Optimization of sand recycle rate in mobile bed filtration

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Rapid sand filters have been used as a final clarifying step in municipal water treatment plants since the early 1900's. In the commonly used rapid filter (conventional filter), after the filter backwash, fine media goes to the top, whilst the coarse portion remains at the bottom. This stratification of media causes major removal of particles only at the top few centimeters of the filter bed. This phenomenon leads to the inefficient use of the entire bed and a relative reduction of the filter run.

To overcome these drawbacks there have been considerable new developments in filter design and operation, over the last few years. These developments have involved changes in either one, or a combination of, the filter media (dual media, mixed media filters), flow direction (upflow, biflow, radial filters), flow rate control (declining rate filters) or backwash method (mobile bed filters).

More recently, further developments in filtration techniques have taken place such as the application of direct filtration. Here, depending on the raw water quality, some pretreatment operations are avoided. Further development in this area is contact-flocculation filtration where the flocculant is added directly into the filter and both flocculation and filtration actions take place within the filter bed itself. The main drawback of this treatment method is frequent clogging of the filter bed, total removal of suspended matter occurs within the bed but necessitates frequent backwashing.

This bed clogging problem during contact flocculation-filtration has led to the development of mobile bed filters. This type of filter arrangement is designed so that filter grains from the bottom layer are recycled to the top of the bed using an air-lift system. Here the recycled filter grains are washed continuously. This filter grain recycle process eliminates the problem of backwashing and functions as a continuous filter.

Allanson and Austin[1] reported from their mobile-bed deep filter experiments that the compressed air used to lift the sand also helped in the separation of retained particles in the sand. Other literature[2] indicates an application of mobile bed radial filters known commercially as the *SIMATOR* continuous sand filter in order to clarify 0.3mgd of the raw water drawn from the river Calder, for the use in a Carlisle textile mill. Another type of mobile bed filter arrangement (plate-form), known commercially as *Tenten*, has been tried to treat the effluent from the secondary clarifier of municipal wastewater treatment in Colombe.[3]

Although these reports indicate that this type of filter operates continuously without any problem, sand recycling was found to be energy consuming process. It is therefore essential to optimize the sand recycle rate. In this study the optimum recycle rate for a particular filtration rate was estimated from the 'filter clogging front theory' using fixed bed experimental results. This sand recycle rate was then verified by experiments with laboratory-scale mobile bed filters.

Theory

The particle removal mechanisms involved in a filter bed are in many ways similar to the adsorption in a packed column. Here the principal removal of particles will be confined to the top layer at the initial stages of filtration. During this stage, the rest of the filter bed would participate in the removal of the remaining particles. Once the maximum particle storage is reached at the top layer, the principal removal layer would move down to the adjacent layer. This process will proceed till the principal removal layer reaches the bottom of the filter bed. After this stage, the effluent quality will start to deteriorate. At this stage of filtration, the process will be stopped for backwashing. Based on this concept, a theory known as 'clogging front velocity' was developed.[4] Clogging front velocity is the rate at which the clogging layer (or principal removal layer) moves down in the direction of flow. This has been quantified as follows:

Clogging Front Velocity (Vf) =

$$\left(\frac{dL}{dt}\right)_\sigma = \left(\frac{\left(\frac{d\sigma}{dt}\right)}{\left(\frac{d\sigma}{dL}\right)}\right)_\sigma \qquad (1)$$

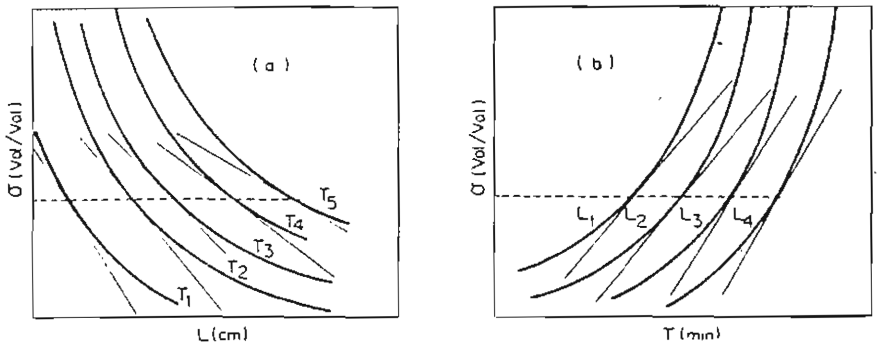

Figure 1: Variation[4] of specific deposit (σ) with filter bed depth (L) and filtration time (T)

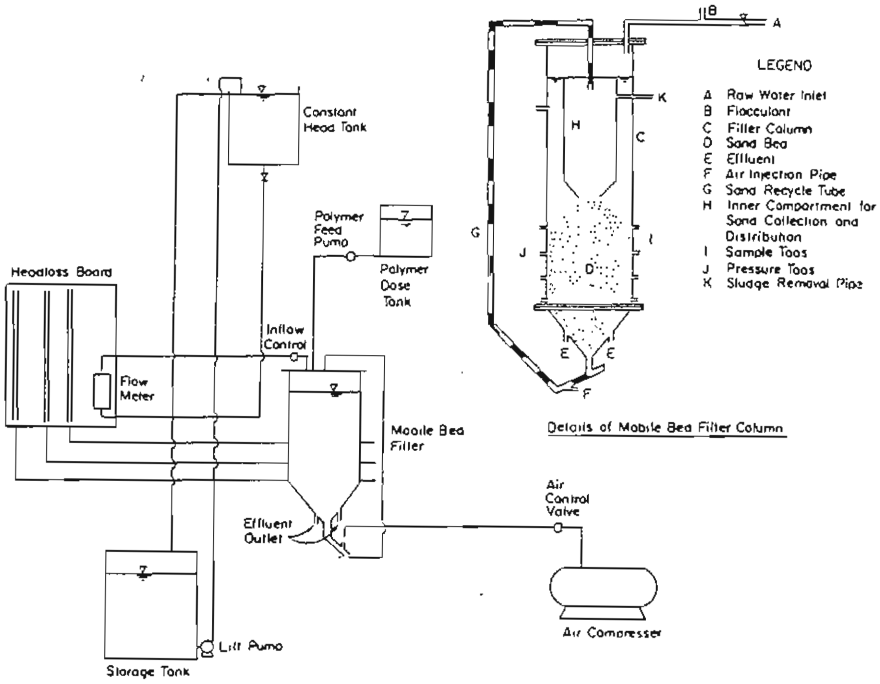

Figure 2: Experimental setup for mobile bed filtration

The variation of specific deposit (σ) with depth can be given by the following equation[4]

$$\frac{1}{\sigma} \cdot \frac{d\sigma}{dt} = -\frac{k}{v} \qquad (2)$$

Where, K is the clogging rate constant (t^{-1})

The variation of specific deposit (σ) with time can be given by the following equation.[5]

$$\frac{d\sigma}{dt} = -v\frac{dc}{dL} = v\lambda c \qquad (3)$$

From these equations it is clear that both $\frac{d\sigma}{dL}$ and $\frac{d\sigma}{dt}$ are constant for different times and depths, respectively, for a given σ as illustrated in Figure 1. The clogging front velocity therefore can be calculated by calculating $\left(\frac{d\sigma}{dL}\right)_\sigma$ and $\left(\frac{d\sigma}{dt}\right)_\sigma$ from the experimental σ versus L and σ versus t graphs and using Equation (1).

Experimental

The experimental set-up of mobile bed filtration studies is given in Figure 2. Sand with sizes ranging from 0.841 — 1.168mm was selected as the filter medium. The specific gravity of the sand was found to be 2.65 and its porosity was maintained at 0.46 in all experimental runs in order to make the comparisons consistent. An artificial suspension of kaolin clay was used in this study in order to control the particle size distribution and concentration. *Cat Floc-T,* with an optimum dose 0.05mg/*l* was used as a flocculant in all experimental runs[6]. The polymer was added directly and continuously to the filter bed to achieve contact-floccculation within the filter bed. The sludge removal rate was maintained at 5% of the influent flow rate in all the mobile bed filter experiments.

Results

Fixed bed experiments: The fixed-bed experimental runs with six different filtration velocities were carried out in order to calculate the clogging front velocity and theoretical recycle rates. The variations of σ at different filtration times and depths are calculated from the local concentration values using the finite difference form of equation (3). The variation of σ with filter bed depth and time for different filtration velocities are plotted to calculate the mean $\left(\frac{d\sigma}{dL}\right)_\sigma$ and $\left(\frac{d\sigma}{dt}\right)_\sigma$ values and the obtained values are presented in Table I. The clogging front velocity is then calculated for each filtration velocity from equation (1). The calculated clogging front velocity (Vf) is used to calculate the time for the entire filter bed of 14cm (mobile bed filter depth) to clog and the required optimum sand recycle rate. The results are summarized in Table I.

Mobile bed experiments: The mobile bed filter experiments were carried out in order to find the optimum sand recycling rate at two different filtration velocities and to compare them with the theoretical recycle rates. For each filtration velocity, the sand recycle rate was varied and the filter performance was measured in terms of effluent turbidity and headloss development.

The results of the mobile bed filter experimental runs, with different sand recycle rates are presented in Figure 3. At the initial stages of the filter run, the effluent turbidity of the filter bed decreased for a short time and then remained constant.

Figure 4 shows the curve of C/C_o ratio after reaching the steady state (when the bed maintains constant effluent turbidity) versus sand recycle rates for the filtration rates of 5 and $10 m^3/m^2.h$. From these figures it can be observed that there is an optimum sand recycle

TABLE I: Optimum sand recycle rate values at different filtration velocities

Filtration velocity (m^3/m^2h)	Mean $\frac{d\sigma}{dL} \times 10^{-4}$	Mean $\frac{d\sigma}{dt} \times 10^{-5}$	Clogging front velocity (Vf) (*cm/min*)	Time for 14cm clogging $t = 14/Vf$ (*min*)	Sand recycle rate (*ml/min*)
5	7.548	4.350	0.0576	242.920	18.00
6	7.318	4.780	0.0653	214.396	20.50
7.5	5.245	5.172	0.0986	141.980	30.98
10	5.649	5.878	0.1041	134.486	32.70
12.5	2.527	5.361	0.2121	66.01	66.63
15	6.526	13.750	0.2107	66.50	66.14

TABLE II: Experimental and theoretical sand recycle rates

Filtration velocity ($m^3/m^2.h$)	Sand Recycle Rate (*ml/min*) Theoretical	Experimental
5.0	18.0	25.0
10.0	32.7	75.0

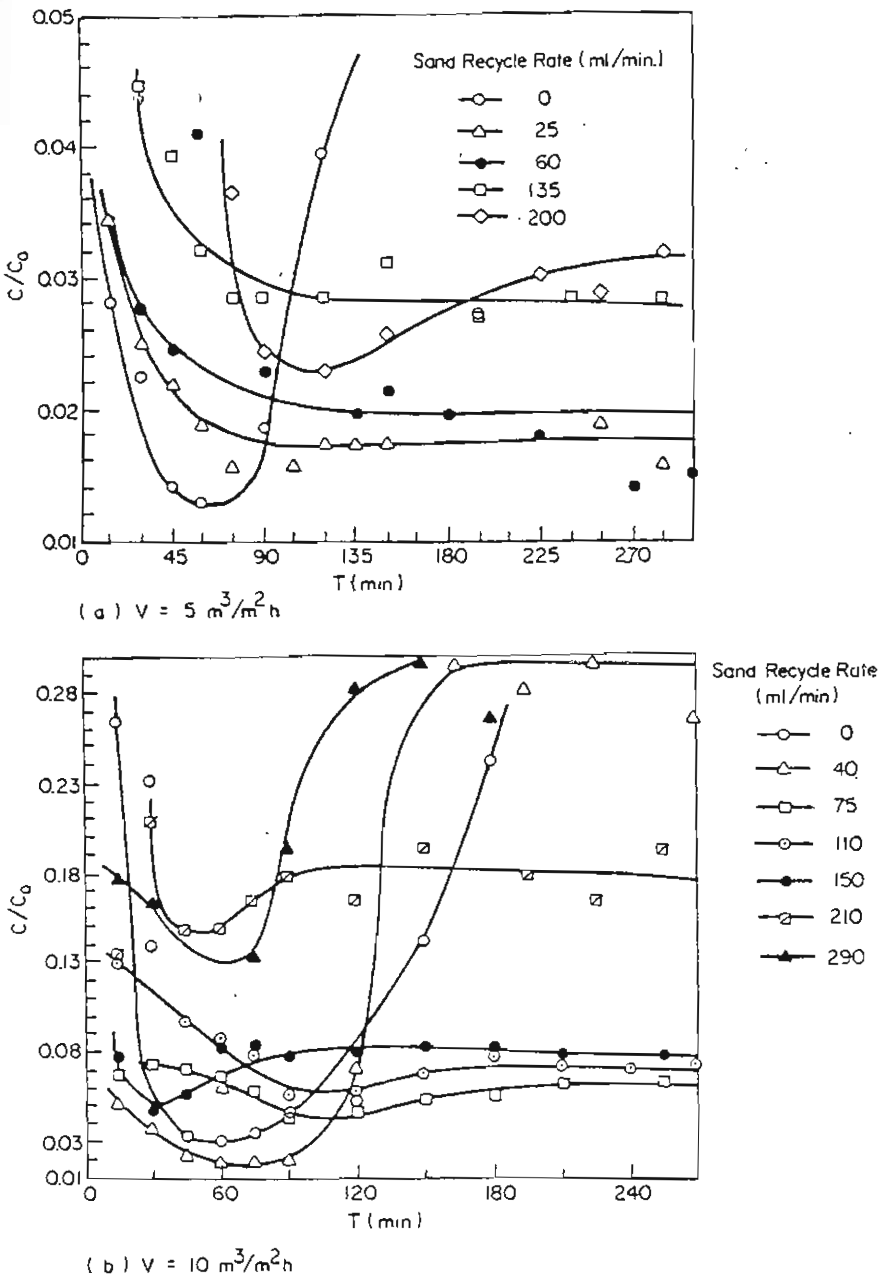

Figure 3: Concentration profile with sand recycle rate
(L = 14cm; Media size = 0.1cm; Polymer dose = 0.05mg/l)

rate for each of the filtration velocities. If the sand recycle rate was either increased or decreased from this optimum value, the effluent quality was found to decrease. From the experimental results with these two different filtration velocities, it was found that the optimum sand recycle rates increase with the increase in filtration velocity.

Experimental/theoretical

The recycle rates obtained from clogging front velocity (theoretical value) and mobile bed experiments are summarized in Table II. It can be seen that the theoretical value is close to the experimental value at the lower filtration velocity ($5m^3/m^2.h$) although they differ at higher filtration velocity. A detailed investigation is necessary to verify this difference at high filtration velocity and to put forward a model to explain the experimental values.

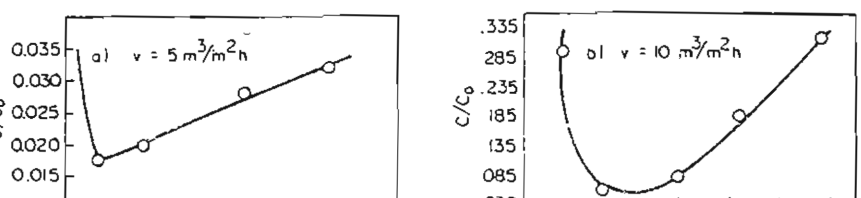

Figure 4: Relation between stead-state C/C_o and sand recycle rate

Conclusions

For each filtration velocity there is an optimum sand recycle rate which gives rise to a high removal efficiency. The experiments performed with two different filtration velocities indicate that the optimum sand recycle rate increases with an increase in the filtration rate.

The concentration profile decreases with time in the initial stages of mobile bed filtration and remains constant once it has reached the steady state. In theory, the steady state corresponds to one cycle time of sand recycle.

The optimum sand recycle rate in mobile bed filters for low filtration velocities ($5m^3/m^2.h$) can be successfully calculated from the clogging front theory with a limited number of laboratory-scale fixed bed experiments.

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