Short-Cut Nitrification of Iraqi Municipal Wastewater for Nitrogen Removal in a Single Reactor

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Short-Cut Nitrification of Iraqi Municipal Wastewater for Nitrogen Removal in a Single Reactor

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Abstract. Nitrogen components removal in wastewater treatment is an updated process that needs a continuous contribution of research. Traditionally, ammonium is removed by two biological ways, denitrification and nitrification. Here, it became necessary to suggest sustainable alternatives to control wastewater treatment strategies. In this work, a single reactor of high ammonium removal over nitrite process was operated, in which ammonium-oxidizing bacteria was used to convert ammonium to nitrite without sludge retention. The system was operated at aerobic conditions and a moderate temperature, at which the higher percentage of the desired ammonium oxidizer bacteria (AOB) over the undesired nitrite oxidizers bacteria (NOB) was achieved. The reactor was tested in a pilot plant scale to treat municipal wastewater with an average influent ammonium concentration value of 147.6 mg/l, flow rate 4.5 l/hr, hydraulic retention time (HRT) 24 hr, temperature 30-35 ºC, dissolved oxygen (DO) concentration 3.7 mg/l, and pH range 6.0–9.0. Removal efficiencies of 65 and 90 % were achieved for ammonium and nitrite, respectively. The Single reactor system is particularly suitable for the treatment of wastewater that contains high ammonium, giving 25% savings of the required oxygen to achieve complete nitrification.

Keywords: Nitrite accumulation; Nitrification; Denitrification; Nitrogen removal; Partial nitrification

1. Introduction

Freshwater resources have become precious with the increase in water demand due to the increase in world population and climate change. Municipal wastewater represents a suitable resource of water for different purposes such as irrigation, industry, and livestock consumption, if it is efficiently and economically treated [1], [2]. Typically, municipal wastewater contains nitrogen compounds in the form of ammonium (NH_4+), nitrite (NO^{-2}), and nitrate (NO^{-3}) ions that are generated from urea and fecal materials [3],[4]. Nitrogen compounds can harmfully affect the environment and organisms if they present in concentrations higher than their standard limits. This may cause dissolved oxygen (O_2) depletion, toxicity, eutrophication, and water aesthetic quality and odor deterioration [5], [6].

While traveling through sewer pipes, the majority of the raw sewage nitrogen is converted from organic-nitrogen to ammonia through a process called hydrolysis. In general, nitrogen compounds are removed from municipal wastewater by merging two processes (i.e. nitrification and denitrification) into a single step. Nitrification is the biological conversion of ammonium (NH^{4+}) to nitrate (NO^{3-}) and then nitrogen (N^2), while denitrification represents the process of converting nitrate (NO^{3-}) to nitrite

NO^{2-}), then nitrous oxide (NO^2), then nitric oxide (NO), and lastly to nitrogen gas (N^2). Further details about these processes and the intermediate steps can be found elsewhere [7], [8].

Recently, the nitrification/denitrification process is commonly used to treat wastewater because of its well-known basics and operation [9], [10]. For instance, in the Netherlands, a plant of wastewater treatment was built to conduct the two steps (i.e. nitrification and denitrification) in a single reactor [11]. Such a process has the advantages of using less oxygen and organic carbon and reducing the reactor volume [12]. As a result, greater denitrification and reduced sludge production rate is obtained comparing with the traditional method [13],[14], which also means less energy consumption and higher efficiency [15].

In this method, NH^{4+} is oxidized at aerobic conditions to NO^{2-} (Nitrification) and the produced NO^{2-} denitrified to N^2 gas under anoxic conditions. This process works at moderate temperatures (higher than 25 0C), at which a higher rate of the desired AOBs than that of the undesired NOBs is achieved. At a temperature of 35 0C, the production rate of the NOBs is nearly half the AOBs [9], [10].

In this research, the single reactor system was applied to treat Iraqi municipal wastewater. A pilot-plant single reactor system was operated to treat a real wastewater feed that was collected from a sewer line. Nitrogen removal via this process can be illustrated by the following pathway:

$$NH_4^+ \rightarrow NO_2^- \rightarrow N_2$$

The performance of the process was tested under different operating conditions such as pH, temperature, and dissolved oxygen.

2. Materials and Methods

2.1. Materials

Table. 1 presents the feed characterization that was used throughout the experimental period. Wastewater was collected in a 500-liter tank and pumped into the reactor at the rate of 4.5 l/hr. The feed wastewater that was used in this study, was collected on a daily basis from a sewer line at the Ministry of Science and Technology.

2.2. Analytical methods

Wastewater samples were taken from the inlet feed and inside the reactor. The pH was measured using WalkLAB TL9000 pH meter and the dissolved oxygen (DO) was determined using WalkLAB DO meter. The concentration of nitrite, ammonium, nitrate, and Chemical Oxygen Demand (COD) were determined by Hach photometric DR3900 spectrophotometer. Mixed liquor suspended solids (MLSS) were measured by direct weight method according to the standard methods [11].

Calculation of the efficiency of the concentration reduction

$$\text{Concentration reduction efficiency} = (C_{in} - C_{out} / C_{in}) * 100\%$$

Where

C_{in}: inlet sample concentration (mg/liter),

C_{out}: outlet sample concentration (mg/liter).

Table 1. Analysis of the feed waste water.

Analysis	**Concentration (mg/L)**
MLSS	500
BOD_5	300 - 350
COD	500
NH_4	100-160
pH	7.5 – 8.5

2.3. The pilot-plant

The process was operated in a pilot-scale (10 L) CSTR with an approximate hydraulic residence time of 1 day. The reactor was run in rounds of 120 minutes in which 80 minutes aerobic and 40 minutes anoxic. The experimental system diagram and real picture were illustrated in figures 1 and 2, respectively. The wastewater was supplied to the system using a peristaltic pump while air was delivered through diffusers placed at the base of the reactor. The system was connected to an online monitoring system to track the temperature, dissolved oxygen, and pH.

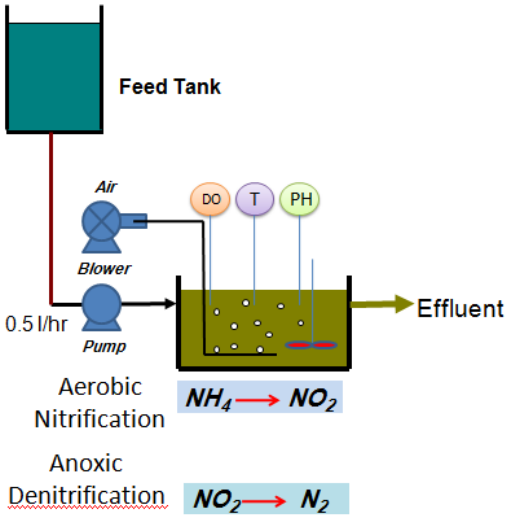

Figure 1. Diagram of the short-cut nitrification process.

2.4. Experimental conditions

Sludge retention time (SRT) was maintained at around 1 day by observing the hydraulic retention time (HRT), levels in the reactor and the effluent. A rotameter was used to adjust the airflow level to control the aeration rate. The pH was controlled by adding the acidic and basic mixtures. Feed flow rate was adjusted at 450 ml/hr, resulting in an HRT of 24 h. All experiments were done at a temperature range of 30–35 0C. The high temperature has another advantage, the optimum growth temperature of AOB and NOB are different. Nitrification and denitrification shortcuts need higher appropriate temperatures (30-35℃), in which AOBs grow sufficiently fast to stay in the reactor, while the NOBs are washed out [13].

Figure 2. Photograph of the pilot-plant system.

3. Results and Discussions

3.1. Effect of pH

Figure 3 illustrates the ammonium removal and nitrite accumulation at various pH levels. It can be noticed that at pH lower than 5, there was no significant change in both variables. At pH of 5.5 and higher, ammonium removal efficiency and nitrite accumulation sharply increased until the pH reached 7-7.5. Further increasing in pH leads to decrease the process performance. The optimum pH valued 7 with NH4-N removal efficiency of 64.7 %, while the nitrite accumulation rate was 82.7 mg/lit at a pH of 7.5.

The decrease in pH had a great effect on the shortcut nitrification in the reactor; the suitable pH ranges for AOB and NOB were 7.0~8.5 and 6.0~7.5, respectively. The decrease in pH destroyed the proper growing environment for the AOB and affected its activity [15]. These findings agree with Suthersan and Ganczarcczyk [17].

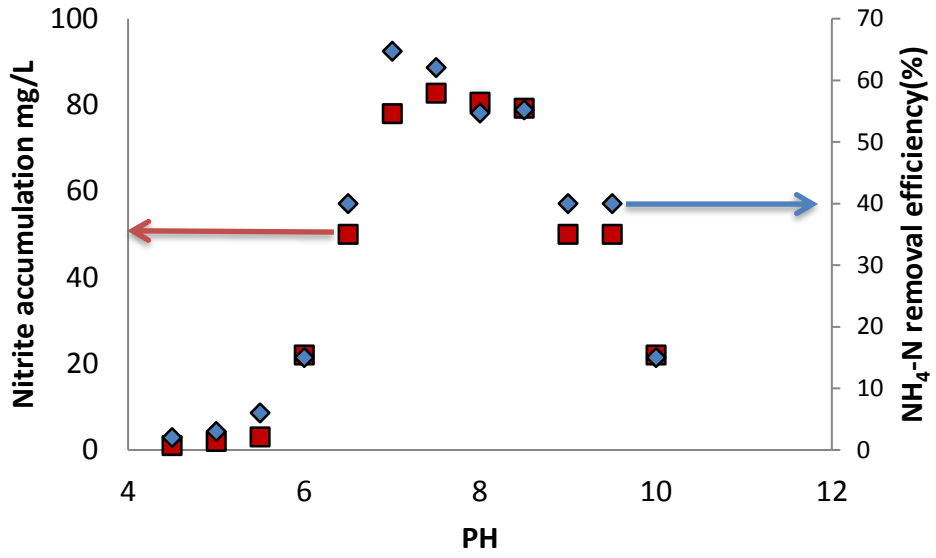

Figure 3. Nitrite accumulation and ammonia removal at various pH levels.

3.2. Effect of DO concentration

The effect of DO concentration on the nitrite accumulation and ammonium removal is presented in Figure 4. It can be seen that the nitrite accumulation increased with the increase of DO concentration up to 3.7 mg/l but stabilized as DO concentration increased more than 3.7 mg/l. At this value of DO concentration, the nitrite accumulation reached its maximum value of 100 mg/L. Similar results were reported by Yongzhenet al. [13]. The removal efficiency of ammonium reached its higher value at DO concentration to 5 mg/l. Based on the reactions involved in this process, this accumulation indicates a 20% decrease in the O2 delivery for nitrification, resulting in economic advantage.

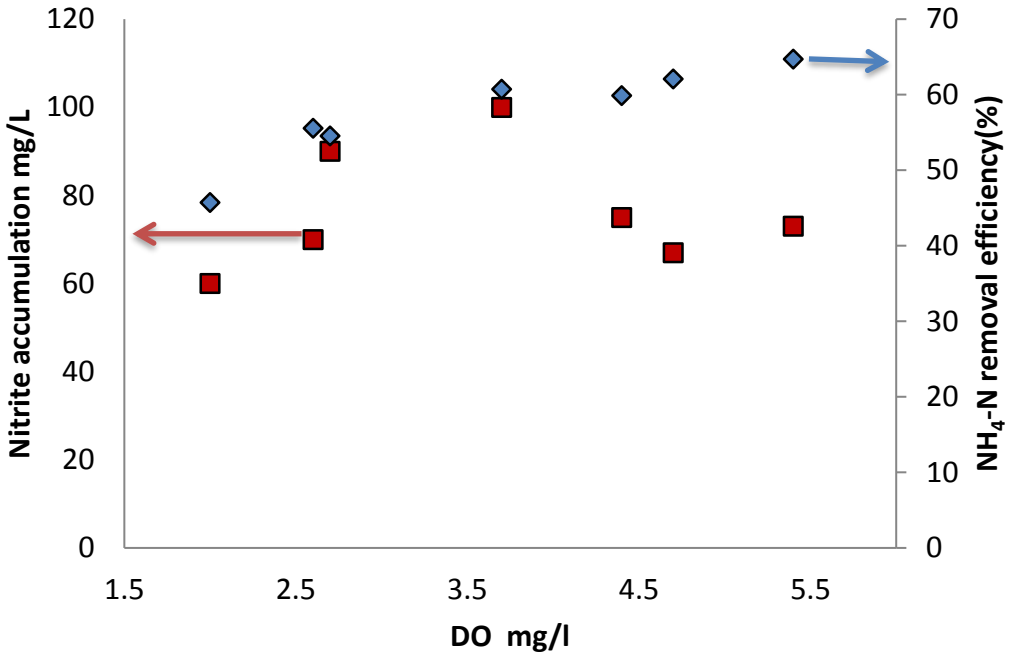

Figure 4. Nitrite accumulation and ammonia removal at different DO concentrations.

3.3. The change of N compounds with time

Change of concentration in ammonium at the influent and the effluent streams with time during the nitrification cycle is shown in **Error! Reference source not found.**. Also, it reveals the nitrite accumulation with the time of the experiment. The influent ammonium concentration was in the range of 130–170 mg/l, with an average value of 147.6 mg/l. The average effluent ammonia was about 63.7 mg/l and the average ammonium removal efficiency was about 59%. Nitrate accumulation was in the range of 75 to 90 mg/L. These results agree with Van Dongen et al. findings [14].

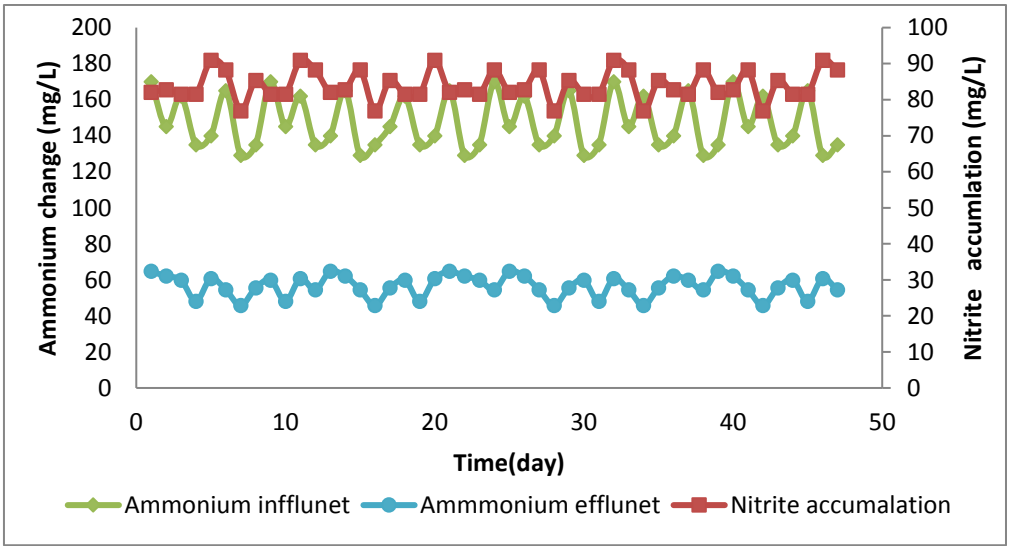

Figure 5. Variation of ammonium change and nitrite accumulation during the nitrification cycle.

Figure demonstrations the change nitrite concentration during Anoxic cycle at the influent and the effluent streams with time. Nitrite concentration at the influent stream was in the range of 30–100 mg/l, while the effluent of nitrite was about 1–5 mg/l. The removal efficiency was about 95% which

indicates that N_2 could be totally removed by the NO_2^- pathway. This increase confirmed the advantages of short-cut nitrification and denitrification in handling municipal wastewater.

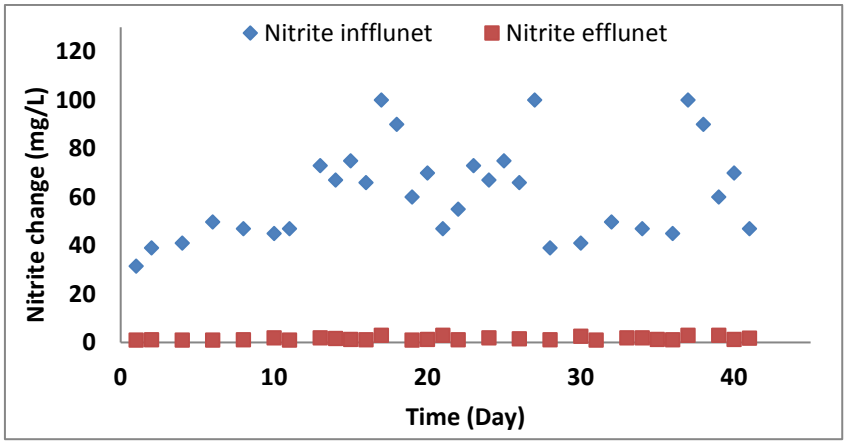

Figure 6. Change in Nitrite concentration during Anoxic cycle (Denitritation).

4. Conclusions

This paper revealed that removing N_2 via NO_2^- from municipal wastewater is achievable at a temperature (30–35^{0}C) in a pilot- plant and the following findings can be stated here:

1- Major nitrite accumulation was measured at the low DO concentration range of 2–5 mg/l and the maximum nitrite accumulation ratio of around 90% observed at a DO concentration of 3.7 mg/l.
2- Complete nitrification was observed in the pH range of 6.0– 9.0, while it was inhibited when pH was lower than 6.0 and higher than 9.0.
3- High ammonium removal can be reached even at a low DO concentration.
4- There was no influence of the suspended solids in the wastewater as the process functions without sludge retention.
5- The reduction in the oxygen demand was about 25 %.

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