How to estimate the run duration of a horizontal-flow roughing filter

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Abstract

Among pre-treatment methods used before slow sand filters (SSF), horizontal-flow roughing filters (HRF) have been found to be the most effective and appropriate for developing country application. This is because they are simple, require no mechanical parts, have low capital cost, can be operated for a long time due to their high solids retention capacity, and with a wide variety of raw surface water characteristics. Most research on HRFs has concentrated on turbidity (solids) removal whereas the way to estimate and design the run duration time before filter (HRF) cleaning is necessary has received little attention. In this research, a large gravel (size 10-20 mm) filter media were placed as a single package, uncovered and outlet at the top. It was found that the laboratory-scale filters used in this study provided a useful physical model with respect to the estimation of filter run over time, and the results were found to be in reasonable agreement with practical field experience. This model is a reasonable basis for design of full scale HRFs and is easy to apply.

1 Introduction

HRF is not only used for improving the physical water quality in order to meet the slow sand filter requirements but also for removing some of bacteria and viruses ranging in size from approximately 10 to 20 µm and 0.4 to 0.02 µm, respectively [1]. The most common type of HRF which has been used widely was developed by Wegelin [2] and is shown in Figure 1. Furthermore Sittivate [3] found that the large gravel media (size 10-20 mm) which were used in the filters with the outlet at the top of a HRF (similar to Wegelin [2]) produced the best results for algae and turbidity removal (more than 95% and 90% on average, respectively) and sedimentation was considered to be the principal mechanism responsible for the removal of algae and turbidity in raw water at the low filtration rate (0.3 m/h).
The objective of this research was to devise a simple method by which horizontal-flow roughing filters could be designed for field application under tropical conditions and their long-term performance predicted. This essentially requires an understanding of the process variables, knowledge of the pertinent mechanisms of removal of particulate matter, including algae, and the availability of equations to describe the time-space variation and accumulation of materials inside the filter media.

Many theoretical equations have been developed to describe the filtration process and, particularly, to try to estimate the time of run duration for HRF design. However, some parameters and constants in these equations are not universal and will, no doubt, vary with each combination of influent characteristics and filtration conditions. Moreover, when designers have applied such equations they have had to make many assumptions of those parameters for the estimation of results.

![Figure 1: Layout of a Horizontal-flow Roughing Filter (Wegelin, 1996)](image)

2 Experimental procedure

2.1 Pilot plant

The pilot plant system [3] shown in Figure 2 consisted of the following: (1) A plastic filter box composed of two symmetrical rectangular channels with dimensions of 1.6 m × 0.39 m × 0.195 m each; the lateral walls of the filter box were fitted with sampling ports. (2) Two plastic cylindrical tanks (total volume of one cubic metre) with an internal diameter of 1.60 m and height of 0.50 m; these were the feed tanks which contained algae and clay to simulate tropical surface water. (3) Two stirrers for mixing the suspension in the large tank. (4) A light source constructed from lightweight steel bars to carry fluorescent tubes; this was suspended over the two large tanks. (5) Two peristaltic pumps used to feed the suspension from the algae inoculation tanks into the filters.

The suspension of turbidity and algae from the large tanks was pumped into the inlet chambers of each filter, passed through the gravel media and discharged into the outlet chambers of each filter. During the filter runs, effluent water samples were analysed following the method of Standard Methods for Examination of Water and Wastewater [4], mainly to determine the turbidity and
pH. The chlorophyll $a$ concentration was also determined as a measure of the algae concentration.

2.2 Design of synthetic raw water

To prepare a medium with a high algae content in the preparation an appropriate raw water, one factor which was considered was turbidity. High turbidity in water inhibits photosynthesis and thus reduces the production of oxygen by algae as well as algal growth [5]. Two types of motile green algae (Euglena gracilis and Chlamydomonas reinhardtii) were chosen as representative algae for this research [3]. Wegelin [2] suggested that the possibility of annual turbidity maximum in raw water sources in tropical areas is normally not higher than 100 NTU. As a result, it was decided to set the turbidity of the synthetic raw water at 100 NTU for every run in this research. The required turbidity was achieved by the addition of a known weight of clay, which would produce turbidity 100 NTU in the water in the large tank and maintained in suspension by continuous stirring [3]. The type of clay used was kaolin clay (Speswhite china clay) supplied by ECC International Ltd, Cornwall, England.

2.3 Experimental planning

Experiments as shown in Table were performed on the 1.60 m long channel. The filtration rate was 0.3 m/h throughout the study.

Table 1: Planning of experiments

<table>
<thead>
<tr>
<th>Run no.</th>
<th>Filter</th>
<th>Algae type</th>
<th>Influent turbidity (NTU)</th>
<th>Influent algae content during the run (µg/l)</th>
<th>Gravel size (mm)</th>
<th>Outlet position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>E</td>
<td>230 to 235</td>
<td>19.48 to 151.95 µg/l</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>C</td>
<td>145 to 198</td>
<td>86.10 to 363.12 µg/l</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>E &amp; C</td>
<td>150 to 260</td>
<td>238.83 to 360 µg/l</td>
<td>L</td>
<td>T</td>
</tr>
</tbody>
</table>

Notes: A=FilterA, E = Euglena gracilis, C = Chlamydomonas reinhardtii.  
L = Large gravel, sized 10 - 20 mm.  
T = Outlet at the top, 0.16 m from the bottom of the filter bed.  
Inlet turbidity (NTU) = Clay turbidity + Turbidity produced by algae. [3]
3 Results

Throughout the study, the filter volumes in which suspended solids and microorganisms accumulated in the pore spaces of the filter media over time were measured. Linear measurements of the dimensions of the clogged area profile along the side of both filters were made at various times in every run and converted into volumes of the filter by multiplication of the filter width (0.195 m). These data are given in Tables 2 to 4. Note that this total volume is composed of the volume of gravel media and solids particles (microorganisms and clay) occupying in the filter media pore spaces.

Table 2: Accumulation of solids mass in the large gravel media (size 10-20 mm) filter volume in Run No.1:

<table>
<thead>
<tr>
<th>Accumulated time (h)</th>
<th>Clogged filter volume (cm³)</th>
<th>Time difference (h)</th>
<th>Clogged filter volume difference (cm³)</th>
<th>(4)/(3)</th>
<th>Influent turbidity (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>25,072.13</td>
<td></td>
<td>-</td>
<td>-</td>
<td>235</td>
</tr>
<tr>
<td>52</td>
<td>32,048.25</td>
<td>24</td>
<td>6976.12</td>
<td>290.67</td>
<td></td>
</tr>
<tr>
<td>82</td>
<td>44,850.00</td>
<td>30</td>
<td>12,801.75</td>
<td>426.73</td>
<td>230</td>
</tr>
<tr>
<td>97</td>
<td>49,530.00</td>
<td>15</td>
<td>4,680.00</td>
<td>312.00</td>
<td>225</td>
</tr>
<tr>
<td>145</td>
<td>61,161.75</td>
<td>48</td>
<td>11,631.75</td>
<td>242.33</td>
<td>230</td>
</tr>
<tr>
<td>average =</td>
<td></td>
<td></td>
<td></td>
<td>317.93</td>
<td>230</td>
</tr>
</tbody>
</table>

Table 3: Accumulation of solids mass in the large gravel media (size 10-20 mm) filter volume in Run No.2:

<table>
<thead>
<tr>
<th>Accumulated time (h)</th>
<th>Clogged filter volume (cm³)</th>
<th>Time difference (h)</th>
<th>Clogged filter volume difference (cm³)</th>
<th>(4)/(3)</th>
<th>Influent turbidity (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>16,321.50</td>
<td></td>
<td>-</td>
<td>-</td>
<td>198</td>
</tr>
<tr>
<td>79</td>
<td>21,674.25</td>
<td>26</td>
<td>5,352.75</td>
<td>205.88</td>
<td>145</td>
</tr>
<tr>
<td>127</td>
<td>29,250.00</td>
<td>48</td>
<td>7,575.75</td>
<td>157.83</td>
<td>150</td>
</tr>
<tr>
<td>223</td>
<td>33,783.75</td>
<td>96</td>
<td>4,533.75</td>
<td>47.23</td>
<td>145</td>
</tr>
<tr>
<td>319</td>
<td>38,288.25</td>
<td>96</td>
<td>4,504.50</td>
<td>46.92</td>
<td>145</td>
</tr>
<tr>
<td>415</td>
<td>55,282.50</td>
<td>96</td>
<td>16,994.25</td>
<td>177.02</td>
<td>145</td>
</tr>
<tr>
<td>487</td>
<td>60,094.13</td>
<td>72</td>
<td>4,811.63</td>
<td>66.83</td>
<td>150</td>
</tr>
<tr>
<td>average =</td>
<td></td>
<td></td>
<td></td>
<td>116.95</td>
<td>154</td>
</tr>
</tbody>
</table>

Table 4: Accumulation of solids mass in the large gravel media (size 10-20 mm) filter volume in Run No.3:

<table>
<thead>
<tr>
<th>Accumulated time (h)</th>
<th>Clogged filter volume (cm³)</th>
<th>Time difference (h)</th>
<th>Clogged filter volume difference (cm³)</th>
<th>(4)/(3)</th>
<th>Influent turbidity (NTU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>78</td>
<td>23,868.00</td>
<td></td>
<td>-</td>
<td>-</td>
<td>260</td>
</tr>
<tr>
<td>105</td>
<td>29,401.13</td>
<td>27</td>
<td>5,533.13</td>
<td>204.93</td>
<td>210</td>
</tr>
<tr>
<td>130</td>
<td>42,237.00</td>
<td>25</td>
<td>12,835.88</td>
<td>513.44</td>
<td>200</td>
</tr>
<tr>
<td>150</td>
<td>47,580.00</td>
<td>20</td>
<td>5,343.00</td>
<td>267.15</td>
<td>185</td>
</tr>
<tr>
<td>191</td>
<td>61,161.75</td>
<td>41</td>
<td>13,581.75</td>
<td>331.26</td>
<td>150</td>
</tr>
<tr>
<td>average =</td>
<td></td>
<td></td>
<td></td>
<td>329.20</td>
<td>201</td>
</tr>
</tbody>
</table>

Note: Clogged filter volume = Filter volume accumulated by suspended solids (SS) and gravel media.
4 Discussion

4.1 Progression of filter volume occupied by suspended solids and filter media

In HRFs, the filtration rate is assumed to remain constant throughout a filter run and the type of flow in filter media is plug flow [2]. Tchobanoglous [6] suggested that, in general, the mathematical characterisation of the time-space removal of particulate matter within the filter is based on a consideration of the equation of continuity, together with an auxiliary rate equation. The equation of continuity for the filtration operation may be developed by considering a suspended solids mass balance for a section of filter of cross-sectional area, and of the thickness, measured in the direction of flow. The mass balance would be as follows:

\[ \text{Rate of accumulation = Rate of flow of solids within the volume element} \]
\[ \text{Rate of flow of solids into the volume element} \]
\[ \text{Rate of flow of solids out of the volume element} \]

**a) General word statement:**

\[ \text{Rate of accumulation} = \text{Rate of flow of solids into the volume element} - \text{Rate of flow of solids out of the volume element} \]

**b) Simplified word statement:**

Accumulation = [inflow - outflow] - degradation

However, it was found that the degradation in HRF occurred very little [3]. Hence, the last term in equation (2) is negligible.

**c) Symbolic representation of equation (1) [6]:**

\[ dV \left( \frac{\partial C}{\partial t} \right) = - Q \frac{\partial C}{\partial x} \]

where, 
\[ dV = \text{differential volume of reactor or filter (L}^3\text{)} \]
\[ \frac{\partial C}{\partial t} = \text{rate of change of suspended solids concentration within the container or filter (ML}^{-3}\text{T}^{-1}\text{)} \]
\[ Q = \text{volumetric rate of flow into and out of the reactor or filter (L}^3\text{T}^{-1}\text{)} \]
\[ \frac{\partial C}{\partial x} = \text{change in concentration of suspended solids in fluid stream with distance (ML}^{-3} \text{L)} \]
\[ \frac{dx}{dt} = \text{differential distance of filter (L)} \]
\[ C = \text{concentration of suspended solids in reactor or filter (ML}^{-3}\text{)} \]

If \[ A \frac{dx}{dt} \] is substituted for \[ dV \], the resulting expression is

\[ \frac{dA}{dt} \left( \frac{\partial C}{\partial t} \right) = - Q \frac{\partial C}{\partial x} \frac{\partial C}{\partial x} \]

where; \[ A = \text{cross-sectional area of filter (L}^2\text{)} \]

Therefore, equation (4) may be rewritten:

\[ A \frac{dx}{dt} \left( \frac{\partial C}{\partial t} \right) = - Q \frac{\partial C}{\partial C} \]

It can be said that the first term of equation (5) is the different weight of solids accumulated in the pore space of the filter media over the different time. Hence, equation (5) may be rewritten as an ordinary differential equation:

\[ \frac{dP_t}{\Delta t} = - Q \frac{dC}{\Delta t} \]

where; \[ P_t = \text{weight of suspended solids retained in the filter media at any time (M)} \]
\[ \Delta t = \text{different time (T)} \]

Therefore, equation (6) can be rewritten in a form suitable for numerical analysis:

\[ \Delta P_t = Q \Delta C \text{ or } \frac{P_{t_2} - P_{t_1}}{t_2 - t_1} = \frac{Q \left[ (C_{SS02} - C_{SS02}) - (C_{SS_{t2}} - C_{SS_{t1}}) \right]}{t_2 - t_1} \]
where; $P_t$ = weight of suspended solids retained in the filter media at any time (g)

$Q$ = flow rate through the cross-sectional area of filter (m$^3$/h)

$C_{SS1t}$ = concentration of suspended solids in the influent at time $t_1$ (g/m$^3$)

$C_{SS2t}$ = concentration of suspended solids in the influent at time $t_2$ (g/m$^3$)

$C_{SSO1}$ = concentration of suspended solids in the effluent at time $t_1$ (g/m$^3$)

$C_{SSO2}$ = concentration of suspended solids in the effluent at time $t_2$ (g/m$^3$)

$A$ = cross-sectional area of filter (m$^2$); $v_F$ = filtration rate (m/h), $t$ = time (h)

This can be rewritten;

$$\frac{(V_2 - V_1)(\gamma_2) - (V_1)(\gamma_1)}{t_2 - t_1} = A v_F \left[ (C_{SS2} - C_{SSO2})_{t_2} - (C_{SS1} - C_{SSO1})_{t_1} \right]$$

(8)

where;

$V_1$ = filter volume occupied by suspended solids and filter media at time $t_1$ (cm$^3$)

$V_2$ = filter volume occupied by suspended solids and filter media at time $t_2$ (cm$^3$)

$\gamma_1$ = total unit weight of solids mass accumulated in the pore space of filter media at time $t_1$ (g/cm$^3$)

$\gamma_2$ = total unit weight of solids mass accumulated in the pore space of filter media at time $t_2$ (g/cm$^3$)

$f_o$ = porosity of the bed when clean ($V_o / V_i$)

The time difference between $t_1$ and $t_2$ is not much. Hence, it can be said that $\gamma_2 \approx \gamma_1$. Therefore, equation (8) may be rewritten;

$$f_o \left( \gamma_1 \right) \frac{(V_2 - V_1)}{t_2 - t_1} = A v_F \left[ (C_{SS2} - C_{SSO2})_{t_2} - (C_{SS1} - C_{SSO1})_{t_1} \right]$$

(9)

where; $\gamma_1$ = total unit weight of solids mass accumulated in the pore space of filter media

The filter volume $(V_2, V_1)$ and porosity $(f_o)$ are easily measured but it is very difficult to measure the total unit weight of solids mass accumulated in the pore space of filter media $(\gamma_1)$. This is because the suspended solids content will be different at any depth or at any length in the pore space of the filter media at the HRF, and at any time as influenced by the drag force of fluid, velocity of flow through the pore space of the filter media, gravity and the characteristic diameter of the solids particles (Fair et al., 1968) during the run duration. So the first term of equation (9) cannot be used to estimate the solids mass retained in the filter. However, all parameters in the last term of equation (9) can be measured and used to estimate the solids mass retained in the filter media

Hence, it follows that $(V_2 - V_1)$ is occupied by gravel media and solids mass $A v_F \left[ (C_{SS2} - C_{SSO2})_{t_2} - (C_{SS1} - C_{SSO1})_{t_1} \right]$. Therefore, the rate of filter volume occupied by gravel media and solid mass, per time, is equivalent to the difference in weight of suspended solids mass accumulated in the pore space of filter media over the time change, divided by porosity of gravel media and total unit weight of solids mass accumulated in the pore space of filter media. Hence, equation (9) after rearranging the terms, yields;

$$\frac{V_2 - V_1}{t_2 - t_1} = A v_F \left[ (C_{SS2} - C_{SSO2})_{t_2} - (C_{SS1} - C_{SSO1})_{t_1} \right]$$

(10)

For the large gravel media filter model, the filter volume occupied by suspended solids and filter media at different times, from Tables 2 to 4, were 317.93, 116.95 and 329.20 cm$^3$/h, respectively. In addition, Sittivate [3] found that the patterns of the removal characteristics for *Euglena gracilis* and *Chlamydomonas reinhardtii*
in HRF were similar. Hence, the average filter volume occupied by suspended solids and filter media at different times

\[ V = \frac{(317.93 + 116.95 + 329.20)}{3} = 254.69 \sim 250 \text{ cm}^3/\text{h} \]

Hence, with the outlet at the top and a filtration rate of 0.3 m/h (at average influent turbidity = [230 + 154 + 201] / 3 = 195 NTU), the average change of filter volume over time accumulated by gravel media and suspended solids mass (clay and algal mass) in the large gravel media (size 10-20 mm) filter is 250 cm\(^3\)/h. Hence, the average change of filter volume accumulated by gravel media and suspended solids mass (clay and algal mass) in the large gravel media filter pore space over time (See equation (10)) is 110 cm\(^3\)/h (=250 cm\(^3\)/h × porosity of gravel media = 250 cm\(^3\)/h × 0.4372). This rate could be the basis of the design of HRFs, and estimates of the run duration times for scaled up HRFs.

4.2 Confirmation of results

Checking this value (110 cm\(^3\)/h ) was achieved by estimating the run duration time of the large gravel filter model which normally failed by solids blocking along the filter length in 10 days [3];
The effective volume pore space of filter model occupied by large gravel media

\[ V_{\text{effective}} = 19.5 \times 20 \times 153 \times 0.4372 = 26,087.72 \text{ cm}^3 \]

\[ \therefore \text{Run duration time} = \frac{26,087.72}{110 \times 24} = 9.88 \text{ days} \sim 10 \text{ days} \]

4.3 Scale-up considerations

As shown in Section 4.2, for the conditions of filtration velocity \((v_F) = 0.3 \text{ m/h})\) and with the filter outlet at the top, it was calculated that:

\[ R \text{ (day)} = \left( \frac{\text{Volume of filter model occupied by gravel media (cm}^3) (f_o)}{110 \text{ (cm}^3/\text{h}) \times 24} \right) \]

where; \( R = \text{Run duration (days)} \text{ before filter cleaning is necessary.} \)

Let, \( A_m = \text{The cross-sectional area of filter model (= 19.5 } \times 20 \text{ cm}^2) \)

\( L_m = \text{The length of filter model (internal)} ; \ W_m = \text{The width of filter model (internal)} ; \)

\( D_m = \text{The depth of filter model (internal)} ; f_o = \text{porosity of the bed when clean (V_o / V_i)} \)

Hence, equation (11) will be;

\[ R = A_m \cdot L_m \cdot (f_o) / 110 \text{ (cm}^3/\text{h}) \times 24 \text{ or } = \frac{(W_m \cdot D_m) \times L_m \cdot (f_o)}{2,640 \text{ (cm}^3/\text{h})} \]

This filter model will also fit the prototype (the large-scale design for field application), on the basis of an implied confidence in the principles of geometrical and dynamical similarity. Henderson [7] suggested that the detailed interpretation of model measurements requires that scale ratios be available for translating model values for various quantities, e.g., velocity, discharge, etc., into the corresponding prototype values. Scales can be deduced for all physical quantities if scales are known for mass, length, time, and the physical properties of prototype and model fluids.

The prototype will have conditions similar to the filter model in this study, for instance the low filtration rate (0.3 m/h), position of the outlet, gravel media
size, and influent turbidity. The scale ratio of this model and the prototype can be obtained from the cross-sectional area of the prototype divided by the cross-sectional area of the model. This is because the filtration rate \((v_F)\) in the design of the prototype is equal to that in the model and the depth of the filter is not significant in the filter behaviors [8]. Hence, this scale model ratio can be calculated as follows:

From \(Q = Av\) \((13)\), therefore, \(Q_p = A_p v_F\) \((14)\); and, \(Q_m = A_m v_F\) \((15)\)

where; \(Q_p = \) flow-rate through the cross-sectional area of filter prototype \((m^3/h)\)

\(Q_m = \) flow-rate through the cross-sectional area of filter model \((m^3/h)\)

Equation (14) / Equation (15) gives,

\[
\frac{Q_p}{Q_m} = \frac{A_p v_F}{A_m v_F} = \frac{A_p}{A_m}
\]

therefore;

\[
Q_p = (A_p/A_m) Q_m
\]

\[
A_p/A_m = m_1
\]

where; \(m_1 = \) scale ratio of prototype and model

Hence, for the large scale of HRF (prototype) with the same conditions as in the model, the run duration can be estimated by;

\[
R = A_p L_p (f_o)_p / 2,640 \text{ (m)}\)

\(R = \) the length of filter prototype \((m)\)

\((f_o)_p = \) porosity of the bed of filter prototype when clean \((V_o/V_F)\)

It was found that \(R \propto 1/ v_F\) and \(R \propto 1/\text{influent turbidity (NTU)}\) \([1]\), therefore, equation (18) could be modified by these proportional relationships for use in the design of a HRF, as follows \([8]\):

\[
R = \frac{A_p L_p (f_o)_p}{2,640 m_1 (v_F)_p / (v_F)_m \cdot (NTU)_p / (NTU)_m}
\]

when; \(m_2 = (v_F)_p / (v_F)_m ; m_3 = (NTU)_p / (NTU)_m\)

Equation (19) becomes,

\[
R = \frac{A_p L_p (f_o)_p}{2,640 \cdot m_1 \cdot m_2 \cdot m_3}
\]

4.4 Model validation

From equation (20), it can be said that the filtration rate and turbidity are the main parameters which affect the run duration and turbidity removal efficiency as Wegelin [2] found. If the gravel media is chosen as in Wegelin [1]'s design guidelines, the porosity of the gravel media size 10-20 mm will not affect this equation. As a result, this model is valid for use in HRF design, for the filtration rate adopted and up to the influent turbidity of raw water used in the study.

Lebcir [8] also found that:

-Laminar flow conditions prevailed when the filtration rate was less than 1 m/h for large gravel media filter (LGF) (outlet at the top). Furthermore the pattern of the turbidity distribution inside the bed is in conformity with that of the sedimentation tanks at flow velocities between 0.5 - 1 m/h. This is because these flow velocities are low enough to not cause turbulence in the gravel filter media.
Hence, equation (20) could be valid if the filtration rate does not exceed 1 m/h for the large and medium gravel filter media and the other conditions are as in this study. This is because within this range the conditions inside the filter media are assumed to not change. This equation should be used with the low filtration rate of 0.3 m/h for the scaled up design as in this study, because it was found that, with these filters used in this study, both algae and turbidity removal were more than 90% at this filtration rate. Moreover, this filtration rate was found to be suitable for operation and has produced turbidity removal efficiencies more than 80% in field installations ([2] and [9]).

4.5 Confirmation of the physical modelling

Although equation (20) has been developed to be a simple tool for the design and estimation of the run duration time of a HRF, it is still not proven on the larger scale. However, the horizontal-flow roughing filters used in the Blue Nile Health Project in Sudan [10], were similar to this model and the results reported by Brown can be used to confirm the applicability of equation (20). A plan view of the HRF series used in the Sudan is shown in Figure 3.

Brown [10] reported on two runs where the run duration of the filter (Figure 3) was terminated when solids accumulated in the filter media pore spaces to the point of breakthrough. In the first run, with a filtration rate of 0.4 m/h and average influent turbidity 300 NTU, the run duration time was 20 days. In the second run (after cleaning), with average filtration rate 0.45 m/h and average influent turbidity 312 NTU, the run duration time was 14 days.

From equation (20); for the first run,

\[
R = \frac{A_p L_p (f_o)}{2640 m_1. m_2. m_3} \\
A_p = 1 \times 0.95 \times 10,000 \text{ cm}^2 \\
m_1 = (0.95 \times 1.00 \times 10,000) / 19.5 \times 20 = 24.36 \\
m_2 = (V_F)P / (V_F)m = 0.4/0.3 = 1.33 ; m_3 = (NTU)P / (NTU)m = 300/195 = 1.54
\]

Substituting these values in equation (20), provides the estimated run duration time for the first run;
\[ R = \frac{1 \times 0.95 \times 1,000,000 \times (2.9 \times 0.575 + 1 \times 0.40 + 1 \times 0.37)}{2,640 \times 24.36 \times 1.33 \times 1.54} = 17.58 \text{ days (cf. 20 days in Brown's results)} \]

For the second run,
\[ m_2 = \frac{(V_F)p}{(V_F)m} = 0.45 / 0.3 = 1.5 \]
\[ m_3 = \frac{(NTU)_p}{(NTU)m} = 312 / 195 = 1.6 \]

Substituting these values in equation (20), provides the estimated run duration time for the second run:
\[ R = \frac{1 \times 0.95 \times 1,000,000 \times (2.9 \times 0.575 + 1 \times 0.40 + 1 \times 0.37)}{2,640 \times 24.36 \times 1.5 \times 1.6} = 15 \text{ days (cf. 14 days in Brown's results)} \]

It would appear that the equation (20) gives a reasonable agreement with practical field experience and the estimation of HRF run duration obtained from the equation is a reasonable bases for design.

5. Conclusion

Due to the fact that there was not sufficient time over the period of the experimental programs to cover a full statistical evaluation of all design variables such as filtration rate, cross-section area of the filter, the length of the filter media, the influent characteristics of raw water (turbidity) etc., a comprehensive design model is not possible. However, based on experimental findings and theoretical considerations, the physical models which have been developed in this study can provide significant improvement on previous design and could be used in the design and estimate the run duration time of HRFs.

References


