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Comparison of Ammonia Removal from Ground Water in Attached Growth Process Using Over-burnt Brick with Suspended Growth Process without Any Media

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Abstract

Rising amount of ammonia in groundwater is rising problem in groundwater of Kathmandu. This has led to various diseases like blue baby syndrome to arise. So, it is necessary for efficient and safe removal of ammonia from drinking water. Since the physical-chemical system includes the major disadvantages of high operation and maintenance cost, the biological nitrification system can only be a good alternative to remove ammonia from ground water. Hence, an attempt is done in this research to treat ammonia contaminated water by biological nitrification process. Three reactors were constructed in series with media of over-burnt brick and other three in series were constructed without media. The study was carried out for five different flow rates of 10, 14.4, 18.8, 27.6 and 38.8 ml/min. Based on laboratory test the efficiency of these five different flow rates was plotted and conclusions were reached. Achievement of continuously increasing efficiency, which reached to 95–100% in the reactor provided with over-burnt media; reflects a success in the assumption that the over-burnt brick is good media to be used in bio filters for nitrification. The reactors with media have more efficiency than reactors without media. An average efficiency of 56.48% for reactors with media and 37.55% for reactors without media was observed for all the flows. The difference of 18.72± 0.2 was found between reactor with media and reactor without media in both series and single reactor. Low flow rates showed better ammonia removal than flow rates with higher flow rates such that a hydraulic retention time of 7.29 hour per reactor can be taken as design criteria for nitrification using over-burnt brick as media.

Keywords: Nitrification, Ammonia, Nitrate, Over-burnt brick

1. Introduction

Clean and safe drinking water is essential for life. Water plays an important role in determining the quality of life as well as health of an individual. A World Health Organization (WHO) report (2021/2022) found, 4.2 million deaths annually from WASH-related diseases (unsafe water, poor sanitation, and hygiene), 1.5 million child deaths from diarrheal diseases each year (primarily caused by poor WASH conditions), 2 billion people without safely managed drinking water services, 3.6 billion people without safely managed sanitation services and 673 million people practicing open defecation. It can be seen that significant proportion of preventable deaths worldwide are linked to limited access to safe drinking water and improved sanitation facilities. Thus, the supply of clean and safe water should always be maintained. (WHO, 2022)

In case Nepal, data from Department of Water Supply and Sewerage Management shows that about 42.4% of the population have water flow that is sufficient for all daily needs, 31.9% has water flow that is sufficient

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for drinking, cooking and washing, 15% has water flow that is sufficient for drinking and 4.9% has water but it is not sufficient for drinking. (Sharma, et al., 2021)

Water demand in the Kathmandu Valley is rapidly increasing due to the growing urban population. The supply of treated water is limited and insufficient to meet the rising demand for domestic use. In this context, groundwater could serve as a potential source of drinking water in the region. Approximately 45% of people in urban and semi-urban areas of the Kathmandu Valley rely on groundwater for drinking and other domestic need. (MOPPW, 2003) Groundwater typically has characteristics such as low temperature, low redox potential, high levels of carbon dioxide and minerals, minimal suspended solids, and is free from microbial contaminants. Because it meets the required standards for drinking water, groundwater is often regarded as a preferred source for public water supplies and is also extensively used for private, domestic, and industrial purposes.

The study done on the quality of ground water in Kathmandu valley showed that the groundwater in the valley was contaminated with iron and coliform bacteria. The highest iron concentration recorded in tube and deep tube well samples was 1.9 mg/L, while shallow well samples had approximately 1.5 mg/L. These values significantly exceeded the WHO guideline for iron in drinking water, which is 0.3 mg/L. The total coliform bacteria count in shallow wells was particularly high, reaching 267 CFU/100 mL, well above the WHO limit. Tube and deep tube wells had bacterial counts of 129 and 148 CFU/100 mL, respectively. In addition to iron and coliform contamination, other factors such as ammonia, nitrates, nitrites, and pesticide residues were found to negatively affect groundwater quality. Physical parameters like electrical conductivity and turbidity also exceeded the WHO's recommended upper limits for drinking water. However, levels of hardness, chloride, arsenic, and fluoride were within the acceptable limits set by WHO guidelines for drinking water. (Pant, 2011)

Nitrate contamination in groundwater of Nepal is much more prevalent at shallow depths due to anthropogenic sources. High ammonia concentrations exist deep in the aquifers due to the geologic deposition. The average concentration of nitrates from urban drinking water sources is 3.9 mg/L $N0_3$ -N. However, the average concentration in rural areas is only 1.2 mg/L $N0_3$-N. The average nitrate concentration in traditional water sources like water spouts and hand dug well was 7.6 mg/L $N0_3$-N (Brittner, 2000).

NH_4–N contamination has several adverse effects. Some of them include (i) displeasure for drinking due to bad taste and smell, (ii) reduction of chlorine disinfection, leading to a contamination of pathogenic microorganisms, and (iii) conversion of NH_4–N to NO_3–N. Further, high NO_3–N level can cause blue baby syndrome or methemoglobinemia. (Ryer-Powder, 1990)Therefore, installing an additional treatment unit for NH_4–N removal is necessary in the existing drinking water supply system. It ensure that the supplied water comply with the standard for drinking for ammonia which is less than 1.5 mg of NH_4–N/L (DWSS, 2005).

Nitrification plant using biological oxidation are compact and can provide the benefits of significant cost savings in construction and land costs. Moreover, there is no toxic waste generated. Some examples of the biological NH_4–N removal system for drinking water and groundwater treatment include biofilter, tricking sand filter and swim–bed reactor.

We conducted research on pilot scale biofilter using over-burnt bricks as media. The research consists of three main parts; lab–scale attached growth reactor to study the effectiveness of over burnt brick as media for removal of ammonia; to compare the rate of ammonia removal by over-burnt bricks in attached growth process with suspended growth method without any media; to find the ammonia removal rate (nitrification rate) per kg of over-burnt brick for different flows and consequently find the best hydraulic retention time for the efficient reactor.

2.Literature Review

Ammonia (NH_3) can be toxic to aquatic life, and its presence in drinking water can also pose health risks. Ammonia removal from water is a critical process in water treatment, particularly in municipal wastewater, industrial effluents, and aquaculture systems. The removal of ammonia generally involves both biological and chemical methods, depending on the specific application, concentration, and water conditions. Several chemical methods can also be used to remove ammonia from water, particularly when biological methods are not feasible or when rapid ammonia removal is required. The key chemical processes are air stripping, ion exchange, and chemical precipitation. Though in this paper we are mostly concerned with biological process of ammonia removal.

The most common and widely used method for Ammonia removal in wastewater treatment is nitrification, a biological process carried out by specialized bacteria. Nitrification occurs in two steps, both carried out by different groups of bacteria. In step one, Ammonia-oxidizing bacteria (AOB) (e.g., Nitrosomonas) convert ammonia (NH_3) into nitrite (NO_2^-). In the second step Nitrite-oxidizing bacteria (NOB) (e.g., Nitrobacter) further oxidize nitrite (NO_2^-) to nitrate (NO_3^-) .

$NH_3 + O_2 \rightarrow NO^-_2 + 3H^+ + 2e^-$ (Equation 1)

$NO^-_2 + O_2 \rightarrow NO^-_3$ (Equation 2)

Ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) require adequate dissolved oxygen (DO) concentrations to thrive and carry out nitrification effectively. Typically, a DO concentration of 2-3 mg/L is considered sufficient for nitrification. The optimal temperature range for nitrification is typically 20-30°C, although it can vary based on the specific bacterial species involved. In cold temperatures (below 10°C), nitrification rates can decrease significantly. This is a critical consideration in colder climates, where additional measures such as temperature control or longer retention times may be necessary (MetCalf and Eddy, 2003).The process works best in a neutral to slightly alkaline pH range (approximately 7.0 - 8.5).If the pH drops below 6.5, it can inhibit the activity of nitrifying bacteria (Amatya, 2011). On the other hand, higher pH values can favor the formation of ammonia gas (NH_3) rather than ammonium ions (NH_4^+), which are more readily converted by bacteria. Nitrification produces hydrogen ions (H^+) during the conversion of ammonia to nitrite and nitrite to nitrate, which can lower the pH of the system. A sufficient buffer (alkalinity) is necessary to prevent the pH from becoming too acidic and impeding the nitrification process (Zhang, (1996)).

In this study we have used over-burnt bricks as media for nitrification. Over-burnt bricks are typically produced when bricks are exposed to excessive heat during the firing process, causing them to become porous, brittle, and structurally weakened. For nitrification, bacteria typically adhere to surfaces (like biofilms), and the material should offer high surface area for bacteria to colonize (Proano-Pena, et al., 2020). Over-burnt bricks tend to be more porous than standard fired bricks, meaning they can provide a greater surface area for the colonization of microorganisms like ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB). Over-burnt bricks have the necessary roughness and porosity to support biofilm development. Over-burnt bricks are often available at a lower cost compared to commercial biofilter media or engineered materials used in nitrification reactors, making them an economical option for large-scale treatment systems. Repurposing over-burnt bricks could contribute to a more sustainable approach by recycling waste material rather than using synthetic or newly manufactured materials.

3. Materials and Methods

3.1. Design and operation of reactors

The model was located within the premises of Girls hostel of Institute of Engineering of Pulchowk. Three reactors in series were constructed by using polyvinylchloride (PVC) pipe as shown in figure 1. The reactors were packed with over-burnt bricks media which allows for the growth of nitrifying bacteria. The carrier material enables easy attachment of biomass. The effective size of the over-burnt brick was 4.3mm and it had an average porosity of 0.302.

Another set of three reactors, in series were constructed by using polyvinylchloride (PVC) pipe as shown in figure 1. These reactors did not have any media. Nitrification was done by suspended growth method. The source of influent water used in the experiment was well water rich in ammonia, present within the premises.

The influent water was pumped to the overhead tank. It was fed to the reactors from the tank by the use of independent pipes with flow control valve. The flow direction for both set of reactors is shown by arrow in figure (1).The reactor were operated in a completely submerged continuous down- flow mode for both set of reactors. Aeration for these reactors was done through aeration stones connected to aerator pump. Temperature was maintained with heating rods inserted within the reactor.

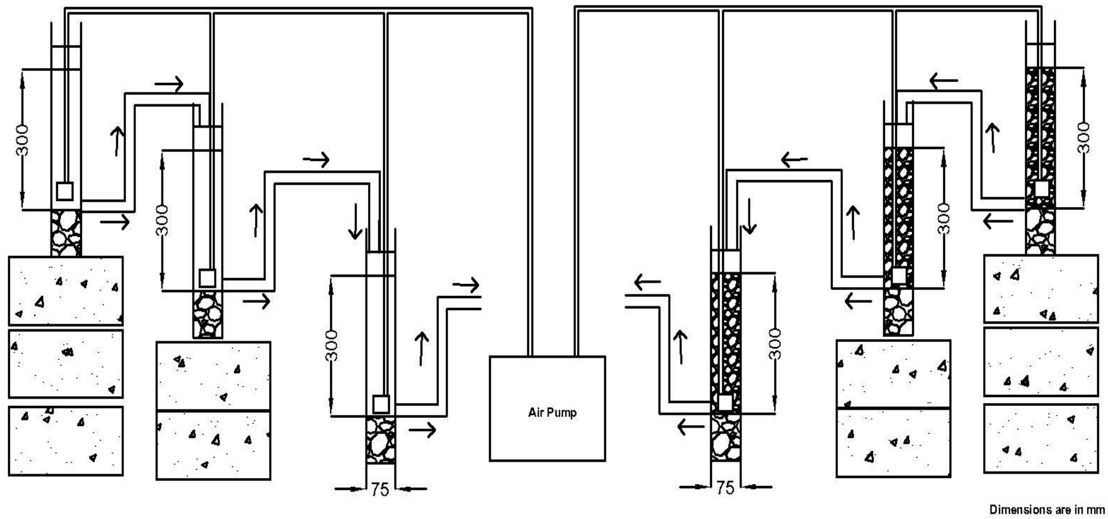

Figure 1. Schematic diagram of series reactors with media and without media

Details of all the experiments and operating conditions are summarized in Table 1.

Table 1. Details of reactor

S.N.	Reactor Dimension	Reactor dimension	Abbreviation Used	Weight of over-burnt bricks in reactor
i.	Series reactor with media	Pipe material = PVC; Diameter= 75mm; Height= 40 cm; Water depth= 30 cm; Free board= 10 cm	First reactor in series= WS1 Second reactor in series= WS2 Third reactor in series= WS3	1st reactor = 0.673 kg 2nd reactor = 0.691 kg 3rd reactor = 0.647 kg
ii.	Series reactor without media	Pipe material = PVC ; Diameter= 75mm; Height= 40 cm; Water depth= 30 cm; Free board= 10 cm	First reactor in series= WOS1 Second reactor in series= WOS2 Third reactor in series= WOS3	No media

Frequency of sample effluent collection was 2 days except for some uncertainties. Samples from each reactor in series reactor and from raw water inlet were collected in sample bottles. DO and temperature was be recorded directly at the site.

2.2. Operation of reactor

The seed nitrifying bacteria was obtained from dripping nitrification system located in UN Park located at Jwagal, Lalitpur. This seed was harvested and implemented on the reactor for two weeks. After two week a flow rate was maintained for all reactor configuration. This marked the startup of the reactor for nitrification. Changes were adopted as per needed. Frequency of sample effluent collection was 2 days except for some uncertainties. Samples from each reactor in series reactor and from raw water inlet were collected in sample bottles. DO and temperature were recorded directly at the site.

The experiment was conducted from October, 2022 to April, 2023 where five different flows were maintained in the reactor for different time periods. The first flow maintained was 10ml/min with 38.8ml/min, 27.6 ml/min, 18.8 ml/min and 14.4ml/min being the consecutive flows.

4. Result and discussion

The results of operating the attached growth and suspended growth reactor are discussed in following sequences; effects of reactor on ammonia nitrogen, nitrate, inorganic carbon and efficiency of NH4–N removal.

4.1. Effect of Reactor on ammonia nitrogen

Figures 4a show concentration of NH_4–N in the effluent of third attached growth reactors with various flow in comparison with the third reactor of suspended growth reactor. Nitrifies (the bacteria responsible for NH_4–N removal) during the operation, varied in all reactors; with lowest concentration of ammonia found to be in flow rate of 10ml/min and 14.4 ml/min. The highest concentration of ammonia was noted to be in the flow 27.6ml/min and 38.8 ml/min. This variation is due to the different hydraulic retention time for different flows. While comparing the ammonia concentration in suspended growth reactor and attached growth reactor there is a notable difference with lower concentration of ammonia found in attached growth process than in suspended growth process for the same raw water concentration. A difference of 20±5 mg/l in concentration of ammonia was found in end reactor of attached growth and suspended growth reactor.

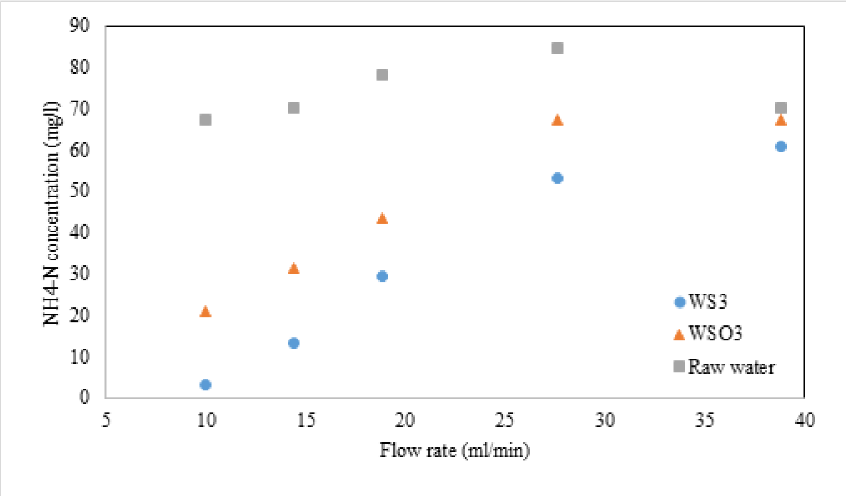

Figure 4a. Concentration of NH4-N in reactor for different flows

4.2. Effect of reactor on nitrate

The NO_3–N was also found to vary in accordance with the ammonia concentration, i.e., highest in third reactor for both attached growth and suspended growth. Similar to ammonia concentration the amount of nitrate nitrogen was highest in flow rates 10 ml/min and 14.4 ml/min, then kept on decreasing with increase in flow rates such that there was little to zero amount of nitrate nitrogen in higher flow rates of 27.6 ml/min and 38.8 ml/min. In comparison amount of nitrite nitrogen was found to be higher in high flow rates. This showed that the ammonia is being converted to nitrite and again to nitrate in reactor but due to insufficient retention time complete nitrification was not possible. Figure 4.b and 4.c shows the concentration of nitrite and nitrate for all the flows. There is a notable difference in concentration of nitrate in the reactors. The attached growth process with over-burnt brick shows higher concentration of nitrate then suspended growth process for same raw water and flow conditions.

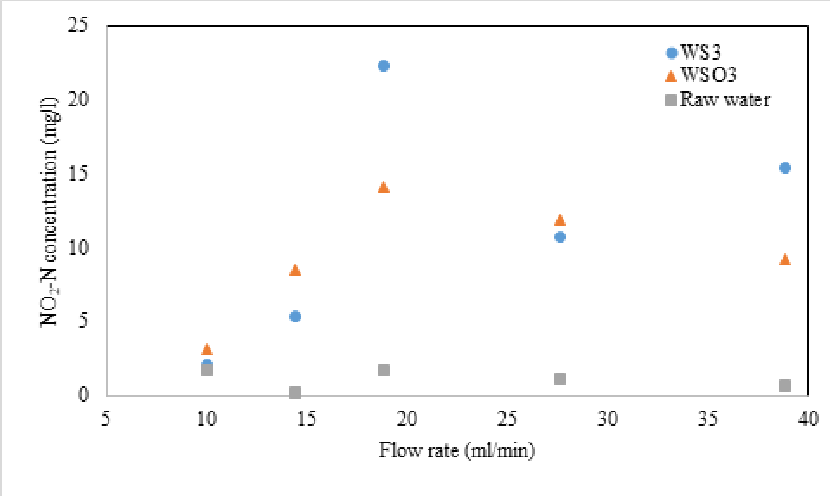

Figure 4b. Concentration of NO_2^- -N in reactor for different flows

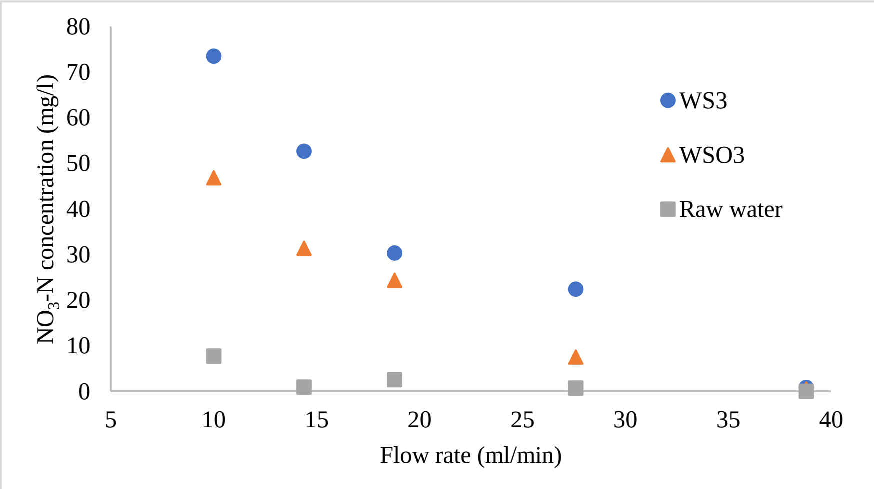

Figure 4c. Concentration of NO_3-N in reactor for different flows

4.3. Removal efficiencies of ammonia nitrogen

From this experiment, it can be concluded that the attached growth reactor operated with over-burnt brick as media and aeration can remove NH_4–N from the water better than suspend growth process with only aeration and no media. Figure 4d shows the removal efficiencies of the reactors of all flows. The NH_4–N removal efficiencies varied in all the reactors; with highest efficiency of 95.02% in reactor with media for flow of 10 ml/min and 81.16% for 14.4ml/min. Comparatively for the same flow of 10ml/min the reactor without any media only has a removal efficiency of 68.29%. There is a marked difference of 26% between the efficiency of two reactor for same flow rate. This difference in efficiency of removal has persisted in all the other four flow rates. From the data in the table 2, we can conclude that the attached grow reactor operated with over-burnt brick can remove NH_4-N from drinking water with better efficiency than suspended growth method where nitrifies are grown without any media.

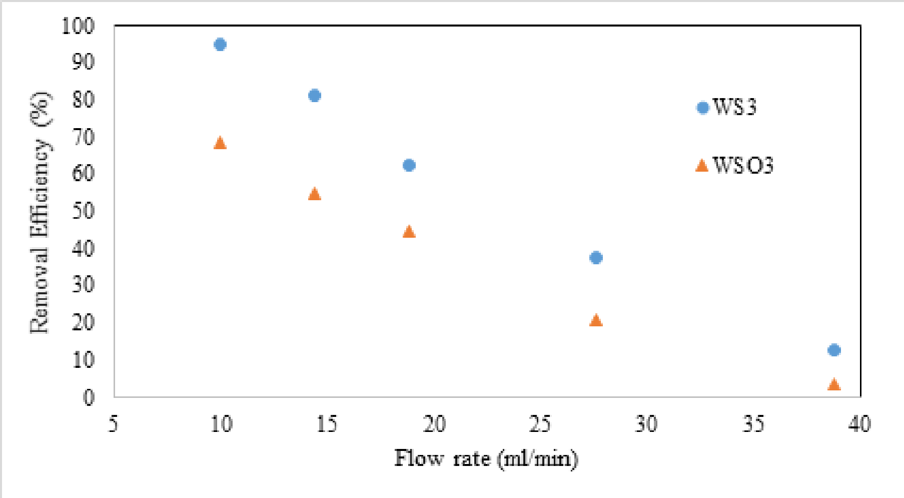

Figure 4d Average removal efficiency of ammonia for five different flows

4.4. Effect of inorganic carbon (IC) contained in groundwater

Nitrifying bacteria are considered as chemo-litho-autotrophy. They use bicarbonate as cellular carbon source. Bacteria consume the bicarbonate during nitrification as a source of inorganic carbon. Hence there is decrease in the concentration of bicarbonate during nitrification process. Since the groundwater contains relatively high IC (480 mg/L), there was no need for addition of bicarbonate externally for nitrification.

Figure 4e shows the variation of bicarbonate in the reactors. The amount of bicarbonate in the raw water was found to be 366 mg/l to 700 mg/l throughout the test period. There is a reduction of bicarbonate in all the reactors. On reactor WS3 an average of 62.94% consumption of bicarbonate was found for flow rate 14.4 ml/l and 78.19% for flow of 10 ml/min. In comparison, consumption in reactor without media was much lesser than that in reactor with media. There is an average 37.02% consumption of bicarbonate in series reactor without media for flow 14.4 ml/min and 45.99% for flow 10 ml/min. The experiment also shows that larger the amount of ammonia removed larger was the amount of bicarbonate consumption. The higher rate of flows like 27.6ml/min and 38.8ml/min show lower percentage of bicarbonate consumption, i.e., 30.82% and 24.15% for attached growth and 20.46% and 20.12% for suspended growth process.

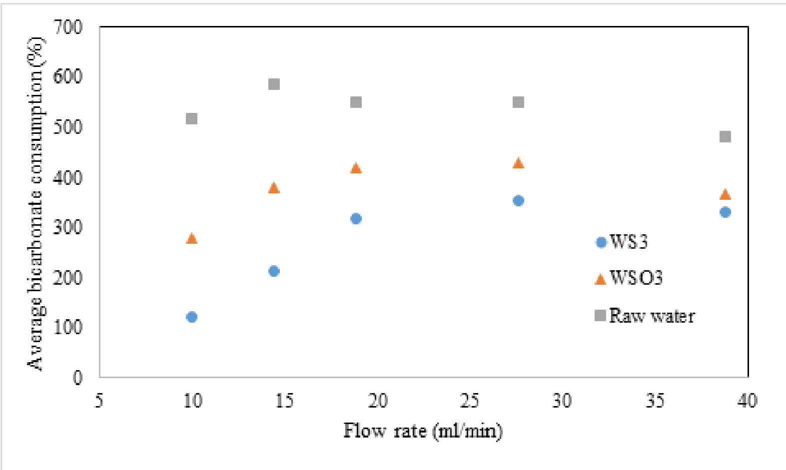

Figure 3e. Average bicarbonate consumption during nitrification for five different flows

4.5. Trend line and general equation

Reactor with media is more efficient in removing ammonia than reactor without media. Hence, a trend line was developed for the reactor with over-burnt brick as media for different flow. The figure 4f gives the change in concentration of ammonia per unit time per 2.011kg of over-burnt brick for different flows. These trend line helps us to develop a general equation for the removal of ammonia for the respective flow rates. These equations are given in table 2.

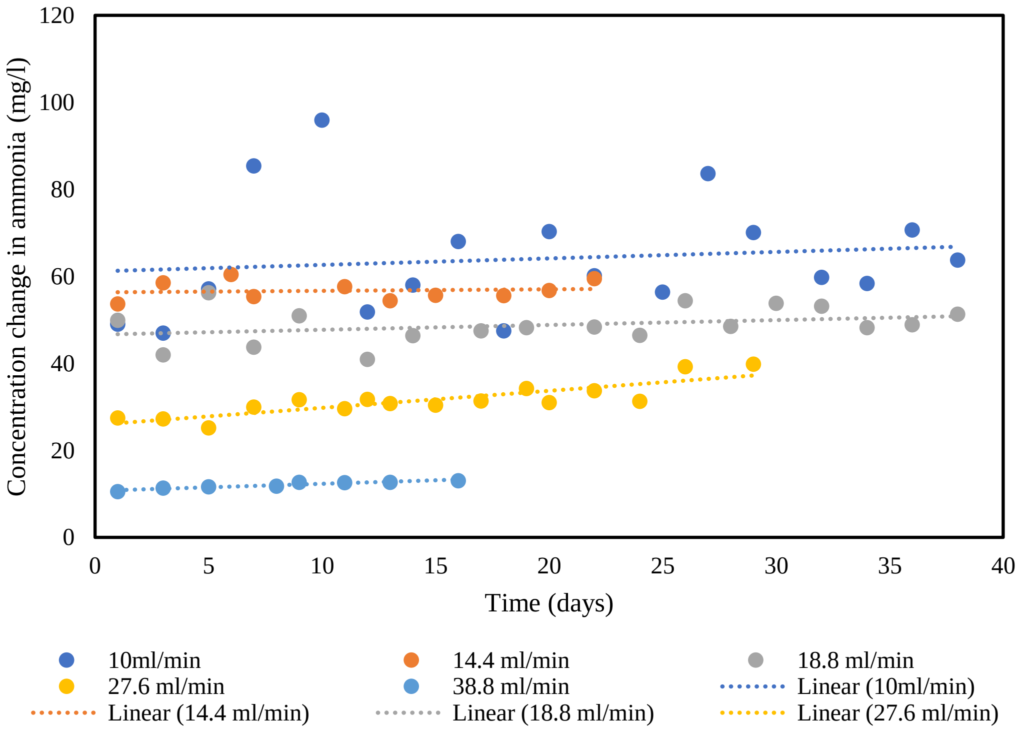

Figure 4f. Trend lines for all five flow for attached growth reactor with over-burnt brick as media

Here the variable x (days) represents the duration of time in which the reactor is operational for the given flow. The variable y gives the change in ammonia concentration in mg/l for x days, when water is flowed through three reactors kept in series with 2.011kg of over-burnt bricks.

Here, ammonia removal rate (nitrification rate) per kg of over-burnt brick for different flows is expressed as follows.

$$\text{Nitrification rate} = \frac{\text{change in concentration of ammonia}}{\text{time} * \text{weight of over} - \text{burnt brick}} \quad \text{(Equation 3)}$$

$$\text{Nitrification rate} = \frac{\text{y}}{\text{x} * 2.011\text{kg of over} - \text{burnt brick}} \quad \text{(Equation 4)}$$

Using these equations, we can find the corresponding rate of ammonia removal for any period of time. Conversely, we can determine the residence time for drinking water to stay in treatment unit for the given rate of nitrification. The results obtained from the pilot-scale reactor using over-burnt brick as media for nitrification provide valuable insights into the efficiency of this media in wastewater treatment. Given the observed nitrification rate and the relationship between the reactor size and media weight, we can estimate the potential performance of this system when applied to larger-scale treatment facilities.

Table 2. Summary of operating conditions for all flow rates

S. N	Flow rate (ml/min)	Days of flow operation	NH_4-N in Raw water (mg/l)	Reactors	HRT (hour) per reactor	NH_4-N (mg/l)	NO_3-N (mg/l)	HCO_3 (%)	Average removal efficiency (%)	Equation
1	10	38 days	63 to 70	WS3	7.295	0 to 18	67 to 102	78.19	95.02	y=0.4087x+86.905
				WOS3	2.21	2 to 38	23 to 74	45.99	68.29	
2	14.4	21 days	68 to 72	WS3	5.06	10 to 18	44 to 58	62.94	81.16	y=0.1802x+47.156
				WOS3	1.534	22 to 41	26 to 38	37.02	55.03	
3	18.8	37 days	78 to 90	WS3	3.88	25 to 36	17 to 38	42.35	62.46	y=0.0654x+58.406
				WOS3	1.175	44 to 45	11 to 37	23.64	44.55	
4	27.6	28 days	68 to 84	WS3	2.64	41 to 64	16 to 31	30.82	33.19	y=0.5958x-24.355
				WOS3	0.8	61 to 74	2 to 15	20.46	18.54	
5	38.8	15 days	70 to 75	WS3	1.88	58 to 64	0.5 to 1.02	24.15	16.52	y=0.2815x-21.272
				WOS3	0.56	65 to 70	0.36 to 0.64	20.12	7.6	

4. Conclusion

Performance of the reactors on the analysis shows that the NH4–N removal efficiency can be enhanced with over-burnt brick as media for attached growth process. The reactors with media have more efficiency than reactors without media. An average efficiency of 56.48% for reactors with media and 37.55% for reactors without media was observed for all the flows. The difference of 18.72± 0.2 was found between reactor with media and reactor without media in both series and single reactor.

The experiment conducted for five different flows show that flow rates of 10 ml/min and 14.4 ml/min give better efficiency for the given size of reactor and mass of over-burnt brick. The reactor with over-burnt media provided removal efficiency of 80 – 100% for flow rates of 10ml/min and 14.4 ml/min. hence HRT of 7.29 hour per reactor can be considered as design parameter for the similar kind of reactor in the future. The high inorganic carbon in raw groundwater had a trend to decrease with increase in the NH4–N removal. Therefore, it was suggested to check amount of bicarbonate present in ammonia removal for better efficiency.

In conclusion, these findings highlight the potential for using over-burnt brick as a nitrifying media in large-scale wastewater treatment systems. By applying the observed nitrification rates and reactor-media size relationships, the results from this pilot study can be used to inform the design and operation of larger treatment plants, ultimately improving efficiency and sustainability in drinking-water management.

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