Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.769490

51 (2013) 4768–4778
June

Taylor & Francis
Taylor & Francis Group

Fluidization of fine particles and its optimal operation condition in multimedia water filter

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Received 15 February 2011; Accepted 24 October 2012

ABSTRACT

Approach: Backwashing process was implemented using column of deep bed filter with different media characteristics to provide optimal operation condition. Minimum velocity of fluidization (V_{mf}) and porosity at minimum fluidization (e_{mf}) were investigated under different operation condition and grains size. The results were compared with Wen and Yu equation and Richardson–Zaki correlation, respectively. Backwashing model was developed to predict the effect of fluid shear strength (τ_a), velocity grade (G), dissipation rate coefficient (C_a), and parameters of random motion ($C_a^{0.5}/\mathrm{Re}$) on the energy dissipation rate during fluidization process. *Results:* The simulated result of proposed models gives a good convergence to observed data. It was seen that a smaller size of sand media need a lower value of backwash velocity than a higher size for lifting filter media. Fixed bed porosity increased from 0.510 to 0.704 at bigger size of sand media (1.18 mm), while it increased to 0.680 at smaller size of sand media (0.5 mm). The simulated result showed that Richardson–Zaki model has a good convergence with experimental result of expanded porosity for all effective size of sand media. *Conclusion:* It was concluded that low superficial velocity produced through the system at higher velocity grade (G). In addition to that the fluid shear strength (τ_a) increased along with expanded porosity. The maximum fluid shear strength (τ_a) was occurred at porosity equal to 0.730 and in large effective size of sand media (1.18 mm). Also, the lighter particles caused a high increasing rate in the random motion parameters compared with heavier particles. The study showed that the effluent suspended solid and hydrodynamics detachment of deposited fine particles reduces with time of fluidization but it rises with backwash discharge. The bigger grain of sand media has a lower peak point of optimum backwash time than smaller grain due to accumulation a large amount of deposit fine particles. The study was shown that the energy dissipation rate and the velocity grade have a dominant mechanism in filter backwashing and increases with increasing particle population in a expanded bed. The result revealed that the random motion parameter increased along with increasing in fraction solids and a higher rate was appeared in the lighter particles that it caused increasing in random motion parameter compared with heavier particles.

Keywords: Fluidization; Fine particle; Media; Water filter; Expanded bed

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1. Introduction

Backwashing of deep bed filters is executed by fluidizing the filter media and is a more critical process than filtration. A backwashed filter roles generally as a particularly expanded bed in which the upward flow of a fluid through the bed at an adequate velocity suspends the particles. A further increase in the velocity led to increased bed expansion and the particles within the bed move randomly. An incorrect backwash velocity and inadequate design of filters is caused operational problems [1–3]. The deposited fine particle leads to blockage the pores of filter media and increases head loss in the bed. Therefore, the quality of a back washed filter and the hydrodynamics detachment rate of deposited fine particle from the filter media should be illustrated. Fluidization of bed is a preferred process to remove the deposited fine particle on the filter bed. In addition, washing with water preceded by an air scour raises the effectiveness of backwashing filters [4,5]. Designers of water filtration plants need to calculate accurately the expansion of filter media. The expansion of filter media is determined via measuring the minimum freeboard between the top of the media and the edge of the backwash trend upward weir to prevent the filter media losing during the backwash process. Best design practice at present is to either conduct experimental tests on the media selected for the plant or, more commonly, to use the grading analysis of an oven-dried sample in conjunction with a theoretical bed expansion model. In the last decade years, observations at numerous treatment suggested that these approaches are possibly damaged media losses always more than anticipated when the surface level of media appeared well below the originally specified media level [6]. As the air bubbles are unintentionally released, the trapping of under flow of air is a well-known reason for media loss. Meanwhile, backwash phase via water could prevent a cloud of media, which is suspended in the water above the media and dropped over the overflow weir before it can settle again. Nevertheless, even where this problem was eliminated, a problem with excessive media loss was evident. This eventually led to a study to the expansion bed experimentally and theoretically in this work during backwash of deep bed water filter. A backwashed filter is described as a particulate expanded bed in fluidization terminology [7]. The expansion and fine particle mixing characteristics of an expanded bed collected of different particles is a complicated function of many variables, counting, particle characteristics, and random motion effects of the fluid [8]. The total energy dissipation rate during backwashing is produced with the power essentially to lift filter particles and the power is dissipated by the turbulent fluctuations. The purpose of this study is to (1) develop a backwashing model which describes influence of different size of filter media on energy dissipation in a backwashed filter through investigating the influence of fluid shear strength (τ_a), velocity grade (G), dissipation rate coefficient (C_a), and parameters of random motion ($C_a^{0.5}/\mathrm{Re}$) on the energy dissipation rate during fluidization process. (2) Investigate the possible ways to remediate dirty filter media during backwashing process by determining the expanded limit of sand layer and prevent losing of filter media. To reach this objective, experimental and theoretical investigations were carried out to predict a minimum velocity of fluidization and expanded bed porosity under different operation condition.

2. Materials and methods

2.1. Experimental pilot scale

Fluidization process was implemented by a pilot scale of multimedia water filter with height (120 cm) and diameter (10 cm). The pilot scale of multimedia water filter has been designed to work identically to full-scale granular water filters. Multigrain size was investigated on this pilot-scale system to provide optimal operation data. All media type was supported on a PVC orifice plate perforated with 5 mm holes and supplied by a wire mesh to not allow for sand particles and granular-activated carbon passing throughout the orifices. A pilot-scale system is fixed in front of tube column to select the bed depth. A pilot scale of multimedia water filter is a obvious acrylic unit fix on a floor standing framework about 2 m high with flanged end pieces to allow easy access. Corrosion-resistant gauze mesh is provided below the system for supporting the media and filled by 1 kg of 0.01 m Ballotini to make sure a high quality of wash water. Plain tubes also penetrate the medium throughout the wall to transmit pressure to a manometer table. These sampling and manometer probes are positioned at 0.02 m depth intervals, but staggered in position, over 0.8 m depth. A number of manometers are positioned beside the filter column to calculate the head loss profile during fluidization process for selecting the minimum fluidized velocity. As shown in Fig. 1 a pilot scale of multimedia water filter consist of pump, sump tank, flow controller, Rota-meter, control valves, tubing, sampling tubes, differential manometers, and the turbidity Meter (LP2000) which is used as a measuring of concentration profile.

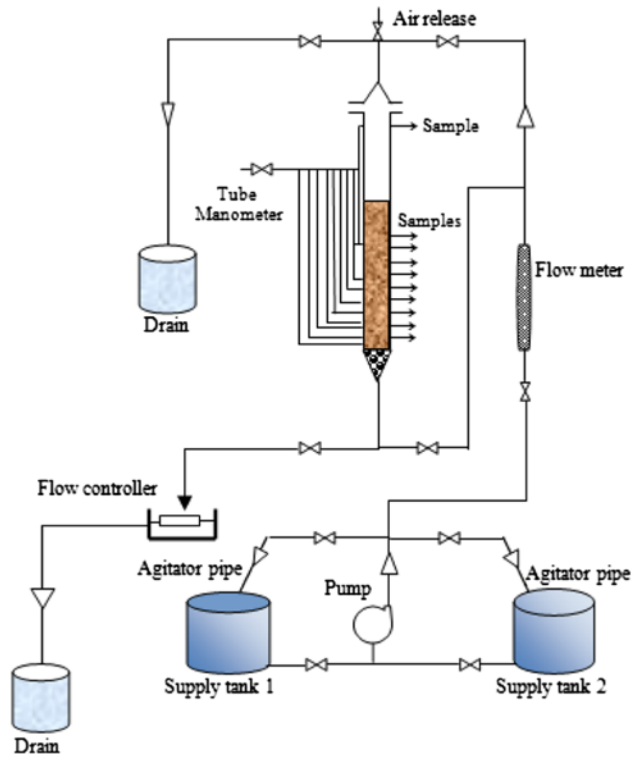


Fig. 1. Schematic diagram of deep bed water filter with all main parts.

2.2. Operation of backwashing process

Raw water was taken from water treatment plant of Wuxi city before entering the filtration units. Then, raw water pumped into a feeding tank of deep bed filter. The characteristics of influent water were showed in Table 1. The under downflow fixed-bed head-loss pattern was calculated subsequent to the backwash completed. The backwash flow was changed at a rate from 3 to 12 L/h before the pump was shut off at the end of every experiment. Three experiments were implemented with different characteristic of grain size media as shown in Table 2. Laser light scattering (Particle Analyzer HORIBA LA-950) was used for analyzing particle size distribution in raw water (Table 3). Each run consisted of filtration and following backwash. The filtration discharge was 30–78 L/h and each filtration run lasted 3 h when the suspended solid (SS) concentration of the filter effluents reached 4 NTU. The backwashing processes were implemented with 54–150 L/h depending on grain media and deposit of suspension particle. The effluent of SS concentration of the backwash water, varied between 2 and 1100 NTU related to the variations of total backwash rate and operation time.

Table 1
Characteristics of raw water

Item	Value
Cl^- (mg/L)	123
HCO_3^- (mg/L)	165
SS (g/L)	14–22
EC (μmhos/cm)	909
SO_4^{2-} (mg/L)	26
pH	7.4
Ca^{2+} (mg/L)	88
Mg^{2+} (mg/L)	34
Na^+ (mg/L)	74
DO (mg/L)	7.1
Total hardness (mg/L)	360

Table 2
Characteristics of sand media with operation data

Parameters	Range	Units
Particle density	2.65	g/cm^3
Feed discharge (filtration)	30–78	L/h
Backwash discharge	54–150	L/h
Height of bed	5–30	cm
Effective size of grain	0.5–1.18	mm
Sphericity	0.7–0.82	–
Porosity, e	0.51–0.44	–
uniformity coefficient (UC)	1.36–1.22	
Porosity at incipient fluidization, e_{mf}	0.49–0.62	–

Table 3
Distribution of fine particle in raw water

Particle diameter dp (μm)	Range (mg/L)	Average (mg/L)	Accumulative (%)
0.01–1	8000–13,000	9300	57.1
1–10	4500–7600	5904	89.2
10–100	1409–1500	1547	99.35

2.3. Analysis of expanded bed

The objective of backwashing study is to know the expanded limit of sand layer for preventing media losing. Therefore, a number of experiments were implemented to determine the expanded length of fluidized media which is using to predict the porosity of expanded bed as shown in Eq. (1).

$$\frac{l_f}{l} = \frac{1-e}{1-e_{mf}} \tag{1}$$

3. Modeling of fluidizing process

3.1. Minimum velocity of fluidization (V_{mf})

A number of experiments were implemented to predict V_{mf} and the experimental results were compared with Wen and Yu equation [9,10].

$$V_{mf} = \frac{\mu}{\rho\, dg} \times (33.7^2 + 0.048\; Ga)^{0.5} - \frac{33.7\mu}{\rho\;\; dg} \tag{2}$$

Discharge flow meter was used for finding the minimum velocity of fluidization. The reading of discharge flow meter represents backwash rate, thus the value of minimum velocity of fluidization was intended by measuring the pressured drop with different discharge. Then, the result is plotted depending on the quantity of compaction of the filter media at incipient fluidization. The variation of pressure drop pattern with backwash rate was found via measuring the height of water in manometer pored.

3.2. Expanded bed model

Expanded bed can be expressed as bed with upward flow of a fluid through it at a sufficient velocity for suspending its particles. The Richardson–Zaki correlation [11] is widely used to demonstrate characteristics of expanded bed as follows:.

$$e^n = \frac{u}{u_i} \tag{3}$$

Since particles in the deep bed water filter are non spherical shape so that the fluidization bed with non spherical particles in the deep bed water filter differs from the fluidization bed with spherical particles. So, the following equation is written as follows:

$$u_i = u_t 0.91 \Phi^{0.4} \tag{4}$$

where the terminal velocity of particles is expressed by (u_t) and the coefficient of expansion (n) is shown in the following equations [12].

$$n = \left(\frac{4.45 + 18\; dg}{D}\right) \mathrm{Re}_t^{-0.1} \Phi^a \quad \text{for } 15 \leqslant \mathrm{Re}_t \leqslant 200 \tag{5}$$

$$n = 4.45 + 18\; \mathrm{Re}_t^{-0.1}\; \Phi^a \qquad \text{for } 200 \leqslant \mathrm{Re}_t \leqslant 503 \tag{6}$$

where

$$a = -2.9237\; \mathrm{Re}_t^{-0.363} \Phi^{0.994} \text{ and } \mathrm{Re}_t = \frac{\rho\, u_t dg}{u}$$

The model is structured in terms of e, which is related to linear bed expansion by Eq. (1).

3.3. Energy dissipation rate

The energy dissipation rate in a deep bed water filter during fluidizing process increases owing to the random motions of particles and turbulent fluctuations in the bed size and density of the deep bed filter materials wholly influence the fluidization behavior of the media. In this work, a model is applied for predicting the energy dissipation rate parameters specifically the fluid shear strength (τ_a), velocity grade (G), the random motion dissipation coefficient (C_a), and the random motion parameter ($C_a^{0.5}/\mathrm{Re}$) in backwashing of deep bed filters for different size of grain sand. The flow regime in a backwashed deep bed water filter is transitional regime ($1 < \mathrm{Re}_t < 500$) between laminar and turbulent conditions. The transition flow regime consists of a transition core at the center of the column and laminar sublayer near the wall. In a multiparticle system, the drag force acting on one particle is affected by the occurrence of the other particles [13] so that the turbulent power produced locally due to turbulent fluctuations equals the power dissipation by random motion. The total energy dissipation in a unit volume P_v can be written as follows:

$$P_v = \psi_1 + \psi_1 = \mu(1+w)\left(\frac{\partial u}{\partial y}\right)^2 \tag{7}$$

where ψ_1 and ψ_2 are the energy dissipation in a unit volume by time-mean motion and the energy dissipation in a unit volume by turbulent motion, respectively, ω is a coefficient which represents the influence of random motion in the velocity of x direction (u). The velocity grade (G) and the fluid shear strength (τ_a) are very important for predicting optimum cleaning of a backwashed deep bed water filter. So that the velocity grade (G) can be defined as follows:

$$G = \left(\frac{\partial u}{\partial y}\right) = (P_v/\mu(1+w))^{0.5} \tag{8}$$

Energy equation of flow during fluidizing process can be expressed as the following equation:

$$\tau \frac{\partial u}{\partial y} = \left(\alpha_1 \rho \frac{{U_*}^3}{KL_m} + \beta \alpha_1 \rho \frac{{U_*}^3}{KL_m} + \rho \frac{{U_*}^3}{KL_m} \right) e^{n-1} \tag{9}$$

The left term of Eq. (9) represents the energy necessary to suspend particles and the first and second of right term of Eq. (9) is the rate of energy removal through motions of suspended particles, while the last term of Eq. (9) represents the energy dissipated rate and diffused by a random motion of liquid phase. β is a coefficient depending on random motion of particles $\alpha_1 = u_i/u_0$ is a coefficient related to particle characteristics, and K is represents constant of flow in suspended particle, the von Karman universal constant, which can be expressed as follows:

$$K = \frac{K_0}{(1 + 2((1 - e))} \tag{10}$$

$$L_m = \frac{{U_*}^3}{kgu_t((\rho_s/\rho) - 1(1 - e))} \tag{11}$$

where L_m is Monin-Obukhov length, K_0 is the von Karman universal constant for pure water (0.4), and $(1-e)$ is concentration of fraction solids. Also, the specific density of fluid and particle mixture ρ_m and the friction velocity U^* are expressed in Eqs. (12) and (13), respectively.

$$U_* = \left(\frac{g\rho^4 \rho_m}{(\rho_s/\rho - 1)D} \right)^{0.5} \tag{12}$$

$$\rho_m = \rho[1 + (\rho_s/\rho - 1)(1 - e) \tag{13}$$

In this work, a model is used to illustrate the influence of different sizes of grain sand on the energy dissipation rate parameters such as the fluid shear strength), velocity grade (G), random motion dissipation coefficient (C_a), and the random motion parameter ($C_a^{0.5}$/Re). The fluid shear strength τ_a is calculated by integrating on the cross section area of the fluidization column.

$$\tau_a = e^{n-1}[a \ \ (1 - e)^{0.5} + b\,(1 - e) \tag{14}$$

where a, b are constants, and from Eq. (14), the coefficient (G_m) can be obtained in an arithmetic mean.

$$G_m = 8U_*[\ln(\rho U_* \ D/23.3\mu) - 1\,)/KD \tag{15}$$

The fluid shear strength can be derived in an arithmetic mean as follows:

$$\tau_a = \rho U_*^2 e^{n-1}[\alpha D/6L_m] + 1/KD \tag{16}$$

$$\alpha = \alpha_1(1 + \beta) = 7\frac{u_i}{u_t} \tag{17}$$

Eq. (16) can be rearranged in an arithmetic mean form. The following equation can be given for the calculation the random motion dissipation coefficient C_a after calculating the τ_a and the G_m values for this model:

$$C_a = \frac{\tau_a}{\mu G_m} - 1 \tag{18}$$

To evaluate the random motion intensity $(\tilde{u}^2)^{0.5}/U$, the random motion parameter ($C_a^{0.5}$/Re) can be determined as:

$$(C_a^{0.5}/\mathrm{Re}) = \left(\frac{\tau_a}{\mu G_m} - 1 \right)^{0.5} / \mathrm{Re} \tag{19}$$

where $(\tilde{u})$ is the fluctuating velocity of random motion. The Reynolds number of the flow can be expressed as follows:

$$\mathrm{Re} = \left(\frac{\rho U \ dg}{\mu} \right) \tag{20}$$

4. Results and discussion

4.1. Simulated results of expanded bed

Several experiments were implemented to investigate the expansion of the deep bed water filter. The results were then compared with Richardson–Zaki model. Fig. 2 depicted the effect of media grain size on the superficial velocity that required for lifting filter media. It is depicted that a smaller grain (0.5 mm) requires a lower backwash velocity of 0.007 m/s to lift bed filter media, while the higher grain (1.18) mm of sand media requires 0.021 m/s as optimal backwash velocity owing to the high surface area and weight of individual partials. Thus, the magnitude of drag force increased for expanding bed media. Fig. 2 depicted that the experimental data gave a good correlation with Richardson–Zaki model. Fig. 3 shows the convergence between model and measurements of expanded bed porosity for each grain media size. It can be seen that a smaller size of sand media need a lower value of backwash velocity than a higher size for lifting filter media. Fixed bed porosity increased from 0.510 to 0.704 at bigger size of sand media (1.18 mm), while it increased to 0.680 at smaller size of sand media (0.5 mm).

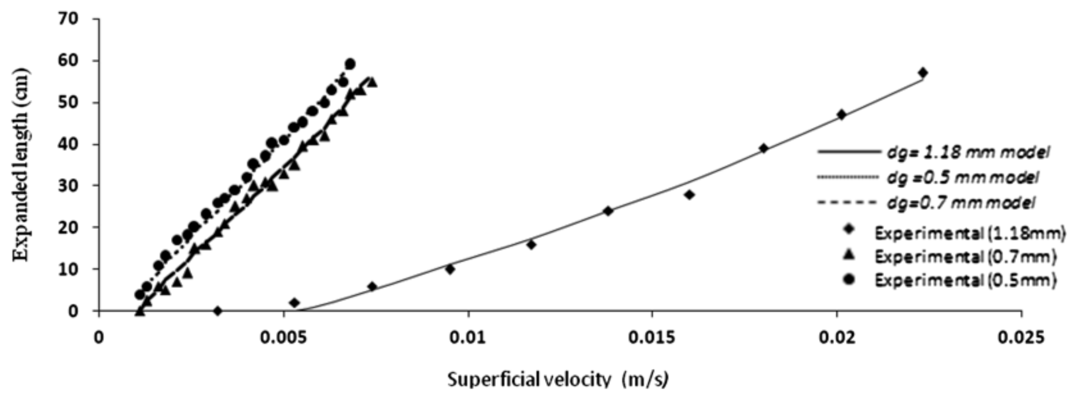


Fig. 2. Predicated and measured expanded bed length vs. superficial velocity for different grains sand.

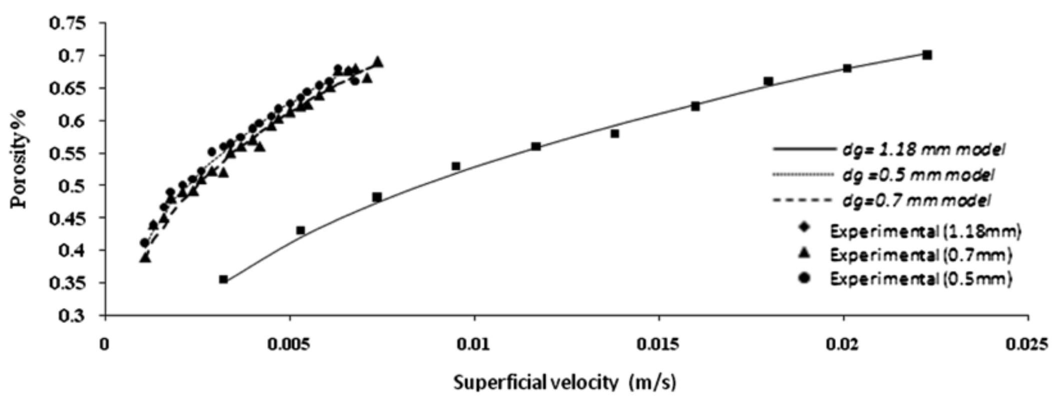


Fig. 3. Predicated and measured porosity vs. superficial velocity for different grains sand.

4.2. Predicting minimum velocity of fluidization

The meeting point between the fixed bed and expanded bed in the head loss profile verses superficial velocity represent the minimum velocity of fluidization. The pattern of head loss increases linearly with backwash velocity while it remains constant across a fully expanded bed. Fig. 4(a-c) showed that the fluidization profile of deep bed filter at various grain sand media and fixed bed height of 60 cm, whereas the value of V_{mf} was found experimentally depends on the degree of compaction of the deep bed filter media at incipient fluidization. The minimum velocity of fluidization is found by interaction two curves fitting of the experimental data, projects it on x-axis, and compares the result with Wen–Yu's equation.

Fig. 4 gives a good agreement between the observed values and the predicting values by Wen and Yu model. It illustrated that the peak of head loss profile is observed at the initial point of fluidization. Furthermore, the maximum peak point is associated with some force essentially to fluidize the packing. This force may be a result of some static friction within the sand medium. One theory that we propose is that forces that are adhering the particles of the grins sand together cause the static friction within the medium. This force could be likened to the forces between the grains of sand in a sand filter. The fine particles of media sticks together owing to the particle–particle interactions have higher stability than the particle–water interactions. Therefore, when water surrounds the sand particles, the attraction of the sand for other sand particles is greater than its attraction for water, which creates a net attractive force and reduces the area of the solid–liquid interface. This effect is called the capillary effect. The result of Fig. 4 demonstrates that the smaller grain size has lower values of minimum fluidizing with a more prominent peak because of these grains would have more particles–particle interaction.

4.3. Effect of media characteristics

In this study, the energy dissipation rate model for filter backwashing was established to predict the energy dissipation rate parameters specifically the velocity grade, the random motion dissipation coefficient, the fluid shear strength, and the turbulent

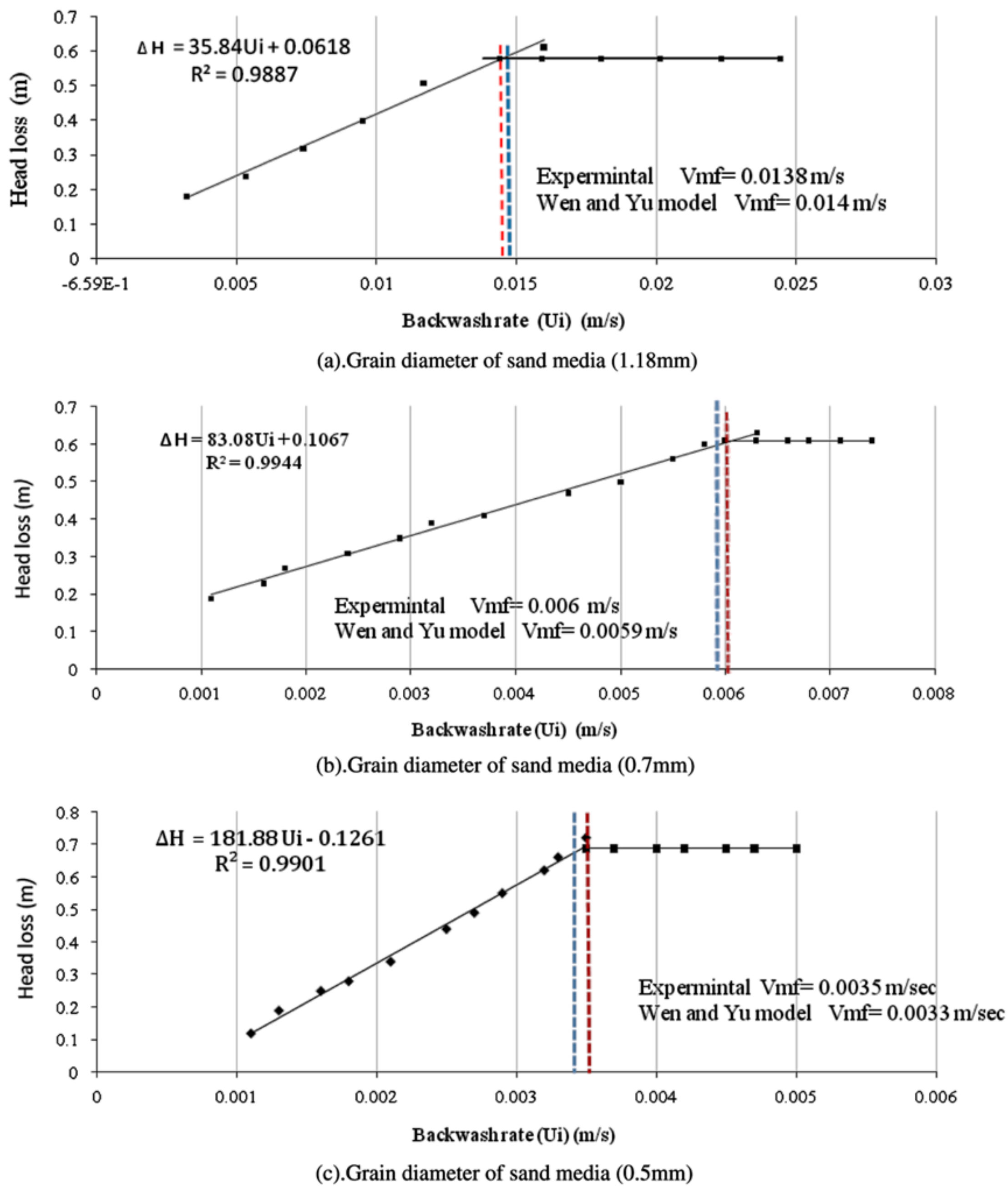


Fig. 4. Minimum fluidization velocity for different grain size. (a) Grain diameter of sand media (1.18 mm); (b) Grain diameter of sand media (0.7 mm); and (c) Grain diameter of sand media (0.5 mm).

parameter for special types of filter media. The superficial velocity of expanded bed was applied according to the results of bed expansion, which is explained in the first section.

4.4. *Effect of velocity grade*

The velocity grade is the most effective factor in the granular bed filters. The mean velocity grade in the present model was plotted in Fig. 5(a) and (b) vs. fraction solids $(1 - e)$. The result shows that the value of velocity grade increases as the fraction solids increase. This means that a lower superficial velocity through the system require a higher velocity grades. At the optimum backwashing conditions as fraction solids of (0.29–0.31) in (1.18–0.5) mm grain sand and the velocity grade varied between $1.0291 \times 10^3\,s^{-1}$ and $1.055 \times 10^3\,s^{-1}$, respectively.

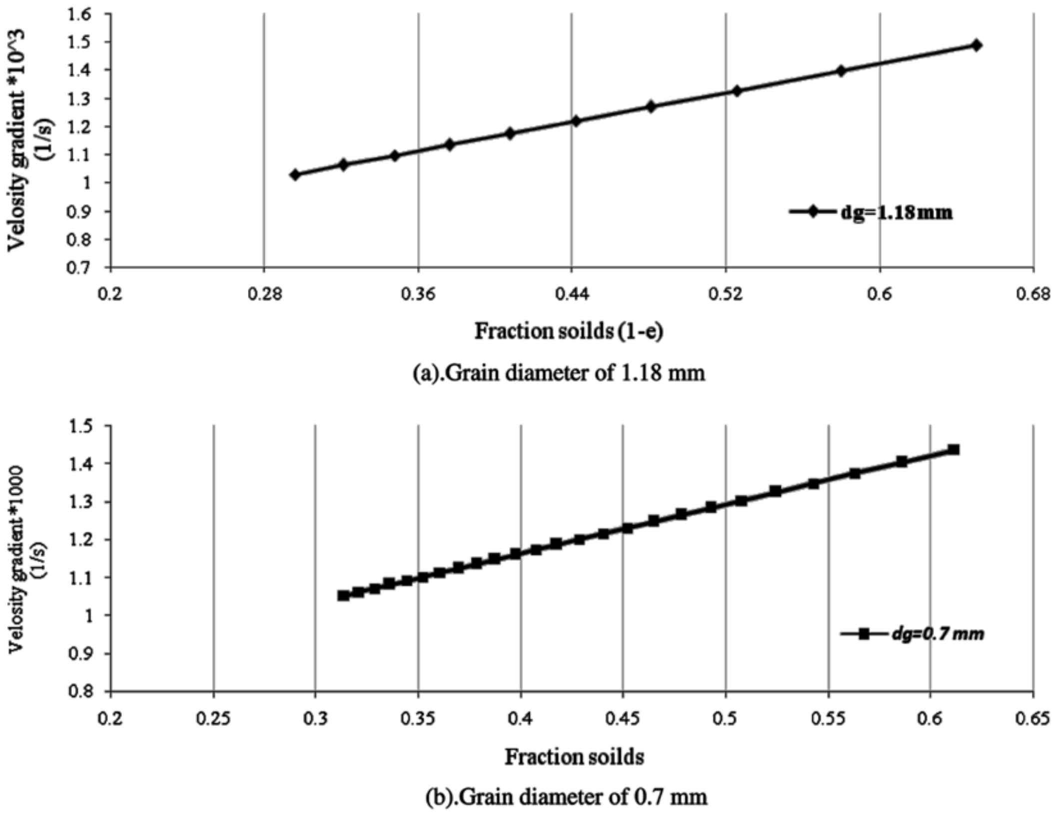


Fig. 5. Effect of velocity gradient on media grain size. (a) Grain diameter of 1.18 mm and (b) Grain diameter of 0.7 mm.

4.5. *Effect of fluid shear strength* (τ_a)

The fluid shear strength was plotted in Fig. 6 as a function of porosity or fraction solid that optimize the best condition of backwashing bed filter, which it has a principal role in the cleaning of granular media during backwashing of deep bed filter. At high superficial velocities in the filter column, fluid shear strength contributes to the detachment of deposited material from the filter particles. It concluded that the fluid shear strength increased with increasing expanded porosity or decreasing the fraction solid in filter. Consequently, the maximum fluid shear strength occurs approximately at fluidized porosity of 0.73 or fraction solids of 0.27 in 1.18 mm grain sand which is higher than in smaller grain sand where the expanded porosity 0.69 or fraction solids of 0.31 owing to the large

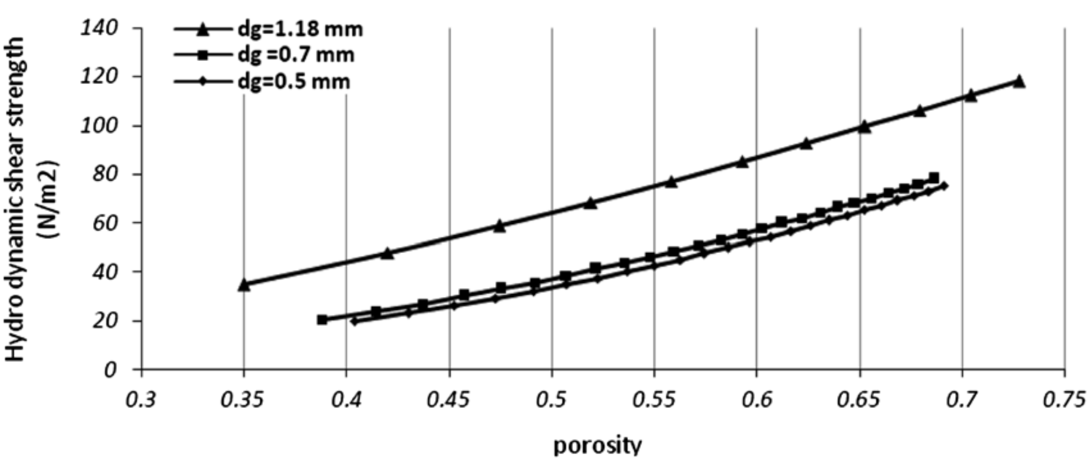


Fig. 6. Fluid shear strength vs. porosity.

drag force acting on a large grain relates the presence of other grains.

4.6. Effect of random motion dissipation coefficient (C_a)

The random motion dissipation coefficient was calculated by means of fluid shear strength and velocity grade values as seen in section three. The influence of random motion dissipation coefficient is plot in Fig. 7. The results indicate that the dissipation coefficient reduced with an increment of fraction solids. Conversely, an increase in grain size causes increasing in the dissipation coefficient.

4.7. Evaluation the effect of random motion fluctuation

Random motion parameter indicates to the effect of random motion in the total power dissipation in filter backwashing characteristics. This is similar to the random motion intensity, since both are functions of root square velocity. Fig. 8 shows that the random motion intensity increases with increasing particle population in a expanded bed and the random motion parameter increases with increasing fraction solids. It can be seen readily from Fig. 8, the random motion parameter increased along with increasing of fraction solids. Also, a higher rate was appeared in the lighter particles compared with larger particles due to the large drag force in a lighter particle, where the energy exclusion due to random motions of suspended particles, and the power dispelled by the random motions fluctuations.

4.8. Effluent of SS during backwashing process

The backwashing process was implemented extremely for 0.33 h with five different expanded porosity from 0.43 to 0.704 in 1.18 mm grain size of sand and 0.37 to 0.69 in 0.5 mm grain size of sand. The effluent backwash water quality was 5.2 mg/L (2 NTU) based on SS (turbidity) which obtained at the end of the process. The results indicated that the effluent SS and detachment rate of deposited fine particles decreases with increasing fluidizing time and total backwash discharge.

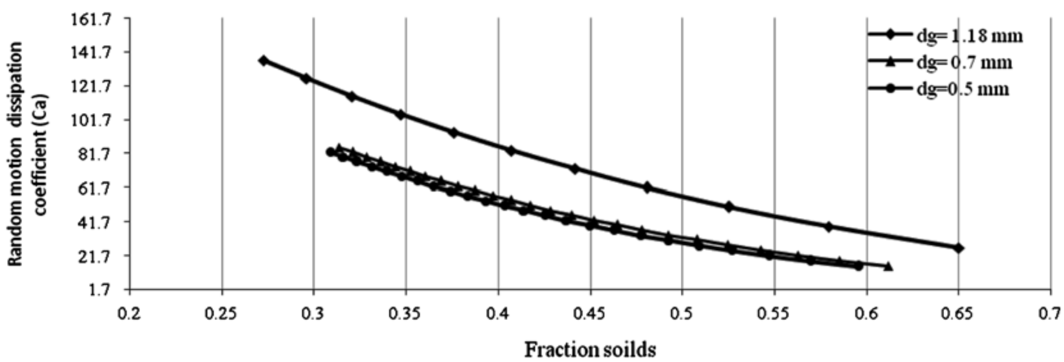


Fig. 7. Random motion dissipation coefficient vs. fraction solids.

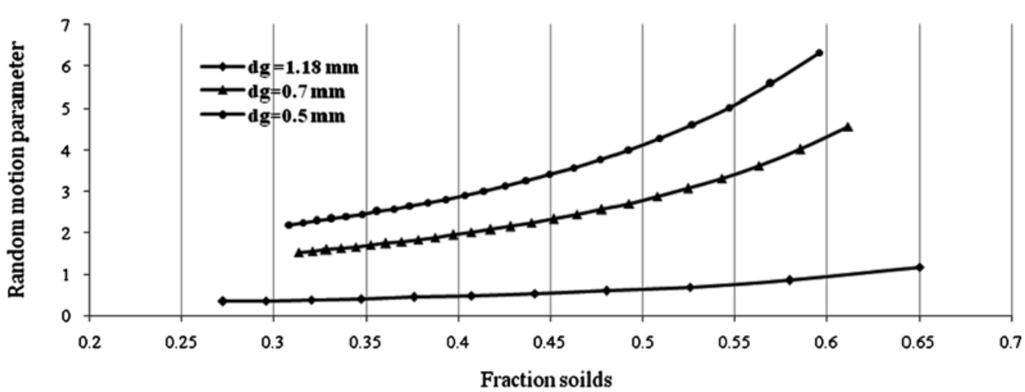
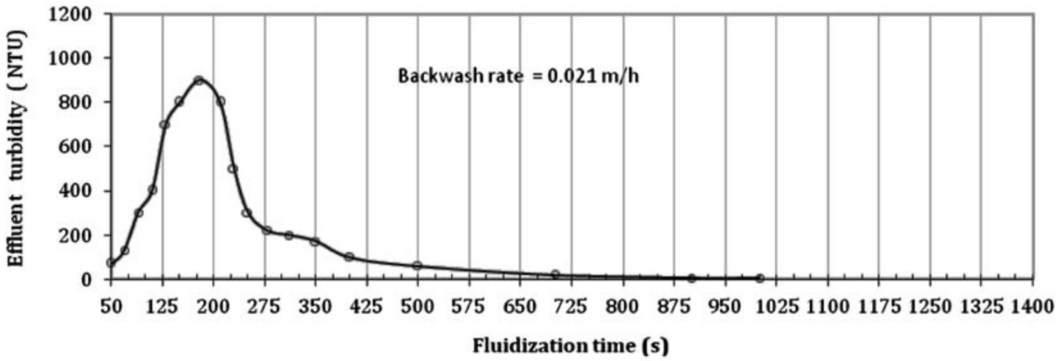
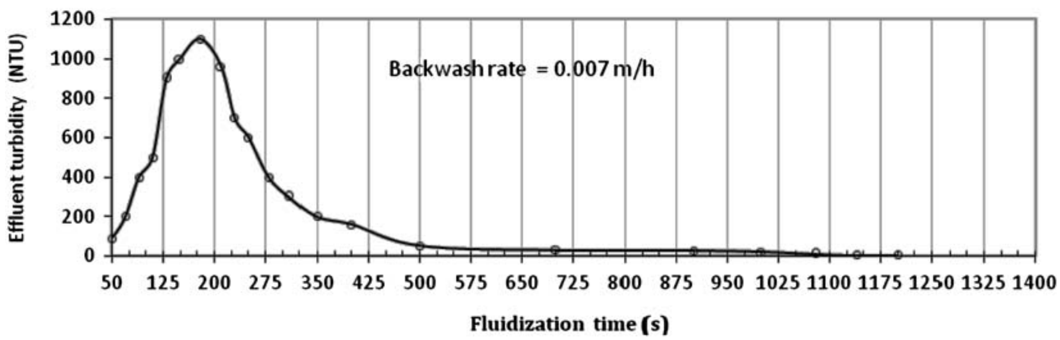


Fig. 8. Random motion parameter vs. fraction solids.



(a).Grain size of sand media 1.18 mm



(b).Grain size of sand media 0.5 mm

Fig. 9. Effluent SS vs. operation time of fluidization. (a) Grain size of sand media 1.18 mm; (b) Grain size of sand media 0.5 mm.

Fig. 9 showed a typical of backwash effluent of SS with operation time of fluidization. There is a little interval period before the maximum of backwash SS (SS) followed by an exponential decay of SS. A high increasing and then fast decreasing in effluent SS during backwashing process indicates relatively efficient fluidization process, while a slow increasing and slow decreasing in effluent SS generally indicates inefficient fluidization process. Efficient fluidization is related to the rate at which the deposit particles are separated hydraulically from the media grains. It can be seen readily from Fig. 9 that the bigger grains of sand media (1.18 mm) has a lower peak than a smaller grains (0.5 mm) owing to the large deposit that accumulate in the smaller grain.

5. Conclusions

According to experimental and a theoretical study, the optimal operation condition of fluidization process was investigated by observing and measuring the expanded bed length, porosity of expanded bed, minimum velocity of fluidization, hydrodynamic characteristics of a backwash filter, and the effect of media characteristics on energy dissipation. In this study, it was concluded the following points.

(1) The experimental data gave good convergence with Wen–Yu's equation for predicting minimum velocity of fluidization. This correlation depicted that the peak of head loss is observed at the starting point of fluidization process. In addition, the experimental results showed that the smaller grain size has a lower value of minimum velocity of fluidization (V_{mf}) with a more prominent peak of backwashing time because of these grains have more particles–particle interaction.

(2) The experimental results showed that a smaller grain size of sand media (0.5 mm) required 0.007 m/s of backwash velocity to lift the filter media, while the higher grain size (1.18 mm) required 0.021 m/s as optimum backwash velocity owing to the high surface area and weight of individual partials.

(3) The results depicted that the fluid shear strength (τ_a), velocity grade (G), dissipation rate coefficient (C_a) and parameters of random motion ($C_a^{0.5}/\mathrm{Re}$) are very effective parameters on energy dissipation rate for removing fine particles from granular media. In addition to that the result showed that the fluid shear strength increases with increasing porosity of expanded bed and the fluid shear

strength (τ_a) occurs approximately at fluidized porosity of 0.730 in a large grains size.

(4) The random motion parameter increases along with increasing of fraction solids and a higher rate appeared in the lighter particles compared with larger particles due to the large drag force in a lighter particle.

(5) The effluent SS and hydrodynamics detachment of deposited fine particles reduces with time of fluidization and rises with backwash discharge rate whereas the bigger grain size of sand media has a lower peak point of optimum backwash time than smaller grain due to accumulation a large amount of deposit fine particles.

Acknowledgment

This research has been financially supported by National natural science foundation of China (51078074) and the Major science and Technology program for water pollution control and treatment (ZX07101-005).

Nomenclature

l_e	length of expanded bed, cm
l	length of fixed bed, cm
L_m	Monin–Obukhov length, m
e	porosity of fixed bed
e_f	porosity of expanded bed
V_{mf}	minimum fluidizing velocity, m/s
u	intercept velocity, m/s
ub_i	superficial velocity, m/s
u_t	terminal settling velocity, m/s
U^*	the friction velocity, m/s
u	point velocity in x-direction at y, m/s
$\tilde{U}$	fluctuating velocity of turbulent flow, m/s
D	filter column diameter, m
dg	particle diameter, m
y	coordinate perpendicular to xm
μ	dynamic viscosity of liquid, $N\,m^{-2}\,s$
ρ	density of water, $kg\,m^{-3}$
ρ_s	density of particle mixture, $kg\,m^{-3}$
ρ_m	specific density of fluid and particle, $kg\,m^{-3}$
P_v	total power dissipation in a unit volume, $N\,m^{-2}\,s^{-1}$
τ_a	Fluid shear strength, m/s
G	velocity gradient, s^{-1}
Ga	Galileo number
n	bed expansion coefficient
K_0	Von Karman universal constant
φ	particle sphericity
α, β	energy dissipation rate constants
Re	Reynolds number of flow
Re_t	particle Reynolds number
G_m	dissipation coefficient
C_a	random motion dissipation coefficient
$C_a^{0.5}/Re$	random motion parameter

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