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5 authors, including:

Mohammad Malakootian
Kerman University of Medical Sciences

Mohammad Ahmadian
Bam University of Medical Sciences

STUDYING THE EFFICIENCY OF A BIOLOGICAL AERATED FILTER (BAF) WITH OYSTER MEDIA ON IMPROVING THE QUALITY OF EFFLUENT PRODUCED BY TREATMENT PLANTS

Seyed Mohsen Azimi[1], Mohammad Malakootian[2], Kamyar Yaghmaeian[3], Mohammad Ahmadian[4] and Sajad Rahimi[5,*]

[1] Department of Natural Resources -Environmental Engineering, Islamic Azad University Bandar Abbas branch, Bandar Abbas, Iran
[2] Environmental Health Engineering Research Center and Department of Environmental Health Engineering, School of Public Health, Kerman University of Medical Sciences, Kerman, Iran
[3] Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[4] School of Public Health, Kermanshah University of Medical Sciences, Kermanshah, Iran
[5] Social Development & Health Promotion Research Center, Kermanshah University of Medical Sciences, Kermanshah, Iran

ABSTRACT

A biological aerated filter (BAF) is an economical, flexible and effective bioreactor for effluent treatment that needs less area than the conventional biological processes. Media materials choice is an essential parameter in the design and operation of a BAF to get the limit determined by environmental standard organization. In this study, oyster shells were used as filter media for the BAF reactor to enhance the quality of the effluent produced by Qom wastewater treatment plant. The BAF reactor was placed at the output of the treatment plant and the effect of hydraulic loading change was investigated. Hydraulic loadings equal to 0.3, 0.6 and 0.9 m^3/m^3.day were discussed. The results of this study revealed that oyster shells as BAF filter media reached $TBOD_5$, TSS, COD, TKN, NH_4-N, TP, TC and FC removal rates of 49.5, 48.2, 52.2, 47.3, 45.4, 45.7, 59.4 and 62%, respectively, at a hydraulic loading equal to 0.3 m^3/m^3.day. In addition, BAF efficiency was decreased for all parameters at a hydraulic loading equal to 0.9 m^3/m^3.day and as the hydraulic loading increased, the filter efficiency decreased consequently. Generally, the efficiency of the filter was higher in ammonia removal with regard to the other parameters. Oyster shells BAF acted as an advanced treatment method for achieving effluent quality requirements.

KEYWORDS: Biological Aerated Filter (BAF), oyster shells media, activated sludge process

1. INTRODUCTION

Uncontrolled population growth, increased demand for water use in various sectors, non-uniform distribution of water resources, and periodic droughts have challenged the provision of clean and healthy water [1]. Thus, making use of purified effluents (at available standard levels) as a reliable source of water has been taken into consideration. The purified effluents can be used for different purposes, such as reuse for agriculture, groundwater recharge, industrial, recreational and aquaculture uses, each of which has a special environmental standard [2, 3]. One of the most conventional methods used for domestic wastewater treatment is activated sludge process. Although this process is a fairly reliable treatment system for domestic wastewater treatment and reduces BOD, COD and nutrients at suitable levels, it usually requires high initial capital costs, trained operators, and large space. Additionally, conventional activated sludge does not have a suitable ability to reduce some of the wastewater parameters including ammonia, fecal coliforms, $TBOD_5$ and TSS [4, 5]. BAF is a new, effective and flexible bioreactor that was developed in Europe during 1980s-1990s, and then spread all over the world. This technology is very similar to the conventional biofilters; however, due to its several advantages, it is preferred over other conventional methods as a novel known method. One of the BAF system advantages is its space-saving layout which requires only one-third of the space required for a conventional activated sludge system. A BAF system also retains biomass concentration at a high level compared to trickling filter, and conventional activated sludge can cause resistance to organic and hydraulic loading shocks. Another advantage of this system is that it does not need secondary treatment, and suspended solids in the wastewater are filtered through submerged media. The basic criterion for designing a BAF system is to select the appropriate media to achieve the required effluent standards. In various studies, different materials, such as natural zeolite, brick-wall, bioceramsite and clinoptilolite are used as the filter media, which have exhibited differences in their efficiency [6-9]. Biplob *et al.* [10] used the BAF system with plastic media for nitrogen removal, and their results indicated a good performance. In another

* Corresponding author

study, the BAF system used with plastic media for the treatment of flushed swine manure was able to remove BOD (88%), COD (75%) and total suspended solids (82%) [11]. He *et al.* [12] have studied BAF systems using natural zeolites as media in domestic wastewater treatment, and a high efficiency was observed in removal of COD and NH_3-N.

The activated sludge process is used to purify Qom wastewater; its effluent is used to irrigate agricultural lands around the plant, especially to irrigate crops, such as barley and wheat. Concerning effluent usage, improving its quality is of great importance. Thus, it is essential to use modern treatment methods, or to use other improvement methods that have lower construction and maintenance costs. In this regard, the present study aims to evaluate the efficiency of biological filters aerated by an oyster shell bed in improving the quality of the effluent produced by Qom treatment plant, which has high levels of ammonia, fecal coliforms, TSS and BOD_5.

2. MATERIALS AND METHODS

2.1 Location

The province of Qom is located in the south of Tehran and Alborz Provinces, north of Isfahan Province, east of Markazi Province, and west of Semnan Province. Its center is Qom city with a population of 1,670,000. Qom wastewater treatment plant has been constructed at a distance of about 12 km from Qom city, and at an altitude of about 890 m. This treatment plant started working in 2009. This descriptive-analytical pilot study was carried out between May 2012 and January 2013 on the effluent produced by Qom sewage treatment.

2.2 Media properties

At first, a pilot filter with an oyster shell medium was made and transferred to the Qom wastewater treatment plant. The medium inside the filter consisted of shells with an average size of 20 mm (Fig. 1) and was prepared from the southern part of the Persian Gulf coast.

FIGURE 1 - Oyster shells used as filter medium.

2.3 BAF experimental set-up

The BAF pilot was made according to the schema presented in Fig. 2. This pilot was installed at the secondary clarifier outlet with a vertical downward flow. Using a pump (Heidolph, model PD 5001, Germany, flow-rate 80 ml/min), the effluent was transferred to a storage tank and then sent to a filter with a defined discharge; samples were taken from the filter inlet and outlet on a daily basis.

2.4 Biofilm development and sampling

The biofilm formation trend and the effects of hydraulic loading (0.3, 0.6 and 0.9 m^3/m^3.day) on purification efficiency and purification rate of BAF were evaluated in this study, which lasted for 6 months. Parameters evaluated in this research include BOD, COD, TSS, TP, NO_3, TC and FC. Sampling was conducted in two simple and complex forms; to measure parameters, such as temperature, pH, NO_3, TP, FC, TC, momentum sampling was done; and to measure parameters like COD, BOD_5 and TSS, composite samples were used. In order to evaluate the efficiency of the existing process in the observation period, both simple and complex sampling methods were done twice a week (totally 45 times) from the determined sections, and the samples were then examined.

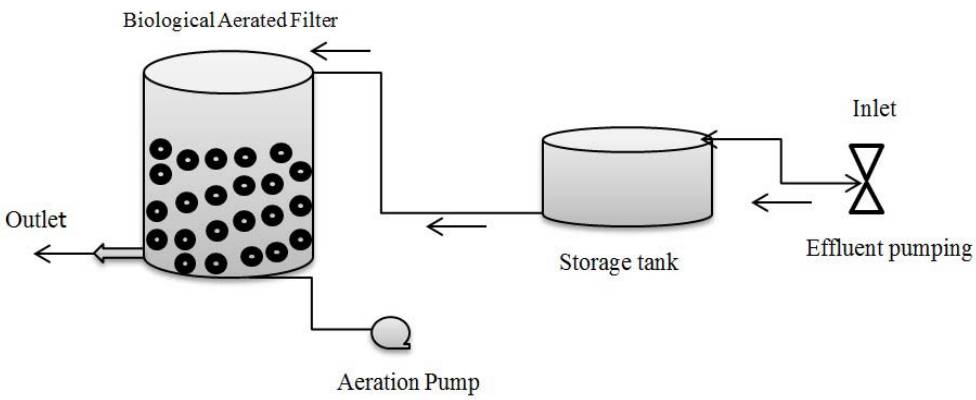

FIGURE 2- BAF pilot scheme.

2.5 Analysis

To examine the organic parameters, nutrients, total coliforms and fecal coliforms, available standard methods were used [13]. To assess pH, a pH-meter (550, WTW) was used. A digital turbidity meter was used to determine the turbidity. To measure dissolved oxygen in samples, a portable Oximeter (Oxi, 597) was used. To conduct COD experiments in an open reactor form and to measure ammonia, nitrate and total nitrogen, a Hatch (DR 5000, USA) spectrophotometer was used.

3. RESULTS AND DISCUSSION

The BAF system has a 2-3m depth bed and partly small-sized filter media made of different materials, to prepare a high surface area, on which a biomass can grow. The filter bed is submerged, and wastewater is pumped either upwards or downwards through the filter. An aeration pump sends air through a diffuser at the bottom of the bed generating bubbles which then rise through the filter, providing a steady stream of oxygen for the biomass to support the oxidation process [14-16]. In this study, the efficiency of biological filters aerated by an oyster shell bed in improving effluent quality for a wastewater treatment plant was investigated.

3.1 Changes of $TBOD_5$ concentration in the filter

As shown in Table 1, the average concentration of $TBOD_5$ decreased from 49.5 to 22 mg/L in the first hydraulic loading, from 47 to 22 mg/L in the second one, and from 47 to 32 mg/L in the third. During the first 6 weeks of operation, the BAF reactor worked with a hydraulic loading of 0.3 m^3/m^3.day. $TBOD_5$ removal efficiency gradually increased and, by the end of the 6^{th} week, the removal efficiency of $TBOD_5$ was 49.5%. Thus, BAF process started stably with hydraulic loading rates of 0.3, 0.6 and 0.9 m^3/m^3 day.

TABLE 1 - Changes of $TBOD_5$ concentration in the filter.

Level of hydraulic loading on the filter (m^3/m^3.day)	Sampling place	Minimum (mg/L)	Maximum (mg/l)
0.3	inlet	48	51
	outlet	20	24
0.6	inlet	46	48
	outlet	21	23
0.9	inlet	45	49
	outlet	31	33

As mentioned earlier, when the hydraulic loading increased from 0.3 to 0.6 m^3/m^3.day, no significant difference was observed in the average $TBOD_5$ of effluent sent out from the filter outlet. However, when the second hydraulic loading increased to 0.9 m^3/m^3.day, a significant difference was observed between the average concentrations of $TBOD_5$ in the filter outlet effluent. In a similar study, Sperling [17] reported that the amount of $TBOD_5$ coming out of the filter was 39 mg/L. With regard to both filters, it can be concluded that the efficiency of that designed herein is higher. In another study, which used an aerated stone filter with a vertical flow and limestone to remove BOD_5, removal efficiency of $TBOD_5$ in the aerated state and non-aerated filter was 89 and 42%, respectively [18]. Concerning the fact that the average $TBOD_5$ of effluent of Qom wastewater treatment plant and the average $TBOD_5$ of effluent sent out of the filter were 49.5 and 22 mg/L, as well as the allowed limit value for discharging effluents to the surface water (30 mg/L) by Iran's Environmental Standard Organization, this filter could decrease the amount of $TBOD_5$ (being much higher than Iran's Standard Organization limit before filter application) to a value much lower than the limit of Iran Environmental Standard [19].

3.2 Changes of concentration of TSS in the filter

As shown in Table 2, average concentration of TSS decreased from 54.5 to 27.5 mg/L (1^{st} hydraulic loading), from 57 to 32.5 mg/L (2^{nd} loading), and from 56.5 to 38 mg/L (3^{rd} loading). According to statistical analysis, a significant difference was observed when the loading rate was changed.

TABLE 2 - Changes of TSS concentration in the filter.

Level of hydraulic loading on the filter (m^3/m^3.day)	Sampling place	Minimum (mg/L)	Maximum (mg/L)
0.3	inlet	52	57
	outlet	25	30
0.6	inlet	55	59
	outlet	30	35
0.9	inlet	55	58
	outlet	37	39

As the hydraulic loading increases, the amount of TSS at the filter outlet increases, too. Devrim [2] used a stone filter with similar hydraulic loading rates and reported that TSS removal level was 89.4%. Comparing the efficiency of both filters (removal efficiency of TSS in the present filter is 43.2%), the low removal rate herein can be mainly due to the differences in the size of media used in both filters. Johnson [18] also reported that 93% of TSS was removed by biological filters; this high efficiency may be due to the horizontal flow of effluent in the filter. In this case, deposition and sedimentation of suspended solids can be done well [18]. In general, as the size of the media and the hydraulic loading increase, the efficiency of the filters decrease. The filter efficiency in removing TSS is proportional to the reduction of suspended BOD_5. The amount of TSS of effluent which exits the clarifier pond is 52 mg/L, while its amount at the filter outlet is 30 mg/L. Thus, this filter can decrease the TSS exiting the clarifier to a level lower than the limit of Iran Environmental standard (40 mg/L) [19].

3.3 Changes of COD concentration in the filter

As shown in Table 3, the average concentration of COD decreased from 81.5 to 50.5 mg/L, from 80.5 to

57 mg/L and from 82.5 to 64.5 mg/L in the 1st, 2nd and 3rd hydraulic loading. At the beginning of the application, the filter reactor started with hydraulic loading of 0.3 m^3/m^3.day. The removal efficiency of COD increased gradually and was 21.2% at the end of the 6th week. Thus, the filter process started stably with hydraulic loadings of 0.3, 0.6 and 0.9 m^3/m^3.day.

TABLE 3 - Changes of COD concentration in the filter.

Level of hydraulic loading on the filter (m^3/m^3.day)	Sampling place	Minimum (mg/L)	Maximum (mg/L)
0.3	inlet	80	83
	outlet	49	52
0.6	inlet	79	82
	outlet	55	59
0.9	inlet	80	85
	outlet	63	66

According to Table 3, effluent COD at the clarifier outlet and the filter inlet decreases to 31 mg/L in the 1st hydraulic loading. While examining a stone filter with two different beds, Sperling [17] observed that COD decreased to 109 mg/L. In his study, Kimwaga [20] used a stone filter to improve the quality of effluent at the clarifier outlet. He observed that the removal efficiency of COD was 84.4% in that filter; the efficiency of this filter in removing COD is higher than that of the biological filter used herein, possibly due to the fact that he used stones with smaller diameters [20]. Increased hydraulic loading and the big size of the stones used in this filter decrease the efficiency of BAFs in removing COD [17]. Thus, low media diameter can be effective in removing COD. In fact, as hydraulic loading increases, COD removal efficiency decreases. Comparing the quality of effluent at the filter outlet with Iran Environmental Standard (60 mg/L for COD), it can be said that this filter can decrease the COD to a level lower than the standard limits [19].

3.4 Changes of concentration of NO_3-N in the filter

The average concentration of NO_3-N decreased from 41.55 to 28.2 mg/L (1st hydraulic loading), 42.55 to 25.25 mg/L (2nd loading), and 41.1 to 23.6 mg/L (3rd loading). According to statistical analysis, a significant difference was observed when loading rate was changed. The results are shown in Table 4.

TABLE 4 - Changes of NO_3-N concentration in the filter.

Level of hydraulic loading on the filter (m^3/m^3.day)	Sampling place	Minimum (mg/L)	Maximum (mg/L)
0.3	inlet	40.2	42.9
	outlet	27.8	28.6
0.6	inlet	40.5	44.6
	outlet	24.1	26.4
0.9	inlet	40.2	42
	outlet	22.7	24.5

Nitrate concentration decreased from 40 to about 24 mg/L. Nitrate changes were in inverse proportion to ammonia changes. This inverse relationship indicated nitrification in the filter because the amount of heterotrophic bacteria and the SBOD concentration of effluent at the filter inlet were lower [21]. So, nitrifying bacteria grow better on the filter media, where they subsequently perform nitrification and change ammonia to nitrate, and then to nitrite as well [21]. The level of dissolved oxygen in the effluent at the clarifier outlet was about 0.8 mg/L; this amount of dissolved oxygen was not enough for nitrification and denitrification. For this reason, filter aeration was required to provide dissolved oxygen. Dissolved oxygen of the filter effluent was about 2.2 mg/L, which showed that this amount of oxygen was sufficient for the activity of nitrifying bacteria. The pH of the filter effluent was in the range of 7.7-8.1 indicating that this pH was enough for nitrification and denitrification; 40 mg/L NO_3-N was observed in the clarifier outlet, while it was 24 mg/L at the filter outlet. Comparing this quality with standards mentioned by Iran Environmental Organization for NO_3-N (50 mg/L), it was observed that this filter decreased NO_3-N of the clarifier effluent; the NO_3-N levels were lower than the limits of Iran Standard Organization both before and after filtration [19].

3.5 Changes of concentration of TP in the filter

According to Table 5, the average TP decreased from 7.85 to 4.65 mg/L in the 1st hydraulic loading, from 8.1 to 5.25 mg/L in the 2nd and from 8.05 to 5.6 mg/L in the 3rd one. Although filter efficiency under hydraulic loading of 0.6 m^3/m^3.day was higher, no statistically significant difference was observed between TP average concentrations of filter effluents in the three hydraulic loadings. As the hydraulic loading increased, TP removal efficiency decreased being 35.1 and 30% for the 2nd and 3rd hydraulic loading rates, respectively.

TABLE 5 - Changes of TP concentration in the filter.

Level of hydraulic loading on the filter (m^3/m^3.d)	Sampling place	Minimum (mg/L)	Maximum (mg/L)
0.3	inlet	7.7	8
	outlet	4.5	4.8
0.6	inlet	7.9	8.3
	outlet	5	5.5
0.9	inlet	7.8	8.3
	outlet	5.3	5.9

Regarding the reduction of effluent TP concentration, as hydraulic loading increased, removal efficiency of TP decreased. In a study carried out by Wareham [22], as the hydraulic loading increased, the amount of phosphorus decreased from 7 to 2 mg/L. Filter medium used in this study was a shell; on average, the amount of phosphorus reduction by this filter was 3 mg/L. Its efficiency was lower than that of the filter used by Wareham. Hydraulic loadings were the same in both studies, and the only difference between both filters was the material. Changes in total P concentrations in BAFs were lower compared to other chemical parameters. TP amount of clarifier effluent was 7.8 mg/L, while it was 4.9 mg/L in filter effluent (lower than Iran Environmental Standard for TP) [19].

3.6 Changes in the amount of FC in the filter

As seen in Table 6, the average number of fecal coliforms increased from 1.65 × 10^6 to 5.1 × 10^5 MPN/100 ml in the first hydraulic loading, from 1.7 × 10^6 to 6.25× 10^5 MPN/100 ml in the second hydraulic loading, and from 2.05 × 10^6 to 8.8 × 10^5 MPN/100 ml in the third hydraulic loading. According to the statistical analysis, a significant difference was observed between average concentrations of the effluent FC in all three hydraulic loadings. The amount of fecal coliforms at clarifier outlet and filter inlet decreased to about 113 × 10^4 MPN/100 ml; therefore, about 68.4% of FC decreased in the first hydraulic loading.

TABLE 6 - Changes in the amount of FC in the filter (MPN/100 ml).

Level of hydraulic loading on the filter (m^3/m^3.day)	Sampling place	Minimum	Maximum
0.3	inlet	1.5×10^6	1.8×10^6
	outlet	4.6×10^5	5.6×10^5
0.6	inlet	1.6×10^6	1.8×10^6
	outlet	5.7×10^5	6.8×10^5
0.9	inlet	2×10^6	2.1×10^6
	outlet	8.5×10^5	9.1×10^5

TC decreases with increasing hydraulic loading rate; this may be due to the fact that some of the coliforms, in the form of suspended solids, are trapped in the filter pores and on media inside the filter, thus being reduced [18]. Since total coliforms decrease, the amount of chlorine required to chlorinate effluent decreases too. According to a study carried out in Tehran, 46.85% of entire coliforms were removed and the amount of chlorine needed to disinfect wastewater effluent decreased significantly (50%) [23]. The total coliform removal by BAFs used in this study was 38% under the best conditions. Although BAF could not decrease the total coliforms to the limits of Iran Environmental Standard Organization (1000 MPN/100 ml) [19], it could reduce the amount of chlorine used for disinfection by 38.5%. As observed above, FC removal efficiency decreases with increasing hydraulic loading. Owing to the reduction of fecal coliforms, the chlorine required to chlorinate effluent decreases, too. Concerning the efficiency of multi-bed filters in removing pathogens from the effluent of Tehran wastewater treatment plant, 45.84% of the fecal coliform were removed by the filter and the amount of chlorine needed to disinfect wastewater effluent decreased to 50% [23]. BAF removal of fecal coliforms herein was 68.4% under optimal conditions. Although the size of the media used in this study was larger than that used in Tehran wastewater treatment plant, the removal of fecal coliforms was higher in the filter due to the provision of attached growth conditions and of self-eating phase conditions for bacteria [18]. Although BAFs could not decrease the amount of fecal coliforms to the limits of Iran Environmental Standard Organization (400 MPN/100 ml) [19], the filter herein could reduce the amount of chlorine used for disinfection by decreasing 68.4% of fecal coliforms.

4. CONCLUSIONS

The vertical downward flow BAF system with oyster shell medium was investigated to improve the quality of effluent produced by treatment plants. The results herein show that the best filter efficiency to remove $TBOD_5$, TSS, COD, TKN, NH_4-N, TP, TC, FC was observed in a hydraulic loading equal to 0.3 m^3/m^3.day, and removal efficiency decreased as hydraulic loading increased. This process, under optimum conditions, is able to remove $TBOD_5$, TSS, COD, TKN, NH_4-N, TP, TC and FC up to 49.5, 48.2, 52.2, 47.3, 45.4, 45.7, 59.4, and 62%, respectively. Based on these results, BAF filter with oyster shell media is able to achieve the required effluent standards for most of the parameters. Therefore, this method is recommended to upgrade wastewater treatment plants.

The authors have declared no conflict of interest.

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CORRESPONDING AUTHOR

Sajad Rahimi
Social Development & Health Promotion Research Center
Kermanshah University of Medical Sciences
Kermanshah
IRAN

Phone: +98 831 4291980
Fax: +98 831 4223210
E-mail: sj.rahimi.b@gmail.com

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