EVALUATE OF HEAD LOSS, SEDIMENT VALUE AND COPPER REMOVAL IN SAND MEDIA (RAPID SAND FILTER)

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Abstract
Along with the technology development and increasing consumption of water resources, we are experiencing low qualities in the mentioned resources. Copper brings about serious environmental pollution, threatening human health and ecosystem. 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 and wastewater treatment plants for water clarification. In this research, a single layer gravity rapid sand filter has used to reduce different concentrations of copper. sediment value and head loss arising 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 copper concentration, arriving time to given head loss, is increasing. In addition, results demonstrated that with increasing in copper concentration in influent, removal efficiency is decreasing somewhat. Results of this research can applied in an appropriate design of rapid sand filter to copper removal, a prediction of rapid sand filter ability to copper removal and an estimation of arising head loss during filter work thus evaluating of time interval backwash.

Keywords: Sand filter, copper concentration, Removal efficiency, Head loss.
Introduction

Copper content in water and its removal

Discharge increasing of heavy metal from wastewater, their poisonous identity, Detroit effect on water supply (Nuhoglu & Oguz, 2003) and in degradable environment has caused to their special importance (Saxena & Souza, 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 (Banejad et al., 2010).

Copper is of the metals that found in many water supplies and they could be considerably troublesome. Copper brings about serious environmental pollution, threatening human health and ecosystem (Wang & Chen, 2009). 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 and wastewater treatment depends on the concentration of heavy metals in the wastewater and the treatment expenses (Daneshi et al., 2009). 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 et al., 2003; Aslam et 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 & Oliveira, 2003).

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; Iritani, 2003). Removal of particle will vary due to size and identity of them (Clasen, 1998). Rapid sand filter used extensively for treatment of water and wastewater (Raju, 2003). 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).

In water and wastewater 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 utilisable 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 be used.

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.

\[ HL = f(L, d, V_s, g, \varepsilon, \nu) \]

Where \( HL \) = head loss in L depth of filter; \( d \) = filter media diameter; \( V_s \) = flow velocity across media; \( g \) = gravity acceleration; \( \varepsilon \) = filter porosity; \( \nu \) = cinematic viscosity.

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

**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 (Boller & Kavanaugh, 1995). The change of various parameters as probity decreases, and the internal surface and the tortuosity of the flow increases during solids deposition are incorporated into the Carman-Kozeny equation (Boller & Kavanaugh, 1995). There 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 \( \sigma_v \) to the initial head loss gradient \( I_0 \) given by the general form (equation 1)

\[
\frac{I}{I_0} = \left( \frac{1 + P \cdot \sigma_v}{\varepsilon_0} \right)^x \left( \frac{1 - \sigma_v}{\varepsilon_0} \right)^y
\]

(1)

Where \( p, x, y \) are empirical constant that are 35, 1.5 and -1 respectively

\[
I = \frac{h}{L}, \quad I_0 = \frac{h_0}{L}
\]

Where \( h, h_0 \) and \( L \) are head loss, initial head loss and depth of purification layer respectively.

**Rose equation**

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

\[
\frac{h_0}{L} = 1.067 C_D \frac{\nu^2}{g \cdot d \cdot \nu \cdot f_0} \frac{1}{\varepsilon_0}
\]

(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; \( f_0 = \) initial porosity involved in filtration; and \( C_D = \) Newton drag coefficient.

\( C_D \) the function of Reynolds number

Amount of \( C_D \) can achieve from equation 3:

\[
C_D = (24 / R) + (3 / \sqrt{R}) + 0.34
\]

(3)

\( R \) is the Reynolds number.
Ψ is the particle shape factor that achieves 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 \( f_0 = \frac{h_0}{T} \) produce between up and down of porous media. With gradient entrance to Rose equation, initial porosity involved in filtration $f_0$ is attainable.

**Gregory equation (Tebbutt, 1998)**

Gregory equation presented by as equation 4:

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

Where $\nu =$ 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.

**Methodology**

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 $\text{cm}^3 \text{g r}$, 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 120cm and laid in the following layers (figure 1).

![Figure 1: Schematic of Filter](image-url)
In order to achieve different copper concentration (25, 75, 125 and 175 ppm), nitrate salt of Copper is used. Then solution separately sent to top the filter and passed through 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 copper concentration in effluent perused by atomic emission spectrometer with ICP source.

**Table 1: Layer of filter**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Grade Size</th>
<th>Manometer below layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Top most</td>
<td>700 mm</td>
<td>0.6-1.18 mm</td>
<td>( h_1 )</td>
</tr>
<tr>
<td>2 Intermediate</td>
<td>100 mm</td>
<td>2.36-4.75 mm</td>
<td>( h_2 )</td>
</tr>
<tr>
<td>3 Intermediate</td>
<td>250 mm</td>
<td>6.7-13.2 mm</td>
<td>( h_3 )</td>
</tr>
<tr>
<td>4 Bottom most</td>
<td>150 mm</td>
<td>26-52 mm</td>
<td>( h_4 )</td>
</tr>
</tbody>
</table>

**Table 2: Characteristics of used water to making solution**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Amount</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>7.2-7.5</td>
<td>pH</td>
</tr>
<tr>
<td>NTU</td>
<td>1.5</td>
<td>Turbidity</td>
</tr>
<tr>
<td>mg/L</td>
<td>0</td>
<td>Chlorine</td>
</tr>
<tr>
<td>mg/L</td>
<td>0</td>
<td>Heavy metal</td>
</tr>
<tr>
<td>Carbonate Calcium</td>
<td>185</td>
<td>Hardness</td>
</tr>
<tr>
<td>µmoh/cm</td>
<td>457</td>
<td>EC</td>
</tr>
<tr>
<td>°c</td>
<td>23-25</td>
<td>Temperature</td>
</tr>
</tbody>
</table>

**Initial porosity involved in filtration (f₀) 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. Ten \( C_D \) calculate from equation 3. In this study \( \psi \) 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.

**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 head loss was assumed. For any discharge and assumed head loss, \( \sigma_v \) calculated from modified Carman-
Kozeny equation. Needed $f_0$ in modified Carman-Kozeny equation, be achieved from step 2.1 from any discharge.

**Gregory equation adaptation**

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

$$f = f_0 - \sigma_v$$

$\sigma_v$ available from step 2.2.

To achieve $K$, following steps must be performed

A: Calculate copper removal efficiency by filter in various steps then figure out the concentration of trapped copper 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 inlet concentration of copper.

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

**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, $h_0, C_0, \nu, h$ and $K$ in Gregory equation for all of the situations (assumptive range of head loss, varied discharge and different concentration of inlet copper), time of reach to certain assumptive head loss ($t$ in Gregory equation) will be accessible.

**Results and Discussion**

*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.

*Assumptive head loss versus f diagrams for all of the discharge*

Figure 2 describe relationship between head loss and decreased porosity ($f$) in different discharge. With attention on fig. 2 and table 3, these points figure out that with increase in discharge $f_0$ decreased. In addition, slope 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**

<table>
<thead>
<tr>
<th>$f_0$</th>
<th>$C_D$</th>
<th>$R_e$</th>
<th>$I_0$</th>
<th>$h_{10}$(cm)</th>
<th>$V$(m/s)</th>
<th>$Q$(lit/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.477130201</td>
<td>51.03696</td>
<td>0.515905</td>
<td>0.15714</td>
<td>22</td>
<td>0.000865</td>
<td>1.5</td>
</tr>
<tr>
<td>0.493656059</td>
<td>38.9537</td>
<td>0.685885</td>
<td>0.185</td>
<td>25.9</td>
<td>0.00115</td>
<td>2</td>
</tr>
<tr>
<td>0.509767521</td>
<td>31.5216</td>
<td>0.858847</td>
<td>0.2064</td>
<td>28.9</td>
<td>0.00144</td>
<td>2.5</td>
</tr>
<tr>
<td>0.519388408</td>
<td>27.44179</td>
<td>0.996024</td>
<td>0.224</td>
<td>31.4</td>
<td>0.00167</td>
<td>2.9</td>
</tr>
</tbody>
</table>
$K$ (Gregory coefficient) amounts in different condition (table 4) and estimated time to arrive given head loss (minute) in different copper concentration and different discharge (fig. 4, 5, 6, 7)

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

$$C_0 = C_1 - C_2$$

Where $C_1$ and $C_2$ is inlet and outlet concentration of Copper, respectively

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**Figure 2: Assumptive head loss versus f in different discharge(Q)**

- $Q=1.5$ lit/min
- $Q=2$ lit/min
- $Q=2.5$ lit/min
- $Q=2.9$ lit/min

**Figure 3: Removal efficiency of copper by filter**
Table 4: K amounts in different condition

<table>
<thead>
<tr>
<th>Discharge (lit/min)</th>
<th>Inlet Copper concentration (mg/L)</th>
<th>25</th>
<th>75</th>
<th>125</th>
<th>175</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>0.007</td>
<td>0.0027</td>
<td>0.0018</td>
<td>0.0015</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.005</td>
<td>0.0019</td>
<td>0.00137</td>
<td>0.00114</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>0.0008</td>
<td>0.00109</td>
<td>0.0015</td>
<td>0.00359</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>0.0022</td>
<td>0.00097</td>
<td>0.00072</td>
<td>0.00064</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Time (min) versus head loss (cm) for discharge equal 1.5 (lit/min)

Figure 5: Time (min) versus head loss (cm) for discharge equal 2 (lit/min)
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 Copper concentration and increasing in discharge, arriving time to same given head loss ($h - h_o$) is increased.

Although increasing in discharge lead to entrance copper 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 copper concentration and given head loss), increasing in discharge lead to decreasing in $\sigma_i$. In other world, hydrodynamic force of water in Copper filtration is more effective on head loss rather than inlet volume of copper.

Line slope comparison in same discharge for any of the figures 4, 5, 6 and 7 shows that in lower inlet copper concentration slope is greater. Therefore, expect that in lower inlet concentration, copper concentration = 25 ppm
copper concentration = 75 ppm
copper concentration = 125 ppm
copper concentration = 175 ppm

Estimated time to arrive given headloss for $Q=2.5$ lit/min

$$y = 113.71x - 9.9359$$
$$y = 93.014x - 8.128$$
$$y = 78.708x - 6.878$$
$$y = 73.068x - 6.386$$

Estimated time to arrive given headloss for $Q=2.9$ lit/min

$$y = 169.5x - 14.318$$
$$y = 133.76x - 11.298$$
$$y = 112.93x - 9.5396$$
$$y = 92.468x - 7.7111$$

Figure 6: Time (min) versus head loss (cm) for discharge equal 2.5 (lit/min)

Figure 7: Time (min) versus head loss (cm) for discharge equal 2.9 (lit/min)
copper concentration, deposit distribution in depth of bed is more homogeneous. However, in higher inlet copper concentration most of deposit formed in upper layers of bed.

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

In lower inlet copper concentration, deposit distribution in depth of bed is more homogeneous. Therefore, if high concentrations of Copper 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 copper 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.

References


