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Combined COD and Ammonium-Nitrogen Elimination – a Comparison between Different Filtration Media on BAFs

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Abstract
The overall aim of this research was to investigate combined COD and ammonium-nitrogen elimination – a comparison between different filtration media in biological aerated filter system BAFs. These experiments used three identical pilot scales downflow of BAF, the first one containing 0.78±0.60 mm activated carbon bed, the second one containing 0.95±0.58 mm sand bed, and the third one containing 3.28±2.14 mm ceramic particle bed, as attached growth zone. As results of the experiments showed that with recirculation of the influent 100%, at HRT 12-hours, the activated carbon-based filtration media bed, were able to effectively nitrify 90.11% of the ammonium-nitrogen NH_4^+ *as well as reduce/remove tCOD of 91.89%, and sCOD of 91.47%. The sand-based filtration media bed, were able to effectively nitrify 87.74% of the ammonium-nitrogen* NH_4^+ *as well as reduce/remove tCOD of 91.60%, and sCOD of 90.96%. The ceramic particle bed, were able to effectively nitrify 85.17% of the ammonium-nitrogen* NH_4^+ *as well as reduce/remove tCOD of 90.51%, and sCOD of 90.51%.*
Key Word*: Ammonium elimination; Attached growth zone; Filtration media bed; Reduce/remove of carbonaceous.*

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I. Introduction

Over the last four decades, different designs have been developed to improve the biological aerated filter BAF treatment efficiency as well as downflow[1] or upflow position and use of different filtration media type[2,3,4]. The BAF method is a 3-stepentombed attached growth zone: Solid-step is the media that support biofilm bed, the Liquid-step is the influent settled wastewater, and Gas-step is the air provided to the system[5]. Down-flow systems with counter-current air/water flow could have the benefit of allowing the supplied air to remain in contact with final effluent for a time period. This is especially critical when the elimination of carbonaceous matter and ammonia is required in a single reactor. The nitrifying microorganisms in this mechanism occupy the lower filter's region collect oxygen-rich air and hence, do not experience oxygen deficiency[6]. Where can be written the equations of ammonium-nitrogen NH_4^+ elimination as follows[7].

Nitrosomonas reaction:

$$2NH_4^+ + 3O_2 \longrightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{New Cells}$$

Nitrobacter reaction:

$$2NO_2^- + O_2 \longrightarrow 2\,NO_3^- + \text{New Cells}$$

Total reaction including cell synthesis and respiration of nitrifiers would be expressed as:

$$NH_4^+ + 1.83\,O_2 + 1.98\,HCO_3^- \longrightarrow 0.98\,NO_3^- + 0.021C_5H_7O_2N + 1.88\,H_2CO_3 + 1.04H_2O$$

As shown previously, 1g of ammonia nitrogen needs 7.14g of alkalinity and 4.33g O_2 forming of 0.15 g-cells.

Table no. 1: Summaries the organic carbon and ammonia elimination levels in BAFs under varying conditions from the literature.

Table no 1: Summaries the organic carbon and ammonia elimination levels in BAFs[8]

Configuration	Ammonia loading rate (kg/m^3day)	COD loading rate (kg/m^3 day)	Media type	Media Size(mm)	NH_4^+-N removal (%)	COD removal (%)
down-flow	0.3 - 0.48 (TKN)	3.5 - 4 (BOD)	Clay	3.4 - 4.4	74 - 80	85
down-flow	0.6	3(BOD)	Sand	3 - 6	95	65
down-flow	–	3 - 5(BOD)	Anthracite	–	–	83
up-flow and down-flow	0.36	3.5 - 11.9	Expanded clay	2.7 - 6	68 - 80 (TKN)	69.8-78.8
up-flow and down-flow	0.4 - 1.5	–	Granular Slate	2.5 - 3.5	–	–
down-flow	0.4	2(BOD)	Sand	–	–	–

According to the literature, a variety of filtration media types use an attached growth zone in the BAFs. Nevertheless, several filtration media are manufactured and proprietary. The usage of readily accessible media has been tested but has not been widely used. In this way, this search investigated the combined COD and ammonium-nitrogen elimination – a comparison between 0.78±0.60 mm activated carbon bed, 0.95±0.58 mm sand bed, and 3.28±2.14 mm ceramic particle bed in biological aerated filter system BAFs.

II. Materials and Methods

Description of the Pilot-Scale Reactors of BAFs

Three identical pilot scales (downflow) of BAF (Figure 1), 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 filtration media bed was 1.00 m. The first pilot-scale of BAF contained 7.855 L of activated carbon-based filtration media bed, the second pilot-scale of BAF contained 7.855 L of sand-based filtration media bed, and the third pilot-scale of BAF contained 7.855 L ceramic particle-based filtration media bed, based on a working volume 65.037 L as 21.679 L in each pilot-scale of BAFs. The average 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 of BAF were backwashed every day for the whole experimental period.

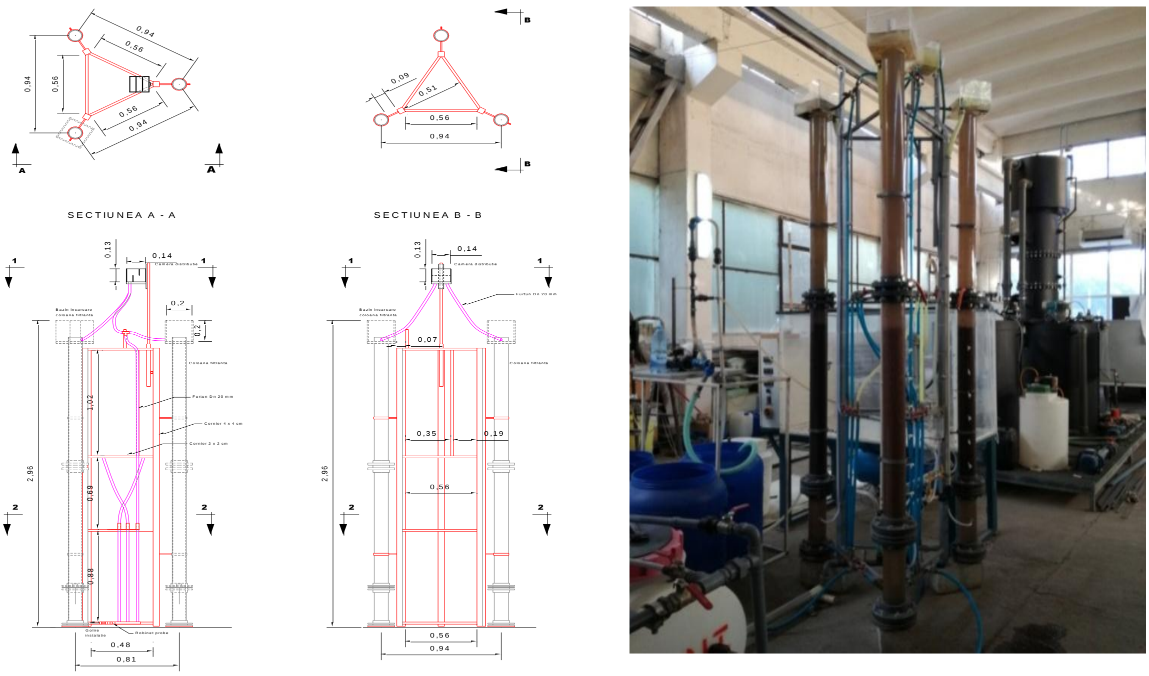


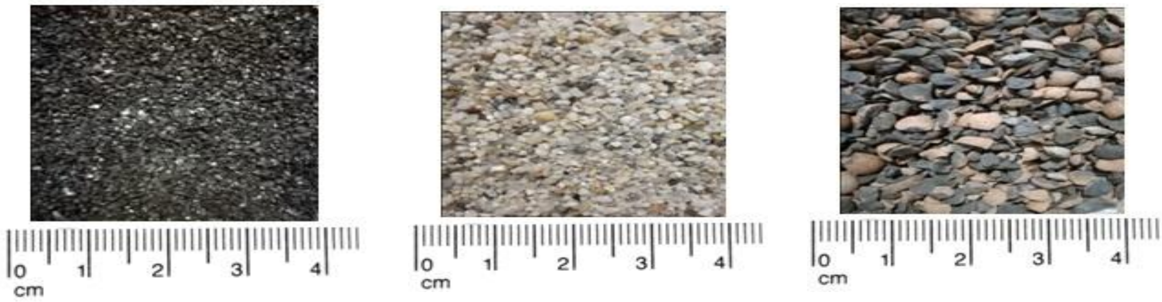
Figure no. 1: Schematic diagram and Photograph of the pilot scales of BAF

Characteristics of the filtration media-based beds

Table no. 2: Shows that the ceramic particle filtration media-based bed has an intermediate particle size of 3.28±2.14 mm. And a fine particle size of 0.78±0.60 mm, 0.95±0.58 mm, respectively for activated carbon filtration media-based bed, sand filtration media-based bed. **As showing in Figure 2.**

Table no. 2: Shows Properties of media-based beds used in the pilot scales of BAF.

Parameter	Activated carbon bed	Sand bed	Ceramic particle 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
Media height	1.00 m	1.00 m	1.00 m



Activated carbon bed Sand bed Ceramic particle bed

Figure no. 2: View of filtration media-based beds used in the pilot scales of BAF.

Start-up of the Experimental Trials

Throughout the duration of the experiments, all the three pilot-scale downflow BAFs were continuously operated fed with raw municipal wastewater containing various pollutants. All the three pilot-scale downflow BAFs were operated at ambient air temperature ranged between 8-29˚C with a average of 17.93±7.27 ˚C. The average influent flowrates were 0.18 L/min, and air: liquid ratio of 10: 1. The hydraulic retention time HRT was 12-hours. The recirculation of the influent was 100% with daily backwashes. As a feed organic and nitrogen loading rates of the three pilot-scales, downflow BAFs was 0.0022±0.00 kg NH_4^+/m^3.d, 0.0072±0.00 kg TKN/m^3.d, 0.0434±0.01kg tCOD/m^3.d, 0.0285±0.00 kg sCOD/m^3.d, and 0.0931±0.17 kg SS/m^3.d.

III. Results and Discussion

Impact of different filtration media on reduce/remove of COD and ammonia-nitrogen

Figure no. 3, 4, and 5: Shows the average influent and effluents concentrations of tCOD, sCOD, and NH_4^+. **Figureno.6:** showed the average removal efficiency of tCOD, sCOD, and NH_4^+ comparison between three pilot-scale downflow BAFs with three different filtration media types.

Performance of the pilot-scale downflow BAFs which used a 0.78±0.60 mm activated carbon-based filtration media bed. Where the influent contains tCOD 63.25±28.62 mg/L, sCOD 41.50±12.86 mg /L, and NH_4^+ was 3.16±2.46 mg/L, with recirculation of the influent 100%, at HRT 12-hours, Where the average final effluent concentration of tCOD was 5.12±0.99 mg/L, sCOD 3.53±0.79 mg/L, and NH_4^+ was 0.31±0.37 mg/L, with reduce/remove of 91.89%, 91.47%, and 90.11%, respectively for tCOD, sCOD, and NH_4^+.

Performance of the pilot-scale downflow BAFs which used a 0.95±0.58 mm sand-based filtration media bed. Where the influent contains tCOD 63.25±28.62 mg/L, sCOD 41.50±12.86 mg /L, and NH_4^+ was 3.16±2.46 mg/L, with recirculation of the influent 100%, at HRT 12-hours, Where the average final effluent concentration of tCOD was 5.31±1.03 mg/L, sCOD 3.75±0.84mg/L, and NH_4^+ was 0.38±0.44 mg/L, with reduce/remove of 91.60%, 90.96%, and 87.74%, respectively for tCOD, sCOD, and NH_4^+.

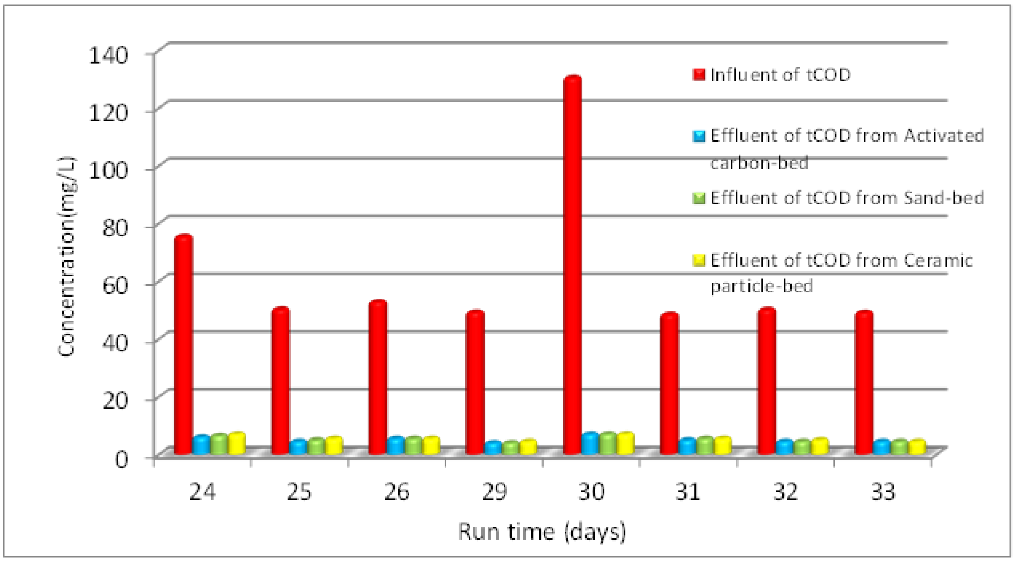


Figure no. 3: The influent and effluent concentration of tCOD comparison.

Performance of the pilot-scale downflow BAFs which used a 3.28±2.14 mm ceramic particle-based filtration media bed. Where the influent contains tCOD 63.25±28.62 mg/L, sCOD 41.50±12.86 mg /L, and NH_4^+ was 3.16±2.46 mg/L, with recirculation of the influent 100%, at HRT 12-hours, Where the average final effluent concentration of tCOD was 5.56±0.97 mg/L, sCOD 3.93±0.97 mg/L, and NH_4^+ was 0.46±0.46 mg/L, with reduce/remove of 90.51%, 90.51%, and 85.17%, respectively for tCOD, sCOD, and NH_4^+.

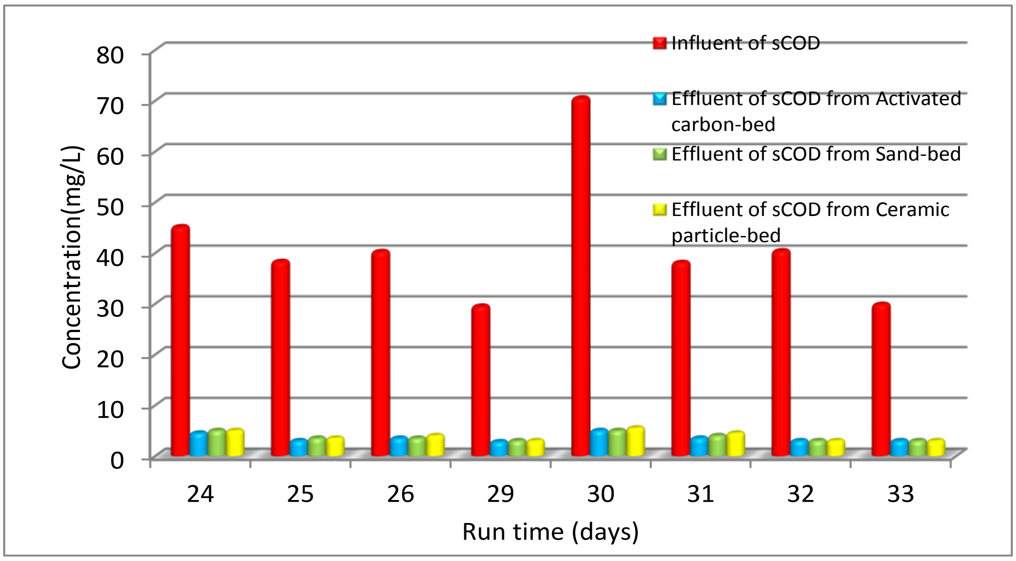


Figure no. 4: The influent and effluent concentration of sCOD comparison.

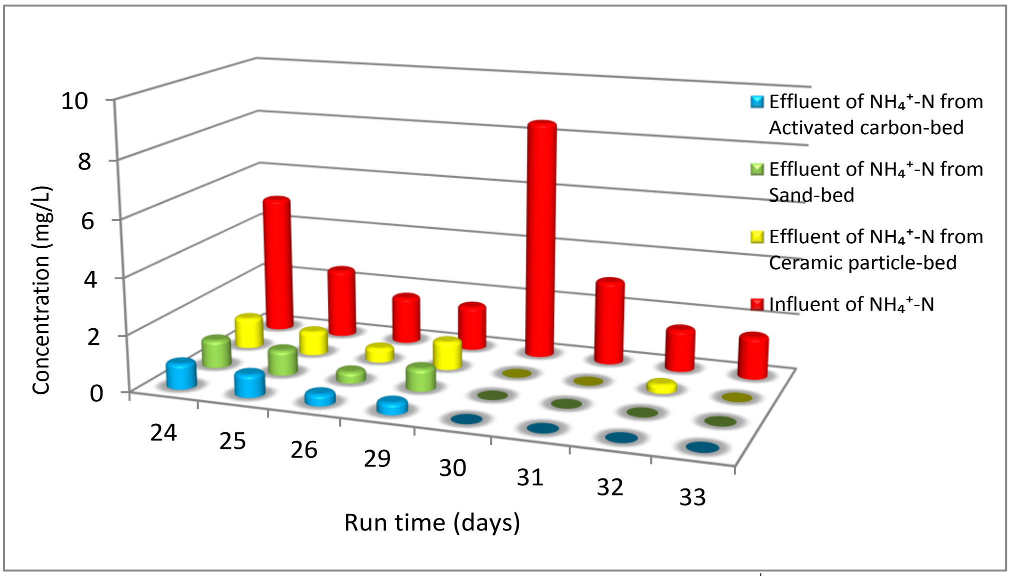


Figure no. 5: The influent and effluent concentration of NH_4^+ comparison.

The experimental results indicate that an activated carbon-based filtration media bed has a better capability for removal of ammonium-nitrogen NH_4^+ than a sand-based filtration media bed and ceramic particle-based filtration media bed in the nitrification process. However, all three media used in the pilot-scale downflow BAFs were able to reach the average final effluent level of NH_4^+ less than 0.47 mg/L. Meanwhile, removal of the COD the experiments showed that all three media-based bed have almost the same removal efficiency of COD there are no major differences, with a average final effluent concentration of tCOD between 5.12±0.99 mg/L to 5.56±0.97 mg/L, and for sCOD between 3.53±0.79 mg/L to 3.93±0.97 mg/L.

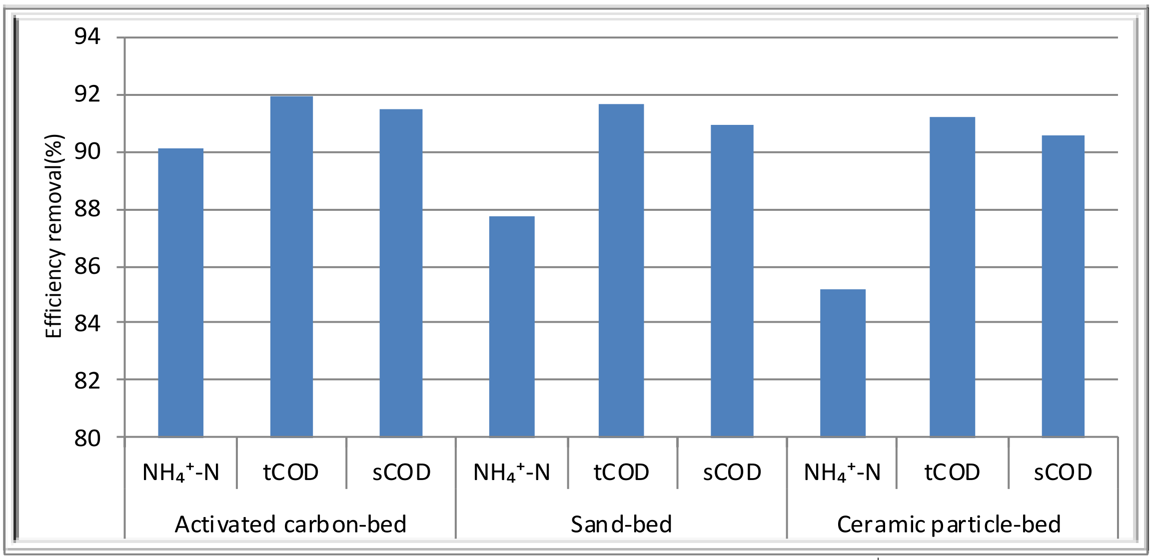


Figure no. 6: The average efficiency removal of tCOD, sCOD, and NH_4^+-N comparison.

According to Gonzalez-Martinez & Wilderer[6], in the downflow of BAFs where carbonaceous matter and ammonia are removed simultaneously, microorganisms living in the filter's low region receive rich-oxygen-air rich and hence would not suffer oxygen inadequacy.[9, 10, 11,] found a modest increase in nitrification efficiency when water velocity was increased through recirculation, which contributed to increased ammonia mass transfer into the biofilms. Another possibility is that the recirculation of the effluent dilutes the influent ammonia and sCOD, causing the lowered level of ammonia that can be converted over a shorter hydraulic holding period[12].

Influence of COD and Ammonium-Nitrogen Loading of the Influent on the Nitrification at Different Filtration Media

For the pilot-scale downflow, BAFs used a 0.78±0.60 mm activated carbon-based filtration media bed. When the average influent the nitrogen and carbonaceous loading rates was 0.0022±0.00 kg NH_4^+/m^3.d, 0.0072±0.00 kg TKN/m^3.d, 0.0434±0.01kg tCOD/m^3.d, 0.0285±0.00 kg sCOD/m^3.d, and 0.0931±0.17 kg SS/m^3.d, with recirculation of the influent 100%, at HRT 12-hours, the activated carbon-based filtration media bed was able to nitrify 0.24±0.21 kg NH_4^+/m^3.d, and 0.78±0.54 kg TKN/m^3.d. As showsin the **Figure no.7**. Meanwhile, was able to achieve a good reduce/remove of the carbonaceous, in terms of tCOD, sCOD, and SS. Where the average mass removal was 5.07±2.42 kg tCOD/m^3.d, 3.31±1.06 kg sCOD/m^3.d, and 5.72±4.08 kg SS/m^3.d. As shows in the **Figure no. 8**.

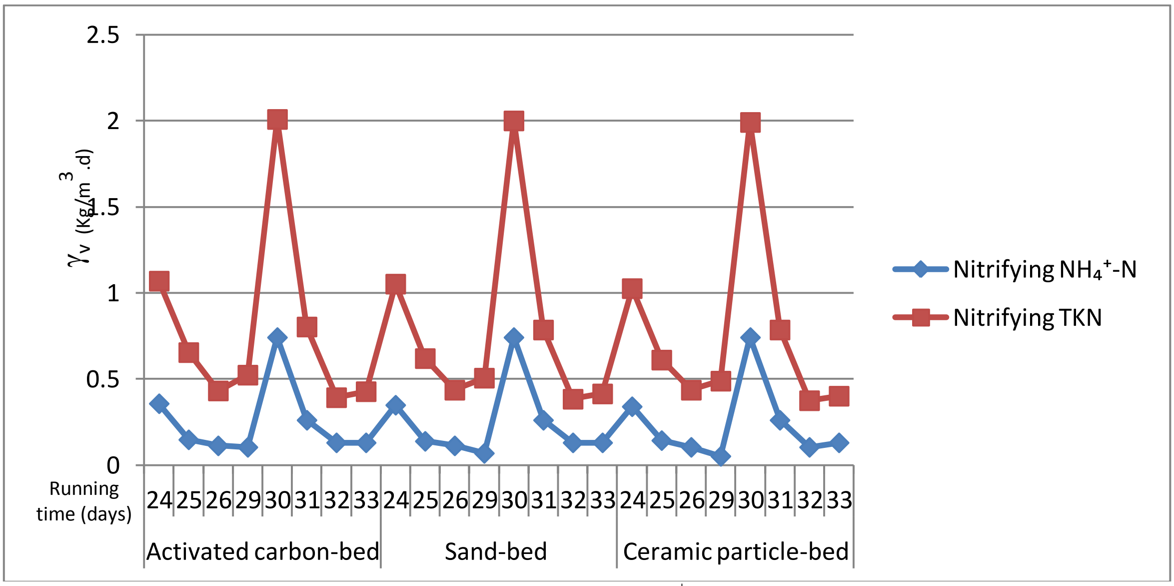


Figure no. 7: Mass removal of NH_4^+ and TKN comparison.

For the pilot-scale downflow BAFs which used a 0.95±0.58 mm sand-based filtration media bed. When the average influent organic and nitrogen loading rates was 0.0022±0.00 kg NH_4^+/m^3.d, 0.0072±0.00 kg TKN/m^3.d, 0.0434±0.01kg tCOD/m^3.d, 0.0285±0.00 kg sCOD/m^3.d, and 0.0931±0.17 kg SS/m^3.d, with recirculation of the influent 100%, at HRT 12-hours, the sand-based filtration media bed was able to nitrify 0.24±0.22 kg NH_4^+/m^3.d, and 0.77±0.54 kg TKN/m^3.d. As shows in the **Figure no. 7.** Meanwhile, was able to achieve a good reduce/remove of the carbonaceous, in terms of tCOD, sCOD, and SS. Where the average mass removal was 5.06±2.42 kg tCOD/m^3.d, 3.28±1.08 kg sCOD/m^3.d, and 5.66±4.03 kg SS/m^3.d. As shows in the **Figure no. 8.**

For the pilot-scale downflow, BAFs used a 3.28±2.14 mm ceramic particle-based filtration media bed. When the average influent organic and nitrogen loading rates was 0.0022±0.00 kg NH_4^+/m^3.d, 0.0072±0.00 kg TKN/m^3.d, 0.0434±0.01kg tCOD/m^3.d, 0.0285±0.00 kg sCOD/m^3.d, and 0.0931±0.17 kg SS/m^3.d, with recirculation of the influent 100%, at HRT 12-hours,the ceramic particle-based filtration media bed was able to nitrify 0.23±0.22 kg NH_4^+/m^3.d, 0.76±0.54 kg TKN/m^3.d. As shows in the **Figure no. 7.** Meanwhile, was able to achieve a good reduce/remove of the carbonaceous, in terms of tCOD, sCOD, and SS. When the average mass removal was 5.03±2.43 kg tCOD/m^3.d, 3.28±1.05 kg sCOD/m^3.d, and 5.05±3.85 kg SS/m^3.d. As shows in the **Figure no. 8.**

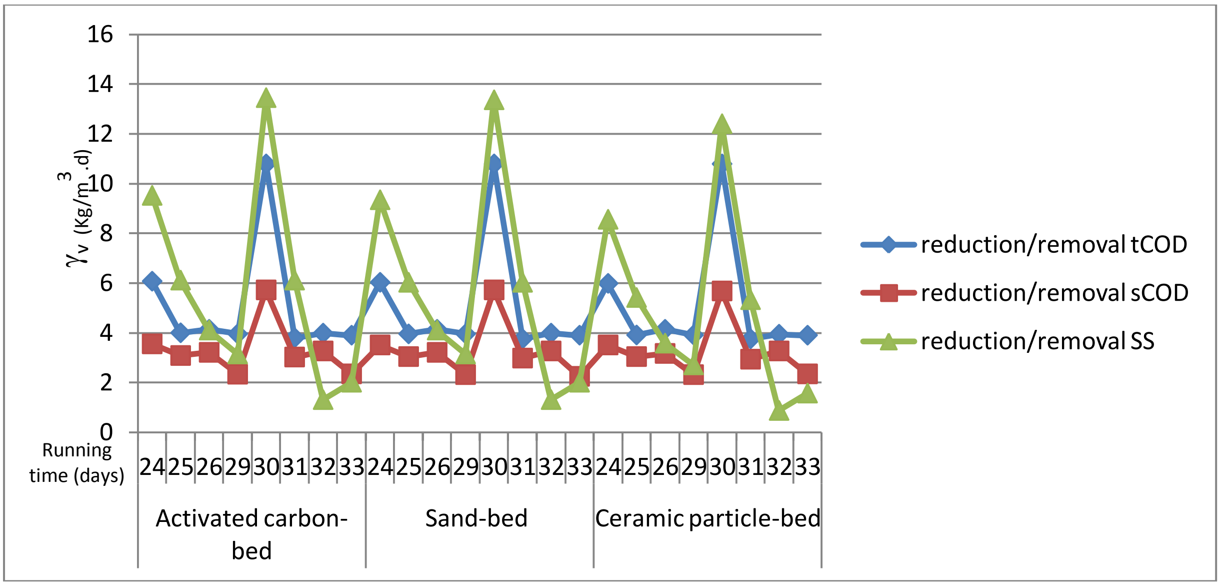


Figure no. 8: Mass removal of tCOD, sCOD and SS comparison.

The results of this study showed that all three filtration media used in the pilot-scale downflow BAFs was able to nitrify between 0.23±0.22 kg NH_4^+/m^3.d to 0.24±0.22 kg NH_4^+/m^3.d, and between 0.76±0.54kg TKN/m^3.d to 0.78±0.54 kg TKN/m^3.d. Ha, Ong, & Surampalli[12], reported that the ammonia mass eliminated for the 3-media were statistically different; for the gravel BAFs, The mass of ammonia extracted increased to about 0.5 kg NH_3/m^3.d. and remained relatively stable as the ammonia loading was increased further. Rogalla & Sibony[13], stated that nitrification rates were about 0.6 kg N/m^3.d. Peladan, Lemmel, & Pujol[9], performed a pilot analysis with the Biofor method for water velocities ranging from 5-20 m h^{-1}. The pilot plant was capable to nitrify 2.7 kg NH_3/m^3.d at 14 °C. According to Rogalla, Lacamp, Bacquet, & Hansen[14], in BAFs with fixed bed and dense media can treat volumetric loads, around 5 - 10 kg COD/m^3.d.

IV. Conclusion

Thus, in conclusion, that all the three-filtration media-based bed which proposed in this research their efficiency of elimination of the COD and NH_4^+Ammonium-Nitrogen was extremely well, with recirculation of the influent 100% at HRT 12-hours. Where all the proposed filtration media-based beds were able to effectively nitrifythe ammonium-nitrogen NH_4^+ more than 90%, with the average final effluent concentration of ammonium-nitrogen NH_4^+-N less than 0.47 mg/L, as well as reduce/remove of the COD more than 90%, with the average final effluent concentration of the COD less than 5.07±2.42 kg tCOD/m^3.d, and 3.31±1.06 kg sCOD/m^3.d.

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