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Research article

Application of novel Modified Biological Aerated Filter (MBAF) as a promising post-treatment for water reuse: Modification in configuration and backwashing process

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A B S T R A C T

Biological Aerated Filter (BAF) reactors due to their plentiful biomass, high shockability, high efficiency, good filtration, availability and lack of need for large land areas, are enjoying from great importance in advanced wastewater treatment. Therefore, in this study, Polystyrene Coated by Sand (PCS) was produced as a novel media and its application in a modified down-flow BAF structure for advanced wastewater treatment was assessed in two steps. In step one, the backwash effluent did not return to the system, while in step two backwash effluent returned to increase the water reuse efficiency. The backwash process was also studied through three methods of Top Backwashing (TB), Bottom Backwashing (BB), as well as Top and Bottom Backwashing Simultaneously (TBBS). The results showed that return of backwash effluent had no significant effect on the BAF effluent quality. In the second step similar to the first one with slight differences, the residual average concentrations of TSS, BOD_5, and COD at the effluent were about 2.5, 8.2, and 25.5 mg/L, respectively. Additionally, in step two, the mean volume of disposal sludge/volume of treated water (v_{ds}/v_{tw}) decreased a large extent to about 0.088%. In other words, the water reuse has increased to more than 99.91%. The backwash time in methods of TB and BB were 65 and 35 min, respectively; however, it decreased in TBBS methods to 25 min. The concentrations of most effluent parameters in this system are in concordance with the 2012 EPA Agriculture Standards, even for irrigation of Non-processed agricultural crops and livestock water consumption.

1. Introduction

Today, shortage of available water resources is one of the problems that many communities struggle with. Using appropriate and available technology in advanced wastewater treatment for water reuse is one of the requirements in dry and semi-dry regions (Franklin Burton et al., 2014; Ehrampoush et al., 2016; Mahvi, 2008). In this regard, municipal advanced wastewater treatment for use in agriculture is more important (Ghaneian et al., 2016; Ordonez et al., 2011). Biological Aerated Filters (BAFs) which are more beneficial than other fixed-film reactors are recommended as effective methods in advanced sewage treatment (Chen et al., 2015). As long as the available land is scarce or expensive, application of BAF systems is one of the main solutions for wastewater treatment (Banerjee et al., 2016; Chen et al., 2011). Application of submerged biological filters such as BAF to remove pollutants (organic martials, nutrients, pathogens, and trace elements) as a polishing and/or post treatment step can be a promising alternative

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to retrofitting (Albuquerque et al., 2012; Han et al., 2013; Mesdaghinia et al., 2010). Biological Aerated Filters, as submerged biological filters, are able to withstand the shock of organic matters and toxicity due to their abundant biomass in the form of attached and suspended growth (Mahvi et al., 2007). They also have a good efficiency in removal of refractory contaminants. In BAF reactors, all the removal processes are performed in a single-unit process and there is no need for sludge return (Albuquerque et al., 2012; Azizi et al., 2013). Major problems of BAF systems are related to energy consumption for aeration as well as backwash processes for excess biological sludge discharge, because the biological sludge causes clogging in the pores of BAF media over time and consequently leads to pressure loss. Another problem of the BAF systems is discharge of backwash effluent into the environment as a highly contaminant wastewater (Yang et al., 2010; Naghizadeh et al., 2008). Design of efficient methods for removal of sludge from the BAF media surface and its disposal through the backwash method, reduces costs and improves efficiency (Canler and Perret, 1994; Moore et al., 2001). The backwash process should be conducted periodically since the clogging phenomenon leads to reduction of pores, pressure loss, and consequently reduction of flow through the filter (Yang et al., 2010). Selection of a suitable BAF media is critical, because it plays a significant role in BAFs' porosity, aeration, clogging, biological growth, and eventually performance (Chen et al., 2011; Zhao et al., 2014). Rough surface media is a proper site for biological growth and preserves the biofilm within the system better than smooth media. Moreover, because porosity preserves the biological sludge on the media surface, it increases the sludge age in the system (Bao et al., 2016). BAFs are designed and operated either in down-flow or up-flow modes. Down-flow configuration with countercurrent air flow has an appropriate efficient mass transfer of oxygen to biofilm attached to media (Pramanik et al., 2012).

Considering the mentioned problems, it is believed in this study that by modification of down-flow BAF, the efficiency of this system can be improved to conduct advanced wastewater treatments. Thus, the following modifications were considered in the structure of BAF. The performance of this system was evaluated through the below modifications:

1 The novel Polystyrene Coated by Sand (PCS) media with a relatively low density and higher total porosity suitable for down-flow system was made and applied.
2 A layer of low porosity silica particles were used at the bottom of BAF to increase the efficiency of system, especially to remove suspended solids (SS), turbidity, and microorganisms.
3 Upgrading the removal of clogging phenomena by two backwash systems, i.e., from top and bottom, being designed and assessed.
4 To increase the efficiency of water production and sludge reduction, a pipeline was employed and effluent from backwash process was returned to the system and its effects on BAF were examined.

2. Materials and methods

2.1. Feeding wastewater characteristics

The secondary effluent of Intermittent Cycle Extended Aeration System (ICEAS) wastewater treatment plant in Yazd, Iran, was used as the influent of this pilot plant. According to the Environmental Protection Agency (EPA) and Metcalf & Eddy this wastewater is still not suitable for reuse (Franklin Burton et al., 2014). The feed flow rate of the pilot plant was 950 L/day throughout the study which entered the pilot continuously. Main characteristics of influent wastewater quality are tabulated in Table 1.

2.2. Experimental set-up

The down flow BAF pilot plant was located next to the wastewater treatment plant of Yazd, Iran, which has annually 60 mm of rainfall and is a very arid region. Biological Aerated Filter was made of polyethylene, with a diameter of 0.25 m and height of 1.8 m. About of 0.3 m upper of which was free space and its lower 0.2 m was filled by silica particles with approximately 0.2–0.4 mm of size. Moreover, the 1.5 m of the reactor's middle part was filled with PCS media. A stainless steel net with 0.1 mm- diameter mesh was placed in the middle of silica and PCS media layer to isolate the silica particles and PCS media. To avoid turbulence in the silica particles, air diffusers were placed on the stainless steel net above the silica layer. The influent to the system was from the top and clean water effluent was considered at the bottom of the reactor. Characteristics of the reactor are represented in Table 2 and its schema is portrayed in Fig. 1. To monitor the water level fluctuations caused by pressure loss in the reactor, which are usually resulted from fouling in media, a graduated piezometer (water level indicator) was applied in the system. Usually during the operation, the flow of injected air varies due to the clogging of the media, so, in order to solve this problem and to fix the air flow rate, an air flow meter was placed in the air transfer line. An air pump was applied for aeration and an air compressor was used for backwashing process. A tanker with an approximate volume of 125 L was applied at the entrance of system to store, mix, and stabilize the influent wastewater, as well as to receive and store the returned backwash effluent. This tanker also is applied as a settling tank for sludge separation in the second step through which the backwash effluent was returned to the system. Two outlet valves; one at the top and the other one between the PCS and silica layer were used for the backwash process.

In order to produce PCS media, initially a cylindrical rotating steel container, containing dry washed sands with approximately 0.2–0.4 mm of size was heated up to about 200 °C. While cylinder was spinning slowly, the crystal granules HIPS7240 polystyrene with the mean size of 2–2.5 mm was added to the sands. Heating process continued for 10 min so that the sands stick to the outer surface of polystyrene granules. In this condition, the entire outer surface of granules was completely covered with sands and connection between the sand particles and polystyrene granules became firm and permanent. Then, cylinder containing PCS granules rotated at the ambient temperature for 8–10 min to cool and produce uniformly round and rough PCS media.

Table 1
Main characteristics of influent wastewater.

Parameter	Units	Average ± SD
pH-value	–	7.2 ± 0.15
Temperature	Ċ	18 ± 2
Turbidity	NTU	19.7 ± 8
TSS	mg/L	40 ± 11
COD	mg/L	57 ± 21
SCOD	mg/L	22.1 ± 5.3
BOD_5	mg/L	21.2 ± 4
N-NO3	mg/L	4.6 ± 1.8
Total-P	mg/L	2.4 ± 0.3
Color	PT-CO	67 ± 26
Fecal Coliform (FC)	MPN/100 mL	$84 \times 10^5 \pm 12 \times 10^4$

Table 2
Operation condition and BAF property in the experiment.

Parameter	Units	Value
Hydraulic retention time (HRT)	min	60
Operation water flow rate	$L/m^2.s$	0.22
Backwash water flow rate	$L/m^2.s$	1.6
Mean of organic loading rate (OLR)	$Kg\ COD/m^3.d$	0.74
Mean of hydraulic loading rate (HLR)	$m^3/m^3.d$	13
Operation air flow rate	$L/m^2.s$	0.9
Backwash air flow rate	$L/m^2.s$	7.3
Mean of dissolve oxygen (DO)	mg/L	5
PCS diameter	mm	2.5–3
Diameter of reactor	cm	25
Volume of reactor	L	73
Total porosity	%	53
PCS Grain density	kg/m^3	730
PCS specific surface area[a]	m^2/m^3	171,623
PCS mean pore diameter[a]	nm	41.2
PCS water absorption[b]	%	1.5

[a] According of BET test.
[b] According of ASTM D 570 (American Society Testing and Materials).

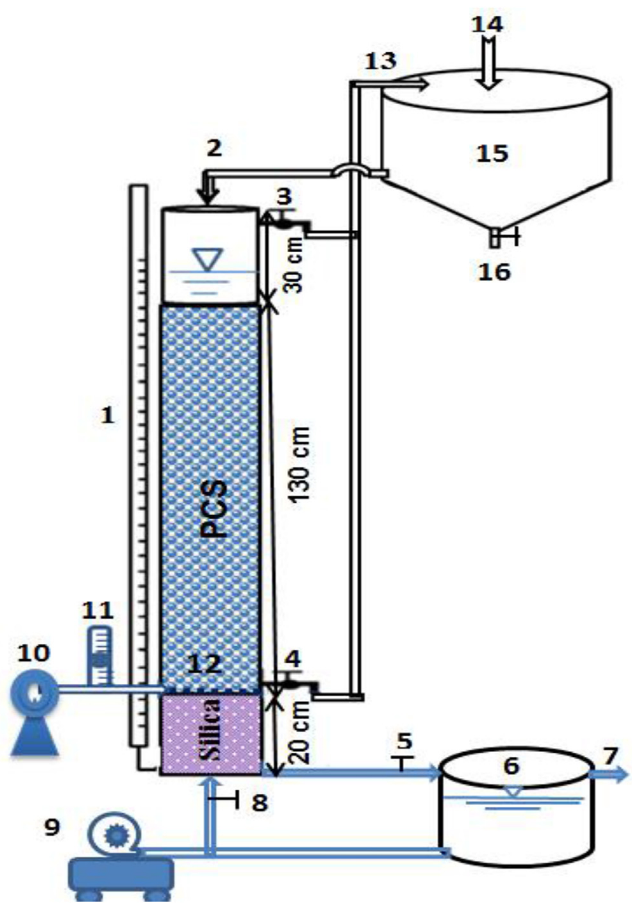

Fig. 1. Schematic diagram of BAF configuration: (1) Piezometer (water level indicator); (2) BAF influent Water; (3) Top backwash valve; (4) Bottom backwash valve; (5) BAF Effluent; (6) Effluent Reservoir tank (7) Reservoir tank effluent; (8) Air and water backwash inlet; (9); Air compressor; (10) Air diffuser; (11) Air flow meter; (12) Stainless steel net (PCS and silica separator device); (13) Backwash effluent; (14) ICEAS plant effluent; (15) Influent reservoir tank; (16) Excess sludge disposal.

2.3. Start-up and running

To achieve the steady state, the system was fed for four weeks. Through this period (Start-up), the sludge clung to the walls of aerated digestion sludge of ICEAS as well as approximately 10gr of milk powder were used daily for development of biological growth. In the literature, it was reported that in secondary wastewater treatment, down-flow BAF systems have a good efficiency in removing contaminants at the hydraulic retention times (HRT) of 20–120 min (Feng et al., 2013; Pramanik et al., 2012; Ha et al., 2010). However, in the current study since the concentration of pollutants in the influent was lower than the influent rates reported in the literature, three HRTs of 30, 60, and 90 min at the three periods of 20 days were studied to achieve the appropriate HRT. The results showed that removal efficiency of BOD_5 and COD at HRT of 60 min was more suitable for continuance of research, so this HRT was used throughout the study. Furthermore, in two periods of 90 days, the system was operated for investigation. During the first 90-day period (step one), the backwash effluent was discharged, but through the second 90-day period (step two) to increase water reuse efficiency and decrease sludge disposal, all backwash effluent was returned to the tank to re-enter the BAF reactor (Fig. 1). Operating conditions during the experiment are summarized in Table 2. In both periods, the amounts of HRT, organic loading rate (OLR), hydraulic loading rate (HLR), and water flow rate were 60 min, 0.74 kg/m^3 d, 13 m^3/m^3 d, and 0.224 L/m^2 s, respectively. In start-up and during operation, the ratio of air to water flow rate (A/W) was controlled at 4:1. In some references (Feng et al., 2013; WU SQ et al., 2011; Zhang et al., 2014) the value of A/W for secondary wastewater treatment in BAF systems was 5–15 and in some other sources (Bao et al., 2016; Pramanik et al., 2012; WU SQ et al., 2011) it was 3–8 for advanced wastewater treatment. In this study, due to the low organic loading rate as well as presence of approximately 2.5 mg/L dissolved oxygen) DO (in the BAF influent, the ratio value of 4:1 was considered for A/W so that during the operation, effluent DO concentration was about 5 mg/L. The system was performed at the ambient air with a temperature mean of 26 ± 11 °C. During both steps of operation, concentration of COD, BOD_5 and Fecal coliform in the influent and effluent were measured regularly, twice a week while other parameters such as turbidity, TSS, DO and temperature, were measured daily. Additionally, some parameters such as color, Cr, Cd, Co, Zn, Cu, B, AL,Fe, Pb, Hg, Na, and Sodium adsorption ratio (SAR) were assessed monthly to be compared with the EPA water reuse recommendations. All experiments were conducted through the APHA Standard Method (APHA, 2005). Scanning Electron Microscopy (SEM) was used to demonstrate media pore architecture, morphology, and sludge growth. Brunauer Emmett Teller (BET) analysis which is an important technique for the measurement of the specific surface area of materials was applied to measure specific surface areas of PCS media. Notice that in the second step, sampling was carried out to examine the influent and effluent characteristics about 1 h after fulfillment of backwashing process.

2.4. Backwashing experiments

The BAF media porosity was clogged over time due to the increase of biological sludge and the fouling caused by TSS. This in turn, led to pressure loss and the system was required to be backwashed periodically. In this regard, the amount of pressure loss caused by media and silica layer clogging was controllable by the piezometric pipe (Fig. 1). Pressure loss at the end of each 18–20 days period was about 13–17 cm. Therefore, during the operation, backwashing process was performed every 18–20 days. The backwashing air and water inlet valve was placed at the lowest part of BAF. Since in conventional BAFs, backwash effluent valve is usually located at the top (Ha et al., 2010; Yang et al., 2010; Abou-Elela et al., 2015; Moore et al., 2001), while the biological sludge derived from the attached growth is denser and heavier than the sludge of suspended growth (Hidaka et al., 2003; Yang et al., 2010). Thus, in the current study, another valve was considered at the bottom of system between the silica and PCS layers. This design was applied so that top backwashing (TB), bottom backwashing (BB), as well as simultaneous top and bottom backwashing (TBBS) processes can be evaluated. In the TBBS technique, backwash effluent flow rate through bottom and top valves were approximately 70% and 30%, respectively. During steps one and two totally, nine backwashes were conducted in TB, BB, and TBBS methods; each one for three times. In each backwashing process, initially the air compressor with an air flow rate of 7.3 L/m^2 s was applied for 3 min to dislodge the solid germs and biological slug mass by creating turbulence in the media and silica layer. Then, the air flow was shut down and immediately clean water with a flow rate of 1.6 L/m^2 s was applied from the same entrance to separate and drive the BAF sludge out. During clean water backwashing, every 5 min, turbidity of backwash effluent was measured and then stopped when turbidity reached 400 NTU or lower. To decrease sludge disposal and increase water recovery, in step two, the entire backwash effluent was returned to influent tank (Fig. 1). The effects of returned backwash effluent on contaminant removal efficiency of BAF reactor were also compared with those of step one. The whole effluent resulted from the first step backwashing process was disposed, but in the second step, only the settled sludge in inlet tanks was separated and disposed. Furthermore, disposed sludge volume was measured in both steps regularly and results are shown in Table 3.

3. Results and discussion

3.1. Evaluation the PCS media and BAF configuration

As Table 2 shows, size of the PCS media is about 2.5–3 mm. Furthermore, based BET analysis specific surface area is 171,623 m^2/m^3. The small size and rough surface of media provide an enormous surface area per unit volume in reactor for biofilm development and also strengthen filtration of the suspended particles. The media used in BAF systems must have appropriate specific surface area of 500–2000 m^2/m^3 to enable a suitable biofilm development and a grain diameter of about 1–4 mm to allow a good hydraulic flow rate (Albuquerque et al., 2012; Tabatabaei et al., 2005). However, as mentioned above, the surface area calculated from BET experiment is much higher than the data mentioned in literature. PCS rough surface also reduces the transmission speed of pollutants through media filter and increases the contact time between organic matter and microorganisms. In addition, abundant deep holes in media surface (Fig. 2) can act as small pools for sedimentation and maintenance of organic matters attached to the suspended solids. Hence, trapped organic pollutants, especially the recalcitrant organic matter were supposed to be adsorbed and degraded by living microbes. It has been asserted in some previous studies that filtration has a very important role in the performance of BAFs (Ha et al., 2010; He et al., 2013). Proper filtration is also possible by selection of appropriate media because suitable media can properly trap pollutants and turbidity and create high biological variety to remove the pollutants (Bao et al., 2016; Qi et al., 2011; Mahmoud et al., 2011). Furthermore, it has been reported that microbe inhabitance increases microorganisms population which intensifies extracellular exopolymers' production during the organism growth. This product acts as a biological flocculant which can adsorb and flocculate the suspended particles to obtain high SS removal and improve biological oxidation (He et al., 2013).

High roughness of PCS media causes high porosity of 53% (Table 2). Increased porosity, increases reactor's useful volume which in turn can decrease the capital cost. Despite the fact that its outer surface is covered by sand, its lightweight polystyrene core has caused the grain density of PCS to be about 730 kg/m^3. So, it slowly precipitates in water and is very convenient for down-flow BAF. Therefore, relative lightness of them, prepares the aeration with less pressure, since air bulbs can easily raise through PCS media bed. Thus, it can be pointed out that low media compaction decreases backwash process cost due to low weight. The 20-cm silica fine particles layer considered at the bottom of BAF column (Fig. 1) has provided high removal possibility of TSS, coliform, parasites, and parasite eggs. It actually functions as a polishing part in BAF for advanced wastewater treatment.

3.2. Pollutants removal efficiency before and after backwash return

The contaminants removal process was monitored in two 90-day steps after reaching the steady state. In the second step, to increase water reuse efficiency and reduce sludge disposal, backwash effluent was returned to the system and its effects on BAF reactor was evaluated. Fig. 3A indicates that during the monitoring period, the influent TSS was in the range of 25–75 mg/L, while the TSS removal efficiency was above 93% in both steps and the effluent TSS concentration decreased to 1.2–3.1 mg/L. During the second step, however, the influent TSS almost doubled temporally due to the high turbidity caused by backwash return, but the removal efficiency remained stable. Generally, Fig. 3A shows that the influent TSS concentration fluctuations did not have any significant effect on the effluent TSS concentration; thus, effluent concentration during the both steps was approximately constant. Additionally, Table 4 shows that generally the average concentration of BAF effluent TSS was surprisingly about 2.5 mg/L. This finding is much lower than those achieved by other researchers (Mahmoud et al., 2011; Abou-Elela et al., 2015). It can be inferred that the high roughness and low diameter of PCS media are major factors in trapping TSS and turbidity agents which most of them are supposed to decontaminate biologically. A number of researchers have emphasized that a simultaneous roughness increase and diameter decrease of media can increase the possibility of trapping and removal of SS (Abou-Elela et al., 2015; Feng et al., 2010). The TSS high removal may be due to biofiltration through a submerged

Table 3
Varied of Sludge disposal and water reuse in various modes of backwash process.

Items	TB method	BB method	TBBS method
Mean V_{bw} during the each backwash throughout experiment (Liter)	305.7	164.6	117.6
Mean V_{bw}/V_r during experiment	4.18	2.2	1.6
Mean of V_{ds}/v_{tw} in step one (%)	1.69	0.91	ND
Mean of water reuse in step one (%)	98.3	99.0	ND
Mean of V_{ds}/v_{tw} in step tow (%)	ND	ND	0.084
Mean of water reuse in step two (%)	ND	ND	99.9

v_{bw}: volume of backwash water.
v_{tw} volume of treated water during the each backwashes interval.
v_{ds}: volume of disposal sludge.
v_r: volume of reactor; ND: Not detect.

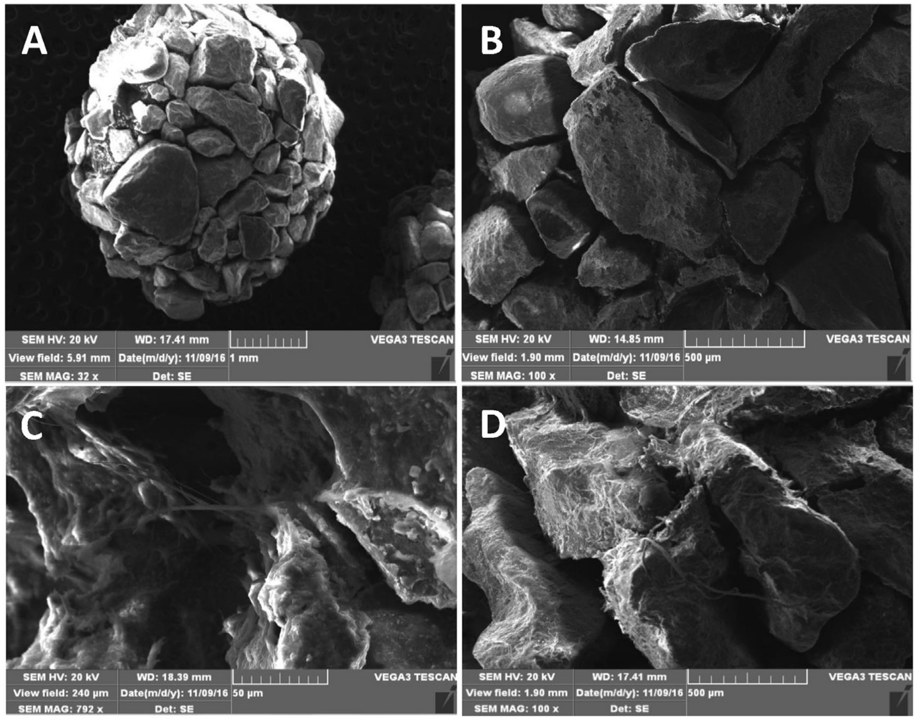

Fig. 2. SEM images of the PCS media: (A) complete external surface of PCS; (B) raw external surface of PCS; (C) Biofilm mass on external and internal surface of PCS after operation; (D) PCS after backwash process.

medium that functions as a biological conversion of pollutant matter by the biomass attached to the media and as a physical maintenance of SS (Abou-Elela et al., 2015). In the present study, the TSS removal efficiency was higher than 93%, while in the similar BAFs with no silica layer, TSS removal were 65–90% (Alfredo et al., 2015) and 82.6% (Qi et al., 2011). Thus, application of silica layer at the lowest point of BAF has certainly caused a high increase in TSS removal. Because the silica layer is located lower than the air diffusers and consequently turbulence caused by air bubbles is absent in this area of BAF, the rest condition and low porosity in silica layer led to removal of the remaining suspended particles which have passed through the upper layers.

Tables 1 and 4 show that the mean influent COD concentration was 57 mg/L, while it decreased more than 55% at the effluent and reached to 25.5 mg/L. Fig. 3B shows that in the first step, fluctuations in the influent COD concentration which was 47–65 mg/L had very little impact on the value of effluent COD. So, the effluent concentration and removal efficiency have been about 23–30 mg/L and 55%, respectively. Since in the second step of operation, backwash effluent was returned to the system every 19 days regularly, the influent COD shocks manifest every 19 days periodically. Therefore, the influent and effluent COD concentration were in the range of 51–79 and 22–33 mg/L, respectively. In the other words, effluent COD concentration during the shock periods of step two increased only 3–4 mg/L approximately. Moreover, the influent COD shocks did not have impact on the concentration of effluent COD in other operating days of the second step. Thus, the average COD removal efficiency in the step two was also about 55% similar to step one.

Results of Tables 1 and 4 show that the average values of influent and effluent BOD_5 concentrations were 21.2 mg/L, 8.2 mg/L, respectively with 61% removal rate in both steps. Fig. 3C represents that in the second step, backwash process caused shocks in the influent BOD_5 concentration and increased it to 63–70 mg/L. But, the effluent concentration had slight changes and increased just 2–3 mg/L. In case of organic loadings' shock resulting from the backwash process, the BAF reactor performance can be justified by the presence of proper biological attached growth in this system. Presence of high biomass, Fig. 2C, abundant oxygen and a relative shortage of organic loading rate (Table 2), provides the possibility for biomass microorganisms to consume the input organic matters at the shock time resulted from backwash effluent return.

As it was mentioned in previous studies, since most of biologically removable BOD_5 and COD are removed in the secondary treatment, generally the biologically removal of organic matter in tertiary biological treatment is not considerable (Pramanik et al., 2012). However, removal of COD, BOD_5, and TSS up to 55, 61, and 93% in this study show that using PCB media in new down-flow BAF structure is very appropriate and fulfills the aims of tertiary treatment. Comparison between data of Tables 1 and 4 showed that the average removal efficiency of fecal coliform without disinfection was about 6.9 logs. These results may be attributed to the mechanism of coliforms removal in biofilter systems which include trapping, settling, die-off, and finally consumption by other microorganisms.

High roughness surface of PCS media can be noted as a reason for improvement of removal efficiency in this type of BAF. However, physically trapped pollutants as well as wide specific sandy surface of PCS media (Table 2) provide a suitable site for development of variety of microorganisms which are responsible for decomposition of trapped organic matters. In addition, plentiful diffused macro holes in PCS media (Fig. 2A–D) function as small ponds to hold pollutants' agents and to provide a more opportunity for the biological degradation. Without increase of contact time between pollutants and microorganisms, most of the organic matters, especially bio-refractory agents could not be transferred into microorganisms' body to be biodegraded. This possibility is available in most of attached growth systems such as BAF reactors (He et al.,

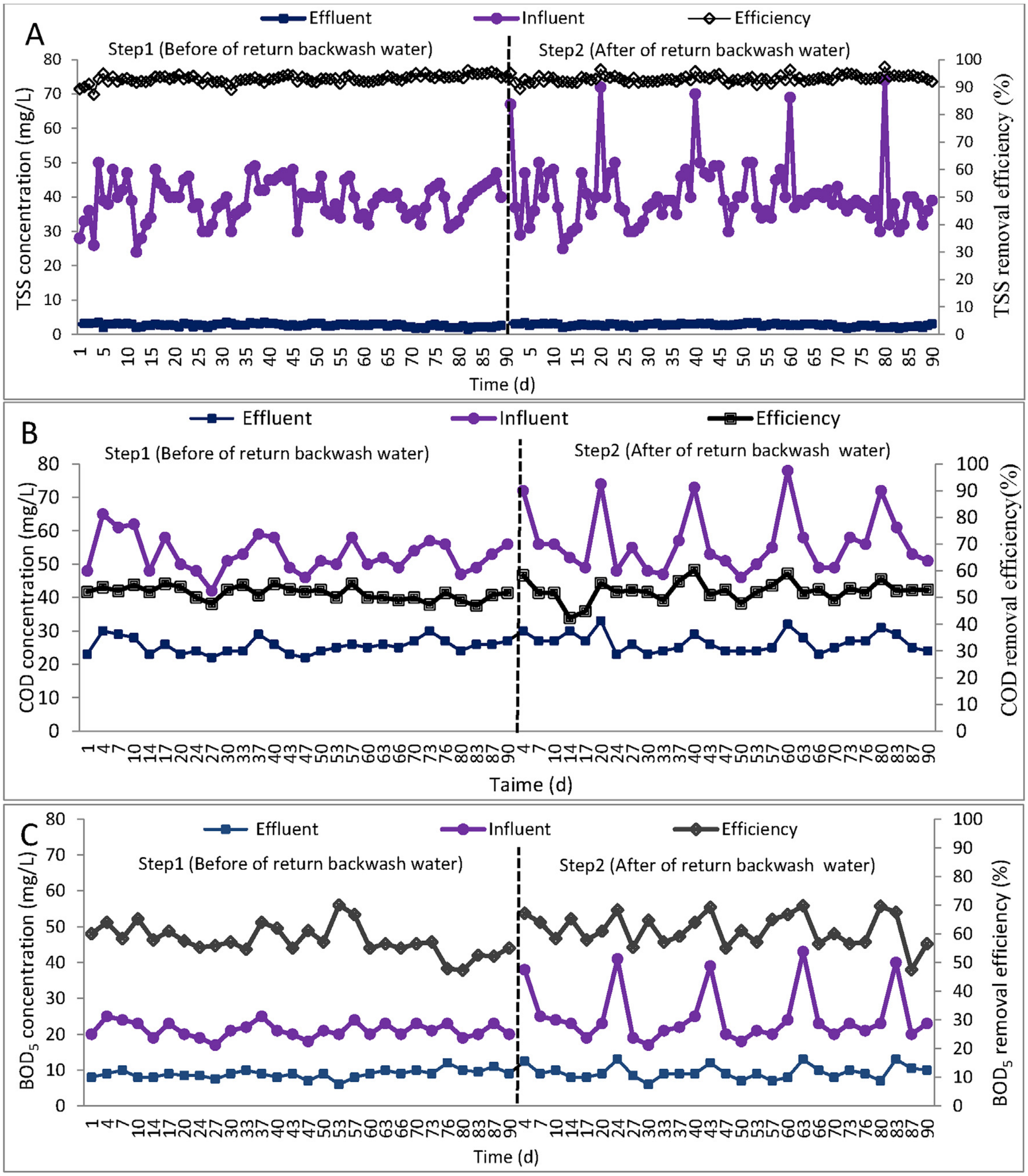

Fig. 3. Removal efficiency of the BAF during the two steps of operations: (A) TSS; (B) COD; (C) BOD_5.

2013).

According to Table 1, the quality of ICEAS effluent was far below the environmental limits stated in the EPA (2012) guidelines for treated wastewater reuse in unrestricted irrigation and livestock drinking water. While comparison of the important BAF effluent parameters and EPA guidelines in Table 4, shows that the quality of effluent water of this system met both "processed and non-processed type" agricultural crops irrigation guidelines. Effluent quality also was appropriate to be consumed in livestock drinking water.

3.3. Backwashing and sludge production analysis

Fig. 4 shows that when backwash is carried out by TB method, the backwashing process was completed after 65 min. This is while in BB method backwashing was conducted for 35 min and in the case of TBBS method, time is reduced to 25 min. Thus, the volume of backwashing water (v_{bw}) in TB, BB, and TBBS methods were 305.7, 164.6, and 117.6 L, respectively (Table 3). Table 3 also shows that means of volume of backwash water/volume of reactor, (v_{bw}/v_r) in the case of using TB, BB, and the TBBS methods were 4.18, 2.2, and 1.6, respectively. Given that v_{tw} in each backwashing period interval was about 18,050 L. In step one, mean volume of sludge disposal/volume of treated water, (v_{ds}/v_{tw}), in TB and BB methods were 1.69 and 0.91 orderly, while water reuse in these methods were 98.3% and 99.0%, respectively. In step two, v_{ds} was only about 16 L which collected from influent reservoir tank, therefore mean of v_{ds}/v_{tw} decreased to about 0.088% and amount of water reuse was increased to more than 99.91%.

Table 4
Main characteristics of effluent wastewater quality and EPA recommendations for water reuse.

Parameter	Units	Average BAF effluents	EPA recommendation		
			Processed agricultural crops	Non-processed agricultural crops	Livestock drinking water
Turbidity	NTU	1.1	10 (max)	2 (max)	30
TSS	mg/L	2.5	5 (mon avg)	5 (mon avg)	NS
Color	PT-CO	37	NS	NS	NS
COD	mg/L	25.5	NS	NS	NS
BOD_5	mg/L	8.2	10 (mon-avg)	10 (mon-avg)	NS
pH	–	7.3	6–9	6–9	6.8–7.5
EC [b]	μS/cm	1300	NS	NS	NS
AL	mg/L	0.011	5 (max)	5 (max)	5
Fe	mg/L	0.83	5 (max)	5 (max)	NS
Pb	mg/L	0.014	5 (max)	5 (max)	0.1
Hg	mg/L	<0.001	0.01 (max)	0.01 (max)	0.01
Cr	mg/L	0.013	0.1 (max)	0.1 (max)	1
Cd	mg/L	<0.001	0.01 (max)	0.01 (max)	0.05
C0	mg/L	0.02	0.05 (max)	0.05 (max)	1
ZN	mg/L	0.3	2 (max)	2 (max)	24
Cu	mg/L	0.003	0.2 (max)	0.2 (max)	0.5
B	mg/L	0.12	0.75 (max)	0.75 (max)	5
As	mg/L	0.019	0.1 (max)	0.1 (max)	0.2
$N\text{-}NO_3+N\text{-}NO_2$	mg/L	5.6	NS		100
Na[b]	meq/L	8.6	3	3	82
SAR[b]	–	3.6	3–6	3–6	NS
Mean FC without disinfection	MPN/100 ml	4200	NS	NS	NS
Mean FC[a] after disinfection in 20 min	MPN/100 ml	0	14 (mon mean)	3 (mon mean)	<1

NS Not specified.
[a] 0.5 mg/L obtained with 1 mg/L Calcium hypochlorite $Ca(OCl)_2$.
[b] Depends on the type of crops.

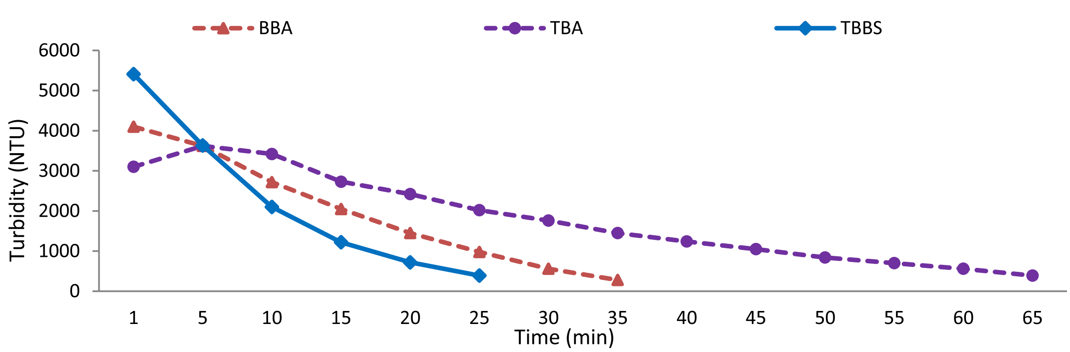

Fig. 4. Varied performance of backwash effluent turbidity removal by three backwash techniques: Bottom backwash (BB); Top backwash (TB); Top and bottom backwash simultaneously (TBBS).

3.4. Scanning electron microscopy (SEM) analysis

Fig. 2 represents SEM images of microstructures from outer surface of PCS media before and after biomass development. In Fig. 2A the complete structure of PCS roundish media is portrayed. The media diameter, connection structure of sand particles with polystyrene, and its surface's macropores are well represented in this figure. In addition, its diameter is consistent with data in Table 2. In Fig. 2B Macropores and Micropores positions on outer surface of media are shown with greater magnification before applying the media. The SEM micrographs of PCS clearly show Macropores with diameters of 50–100 μm that are distributed irregularly on the surface. The surface morphology agreed with the data about specific surface area in Table 2. Given the mentioned special properties, it could be concluded that PCS media is more favorable to the immobilization of microorganisms. It has been reported in several studies that the rough and irregular surface of media has provided a suitable site for biological attached growth (Bao et al., 2016; Zhao et al., 2014; Chen et al., 2011). Fig. 2C is related to SEM of sludge grown on the outer surface of PCS media after 6 months of use. Biofilm mass can be clearly represented on the surface of external and internal pores after the growth of bacterial populations. Fig. 2D shows the PCS surface after the backwash process. Comparing Fig. 2C with 2D indicate that despite the fact that after backwash process, most of sludge on media surface has been properly removed, still small amounts of biofilms and microorganisms, such as Filamentous-shaped bacteria have been immobilized on the inner and outer surfaces of pores in PCS. Thus, immediately after backwash and start of re-operation, these microorganisms began to grow and started decomposition of organic materials and nutrients. Since PCS media surface is cleared from excess sludge (Fig. 2D), it can be concluded that the backwash parameters in Table 3, such as air backwashing and water flow rates, backwash time, as well as backwash technique were designed properly.

3.5. Microscopic detection for metazoan and protozoan populations in biofilm

Fig. 5 shows that variety of metazoan and protozoan organisms

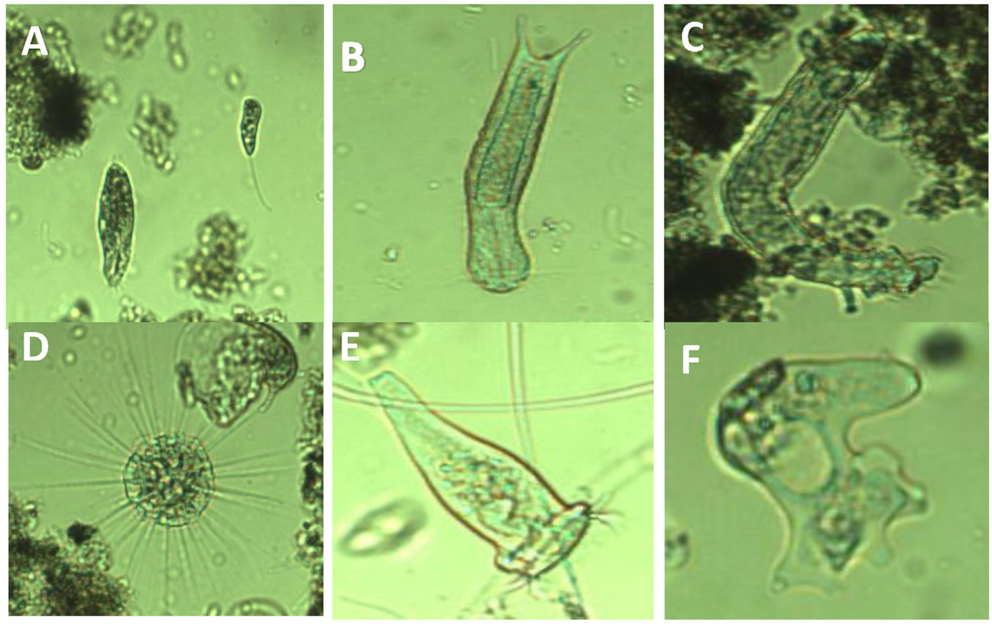

Fig. 5. Microscopic observation in the sludge of BAF system.

appeared in BAF biofilm. This observation indicates that PCS media is adaptable for biological growth and development of biofilm, which caused improvement in BOD_5 and COD removal.

Fig. 5 represents that dominant species in the PCS media are Bodo caudatus and Mastigamoeba invertens; Fig. 5A, Gastrotricha; Fig. 5B, Rotifer; Fig. 5C, Actinophrys; Fig. 5D, Vorticella sp; Fig. 5E, and Amoeba terricola; Fig. 5F. Protozoans are introduced as indicators of aerated biological wastewater treatment plants' appropriate performance (Bao et al., 2016; Khazaei et al., 2016) Moreover, finding Vorticella sp, as represented in Fig. 5E in the wastewater treatment plants demonstrates the biological attached growth (Gholikandi, 2004). Despite the relative shortage of organic matter and other substrates in the secondary treatment effluent (Table 1), the growth and accumulation of plentiful microorganisms on the pores and surface of PCS media indicate that the characteristics of mentioned media are efficient and also expedite biological growth in advanced wastewater treatment. This finding can be attributed to the porous and natural structures of PCS media surface.

4. Conclusion

According to obtained results, the following conclusions can be drawn:

(1) In the novel modified down-flow BAF with PCS media the influent TSS, COD, and BOD_5 were in the ranges of 40 ± 11, 57 ± 21, and 21.2 ± 4 mg/L, respectively, while the removal efficiencies were about 93%, 55%, and 61% in both steps. TSS, COD, and BOD_5 decreased at the effluent to about 2.5, 25, and 8.2 mg/L, respectively.
(2) The return of backwash effluent to the BAF has reached the water reuse to about 99.91%. It also has decreased the V_{ds}/V_{tw} to the negligible percentage of 0.088, while it did not have any significant effect on the BAF performance.
(3) Growth and accumulation of plentiful microorganisms, metazoan, and protozoan on the pores and surface of PCS media indicate that PCS characteristics are efficient and expedite for biological growth in advanced wastewater treatment processes.
(4) The backwash time in TB and BB methods were 65 and 35 min, respectively, however, it decreased in TBBS methods to 25 min.
(5) Increase of OLR shocks caused by backwash has a very low effect on increase of BOD5, COD, and TSS in BAF effluent.
(6) The proposed BAF system can treat secondary effluent wastewater appropriately, and it is capable of producing an effluent with a quality suitable for reuse in unrestricted irrigation according to the EPA (2012) guidelines as well as livestock drinking water.

References

Abou-Elela, S., Fawzy, M., El-Gendy, A., 2015. Potential of using biological aerated filter as a post treatment for municipal wastewater. Ecol. Eng. 84, 53–57.

Albuquerque, A., Makinia, J., Pagilla, K., 2012. Impact of aeration conditions on the removal of low concentrations of nitrogen in a tertiary partially aerated biological filter. Ecol. Eng. 44, 44–52.

Alfredo, J.B., Juaquin, S.L., Pablo, U.R., 2015, Biological aerated filters, Technology fact sheetsfor effluent treatment plantsof textile industry, 1-17.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater. American Public Health Association (APHA), Washington, DC, USA.

Azizi, S., Valipour, A., Sithebe, T., 2013. Evaluation of different wastewater treatment processes and development of a modified attached growth bioreactor as a decentralized approach for small communities. Sci. World J. ID 156870, pages 8.

Banerjee, P., Kumar, Dey, T., Sarkar, S., Swarnakar, S., Mukhopadhyay, A., Ghosh, S., 2016. Treatment of cosmetic effluent in different configurations of ceramic UF membrane based bioreactor: toxicity evaluation of the untreated and treated wastewater using catfish (Heteropneustes fossilis). Chemosphere 146, 133–144.

Bao, T., Chen, T., Wille, M.-L., Chen, D., Bian, J., Qing, C., Wu, W., Frost, R.L., 2016. Advanced wastewater treatment with autoclaved aerated concrete particles in biological aerated filters. J. Water Process Eng. 9, 188–194.

Canler, J., Perret, J., 1994. Biological aerated filters: assessment of the process based on 12 sewage treatment plants. Water Sci. Technol. 29, 13–22.

Chen, Y., Li, B., Ye, L., Peng, Y., 2015. The combined effects of COD/N ratio and nitrate recycling ratio on nitrogen and phosphorus removal in anaerobic/anoxic/aerobic (A 2/O)-biological aerated filter (BAF) systems. Biochem. Eng. J. 93, 235–242.

Chen, Y., Peng, C., Wang, J., Ye, L., Zhang, L., Peng, Y., 2011. Effect of nitrate recycling ratio on simultaneous biological nutrient removal in a novel anaerobic/anoxic/oxic (A 2/O)-biological aerated filter (BAF) system. Bioresour. Technol. 102, 5722–5727.

Ehrampoush, M.H., Miri, M., Momtaz, S.M., Ghaneian, M.T., Rafati, L., Karimi, H., Rahimi, S., 2016. Selecting the optimal process for the removal of reactive red

198 dye from textile wastewater using analytical hierarchy process (AHP). Desalin. Water Treat. 57, 27237–27242.
Feng, Y., Qi, J., Chi, L., Wang, D., Wang, Z., Li, K., Li, X., 2013. Production of sorption functional media (SFM) from clinoptilolite tailings and its performance investigation in a biological aerated filter (BAF) reactor. J. Hazard. Mater. 246, 61–69.
Feng, Y., Yu, Y., Duan, Q., Tan, J., Zhao, C., 2010. The characteristic research of ammonium removal in grain-slag biological aerated filter (BAF). Desalination 263, 146–150.
Franklin Burton, G.T., Ryjiro Tsuchihashi, H., David Stensel, Metcalf, Eddy, 2014. Wastewater Engineering: Treatment and Resource Recovery.
Ghaneian, M.T., Ehrampoush, M.H., Ehsanzadeh, E., Nikoonahad, A., Miri, M., 2016. Upgrading secondary wastewater plant effluent by modified coagulation and flocculation, for water reuse in irrigation. J. Water Reuse Desalin. JWRD 049, 2016.
Gholikandi, G.B., 2004. Microbiology of Water & Wastewater, Tehran, Nopardazan.
Ha, J.-H., Ong, S.K., Suranpalli, R., 2010. Impact of media type and various operating parameters on nitrification in polishing biological aerated filters. Environ. Eng. Res. 15, 79–84.
Han, M., Zhao, Z.-W., Gao, W., Cui, F.-Y., 2013. Study on the factors affecting simultaneous removal of ammonia and manganese by pilot-scale biological aerated filter (BAF) for drinking water pre-treatment. Bioresour. Technol. 145, 17–24.
He, Y., Wang, X., Xu, J., Yan, J., Ge, Q., Gu, X., Jian, L., 2013. Application of integrated ozone biological aerated filters and membrane filtration in water reuse of textile effluents. Bioresour. Technol. 133, 150–157.
Hidaka, T., Tsuno, H., Kishimoto, N., 2003. Advanced treatment of sewage by pre-coagulation and biological filtration process. Water Res. 37, 4259–4269.
Khazaei, M., Namizadea, R., Mahvi, A.H., Izanloo, H., Ansari Tadi, R., Gharagazloo, F., 2016. Nitrogen and phosphorous removal from aerated lagoon effluent using horizontal roughing filter (HRF). Desalin. Water Treat. 57, 5425–5434.
Mahmoud, M., Tawfik, A., El-Gohary, F., 2011. Use of down-flow hanging sponge (DHS) reactor as a promising post-treatment system for municipal wastewater. Chem. Eng. J. 168, 535–543.
Mahvi, A., 2008. Sequencing batch reactor: a promising technology in wastewater treatment. J. Environ. Health Sci. Eng. 5, 79–90.
Mahvi, A., Mesdaghinia, A., Saeedi, R., 2007. Upgrading an existing wastewater treatment plant based on an upflow anaerobic packed-bed reactor. J. Environ. Health Sci. Eng. 4, 229–234.
Mesdaghinia, A., Mahvi, A., Saeedi, R., Pishrafti, H., 2010. Upflow Sludge Blanket Filtration (USBF): an innovative technology in activated sludge process. Iran. J. Public Health 39, 7.
Moore, R., Quarmby, J., Stephenson, T., 2001. The effects of media size on the performance of biological aerated filters. Water Res. 35, 2514–2522.
Naghizadeh, A., Mahvi, A., Vaezi, F., Naddafi, K., 2008. Evaluation of Hollow Fiber Membrane Bioreactor Efficiency for Municipal Wastewater Treatment.
Ordonez, R., Hermosilla, D., Sanpio, I., Blanco, A., 2011. Evaluation of MF and UF as pretreatments prior to RO applied to reclaim municipal wastewater for freshwater substitution in a paper mill: a practical experience. Chem. Eng. J. 166, 88–98.
Pramanik, B.K., Fatihah, S., Shahrom, Z., Ahmed, E., 2012. Biological aerated filters (BAFs) for carbon and nitrogen removal: a review. J. Eng. Sci. Technol. 7, 428–446.
Qi, L., Wang, X., Xu, Q., 2011. Coupling of biological methods with membrane filtration using ozone as pre-treatment for water reuse. Desalination 270, 264–268.
Tabatabaei, Z., Mahvi, A.H., Saeiddi, M.R., 2005. Advanced wastewater treatment using two-stage sand filtration. Editor. Advis. Board 17, 48–54.
US EPA, 2012. United State Environmental Protection Agency, Guidelines for Water Reuse, Washington, D.C.
Wu sq, Y., QI Yf, G., Han, S., Yue, M., 2011. Preparation of ultra-lightweight sludge ceramics (ULSC) and application for pharmaceutical advanced wastewater treatment in a biological aerobic filter (BAF). Bioresour. Technol. 102, 2296.
Yang, J., Liu, W., Li, B., Yuan, H., Tong, M., Gao, J., 2010. Application of a novel backwashing process in upflow biological aerated filter. J. Environ. Sci. 22, 362–366.
Zhang, S., Zheng, J., Chen, Z., 2014. Combination of ozonation and biological aerated filter (BAF) for bio-treated coking wastewater. Sep. Purif. Technol. 132, 610–615.
Zhao, X.-L., Zhu, L., Bai, S.-J., Zhou, M., Qian, J., Wu, W., 2014. Performance of a double-layer BAF using zeolite and ceramic as media under ammonium shock load condition. Water Sci. Eng. 7, 81–89.