Research Journal of Applied Sciences, Engineering and Technology 3(11): 1304-1309, 2011
ISSN: 2040-7467

Submitted: August 08, 2011 Accepted: September 25, 2011 Published: November 25, 2011

Fluidization and Optimum Backwashing Conditions in Multimedia Filter

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Abstract: The aim of this study is to study and evaluate the fluidization and optimum backwashing conditions which include minimum fluidization velocity, expanded bed porosity and energy dissipation under different operation conditions with different media grain size in multimedia filter. Theoretical and experimental study was performed to evaluate the backwashing process of multimedia filter by fluidizing the filter media whereas backwashing Process was carried out by a pilot laboratory filter of multimedia filter column using different characteristics of filters media. A model was built to predict the expanded bed filter and the fluidized porosity. The result showed that proposed model give a good fit with observed data. It is observed that smaller grain sand was needed a lower value of backwash rate then of the higher grain sand to rise the filter media and the fixed porosity 0.51 will expand to the optimum fluidized porosity 0.704 for a bigger value of grain sand while the smaller value of grain diameter 0.5 mm was expanded to the optimum fluidized porosity 0.68. It is also concluded that the effluent turbidity and detachment rate of deposited material decreases with increasing backwashing time and increasing total backwash rate. It is also concluded that the energy dissipation and the velocity gradient have a dominant mechanism of filter cleaning.

Key words: Backwashing models, energy dissipation, fluidization, minimum fluidizing velocity

INTRODUCTION

Granular media filtration has growing importance in drinking water production and generally is applied prior to disinfection in the water treatment process, thus at the end of filter run, the media should be washed. A backwashing filter is a water filter that cleans itself periodically by rinsing away impurities whereas the particles are removed from suspension primarily by transport to, collision with and adhesion to the filter grains. Periodic washing is required to unclog the filter and to avoid turbidity break through when its floc holding capacity is exceeded (Cleasby, 1990). The fundamental purpose of filter backwash is to detach the maximum amount of floc from the filter grains with the smallest possible cost in water and energy. A further increase in the velocity increases bed expansion and the particles within the bed move randomly (Turan and Eroglu, 2001). The influent and effluent backwash water qualities can be determined on the basis of turbidity. the expansion of filter media will be predicted when the filters backwash. This expansion can be select the minimum freeboard between the top of the media and the lip of the backwash overflow weir to prevent the pilot plant of deep bed filter-washout of filter media during the backwash cycle (Turan and Environ, 1992). In this study, the backwashing models will be proposed to predict the minimum fluidization velocity, the expanded bed porosity and the energy dissipation during backwash filter under different operation conditions with different grain size of media.

MATERIALS AND METHODS

Experimental set up: Backwashing Process was carried out by a pilot laboratory filter in Wu- Xi city from May 2010 through August 2011. The laboratory scale of multimedia filter column has been designed to operate identically to full scale granular filters using different filter media with different bed depth tests on this unit to provide a set data. The media in each filter was supported on a PVC orifice plate drilled with 5 mm holes and covered by a wire mesh to prevent sand and GAC passing through the orifices. A scale was made in front of tube column to estimate bed height. Deep Bed Filter Column is a clear acrylic unit mounted in a floor standing framework approximately 2 m high with flanged end pieces to allow easy access. The medium is supported on a corrosion resistant gauze mesh below is packed 1kg of 0.01 m Ballotini to ensure good wash water distribution . Plain tubes also penetrate the medium through the wall to transmit pressure to a manometer system. several manonometer is located beside the filter column to measure the head-loss profile during backwashing filter which that can select the minimum fluidized velocity. as shown in Fig. 1. The filter media was used with different grains size from 0.5 to 1.18 of sand media and the turbidity measurement were carried out by turbidity Meter, (LP200).

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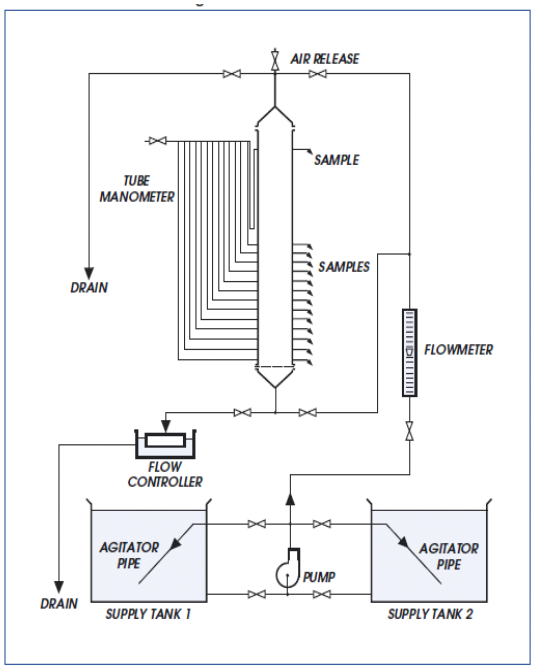

Fig. 1: Laboratory Pilot Filtration and backwashing Unit schematic

Operation of backwash filter: In the current study, at the end of each filter run, the deposited material causes clogging the filter pores and increases head loss in the bed. Clean water was pumped into the filter under drain and entered the filter passing through the orifice plate. At the beginning of back wash, the manual flow control valve was set with the flow being set. During the back wash process, the new length of filter was record with backwashing time. After the backwash completed, the down flow fixed bed head-loss profile was measured. The filtration flow rate was 500-1300 cm^3/min and each filtration run lasted 3 h when the turbidity of the filter effluents reached 4 NTU. The backwashing processes were carried out with the flow of 900-2500 cm^3/min depending on grain media and deposit of suspension particle.

Fluidized bed analysis: The aim of backwashing study is to know the expanded limit of sand layer which prevent the loss of media. Therefore, several experiments were implanted to determine the expended length of fluidized media which is using to predict the fluidized porosity from Eq. (1) as follow:

$$\frac{lf}{l} = \frac{1-e}{1-ef} \qquad (1)$$

The minimum fluidization velocity of a media sample was found using flow meter valve where the reading of flow meter will be represent back wash rate, thus the value of minimum fluidization velocity was achieved by measuring the pressured drop with different flow rate.

Backwashing modeling:

Minimum fluidized velocity: In this study, several experiments were carried out to determine the minimum fluidization velocity. Then the results were compared to Wen and Yu (1966) Correlation equation for the minimum fluidized velocity which is (Robert, 2002)

$$umf = \frac{\mu}{pdg} * (33.7^2 + 0.048Ga)^{0.5} - \frac{33.7\mu}{pdg} \qquad (2)$$

Fluidized bed expansion model: A backwashed filter has the characteristics of a particularly fluidized bed that can be explained as the upward flow of a fluid through the bed. (Richardson, 1954) correlation is widely used to describe bed expansion characteristics of fluidized beds (Wen and Yu, 1966).

$$e^n = \frac{U}{U_i} \qquad (3)$$

where, Ui is the intercept velocity. Since, particles in the filter bed are non spherical, so, backwashing of the filter media differs from the fluidization of beds with spherical particles. Therefore, the following equation can be given as:

$$U_i = U_t 0.91\phi^{0.4} \qquad (4)$$

Ut Indicated to the terminal settling velocity, the bed expansion coefficient is given as (Turan, 2000)

$$n = \left(\frac{4.45 + 18dg}{D}\right) \mathrm{Re}_t^{-0.1} \phi^a \text{ For } 15 < \mathrm{Re}_t < 200 \qquad (4a)$$

$$n = 4.45 \mathrm{Re}_t^{-0.1} \phi^a \text{ For } 200 < \mathrm{Re}_t < 503 \qquad (4b)$$

$$a = -2.9237\ \phi^{0.884} \qquad (5)$$

Energy dissipation model: In this study, a model was used for describing the energy dissipation parameters namely the hydrodynamic shear stress, the velocity gradient, the turbulence dissipation coefficient, and the turbulence parameter in backwashing of filters for different grain sand. The total power dissipation in a unit volume P_v can be written:

$$P_v = \psi_1 + \psi_2 = \mu(1+\omega)\left(\frac{\partial u}{\partial y}\right)^2 \quad (6)$$

where, Ψ_1 and Ψ_2 are the power dissipation in a unit volume by time-mean motion and the power dissipation in a unit volume by turbulent motion respectively, ω is a coefficient which indicates the effect of turbulence in the u is the point velocity in x direction; y is the coordinate perpendicular to x. The velocity gradient and the hydrodynamic shear stress are very important for predicting optimum cleaning of a backwashed filter. So that the velocity gradient can be defined as:

$$G = \frac{\partial u}{\partial u} = (P_v / \mu(1+\omega))^{0.5} \quad (7)$$

Energy equation for flows in a backwashed filter can be expressed as:

$$\tau\frac{\partial u}{\partial u} = \left(\alpha_1\rho\frac{U*^3}{K\,L_m} + \beta a_1\rho\frac{U*^3}{K\,L_m} + \rho\frac{U*^3}{K\,L_m}\right)e^{n-1} \quad (8)$$

where, the left-hand side of equation (8) represents the energy production by the Reynolds stress. The right-hand side expresses an energy distribution in the flow: the first term is the energy necessary to suspend particles; the second term is the rate of removal of energy through motions of suspended particles such as rotation, rectilinear motion relative to the fluid, collision, and the reduction of effective space to dissipate energy into heat; and the last term indicates the rate of energy loss dissipated and diffused by a turbulent motion of the liquid phase (Michele and Johannes, 2006).

β : is a coefficient depending on random motion of particles

a_1: (Ui/Uo) is a coefficient related to particle characteristics

K: is the von Karman universal constant of flow with suspended particles, which can be defined as:

$$k = \frac{K_0}{(1+2(1-e))} \quad (9)$$

L_m Is the length, of Monin-Obukhov, is given by:

$$Lm = \frac{U_*^3}{KgU_t\left((\rho_s/\rho)-1\right)(1-e)} \quad (10)$$

K_0: is the von Karman universal constant for water flow 0.4 , and (1-e) is the fraction solids concentration.

Also the specific density of fluid and particle mixture p_m and the friction velocity U* are respectively defined as:

$$U_* = \left(\frac{g\rho 4\rho_m}{(\rho_s/\rho-1)D}\right)^{0.5} \quad (11)$$

$$\rho_m = \rho\{1+(\rho_s/\rho-1)(1-e)\} \quad (12)$$

The arithmetic mean shear stress τ_a is calculated by integrating τ on the cross section of the fluidization column as:

$$\tau_a = e^{n-1}(a(1-e)^{0.5} + b(1-e)) \quad (13)$$

where, a, b are constants, and from the last equation the coefficient C can be obtained in an arithmetic mean.

$$Gm = 8U_*(In(\rho\,U_*D/23.3\mu)-1)/KD \quad (14)$$

The hydrodynamic shear stress $<\tau_a>$ can be obtained in an arithmetic mean way as follows:

$$\tau_a = \rho\,U^2\,e^{n-1}[\alpha\,D/6L_m]+1 \quad (15)$$

$$\alpha = \alpha_1(1+\beta) = 7\frac{U_i}{U_t} \quad (16)$$

If (15) is rearranged in an arithmetic mean form, the following equation can be given for the calculation the turbulence dissipation coefficient Gm after calculating the τ_a and the G_m values for this model:

$$G_m = \frac{\tau_a}{\mu G_m} - 1 \quad (17)$$

To evaluate the turbulence intensity($\tilde{u}^2$)$^{0.5}$/U, the ratio of $G_m^{0.5}/R_e$ can be det

$$G_m^{0.5}/R_e = \left(\frac{\tau_a}{\mu G_m} - 1\right)^{0.5}/R_e \quad (18)$$

RESULTS AND DISCUSSION

Simulation of fluidized bed expansion: Figure 2 illustrates the result of influence of the filter media characteristic on the backwash rates required to fluidize the media .It illustrates that a smaller grain (0.5 mm) was needed a lower value of backwash rate which is 0.007 m/s to rise the filter media while the higher grain (1.18) mm

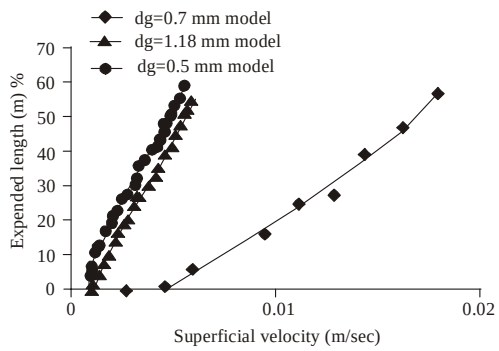

Fig. 2: The change of the expanded bed length with superficial velocity for different grain sand media

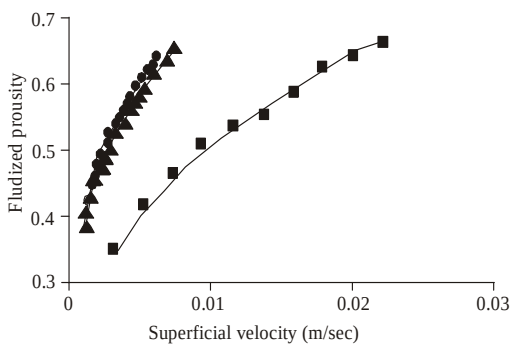

Fig. 3: Predicated and measured porosity vs. superficial velocity for different grain sand media

of sand media was expanded with 0.0021 m/s optimum back wash rate owing to the high surface area and the weight of individual partials. Thus, the magnitude of drag force to expand the media will increase.

Figure 3 shows the agreements between model and measurements of fluidized bed porosity for each grain media size. It observe that the fixed porosity 0.51 will expand to the optimum fluidized porosity 0.704 for a bigger value of grain sand while the smaller value of fixed bed 0.5 mm was expanded to 0.68.

Minimum fluidized velocity prediction: The minimum fluidization velocity V_{mf} of a media sample was measured experimentally from the intersection the fixed bed and fluidized bed head-loss curves with superficial velocity whereas it found by interaction the two curves fitting of the experimental data and project on x- axis. The head-loss increases linearly with backwash rate whereas the head-loss across a fully fluidized bed remains constant. Fig. 4 depicts the fluidization curves for the sand filter beds at various grain sand of media and fixed bed height of 60 cm.

Figure 4 gives a good agreement between the observed values and the predicting values by Wen and Yu (1966) model. It illustrates that the peak of head-loss is observed at the initial point of fluidization.

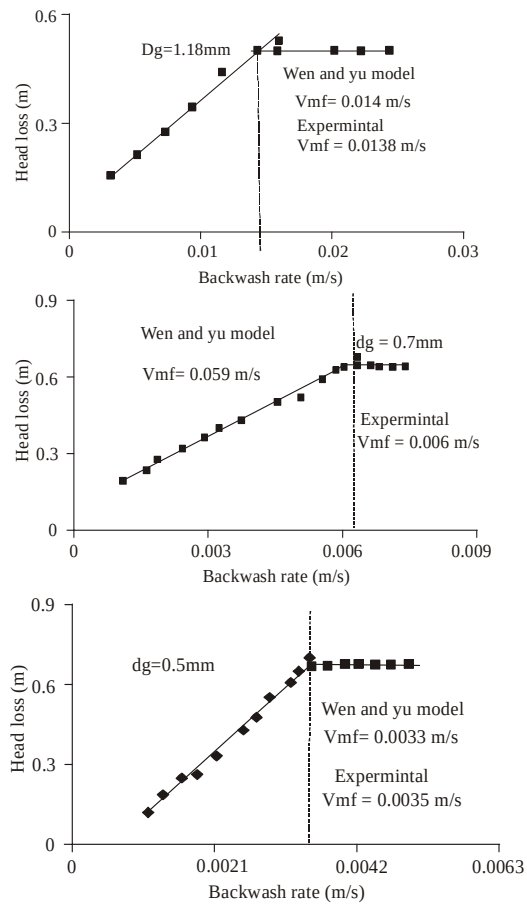

Fig. 4: Determining the minimum fluidization velocity for different grain size

Furthermore, this fluidize the packing. The result in 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.

Influence of velocity gradient on filter:

Backwashing: The velocity gradient is the most effective factor in the granular bed filters. The mean velocity Gradient for the present model was plotted in Fig. (5a and b) versus fraction solids (1-e). The result shows that the value of velocity gradient increase with increasing fraction solids. This means that lower superficial velocity through the system will result in higher velocity gradients

Influence of hydrodynamic shear stress on filter back washing: In order to optimize the best condition for backwashing the deep bed filter, the hydrodynamic shear stress was plotted in Fig. 6 as a function of porosity or fraction solid, which it has a dominant role in the cleaning of granular media during backwashing of multimedia

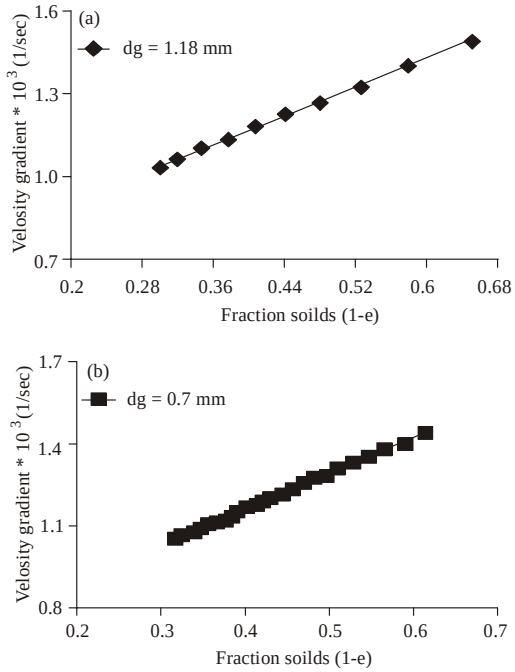

Fig. 5: The affect of velocity gradient on media characteristic

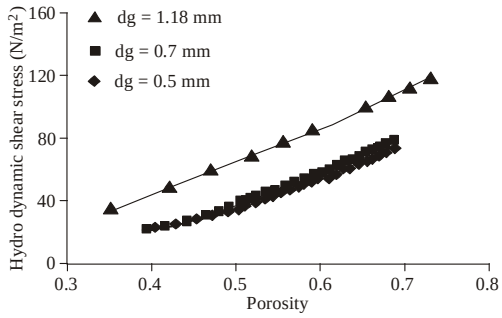

Fig. 6: Variation of hydrodynamic shear stress as a function of Porosity

maximum is associated with some force required to increase with increasing expended porosity. Consequently, the maximum shear stress occurs approximately at fluidized porosity of 0.73 in 1.18 mm grain sand which is higher than in smaller grain sand where the expanded porosity 0.69 owing to the large drag force acting on a large grain relates the presence of other grains.

Influence of turbulence dissipation coefficient: Figure (5-7) indicated that the dissipation coefficient decreases with an increment of fraction solids. Conversely, an increase of grain size causes increasing in the dissipation coefficient.

Evaluation of turbulence fluctuation effects: Turbulence parameter is indicating to the effect of turbulence in the total power dissipation in filter

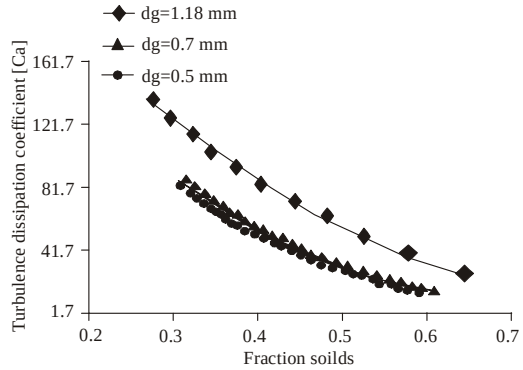

Fig. 7: Variation of the turbulence dissipation coefficient with fraction solids

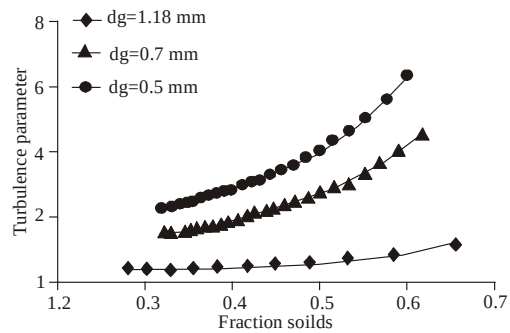

Fig. 8: Turbulence parameter versus fraction solids

backwashing Characteristics. Figure 8 showed that the turbulence intensity increases with increasing particle population in a fluidized bed and the turbulence parameter increases with increasing fraction solids. it can be see readily, that the Lighter particles appear to cause a higher rate of increase in turbulence parameter compared to heavier particles owing to the large drag force in a small particle ,where the energy removal due to random motions of suspended particles, and the power dissipated by the turbulent fluctuations.

Backwash effluent quality: The backwashing processes were carried out extremely 20 min with five different expanded porosities from (0.43 to 0.704) in 1.18 mm grain sand and (0.37–0.69) in 0.5 mm grain, The results illustrates that the effluent turbidity and detachment rate of deposited material decreases with increasing backwashing time and increasing total backwash rate as shown in Fig. 9

Figure 9 shows a typical backwash Effluent profile with time. There is a short lag period before the backwash turbidity peaks followed by an exponential decay in turbidity. A high initial peak and rapid decline in backwash turbidity indicates relatively efficient backwash while a low peak and slow decline in turbidity usually indicates inefficient backwash.

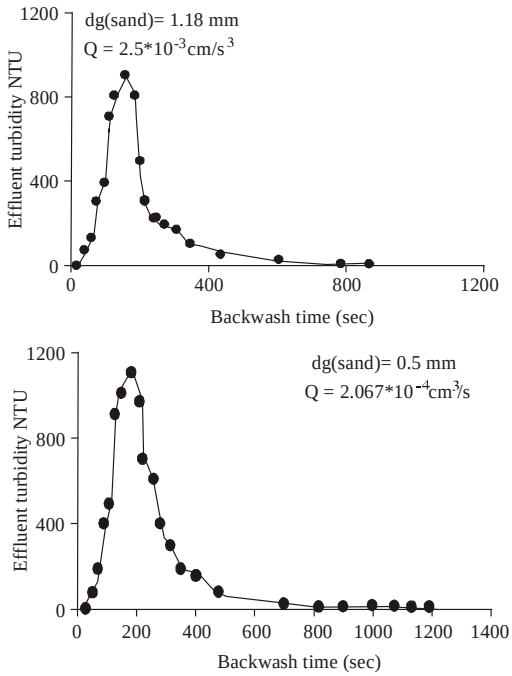

Fig. 9: The Effluent turbidity profile with backwashing time

CONCLUSION

In the present study, the following item was concluded as follows:

- The experimental data give good agreements with Wen -Yu's equation to predict the minimum fluidizing velocity whereas this correlation illustrates that the peak of head-loss is observed at the initial point of fluidization
- The results conclude that a smaller grain sand which is (0.5 mm) was needed a lower value of backwash rate of 0.007 m/s to rise the filter media while the higher grain sand which is (1.18) mm of sand media was expanded with 0.0021 m/s optimum back wash rate owing to the high surface area and the weight of individual partials
- The result shows that the values of velocity gradient, hydrodynamic shear stress and the turbulence dissipation coefficient are very effective parameters for cleaning the granular media
- The Lighter particles appear to cause a higher rate of increase in turbulence parameter compared to heavier particles Owing to the large drag force in a small particle ,where the energy removal due to random motions of suspended particles, and the power dissipated by the turbulent fluctuations
- The effluent turbidity and detachment rate of deposited material decreases with increasing backwashing time and increasing total backwash rate and the bigger grain sand has a lower value of initial peak then a smaller grain.

ACKNOWLEDGMENT

This research was supported by Taihu Lake water and Environment control Program of Jiangsu Science And Technology Department (BS2007114), Major program on Scientific Research. (BS2008667) of Ministry of Education (308010) and Key Technology R and D program of Jiangsu Province (BS2008667).

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