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To cite this article: A S Faskol and G Racovițeanu 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **664**
012079

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Effect of DO, Alkalinity and pH on Nitrification Using Three Different Sunken Materials Types in Biological Aerated Filter BAFs

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Abstract. The overall aim of this search investigated the effect of DO, alkalinity, and pH on nitrification in biological aerated filter system BAFs. The laboratory experiments by three identical pilot-scales downflow of BAFs using three different sunken materials types, 0.78±0.60 mm activated carbon-based material bed, 0.95±0.58 mm sand-based material bed, and 3.28±2.14 mm ceramic particle-based material bed, as attached growth zone in the treatment of municipal wastewater. As results of the experiments showed that activated carbon-based material bed when the mean concentration of dissolved oxygen was 6.76±2.25 mg/L and the mean alkalinity concentration was 77.25±2.60 mg CaCO₃/L and the mean pH value was 7.21±0.20 the mean nitrification efficiency has reached of 90.11%. In the sand-based material bed when the mean concentration of dissolved oxygen was 7.33±1.82 mg/L and the mean alkalinity concentration was 77.56±2.77 mg CaCO₃/L and the mean pH value was 7.22±0.20 the mean nitrification efficiency has reached of 87.74%. In the ceramic particle-based material bed when the mean concentration of dissolved oxygen was 6.37±1.84 mg/L and the mean alkalinity concentration was 77.31±2.71 mg CaCO₃/L and the mean pH value was 7.22±0.20 the mean nitrification efficiency has reached of 85.17%.

1. Introduction

The first full-size plants of biological aerated filters systems BAFs were constructed in the early 1980s [1, 2, 3]. In 1992, there were approximately 50 plants throughout the world. These plants were mainly located in the United States, Canada, Japan, and several European countries [4]. Where the BAFs is a flexible and effective bioreactor that requires less space than traditional biological methods and can process a range of wastewaters. It can be utilized widely in the tertiary processing stages of wastewater treatment, removing simultaneously BOD, suspended solids SS and T-N to generate water suitable for reuse [5].

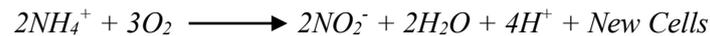
In a BAF system, packing media plays a significant role to meet effluent quality requirements. The granular media employed the composition of the biofilter bed for solid interception and solid-liquid separation, as well as the carrier of biofilm. The characteristics of the filter media have a great impact on the treatment efficiency [6]. Media used in BAFs are usually granular in nature and have traditionally consisted of natural materials such as sand, shale, and expanded clays. More recently synthetic materials have been used such as polystyrene [7]. The production of synthetic material is usually costly though and media may not be significantly more effective than natural materials [8].



1.1. Nitrification principle

Autotrophic nitrifying microorganisms grow relatively slowly and are more sensitive to environmental conditions than heterotrophic microorganisms. As such the amount of degradable organic matter has an impact on the growth of autotrophic nitrifying microorganisms. Nitrification can be written as follows [9].

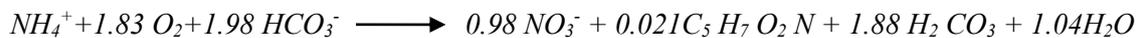
The reaction by *Nitrosomonas*:



The reaction by *Nitrobacter*:



The total reaction with respiration and cell synthesis of nitrifiers can be written as:



As written above, 1g of $\text{NH}_3\text{-N}$ requires 4.33 g of O_2 and 7.14 g of alkalinity with the production of 0.15 g of cells.

Many environmental factors affect the performance of nitrifying bio-films in BAFs. In addition to the hydraulics and nutrient/substrate transport (diffusion) into the bio-film, the reactor configuration and the air-liquid mass transfer have an impact on nitrification. Besides the physical factors, nitrification is affected by the concentrations of dissolved nutrients and substrates (COD , NH_4^+ , NO_2^- , NO_3^- and O_2), alkalinity (HCO_3^-) and pH, the concentration of toxic substances, and the relative diversity of microbial species (heterotrophs, *Nitrosomonas*, *Nitrobacter*), biomass density and bio-film thickness.

2. Materials and Methods

2.1. Operation the pilot-scales downflow of BAFs

Three identical pilot-scales downflow of biological aerated filter system BAFs (Figure 4, and 5), were constructed using PVC pipe. Each pilot-scale reactor was 0.10 m internal diameter, 2.76 m height, and 0.20 m clearance at the head of the reactors to allow the influent recirculation. The total height of each pilot-scale reactor 2.96 m. The height of the materials bed was 1.00 m. The first pilot-scale downflow of BAFs contained 7.855 L of activated carbon-based material bed, the second pilot-scale downflow of BAFs contained 7.855 L of sand-based material bed, and the third pilot-scale downflow of BAFs contained 7.855 L ceramic particle-based material bed, (Table 1) based on a working volume 65.037 L as 21.679 L in each pilot-scale downflow of BAFs. The mean influent flowrates were 0.18 L/min, and the hydraulic retention time HRT was 12-hours. The recirculation of the influent was 100%. While airflow was controlled by a glass VA flow-meter at air : liquid ratio 10 : 1 capacity during normal operation, the pilot-scales downflow of BAFs were backwashed every day for the whole experimental period. The pilot-scales downflow of BAFs operated at ambient air temperature ranged from 8 °C to 29°C with a mean of 17.93 ± 7.27 °C. The pilot-scales downflow of BAFs were operated in the laboratory of the Technical University of Civil Engineering of Bucharest at Colentina. The whole experimental period 33 days including fed of the pilot-scales downflow of BAFs with real raw municipal wastewater and resolved the operating problems.

2.2. Characteristics of the materials-based beds used in the pilot-scales downflow of BAFs

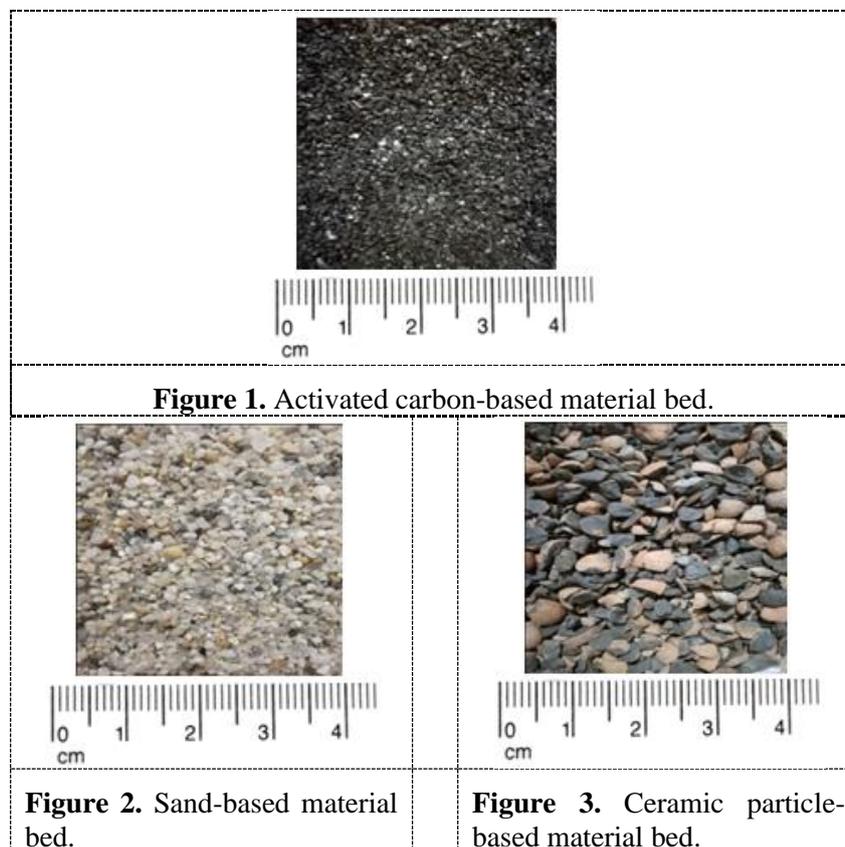
Biomass attachment is an important consideration in biological aerated filter system BAFs. From Table 1. it can be seen that the ceramic particle-based material bed has an intermediate particle size of

3.28±2.14 mm, and fine particle size of 0.78±0.60 mm, 0.95±0.58 mm, respectively for activated carbon-based material bed, and sand-based material bed. As showing in the figure 1,2, and 3.

Table 1. Properties of material-based beds used in the pilot-scales downflow of BAFs.

	Activated carbon-based material bed	Sand-based material bed	Ceramic particle-based material bed
Particle size	0.78±0.60 mm	0.95±0.58 mm	3.28±2.14 mm
Volume bed	7.855 L	7.855 L	7.855 L
Materials bed height	1.00 m	1.00 m	1.00 m

Note: particle size shown are the mean ± standard deviation.

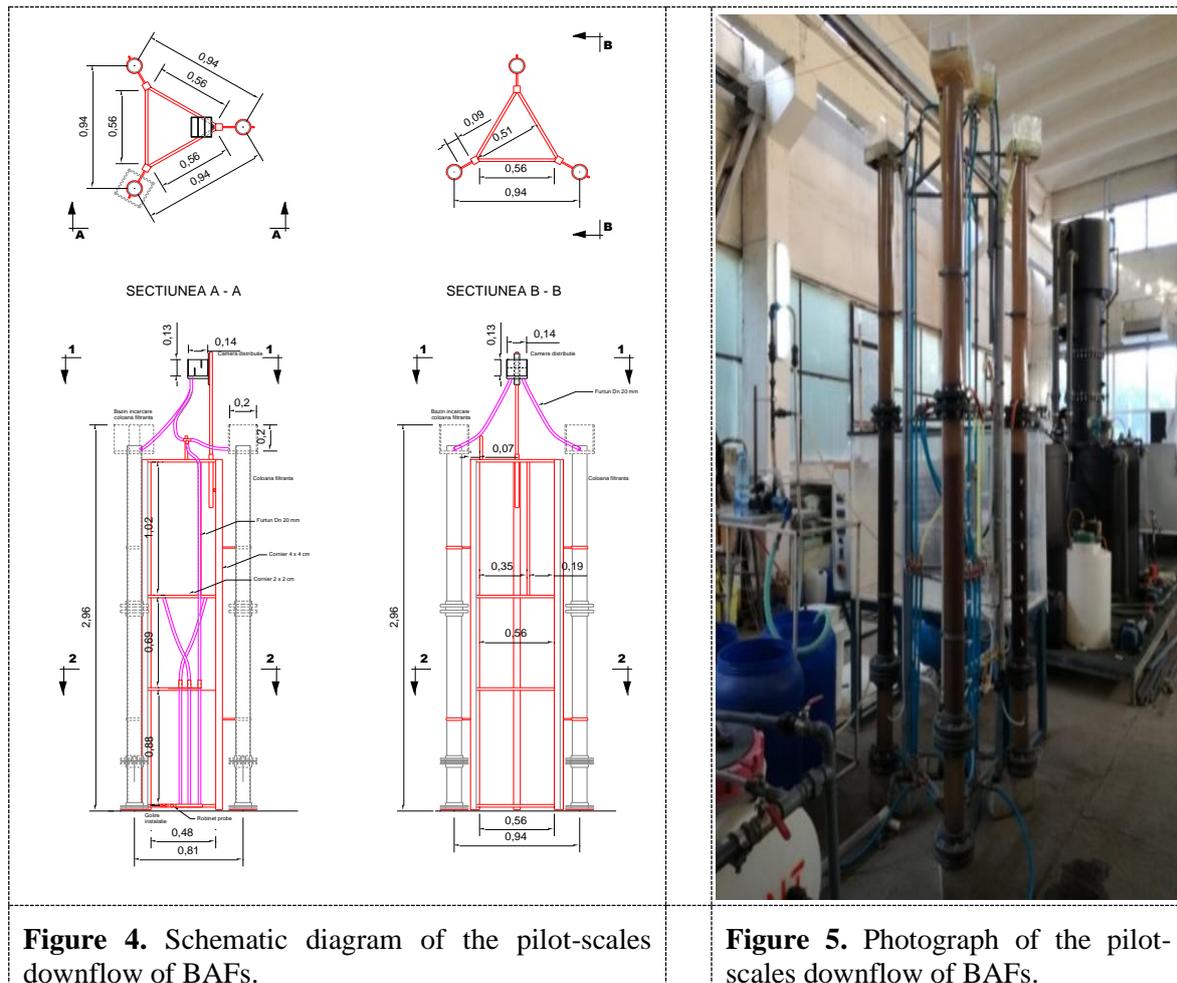


Generally, all three material-based beds (Figures 1, 2, and 3) which used in the pilot-scales downflow of BAFs, are resistant to attrition, chemically inert, had different particle sizes, It can be considered acceptable for use as biomass support as attached growth zone.

2.3. Sampling and laboratory analyses

During the experimental period, composite samples were collected of influent and effluent from the pilot-scales downflow of BAFs for laboratory analysis that took place on a daily basis five times

weekly. Throughout this period the effluent samples were drawn at the end of the pilot-scales downflow of BAFs run (Figure 4, and 5). The influent and effluent samples were evaluated for the following quality indicators: total chemical oxygen demand tCOD, soluble chemical oxygen demand sCOD, suspended solids SS, ammonium-nitrogen $\text{NH}_4^+\text{-N}$, nitrite-nitrogen $\text{NO}_2^-\text{-N}$, nitrate-nitrogen $\text{NO}_3^-\text{-N}$, total Kjeldahl Nitrogen TKN, dissolved oxygen DO, alkalinity as CaCO_3 , potential hydrogen pH, and temperature of the samples °C. Analyses of the samples were conducted according to standard methods APHA, 2017 [10].



3. Results and Discussion

3.1. Characteristics of the municipal wastewater

As a feed organic and ammonium-nitrogen loading rates of the three pilot-scales downflow BAFs was $0.0022 \pm 0.00 \text{ kg NH}_4^+\text{-N/m}^3\text{.d}$, $0.0072 \pm 0.00 \text{ kg TKN/m}^3\text{.d}$, $0.0434 \pm 0.01 \text{ kg tCOD/m}^3\text{.d}$, $0.0285 \pm 0.00 \text{ kg sCOD/m}^3\text{.d}$, and $0.0931 \pm 0.17 \text{ kg SS/m}^3\text{.d}$. The nitrification was first observed on day 24 where the three pilot-scales downflow BAFs have achieved the steady-state conditions, where the number of microorganisms increased, nitrification dominated. The mean characteristics of the influent and the effluent with the efficiency removal showed in Table 2.

Table 2. Characteristics of the influent and the effluent with the efficiency removal during a period of testing conditions.

	Activated carbon-based material bed			Sand-based material bed		Ceramic particle-based material bed	
	Influent mg/L	Effluent mg/L	Removal %	Effluent mg/L	Removal %	Effluent mg/L	Removal %
NH ₄ ⁺ -N	3.16±2.46	0.31±0.37	90.11	0.38±0.44	87.74	0.46±0.46	85.17
NO ₂ ⁻ -N	2.46±2.07	0.24±0.31	90.10	0.25±0.32	89.84	0.28±0.34	88.32
NO ₃ ⁻ -N	1.99±1.76	0.16±0.24	91.84	0.19±0.27	90.28	0.21±0.29	89.03
TKN	10.46±6.74	1.42±0.95	86.37	1.58±0.97	84.82	1.70±1.00	83.69
tCOD	63.25±28.62	5.12±0.99	91.89	5.31±1.03	91.60	5.56±0.97	90.51
sCOD	41.50±12.86	3.53±0.79	91.47	3.75±0.84	90.96	3.93±0.97	90.51
SS	59.50±48.59	4.00±1.92	94.24	4.62±2.50	93.34	11.62±4.62	83.27
pH	7.22±0.20	7.21±0.20		7.22±0.20		7.22±0.20	
DO	3.45±1.03	6.76±2.25		7.33±1.82		6.37±1.84	
alkalinity CaCO ₃	207.25±8.97	77.25±2.60	62.72	77.56±2.77	62.57	77.31±2.71	62.69
Sample °C temperature	17.65 ±1.02	16.48±1.68		16.70±1.44		17.12±1.37	

Note: *concentration shown are mean ± standard deviation.

*data shown are 33-day running mean.

3.2. Effect dissolved oxygen (DO) on nitrification

DO concentrations have a direct effect on the growth rates of nitrifying bacteria. In the presence of low dissolved oxygen, incomplete nitrification occurred, which led to a build-up of ammonium within the BAFs (due to the insufficient aeration time to convert the ammonia to nitrate). Zhu & Chen [11], reported that it was more important to maintain sufficient DO in the fixed film process than in the suspended growth processes due to the nature of diffusion transport with fixed film. Where the experiments showed that in the pilot-scale downflow of BAFs used 0.78±0.60 mm activated carbon-based material bed when the mean concentration of dissolved oxygen was 6.76±2.25 mg/L the mean nitrification efficiency has reached of 90.11%. In the pilot-scale downflow of BAFs used 0.95±0.58 mm sand-based material bed when the mean concentration of dissolved oxygen was 7.33±1.82 mg/L the mean nitrification efficiency has reached of 87.74 %. In the pilot-scale downflow of BAFs used 3.28±2.14 mm ceramic particle-based material bed when the mean concentration of dissolved oxygen was 6.37±1.84 mg/L the mean nitrification efficiency has reached of 85.17%. Relative to dissolved oxygen to the percentage nitrification was plotted figure 6. The dissolved oxygen half-saturation coefficients of Nitroso-bacteria or Ammonia Oxidizing Bacteria AOB and Nitro-bacteria or Nitrite oxidizer Bacteria NOB are 0.2–0.4 mg/L and 1.2–1.5 mg/L, respectively [12]. Therefore, low DO concentration is more restrictive for the growth of NOB than AOB, which will result in nitrite

accumulation [13]. Although many researchers reported that lower DO might inhibit the growth of NOB and cause AOB accumulation, the critical values of DO recorded in the literatures were different [14,15,16].

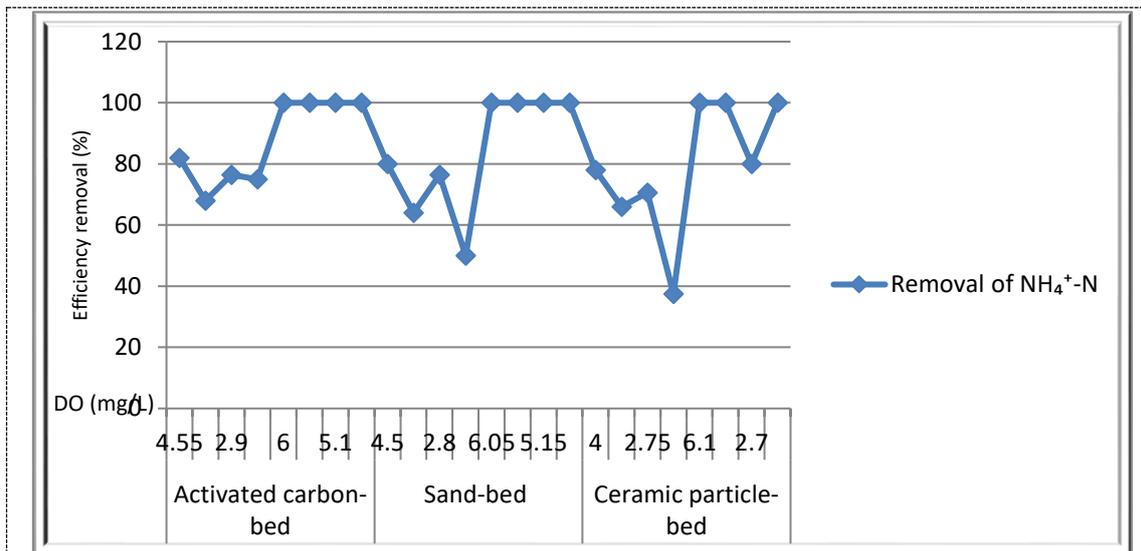


Figure 6. Relationship between DO and NH_4^+ removal efficiency comparison between Activated carbon-bed, Sand-bed, and Ceramic particle-bed.

3.3. Effect of alkalinity and pH on nitrification

Alkalinity is important not only for nitrification but also to indicate system stability. The decrease in pH is caused by the removal of ammonia from the system, and ammonia was also strongly correlated to the alkalinity of the wastewater. The relationship between alkalinity as CaCO_3 and NH_4^+ -N removal efficiency is shown in figure 7. The experiments showed that in the pilot-scale downflow of BAFs used 0.78 ± 0.60 mm activated carbon-based material bed, the mean alkalinity concentration was 77.25 ± 2.60 mg CaCO_3/L when the mean pH value was 7.21 ± 0.20 the mean nitrification efficiency has reached of 90.11%. In the pilot-scale downflow of BAFs used 0.95 ± 0.58 mm sand-based material bed the mean alkalinity concentration was 77.56 ± 2.77 mg CaCO_3/L when the mean pH value was 7.22 ± 0.20 the mean nitrification efficiency has reached of 87.74%. In the pilot-scale downflow of BAFs used 3.28 ± 2.14 mm ceramic particle-based material bed, the mean alkalinity concentration was 77.31 ± 2.71 mg CaCO_3/L when the mean pH value was 7.22 ± 0.20 the mean nitrification efficiency has reached of 85.17% during the entire period of this study. The relationship between pH and NH_4^+ -N removal efficiency is shown in figure 8.

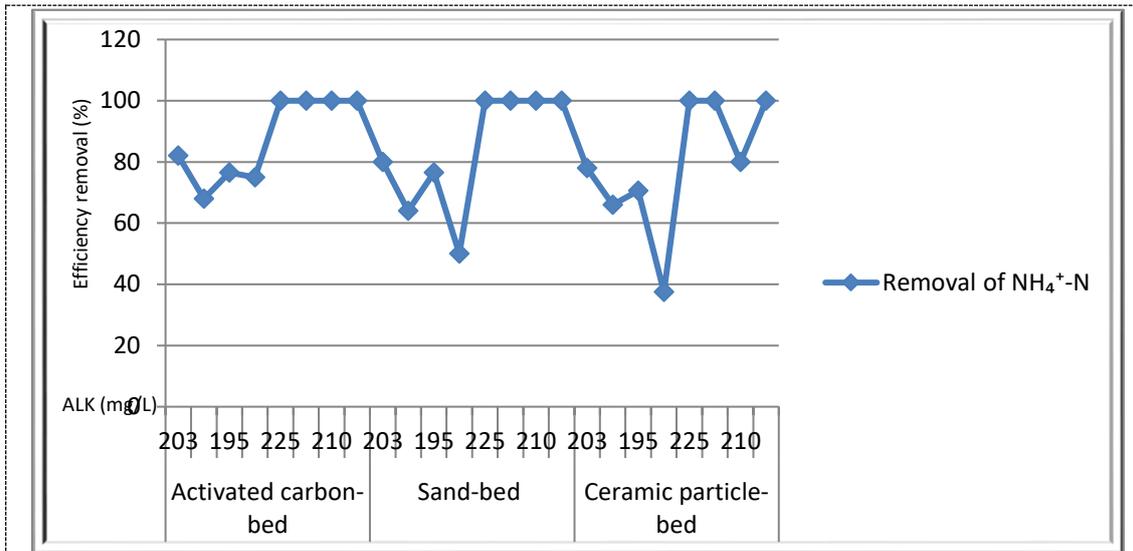


Figure 7. Relationship between alkalinity and NH₄⁺ removal efficiency comparison between Activated carbon-bed, Sand-bed, and Ceramic particle-bed.

As direct evidence of nitrification, more than 60 % of the influent alkalinity as CaCO₃ was consumed. While the mean effluent of NH₄⁺-N oxidized was 0.31±0.37 mg NH₄⁺-N/L, 0.38±0.44 mg NH₄⁺-N/L, and 0.46±0.46 mg NH₄⁺-N/L, respectively for the activated carbon-based material bed, sand-based material bed, and ceramic particle-based material bed. The NH₄⁺ was removed along with the COD consumption when the traditional nitrification [17]. The pH value decreases during the aeration period due to alkalinity consumption by nitrification. Theoretically, pH value in the course of converting nitrite to nitrate should not vary because there is no hydrogen ion produced, which is contrary to the process of ammonia conversion to nitrite. But when both nitritation and nitrification are completed, pH will increase because of O₂ stripping. So there would be an inflexion of pH value in the liquid phase at the end of nitrification [18].

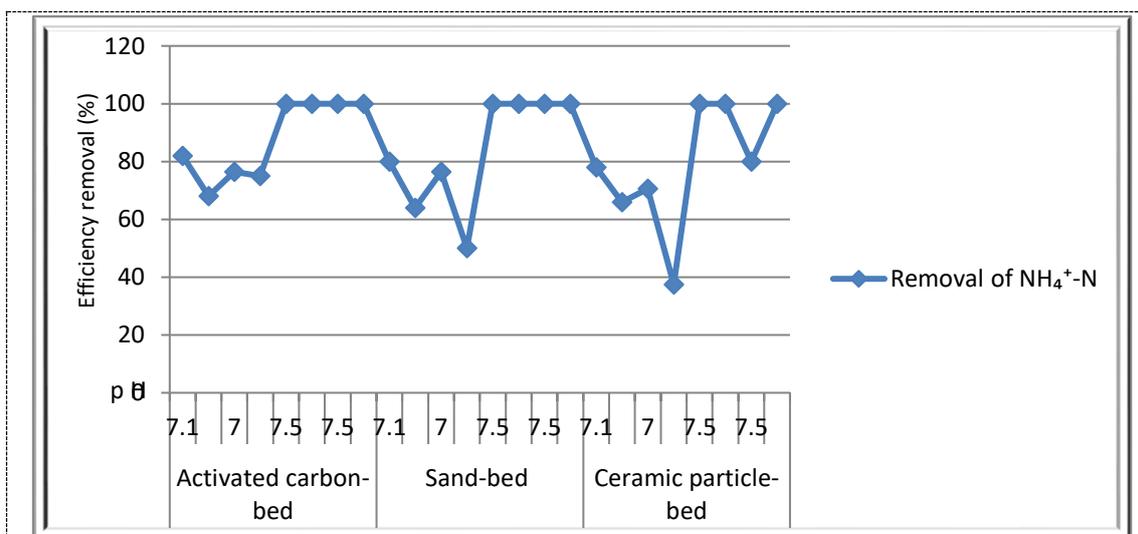


Figure 8. Relationship between pH and NH₄⁺ removal efficiency comparison between Activated carbon-bed, Sand-bed, and Ceramic particle-bed.

4. Conclusion

Thus, in conclusion, that all the three different sunken materials types, 0.78 ± 0.60 mm activated carbon-based material bed, 0.95 ± 0.58 mm sand-based material bed, and 3.28 ± 2.14 mm ceramic particle-based material bed proposed in this research as biomass support as attached growth zones in the treatment of municipal wastewater was extremely well in nitrification process, where the mean nitrification efficiency was between 85.17% to 90.11%. Furthermore, economically should be control of DO concentration within limits. DO concentrations have a direct effect on the growth rates of nitrifying bacteria. In the presence of low dissolved oxygen, incomplete nitrification occurred, which led to a build-up of ammonium within the BAFs. In addition, Alkalinity is important not only for nitrification but also to indicate system stability. The decrease in pH is caused by the removal of ammonia from the system, and ammonia was also strongly correlated to the alkalinity of the wastewater.

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