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Effects of filter materials on the removal efficiency of phosphorus and nitrogen from wastewater in an enhanced AO-BAF system

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Abstract

Phosphorus and nitrogen are some of the major nutrients easily found in waste water that pollutes our water bodies. For years, economical and effective ways have been sorted out to reduce the influx of these nutrients into our water bodies. Biological Aerated Filter (BAF) technology has been one of them, but some challenges have been found to affect the removal efficiency of phosphorus and nitrogen through the use of an ordinary AO BAF system. In that, the effluents from a normal AO BAF system hardly meet the environmental standard of effluents discharging into the local water bodies.

The research objective of this study is to determine the best condition for phosphorus and nitrogen removal in an enhanced AO BAF system and the role of filter materials on the removal efficiency has been investigated to determine, if the effluents meet with the environmental standards. The AO BAF and the sponge iron and manganese sand system filter materials were composed of ceramic, zeolite, sponge iron and manganese sand. The following setting parameters were used: Reflux ratio was set at 100% and 200%, Hydraulic load at 0.5 $m^3 / m^2 \cdot h$., Air/Water ratio at 10:1. The removal efficiency of phosphorus and nitrogen on various settlings and filter materials were compared. And it was shown that sponge iron mixed with manganese sand showed high removal efficiency for phosphorus, which fulfilled the environmental standard for phosphorus effluents discharging into local water bodies.

Keywords: Biological aeration filter (BAF); manganese sand; phosphorus and nitrogen removal; sponge iron.

1. Introduction

Rapid growth of population, modern agriculture, development of new industries and domestic wastes are responsible for discharge of waste water (Thilagavathi *et al*., 2015**)**. Waste water with harmful presences of organic and inorganic wastes can have adverse effect on our health. Waste water contamination comes in diverse forms such as; pathogens, organic compounds, nutrients, heavy metals, synthetic chemicals and lots more. All these affect the water quality and cause problems, not just to the agricultural sector, but can have (bio-) cumulative, persistent and synergistic characteristics affecting ecosystem's health and function, food production and public health.

Biological aerated filters system (BAFs) have been know as a fixed-film system on which the biofilm support media are stationary during normal operations, The primary purpose of BAF technology were to simultaneously accomplish the biological oxidation of organic and physical filtration of suspended solids, (Peladan *et al*., 1996; Westerman *et al*., 2000). It is also known as a powerful system to treat a stream having variations of PH and high organic content (Montgomery, 1990). BAF, as well as the other fixed-film processes, is advantageous in comparison to the activated sludge systems due to the higher volumetric loads, increase process stability, and compactness of the reactors caused by higher biomass concentration and higher specific removal rate (Kallabo, 1997), Furthermore, removal of organic materials and nitrification can be carried out in a single unit (Polano *et al*., 2000).

In achieving desirable results in a BAF system, the selection of packing media plays an important role in maintaining a high amount of active biomass and a variety of microbial populations (Chang *et al*., 2009). Natural materials involved such as sand, shale, and expanded clays have been frequently applied (Moore *et al*., 1999; He *et al*., 2007). In addition, synthetic materials have also been used (e.g. polystyrene, polyethylene). However, these materials are costly and synthetic materials may not be significantly more effective than natural materials (Kent *et al*., 1996).

In this work, AO BAF system and AO BAF with sponge iron and manganese sand system were used for remediating the sewage water with the objective of solving the deficiencies of an ordinary AO BAF system in terms of removing phosphorus from waste water to meet the environmentally acceptable standard.

2. Materials and methods

2.1 Experimental set-up

The schematic diagram of the enhanced AO BAF system consisting of AO BAF system/ sponge iron and manganese sand system is shown in Figure 1, The AO BAF system is composed of the anaerobic and aerobic column (AC), which was designed with a total height of 3 m and 2 m respectively, with a column diameter of 8 cm each. The sponge iron and manganese sand system is composed of the sponge Iron and manganese sand column (SMC), with a total height of 1 m and a diameter of 8 cm. The anaerobic column is divided into two units; upper and lowers unit. The upper unit mainly serves for filtering suspended solids coming from the influent tank, and the filter packing materials stands at 0.75 m in height inside the column, while the lower unit is mainly for denitrification purposes and the filter packing materials stands at a total height of 1 m inside the column. The influent and effluent tank has a total height of 0.83 m and diameter of 56 cm respectively.

The aerobic filter column serves mainly for the removal of organic chemicals, nitrification and partial absorption reaction of phosphorus, and the filter packing materials stands at a total height of 0.70 m in the column. The pool of microorganism was received from Qilihe district sewage plant. It was pumped into the anaerobic and aerobic column for a total period of 7 days, and the microorganisms were cultured and left to grow for one month before the start of the experiment.

The treated effluents were periodically used for backwashing of both columns to remove the suspended solids, to allow the proper flow of the waste water through the filter materials and subsequently the biomass. The backwash was carried out once every 48 hours. During backwashing, the air flow rate was raised to allow an increase in the column's liquid volume, which enables the outflow of suspended solids from the column through backwash outflow chamber. Air flow into the aerobic column was achieved by a compartment at the end of the column as shown in Figure 1.

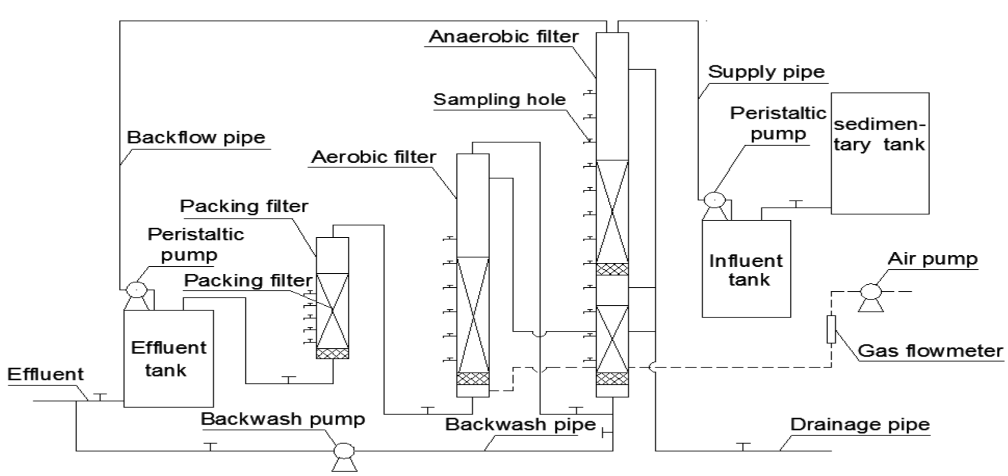

Fig. 1. The schematic diagram of the enhanced AO BAF system

2.2. Packing materials

The packing materials were made of locally available ceramic with size ranging from 5 - 12 mm, zeolite filter materials with size ranging from 3 - 5 mm and pebbles. The pebbles were laid up to 15 cm in height in all columns, while the manganese sand softens the sponge iron to increase its efficiency. The sponge iron has a density of 2.49 g/cm^3. Table 1 shows the BAF & sponge iron column (SIC) filter parameters.

2.3. Test materials

① Sponge Iron: gray and black, porous sponge-like solid. Chemical composition: Total iron content of 96% to 97%, metallic iron content ≥90%, CaO, Mn, Cr, Ni, C, and other impurities were 0.013%, 0.281%, 0.010%, 0.036%, 3% to 4% , P content ≤0.030%, density and bulk density was 2.49 g/cm^3 and 1.76 g/cm^3.

② Zeolite: red-brown, aluminosilicate mineral, adsorption, ion exchange and catalytic properties. Chemical composition: SiO_2, Al_2O_3, FeO, CaO, MgO, K_2O, Na_2O and TiO_2 contents were 68.52%, 11.59%, 1.04%, 3.27%, 1.13%, 1.69%, 0.66%, 0.1% respectively.

Table. 1. BAF & Sponge iron column filter parameters

Project	Filter materials Name	Filter materials diameter (mm)	Packing materials height (m)	Filter height In column (m)	Column total height (m)
1. Anaerobic filter column (Upper Unit)	Ceramic	8-12	0.1	1	2
2. Anaerobic filter column (Lower Unit)	Ceramic	5-8	0.1	0.75	1
3.Aerobic filter Column	Zeolite	3-5	0.1	1.2	2
4. Sponge Iron and manganese sand Column	1. Sponge Iron and	5-8	0.1	0.7	1
	Zeolite	3-5			
	2. Sponge Iron and	5-8			
	Manganese sand	2-4			

2.4. Sewage water characteristics

The sewage water was obtained from the Lanzhou Jiaotong university sewage system by a pump. The sewage is a centralized one that collects the water runoff from residential areas and laboratories inside the university. The waste water was collected into the secondary tank, before it was discharges by a pump into the influent tank. From there, it was pumped into the anaerobic column with a peristaltic pump. The sewage water testing showed presence of organic and inorganic nutrients and suspended solids, as a result of the diversity of the waste water from the campus. The tested influent total phosphorus concentration had a range of 3.58 to 4.94 mg/L, while total nitrogen concentration had a range of 53.87 to 62.11 mg/L.

3. Results and discussion

The experimental results for phosphorus (P_4O_{10}) and nitrogen (NH_3) removal in an enhanced AO BAF system are presented. The removal efficiencies of phosphorus and nitrogen were examined, putting into consideration the effects of packing filter materials and parameter settings of the experiment. The experiment seeks to find the best removal efficiency across three basic packing materials. All three conditions such as, the effects of ceramic and zeolite packing filter materials, the effects of zeolite mixed with sponge iron and the effects of sponge iron mixed with manganese sand were compared to find the best filter packing materials that best remove nitrogen and phosphorus from waste water.

Total phosphorus and nitrogen standard curves are presented; Total phosphorus standard curve: $y = 134.48x + 0.0978$ ($R^2 = 0.9989$), and Total nitrogen standard curve $y = 94.881x - 0.3205$ ($R^2 = 0.9998$).

3.1. Effects of ceramic and zeolite filter packing materials

In this stage of the experiment, only the AO BAF system was used without the installation of the sponge iron and manganese sand system. The anaerobic column upper and lower unit had ceramic as its filter packing materials. The parameters at this stage were set at; air-water ratio (A / W) = 10: 1, hydraulic load q = 0.5 m^3 / m^2 • h, and a reflux ratio of 200%. The system process with the newly adjusted operational conditions was left to stabilize for a period of one week, before testing the water samples. The experiments were carried out three (3) times, once every 48 hours to achieve reproducibility of results. Backwash of the system was done after the conclusion of the experiments. After testing, it was shown that the removal efficiency of phosphorus was 37% and nitrogen was 45% respectively. Figure 2 and Figure 3 show the removal efficiency of total phosphorus and nitrogen respectively.

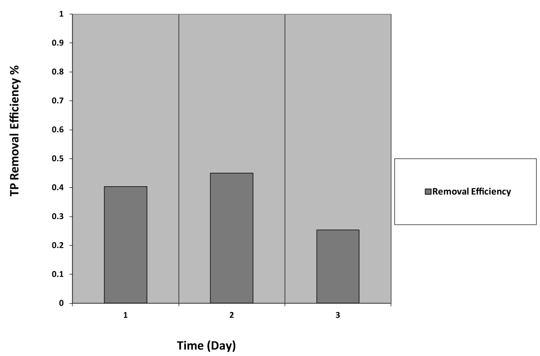

Fig. 2. Removal efficiency of TP concentration

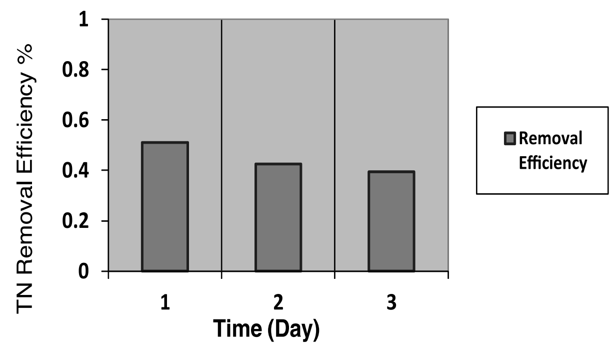

Fig. 3. Removal efficiency of total nitrogen absorbency

The packing materials in this phase had the ceramic filter materials in the anaerobic column with zeolite materials in the aerobic column. The water testing was conducted once every 48 hours. Just before backwashing, water sample was collected in order to achieve proper reliable results. It can be seen from Figure 2 that the removal rate of phosphorus at this phase was at 37%, which is not up to the government allowed discharge effluent. A gradual decrease in the removal rate of total nitrogen from day one to three was observed. Nevertheless, total nitrogen had an average removal efficiency of 45% at this stage. Figure 4 shows a graph of dissolved oxygen at a reflux ratio 200%.

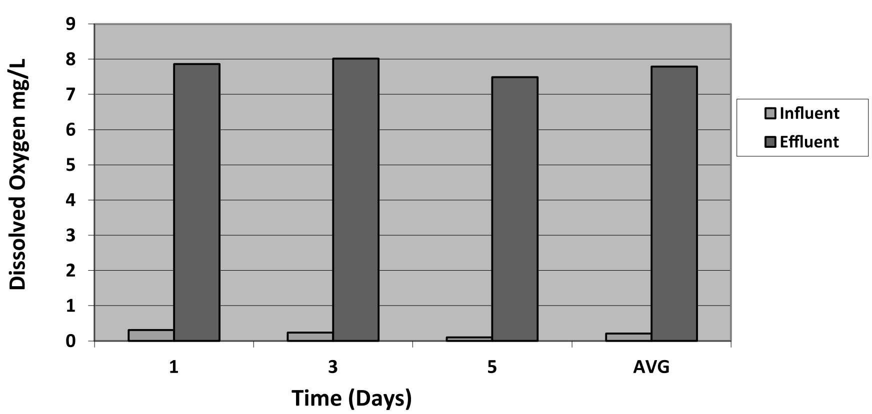

Fig. 4. Dissolved oxygen at 200% reflux ratio

3.2. Effects of Zeolite mixed with sponge iron filter packing materials

This stage features the addition of the sponge iron and manganese sand system to the AO BAF system, Zeolite was mixed with sponge iron packing materials at a ratio of 1:3. The already mixed packing materials were placed in the sponge iron and manganese sand column. The anaerobic and aerobic filter column had the same materials as present in experiment I.

The operational settings parameters of this experiment was as follows: The reflux ratio was set at 200%, Air water ratio at 10:1, hydraulic load q = 0.5 m3 / m^2 • h, Figure 5, the experiments were conducted three (3) times at an interval of 48 hours, Figure 6 shows the removal efficiency of total phosphorus and nitrogen respectively in this stage.

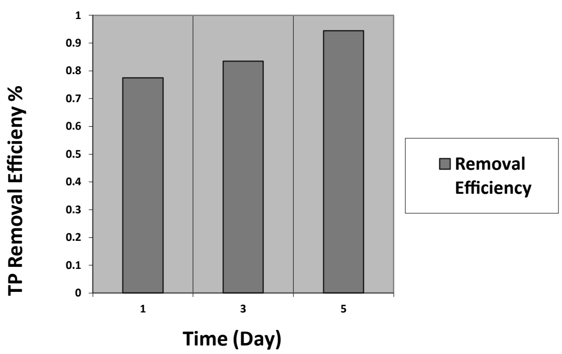

Fig. 5. Removal efficiency of TP Conc. with reflux ratio 200%

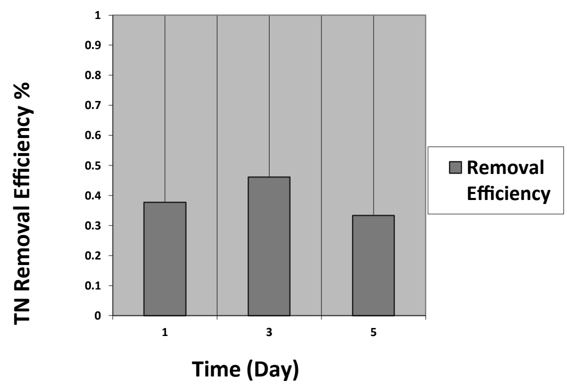

Fig. 6. Removal efficiency of TN with reflux ratio 200%

After the installation of the sponge iron and manganese sand system at the end of the AO BAF system, there was an increase in the total phosphorus removal rate. The average total phosphorus and nitrogen removal efficiency in this stage was 85% and 38.93% respectively, which is a 48% percentage increase from the removal efficiency in experiment I (effects of ceramic and zeolite filter packing materials stage) for total phosphorus, unlike total nitrogen, which shows a 6.07% decrease in removal efficiency. The concentration of the total iron was at 0.13 mg/L and 0.53 mg/L in influent and effluent respectively. This supports the performance of the sponge iron in removing phosphorus in the system. Figure 7 shows dissolved oxygen in zeolite mixed with sponge iron stage.

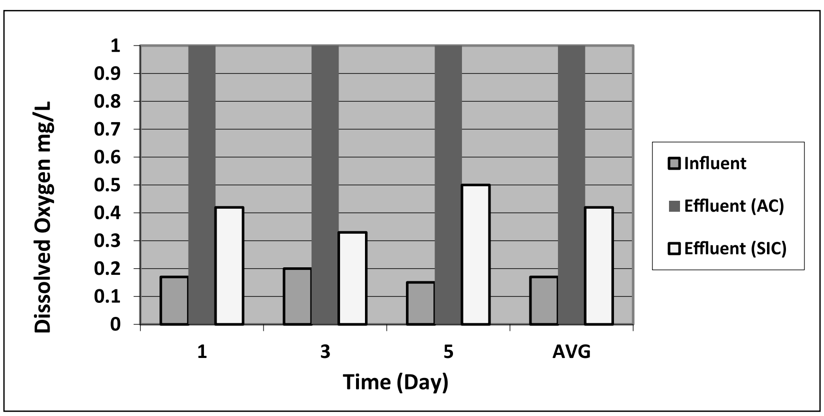

Fig.7. Dissolved oxygen (zeolite mixed with sponge iron stage)

3.3. Effects of sponge iron mixed with manganese sand filter packing materials

This experiment features the addition of the sponge iron and manganese sand system to the AO BAF system, The following experiments were repeated three (3) times at an interval of 48 hours to achieve reliability and reproducibility of results. The time in the graphs shows the different time the experiments were conducted, its concentration and removal efficiency of each experiment. After observing the removal effect of the introduction of sponge iron mixed with zeolite, further experiment was carried out mixing sponge iron with manganese sand to observe the removal efficiencies in both total phosphorus and nitrogen. Sponge iron was mixed with manganese sand packing materials at a ratio of 3:1, the mixed packing materials replaced the zeolite and sponge iron mixing in the sponge iron and manganese sand column, the anaerobic and aerobic column filter materials remained the same. The operational parameters were as follows: The reflux ratio was set at 200%, Air water ratio at 10:1, and hydraulic load at $q = 0.5\ m^3 / m^2 \cdot h$. Figure 8 and Figure 9 shows the removal efficiency of total phosphorus and nitrogen at a reflux ratio of 200%, and the addition of sponge iron and manganese sand respectively.

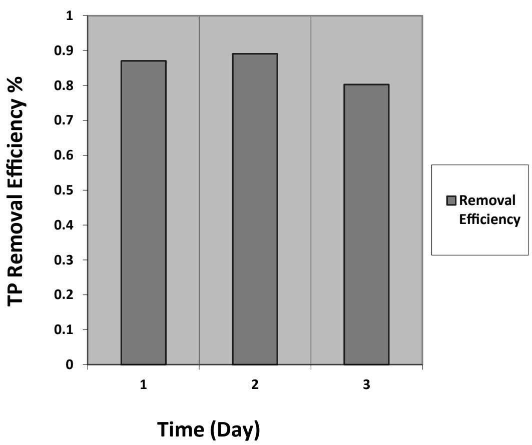

Fig. 8. Removal efficiency of TP Conc. with reflux ratio 200%

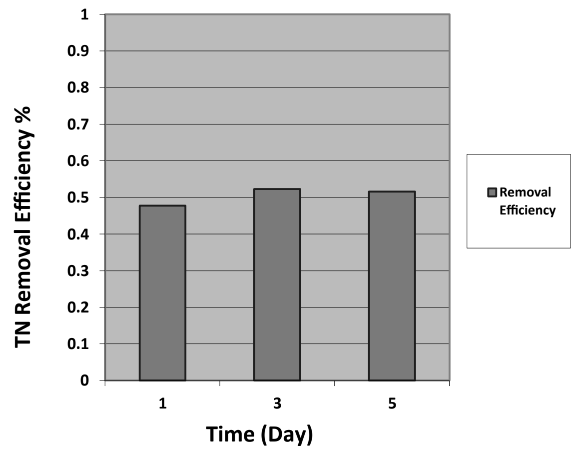

Fig. 9. Removal efficiency of TN with reflux ratio 200%

The sponge iron mixed with manganese packing showed the best results of the experiments with enhanced removal efficiency in both total phosphorus and nitrogen. It was shown to have a phosphorus removal efficiency of 86% and a nitrogen removal efficiency of 50.60%, showing 1 and 11.67% increase in removal efficiency from previous experiment II (effects of zeolite mixed with sponge iron filter packing materials stage) in total phosphorus and nitrogen removal efficiency.

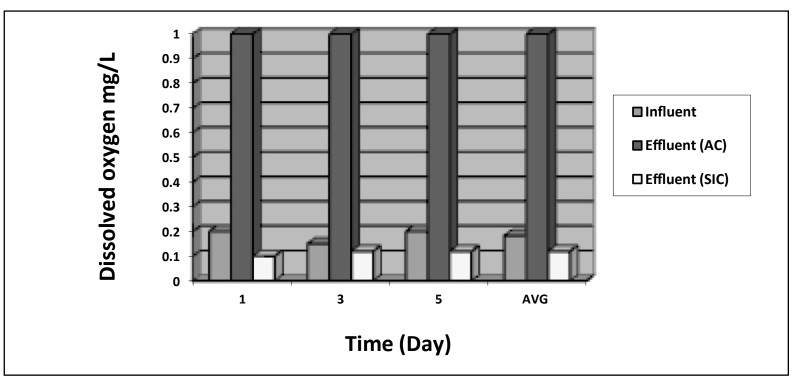

Fig. 10. Dissolved oxygen (sponge iron mixed with manganese sand stage).

The total iron concentration in influent and effluent columns was 0.115 and 0.373 mg/l respectively. The results show a reduction in dissolved oxygen from the effluent of the sponge iron and manganese sand column, which can be seen in Figure 10. It further shows that the influent had little dissolved oxygen, which however increased after the aerobic column. This increase was linked to the supply of oxygen into the aerobic column by an air pump. Upon exit from the sponge iron and manganese sand system, the dissolved oxygen was significantly reduced due to the oxidation reduction reaction of sponge iron in the column.

4. Conclusion

For the sake of reproducibility and reliability of results, the experiments for each of the conditions were carried out three (3) times, once every 48 hours to achieve reliable total average of concentration and removal efficiency of the tested nutrients. Based on the analysis of the results obtained from the investigation of the effects and roles of packing materials on the removal efficiency of total phosphorus and nitrogen, the following conclusion can be drawn;

In the removal of total phosphorus as shown in Figures 2, 5 and 8, there was a removal efficiency of 37, 85 and 86% respectively, which is a 49 % increase from ceramic and zeolite filter packing stage, to sponge iron mixed with manganese sand filter packing stage. The removal efficiency of total nitrogen was 45, 38.93 and 50.60% as shown in Figures 3, 6 and 9, which is a 5.6% increase from ceramic and zeolite filter packing stage, to the sponge iron mixed with manganese sand filter packing stage.

These results prove the addition of sponge iron and manganese sand packing materials to an ordinary AO BAF system helps increase the removal efficiency of total phosphorus and nitrogen, producing effluents that meet the water quality of China's municipal wastewater treatment plant pollutant emission standards GB18918-2002.

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آثار مواد التنقية على كفاءة إزالة الفوسفور والنيتروجين من مياه الصرف الصحي في نظام الفلتر المُهوىَ بيولوجياً AO-BAF والمُعزز

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ملخص

الفوسفور والنيتروجين هما بعض العناصر الغذائية الرئيسية التي نجدها بسهولة في مياه الصرف الصحي التي تلوث مسطحاتنا المائية. لسنوات، تم التعرف على طرق اقتصادية وفعالة للحد من تدفق هذه العناصر الغذائية إلى مسطحاتنا المائية. وكانت تقنية الفلتر المُهوىَ بيولوجياً (BAF) واحدة منها، ولكن كانت هناك بعض التحديات لتؤثر على كفاءة إزالة الفوسفور والنيتروجين من خلال استخدام نظام الفلتر المُهوى بيولوجياً AO BAF العادي. ففي هذا النظام، إن النفايات السائلة من نظام AO BAF العادي لا تكاد تلبي المعايير البيئية للنفايات السائلة التي يتم تصريفها في المسطحات المائية المحلية.

الهدف البحثي لهذه الدراسة هو تحديد أفضل ظروف لإزالة الفسفور والنيتروجين في نظام الفلتر المُهوى بيولوجياً AO BAF المعزز وتم فحص دور مواد التنقية على كفاءة الإزالة، إذا كانت النفايات السائلة تفي بالمعايير البيئية. تكونت مواد تنقية نظام الفلتر المُهوى بيولوجياً AO BAF والحديد الاسفنجي ورمل المنغنيز من السيراميك، الزيوليت، الحديد الإسفنج ورمل المنغنيز. تم استخدام معلمات الإعداد التالية: تم تعيين نسبة الارتداد عند 100% و 200%، والحمل الهيدروليكي عند 0.5 م^3/ م^{2}h، نسبة الهواء / الماء عند 10: 1. تمت مقارنة كفاءة إزالة الفوسفور والنيتروجين على رواسب مختلفة ومواد التنقية. وقد تبين أن الحديد الاسفنجى المخلوط برمال المنغنيز أظهر كفاءة عالية في إزالة الفسفور، وهو ما استوفى المعيار البيئى لتدفقات الفوسفور السائلة التى تصب فى المسطحات المائية المحلية.