

TREATMENT CHARACTERISTICS AND OPERATIONAL PARAMETERS OF A NEWLY DEVELOPED REACTOR WITH SLUDGE SEPARATION FILTER AND AIRLIFT PUMP FOR CARBON AND NITROGEN REMOVAL

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Abstract:

Nutrient removal from sewage is one of the most urgently required issues from the viewpoint of prevention of eutrophication and preservation of water quality for water supply system. Among several nutrient removal methods, biological treatment, which is a modified activated sludge system, is widely applied. However, biological nitrogen removal process, which consists of nitrification and denitrification steps, needs opposite operations at several stages such as necessity of oxygen and requirement of electron donor of organic compounds. In this study, treatment characteristics of a reactor with both sludge separation filter and airlift pump are investigated. This reactor has sludge separation filter in the middle part and airlift pump that supplies oxygen and circulate liquid from aerobic zone to anoxic zone in order to cut down the required energy. From laboratory scale experiments, design and operational parameters are investigated and it is shown that $\text{NH}_4\text{-N}$ loading rate of 35 mgN/(L-media · hr) at aerobic zone and DO loading rate of less than 0.15 kgDO/(kgMLSS · d) to anoxic zone are required for stable treatment.

Keywords: Airlift pump, Sludge separation filter, Nitrogen removal, Sewage treatment, Biological nitrification-denitrification

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INTRODUCTION

Biological nitrification/denitrification process is being widely applied for nitrogen removal from the sewage, as it is based on activated sludge process and has comparatively easy operation. The removal of nitrogen by biological nitrification /denitrification is a two-step process. In the first step, ammonia is converted aerobically to nitrate, and in the second nitrates are converted to nitrogen gas. However, these steps require different operations in several stages, for example, the necessity of oxygen, the requirement of organic carbon sources, and so on, because bacteria concerning each step are different. Therefore the combination of both steps characterizes the processes which have been proposed (U.S.EPA, 1975; George *et al.*, 1991, Chan *et al.*, 2009). Above all, anaerobic -aerobic circulating process such as Bardenpho process has several advantages, for example, the possibility of practical using the organic compounds in the influent as electron donors for denitrification, the possibility of the supplement of alkalinity which is diminished at the nitrification step, and so on. From these points, this process can be a resource-saving system which is expected to apply actual wastewater treatment process; however, nitrogen removal efficiency depends on the recirculation ratio. In order to attain high removal efficiency, high recirculation ratio is required and the energy for recirculation is also needed.

On the other hand, in nitrification stage, aeration is required in order to supply oxygen and to create the aerobic condition. At the same time, aeration generates

an upward flow, which is called airlift pump (JSME, 1989). If this upward flow can adequately be utilized, recirculation of liquid can be generated by aeration only. Therefore, in order to use aeration for both recirculation of liquid and DO supply, a kind of anaerobic-aerobic circulating system in which aerobic zone and anaerobic zone are arranged vertically is devised (Nishimura, 1999). Dual draft tube reactor with airlift pump function has also been developed as simultaneous nitrification and denitrification process (Dhamole, 2009; Zhang *et al.*, 2013), however sludge will be also exposed under aerobic and anoxic /anaerobic condition in such a system, which may deteriorate denitrification efficiency.

Our developed reactor is characterized by airlift pump and sludge separation filter. The outline of the airlift pump is as follows; the reactor has diffuser tubes at the middle; and the upper part of the reactor is the aerobic zone and the lower part of it is the anaerobic zone. The upward flow is generated by aeration and the liquid flows from anaerobic zone to aerobic zone and then returns back to the anaerobic zone again through the circulation line attached with the reactor.

The outline of the sludge separation filter is as follows; the filter is a mesh type one. It is settled just below the diffuser tube in order to prevent the outflow of the sludge to the aerobic zone and to condense SS in the anaerobic zone. In this study, treatment characteristics of this reactor are investigated, and design parameters and operational parameters are examined.

MATERIALS AND METHODS

Experimental apparatus is shown in Fig. 1. It consists of a reactor, an air pump and a wastewater tank. Sludge separation filter is horizontally fitted in the reactor and diffuser tube is placed just above it. Therefore the upper part of the filter is under aerobic condition and the lower part of it is controlled to be in an anaerobic (anoxic) condition. Polyurethane foams which are connected each other by a wire are placed in the aerobic zone so as to make it an attached growth medium for nitrifying bacteria. The polyurethane foam is a rectangular parallelepiped which size is 15×12×12 mm. The ratio of the medium volume to the whole volume of the aerobic zone is 0.2. Activated sludge sampled from a municipal sewage treatment plant is thrown into the anoxic zone. The volume of the reactor is 3L and the area of its horizontal section is 81 cm² (9cm×9cm). The filter is a mesh type whose opening is 0.64 mm² and the ratio of the opening to the whole filter area is 0.44 mm²/mm².

Three reactors which have different ratio of aerobic-anoxic zones are used in this study. The volume ratio of

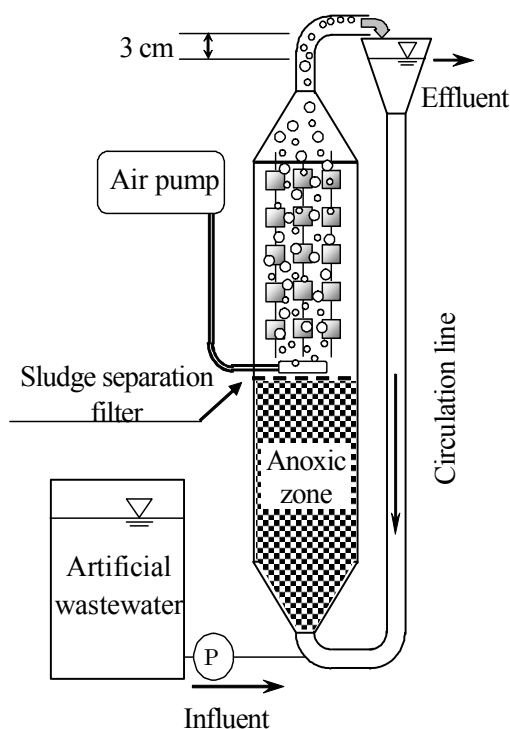


Fig. 1 Experimental apparatus

aerobic-anoxic zones in case 1 is 7:3, in case 2 is 5:5, and in case 3 is 3:7. Water temperature in each case is controlled to be 22°C by the water jacket installed around the reactor. The composition of the artificial wastewater used in this study is shown in **Table 1** and experimental conditions of each case are shown in **Table 2**. Experimental conditions are classified into two major groups (Run A and Run B). In Run A, effects of air flow rate and organic compound concentration in the influent are investigated. In Run B, effects of Hydraulic Retention Time (HRT) are studied.

In Run A-1, air flow rate is controlled at 75 mL/sec and organic compounds loading rate is set to the low case (COD concentration of influent is 160mg/L); in Run A-2, it is reduced from 75 mL/sec to 30 mL/sec in order to examine the influence of the air flow rate on airlift pump and oxygen supply; in Run A-3, it is kept same as in Run A-2 and organic compounds loading rate is increased to high case, which is double of low case in order to investigate the influence on organic compounds removal efficiency, DO concentration at anoxic zone and denitrification efficiency. HRT is controlled at 10h all through Run A.

During Run B, HRT is decreased from 10h to 6h. At the start up stage of Run B-1, air flow rate is controlled about 60mL/sec to promote the bacterial growth and attachment to the media. The other experimental conditions are same as Run A-3.

Table 1. Artificial wastewater

CH ₃ OH	160 mgCOD during Run A-1 and A-2 320 mgCOD during Run A-3 and B
NH ₄ Cl	30 mgN
NaHCO ₃	214 mgCaCO ₃ (as alkalinity)
KHPO ₄	3.2 mgP
MgSO ₄	1 mgMg
Tap water	1 L

Table 2. Experimental conditions

Run No.	Time (day)	Air flow rate (mL/sec)	Influent organics (mgCOD/L)	HRT (hr) (Reactor base)
A-1	0 - 44	75	160	10
A-2	44 - 56	30	160	10
A-3	56 - 70	30	320	10
B-1	0 - 58	30-60	320*	10
B-2	58 - 119	30	320*	8
B-3	119-140	30	320*	6

320(mgCOD/L) = 80(mgC/L)

RESULTS AND DISCUSSION

Separation characteristics of sludge with sludge separation filter

Time course of MLSS concentration at both aerobic and anoxic zone during Run A is shown in **Fig. 2**. In all cases, except the start-up stage, the MLSS concentration at aerobic zone is maintained in a range from 50 to 200 mg/L, and it at anoxic zone is maintained in a range from 2500 to 6500 mg/L. It shows that the filter used in this study can separate the sludge successfully and keep it at a high concentration in the anoxic zone. **Figure 3** shows the time course of head-loss caused when liquid flow through the filter. The value of head-loss is less than 15 cm and using the sludge separation filter and airlift pump, more than 200% of recirculation ratio is obtained in all cases; in other words, air flow rate required for supplying DO can create water flow whose amount is enough for biological nitrogen removal.

Treatment characteristics (removal of organic compounds and nitrogen)

Time course of soluble organic compounds, NH₄-N, NO_x-N and SN are shown in **Fig. 4** to **Fig. 7**, respectively. Although the value of COD_{Cr} is more than 50mg/L at start-up stage and at some points in the case

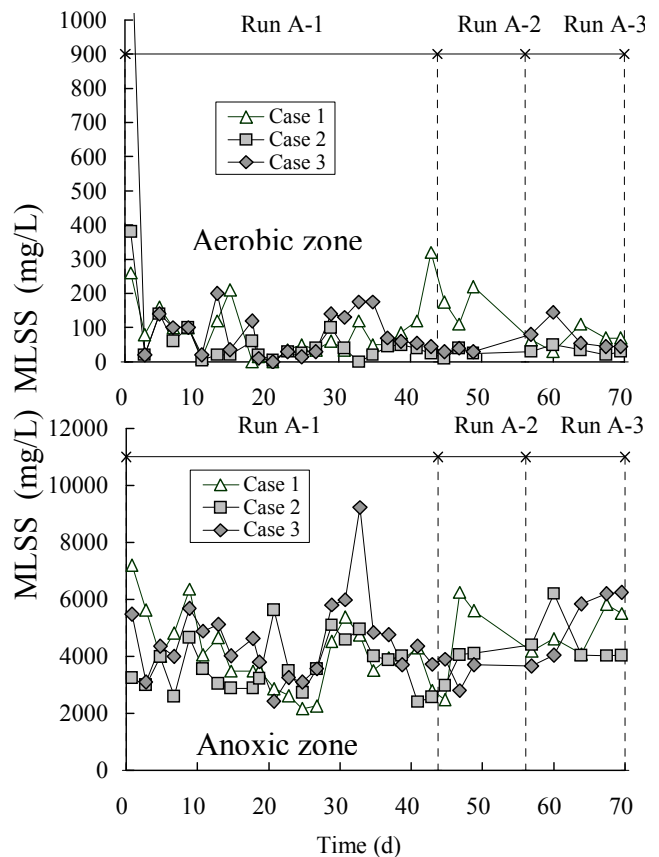


Fig. 2 Time course of MLSS

1 during Run A-3, the removal efficiency of COD_{Cr} during the other period of Run A is more than 80%. In the case 1, the volume of anoxic zone is smaller and the amount of activated sludge is also smaller, therefore COD_{MLSS} loading rate during Run A-3 becomes higher. This high loading rate causes high COD concentration in the effluent. The same treatment characteristics are shown during Run B.

NH_4-N is removed by more than 90% except at the start-up stage in all cases during Run A-1. However, the volume of aerobic zone is smaller in the case 3, therefore NH_4-N whose concentration is about 8 mgN/L remains during Run A-2, 3. On the other hand, $NOx-N$ concentration is more than 20 mgN/L in all cases during Run A-1. However, $NOx-N$ concentration decreases during Run A-2 according to the reduction of the air flow rate, and it is removed to be less than 8 mgN/L in Run A-3, during which COD loading rate is increased. Dissolved nitrogen removal efficiency of more than 80% is accomplished in the case 2 during Run A-3. In this case, head-loss at the sludge separation filter becomes higher and the flow rate of circulating water is decreased, but DO loading rate to the anoxic zone is reduced and DO concentration in anoxic zone becomes less than 1 mg/L. As a result, denitrification is promoted.

Similar treatment characteristics are observed during Run B. NH_4-N is removed by more than 90% in case 1. NH_4-N removal efficiency is sometimes reduced in case 2 during Run B-3 and in case 3 for the whole duration of Run B. The frequency of low removal efficiency becomes higher according to the increase of NH_4-N loading rate. $NOx-N$ concentration is reduced according to the reduction of the air flow rate. Reduction of the air flow rate promotes making anoxic condition and denitrification. However nitrification efficiency becomes lower in case 3 of Run B-1. In this point, DO remains more than 4 mg/L in the aerobic zone. It is considered that the reduction of nitrification

efficiency is related to reduction of the mixing efficiency caused by aeration. From the viewpoint of the nitrogen removal, case 1 and 2 is more effective than case 3. In these cases, nitrification is more stable and head loss is a little higher. The higher head loss reduces recirculation flow rate and makes anoxic condition in the lower part easily, which promotes denitrification.

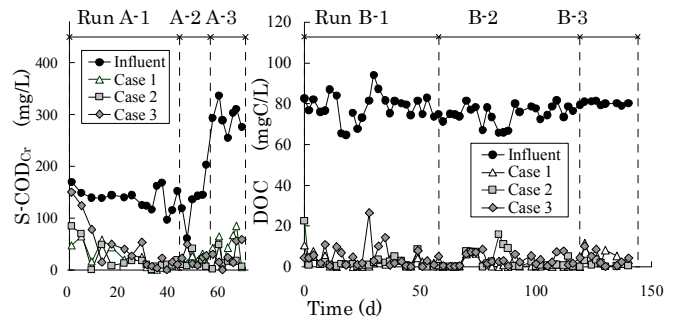


Fig.4 Time course of soluble organic compounds

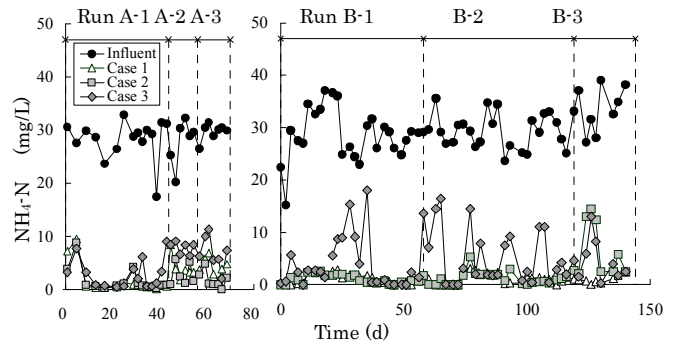


Fig.5 Time course of NH_4-N

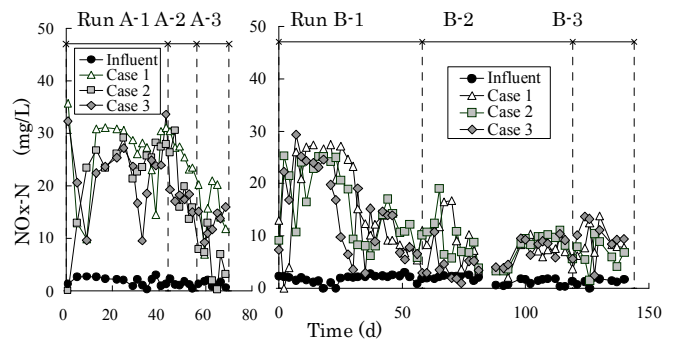


Fig.6 Time course of $NOx-N$

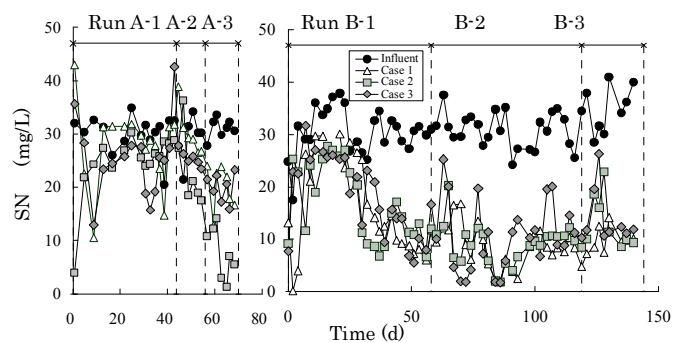


Fig.7 Time course of SN

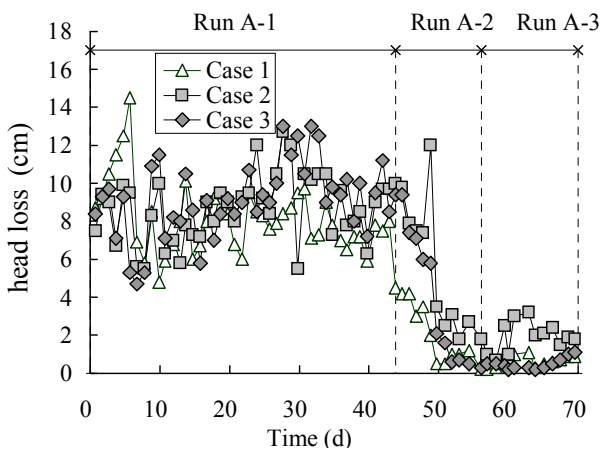


Fig. 3 Time course of head loss

In Fig. 8, material balance of carbon and nitrogen in Run B in case 1 is shown. Remain of NO_x-N in the anoxic zone is observed in Run B-1, because denitrification is not occurred sufficiently in the start-up stage. However nitrogen is removed in the range from 60 % to 70 % during Run B-2 and B-3. About 70% of organic carbon is decomposed at the anoxic zone. This amount is two to three times larger than the amount which is estimated from the amount of denitrification as the electron donor. This shows that aerobic decomposition is occurred in the lower part of the reactor. The ratio of organic carbon in the effluent to the whole amount of organic carbon is about 10%. In this reactor, mineralization ratio is higher. For the reason of this fact, followings are suggested; (1) Organic carbon is utilized for denitrification besides aerobic decomposition. (2) Because of using attached growth media and the sludge separation filter, solid retention time (SRT) becomes longer. Therefore mineralization is promoted.

Relationship between NH₄-N loading rate and nitrification rate is shown in Fig. 9. In the case 1 and 2, NH₄-N loading rate is less than 35 mgN/(L-media•hr) and nitrification efficiency of more than 95% is obtained; whereas it is more than 35 mgN/(L-media•hr) in the case 3 and the nitrification efficiency is sometimes lowered. It is clear that the appropriate NH₄-N loading rate at the aerobic zone is shown to be less than 35 mgN/(L-medium•hr) for nitrification.

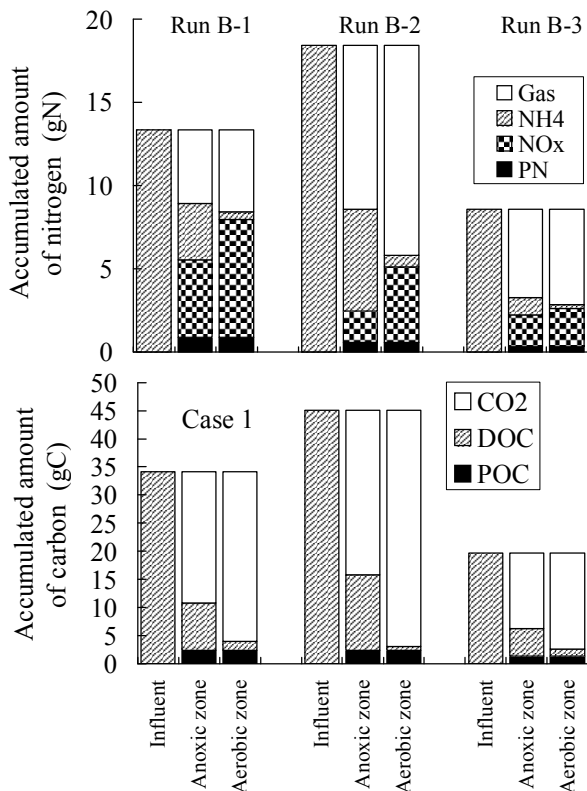


Fig. 8 Material balance of nitrogen and carbon in case 1

Relationship between DO loading rate at the anoxic zone and DO concentration in the anoxic zone is shown in Fig. 10, and relationship between DO concentration in the anoxic zone and denitrification rate is also shown in Fig. 11. It is clear that DO concentration is reduced to less than 1 mg/L when DO loading rate at the anoxic zone is less than 0.15 kgDO/(kgMLSS•d).

In this condition, denitrification is promoted. DO loading rate of less than 0.15 kgDO/(kgMLSS•d) at anoxic zone is shown to be necessary for creating anoxic condition and fine denitrification. Although the denitrification rate is smaller than its possible potential (Sage *et al.*, 2006), the system can accomplish more

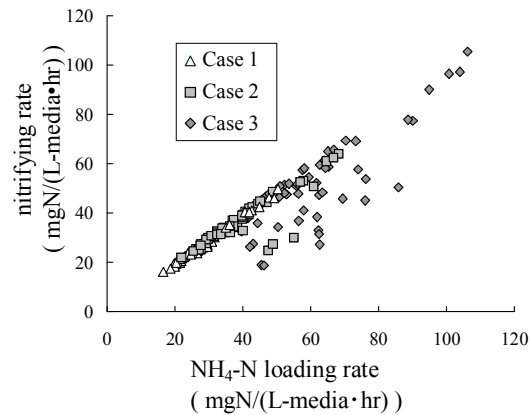


Fig. 9 Relationship between NH₄-N loading rate and nitrifying rate

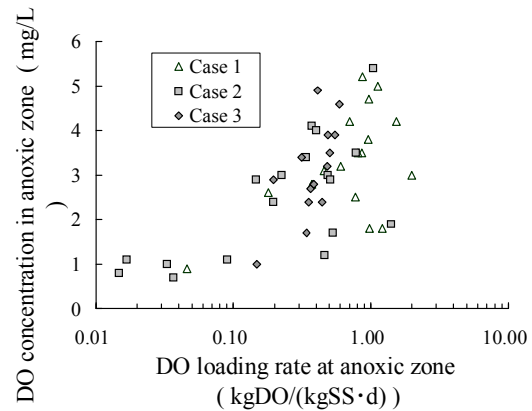


Fig. 10 Relationship between DO loading rate to anoxic zone and DO concentration in anoxic zone

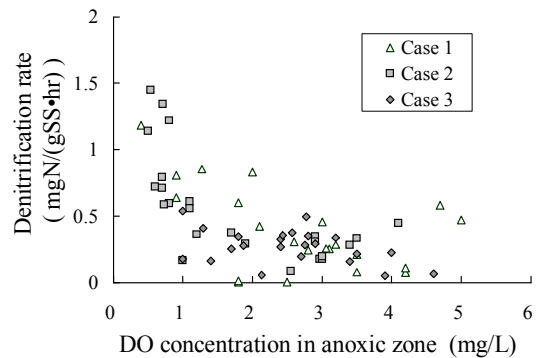


Fig. 11 Relationship between DO concentration in anoxic zone and denitrifying rate

than 60% removal. The smaller denitrification rate is considered to be due to the substrate concentration and continuous loading of DO.

CONCLUSIONS

In this study, a biological nitrogen removal system is developed, which is an anoxic-aerobic system of vertical type characterized by both sludge separation filter and airlift pump in order to save energy and resources. Treatment characteristics of this system are investigated and operational parameters are examined. Main results obtained from the study are as follows:

- 1) Mesh type filter which has 0.64 mm² size openings is used for sludge separation. The filter can separate sludge successfully and keep sludge at the anoxic zone in high concentration with low head loss.
- 2) The airlift pump can supply required amount of oxygen and can accomplish sufficient recirculation ratio of more than 200% simultaneously. This shows the possibility of energy-saving type reactor for nitrogen removal.
- 3) NH₄-N loading rate at the aerobic zone can be increased to 35 mgN/(L-medium·hr) for fine and stable nitrification.
- 4) DO loading rate of less than 0.15kgDO/(kgMLSS·d) at anoxic zone is shown to be necessary for creating anoxic condition in which DO concentration is less than 1 mg/L. Under this condition, fine denitrification can be accomplished.
- 5) From material balance analysis, 90% of organic carbon in influent can be decomposed because of the denitrification and long term SRT accomplished by the sludge separation filter.

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