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Treatment Characteristics of Wastewater with Flow Rate Variation in Anaerobic-Aerobic Activated Sludge Process

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The treatment performances of anaerobic-aerobic activated sludge process were investigated under various operation conditions. The treatment system proposed in this study gave a relatively stable performance against hourly change of the flow rate and showed a satisfactory removal efficiency of nitrogen and phosphorus compounds under experimental conditions. The average removal efficiency of total nitrogen gradually decreased as the influent total nitrogen concentration was increased. High C/N ratio of the wastewater was required for the complete removal of nitrogen. Glucose as a carbon source was more efficient than starch and the removal ability for all components become higher with the increase of the fraction of glucose.

Keywords : nitrogen removal, flow rate variation, aerobic, anaerobic

1. Introduction

Fixed forms of nitrogen, such as ammonia, organic nitrogen, nitrate and nitrite can pollute receiving waters by stimulating eutrophication and the domestic wastewater holds a large portion in pollutant factors of water quality. Thus, nutrient removal from the domestic wastewater is one of the urgent problems to be solved in order to depress the eutrophication in lakes and enclosed bays(Ramadori, 1987).

Although several processes utilizing physical-chemical removal mechanisms have been developed to remove nitrogen and phosphorous compounds together with BOD from wastewater, they are difficult to accept totally because of high costs and problems of treating inorganic residuals(Karanaugh et al., 1977; Gregory and Dhond, 1972; Malhatra et. al., 1964). The biological wastewater treatment is considered as the most promising way from economical viewpoints in a variety of treatment systems proposed so far(Tom et al., 1992; Tabak et al., 1981; Hano *et al.*, 1992). Also, the conventional biological treatment systems has a disadvantage which requires a large space.

Recently, some researchers(McClintock *et al.*, 1988; Rittmann and Langeland, 1985) suggested that when nitrate respiration was incorporated in the activated sludge process, sludge production was reduced and an effluent of equal or superior quality was maintained and indicated that sludge yields were lower and substrate utilization rates were higher for nitrate versus oxygen respiration. New treatment systems termed as anaerobic-aerobic activated sludge processes which employ the single sludge in the same unit by recycling the mixed liquor between aerobic and anaerobic regions alternately have been developed by Barnard(1973), Hashimoto(1989) and Others(Argaman, 1985; Argaman and Brenner, 1986). Two examples of this process are shown in Fig. 1

and the difference of both systems is the position from which effluent is withdrawn. Especially, one of the advantages of these processes is that the organic carbon compounds in the wastewater can be utilized as a hydrogen donor of denitrification. In addition, the treatment system clearly becomes simple.

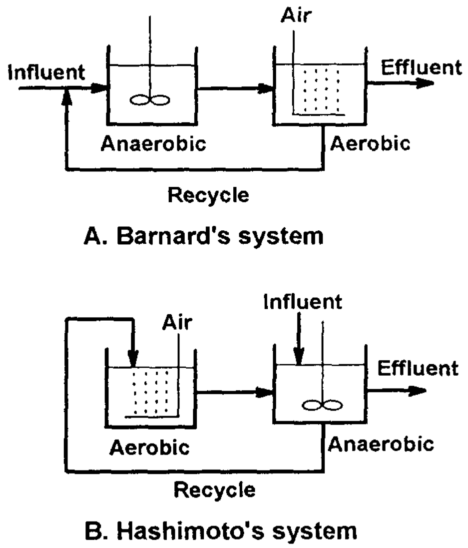


Fig. 1. Typical two systems in anaerobic-aerobic activated sludge processes.

In general, the development of small scale treatment unit is desired eagerly at the community of low population density where the concentrated treatment system has not been established yet and space for large treatment system is limited, though the overall system design depends upon the type and amount of wastewater to be treated and economic and environmental considerations. The domestic sewage, on the other hand, has an important characteristic, which is the hourly variation in hydraulic flow pattern and in composition and concentration of wastewater during a day according to our usual mode of living. The unsteady-state behavior that results from load changes in environmental conditions affects the performance of treatment units and is important in the engineering perspective and process design.

In the present study, a small treatment unit to perform anaerobic-aerobic operation by recycling the mixed liquor between two regions was applied and its possibility as a simple technique of gray water treatment was studied. When the load variation of flow rate according to our actual life style was added to the treatment units, the transient behavior of the system was examined. Also, the treatment performance was investigated under various operating conditions.

2. Materials and Methods

The experimental apparatus of anaerobic-aerobic activated sludge process used in this study was similar to Barnard system as shown in Fig. 2. The reactor was constructed of acryl and a baffle plate was placed in the tank having total volume of 10 L as to be equal volume for both anaerobic and aerobic regions. Thus, each region had a total volume of 5 L. The synthetic wastewater listed in Table 1 was introduced to anaerobic zone first to promote the denitrification by utilizing the organic carbon compound in the wastewater. The synthetic wastewater contained glucose and/or starch as main carbon sources and some inorganic salts as nutrients. The mixed liquor overflowed into aerobic region where ammonification and nitrification proceeded under aeration. The sludge was recycled from the setter to anaerobic region and a small amount of mixed liquor was recycled from aerobic to anaerobic region. The effluent was withdrawn from the aerobic region. Also, the influent flow rate was changed according to actual life style with two peaks in the morning and evening. In this study, the peak coefficient was defined as the ratio of a maximum to an average flow rate and the recycle ratio was defined as recycle flow rate versus average influent flow rate. The performance of this unit was investigated under the standard operating conditions, such as average hydraulic residence time of 24h, recycle ratio(γ) of 1, aerobic/ anaerobic volume ratio of 1, temperature of 25°C, MLSS of 3,000 to 3,600 mg/L and sludge age of 30d. The average concentration per day of wastewater was as follows: COD_{Mn}=125mg/L, T-N(total nitrogen)=10 mg/L, and PO_4^--P=1.2mg/L.

Table 1. Composition of synthetic wastewater

Components	Concentration(mg/L)
Glucose	200
Polypepton	40
$(NH_4)_2SO_4$	21.7
KH_2PO_4	6.6
$NaHCO_3$	37.5
$MgSO_4 \cdot 7H_2O$	56.3
$CaCl_2 \cdot 2H_20$	37.5
NaCl	37.5

Org-N : NH_4^+-N = 5.4 : 4.6
BOD = 150mg/L
T-N = 10mg/L
T-P = 1.2mg/L

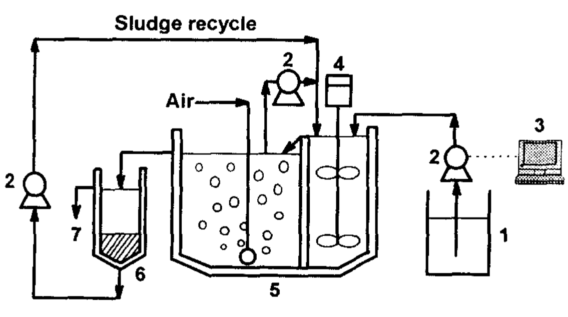


Fig. 2. Schematic of experimental apparatus.

3. Results and Discussion

3.1. Treatment characteristics of wastewater against the hourly variation of flow rate

The hourly variation of flow rate of wastewater is an important characteristic of domestic gray water. Such an hourly load variation gives a treatment performance different from steady-state operation and affects the removal efficiency of organic matter. The response of anaerobic-aerobic activated sludge process against the variation of flow rate during the day was measured while keeping the influent concentration constant. The treatment characteristics at the recycle ratio of 1 is shown in the Figs. 3 and 4. The influent flow rate was set by stepwise change as shown in the upper part of figures. Two peaks of flow rate were set in the morning and evening according to our usual mode of living. In this case, glucose was used as a organic carbon source. The experimental data was taken when 10 days passed after the start

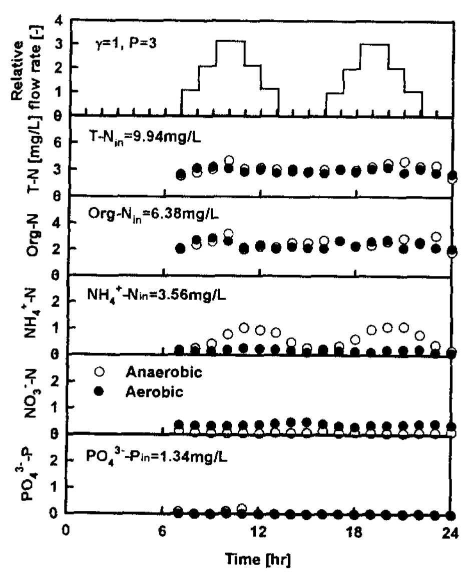


Fig. 3. Effect of flow rate variation on treatment performance at peak coefficient of 3.0.

of hourly flow rate change. As shown in Fig. 3, which was the result at peak coefficient of 3, average removal efficiency of total nitrogen of about 73% was achieved. Although it showed relatively high concentration of ammonia nitrogen at the peaks of flow rate in anaerobic region, ammonium nitrogen was removed substantially at exit(aerobic region). The nitrate concentration was changed slightly in both regions and phosphorous was kept almost zero.

Figure 4 shows the response of each components for the run of high peak coefficient of 5. In spite of sharp change of flow rate, a relatively constant removal for nitrogen was obtained at exit. Phosphorous concentration shown in Fig. 4 increased slightly at the point of two peaks. However, phosphorus level at the exit was kept almost zero. This feature demonstrated that the assimilation of phosphorus in the aerobic zone was carried out by stopping the influent of wastewater and maintaining in a batch state over the night.

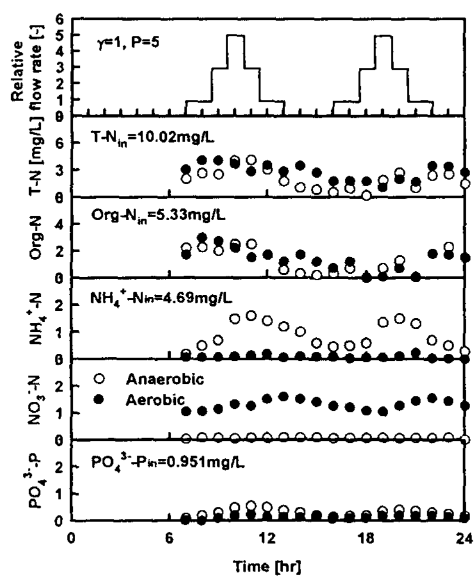


Fig. 4. Effect of flow rate variation on treatment performance at peak coefficient of 5.0.

3.2. Effect of influent total nitrogen concentration

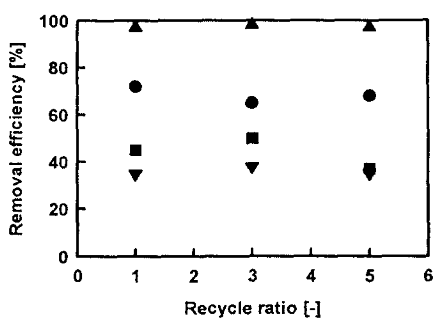
The variation of concentration in the domestic wastewater is greater than that in the industrial wastewater. Thus, it is important to know the treatment performance changes on the concentration change of influent wastewater. All experiments in this case were carried out while keeping the ratio of BOD, T-N, and T-P constant as the previous experiment. The results were summarized in Table 2. As shown in Table 2, the average removal efficiency of total nitrogen gradually decreased as the influent total nitrogen concentration was increased, but the average total nitrogen concentration of the effluent could not be reduced below 2.7 mg/L. This result arose from the lack of hydrogen donors since BOD in the wastewater decreased in proportion to nitrogen concentration. The depression of nitrogen removal was overcome by increasing the BOD/T-N ratio in the wastewater about two to three times the standard one. Thus, in anaerobic-aerobic activated sludge processes, it was considered that the treatment performance was influenced by C/N ratio of the wastewater more strongly compared to the conventional processes.

Table 2. Effect of influent total nitrogen concentration on total nitrogen removal efficiency.

$T-N_{in}$ [mg/L]	Average T-N removal efficiency [%]
45	85
34	80
18	78
10	73

3.3. Effect of the recycle ratio

The recycle ratio of mixed liquor is the most characteristic parameter in the aerobic-anaerobic activated sludge processes. Figure 5 demonstrates the effect of average removal efficiencies on recycle ratio. For the most part, the removal efficiency increased as the recycle ratio was increased, whereas a very high removal efficiency of ammonium nitrogen was obtained regardless of recycle ratio. The removal efficiency of organic nitrogen was as low as 50% and the average removal efficiency of total nitrogen was about 73%. On the other hand, the removal efficiency of phosphorus was highest at the recycle ratio of 3 and 5. The increase of recycle ratio results in an increase of the mixing degree, therefore the concentration difference between anaerobic and aerobic regions becomes insignificant.



(●: T-N, ■: Org-N, ▲: NH_4^+-N, ▼: PO_4^{3-}-P)

Fig. 5. Effect of recycle ratio on removal efficiency at peak coeffieient of 3.0.

3.4. Effect of organic carbon source

Figure 6 shows how the variation of the ratio of starch and glucose affects the removal efficiency. The ratio of starch and glucose used in this study were 1:0, 1:1, 1:2, and 0:1. Experiment was carried out at recycle ratio of 1 and peak coefficient of 3. As shown in Fig. 6, the removal efficiency of total nitrogen with glucose as carbon source was higher than that with starch and the removal ability for all components become higher with the increase of the fraction of glucose. These features were considered because the glucose was readily degradable substrate and was superior to starch as hydrogen donor.

(●: T-N, ■: Org-N, ▲: NH_4^+-N, ▼: PO_4^{3-}-P)

Fig. 6. Effect of the fraction of glucose and starch on romoval efficiency.

3.5. Effect of drain pattern

The anaerobic-aerobic activated sludge processes could be classified into two kinds of Barnard and Hashimoto system according to the drain pattern. As shown in Fig. 1, the most important difference of both system is the position of exit of effluent and it will affect the quality of treated water.

In order to compare the treatment performance of two systems in the case of high concentration unsteady-state operation with the variation of flow rate according to actual life style, the removal efficiencies of each components was observed. The total nitrogen concentration in feed was 34 mg/L. The result is illustrated in Fig. 7. Hashimoto(1989) showed that the performance in his system was a little higher than Barnard system from his model calculation under high concentration steady-state operation. As shown in Fig. 7, however, the removal efficiency of total nitrogen removal in Barnard way was a little higher than that in the Hashimoto way, though the removal efficiencies of other components did not show a great difference for the most part. It might be regarded that flow rate load, especially at high peak, was moderated during flowing from anaerobic to aerobic(exit) region as a results that the feed in Barnard way was entered in the anaerobic region.

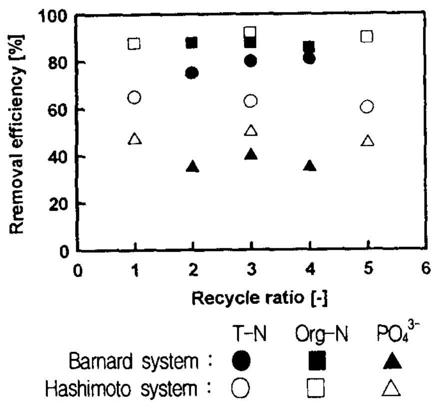


Fig. 7. Comparison of the performance of two systems with flow rate variation.

3.6. Effect of temperature

Figure 8 shows the dependence of removal efficiency on operating temperature. The removal efficiencies reached the maximum at 30°C and decreased with decreasing temperature gradually.

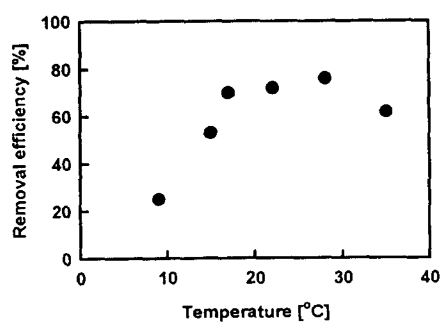


Fig. 8. Effect of temperature on removal efficiency of total nitrogen.

Although the result was not shown in this figure, it was obtained that both ammonification and nitrification activities showed a weak temperature dependencies, whereas denitrification activity changed appreciably with temperature. These findings suggest that increasing the denitrification activity of the sludge is essential for the treatment at cold area.

4. CONCLUSION

A small treatment unit to perform anaerobic-aerobic operation by recycling the mixed liquor between two regions was applied and its possibility as a simple technique of gray water treatment was studied. The transient behavior of the treatment units against load variation of flow rate was examined according to the actual variation of load and the treatment performance was investigated under various operation conditions. The treatment system proposed in this study gave a relatively stable performance against hourly change of the flow rate and showed a satisfactory removal efficiency of nitrogen and phosphorus compounds under experimental conditions. The average removal efficiency of total nitrogen gradually decreased as the influent total nitrogen concentration was increased. High C/N ratio of the wastewater was required for the complete removal of total nitrogen. The removal efficiency of total nitrogen with glucose as a carbon source was higher than that with starch and the removal ability for all components become higher with the increase of the fraction of glucose. The removal efficiencies reached the maximum at 30°C and decreased with decreasing temperature gradually.

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