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Study on performance of three backwashing modes of filtration media for oilfield wastewater filter

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ABSTRACT

Backwashing process is critical for the normal operation of oilfield wastewater filter with walnut shell media. As the walnut shell media is different from the conventional media such as sand media in terms of surface physicochemical properties and the pollutants in oilfield wastewater are different from drinking water or municipal waste water, investigation on the backwash characteristics of walnut shell media used for the filtration of oilfield wastewater are necessary. In this paper, the performances of three backwashing modes including fluidization, hydraulic swirling, and blade stirring modes are experimentally evaluated for the dirty walnut shell media from an oilfield wastewater filter in Shengli oilfeild of China. The results show that blade stirring mode behaved well with the least backwashing water in comparison to the other two backwashing modes. The optimum rotating speed of blade for the blade stirring mode is about 120 rpm, and a sediment removal efficiency of near 90% is obtained when the residence time of filtration media is about 11 min in the vessel. Continuous backwashing operation of blade stirring mode is also demonstrated and the sediment removal efficiency of above 80% is obtained at a reasonable flow of clean water.

Keywords: Filtration media; Backwashing process; Blade stirring mode; Experimental study

1. Introduction

Oilfield wastewater containing suspended solids, dispersed oil drops, and some polymers used for the enhancement of oil recovery is harmful to the natural environment and must be treated before recycling [1,2]. Of all the treatment steps in the treatment process of oilfield waste water, filtration is the last step and considered to be very important. To date, various solid materials have been used as filter media, such as sand, anthracite, and walnut shell. In China, sand filters were widely adopted in the oilfields as a kind of effective filter to remove the suspended solids in wastewater before 1980s. With the growing concern on the improvement of oil recovery after 1980s, polymers have been extensively adopted in many oilfields, which results in the polymer concentrations in the oilfield wastewater becoming higher. As the walnut shell media have the pollutant-trapping function like ordinary media and the unique physicochemical properties to effectively absorb the dispersed oil and

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other organic substance droplets, more walnut shell filters are used to replace sand filters.

During the operation of walnut shell filter, the filter media would be saturated when the pollution content of treated water or the total pressure drop of filter bed reaches a certain value, and then a backwashing process is necessary [3,4]. Currently, three backwash modes have been proposed, including fluidization, fluidization assisted by mechanical stirring, and combined backwash of air and water, all these three modes have been confirmed to be feasible for the regeneration of used sand or walnut shell media [5–7]. The backwashing mechanisms of used filter media include the hydraulic shearing between media particles and water and the collisions between media particles [8]. As the combined backwash mode of air and water is more complex in system and consumes more energy, simple fluidization and fluidization assisted by mechanical stirring backwashing modes are most widely used in the oilfields of China now.

The related parameters of fluidization backwashing processes for walnut shell and quarts sand filter media are listed as follows:

For walnut shell media, the diameter is 0.5–1 mm, the density is 1,334 kg/m^3, filter media bed height is 0.7–1 m, backwashing rate of water is 8–10 $L/(m^2\,s)$, initial pressure of backwash water is 0.03–0.08 MPa, and the pressure drop during backwashing process is about 20%.

For sand media, the diameter is 0.5–1 mm, the density is 2,650 kg/m^3, filter media bed height is 0.7–1 m, backwashing rate of water is 12–15 $L/(m^2\,s)$, initial pressure of backwash water is 0.12–0.22 MPa, and the pressure drop during backwashing process is about 30%.

In conventional backwashing process, when low-density walnut shell media is used as the filtration media, some dirty media located at the corners of filter may not be effectively washed. In addition, some media will be washed out of the filter along with the backwash water flow when the backwash flow rate is too high, thus resulting in the media loss. To overcome these problems, an innovative backwash method is proposed, in which dirty media are firstly transported by a slurry pump to a separated regenerator and the washing process is completed there, then those clean media are returned to the filter by the recycled slurry pump.

For the design of compact separated backwashing equipment with high efficiency, studies on backwashing process are important. However, the existing literature on the backwash of filter media mainly focuses on the conventional sand and anthracite media for the treatment of drinking water or municipal waste water [3,4], and the main backwash modes are fluidization [8–10] and the combined water and air backwash modes [7,11–13], the study concerning on the walnut shell media for the treatment of oilfield-produced wastewater is rare. As the pollutants in oilfield wastewater are different from the drinking water or municipal waste water (there are more organic substances in oilfield waste water) and the physicochemical properties of walnut shell media are different from the conventional media (walnut shell media has lower density and better absorptive ability), the backwash characteristics of walnut shell media used for oilfield wastewater filtration should be different and more specific studies are needed.

In this paper, three types of backwashing modes (fluidization, hydraulic swirling, and mechanical stirring mode) are experimentally studied and compared in terms of their backwashing performances. In addition, those factors affecting the performance of mechanical stirring mode are further investigated.

2. Methodology

2.1. Introduction to three kinds of backwash modes

In the backwashing equipment, pollutants deposited on the surface of media particles are firstly removed by the interaction force between particles and the particles with water flow [8], and then taken out of the equipment by backwashing water. Therefore, intensifying the interactions between particles and the particles with water flow is the key to improve the backwashing performance.

For the fluidization backwash, clean water is injected into the filter media layer by a branched tube distributor located at the bottom of the backwash equipment, the fluidized media particles are lifted by the water jets. The detachment of pollutants adhered to the surface of media particles is accomplished mainly by the turbulent movement of media particles in water.

For the hydraulic swirling backwash, four vertical tubes with many nozzles on them are inserted into the vessel from the top along the inner wall of the vessel. During the backwashing process, some water from the nozzles of two vertical tubes is injected into the vessel in tangential direction, making the media particles swirling in the vessel, while the rest of the water from the nozzles of two other vertical tubes is injected into the vessel in radial direction. The pollutants on the surface of media particles are removed off by the interactions between swirling particles and radial water jets.

For the mechanical stirring backwash mode, water is sent into the vessel from the inlet at the bottom of the vessel, and meanwhile, filter media are stirred by the blades driven by a motor. The interactions between particles and the particles with water are intensified by the movement of the blades.

2.2. Experimental setup for fluidization and hydraulic swirling batch backwashing modes

The experimental setup of fluidization batch backwash is shown in Fig. 1. The vessel is made of plexiglass to observe the movement of water and filter media in the vessel, the height and diameter of the vessel are 0.7 and 0.2 m, respectively. A branched pipe distributor located at the bottom of the vessel is used to distribute the backwashing water flow, the backwash water flows out of the vessel from the overflow outlet, the screen meshes located at the overflow outlet are fixed in the inner wall of vessel to make sure that filter media are kept inside the vessel. When the backwash process is finished, clean filter can be drained from the bottom outlet.

The experimental setup of hydraulic swirling batch backwash is shown in Fig. 2. The vessel used here is the same as that in the fluidization backwash process. Four brass tubes with 12 small holes in the diameter of 1 mm on each tube are inserted from the top of the vessel to inject the backwashing water (only two vertical tubes are shown in Fig. 2), the jet direction of water from each brass tube can be adjusted by rotating the brass tubes.

2.3. Experimental setup for blade stirring backwashing mode

Experimental setup for mechanical stirring backwashing of filter media is shown in Fig. 3. The vessel is also made of plexiglass, and the height and diameter of the vessel are 0.6 and 0.14 m, respectively.

When the backwash experiment is in batch mode, a certain amount of dirty filter media is firstly put into the vessel, then backwash water is pumped into the vessel from the inlet on the left side of the vessel, and the blade begins to rotate to backwash the dirty filter media. Meanwhile, the used backwash water flows out of the vessel from the overflow outlet on the right side of the vessel, walnut shell media are kept inside the vessel by the screen meshes during the backwashing process.

When continuous backwash experiment is conducted in the experimental setup, dirty filter media are fed into the vessel by a screw feeder, with the backwash water simultaneously sent into the vessel from the inlet on the same side. Clean filter media and backwash water flow out of the vessel together from the overflow outlet on the right side of the vessel.

The mechanical stirring setup consists of two rectangle blade surfaces as shown in Fig. 4(a). One blade surface is 0.2 m high and 0.12 m wide with a rectangle gap in the blade surface, the height and width of the rectangle gap are 0.18 mm and 0.06 m, respectively. The other blade surface is 0.2 m high and 0.08 m wide without any processing on the surface. This kind of blade design could intensify the collisions between solid particles and the particles with water.

The pollutant sediment on dirty particles is mainly detached by the interactions between particles and the particles with the water flow. The trajectory of solid particles in our designed backwashing setup is described qualitatively in Fig. 4(b). The particles before narrow blade will be pushed forward by the blade surface; meanwhile, some particles will flow to

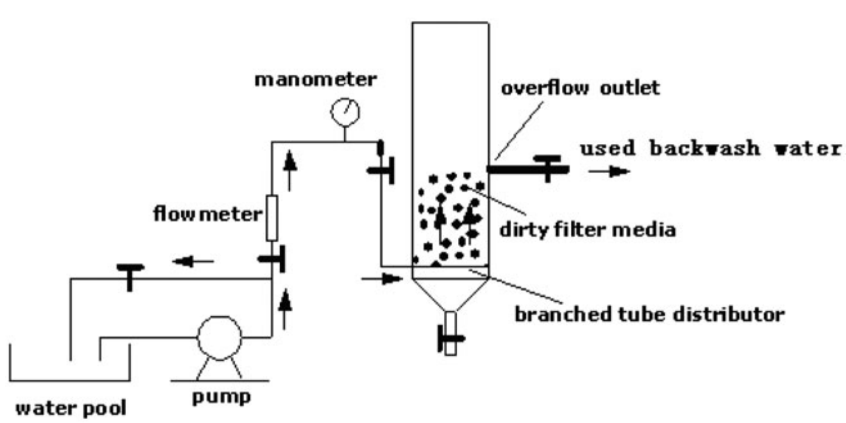

Fig. 1. Schematic diagram of experimental setup for fluidization batch backwash.

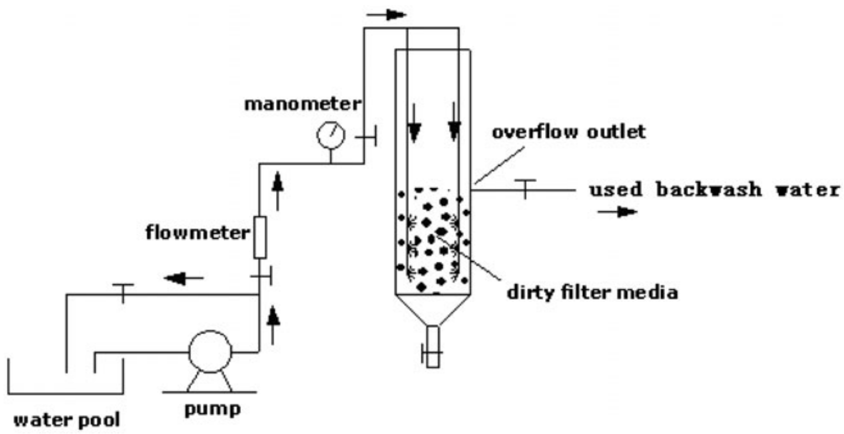

Fig. 2. Schematic diagram of experimental setup for hydraulic swirling batch backwash.

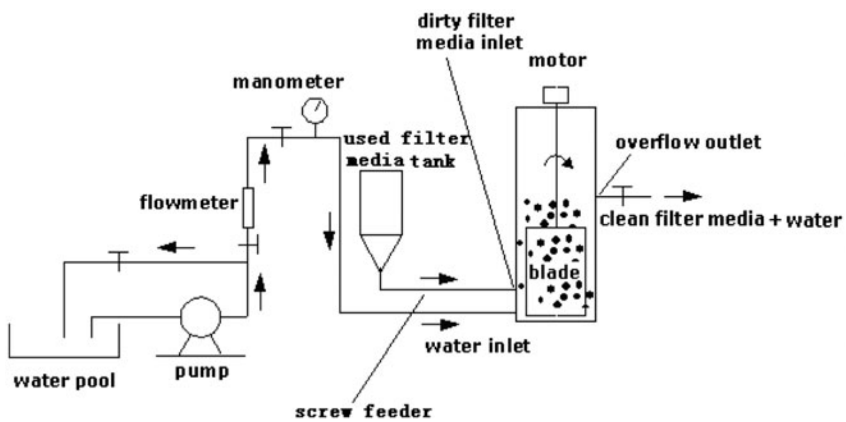

Fig. 3. Schematic diagram of mechanical blade stirring backwashing setup.

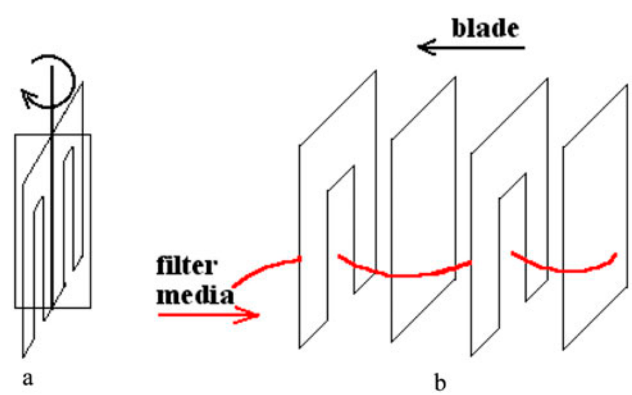

Fig. 4. Schematic diagram of blades and the movement trajectory of solid particles in vessel.

the back of the blade through the gap between the narrow blade and the inner wall of the vessel. The particles are subsequently pushed by the wide blade surface, some particles will change their movement direction and flow backward through the gap part in the middle of the wide blade surface. Thus, the solid particles will continually move in a wave-like way in the vessel. Through the continuous collision of particles with blade surface and the impact between particles, the pollutant sediment on the surface of particles can be removed effectively.

Pollutant removal rate is used to evaluate and compare the performance of different filter media backwashing modes. It is defined as the ratio of the pollutant mass removed from the media surface to the total pollutant mass adhered to the media surface prior to the backwashing process. The pollutant mass in filter media is determined by the weight difference of the used filter media (in dry state) before and after the pollutant removal. Chemical solvent is used to remove the pollutant in the used filter media.

3. Results and discussion

3.1. Comparison of different filter media backwashing modes

In this section, hydraulic swirling, fluidization, and mechanical stirring backwashing modes with walnut shell as filter media are evaluated and compared to identify the optimal filter media backwashing modes.

The dirty walnut shell filter media used in the experiment are from a fixed bed filter of Shengli oilfield in Shandong province of China. The properties of walnut shell filter media in dry and clean states are described as following: mean diameter of 0.5–1.0 mm, bulk density (also called as packed density) of 900 kg/m^3, true density of 1,334 kg/m^3, and shape factor of 1.3.

During the experimental process, batch operation mode is firstly adopted, with the same amount of dirty media (1 kg) into the backwashing setup and the same backwashing time (5 min) in each experiment.

The water flow rate required for the stable operation of experimental setup is the minimum flow rate in the hydraulic swirling and fluidization methods. The minimum water flow rates determined in both backwashing methods are different. In fluidization backwash, the minimum water flow rate is the one to make the media fluidized completely, whereas the minimum water flow rate in the hydraulic swirling backwash is the one to make all the media in the vessel agitated completely by the water jets from the nozzles. As for mechanical stirring method, water flow rate is 180 L/h (equivalent to the backwash rate of 3.244 L/m^2 s, here backwash rate is defined as the water flow rate per square meter cross section surface of filter) and the rotation speed of blade is 90 rpm. The experimental results of three backwashing modes are listed in Table 1.

It can be seen that three backwashing modes have similar pollutant removal rate, but different water consumptions under the experimental backwash conditions. Fluidization mode needs the highest water consumption, and the water amount in mechanical stirring and hydraulic swirling modes is less.

For hydraulic swirling method, the pollutant on the particle surface is mainly removed by water shearing action. As the movement directions for most of the particles are the same as the flow direction of water flow under the experimental condition, which results in the relatively weak water shearing action, the pollutant removal efficiency is not high enough.

For fluidization backwashing method, the fluidized particles have stronger movements relative to the water flow in the vessel; this could result in a strong water cleaning action. Meanwhile, the high particles concentration in the vessel could also lead to the strong interactions between particles. The combined removal mechanisms of water flow jet and particle impacts make fluidization method having better pollutant removal result. However, this kind of mode needs high water jet velocity and high initial pressure of backwash water.

For mechanical stirring backwashing method, the forces exerted on particles include the forces between particles, particles and blade surface, particles and wall surface of vessel, and hydraulic force caused by water stream. The main pollutant removal mechanism is the combination of all kinds of impact actions instead of water jet. The main function of water is to carry away the removed pollutant from the particle surface. For this reason, mechanical stirring method behaves well with the lowest water consumed.

The energy consumptions of three backwashing modes are also compared in this study. The energy required in backwashing process is consumed by motor for driving the blade under mechanical stirring mode and by pump for all three modes. The flow rate of backwash water for mechanical stirring mode, hydraulic swirling mode, and fluidization mode is 3.244, 6.137, and 14.44 L/(m^2 s), respectively. The initial pressure of backwash water is 0.05, 0.12, and 0.08 MPa, respectively. The motor output for mechanical stirring is 750 W, therefore the consumed total energy for three backwashing modes is 912, 736, and 1,155 W, respectively. Based on the above energy consumption results, the backwashing mode consuming the highest energy is fluidization mode; the mechanical stirring mode and hydraulic swirling mode use less energy.

Compared with the other two backwashing modes, mechanical stirring backwashing equipment is easy to

Table 1
Experimental result of three backwashing modes

Mode	Backwash rate (L/m^2 s)	Pollutant removal rate
Mechanical stirring	3.244	0.7164
Hydraulic swirling	6.137	0.6970
Fluidization	14.44	0.7313

scale up and could treat near all kinds of filter media with low water consumption. In addition, the operation parameters of this method are also convenient to control because of the mechanical movement characteristic of the blades.

3.2. Experimental study on the batch operation of mechanical blade stirring backwashing method

Though its energy consumption is a little higher than hydraulic swirling mode, mechanical stirring method is a good backwashing method compared with the other two kinds of methods in backwashing water consumption, pollutant removal rate, and adaptability of filter media kinds; therefore, further studies are carried out to investigate the effects of blade rotation speed and operating time on the pollutant removal.

3.2.1. Effect of blade rotation speed

The experimental conditions are listed as follows: the water backwash rate is 3.244 L/m^2 s, static bed height of filter media is 0.07 m, and the operating time is 3 min. The experimental results are shown in Fig. 5. It can be seen that firstly the backwashing performance of filter media is significantly enhanced and then the improvement extent gradually decreases with the blade rotation speed increasing to 120 rpm. However, the backwashing performance deteriorates with the blade speed further increasing.

The reasons causing the above results are listed as follows:

At first, the blade speed is rather low, the impacting and detaching action intensity between particles and blade surface as well as the turbulent degree of particle movement could be easily enhanced with the increase of blade rotation speed.

When the blade speed exceeds certain critical speed, the high-speed rotation of blade would result in the solid particles in the vessel entrained by the water flow; this will decrease the particle concentration in the bottom of vessel and weaken the impact action between particles. Meanwhile, the movement direction of more particles will be the same as that of blade rotation, so the interaction intensity between particles and blade surface will become low.

The combination of the above two reasons results in the deterioration of backwashing results in the case of high blade speed.

3.2.2. Effect of backwashing time on backwashing results

The experimental conditions are listed as follows: the blade rotation speed is 90 rpm, the water backwash rate is 3.244 L/m^2 s, and the static bed height of filter media is 0.07 m. The experimental results are shown in Fig. 6. It is clear that the pollutant removal rate shows an increased trend with the increase of operation time, indicating that the longer backwashing time could result in better backwashing result of filter media. After 11 min of operation time, near 90% pollutant removal rate is reached.

In some cases, the oil pollutants on the dirty walnut shell media are difficult to be removed due to

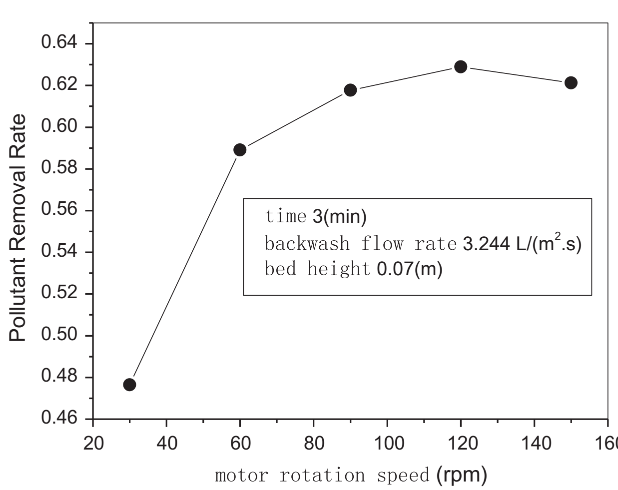

Fig. 5. Effect of blade rotation speed on backwashing performance.

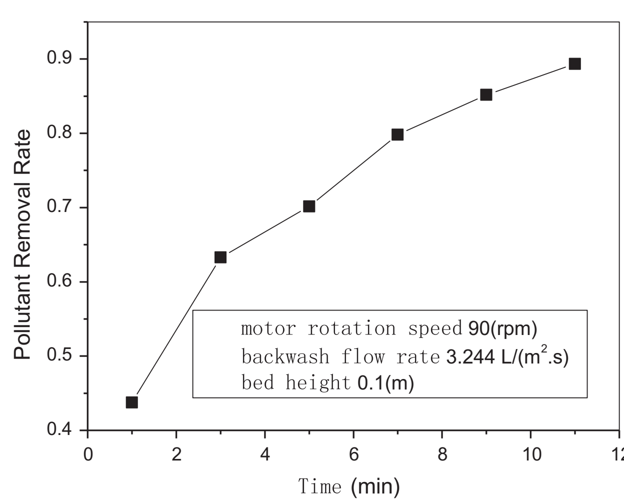

Fig. 6. Effect of operating time on the backwashing result of filter media.

the strong binding force between particle surface and oil pollutants. To improve the backwashing performance of walnut shell media, chemical additives such as surfactants have been tested and applied in some oilfields of China. If such chemical additives are applied in the backwashing experiments, the required time to satisfy the backwashing demand of filter media will be decreased further.

3.3. Experimental study of continuous operation of blade stirring backwashing method

During the continuous operation, the dirty filter media and backwash water are continuously sent into the vessel. After the backwash, the clean filter media is also continuously drained out of the vessel along with the water flow from the overflow outlet.

The key to the successful operation of continuous backwashing equipment is that the residence time of filter media in vessel should be longer than the minimum time required for the filter media cleaning. Here, the mean residence time of particles is defined as the ratio of filter media reserve in vessel to the discharging flow rate of filter media. The mean residence time of particles in vessel could be prolonged by increasing the media reserve in vessel or decreasing the discharging rate of filter media.

In addition, to obtain a good backwashing result, the backmixing degree of particles in vessel should be low enough to make different particles having similar residence time in vessel. Of the three tested backwashing methods, mechanical stirring method has the lowest backmixing degree in axial direction. The reason is that the particle movement is mainly caused by the rotated blade in the mechanical stirring backwashing process, so the velocities of particles in radial and tangential direction are high but the velocity of particles in axial direction is relatively low, resulting in the low backflow extent of particles in axial direction. Therefore, mechanical stirring method is suitable for the continuous operation of filter media backwashing.

In the continuous backwash experiment, used filter media is fed into the vessel by a screw feeder from the inlet at the bottom position of vessel wall, and clean filter particle is drained out along with the water flow from the overflow outlet at the top position of opposite wall of filter media inlet.

The experimental conditions of continuous operation of mechanical stirring backwashing method are listed as follows: the blade rotation speed is 60 rpm, the water backwash rate is 3.244 L/m^2 s, pollutant mass content of used filter media is 1.7396%, the reserve volume of filter media and water mixture in vessel is 4 L, the discharging rate of filter media and water mixture is 0.5 L/min, therefore the mean residence time of filter media in vessel is 8 min.

Table 2
Backwashing results of continuous operation of mechanical stirring method

Backwashing time (min)	10	13	16	19	22
Pollutant removal rate (%)	82.6	84.9	86.3	85.9	86.2

Prior to the equipment operation, clean filter media are firstly put into the vessel, then the experimental setup begins to run, and dirty filter media are put into the vessel continuously at the flow rate of about 0.315 L/min by the screw feeder. After 10 min of continuous operation, the discharged filter media sample is taken at the outlet every 3 min. The backwash results of filter media samples are shown in Table 2.

Based on the above experimental results, more than 80% pollutant removal rate can be reached under the experiment condition in this paper. However, better backwashing results can be achieved if blade rotation speed, water flow intensity, filter media reserve, and filter media discharging rate could be optimized, and chemical additive is used.

4. Conclusion

(1) Fluidization, hydraulic swirling, and mechanical blade stirring modes have similar pollutant removal rate but different water consumptions in the batch backwashing experiments with the same backwashing time. Of the three tested backwashing modes, hydraulic swirling and mechanical blade stirring behave well with less backwashing water, whereas the water consumption of fluidization backwashing method is much higher.
(2) The batch operation study on mechanical blade stirring method shows that the backwashing result is the best when the blade speed of experimental setup is about 120 rpm, and near 90% pollutant removal rate can be reached after 11 min of operation at the blade speed of 90 rpm.
(3) In the case of continuous operation of mechanical stirring method, more than 80% pollutant removal rate can be reached under the low water flow intensity. Better backwashing results can be obtained if related operating parameters are further optimized.

(4) The other advantages of mechanical stirring backwashing method are the relatively easy control of operation parameters and the low backmixing degree of filter media in axial direction in vessel.

References

[1] F.R. Ahmadun, A. Pendashteh, L.C. Abdullah, D.R.A. Biak, S.S. Madaeni, Z.Z. Abidin, Review of technologies for oil and gas produced water treatment, J. Hazard. Mater. 170 (2009) 530–551.

[2] F. Li, X. Wu, J. Wu, X. Xu, S. Ma, Kinetic study of adsorption of oil from oilfield produced water using modified porous ceramics filtration media in column mode, in: Proceedings of the Second International Conference on Bioinformatics and Biomedical Engineering, Shanghai, May 16–18, 2008.

[3] J.C. Crittenden, Water Treatment: Principles and Design, second ed., John Wiley, Hoboken, 2005.

[4] Metcalf and Eddy Inc., Waste Water Engineering: Treatment, Disposal and Reuse, third ed., McGraw-Hill, New York, NY, 1991.

[5] F.Y. Zhang, A.X. Jiang, L. Zhang, B. Yan, F. Li, The backwashing mechanism and efficiency of low pressure and steady flow walnut shell filter, Water Waste Water Eng. 33 (2007) 89–93 (in Chinese).

[6] C.Y. Liu, L.Q. Chen, F. Li, Paddle type influence on backwashing flow field of walnut shell filter, Chem. Eng. Mach. 40 (2013) 211–214 (in Chinese).

[7] F.J. Xia, Y.Z. Ren, X.N. Sui, Gas water back-flushing technology for improving the regeneration effects of oilfield produced water filter, Environ. Prot. Oil Gas Fields 24 (2014) 42–45 (in Chinese).

[8] C.S.B. Fitzpatrick, Observations of particle detachment during filter backwashing, Water Sci. Technol. 27 (1993) 213–221.

[9] B. Quaye, Predicting optimum backwash rates and expansion of multi-media filters, Water Res. 21 (1987) 1077–1087.

[10] I. Sholji, F. Johnson, Comparison of backwash models for granular media, J. Environ. Eng. 113 (1987) 516–531.

[11] A. Amirtharajah, Optimum backwashing of filters with air scour: A review, Water Sci. Technol. 27 (1993) 195–211.

[12] D. Stevenson, Process conditions for the backwashing of filters with simultaneous air and water, Water Res. 29 (1995) 2594–2597.

[13] D.G. Heminings, C.S.B. Fitzpatrick, Pressure signal analysis of combined water and air backwash of rapid gravity filters, Water Res. 31 (1997) 356–361.