency (>70%) satisfying the water quality standards of sewage treatment in Korea. It is well known that the COD removal is affected by various factors including F/M ratio, COD/N ratio, DO, and pH [13]. Because the COD removal rate was relatively high for all tested condition in this experiment, it was judged that these factors did not change to such an extent as to affect COD removal. In other words, it can be concluded that COD removal rate of biological wastewater treatment process is not sensitive to changes in influent flowrate.

3.2. T-N and T-P removal efficiency

At the 100% of influent flowrate condition, T-N removal rate was similar for A_2O, MBR, and SBR process and ranged 72%–75% (Fig. 2). In general, it is difficult to expect a high T-N removal rate by MBR process alone, but it is considered that a high removal rate of T-N was obtained due to pre-denitrification reactor [14]. In case of the A_2O and MBR process, T-N removal rate did not show a clear trend depending on the influent flowrate. This is partially due to the influent T-N concentration greatly fluctuated during the experimental period (data not shown). T-N removal efficiency was higher than 73% in all processes even though the influent flowrate is reduced to 40% of designed flowrate. However, the T-N removal rate greatly decreased at the influent flowrate of 10% condition. The MBR process showed highest T-N removal efficiency of 78%, with much lower efficiency of 55% for A_2O and 31% for SBR. The lowest T-N removal was obtained for SBR process, and it can be improved through change of influent feed method or operation cycle [15]. T-N removal rate is considered to be influenced not only by influent flowrate but also by the characteristics of nitrifying/denitrifying microorganisms in the reactor, which are known to be changed by the environmental factors including pH and temperature [16,17]. Further studies are needed to characterize the microorganisms involved in nitrogen removal.

In case of T-P removal, MBR process showed the lowest removal efficiency of 42% at 100% of influent flowrate condition as the MBR is not designed for biological phosphorus removal [18]. Both of A_2O and SBR process showed relatively high T-P removal (>80%) (Fig. 3). The MBR process showed a T-P removal rate of 41%–45% irrespective of the change in influent flowrate. It may be related to the particulate phosphorus removal rate which can be removed by solid–liquid separation. In case of A_2O and SBR processes, the T-P removal rate decreased markedly as the influent flowrate decreased from 100% to 40% of designed flowrate.

At 10% of flowrate condition, effluent T-P concentration of A_2O and SBR process was higher than influent T-P concentration. It is considered that the phosphorus removal mechanism was not properly performed under the condition of 10% of the influent flowrate condition. This is because the F/M ratio decreased as the influent flowrate decreased and the endogenous respiration of the sludge increased, resulting in phosphorus contained in the microorganisms is released. The mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) concentrations in the reactor was gradually decreased at the influent flowrate of 10% condition (data not shown), which is also proving that sludge endogenous respiration is taking place at this condition.

The biological phosphorus removal mechanism is known to be greatly influenced by changes in microbial population due to changes in environmental conditions. It will be necessary to examine the changes in microbial population to better understand the changes in T-P removal rate according to the influent flowrate [19].

4. Conclusions

The efficiency of the pilot-scale biological WWTPs was evaluated at different influent flowrate conditions. The organic removal was found to be higher than 70% even if the influent flowrate decreased to 10% of design flowrate. However, the T-N and T-P removal efficiency decreased significantly with decreasing influent flowrate. In particular, the T-N removal rate of the SBR process decreased to 31% at 10% of flowrate condition. In the case of T-P removal, it fluctuated more than COD and T-N removal. At 10% of flowrate condition, T-P was not removed possibly due to increased endogenous respiration resulted from low F/M ratio in the reactor. It can be concluded that at least ~40% of design flowrate should be maintained for the efficient treatment in biological WWTPs.

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