Evaluate of Head Loss, Sediment Value and Iron Removal in Rapid Sand Filter

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Abstract: Quality and appropriate quantity of water is necessary for human kind to survive. Along with the technology development and increasing consumption of water resources, we are experiencing low qualities in the mentioned resources. Iron is the fixed element found in the crust of the earth. This metal found variously in water resources and industrial activities. Therefore, it needs to treat the water resources from these excessive amounts. Different methods have used for this reason but the most used method during recent years has been the absorption by economic absorbers such as sand. Rapid sand filters usually used in water treatment plants for water clarification. In this research, a single layer gravity rapid sand filter has used to reduce different concentrations of iron. sediment value and head loss arising from it specially oxidized iron sediments in filter media is simulated by using combination of Carman-Kozeny, Rose and Gregory models in different discharges of rapid sand filter. Results have shown that with increasing in discharge and decreasing in input iron concentration, arriving time to given head loss, is increasing. In addition, results demonstrated that with increasing in iron concentration in influent, removal efficiency is decreasing somewhat. Results of this research can applied in (1) appropriate design of rapid sand filter to iron removal, (2) prediction of rapid sand filter ability to iron removal and (3) estimation of arising head loss during filter work thus evaluating of time interval backwash. [Hossein Banejad, Reza Pirtaj Hamedany, Navab Daneshi. Evaluate of Head Loss, Sediment Value and Iron Removal in Rapid Sand Filter

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1. Introduction

1.1. Iron content in water and its removal

In the past few decades using of heavy metals lead to increasing the concentration of this metals in water supply and environment. Discharge increasing of heavy metal from wastewater, their poisonous identity, Detroit effect on water supply (Nuhoglu et al., 2003) and indegradable in environment has caused to their special importance (saxena et al., 2006). Considering the increasing of industrial activity and problems due to the existence of heavy metals, removal or reduction of their concentration for achieving the acceptable level before discharge in environment is essential.

Iron is of the metals that found in many water supplies and they could be considerably troublesome. Soluble of iron is colorless but in exposure with air or known chemical materials convert to insoluble form and create the colors in water. Some of problems that create by high concentration of iron in water can refer to interfere in disinfection process, slime formation in piping, taste and color**.** Removal the metal ions of industrial wastewater has been achieved by ion exchange, membrane separation (Katsumata et al., 2003), evaporation (Mouflih et al., 2005) electrolysis, absorption processes and reverse osmosis (Sarioglu et al., 2005, Pehlivan, et al., 2006). Choosing the best method to water treatment depends on the concentration of heavy metals in the wastewater and the treatment expenses. Depositing has used extensively for removal of heavy metals due to low performance expenses. However, default of this method is production of high volume of sludge (Raju., 2003). On the other, hand absorption method such as ion exchange method in easy for removal of metals but ion exchanging resins are expensive (Katsumata el al., 2003, Aslam el al., 2004). Among the mentioned methods, we should look for a method that is economic and easily applicable for developing countries and can use efficiently. Adsorption method has suggested for removal of heavy metals because it is cheaper and more effective than other technologies (Pehlivan et al., 2006). A method for metal removal can be applied to industrial wastes without prior treatment using solid adsorbents such as sand and silica (Yabe et al., 2003). In recent years, liquid content iron filtration through granular media such as silica is very considerable (Aklil el al., 2004, Mouflih el al., 2005). Effluent iron concentration is an important water quality criterion used for the assessment of the performance of rapid sand filters, in addition to other criteria (Cakmakci et al., 2010).

1.2. Rapid sand filter and head loss

Filtration is the process in which the suspended particles removed from a flow by passing through a prose media (hamoda et al., 2004, vissman et al., 2004, Tebbutt, 1998, iritani, 2003). During the filtration process, water passed trough the bed under pressure or gravity. Removal of particle will vary due to size and identity of them (classen, 1998). Rapid sand filter used extensively for treatment of water and wastewater (Raju, 2003). Two factors, effective size and uniformity coefficient should consider for filter media. Usually the effective size and uniformity coefficient are considered 0.45 – 0.7 (mm) and 1.3 – 1.7 respectively in rapid sand filters (Punmia et al., 1995).

Different parameters involved in filtration affect the efficiency of these filters. Studies have shown that if the filter has smaller grains, lower rate and is deeper, the removal of manganese will be more efficient.

In drinking water treatment, granular media or rapid gravity filter is used. Filters clogged with deposits and this event lead to head loss in through of filter media. Therefore, filter backwashing have been necessary. To design an appropriate rapid sand filter utilizable effectively in removal of specific pollutant, head loss prediction before establishing is essential. Because of this, the equations that show relationship between involved hydraulic parameter must used.

1.3. Granular media hydraulic equations

During filtration, the clogging of the pores increases thus the resistance in the filter bed. When the filter reaches to the maximum available head loss, the filter needs to backwash to avoid a decrease in the filtration velocity**.** Head loss effective factors presented by below equation.

$$H_L = f(L, d, V_S, g, e, \upsilon)$$

Where H_L = head loss in L depth of filter; d= filter media diameter; V_s = flow velocity across media; g= gravity acceleration; e= filter porosity; υ = cinematic viscosity.

To calculate head loss the most common equation are (1) Carman-Kozeny, (2) Rose and (3) Gregory

1.3.1. modified Carman-Kozeny equation

The Carman-kozeny equation is a semi-empirical relationship and its extension to the particle deposition phase has to be based on experimental data because no theoretical description of the processes governing the head loss development have been developed to described the head loss as a function of time or increasing solids deposits. Summarizes of the wide variety of head loss development model during filtration by Herzig et al. (1970) and Sakthivadivel et al. (1972) also show that all head loss models have used on modifications to the Carman-Kozeny equation. The change of various parameters as probity decreases, and the internal surface and the tortusity of the flow increases during solids deposition is incorporated into the Carman-Kozeny equation (Boller et al., 1995). Must be attention that Carman-Kozeny equation can be applied to estimate head loss, but can only be applied to clean filter beds. Therefore, this promoted and modified along the time.

Most of the models lead to an equation relating the head loss gradient I at the certain floc volume deposit σ_V to the initial head loss gradient I_0 given by the general form (equation 1)

$$\frac{I}{I_o} = \left(1 + P . \frac{\sigma_V}{f_0}\right)^x . \left(1 - \frac{\sigma_V}{f_0}\right)^y \qquad (1)$$

Where *p*, *x*, *y* are empirical constant that are 35, 1.5 and -1 respectively. f_0 is the clean bed porosity (in the other word initial porosity involved in filtration).

$$I = \frac{h}{L} \qquad I_o = \frac{h_o}{L}$$

Where h, h_o and L are head loss, initial head loss and depth of purification layer respectively.

1.3.2. Rose equation

Rose equation in order to use for rapid sand filter in state that the filter bed considered homogeneous is shown as a equation 2:

$$\frac{h_0}{l} = 1.067 C_D \frac{v^2}{g \cdot d \cdot \psi} \frac{1}{f_0^4} \qquad (2)$$

Where g = gravity acceleration; h_0 = head loss between up and down of porous media; l = length of path that fluid travel through media; d = effective size of bed particles; f_o = initial porosity involved in filtration; and C_D = Newton drag coefficient.

C_D is the function of Reynolds number. Amount of C_D can achieve from equation 3:

$$C_D = (24/R) + (3/\sqrt{R}) + 0.34 \qquad (3)$$

R is the Reynolds number by below equation:

$R = \frac{v\,d}{\upsilon}$ v and υ are apparent velocity and cinematic viscosity, respectively. ψ is the particle shape factor that achieve from below equation:

$$\psi = \frac{A_0}{A}$$

Where A_0 = area of sphere that have a same volume with filter media particle; A = real area of filter media particle. Amount of this parameter suggested between 0.79 and 1 for sand (Tebbutt., 1998).
After filter backwashing and start of filtration, due to fluid velocity in porous media, initial pressure gradient $\left(I_0 = {}^{h_0}\!/_{l}\right)$ produce between up and down of porous media. With gradient entrance to Rose equation, initial porosity involved in filtration (f_0) is attainable.

1.3.3. Gregory equation (Tebbutt, 1998)

Gregory equation presented by as equation 4:

$$h = h_0 + \frac{K v C_0 t}{(1 - f)} \qquad (4)$$

Where v = apparent fluid velocity; f = involved porosity in filtration with respect to head loss (h); t = time (minute); C_0 = concentration of substance in fluid that lead to lead loss; and K = Gregory equation coefficient that variable in each of condition.
In this study by combination of modified Carman-Kozeny, Rose and Gregory equation the time that head loss in granular media reach to premises level, estimated. This method is a benefit way to design the filter.

2. Materials and methods

To do this study, a single layer rapid sand filter by below characteristics is constructed. Filter surface size is 17*17 cm; length of effective layer in treatment is 70 cm that included sand with 0.42-1.8 mm diameter, actual density is 2.65 ${}^{gr}\!/_{cm^3}$, 0.6 mm effective size and uniformity coefficient is 1.5.

The filter media supported on base material consisting of graded gravel layers (table 1). The gravel should be free from clay, dirt, vegetable and organic matter, and should be hard , durable and round, its total depth is 120 cm and laid in the following layers (figure 1).

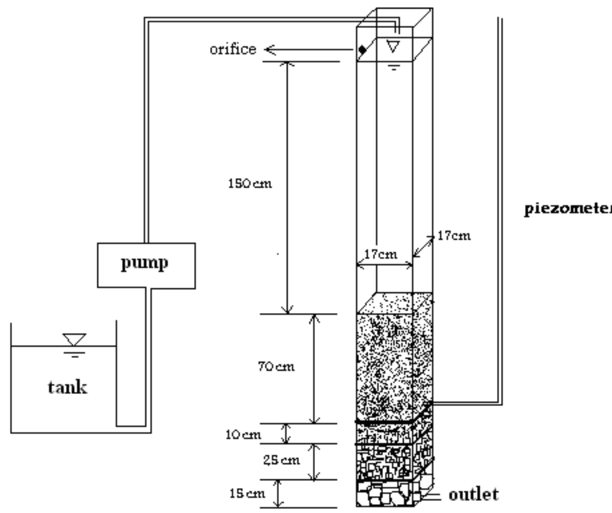

Fig 1. Schematic of filter

In order to achieve different iron concentration (25, 75, 125 and 175 ppm), nitrate salt of iron is used. Then solution separately sent to top the filter and they to passed trough the granular media in various discharge (1.5, 2, 2.5 and 2.9 ${}^{lit}\!/_{min}$) separately.

The characteristics of used water to making solution have shown in table 2.
Sampling carried out from established tap under filter drain. Given samples acidified immediately by nitric acid. Then iron concentration in effluent perused by atomic emission spectrometer with ICP source.

Table 1. Layer of filter

	Layer	Depth	Grasde size	Manometer below layer
1	Top most	700 mm	0.6-1.18 mm	h_1
2	Intermediate	100 mm	2.36-4.75 mm	h_2
3	Intermediate	250 mm	6.7-13.2 mm	h_3
4	Bottom most	150 mm	26-52 mm	h_4

Table 2. characteristics of used water to making solution

Unit	Amount	Characteristic
-	7.2-7.5	pH
NTU	1.5	Turbidity
mg/L	0	Chlorine
mg/L	0	Iron
mg/l	0	Manganese
mg/L as carbonate calcium	185	Hardness
$\frac{\mu\, mho}{cm}$	457	Electrical conductivity
^{0}C	23-25	Temperature

2.1. Initial porosity involved in filtration (f_0) calculating

One of most important factors in modified Carman-Kozeny equation is the f_0. Since that recognizing the amount of porosity that participate in filtration is impossible specially when deposits by complex morphology formed in granular media and f_0 will varied with each discharge to other, estimating of this factor is a hard work.

To do above aim for each discharge, initial head loss (h_0) was perused from installed piezometer at the purification layer (upper layer) below. Then C_D calculate from equation 3. In this study ψ considered equal to 0.85. f_0 calculate from Rose equation. Noticeable attention in Rose equation is on l. In the case of granular media l is length of path that fluid travel through filter. Because of this, purification layer height multiplied to tortuosity coefficient. Carrier (2003) explained that this amount is two.

2.2. Head loss in filter and porosity amount relationship with emphasis on different passed discharge

In this step, the range between initial head loss (h_0) and permissible headloss was assumed. For any discharge and assumed head loss, σ_v calculated from modified Carman-Kozeny equation. Needed f_0 in modified Carman-Kozeny equation, be achieved from step 2.1 for any discharge.

2.3. Gregory equation adaptation

Unknown parameters in Gregory equation are K and f . In each step of experiment f will be achived from below equation.

$$f = f_0 - \sigma_V$$

σ_v available from step 2.2.

To achieve K , following steps must perform.

A: Calculate iron removal efficiency by filter in various steps then figure out the concentration of trapped iron that lead to lead loss in filter (C_0).

B: h_0 peruse from installed piezometer at the beginning of filtration for each of discharges. h peruse from piezometer at certain time after filtration (in this case 50 minute) for each of discharges and inlet concentration of iron,

C: entrance C_0 , f , h , h_0 , v and t in Gregory equation for each of experiments step. Therefore K is available in each step of experiment.

2.4. Time estimation of certain head loss arriving

In this step, assumptive range of head loss (h) (between initial head loss and permissible head loss) is considered. Now from 2.2, decreased porosity respect to assumptive head loss (f) is available. By entrance f , h_o , C_o , v , h and K in Gregory equation for all of the situations (assumptive range of head loss, varied discharge and different concentration of inlet iron), time of reach to certain assumptive head loss (t in Gregory equation) will be accessible.

3. Results

3.1. Hydraulic parameters for different discharge

Achieved amounts for initial head loss, initial head loss gradient, Reynolds number, drag coefficient and initial porosity shown in table 3. As observed all of the Reynolds number have amount of less than one. Thus, laminar flow dominates on filter bed.

3.2. Assumptive head loss versus f diagrams for all of the discharges

Figure 2 describe relationship between head loss and decreased porosity (f) in different discharge. With attention on fig. 2 and table 2, these points figure out that with increase in discharge f_0 decreased. In addition, slop of lines in fig. 2 approximately is same. Then can be expected that porosity decreasing trend in different discharge be similar. In other word, increasing deposit rate in discharge range is similar.

Table 3. Initial head loss, initial head loss gradient, Reynolds number, drags coefficient and initial porosity amounts respect to apparent velocity .

f_0	C_D	R	I_0	h_0(cm)	v(m/sec)	Q(lit/min)
0.477130201	51.03696	0.515905	0.15714	22	0.000865	1.5
0.493656059	38.9537	0.685885	0.185	25.9	0.00115	2
0.509767521	31.5216	0.858847	0.2064	28.9	0.00144	2.5
0.519388408	27.44179	0.996024	0.224	31.4	0.00167	2.9

3.3. K (Gregory coefficient) amounts in different condition (table 4) and estimated time to arrive given head loss (minute) in different iron concentration and different discharge (fig. 4, 5, 6, 7)

To achieve C_0 in Gregory equation, removal efficiency of iron by rapid sand filter (E %), must calculate (fig. 3). Then by using below equation, C_0 be accessible.

$$C_0 = C_1 - C_2 = C_1 - (E\%) \times C_1$$

Where C_1 and C_2 is inlet and outlet concentration of iron, respectively.

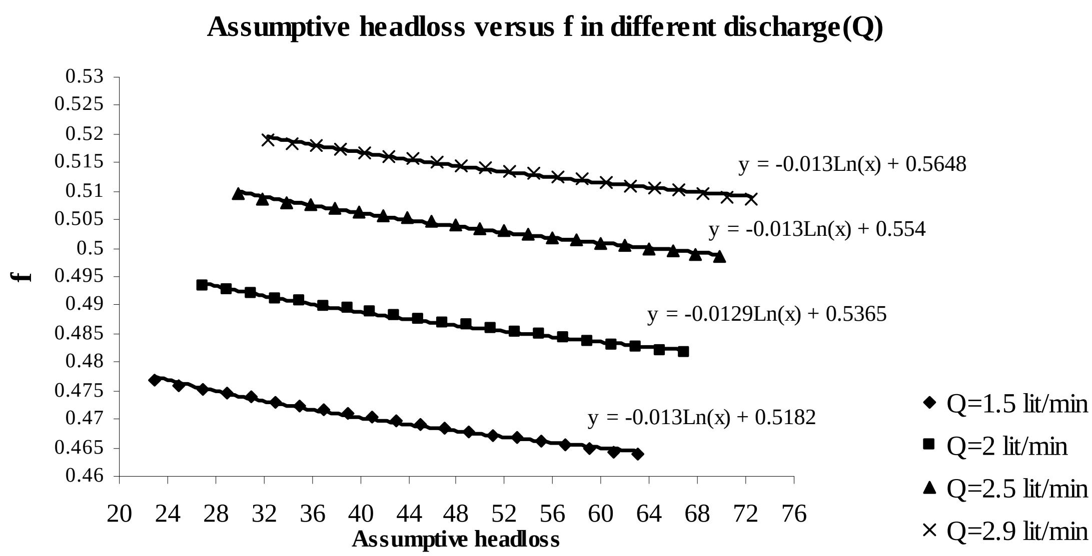

Fig.2. Assumptive head loss versus f

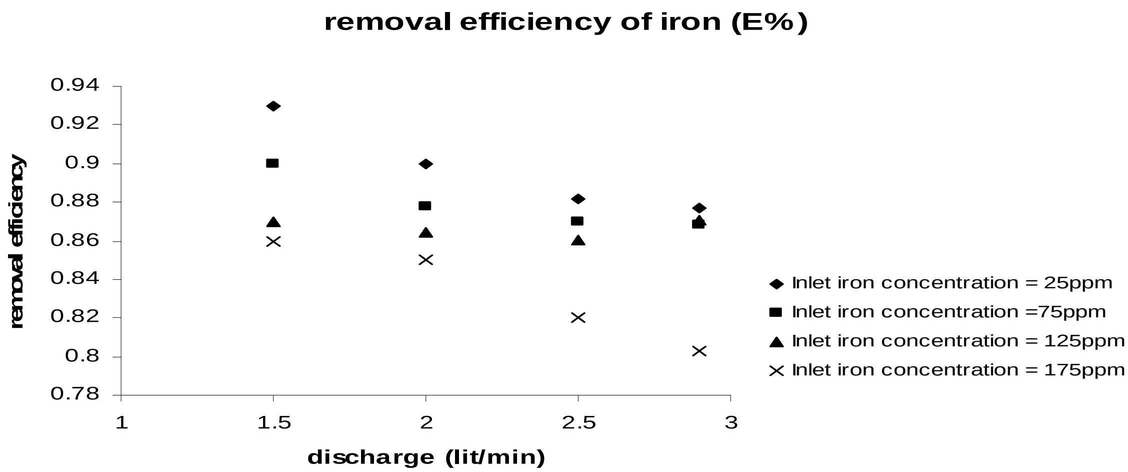

Fig.3. Removal efficiency of iron by filter

Table 4. K amounts in different condition

	Inlet iron concentration (mg/L)			
Discharge (lit/min)	**25**	**75**	**125**	**175**
1.5	0.036058668	0.01317152	0.008362015	0.00617717
2	0.010762841	0.004235695	0.002854978	0.002369632
2.5	0.006683628	0.002780231	0.002004233	0.001660144
2.9	0.003943624	0.001623595	0.001148426	0.001094495

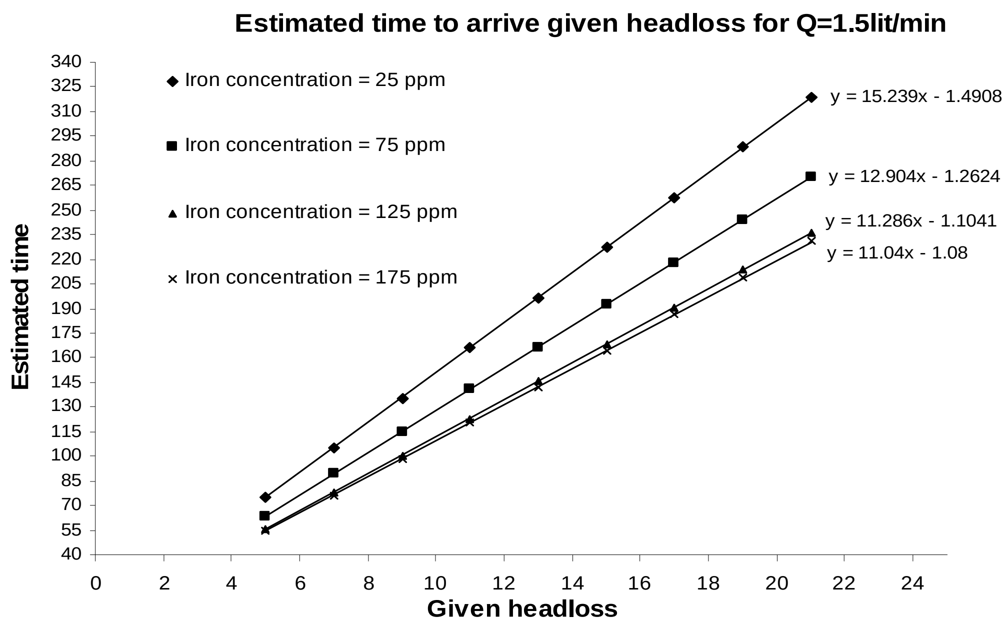

Fig.4. Time (min) versus head loss (cm) for discharge equal 1.5 (lit/min)

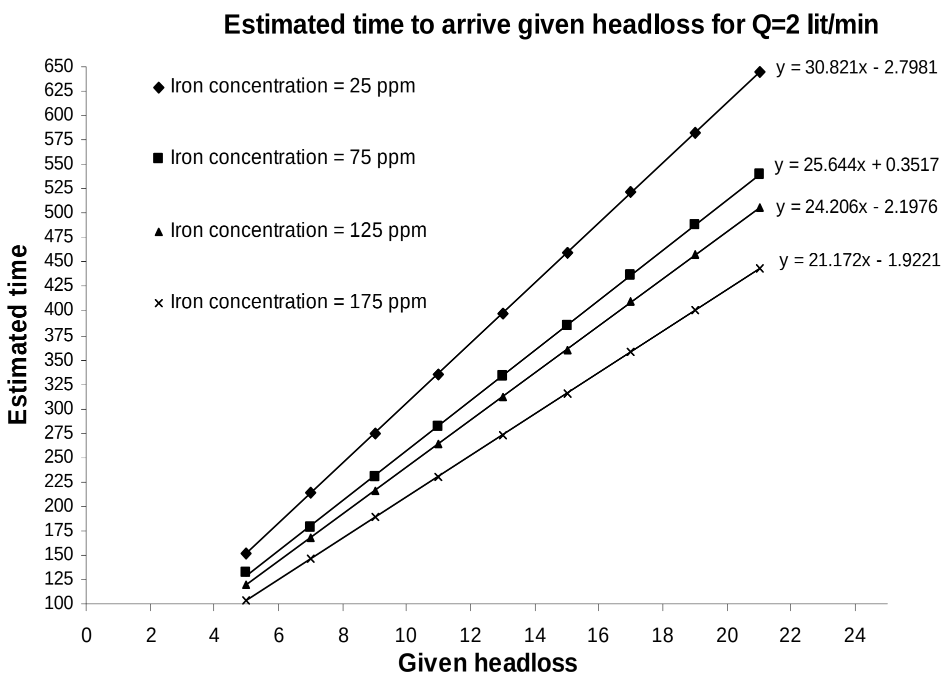

Fig.5. Time (min) versus head loss (cm) for discharge equal 2 (lit/min)

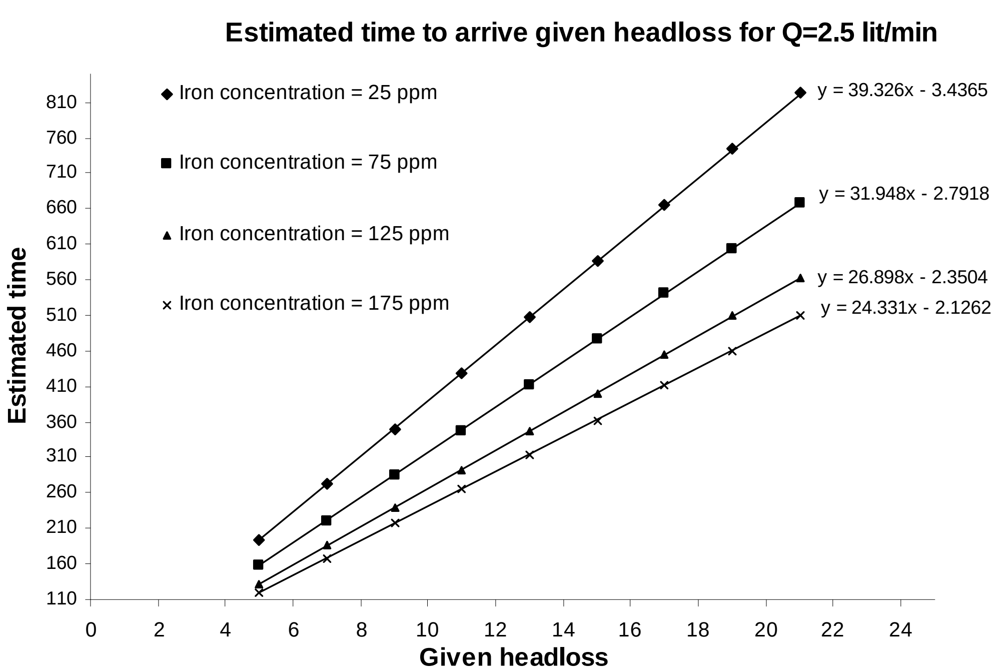

Fig. 6. Time (min) versus head loss (cm) for discharge equal 2.5 (lit/min)

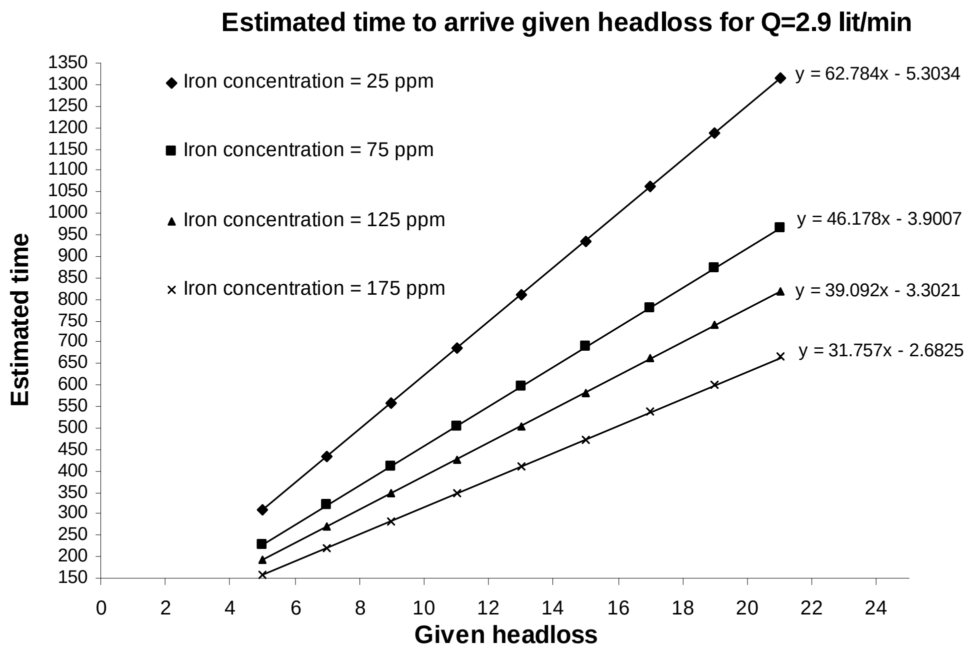

Fig 7. Time (min) versus head loss (cm) for discharge equal 2.9 (lit/min)

R^2 in figures 4, 5, 6 and 7 by linear regression is closely to 1. In addition figures 4,5,6 and 7 show that with decreasing in inlet iron concentration and increasing in discharge, arriving time to same given head loss ($h - h_0$) is increased.

Although increasing in discharge lead to entrance iron to filter is increased, the higher rate of water in bed causes that removal efficiency decreased, in addition deposit that is more compact form in granular media (because of more hydrodynamic force). Thus in same circumstance (same inlet iron concentration and given head loss), increasing in discharge lead to decreasing in σ_V. In other world, hydrodynamic force of water in iron filtration is more effective on head loss rather than inlet volume of iron.

Line slope comparison in same discharge for any of the figures 4, 5, 6 and 7 shows that in lower inlet iron concentration slope is greater. Therefore, expect that in lower inlet iron concentration, deposit distribution in depth of bed is more homogeneous. However, in higher inlet iron concentration most of deposit formed in upper layers of bed.

4. Discussions

Increasing in iron concentration lead to removal efficiency decreased. Then if high concentrations of iron exist, a series of rapid sand filters must used. Considering that rapid sand filter has relatively establishing and reclamation low cost rather than other method for iron removal, its recommend that this type of filter used for iron removal from water.

In lower inlet iron concentration, deposit distribution in depth of bed is more homogeneous. Therefore, if high concentrations of iron exist, rapid sand filters series consequence must be from filter by less depth to filter by more depth.

With increasing in discharge and decreasing in inlet iron concentration, arriving time to given head loss increased.

Following trend of this study can be useful to better rapid sand filter design (depth of filter, discharge, and grain size of filter media)

Determining of arising head loss during filtration by presented method in this research lead to more exact estimation time interval for rapid sand filter backwashing.

Using of filter media variable size in calculation and following of mentioned methodology, can aid to appropriate rapid sand filter particle size select.

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