Removal of High C and N Contents in Synthetic Wastewater Using Internal Circulation of Anaerobic and Anoxic/Oxic Activated Sludge Processes

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Abstract. Internal circulation (IC) of activated sludge anaerobic and anoxic/oxic processes was used to treat high carbon (C) and nitrogen (N) synthetic wastewater in order to achieve an effluent standard. The 1st & 2nd internal circulation anoxic (ICA) has shown a great advantage. Because under anoxic conditions heterotrophs utilize organic matter (OM). OM and NO_3^--N are an electron donor and an electron donor, respectively. As a result, under conditions high carbon and NO_3^--N, N_2 production can generate higher than with 1st ICA BNR system only. Aerobic IC to anoxic, 1st ICA, and effluent IC to anoxic, 2nd ICA, could remove 100% of COD, 99.60% of TKN, and 99.90% of NH_4^+-N. The organic loading rate and NH_4^+-N loading rate are 68.38 kg-COD m^{-3} d^{-1} and 9.86 kg NH_4^+-N m^{-3} d^{-1}, respectively in synthetic wastewater. Performance of these ICA activated sludge treatment was achieved the discharge standard with effluent COD less than 0 mg L^{-1},effluent NH_4^+-N less than 4 mg NH_4^+-N L^{-1}, effluent NO_2^--N less than 0.1 mg NO_2^--N L^{-1}, and NO_3^--N less than 0.02 mg NO_3^--N L^{-1}.

1 Introduction

Biological nitrification-denitrification is the most commonly used process for nitrogen removal from industries handling protein-rich materials or other nitrogen compounds generate, effluents with very high loads of ammonia. The degree of treatment required and the selection of suitable treatment technique are usually dependent upon the wastewater composition. A post treatment may be required mainly to remove ammonia before discharge and biological nitrification–denitrification being the most extensively used process. As the C/N ratio after anaerobic digestion is generally insufficient for denitrification, the main challenge in combining the anaerobic digestion process with an activated sludge nitrification/denitrification process lies in the management of organic matter (OM). Optimize the management of OM between the anaerobic and anoxic/oxic reactors. For that, proposed a combined process based on an anaerobic phase followed by an anoxic/oxic reactor in order to removal nitrogen by nitrification/denitrification. To provide enough effluent denitrification in the anoxic/aerobic reactor, a fraction of the effluent was fed directly to the anoxic/oxic reactor. This study focused on the use of recycled effluent. Operating reactor with pumping the water from effluent to anoxic zone could significantly increase the effluent quality. The purpose of this work was to present the design and functionality of a lab-scale dynamic effluent activated processes for biological removal of organic substrate and nitrogen applying anoxic-oxic process.

2 Material and methods

2.1 Process configuration

The system (Fig. 1) and the operating design for each instance of influent flow rate, reactor volumes, return sludge ratio, internal recirculation flow rate ratios, hydraulic retention time (HRT), solid retention time (SRT) and O_2 concentration were obtained from lab scale results. These are given in Table 1. This lab scale processes consisted of four reactors in series. They included anaerobic, anoxic, aerobic phase and clarifier stages with effective volumes 5, 5, 20 and 30 L, respectively. In addition, the total HRT of anaerobic, anoxic and aerobic conditions, and SRT were 12 h and 20 days, respectively. The operating conditions of this system were: influent wastewater flow rate, return activated sludge (RAS) flow rate, 1st and 2nd internal circulation anoxic (ICA) flowrate. O_2 concentration was maintained between 2-4 mg L^{-1} in the aerobic zone. Average process temperature was maintained at 37 °C.

Table 1. The operation condition for lab-scale biological nutrient removal (BNR) treatment plant.

Flow rate	Unit ($L\ h^{-1}$)	HRT	Unit (h)
Influent	2.5	Anaerobic	2
RAS	2.5	anoxic	2
1st and 2nd ICA	7.5 and 0.75	Aerobic	8

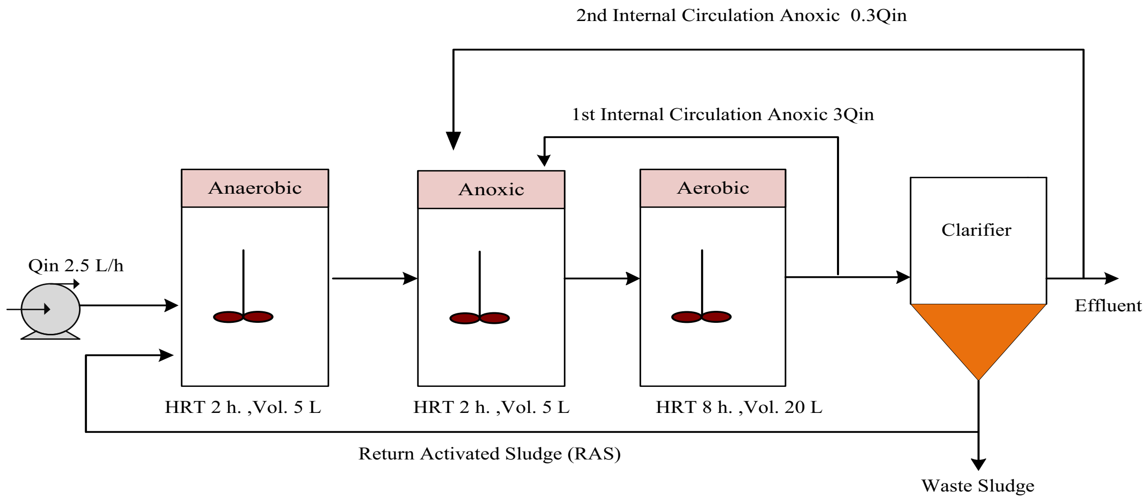

Figure 1. Schematic diagram of lab-scale BNR processes.

2.2 Wastewater feed

Synthetic wastewater used in this study was prepared according to Coelho et.al [1], with some modification. Wastewater contained ammonium chloride and urea as the nitrogen sources. The average concentrations of TKN and ammonia nitrogen in the fluent were 967.28 ± 109.41 mg L^{-1} and 786.33 ± 210.95 mg L^{-1}. The COD in influent averaged 5,465.44 ± 232.91 mg L^{-1}. The C/N ratio is 6.95±0.47.

2.3 Analytical methods

The experiment carried on about 41 days and was considered complete when the range of changes of particular parameters in the effluent (soluble chemical oxygen demand (SCOD), total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_4^+-N), nitrite-nitrogen (NO_2^--N), nitrate-nitrogen (NO_3^--N) within 7 days did not exceed 5%-10%. Daily measurements of all reactors include SCOD, TKN, NH_4^+-N, NO_2^--N, NO_3^--N), pH, dissolved oxygen (DO), mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS). The analyses were performed according to APHA [2].

3 Results and discussion

3.1 Mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and SCOD

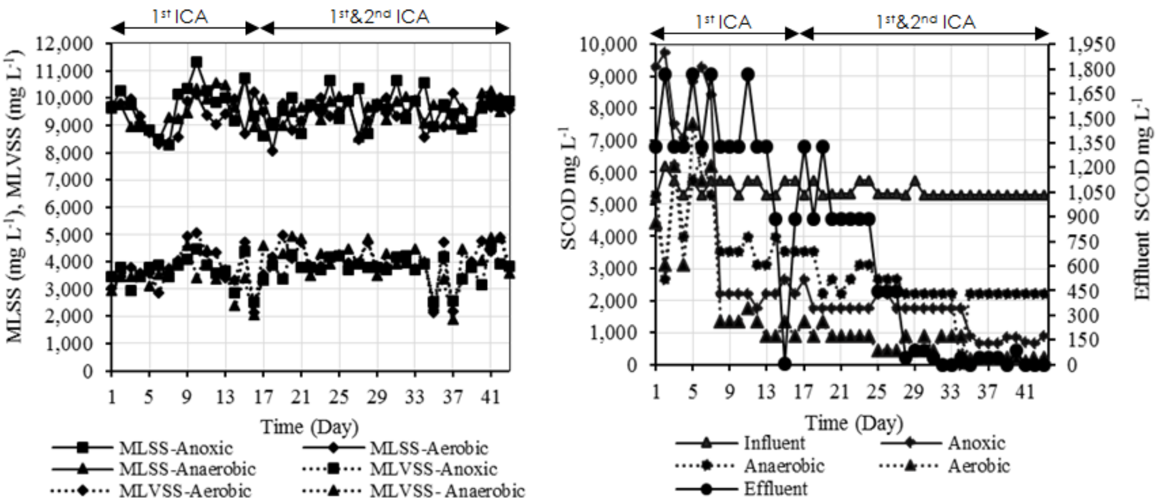

Figure 2. Performance of A^2/O processes: (A) MLSS and MLVSS in various tanks (B) SCOD under different conditions

As shown in Fig. 2, MLSS concentration in various tanks fluctuated similarly for all conditions from day until day 41, whereas under anoxic phase MLSS was slightly higher than others. Under conditions 1st and 2nd ICA, from day 17 up to day 41 effluent SCOD removal was very high (Fig. 2) in comparison to under condition 1st ICA only. Operation of 1st ICA was between day 1 and day 16.

The overall combined process removed 100% of SCOD. Considering that all biodegradable SCOD was then possible to calculate the biodegradable SCOD at the influent and the SCOD removal in each reactor. A quantity of SCOD removal in anaerobic, anoxic and aerobic reactors were 58.34%, 60.01%, and 75.03 respective under 1st & 2nd ICA. However, the MLSS trend is similar in both situations, 1st ICA only and 1st & 2nd ICA. The 2nd ICA did not affect the MLSS. MLSS and MLVSS concentration in all the three chambers were same during the operation and remains almost constant during the whole operation period. This might be due to the equal HRTs and SRTs of all the three chambers. During 20-day SRT period the average MLSS and MLVSS concentration for all the three chamber remained constant. Within the chambers there was no noticeable effect of circulation change but on the day 35 and 37, decrease in the average MLVSS concentration in the three chambers, where it rapidly drop to 2,345 mg L^{-1} and 2,195 mg L^{-1}, respectively. After that both MLSS and MLVSS was almost stable for the three chamber at 9,620 mg L^{-1} and 4,080 mg L^{-1}, respectively. COD removal rate for both conditions was different through the operation, affected by the changes in the circulation. Based on the average incoming SCOD concentration of 5,465.44 ± 232.91 mg L^{-1}, the removal efficiency was between 69.23% and 84.62% with the average 75.39% (Std. Dev. = 4.27) for 1st conditions, and between 99% and 100% with average 99.38% (Std. Dev. = 0.61) for 2nd condition, respectively.

3.2 Dissolved Oxygen (DO) and Total Kjeldahl Nitrogen (TKN)

Aeration to all the aerobic chamber was supplied between 2.5-5 mg-O_2 L^{-1}. DO concentration decreased with the increase in concentration of influent COD and ammonia. Fig. 3, the DO concentration in the average, and increase to 0.65 mg-O_2 L^{-1} for 2nd chamber, anoxic phase, the last chamber, aerobic first chamber, anaerobic phase, was 0.37 mg-O_2 L^{-1} on phase, and increase to 3.92 mg-O_2 L^{-1}. DO concentration influenced TKN removal efficiency, which was about 62.47% - 73.35% and 93.06% - 100% at conditions of only 1st ICA and 1st & 2nd ICA as shown in Fig. 3. Higher organic carbon concentration in the discussed accelerated the activity of heterotrophic bacteria that utilize oxygen for COD oxidation. For this reason, high initial COD concentration may result in oxygen depletion zones in activated sludge that favor nitrogen removal. Zhu et al., [3] also observed a linear relationship between SND and DO concentration, but SND was obtained even under high DO concentration (4.5 mg L^{-1}). The average of maintained DO concentration in 1st & 2nd ICA is higher, 4.31 mg-O_2 L^{-1}, than in 1st ICA only, 3.34 mg-O_2 L^{-1}, as shown in Fig. 2. The median DO level, defined as the mid-value between the minimum and maximum DO values in given aeration period for only 1st ICA and 1st & 2nd ICA, were 3.34 mg-O_2 $L^{-1}$and 4.04 mg-O_2 L^{-1}, respectively. To obtain the true average DO concentration, integration must be performed for the DO curve during the aeration period and the division by the time; however, such integration was not performed in this experiment. Using the average DO concentration together with the minimum and maximum concentration would be the accurate way to describe the pattern of DO level.

3.3 Removal of Ammonia by nitrification

Nitrites was not observed at any reactor during the experiment. It was detect only in effluent. At specific circulation showed a significant impact on rate of nitrification. Working at 1st ICA and 1st & 2nd ICA, nitrification efficiencies were about 79.61% and 98.45%, respectively. When 1st ICA and 1st & 2nd ICA, the residual $NH4^+$-N the effluent was decrease to 151.76 mg- NH_4^+-N L^{-1}, and 8.87 mg-NH_4^+-N L^{-1}, influent 924.65 mg-NH_4^+-N L^{-1}.

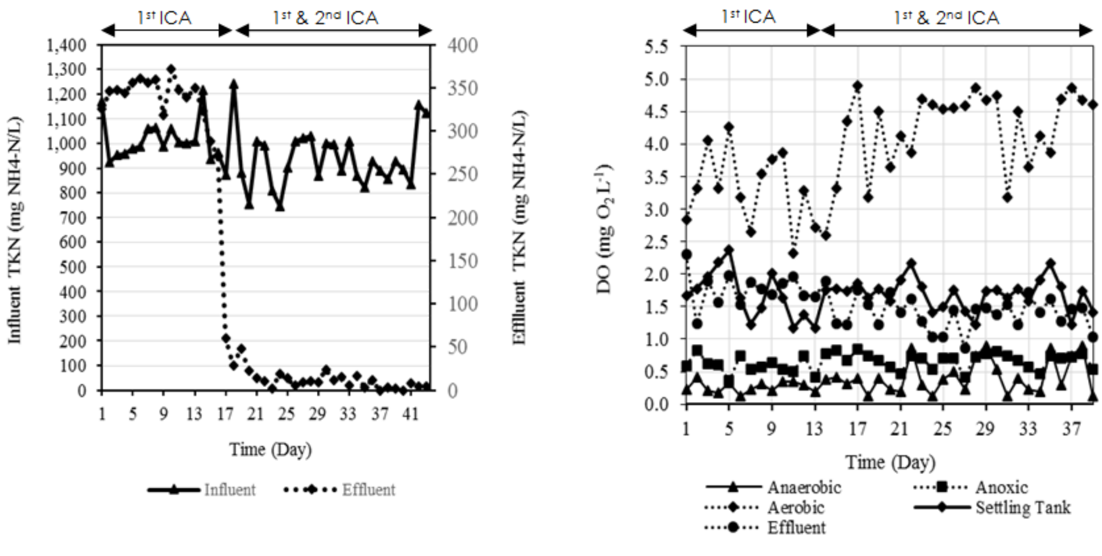

Figure 3. Performance of A^2/O processes: (A) TKN variation influent and effluent (B) DO under different conditions

Fig. 4 (A) depicts the influent, and effluent NH_4^+-N profiles with different conditions of operations. NH_4^+-N was not completely converted into NO_3^- and also NO_2^- was also detected in effluent. This is may be due to some ammonia gas losses favoured by the high pH in the reactor. The aerobic reactor can be operated at high pH value, higher than 7.5, at this condition without affecting the nitrification process. In some of the cases the dissolved oxygen concentration was lower than 1 mg- L^{-1} in the aerobic chamber because of the high COD and ammonia loading rates. Under this condition, there may be the creation of some anoxic zones which resulted in the loss of NO_3^- by simultaneous nitrification and denitrification process. Nitrogen could be removed by both assimilation into biomass and biological nitrification-denitrification process. It has been demonstrated that cell assimilation is another factor which contribute up to 15-20% of the influent TN concentration in a pre-denitrification process. The pre-denitrification was carried out by internal aerobic circulation nitrate rich both MLSS and liquid containing back to the anoxic reactor. The anoxic reactor was fed with the anaerobic wastewater with almost negligible NO_3^-. Average effluent NO_3^- and NO_2^- was 0.02 mg-NO_3^--N L^{-1} and 0.10 mg-NO_2^--N L^{-1}, respectively. Effluent profile of NO_3^- and NO_2^- are shown in Fig. 4 (B). During aerobic mode average NO_3^- concentrations for 1st ICA and 1st & 2nd ICA due to nitrification were 0.44 mg- NO_3^--N L^{-1}, 0.49 mg-NO_3^--N L^{-1}, respectively. During anoxic phase average NO_3^- concentrations for 1st ICA and 1st & 2nd ICA in the denitrifying chamber were 0.36 mg-NO_3^--N L^{-1}, 0.39 mg-NO_3^--N L^{-1}, respectively. Denitrification process requires organic carbon as electron donor. Insufficient availability of suitable organic substrate may result in poor denitrification. According to the literature, 3.3 – 5.0 g-COD g-NO_3^--N^{-1} ratio is required to achieve complete denitrification [4]. It can be noticed that in this study the supplied COD/NO_3^- was more than the required, so it could not be a reason for comparatively low denitrification efficiency. The denitrification efficiency was dependent on the NO_3^- and NO_2^- recycle rate. In this experiment, NO_3^- and NO_2^- was mainly dependent on the circulation rate of both MLSS and liquid from aerobic and effluent to anoxic chamber.

3.4 Biomass Characteristics and Variation in pH

Flocs with poorer settling properties are normally generated in an activated sludge treating organic matter, when the organic loading rate is high. The biomass concentration and organic loading rate (ALR) were 6.84 kg-NH_4^+-N m^{-3} $d^{-1}$and 10.97 kg-NH_4^+-N m^{-3} d^{-1} for 1st ICA and 1st & 2nd ICA, respectively. This index was between the 50 – 100 mL g-VSS^{-1} usually found for sludge with good settling characteristic in activated units treating organic matter [5]. A sludge with SVI of 80.79 mL g-VSS^{-1}, 85.31 mL g-VSS^{-1} for 1st ICA and 1st & 2nd ICA, respectively was obtained as shown in Fig. 5 (A). In this study, fed only with ammonia, a slightly compact sludge with high SVI was developed and, thus, it was possible to operate at slightly higher loads while maintaining higher biomass concentration in the system than those indicated for organic matter treatment. Fig. 5 (B) depicts pH profiles, along the length of reactor in all the three chamber (anaerobic, anoxic and aerobic), final clarifier, and effluent. The pH decreased in the first anaerobic chamber, and then remained almost constant from anoxic to the last aerobic chamber. Constant pH value from aerobic chamber suggested that the complete nitrification was achieved at this point. This was also confirmed by the NH_4^+-N residual concentration, which was almost zero in effluent (Fig. 4 (A)). The pH variations along the aerobic zones are believed to be jointly caused by a number of factors. The nitrification is the most pH influencing process, which causes the pH to decrease due to alkalinity consumption. It is very important to maintain pH to a certain level for efficient nitrification as researchers have reported that nitrification is inhibited at a low pH value (>6.5) [6]. However, in the present system pH remained above 6.5.

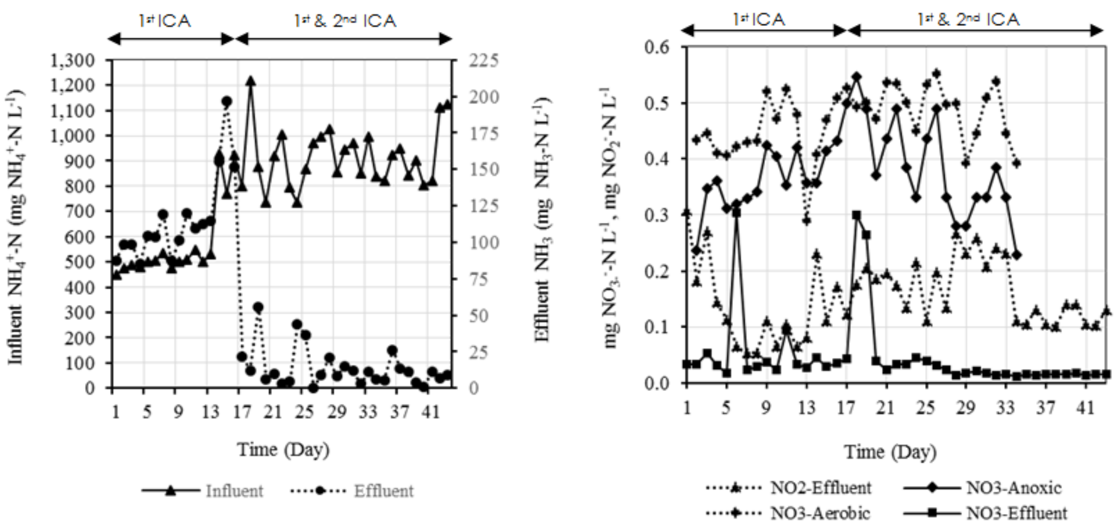

Figure 4. Performance of A^2/O processes: (A) NH_4^+-N concentration profiles (B) NO_3^- and NO_2^- under different conditions

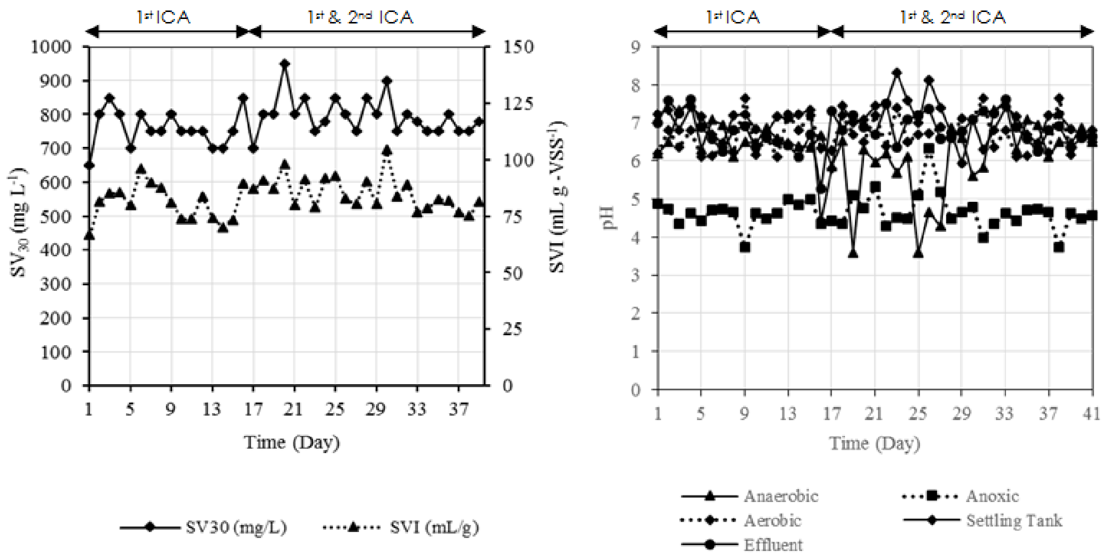

Figure 5. Performance of A^2/O processes: (A) Variation of SV_{30} and SVI (B) Variation in pH change

3.5 Performance of the 1st ICA versus 1st & 2nd ICA BNR system

The overall performance of the 1st ICA versus 1st & 2nd ICA BNR system is shown in Table 2. The pollutants were efficiently in 1st & 2nd ICA BNR system removed with SCOD 100%, TKN removal 99.60% and NH_4^+-N removal 99.90%, respectively. These parameters were better than 1st ICA only. The removal of SCOD, TKN and NH_4^+-N are 84.62%, 73.35% and 97.27%, respectively. The 1st & 2nd ICA BNR system is superior to the 1st ICA BNR system only using in coupling 2nd ICA. Because under anoxic conditions heterotrophs utilize organic matter as electron donor and NO_3^-N act as electron donor. As a result, under conditions high carbon and NO_3^-N, N_2 production can generate higher than with 1st ICA BNR system only.

Table 2. Overall effluent by 1st and 1st & 2nd ICA BNR system

Sys.	SCOD mg L^{-1}	TKN mg-NH_4^+-N L^{-1}	NH_4^+-N mg-NH_4^+-N L^{-1}	NO_3^--N mg-NO_3^--N L^{-1}
1st ICA	1,328	60.48	21.75	0.04
1st&2nd ICA	0	0	1.12	0.01

4. Conclusion

Internal circulation (IC) of activated sludge anaerobic and anoxic/oxic processes was used to treat high carbon and nitrogen synthetic wastewater. The research proved that return effluent to anoxic phase can achieve discharge standard. Treatment only with 1st ICA BNR system, the discharge cannot meet the standard. The 2nd ICA with 0.3Qin has shown a great advantage. The 1st & 2nd ICA BNR system could remove 100% of SCOD, 99.60% of TKN, and 99.90% of NH_4^+-N. The organic loading rate and NH_4^+-N loading rate are 68.38 kg-COD m^{-3} d^{-1} and 9.86 kg NH_4^+-N m^{-3} d^{-1}, respectively.

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