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Nitrification Efficiency Variation of Ground Water by using Sponge Media in Single and Series Reactor

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Abstract
Groundwater is used as the major source in Kathmandu valley. Groundwater quality is found to be degraded from various anthropogenic and natural sources. Threat to the groundwater remains in the Valley due to over-extraction and population growth. Nitrogen contamination of groundwater has become one of the major issues. This research was conducted to study the efficiency of ammonium nitrogen oxidation in the single and series reactors using sponge media. Nitrification was performed at the varying hydraulic retention time.pH in the range of 6.7 to 8.9 and Dissolved Oxygen (DO) in the range of 2.5 to 5.7 mg/l was recorded throughout the study period. The temperature of all the reactors was maintained constant at $25\pm2°C$ throughout the research. The alkalinity of raw water influent ranges from 882.47 to 980.07 mg/l. The alkalinity of the raw water sample was higher enough to carry out the nitrification.The concentration of ammonium nitrogen varied from 96.81 mg/l to 125.12 mg/l in the initial storage tank. The average ammonium nitrogen conversion efficiency was found to be 99.43% and 66.03% for Series Reactor (RSE), 27.41% and 13.01% for Blank Series Reactor (RSB), 96.55% and 61.72% for Single Reactor (RS) and 24.27% and 9.35% for Single Blank Reactor (RB) at HRT of 9.123 and 1.824 hrs respectively .The maximum conversion of ammonium nitrogen is found to occur at the Hydraulic Retention Time (HRT) of 9.123 hrs as the contact with oxygen and the bacteria is high during this time period as compared to the HRT 1.824 hrs. The ammonia conversion performance is found to be high in the case of series reactors as compared to the single reactor. The series reactors are more effective in the conversion of ammonium nitrogen than single reactors.

Keywords
nitrification, groundwater, ammonia, sponge, single and series reactors

1. Introduction

Clean and safe drinking water is crucial for life. Good water quality helps to maintain the healthy life of an individual. The provision of clean and safe drinking water helps to build a healthy society. Kathmandu Valley is the most populated area of Nepal which has an acute water shortage due to rapid increase in population and poor water quality. In Kathmandu valley, about 45% of population fulfill their water demand from ground water [1]. Approximately half of the total water supply is achieved through Kathmandu Upatayka Khanepani Limited (KUKL) and the government authentic operator during the rainy season and 60-70% is derived from groundwater sources during the dry season [2].

The increasing population, rapid and haphazard urbanization has severely deteriorated the surface water quality leading to increased dependency on groundwater. Over exploitation, the anthropogenic activities and the natural sources has caused the degradation of ground water quality in many places. Contamination from sewage lines, septic failures, open pit latrines, leaching from landfill sites, and direct disposal of domestic as well as industrial wastes to the surface water source are the problems that degraded groundwater quality of Kathmandu Valley [3]. Ammonia contamination of shallow groundwater has been one of the major issues in Kathmandu valley. Field investigation and lab tests have shown most of the underground water at Kathmandu valley have high concentration of ammonia.The concentration of ammonia varies widely from less than 10 mg/l to greater than 100 mg/l within the core area of Kathmandu valley [4].

The possibility of health hazard is significant at ammonia concentrations exceeding 1.5 mg/l for infants.The presence of ammonia can result in the formation of nitrite as an intermediate product during the oxidation process of ammonia. At a concentration of nitrite above 45 mg/l, it can result in anemia in infants and pregnant women [5].Also, ammonia concentration in the range of 0.2 – 0.5 mg/l is found to be fatal for the fishes [6].

2. Literature review

Nitrification of ammonia occurs from consecutive action of two different groups of chemolithotropic organisms, Nitrosomanas which is an ammonia oxidizing bacteria and Nitrobacter which is nitrite oxidizing bacteria [7]. These chemolithotrophs use nitrite or ammonia as their energy source and carbon dioxide as a carbon source. Thus, Nitrification is a two step oxidation process employing two different groups of bacteria.

For Nitrosomanas,

$$55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_2O + 104H_2CO_3 \quad (1)$$

For Nitrobacter,

$$_{400}NO_2^- \equiv NH_4^+ \equiv {}_4H_2CO_3 \equiv HCO_3^- \equiv {}_{195}O_2 \rightarrow C_5H_7O_2N \equiv {}_3H_2O \equiv {}_{400}NO_3^- \quad (2)$$

The stoichiometric equations are

$$NH_4^+ \equiv {}_1 \cdot {}_5O_2 \rightarrow {}_2H^+ \equiv H_2O \equiv NO_2^- \quad (3)$$

$$NO_2^- \equiv {}_0 \cdot {}_5O_2 \rightarrow NO_3 \quad (4)$$

It is found theoretically that the alkalinity of 7.2 pounds is destroyed while destroying 1 pound of ammonia to nitrate. For the control of alkalinity and pH, quick lime CaO or Calcium hydroxide $Ca(OH)_2$ is often used. In the process of oxidation from ammonia to nitrite, formation of hydrogen ions occurs. Bicarbonate ions present in the raw water will neutralize the hydrogen ions of water if the pH is less than 8.3.

$$H^+ \equiv HCO_3^- \rightarrow CO_2 \equiv H_2O \quad (5)$$

It is found that for the oxidation of 1 mg of ammonia nitrogen to nitrate nitrogen, consumption of nearly 4.3 mg of O_2 and 8.64 mg of alkanity in the form of HCO_3^- occurs [8].

3. Materials and methods

3.1 Experimental Setup

The model is located within the premises of the Water Supply Department of the Institute of Engineering, Pulchowk. Two single reactors and the other two series reactors having equal volume were constructed by using a Polyvinylchloride (PVC) pipe. Each series reactor consists of three equal reactors in series. Out of two single reactors, one was filled with sponge media and another was left blank. Out of two series reactors, one series reactor filled with sponge media and another series reactor was left blank. The reactor was operated in a continuous down-flow mode. The reactors were made by using Polyvinyl chloride (PVC) pipe columns with a diameter of 75 mm and height of 1.1m and 0.5m respectively for single and series reactors. The Bio-sponge media purchased from aquarium shop were cut into a circle of diameter 7 cm and woven in nylon thread by placing a circle alternately with the help of a 1cubic cm sponge. 0.9 m and 0.3 m of bio-sponge media were placed in single and series reactors respectively. The oxygen was supplied from the bottom of the reactor by injecting air from the air pump into the nitrification reactors using cylindrical air stones. A sampling port was provided in each reactor. The source of water used in the experiment is the deep boring water. This water was pumped to the overhead tank and fed to the reactors from the tank through pipes with flow control valves. An aquarium heater was placed in each reactor to maintain a constant temperature of 25°C. To control temperature and prevent heat loss, the reactors were insulated from outside using foam. SOBO aquarium air pump (SB-30B) was used for the aeration.

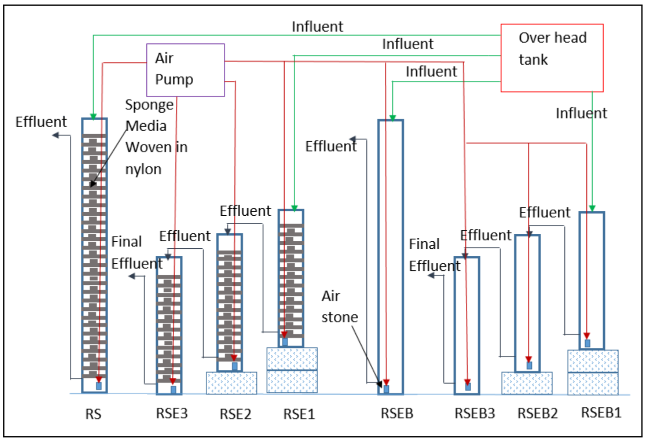

Figure 1: Schematic diagram

3.1.1 Startup and operation of Reactor

The seed nitrifying culture was obtained from the nitrification plant located at Jwagal water supply plant. The reactors were allowed to work in batch mode with sufficient supply of air for 21 days for the proper growth of nitrifying bacteria. The reactors were then operated in continuous mode and the samples were collected for analysis.

3.1.2 Collection and analysis of Sample

The samples were collected every alternate day from the outlet pipe from each of the reactors for analysis. Thus, eight effluent samples from eight different reactors and one raw influent water sample, a total of nine water samples were collected for analysis. The temperature and DO of reactors were recorded at the site during sample collection. The pH, bicarbonate and NH_4-N were measured in the lab following the standard procedure.

4. Result and Discussion

The bicarbonate alkalinity of raw water influent ranges from 882.47 to 980.07 mg/l throughout the study period. The alkalinity of the raw water sample was higher enough to carry out the nitrification. The pH in the range of 6.7 to 8.9 was found throughout the study period.The Dissolve Oxygen (DO) was maintainted in the range of 2.5 to 5.7 mg/l throughout the study period.The temperature of all the reactors was maintained constant at $25 \pm 2°C$ throughout the study period.The concentration of ammonium nitrogen varied from 96.81 mg/l to 125.12 mg/l in the initial storage tank and after passing through the nitrification reactors, it got reduced as the biological oxidation process occurs in the reactors.The analysis of ammonium nitrogen concentration reduction through the reactors at Hydraulic Retention Time (HRT) 9.123 hrs and 1.824 hrs were done by comparing it with influent raw water ammonia concentration which is shown in Figure 2 and Figure 3.

Ammonia is the main parameter to be reduced through nitrification process. The maximum conversion of ammonium nitrogen was found to occur at the HRT of 9.123 hrs as the contact with oxygen and the bacteria is high during this time period as compared to the HRT 1.824 hrs.

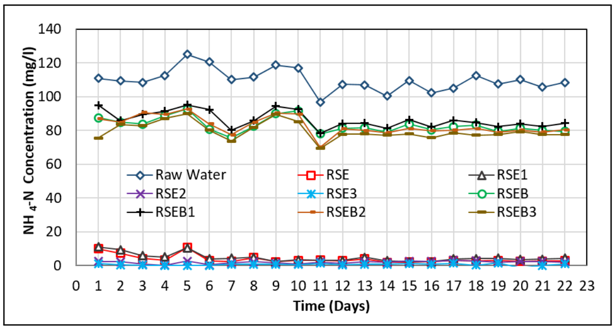

Figure 2: NH_4-N concentration at HRT 9.123 hrs

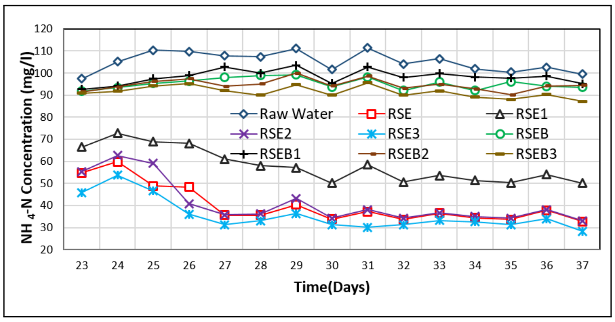

Figure 3: NH_4-N concentration at HRT 1.824 hrs

The ammonium nitrogen conversion efficiency for single and series reactors for HRT 9.123 and 1.824 hrs are shown in Figure 4 and Figure 5 respectively.For HRT 9.123 hrs, the average ammonium nitrogen conversion efficiency was found 96.55%, 99.43%,24.27% and 27.41% for the effluent from Single Reactor (RS), Series Reactor (RSE), Blank Single Reactor (RB) and Blank Series Reactor (RSB) respectively.

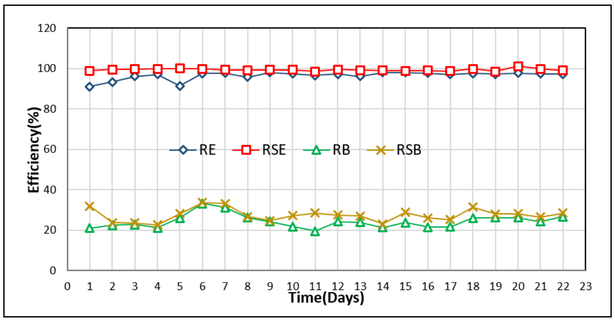

Figure 4: NH_4-N conversion efficiency at HRT 9.123 hrs

For HRT 1.824 hrs, the average ammonium nitrogen conversion efficiency was found 61.72%, 66.03%,9.35% and 13.01% for the effluent from RS, RSE, RB and RSB respectively.The conversion efficiency of ammonia is found to be higher in the reactor in the HRT of 9.123 hrs. Low conversion efficiency was observed at HRT of 1.824 hrs.This is low retention time allowing less time of contact of water with oxygen and the bacteria. The conversion percent of ammonia was observed higher in the case of higher ammonia load in the reactor as compared to low ammonia concentration and in high HRT in the reactor.The ammonia conversion performance is found to be high in case of series reactors as compared to the single reactor.

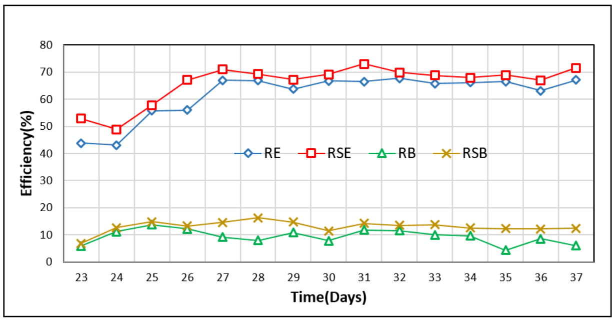

Figure 5: $NH_4 - N$ conversion efficiency at HRT 1.824 hrs

5. Conclusions

pH in the range of 6.7 to 8.9 and Dissolved Oxygen (DO) in the range of 2.5 to 5.7 mg/l was recorded throughout the study period. The temperature of all the reactors was maintained constant at 25 ± 2°C throughout the study period. The alkalinity of raw water influent ranges from 882.47 to 980.07 mg/l throughout the study period. The alkalinity of the raw water sample was higher enough to carry out the nitrification.The concentration of ammonium nitrogen varied from 96.81 mg/l to 125.12 mg/l in the initial storage tank. The maximum conversion of ammonium nitrogen is found to occur at the Hydraulic Retention Time (HRT) of 9.123 hrs as the contact with oxygen and the bacteria is high during this time period as compared to the HRT 1.824 hrs respectively.The average ammonium nitrogen conversion efficiency was found to be 99.43% and 66.03% at HRT of 9.123 and 1.824 hrs respectively for Series Reactor (RSE).For Blank Series Reactor (RSB), average ammonium nitrogen conversion efficiency was found as 27.41% and 13.01% at HRT 9.123 and 1.824 hrs respectively.The average ammonium nitrogen conversion efficiency of 96.55% and 61.72% were found at HRT 9.123 and 1.824 respectively for Single Reactor (RS).For Single Blank Reactor (RB), average ammonium nitrogen conversion efficiency was found as 24.27% and 9.35% at HRT 9.123 and 1.824 hrs respectively.

The removal percent of ammonia was observed higher in case of higher ammonia load in the reactor as compared to low ammonia concentration and in high retention time in the reactor.The series reactors are effective in removal of ammonium nitrogen than single reactors.Also, ammonium nitrogen removal efficiency is higher for higher Hydraulic Retention Time(HRT) due to higher time of contact of water with oxygen and the bacteria.

Acknowledgments

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