Advanced Treatment of Effluent Extended Aeration Process Using Biological Aerated Filter (BAF) 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, with a meshing sand filter separated by a standard metal grid from the natural filter section used at the end of the reactor. This can be considered an innovation in the media and filtration. Aeration in the related reactor with 160 cm height was performed bilaterally as up-flow and continuously by nozzles throughout the reactor media. 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. 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. According to the results obtained in this study, the removal efficiencies of inorganic and microbial contaminants, amoxicillin and azithromycin were obtained as follows: BOD_5: 98.48%, COD: 92.42.8%, $NO^-{}_3$: 99.4%, P: 93.3%, Coliforms: 97%, Color: 42.8%, Turbidity: 95%, Sulphate: 30%, TSS: 98.9%, Amoxicillin: 20% and azithromycin: 13%. The TBBS method was selected as the optimal method. The effect of backwashing effluent return was evaluated on the results of the parameters. The concentration of most of the outflow parameters was less or in accordance with EPA agriculture standard 2012.

Introduction

Hospital wastewaters (HWW) 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 disrupters (Zou, 2015, Liu et al., 2010). The concentration of micro-pollutants existing in these wastewaters is 4 to 150 times higher than that in 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). Thus, 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, Bohm, 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). Through filtration, absorbtion and biodegradation mechanism of the compounds, BAF contributes to 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, operating at 10 h hydraulic retention time (Ding et al., 2018, Blumenthal et al., 2000, Amin et al., 2018). Nikoonahad in 2017 used a BAF reactor with a modified polystyrene medium in Iran, which was coated with sand as a new medium for advanced domestic wastewater treatment (Nikoonahad et al., 2017). Liu Jianguang in China treated hospital wastewater using BAF method in 2003 (Jianguang, 2003). YI Biao et al. in 2007 treated urban wastewater applying a BAF reactor and achieved 94.7% BOD removal (Biao et al., 2007).

City of Bam in Kerman Province is located in southeastern Iran with the average rainfall of 56.7 mm per year, and producing 200,000 tons of dates. Date is a fruit from phoenix dactylifera family. Date kernel has a length between 2.5 to 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., 2004).

In a study in Tunisia by Soheil (2004), chemical and physical properties of date kernel were analyzed. 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 in 2017 evaluated date kernel powder as a probiotic material containing large amounts of *lactobacillus paracasei* (Al-Thubiani and Khan, 2017). Thus, due to the presence of these nutrients in date kernel, in the current study, applicability of biological aerated filter (BAF) with natural date kernel media in the removal of nitrate, phosphate, total suspended solids (TSS), biological oxidation demand (BOD), chemical oxygen demand (COD), Color, sulphate, coliforms, turbidity, azithromycin and amoxicillin from the outflow effluents of Pastor Hospital in Bam city were evaluated, This study has the following innovations:

1. Use of natural date kernel media, instead of synthetic media (such as polystyrene)
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, as the first study done so far
4. Obtaining outflow effluent from a very high-quality reactor
5. Use of different media in the backwashing process

Materials And Methods

In this study, the outflow effluent from Pastor Hospital wastewater treatment plant of Bam city, Iran, was treated with BAF with aerated activated sludge per capita with wastewater production capacity of 310 to 483 liters per day for each hospital medium. The 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_5(mg/L)
15±198	100	COD(mg/L)
5±30	50	NO^-_3(mg/L)
5±30	6	PO^-_4(mg/L)
2±10	50	Turbidity(NTU)
5±105	550	Color (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 a height of 110 cm and inner diameter of 10 cm filled to the height of 60 cm from the date kernel natural media was used to fabricate the reactor (Figure 1). The date kernel medium is a natural media containing sufficient amounts of date residues 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 the 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 as up-flow to save and facilitate energy. To review the effect of the reactor height on removal of the desired pollutants, a recovery valve was inserted every 25 cm from the tube length.

In order to check the pressure inside the reactor, a 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^2.s. To wash the filter media and prevent filter obstruction as well as outflow of additional biomass from the bottom of the reactor, backwashing was performed by an air pump with discharge of 8 L/m^2.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 for initial sedimentation of the effluent entering 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. Other specifications are listed in Table 2.

Table 2 Reactor Hydraulic Properties

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

Analytical methods

For biological adaptation and biofilm formation on the date kernel media, the outflow effluent from the hospital was aerated on a BAF filter for 4 weeks. After biofilm formation and confirmation through biofilm thickness measurement by Field Emission Scanning Electron Microscopes (FESEM) (Fig. 2), 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, all parameters of this study including; pH, temperature, dissolved oxygen, oxidation potential, and analysis reduction were analyzed by multi-parameter HANNA (model, HI98196, made in Italy) (Romero et al., 2008), while turbidity was measured by HACH portable turbidimeter (model 2100Q). BOD_5 was also measured by BOD 6-chamber device (BOD Oxidirect manufactured by Lavi band company, Germany) (Beszédes et al., 2018).

COD was measured through 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 via gravimetric method (Alkarkhi et al., 2008), coliforms (based on the most probable number of coliforms per 100 cc) (Evans et al., 1981), as well as nitrate and phosphate according to the procedures addressed in Water and Wastewater Standard Method. Eddy. "eddition",23 (2017) (Metcalf et al., 1979). Based on Eq. 1, the efficiency of the BAF process in removing pollutants was obtained.

Eq. 1

$$Removal(\%) = \left(\frac{C0-Ct}{C0}\right) * 100$$

Where: C_0, initial concentration of pollutant (mg/L); C_t, residual concentration of pollutant (mg/L)

Backwashing Process

The backwashing process was performed based on the pressure drop in the piezometer between 13 and 17 cm. Initially, 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. 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. In all cases, the outflow turbidity was evaluated from the release valves. 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 8 L/m^2.s was applied for 20 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.

Preparation and analysis of date kernel

Nutrient tests were performed to investigate the nutrients and other organic and inorganic constituents of the date kernel to be used as a natural substrate for the MBBR reactor. The date kernels were firstly isolated and then collected from the palm mantle, and after repeated washing with warm water, the final rinse was deionized. Afterward, they were kept under the sun light for 2 days. Subsequently, they were dehydrated for 24 hours at 50 ° C. The cores were then powdered through the mill and dissolved in 100 ml of chloroform and acetone and finally allowed to stand for 48 hours at room temperature. After passing the homogeneous solution of Whitman filter, physicochemical and Brunauer-Emmett-Teller (BET) analyses were determined (Platat et al., 2014, Baliga et al., 2011).

Statistical Analysis

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

Results

The results of the physicochemical and Brunauer-Emmett-Teller (BET) properties tests of dates kernel

The results of the physicochemical properties of date kernel are shown in Table 3, and the results of date mineral analysis were as follows: sodium: 25.33, calcium 25.33, manganese 4.5, potassium 0.6 and iron 43.76 eq/L, which was the highest amount of mineral related to iron. The results of the Brunauer-Emmett-Teller (BET) properties of date kernel are shown in Table 4.

Table. 3: Physico-chemical properties of date kernels

Value	Parameter
1.52	Ash content %
2.33	Moisture %
65.4±3.5	Volatile content %
25±3	Fixed carbon content %
28	C %
0.8	N %
12	Fat %
650	Particle density Kg/m3
24	Prosity %
79.33	Total carbohydrate %
26.18	Crude Fiber %
4.44	Protein %
4.7±0.3	pH

Table 4. BET Plot of date kernel

Unit	Value	*Parameter*
[cm^3(STP) g^{-1}]	0.2304	V_m
[m^2 g^{-1}]	1.0029	$a_{s,BET}$
	67.951	C
[cm^3 g^{-1}]	0.0023731	Total pore volume(p/p_0=0.990)
[nm]	9.4649	Mean pore diameter

The Field-emission Scanning Electron Microscope of the date kernel

The Field-emission Scanning Electron Microscope (FESEM) of the date kernel media indicated the size of the biofilm thickness formed on it, fig 2. It was found that the size of the biofilm thickness was confirmed at a range of 0.36 to 22.59 um

The results of biological filtration in removal of pollutants

The results of biological filtration by date kernels are presented in Table 5. In this study, upon increasing the filtration height from 25 cm to 100 cm, the removal efficiencies of inorganic and microbial contaminants, amoxicillin and azithromycin were obtained as follows: BOD_5: 98.48%, COD: 92.42.8%, NO^-_3: 99.4%, P: 93.3%, Coliforms: 97%, Color: 42.8%, Turbidity: 95%, Sulphate: 30%, TSS: 98.9%, Amoxicillin: 20% and azithromycin: 13%.

Table 5 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	Inlet Wastewater To the reactor	Parameter
—	1±7	0.5±8.1	8.1	8.1	8.1	8.1	PH
—	0.3±5	0.3±5	0.3±5	0.3±5	0.2±5	2	DO(mg/L)
98.48	0.6±3	5±10	5±20	5±50	5±80	5±100	BOD^{-}_{5}(mg/L)
92.42	3±15	5±20	5±30	7±70	10±150	10±198	COD(mg/L)
99.4	0.3±0.6	0.5±3	1±8	1.5±15	2±20	5±30	NO^{-}_{3}(mg/L)
93.3	0.3±1	0.8±2	1±4	1.5±8	2±10	3±15	PO^{-}_{4}(mg/L)
95	0.5	0.5±6	0.5±7	0.5±8	0.5±9	0.5±10	Turbidity(NTU)
42.8	10±60	10±65	10±75	10±80	10±100	10±105	Color(TCU)
30	50±420	60±430	80±450	80±480	80±580	80±600	Sulfate(mg/L)
98.9	0.2±1	0.2±9	0.2±15	0.2±22	0.2±40	0.2±90	TSS(mg/L)
—	+214	+200	+120	+85	+50	+10	ORP(mv)
20	1±8	——	——	——	——	3±10	Amoxicillin(mg/L)
13	0.05±1.3	——	——	——	——-	0.3±1.5	Azithromycin(mg/L)

Evaluating Backwashing Finishing Time Process

Based on the pressure drop in the piezometer, the backwashing process was performed every 20 days. According to the results obtained in this study, 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 within 20 min. 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.

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 6. The lowest and highest COD removal efficiencies were related to Reactor output without return effluent and TBBS methods, respectively. The removal efficiency of other Parameters by the studied methods was slightly different.

Table 6 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

Discussion

According to the results obtained in Fig. 2, it was found that the FESEM techniques, the size of the biofilm thickness was confirmed at a range of 0.36 to 22.59 um. So, 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 in other studies using polymeric and synthetic media (Nikoonahad et al., 2018). In this study, BET test was used to measure the amount of porosity and effective surfaces of the date bed, with its results shown in Table 4. Based on the results, it was observed that there was a direct relationship between the amount of bed pores and the amount of adsorption and decomposition of contaminants. According to the results presented in Table 5, the removal efficiencies of BOD_5, COD, NO^-_3, P, Total Coliforms, Color, Turbidity, Sulphate, TSS, Amoxicillin and azithromycin were obtained, 98.48, 92.42.8, 99.4, 93.3, 97, 42.8, 95, 30, 98.9, 20 and 13%, respectively. Thus, the concentration of pollutants in the effluent was observed in the range of environmental standards.

Yao-Xing Liu (2009) in China treated domestic wastewater by a BAF reactor with oyster shell media as well as plastic ball media. They achieved COD, PO_4, and 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).

Abou -Elela (2014) in Egypt used a BAF reactor to treat domestic wastewater and reached the BOD and COD removal efficiency of 92% and 89%, respectively (Abou-Elela et al., 2019), in this study, yielding a higher removal efficiency in current study than other studies, It could be due to the use of natural date kernel media. Also, ORP was reported at lower +50 mV depth and, with the increase in the reactor floor height, ORP levels were increased as well. In aerobic processes due to increased dehydrogenase enzyme activity, ORP levels also increased, improving and facilitating organic material degradation (Toolabi et al., 2017, Toolabi et al., 2018, Toolabi et al., 2019).

According to Rebecca's Moore’s studies carried out in 2001 in the UK, as the media depth increased, so did the removal efficiency of parameters such as BOD, COD, and TSS due to longer retention time and greater opportunity for the degradation of pollutants by biofilm microorganisms (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 residual zones of organic matter and ammonium (Pramanik et al., 2012). Phosphorus removal from wastewater is accomplished by sedimentation and absorption (Ha, 2006). So, in current study we observed enhanced removal efficiency for all pollutants with increasing retention time and reactor length.

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 for discharge into receiving waters. Due to the interstices 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, Platat et al., 2014, Baliga et al., 2011).in this study, according to the results obtained, date kernel, it contains a large amount of nutrients such as calcium, magnesium, phosphorus, iron, zinc, and flavonoids. Similar to this study, In the experiments performed on Bam Mazafati date kernel by Dehdivan et al (2017) in Iran, It was found that date kernels, contain large amounts of organic and mineral nutrients (Dehdivan and Panahi).

According to the results obtained in this study, 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 within 20 min. 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 (2017) on a BAF reactor with polystyrene media about backwashing media, TBBS method with 35 min was selected as an optimum method (Nikoonahad et al., 2017)

In this study, to prevent biofilm out flow, a three-layer sand grading filter was considered, which would further remove 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.

In this work, the effluent backwashing return to the reactor and its outflow was investigated over two three-month periods. Then, the results of the pollutant analysis were compared with the reactor outflow without return of effluent. According to the data in Table 6, slight changes were observed in the removal of pollutant parameters with the return of the backwash effluent to the BAF reactor due to the increased presence of microorganisms in the effluent. 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 wastewater treatment by attach growth methods, we usually see the presence of *protozoan* and *metazoan*, microorganisms such as *mastigamoeba, vorticella*, and *rotifer* (Madoni, 2011).

In this study, the removal efficiency of amoxicillin and azithromycin by BAF process were observed 20% and 13%, respectively. Antibiotics are not easily degraded via biological processes due to their complex structure and require complex processes such as photocatalytic processes as well as advanced oxidation for complete removal (Manaia et al., 2018). In this study, wastewater treatment was performed 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 as well as other physical and chemical parameters. Some of the results that were concerned with the percentage of TSS (1 mg/L), turbidity (0.5 NTU), sulphate (420 mg/ L), nitrate (0.18 mg/L), COD (14.9 mg/L), BOD_5 (1.52 mg/L), and phosphate (2 mg/L), which were in accordance with EPA guidelines, as in Table 1 and 5. Given that the natural medium of date kernels has a porous surface and contains nutrients for the growth of microorganisms, it forms a good biofilm of acceptable thickness, thus significantly removing pollutants in proper aeration compared to other media. Also, in comparison with other synthetic media, it does not need adding nutrients for the growth of microorganisms and biofilm formation. Effluents recirculation of backwashing in all three methods top, bottom, and top-bottom backwashing, as compared in Table 6, did not show any significant effect on the removal of pollutants in these three methods as well as effluents without recirculation method.

When measuring oxidation and reduction potential (ORP) for determining adequacy of system's aeration, to prevent anoxic media along the reactor at different heights, oxidation and reduction potential sample was measured. The results ranged from +10 mV in raw wastewater to + 214 mV in outflow effluent, indicating optimum aeration performance. 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

Authors' contributions

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

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Figures

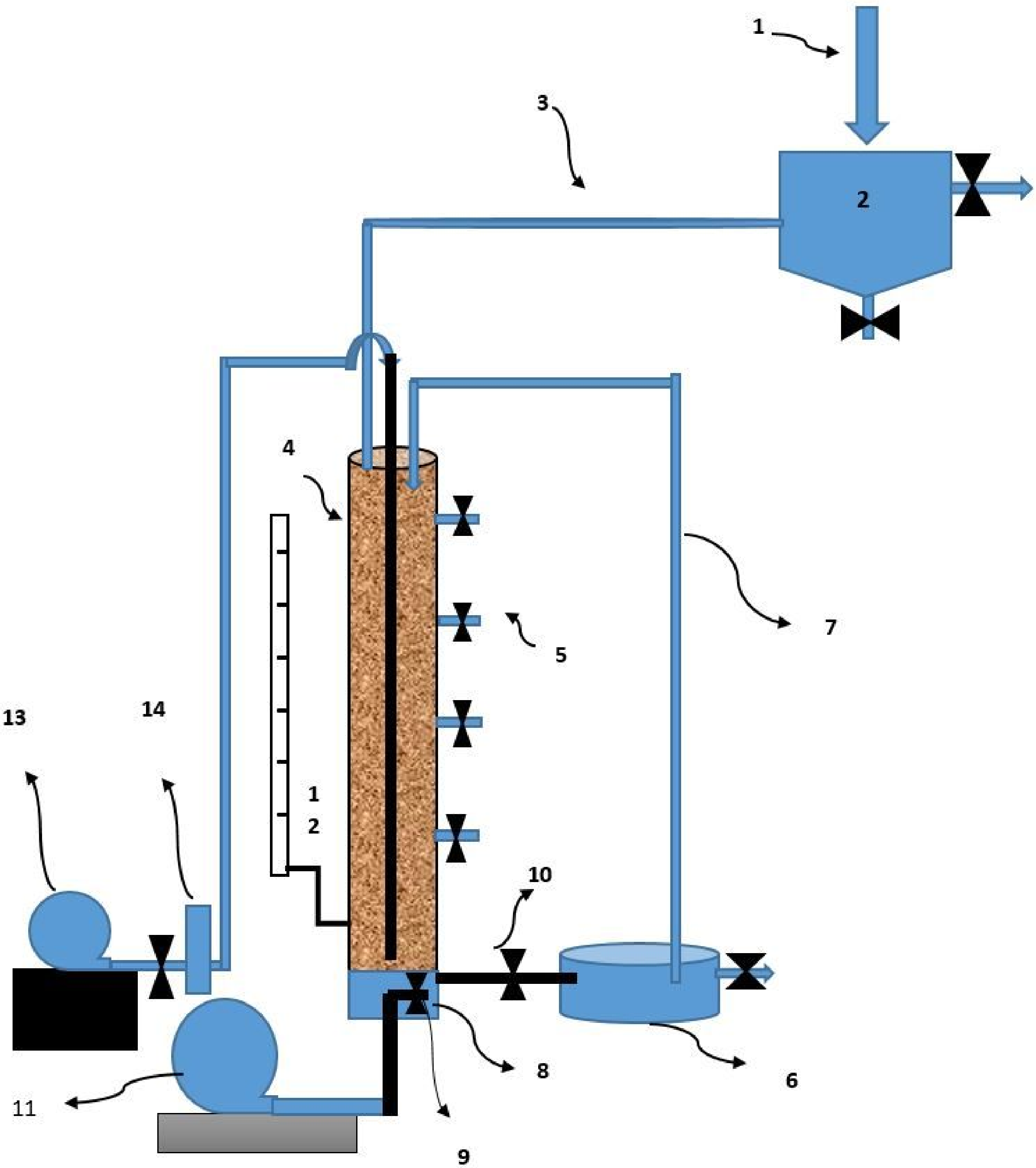

Figure 1

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)

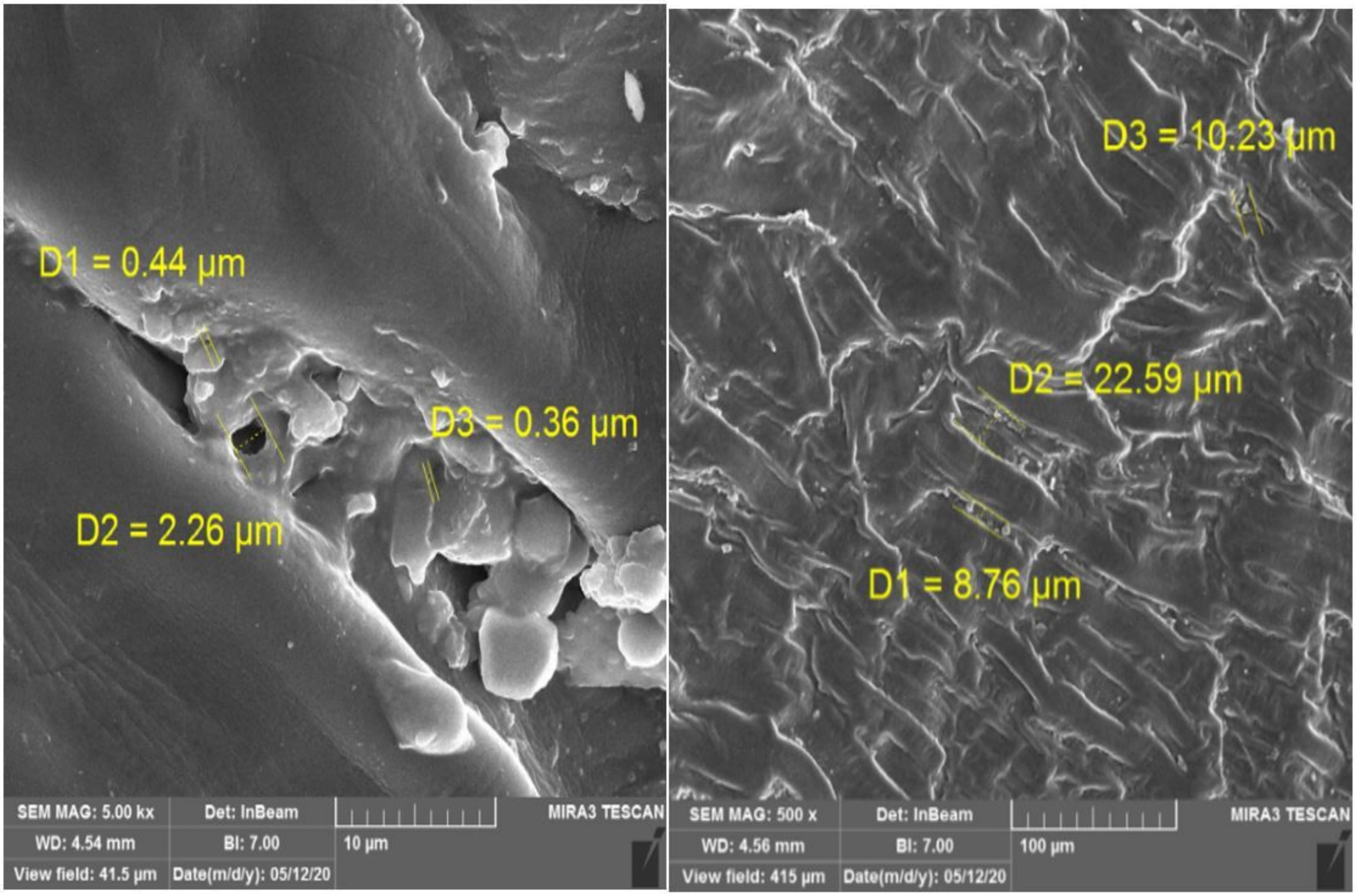

Figure 2

FESEM of date kernel Media