A Report on
Backwashing of Sand Filter medium
Experiment

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To

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1.Introduction

Granular media Filtration is a unit operation in water treatment plants and is even more important today in wastewater treatment because of higher effluent quality standards being set by the regulatory agencies. Usually these sand filters are operated over a period of time, until which their functioning is normal. But over repeated use of the filter solid particles begin to get accumulated among the pores of the sand bed. Task of engineers is to cleanse those unwanted solid particles which act as a deterrent to the filtration efficiency of the sand bed. Back washing is a very popular method which achieves this purpose. Additionally ,engineers also face the task of designing the backwashing operation by choosing parameters like flowrate required to fulidize the bed , bed expansion expected for different flowrates etc. Mathematical models already developed and presented in various books can be used for this purpose.

Backwashing cleans the filter by reversing the flow and causing the water to flow upwards through the bed. The backwash water action tends to slightly expand the bed, causing the sand particles to tremble and the soil particles rub against each other. This results in the unwanted solid particles deposited on the sand to break free. The time of a backwash cycle as it is called varies from the type of filter system we are looking at. There are rapid filter systems where the backwashing cycle needs upto 10 minutes and there are even faster high rate filters where the cycle is finished within two minutes. It is faster in the second case, simply because it is operated at a higher backwash flow rate.

A typical backwash cycle can be described in the following steps. Firstly, Water is drained from filter, the influent valve is shut and the drain and backwash line is opened. Backwash velocity is slowly increased until the bed is fluidized. Fluidized bed is typically 40% to 60% deeper. The fluidized bed is washed for 5 min to 15 min, the usual range of cycle times. Finally, Backwash velocity is slowly decreased, and the bed is restratified.

What actually occurs when we pass the fluid upwards into the bed of sand particles is it encounters a resistance to flow and a resultant pressure drop (d_p). Energy loss (pressure drop) across the fixed bed will be a linear function of flow rate at low superficial velocities when flow is laminar. As the back wash velocity is increased, a point is reached at which the pressure drop is sufficient to bear the weight of the solid particles. Any further increase in flow rate causes the bed to expand. Since the bed expands, the increased flow is accomodated by it and the effective pressure drop (d_p) would stll remain unchanged. Now, the particles of the bed are in a state of equilibrium , though they are moving . This phenomenon is what we call fluidization of bed particles.

During backwashing the flow is in the transitional region between laminar and turbulent flow. The Carman-Kozeny formula is not valid anymore. For this type of flow only empirical formulae can be used. A good approach is:

$$\Delta H = 130 \frac{\nu^{0.8}}{g} \frac{(1-p_e)^{1.8}}{p_e^{\,3}} \frac{v^{1.2}}{d_h^{\,1.8}} L_e$$

p_e = porosity of the expanded bed (-)
L_e = the height of the expanded bed (m)

The porosity of the expanded bed can be calculated from the original porosity and the expansion according to:

$$p_e = \frac{p+E}{1+E}$$

E = $(L_e - L)/L$ = expansion

Rewriting gives $(1 - p)\, L = (1 - p_e)\, L_e$

When the head loss equals the weight of the bed expansion begins, shown by the following equation:

$$H = (1-p) L \frac{\rho_f - \rho_w}{\rho_w}$$

ρ_w = density of water (kg/m^3)

ρ_f = density of filter material (kg/m^3)

In this experiment, we have measured two parameters primarily, Bed Expansion and Pressure Drop across the sand bed. A quantitative analysis was done using Theory from the Water and Wastewater Treatment textbook and were compared with the Experimental results obtained. The setup, experimental procedure and results have been described in the following sections.

2. Materials and methods

2.1 Glass Column with the Filter Bed

Figure 1 setup of the filter column

The Filter column was fabricated from clear plastic tubing and connected with a connector. The inner diameter of the tube is 3 inches and outer diameter is 4 inches, the height of the tube is 8 feet. A distributor plate was placed on the bottom of the equipment. Water was introduced into this column from the inlet attached on the wall of the distribution plate and follows an upflow direction until the outlet in the wall of the upper side of the column. A flowmeter was connected with the inlet of the column to measure the flowrate. The other side of the flowmeter was connected with the tap water. A ruler was sticked on the wall of the column to detect the bed expansion. An outlet in the upper side of the column was fabricated to lead the water flow out from the column. The water was discharged into the sink.Figure 1 is the picture of the equipment.

2.2 Uniform sand in the column

Uniform sand particles were employed as the filter medium. After sieve analysis, the diameters of the uniform sand are about 450 µm. The height of the sand is 47cm from the bottom of the sand. Figure 2 demonstrates the uniform sand in the column. The distributor plate can also be seen from this figure. Some gravels were put on the bottom of the column, which is employed to distribute the water uniformly. A sieve was placed between the uniform sand and gravel in order to prevent the mixture of the sand and gravel.

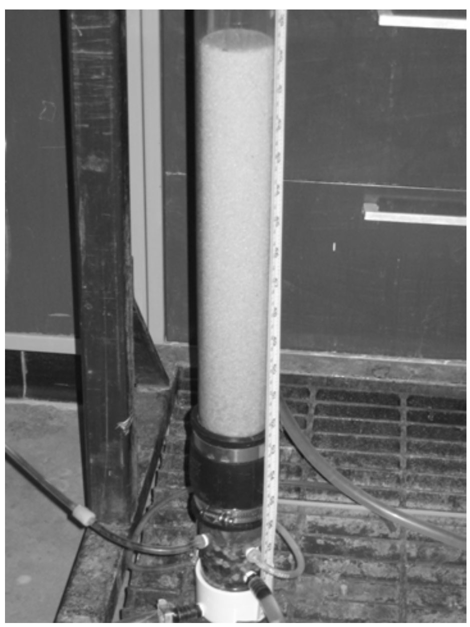

Figure 2 The uniform sand and the distributor plate

2.3 Set-up Parts

A U-tube manometer (dwyer, 1223-1221-36-W/M) was used to detect the pressure difference during the bed expansion. The range of the U-tube manometer is 18-0-18 inches H_2O.A metric ruler was stick to the outside wall of the equipment for scale reading. A flowmeter was utilized to control the flowrate of the influent. Figure 3 is the photograph of the U-tube manometer.

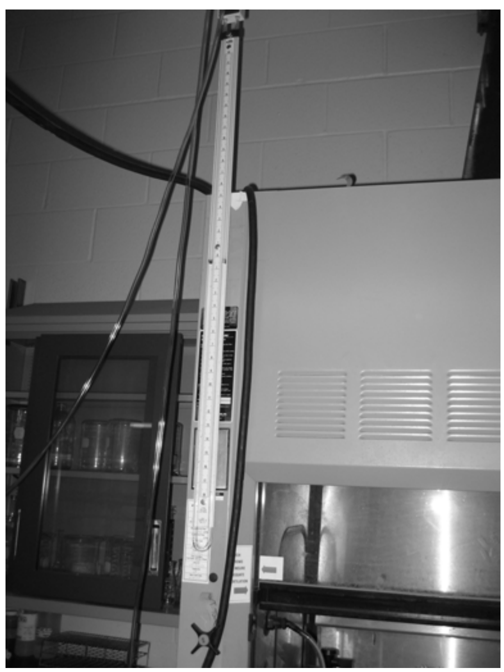

Figure 3 the U-tube manometer

3. Experimental Procedure

1. Conduct sieve analysis before experiment.
2. Connect one end of the U-tube manometer on the bottom of the Column.
3. Turn on the water and let the water flow into the column in the upward direction.
4. Use the flowmeter to measure the inlet flowrate.
5. Wait for the bed expansion under different flowrate and read the scale of the height of the bed when it reaches the fully fluidization.
6. Put another movable end of the manometer on the top of the bed and read the scale of the U-tube manometer.
7. Record all these values mentioned above.

3.1 Bed expansion and pressure difference experiment

When the uniform sand fluidized, the height of the sand was recorded for the bed expansion by reading the ruler stick to the outside wall of the column. The pressure difference was recorded simultaneously. A movable probe was connected with one end of the U-tube manometer was put on the top of the expanded bed and another was fixed on the bottom of the column, the reading of the U-tube manometer is the pressure difference of the fluidization at the certain flowrate.

4. Results

4.1 Bed expansion

Bed expansion is the one of the two important parameters in this experiment. The plot of the bed expansion under different flowrate is shown in Figure 4. Table 1 is the datasheet of our experiment.

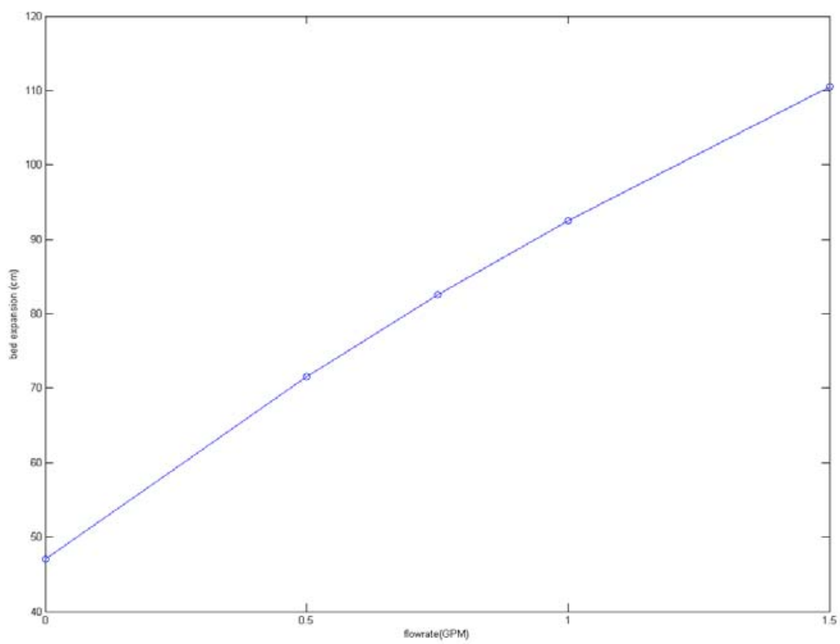

Figure 4 the plot of the bed expansion and the flowrate

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Flowrate (gpm)	Bed height(cm)	Pressure difference(in H_2O)
0	27	5
0.5	41	10.5
0.75	48	11.5
1.0	58	12.5
1.25	72	14.3
1.5	104	18.5

Table 1 bed height and pressure difference under different flowrate

4.2 Pressure Difference

We mainly focused on two parameters, bed expansion and pressure difference in this experiment. The pressure difference graph is illustrated on the figure 5. The pressure difference was obtained by reading the scale of the u-tube manometer. In fluidization , water was passed through the bed of sand particles which are present over the gravel and the screen. At flowrates that are less than the fluidization velocity, the bed is a fixed bed and there is no movement of the particles. At flowrates above the the minimum fluidization the bed expands.

The flow velocity that corresponds to a pressure drop that just equals the weight of the bed is the minimum fluidization velocity.

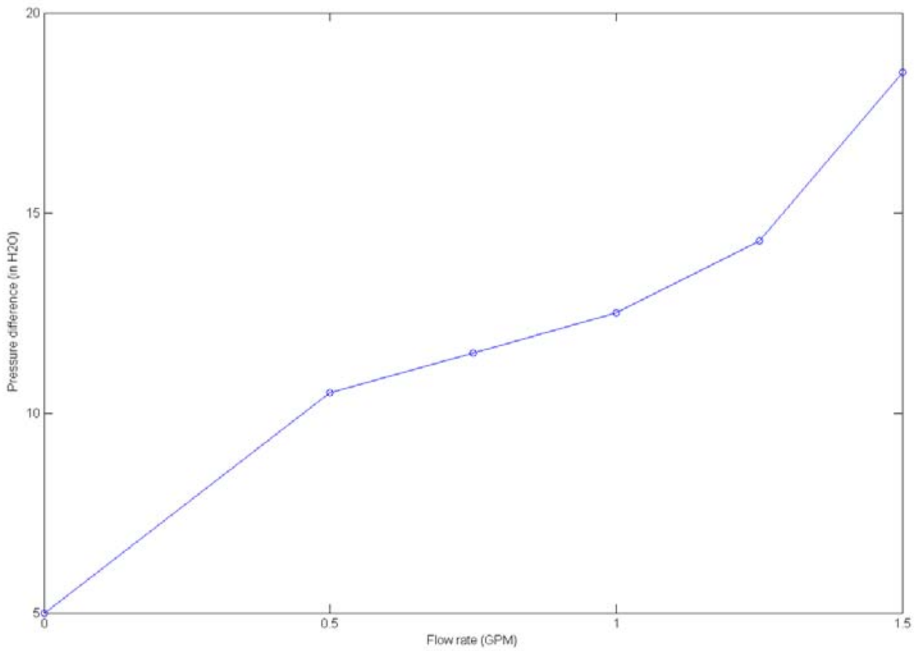

Figure 5 the plot of the pressure difference and the flowrate

5.Discussion

5.1 Fluidization

The efficient fluidization of the bed with uniform sand depended on the velocity of fluid across the column. In this experiment, bed expansion was achieved under low flowrate, which is about 0.3 gpm in this case. The good characteristic of the uniform sand might contribute to the bed expansion. In fluidization, the sand became cloudy-form substance and kept on a stable height. In order to distribute the fluid uniformly, gravels were placed at the bottom of the distribute plate. The bed expansion curve is approximate to a linear demonstrated from figure 6. Another important parameter for this equipment is pressure difference. We will give some detailed discussion in the following part.

5.2 Bed expansion

The degree of expansion is affected by many variable associated with the filter medium and the water. The ability to predict the bed expansion is very important such as to predict whether the filling medium will rise too high above the outlet, in this experiment, because of the drawbacks of the existing column, the sands were lost when the flowrate reach 1.5GPM, which demonstrate the importance of the bed expansion from another side. The calculation of the bed expansion are as follows,

$V = \frac{1.5gpm}{0.05\text{ ft2}}$ =309gpm/ft^2 =2.04cm/s

$\rho = 0.998\text{ g/m}^3$

$\mu = 0.01002 g/(cm)(s)$

$\frac{\mu}{\rho} = \nu = 0.01003 cm2/s$

d = 450 μm=0.045cm

Sv=242.42cm^{-1}

$Re_1 = \frac{0.84}{(1-\varepsilon)}$

$A_1 = \frac{\varepsilon\text{^}3}{(1-\varepsilon)\text{^}2}\frac{\rho(\rho s-\rho)g}{Sv\text{^}3\mu\text{^}2} = 1.14\frac{\varepsilon\text{^}3}{(1-\varepsilon)\text{^}2}$

Put what we get into the equation

logA1=0.56543+1.09348logRe_1+0.17971(log Re_1)^2-0.00392(log Re_1)^4-1.5(logψ)^2

we get the value of the ε using the aid of excel.

$$\frac{l}{l0} = \frac{1-\varepsilon 0}{1-\varepsilon} = 2.2$$

where, g=acceleration of gravity

ε =porosity

μ=absolute viscosity of fluid

ρ=mass density of fluid

d=diameter of the sand

Sv=specific surface of the grains

Re_1= modified reynolds number

Thus the material in the column would be expanded by 120 percent.

The above calculation is the theoretical prediction of the bed expansion, we can turn to the measurement in our experiment.

Figure 6 displayed the relationship between the flowrate and bed expansion, it is near a linear and the value of R^2 is 0.9937, which indicate the curves converge very well.

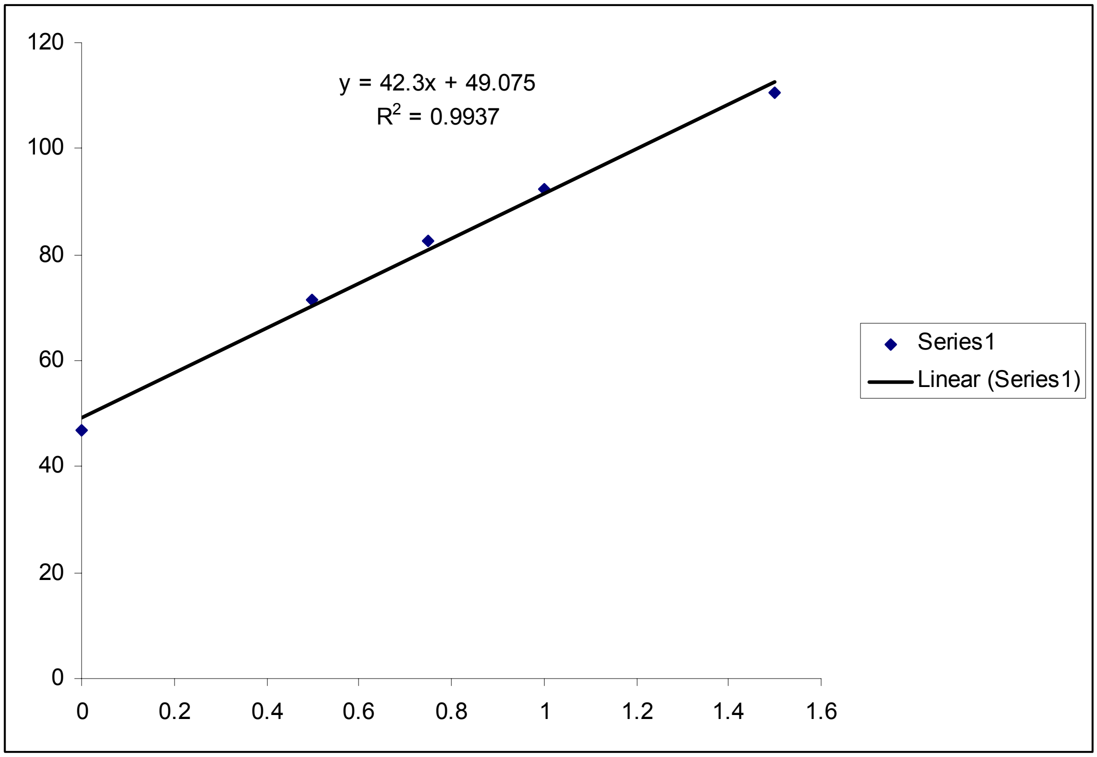

Figure 6. The quantity analysis of the flowrate and the bed expansion

The influence of the flow rate on the fluidized bed height is shown in fig.4. Within the range of applied flowrate, the bed expansion responded as a linear function of the flow rate and hence of the linear velocity. This empirical curve allows for the calculation of the optimal reactor height.

Another plot (Figure 7) is about the relationship between the flowrate and the bed expansion rate, which means the ratio between the expanded bed and the initial bed. The maximum bed expansion percent under 1.5 GPM is 134, the theoretic value is 120,which is very near considering the measuring error and some factors resulting error.

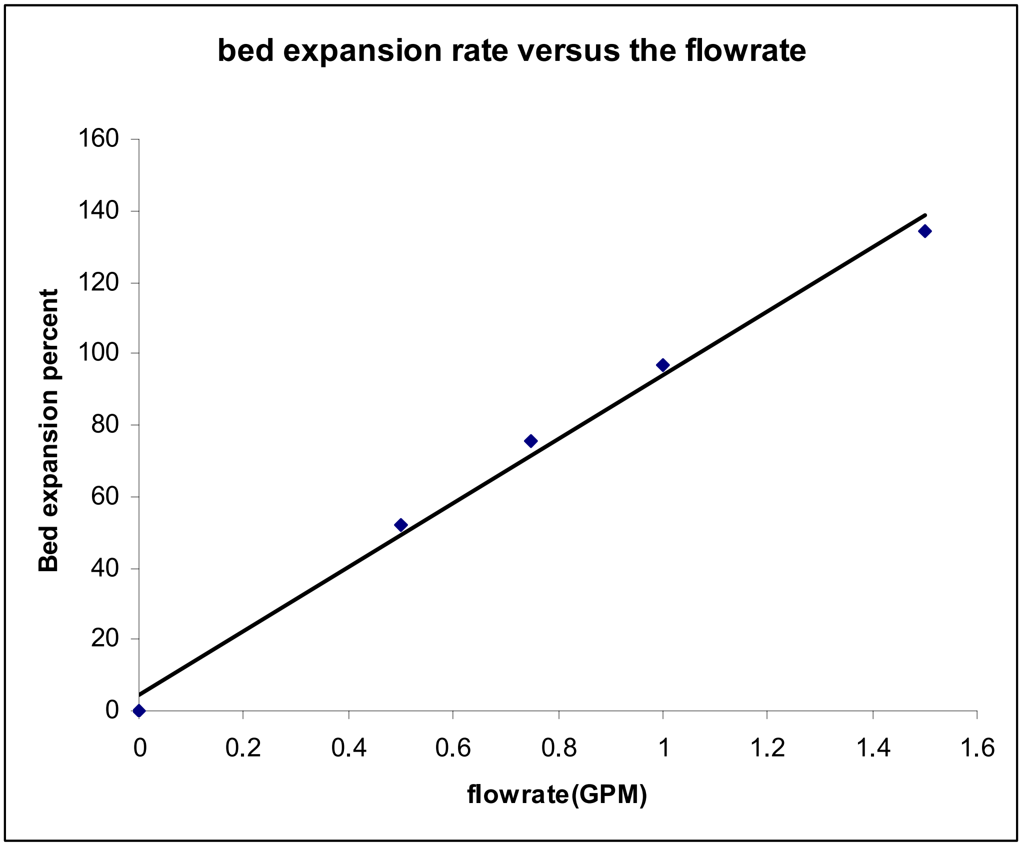

Figure 7. the relationship between the flowrate and the bed expansion percent

5.3 Pressure difference

pressure drop is the energy loss across the fliter column it is a linear column. It is a linear function of the flowarate at low superficial celocities when flow is laminar. We calculate the pressure in the design of the column as follows.

Pressure Calculations for design of the Column

Density of Sand ,wet = 1922 Kg/m3

Height of the sand in the column = 40 cm = 0.4 m

g = 9.8 N / Kg

Pressure = Density $\times$ g $\times$ H

$= 1922 \times 9.8 \times 0.4$

= 7534 N / m2

Density of Water = 997.8 Kg/ m3

Height of the Column = 6 feet = 72 inches = 182. 88 cm = 1.83 m

= 5 feet = 60 inches = 152.54 cm = 1.53 m

g = 9.8 N / Kg

Pressure = Density $\times$ g $\times$ H

= 997.8 $\times$9.8 $\times$1.53

= 14829.066 N / M2

Total = 22,363 N/ m2

= 0.22 atm

To get in Inches of H20 = 0.22 $\times$ 406.86

= 89.52 Inches of $H_2$0

Water is passed throught the bed of solid particles which are supported on a perforated screeen and gravel. The frictional force acting on the particles or in other words the pressure drop of the flow throught the bed equals or exceeds the weight of the bed. So, at flow rates less thean the fluidization velocity the bed is a afiexed bed and there is no movement of particles. At flowrates above minimum fluidation the bed expands.

The velocity corresponding to this pressure drop equals the weight of the bed and is referred to as the minimum fluidization velocity. At this velocity all the sand particles are supsended in the water. The aim of the second experiment was to determine this from developing a plot between the pressure drop and the flowrate.

In this experiment, we fix a probe on the bottom of the column to monitor the pressure of the water and the sand, another movable probe was moved along the top of the bed under different flowrate. The scale reading from the u-tube manometer is the pressure difference between the top of the bed and the bottom of the column. Because the limitation of the column (there is one hole in the middle of the column, which made the loss of the sand when high flowrate fluid reached.), the equipment can not reach at higher flowrate, thus the whole system can not be fully fluidization. In the predicted curve, a horizontal linear would be obtained finally. From the plot, 0.5 gpm is the minimum fluidization velocity.From some relative literatures, we predict the pressure drop under higher flowrate in our experiment. In this experiment, we do not have the opportunity to veryfy the curve of the pressure drop because ofthe limitation of the column ,however, we could use theoritical concept to obtain a explanation. When the sand is fully fluidization, which means the flowrate is large enough to expand the sand thoroughly, there is no any friction between these uniform sand, in other ways, there is no any energy loss in the system, thus the pressure drop will keep constant under fully fluidization.

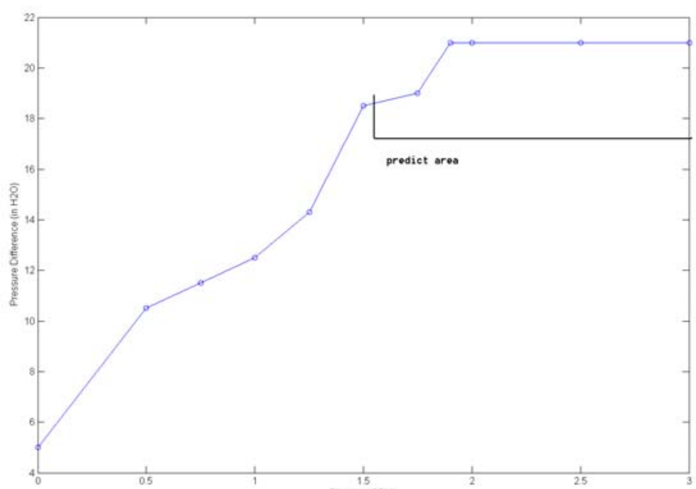

figure 8. prediction of the pressure drop under high flowrate.

6. Conclusions

It is regretful that we can not obtain the whole range of the pressure difference curve because of the limitation of the column. The exit flow has to be faster than what we had, so that the entire flow range could be utilized with the column.

1.From this experiment, the bed expansion is almost linear ,which can verify the conclusion from previous experiment. We can use the empirical equation to predict the bed expansion and our column design could be aslo benefit from the equation.

2. the pressure drop is also a linear curve and we predicted that it would keep constant when fully fluidization.

In this experiment, we found the good fluidized characteristics in the filter column.it is good for biological treatment. It is a good assumption to employ the column as an activated sludge bioreactor, which could offer enough oxygen and also stir the biomass thoroughly. Only some minor special design will employ into the column.

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