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Nitrification Efficiency Analysis in Single Reactor Bio-Filter Column Using LECA balls and Over-burnt brick bats

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Abstract

Groundwater, one of the major source of drinking water in Kathmandu valley is deteriorated due to natural and anthropogenic sources. Contamination of groundwater with high levels of ammonia has been found in several locations within the valley. Elevated levels of ammonia in groundwater leads to various health hazards. This research aims to study and analyze the nitrification removal efficiencies at varying Hydraulic Retention Time (HRT). Two different medias, LECA (Lightweight Expanded Clay Aggregate) balls and Over-burnt brick bats were considered in this study and their equal volume of solids was taken. Sieve analysis was done and media passing and retaining in sieve sizes, 12.5 and 10 mm were used to conduct the study. LECA reactor, Blank reactor and Over-burnt brick bats reactor were setup for the study. Throughout the study, the DO was kept between 3.1 and 5.1 mg/l and the reactor temperature was kept at 30±2 ℃. The alkalinity concentration range of 888.77 to 953.24 mg/l present in the influent water was sufficient enough to carry out the nitrification process. Ammonium nitrogen concentration in the influent water varied from 109.72 to 148.14 mg/l. At 9.123 hours and 1.824 hours, respectively, the average ammonium nitrogen conversion efficiency was found to be 98.99±0.18% and 61.93±1.08% for over-burnt brick bats, 27.99±11.55% and 10.91±5.11% for blank reactors, and 92.60±4.09% and 38.50±4.38% for LECA balls. Higher the HRT, higher will be the contact time which results in the better conversion efficiency. The efficiency of Over-burnt brick bats was found to be higher in comparison to the LECA balls due to higher void ratio. At HRT of 9.123 hrs, over-burnt brick bats had an effluent concentration less than accepted value as per NDWQS (i.e. less than 1.5 mg/l).

Keywords

Nitrification, Groundwater, Ammonia, Over-burnt brick bats, LECA balls, Void ratio, Porosity

1. Introduction

In Nepal, especially in the Kathmandu Valley, groundwater is a crucial source of drinking water. Despite the increasing demand, Kathmandu Upatyaka Khanepani Limited (KUKL), the area's water delivery agency, can only offer 115 million liters per day during the rainy season and 69 million liters per day during the dry season [1]. To address the importance of surface water supply during the dry season, a conjunctive use policy has been adopted to utilize both groundwater and surface sources. On average, surface sources continue to provide approximately 50% of the total water supply [2].

The rapid and haphazard urbanization in Kathmandu valley, coupled with increasing population, has resulted in the over-exploitation of water resources and degradation of groundwater quality at shallow depth due to contamination from various sources such as sewer lines, latrines, industrial and domestic wastes, and landfill sites[3]. The deep groundwater is found highly contaminated by ammonia in the valley. One of the significant problems in the Kathmandu valley is the contamination of both shallow and deep groundwater with ammonia. During the assessment of groundwater, it was found that approximately 96.51% of the sampled wells contained ammonia levels higher than the NDWQS - recommended limit of 1.5 mg/l [4]. For shallow groundwater samples, the average concentration of ammonium nitrogen was 5.3 mg/l, with a maximum concentration of 12.3 mg/l. In deep groundwater samples, the average concentration of ammonium nitrogen was 23.3 mg/l, while the maximum concentration found was 119.8 mg/l [5].

At ammonia concentrations above 1.5 mg/l, health hazard is significant for the infants. Nitrate formation occurs when ammonia is oxidised, which can be harmful to health. The main risk to health is from nitrate conversion that occurs before ingestion, rather than in the digestive system of humans [6]. According to the domestic water supply guidelines established by the WHO, the permissible level of Nitrate concentration should not exceed 45 mg/L. Elevated levels of Nitrate toxicity pose a higher risk for anemia in pregnant women and infants, as well as the creation of nitrosamines that have carcinogenic properties [7].

2. Literature Review

Ammonia removal can be done by several processes. The most effective process for ammonia removal upto the acceptable limit is biological process. In this study we deal with the biological nitrification process as we aim to analyse the nitrification efficiency. The process of nitrification, which involves the conversion of ammonia, is carried out by two groups of chemolithotropic organisms in succession. The first group, Nitrosomonas, comprises ammonia oxidizing bacteria, while the second group, Nitrobacter, comprises nitrite oxidizing bacteria [8]. The equation below illustrates the two-stage process of oxidizing ammonia to nitrate:

For Nitrosomonas,

$$55NH_4^+ + 76O_2 + 109HCO_3^- \rightarrow C_5H_7O_2N + 54NO_2^- + 57H_2O + 104H_2CO_3 \quad (2.1)$$

For Nitrobacter,

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 \rightarrow C_5H_7O_2N + H_2O + 400NO_3^- \quad (2.2)$$

The stoichiometric equations for nitrification are;

$$2NH_4^+ + 3O_2 \rightarrow 4H^+ + 2H_2O + 2NO_2^- \quad (2.3)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \quad (2.4)$$

Theoretical calculations have shown that the destruction of one pound of ammonia to nitrate results in the loss of 7.2 pounds of alkalinity. Quick lime or Calcium hydroxide is generally employed to regulate alkalinity and pH levels. The oxidation of ammonia to nitrite generates hydrogen ions, which can be neutralized by bicarbonate ions present in the raw water if the pH is below 8.3.

$$H^+ + HCO_3^- \rightarrow CO_2 + H_2O \quad (2.5)$$

One milligram of ammonia nitrogen requires about 4.3 mg of oxygen and 8.64 mg of bicarbonate alkalinity to be converted to nitrate nitrogen. In other words, oxygen and alkalinity are necessary for the nitrification process to be effective [9].

High surface area for bacterial adhesion and low clogging features should be included in the filter media employed for maximum nitrification rate [10]. Two such medias LECA and Over-burnt brick bats are taken in this study.

3. Materials and Methods

3.1 Experimental setup

The location of the model was setup on the premises of the Water Supply Plant of IOE, Pulchowk Campus. Three single column reactors were constructed by using polyvinyl chloride (PVC) pipe as shown in Figure 1. The reactor was run in a continuous down-flow mode while fully submerged. To stop heat loss from the system, the reactors were built using 75 mm-diameter PVC tubing and insulated with plastic and polyurethane foam. LECA balls and Over-burnt brick bats were used as a media in the first and third reactor while second reactor was blank. The water from the deep boring was pumped into the overhead tank of 1000 liters capacity and then was supplied to the reactors through pipes with flow control valves. To maintain the constant temperature of 30±2°C in the reactors, aquarium heater was placed in each reactor. In order to maintain the DO of the reactor, air was injected into the nitrification reactors using cylindrical air stones, using the SOBO aquarium air pump (SB-30B) to supply air to the bottom of the reactor.

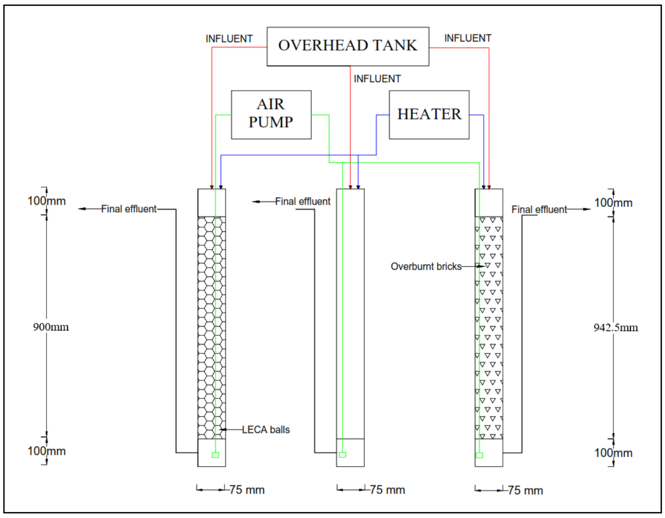

Figure 1: Schematic Diagram of Reactor

3.2 Media for Bio-filtration

LECA, Blank (no media), Over-burnt brick bats were packed in the single column reactor in reactors in the first, second and third respectively. The carrier material enable easy attachment of biomass.

Sieve analysis was done using standard sieve sizes of 19 mm, 16 mm, 12.5 mm, 10 mm, 6.3 mm, 4.75 mm. LECA and Over-burnt brick bats retained on sieve sizes, 12.5 and 10 mm were used as media for the research. The void ratio of LECA and Over-burnt brick bats were 1.083 and 1.182 and porosity of the medias were 0.52 and 0.542 respectively. The reactor columns were set such that both the reactors containing media had same volume of solids. For same volume of solids, the media height containing LECA balls and Over-burnt bricks were 90 cm and 94.25 cm respectively.

3.3 Initiating and Running the Reactor

The nitrification unit of the Jwagal Water Supply unit provided the seed nitrifying bacteria. This seed culture was harvested and implemented on the reactor for about 14 days and then the process was startup after some time.

3.4 Collection of Sample

Standard procedure was used for sampling. Frequency of sampling was 2 days. Samples from LECA reactor, blank reactor, Over-burnt brick bats reactor and from raw water inlet were collected in sample bottles. DO and temperature were recorded directly at the site.

3.5 Analytical Methods

The following sample parameters were examined in accordance with the American Public Health Association's Standard Method of Examination of Water and Wastewater, 20th Edition, and the analysis techniques utilized are detailed in Table 1.

Table 1: Analysis Parameters, Methods and Instruments

S.N	Parameters	Methods/Instrument
1	$NH_4^+ - N$, $NO_3^- - N$ and $NO_2^- - N$	Spectrophotometer (Instrument- UV mini,-1240 UV-VIS Spectrophotometer)
2	pH	Standard pH meter by Hanna Instruments
3	HCO_3^-	Volumetric analysis by titration method
4	DO and Temperature	Oxyeye DO meter ID-150 by Iijma electronics group

4. Results and Discussions

The influent water had alkalinity concentration ranging from 888.77 to 953.24 mg/l. The influent's level of alkalinity was adequate to complete the nitrification process. pH in the influent wastewater ranged from 7.49 to 8.35. The influent water had ammonium nitrogen concentration ranging from 109.72 to 148.14 mg/l when held at the storage tank. The ammonium nitrogen concentration decreased after passing through the reactors due to the biological nitrification process. Alkalinity in the reactors decreased in proportion to the ammonium nitrogen conversion due to the consumption of bicarbonate during the nitrification process. Concentrations of ammonium nitrogen at HRT of 9.123 hrs and 1.824 hrs was analysed by drawing the plots as shown in Figure 2 and Figure 3.

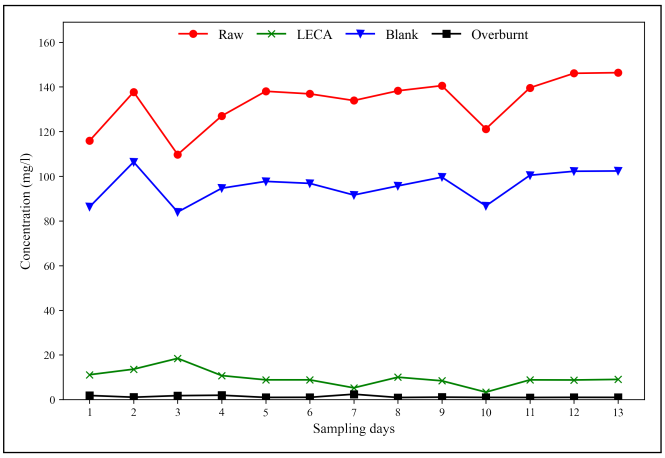

Figure 2: Concentration of Ammonium-N at HRT 9.123 hrs

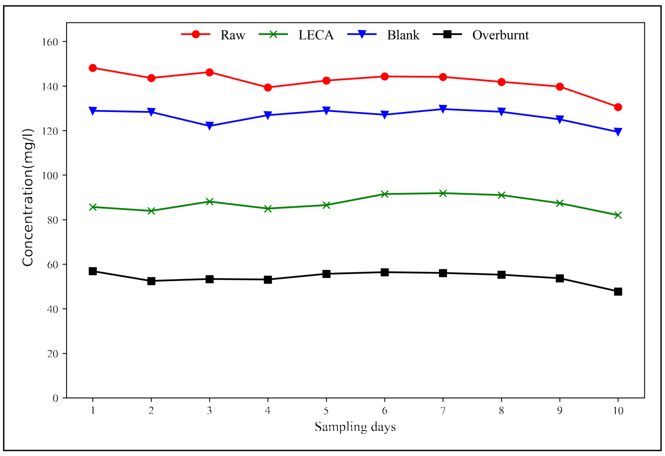

Figure 3: Concentration of Ammonium-N at HRT 1.824 hrs

Ammonium nitrogen conversion efficiency was higher at HRT of 9.123 hrs due to more contact time of influent water with air and microorganism. The conversion efficiency of Over-burnt brick bats was found to be higher than the LECA balls. LECA balls efficiency might have been decreased due to more number of voids inaccessible for the attachment of biomass [11]. The Over-burnt brick bats had more effective void ratio in comparison to LECA balls. While taking same solids volume of both of these media, Overburnt brick bats reactor had more height of bio-filter column due to which voids available for micororganism attachment was more. Blank reactor did not perform effective conversion due to no surface available for the attachment of biomass, although some conversion may have been due to the suspended growth process and biomass attached to the circumference of the PVC pipe.

The ammonium nitrogen conversion efficiency is displayed in Figures 4 and 5, respectively, at HRT of 9.123 hours and 1.824 hours. Ammonium nitrogen conversion efficiency was determined to be 98.99±0.18% in over-burnt brick bats, 92.60±4.09% in LECA balls, and 27.99±11.55% in blank reactors at a heat tolerance of 9.123 hours.

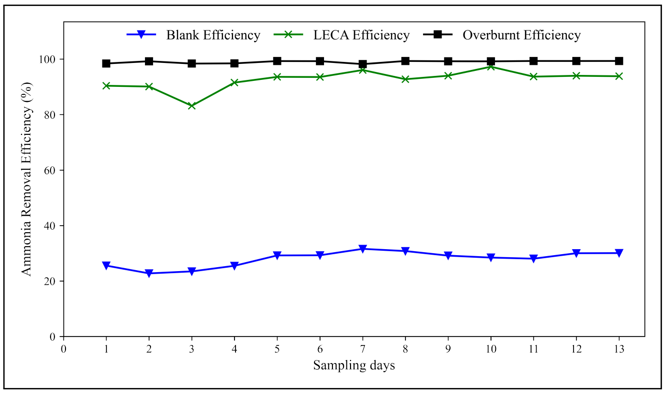

Figure 4: Ammonium-N removal efficiency at HRT 9.123 hrs

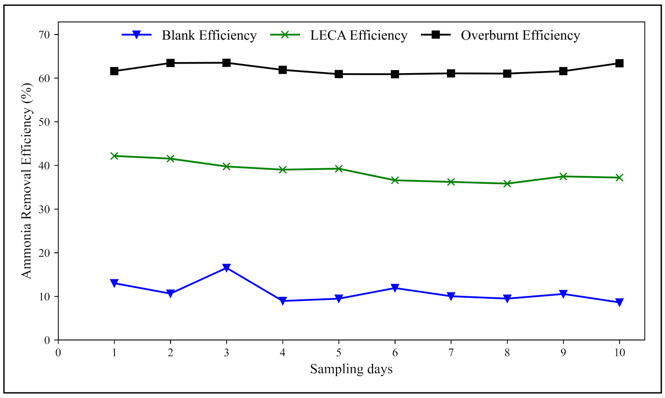

Figure 5: Ammonium-N removal efficiency at HRT 1.824 hrs

For HRT of 1.824 hrs, ammonium nitrogen conversion efficiency was found to 61.93±1.08% in Over-burnt brick bats, 38.50±4.38% in LECA balls and 10.91±5.11% in blank reactors. At less hydraulic retention time, the contact of influent water with air and microorganism is not sufficient for effective conversion of ammonium nitrogen. The ammonium nitrogen conversion efficiency was found to be higher in case of use of Over-burnt brick bats as a media. The conversion efficiency was higher at higher HRT of 9.123 hrs.

5. Conclusions and Recommendations

Ammonium conversion was found satisfactory in both the media. Owing to the longer water contact time with oxygen and bacteria at 9.123 hours, the conversion was higher. Over-burnt brick bats performed more effective conversion of ammonia than LECA balls due to the higher void ratio and porosity of the over-burnt brick bats.

Over-burnt brick bats at HRT of 9.123 hrs had an effluent concentration less than 1.5 mg/l in most cases, which is in accordance with the NDWQS standards. Thus, it is seen that it can be used as an media for effective nitrification process maintaining HRT of 9.123 hrs.

The efficiency of ammonium nitrogen conversion can be increased by use of the filter medias which have higher void ratio and porosity as it provides more volume for the attachment of biomass. Alternative media such as klayton [11] with such properties may help enhance the nitrification process and may lead to cost effectiveness of the process in large scale.

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References

[1] Bhesh Raj Thapa, Hiroshi Ishidaira, Vishnu Prasad Pandey, and Narendra Man Shakya. Impact assessment of gorkha earthquake 2015 on portable water supply in kathmandu valley: preliminary analysis. *Proceedings of the Society of Civil Engineering B1 (Hydraulic Engineering)*, 72(4):I_61–I_66, 2016.

[2] NR Khatiwada, S Takizawa, TVN Tran, and M Inoue. Groundwater contamination assessment for sustainable water supply in kathmandu valley, nepal. *Water Science and Technology*, 46(9):147–154, 2002.

[3] Samita Ghartimagar, Puja Khatri, Swekshya Neupane, Dev Raj Joshi, and Tista Prasai Joshi. Evaluation of ground water quality of kathmandu valley and antibiotic susceptibility test against klebsiella pneumoniae. *Tribhuvan University Journal of Microbiology*, 7:83–90, 2020.

[4] Razim Ganesh, Rebika Koju, and Raja Ram Prajapati. Assessment of groundwater quality and water table mapping of bhaktapur municipality. 2018.

[5] Sangam Shrestha, D Pradhananga, and VP Pandey. Kathmandu valley groundwater outlook. *Asian Institute of Technology (AIT), The Small Earth Nepal (SEN), Center of Research for Environment Energy and Water (CREEW), International Research Center for River Basin Environment-University of Yamanashi (ICRE-UY), Kathmandu, Nepal*, 2012.

[6] WEJ Phillips. Naturally occurring nitrate and nitrite in foods in relation to infant methaemoglobinaemia. *Food and cosmetics toxicology*, 9(2):219–228, 1971.

[7] JC Akan, FI Abdulrahman, and JT Ayodele. Studies on the effect of municipal waste and industrial effluents on the pollutant level of river challawa, kano state, nigeria. 2007.

[8] Metcalf Eddy. Inc., wastewater engineering, treatment and reuse, 2003.

[9] Iswar Man Amatya, Bhagwan Ratna Kansakar, Vinod Tare, and Liv Fiksdal. Role of ph on biological nitrification process. *Journal of the Institute of Engineering*, 8(1-2):119–125, 2011.

[10] LL Hargrove, PW Westerman, and TM Losordo. Nitrification in three-stage and single-stage floating bead biofilters in a laboratory-scale recirculating aquaculture system. *Aquacultural engineering*, 15(1):67–80, 1996.

[11] Jover Nuevaespana and Jonathan R Matias. Comparison of the physical profile of klayton and leca as media for aquaponics, 2022.