

# Advanced treatment of effluent extended aeration process using biological aerated filter with natural media: modification in media, design and backwashing process

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# Abstract

Due to their tolerance of hydraulic and organic shocks, biological aerated filters (BAFs) have high filtration efficiency and are suitable for the treatment of complex and sanitary wastewater. In this study for the first time, natural media of date kernel from Bam city was used as the BAF reactor media and, at the end of the reactor, a meshing sand filter separated by a standard metal grid from the natural filter section was used. This can be considered innovations in the media and filtration. In this work, the actual effluent of the hospital wastewater treatment plant was employed as the inflow wastewater to the reactor, and its organic and inorganic parameters were measured before and after the treatment by the BAF reactor. Reactor effluent measurement was studied in two steps. In one step, the effluent from the backwashing was returned to the reactor and, in the other step, effluents did not return to the reactor, the comparison of which showed that the backwashing effluent return method had more removal efficiency. The backwashing process was also studied in three ways: bottom backwashing (TB), top backwashing (BB), and top and bottom backwashing (TBBS), to determine the amount of water consumed and to achieve the desired result. Finally, the TBBS method was selected as the optimal method. The effect of backwashing effluent return was evaluated on the results of the parameters. Concentration of most of the outflow parameters was less or in accordance with EPA standard 2012.

## Introduction

Hospital wastewaters are considered an important source of water contamination. These wastewaters contain large amounts of dangerous pollutants including pathogens, fats, proteins, carbohydrates, pharmaceuticals, resistant chemicals, and endocrine disruptors (Zou, 2015, Liu et al., 2010). Concentration of micro-pollutants existing in these wastewaters is 4 to 150 times higher than the urban wastewaters (Kovalova et al., 2013). Some components of hospital wastewater are genotoxic and carcinogenic to humans (Gurjar et al., 2019).

These wastewaters can enter water sources, sediments, and soil through incomplete wastewater treatment systems (Huang et al., 2011, Gros et al., 2007, Navasero and Oatman, 1989, Aboltina et al., 2017). Therefore, due to the existence of diverse and complex compounds in hospital wastewaters, conventional wastewater treatment plants cannot completely remove them and advanced treatment methods should be used (Aboltina et al., 2017, Verlicchi et al., 2012, Nikoonahad et al., 2017). Biological aerated filters (BAFs) are a novel, flexible, and economical method with low footprint in the formation of active microbial biofilms and high organic charge (Lee et al., 2013, Liu et al., 2015, Antoniou et al., 2013, Böhm, 2007, Shi et al., 2011). These filters are used as a desirable biological process for treating waste leachates, waste-containing pathogens, volatile organic compounds, nitrate, ammonium, phosphorus, suspended solids, acetate, fats, dyes, and nitro-aromatic compounds (Shi et al., 2011, Gehr et al., 2003, Sheng et al., 2010, Xu et al., 2012, Tudor and Lavric, 2011).

Via filtration and biodegradation mechanism of the compounds, BAF causes wastewater treatment (Nikoonahad et al., 2018). The most important materials used in BAF media are sand, concrete, clay,

shale, polyethylene, polystyrene, and plastic materials (Abou-Elela et al., 2019, Bilotta and Brazier, 2008). The diameter of these media is about 4 mm, which is operated at 10 h hydraulic retention time (Ding et al., 2018, Blumenthal et al., 2000, Amin et al., 2018). Nikonahad et al. in 2017 used BAF reactor with a modified polystyrene media in Iran, which was coated with sand as a new media for advanced domestic wastewater treatment (Nikoonahad et al., 2017). Liu Jianguang et al. in China treated hospital wastewater by using BAF method in 2003 (Jianguang, 2003). Yi Biao et al. treated urban wastewater by using BAF reactor and achieved 94.7% BOD removal (Biao et al., 2007). City of Bam in Kerman Province located in southeastern Iran with the average rainfall of 56.7 mm per year produces 200,000 Ton of dates. Date is a fruit from *Phoenix dactylifera* family. Date kernel has length between 2.5 and 2.8 cm, width of 0.8 to 0.9 cm, and thickness of 0.5 to 0.6 cm (Zayed and Eisa, 2014). Date kernel contains a large amount of nutrients for the growth of microorganisms (Besbes et al., 2004a).

In a study in Tunisia by Soheil et al. (2004), chemical and physical properties of date kernel were analyzed and it was found that date kernel contains high amounts of protein and unsaturated fats such as oleic acid and carbohydrates, which are essential for the growth of living creatures (Besbes et al., 2004b). In Saudi Arabia, Al-Thubiani et al. evaluated date kernel powder as a probiotic material containing large amounts of *Lactobacillus paracasei* (Al-Thubiani and Khan, 2017). Therefore, due to the presence of these nutrients in date kernel, this study aims to evaluate the performance of BAF with natural date kernel media in the removal of organic and inorganic alkaloids, phosphate, suspended solids, biological oxidation demand, chemical oxygen demand, coliforms, and turbidity from the outflow effluents of Pastor Hospital, Bam. This study has the following innovations:

1. Use of natural date kernel media, instead of synthetic media (such as polystyrene etc.)
2. No need to add nutrients for biofilm growth due to use of natural date kernel media, which is known to have nutrients for the growth of microorganisms
3. Use of actual hospital wastewater effluent to reactor with natural media
4. Obtaining outflow effluent from a very high-quality reactor
5. Use of different media backwashing methods

## Materials And Methods

In this study, outflow effluent from Pastor Hospital wastewater treatment plant of Bam city, Iran, was treated by BAF with aerated activated sludge per capita with wastewater production capacity of 310 to 483 liters per day for each hospital media. Sampling was compounded for 6 consecutive months.

### Inflow Wastewater Features

After sampling the outflow effluent from the hospital wastewater treatment plant, the samples were transferred to a specialized laboratory for analysis. The results are reported in Table 1.

**Table 1** Characteristics of raw wastewater in Pasteur Hospital

Mean Hospital Effluent	EPA Standards	Parameter
8.1	6-9	pH
2±18	---	Temperature
5±90	5	TSS(mg/L)
2±2	2	DO(mg/L)
15±100	10	BOD <sub>5</sub> (mg/L)
15±198	100	COD(mg/L)
5±30	50	NO <sub>3</sub> <sup>-</sup> (mg/L)
5±30	6	PO <sub>4</sub> <sup>-</sup> (mg/L)
2±10	50	Turbidity(NTU)
5±105	550	Colour(TCU)
20±600	1500	Sulfate(mg/L)
100±1660	1000	Coliforms(MPN)
3±10	----	Amoxicillin(mg/L)
0.3±1.5	----	Azithromycin(mg/L)

## Reactor Construction and Operation

The hydraulic properties of the designed reactor are shown in Table 2. A cylindrical tube made of polyvinyl chloride with height of 110 cm and internal diameter of 10 cm that was filled to the height of 60 cm from the date kernel natural media was used to make the reactor, **Fig 1**.

**Table 2** Reactor Hydraulic Properties

Value	Unit	Parameter
60	Min	Hydraulic retention time
0.22	L/m <sup>2</sup> .s	Wastewater flow rate
1.6	L/m <sup>2</sup> .s	Back wash flow rate
0.9	L/m <sup>2</sup> .s	Flow rate of aeration pump
7.3	L/m <sup>2</sup> .s	Reverse Aeration Pump Flow Rate
0.76	Kg COD/m <sup>3</sup> .d	Average organic loading
5	mg/L	Mean dissolved oxygen
100	ml/min	Inlet discharge to the reactor

The date kernel media is a natural media containing amounts of date residues that are sufficient for the initial feeding of microorganisms (Chandrasekaran and Bahkali, 2013). To maintain the equilibrium of the main media and to prevent possible biofilm particle outflow, three clay layers with 0.2, 0.4, and 0.6

mm meshing and 20 cm height were placed, where bottom of the reactor was separated by a metal filter of stainless steel in 0.1 mm diameter from the above section of the reactor.

The inflow to the reactor was used in the up-flow manner to save and facilitate energy. To review the effect of the reactor height on removal of the desired pollutants, a sampling valve was inserted every 25 cm from the tube length. In order to check the pressure amount inside the reactor, piezometer was used in it. The aeration was performed continuously by an external pump with the discharge of 0.3 to 0.9 L / m<sup>2</sup>.s. To wash the filter media and prevent filter obstruction as well as exit of additional biomass from the bottom of the reactor, backwashing was performed by an air pump with discharge of 8 L / m<sup>2</sup>.s every 20 days for 20 min. To avoid turbulence in the sand filter, the backwashing pump hose was connected to a one-way valve mounted in the middle of the stainless-steel filter. A 100-liter tank was employed for balancing and initial sedimentation of the inflow effluent to the reactor. The effluent in the tank was gravity-fed into a biological reactor by a number of control valves. To reach the end of the backwashing, the outflow effluent turbidity was measured continuously.

### Analytical procedures

For biological adaptation and biofilm formation on the date kernel media, the outflow effluent from the hospital was aerated on the BAF filter for 4 weeks. After biofilm formation and confirmation by biofilm thickness measurement, the outflow of actual hospital treatment plant effluent was injected continuously at 100 ml / min discharge from the top of the reactor. After satisfying the above conditions, analysis of all parameters of this study such as pH, temperature, dissolved oxygen, oxidation potential, and analysis reduction was carried out by multi-parameter HANNA (model, HI98196, made in Italy)(Romero et al., 2008) and turbidity was measured by HACH portable turbidimeter (model, 2100Q). BOD<sub>5</sub> was also measured by BOD 6-chamber device (BOD OXIDIRECT manufactured by Laviband company, Germany) (Beszédes et al., 2018), COD with standard reflux method (Vyrides and Stuckey, 2009), and azithromycin and amoxicillin antibiotics were analyzed using high-performance liquid chromatography device (HPLC) as well as C18 specific column, mobile phase (95% phosphate buffer and 5% acetonitrile)(Cazorla-Reyes et al., 2014). TSS was analyzed by gravimetric method (Alkarkhi et al., 2008), coliforms (based on the most probable number of coliforms per 100 cc)(Evans et al., 1981) and nitrate and phosphate according to the procedures addressed in "Water and Wastewater Standard Method. Metcalf and Eddy, Edition 23th (Metcalf et al., 1979) .Based on **Eq. 1**, the efficiency of BAF process in removing pollutants was obtained.

$$\text{Removal (\%)} = (1 - C_t / C_o) \times 100 \quad (1)$$

Where C<sub>o</sub> is the initial concentrations of pollutants (mg/L) and C<sub>t</sub> is the residual of pollutants (mg/L) after the specified time.

### Backwashing Process

The backwashing process was performed based on the pressure drop in the piezometer between 13 and 17 cm. At first, the backwashing pump was turned on for 20 min and, during the washing, the effluent

from the turbidity was evaluated until the desired turbidity was reached. In this study, the following methods were employed for backwashing. Results were evaluated for effluent quality and pollutant removal efficiency.

1. Bottom backwashing (BB)
2. Top backwashing (TB)
3. Top and bottom backwashing (TBBS)

In all cases, the outflow turbidity was evaluated from the release valves.

### **Statistical Analysis**

Data on pollutant removal efficiency were analyzed by SPSS (ver. 22) software and one-way analysis of variance statistical test.

## **Results**

Results of biological filtration by date kernels are presented in Table 3. In this study, by increasing the filtration height from 25 cm to 100 cm, the removal efficiency of  $PO_4$ ,  $NO_3$ , COD,  $BOD_5$ , turbidity, dye, sulfate, and TSS was increased to 93.3, 99.4, 92.42, and 98.48, respectively.

**Table 3** Results of biological filtration by date kernels

Average final removal percentage	Average output from drain valve reactor	average output of the reactor at a height of 100 cm	average output of the reactor at a height of 75 cm	Average output of the reactor at a height of 50 cm	Average output of the reactor at a height of 25 cm	Parameter
----	1±7	0.5±8.1	8.1	8.1	8.1	PH
----	0.3±5	0.3±5	0.3±5	0.3±5	0.2±5	DO (mg/L)
98.48	0.6±3	5±10	5±20	5±50	5±80	BOD <sub>5</sub> (mg/L)
92.42	3±15	5±20	5±30	7±70	10±150	COD (mg/L)
99.4	0.3±0.6	0.5±3	1±8	1.5±15	2±20	NO <sub>3</sub> (mg/L)
93.3	0.3±1	0.8±2	1±4	1.5±8	2±10	PO <sub>4</sub> (mg/L)
95	0.5	0.5±6	0.5±7	0.5±8	0.5±9	Turbidity (NTU)
42.8	10±60	10±65	10±75	10±80	10±100	Color (TCU)
30	50±420	60±430	80±450	80±480	80±580	Sulfate(mg/L)
98.9	0.2±1	0.2±9	0.2±15	0.2±22	0.2±40	TSS (mg/L)
----	+214	+200	+120	+85	+50	ORP (mv)
20	1±8	-----	-----	-----	-----	Amoxicillin(mg/L)
13	0.05±1.3	-----	-----	-----	-----	Azithromycin(mg/L)

## Evaluating Natural Date Kernel Media

Given the high per capita production of dates in Bam, it is important to use natural date kernel media for secondary high-quality treatment of wastewater and effluent to discharge into the receiving waters. Due to the interstice on the kernel and large amount of residual nutrients in the kernel shell, or so-called endocarp, it is a suitable environment for the growth of microorganisms decomposing organic matter of wastewater (Ravi, 2017, Dehdivan and Panahi). According to the studies performed on date kernel, it contains a large amount of nutrients such as calcium, magnesium, phosphorus, iron, zinc, and flavonoids (Platat et al., 2014, Baliga et al., 2011). In the experiments performed on Bam Mazafati date kernel by Dehdivan et al. (2017) in Iran, organic and inorganic compounds were determined as in Table 4 (Dehdivan and Panahi).

**Table 4** Properties of Natural Date Kernel

Value	Composition(%)
2.33%	Moisture
12%	Fat
4.44%	Protein
1.5	Ash
79.33	Total carbohydrate
26.2	Crude fiber
Value	Minerals(meq/L)
25.3	Sodium
25.3	Calcium
0.6	Potassium
4.5	Mangenes
0.06	Phosphorous
25.3	Copper
6.25	Zinc
43.5	Iron

### Evaluating Backwashing Finishing Time Process

Based on the pressure drop in the piezometer, the backwashing process was performed every 10 to 20 days. Based on **Fig. 2**, the TB backwashing method was completed in 75 min, while in the BB method, the optimum turbidity was completed in 45 min. In the TBBS method, the optimum turbidity removal rate was obtained in 20 min. The amount of water consumed in these three TB, BB, and TBBS methods was 300, 164, and 118 liters, respectively.

### Evaluating Effluent Backwashing Return to Reactor

In this work, the effluent backwashing return to the reactor and its outflow was investigated over two three-month periods and the results of the pollutant analysis were compared with the reactor outflow without return of effluent, Table 5.

**Table 5** Properties of effluent backwashing return to the reactor

Turbidity (NTU)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	Method
0.5	1	15	3	Reactor output without return
0.5	1	13	2	Reactor output with TB rotation
0.5	1	13	2	Reactor output with BB rotation
0.5	1	12	2	Reactor output with TBBS rotation

### Evaluating Amoxicillin and Azithromycin Antibiotics Removal Efficacy

In this investigation, the removal efficiency of amoxicillin and azithromycin by BAF process was 20% and 13%, respectively.

## Discussion

In this study, by increasing the filtration height from 25 cm to 100 cm, the removal efficiency of  $\text{PO}_4$ ,  $\text{NO}_3$ , COD,  $\text{BOD}_5$ , turbidity, dye, sulfate, and TSS was increased to 93.3, 99.4, 92.42, 98.48, 95, 42.8, 30 and 98.9 respectively. No significant change was observed in pH and DO parameters by increasing filtration height, Table 3.

Based on the results obtained in this study, the removal efficiency of amoxicillin and azithromycin by BAF process was 20% and 13%, respectively, Table 3. Antibiotics are not easily degraded due to their complex structure with biological processes and require compound processes such as photocatalytic processes and advanced oxidation for complete removal (Manaia et al., 2018)

Yao-Xing Liu et al. (2009) in China treated domestic wastewater by BAF reactor with oyster shell media as well as plastic ball media and achieved the COD,  $\text{PO}_4^-$ , and  $\text{NO}_3^-$  removal efficiency of 85.1%, 98.1%, and 79.9% for oyster shell media and 80%, 93.7%, and 90.6% for plastic ball media, respectively (Liu et al., 2010). SI Abou-Elela et al. (2014) in Egypt used BAF reactor to treat the domestic wastewater and reached the BOD and COD removal efficiency of 92% and 89%, respectively (Abou-Elela et al., 2019), which resulted in higher removal efficiency than other studies due to the use of natural date kernel media.

In this study, to prevent anoxic media along the reactor at different height, oxidation and reduction potential sample was measured. Results ranged from +10 mV in raw wastewater to + 214 mV in outflow effluent, indicating optimum aeration performance. In the aerobic processes due to increased dehydrogenase enzyme activity, ORP levels were also increased, making organic material degradation better and easier (Toolabi et al., 2017, Toolabi et al., 2018, Toolabi et al., 2019).

According to Rebecca's Moore et al.'s studies carried out in 2001 in the UK, with increasing media depth due to longer retention time and greater opportunity for the degradation of pollutants by biofilm microorganisms, removal efficiency of parameters such as BOD, COD, and TSS increased (Moore et al., 2001). BAF reactors have both oxic and anoxic zones. Anoxic zones are suitable for nitrification and denitrification, removing organic matter and nitrate, as well as removing oxic residue zones of organic matter and ammonium (Pramanik et al., 2012). Phosphorus removal from wastewater is accomplished by sedimentation and absorption (Ha, 2006). In the BAF reactor via increasing retention time and reactor length, we observed increased removal efficiency.

Based on the results obtained in this study, the date kernel formed a thicker biofilm than synthetic and polymeric materials. The removal pollutant efficiency was also reported higher than other studies using polymeric and synthetic media (Nikoonahad et al., 2018). In this study, in addition to removing natural media of date kernel, to prevent biofilm outflow, a three-layer sand grading filter was considered, which furthermore removed the turbidity of the outflow effluent from the reactor. The date kernel as a food

source for the growth of microorganisms as well as the presence of viscos layer compounds on the date kernel slowed down the movement of wastewater, resulting in small water ponds throughout the reactor(Song et al., 2014). In addition, more meshing and degradation of pollutants were observed by biofilm.

According to the results obtained in this study, the amount of water consumed in these three TB, BB, and TBBS methods was 300, 164, and 118 liters, respectively. The lowest amount of water consumed for washing was related to the TBBS process, so this method was selected as the optimal method. In the study by Nikonahad et al. (2017) on BAF reactor with polystyrene media about backwashing media, TBBS method with 35 min was selected as an optimum method (Nikoonahad et al., 2017). According to the data in **Fig. 2**, slight changes were observed in the removal of pollutant parameters by the return of the backwash effluent to the BAF reactor due to the increase of microorganisms present in the effluent.

In this study, *protozoan*, *metazoan* and microorganisms such as *mastigamoeba*, *vorticella*, and *rotifer* were observed. In aerobic wastewater treatment processes, the observation of *protozoan* and *metazoan* microorganisms is an indication of adapted microbial biofilm for the decomposition of wastewater organic matters (Kamika and Momba, 2013). In addition Observation of *vorticella sp.* in aerobic systems of wastewater treatment indicates high system performance (Madoni, 2011).

## Conclusion

1. In this method, wastewater treatment was conducted by aerated biological filters with modifications and innovations in media (date kernel) as well as three methods of backwashing and outflow effluent evaluation. Here, very favorable results were achieved in the removal of indicator pollutants and other physical and chemical parameters. Some of the results that were concerned with the percentage of TSS (1 mg/L), turbidity (3 mg / L), sulphate (420 mg / L), nitrate (0.6 mg / L), COD (15 mg / L), BOD (3 mg / L), and phosphate (1 mg / L), which were in accordance with EPA guidelines, as in Table 6.

**Table 6** EPA Recommendation for reuse of wastewater effluents

Livestock drinking water	EPA recommendation		Average BAF effluents	Units	Parameter
	Non-agricultural crops	Processed agricultural crops			
30	2(max)	10(max)	0.5	NTU	Turbidity
NS	5(mon avg)	5(mon avg)	1	mg/L	TSS
NS	10(mon-avg)	10(mon-avg)	3	mg/L	BOD
NS	NS	NS	15	mg/L	COD
6.8-7.5	6-9	6-9	7	---	pH

2. Given that the natural media of date kernels has a porous surface and contains nutrients for the growth of microorganisms, it forms a good biofilm of acceptable thickness and, therefore, significantly removes pollutants in proper aeration compared to other medias. Also, in comparison with other synthetic media, it does not need adding nutrients for the growth of microorganisms and formation of biofilm.
3. Effluents recirculation of backwashing in all three methods, i.e. top, bottom, and top-bottom backwashing, as compared in Table 5, did not show any significant effect on the removal of pollutants in these three methods as well as effluents without recirculation method.
4. Measuring oxidation and reduction potential (ORP) for determining adequacy of system's aeration: To prevent anoxic media along the reactor at different height, oxidation and reduction potential sample was measured. Results ranged from +10 mV in raw wastewater to + 214 mV in outflow effluent, indicating optimum aeration performance.
5. The proposed aeration biological filter system can be used as an effective method for secondary treatment of wastewater effluent.

## Abbreviations

HRT: Hydraulic Retention Time; BAF: Biological Aerated Filters; COD: chemical oxygen demand; ORP: Oxidation Reduction Potential; HPLC: High Performance Liquid Chromatography; HWW: Hospital Waste Waters; BB: Bottom backwashing; TB: Top backwashing; TBBS: Top and bottom backwashing

## Declarations

AT, SH carried out experiments; MM and AT conceived and designed the experiments; SH and MM made a substantial contribution to the analysis and interpretation of the data presented; MM, AT and SH wrote the paper. All authors read and approved the final manuscript.

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## Figures

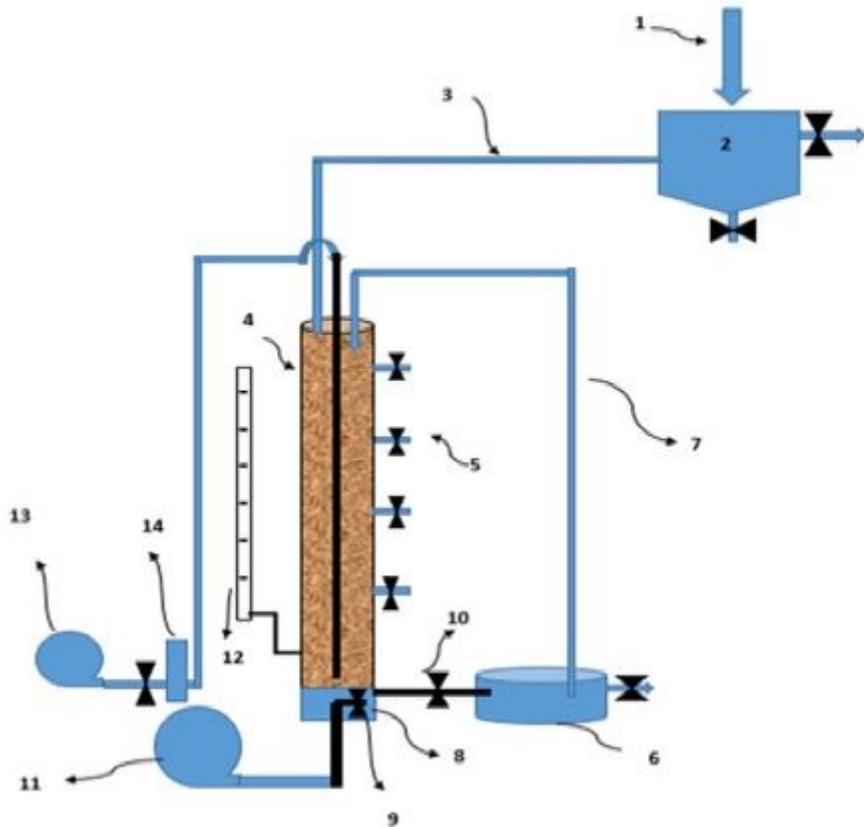
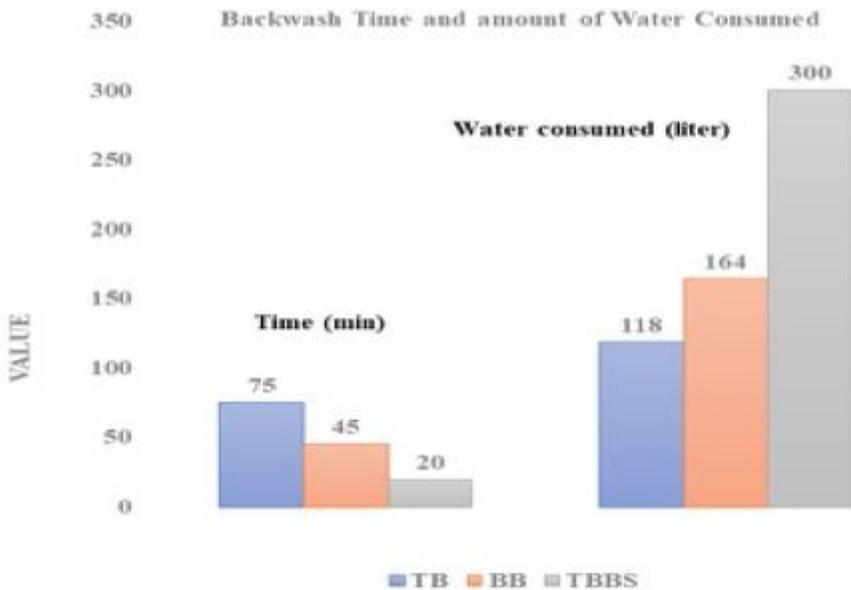


Figure 1

Schematic of the BAF reactor (1. Wastewater Inlet 2. Primary settling tank 3. Wastewater inlet line 4. Reactor chamber 5. Sample valves 6. Secondary settling tank 7. Return sludge line 8. Sand filter 9. One-way valve 10. Effluent Valve 11. Backwash pump 12. piezometer 13. Aeration pump 14. Aeration regulator)



## Figure 2

backwash time and amount of water consumed