ABSTRACT

The use of filter aid to improve the performance of conventional rapid sand filter is a comparatively recent development in drinking water treatment. Use of filter aid generally results in reduction in ripening period, higher turbidity removal as well as relatively stable effluent quality while the limitations includes the reduction in filter rate as well as reduction in filter run. To overcome the limitations attempt is made to devise the RSF with media having higher effective size (around 0.85mm) and lower coefficient of uniformity (around 1.2) as compared to conventional filter media, with use of poly-aluminum chloride (PACl) as a filter aid. The study was conducted at one of the water treatment plant at Ichalkaranji, Maharashtra by installing a pilot scale model. Various dosages were tried to determine the better performing dose. High turbidity removal, extended filter run, and low head loss as compare to conventional rapid sand filter was observed. The net backwashing requirement also was reduced.

Keywords: filter aid, effective size, coefficient of uniformity, turbidity removal, pilot scale model

Cite this article: Mr. Manoj, H Mota Dr. P S Patil and Dr. V D Salkar Improving The Performance Of Rapid Sand Filter Using Coarser And More Uniform Media With Poly-
1. INTRODUCTION

In most of the developing countries the supply of water in required quantity and of acceptable quality is not certainty. The major hurdles include lack of expertise and use of conventional treatments only. The proper operation and maintenance cycle to be followed is even not appropriately followed by large number of water treatment plant. Once again, the prime reasons being the lack of awareness of modernization, availability of funds and expertise. On other hand the demand of water is ever increasing because of rapid urbanization and industrialization. Under these conditions the modernization of filtration is a need of an hour.

Filtration is a fundamental unit process that is commonly used to remove turbidity causing particulate matter in the treatment of drinking water which finds its way by escaping through the processes like clarification. Unlike other microorganisms C.Parvam Oocysts are usually resistant to traditional disinfectants like chlorine and chloramines [1,2] thus protection of municipal potable water source often relies on granular bed filtration as an robust, simple and inexpensive method to prevent penetration of disinfectant resistant pathogenic microorganism [3].

The experience has suggested that, for silica sand, the effective size should be in the range of 0.35mm to 0.55mm. The uniformity coefficient should range between 1.3 & 1.7. Higher effective sizes with lower coefficient of uniformity results in, a product water that is higher in turbidity and longer operating cycles between cleaning.

1.1. operational cycle of conventional rapid filtration

During the operational cycle of conventional rapid filtration, which typically ranges from 12 to 36 h, three phases can be observed: A ripening stage, working stage and break-through stage. A ripening stage, at the beginning of the filter run, is characterized by very low head loss and low turbidity removal. The duration of the ripening period in rapid sand filters depends on various factors like backwash procedure, filter influent characteristics, and backwash water chemistry [4]; it may last from few minutes to several hours [4,5]. This is the phase where maximum particles and micro-organisms which are generally removed by filtration are able to escape. Filter ripening is important because the bulk of the particles that pass through a filter, do so during the initial ripening period. [6]

A working stage is stage during which the filter performance is most favorable, and the head loss gradually increases. It is the stage where the filter is able to remove most of the particles as well as some extent of bacteria and viruses [3]. It forms the largest stage of filtration cycle. A breakthrough stage is a stage during which turbidity removal slowly deteriorates and the head loss rapidly accumulates. Typically, the maximum permitted head loss is in the range 2.5 to 3 m. [7,8] This stage indicates the need of backwashing of filter media.

The removal of suspended particles within a filter is considered to have at least two sequential steps: transport and attachment. In the first step, the particles are transported from the bulk fluid to the immediate vicinity of solid-liquid interface presented by the filter (i.e., to a grain of the media or to another particle previously retained in the filter bed). The transport of particles to the filtering media may occur through three mechanisms: Brownian diffusion...
(molecular effects), interception (contact as a result of fluid flow near the surface of the porous media), and sedimentation (gravity effects). Particle attachment to the media is thought to be dominated by electrical and chemical interactions such as electrostatic attraction or repulsion within the electrical double layer and van-der Waals attractive forces that act between particles and surfaces at short distances [9].

1.2. Conceptual model

A conceptual model suggested by some authors can be used to help understand the attachment process. Figure 1 shows the relationship of forces known to be acting in the process as a particle approaches a grain of sand (collector). These forces, $F_x$ (where $x$ is London–van der Waals or $FL$, electric double layer or $F_{EDL}$, gravity or $FG$, and fluid drag or $FD$), can determine the ability of the particle to get filtered. In general, $FL$ and $FG$ can help bring the particle closer to the collector, and $F_{EDL}$ can serve to keep the particle apart enough to attach. $FG$ may or may not help as it depends on whether the pull of gravity will bring the particle into contact with the filter media. [6]

![Figure 1: Conceptual model of attachment of particle to filter media (Origin: Optimizing Your Plant’s Filter Performance, Nick Pizzy, Opflow, AWWA, June 2000)](image)

1.3. Effect of humic substances present in water

Natural organic matter (NOM) concentration in surface water generally ranges from 0.1mg/lit to 20mg/lit and is mainly composed of humic substances. Humic substances are reported to reduce particle capture by porous medium filters. [10] Humic substances constitute a major fraction (40–60%) of dissolved organic matter in natural aquatic systems. In addition to their detrimental effect on filtration, humic substances are undesirable in a potable water supply for a number of reasons, ranging from aesthetics to the fact that they are precursors of potentially carcinogenic disinfection by-products in the presence of chlorine, such as trihalomethanes (THMs), haloacetic acids (HAAs), and total organic halogen (TOX) [11,12]. Humic substances have properties of anionic polyelectrolytes and carry weakly acidic functional groups, including carboxylic and phenolic groups. Dissolved aquatic humic substances, which are
net negatively charged macro-molecules because of the ionization of those acidic functional groups, can adsorb onto the surface of clay and other natural particles, further increasing their negative charge.  

The use of filter aid to improve the performance of conventional rapid sand filter is a relatively recent development in drinking water treatment. In developing countries still nowhere, such use is observed. Different advantages claimed by such use of filter aid includes reduction in ripening period, higher turbidity removal as well as relatively stable effluent quality while the limitations includes the reduction in filter rate as well as reduction in filter run.

Alum (Al\(_2\)(SO\(_4\))\(_3\), 14H\(_2\)O) and polyaluminum chloride (PACl) are both widely used coagulants in water treatment. PACl has been reported to be superior to alum in removal of particles, the advantages of reduced alkalinity consumption, less sludge production, decreased temperature and pH dependence, and reduction of cost. The authors have selected PACl as filter aid for the research described in this paper. The attempt is made to devise the RSF by increasing the effective size (around 0.85mm) and lowering the coefficient of uniformity of media (around 1.2) with use of poly aluminum chloride (PACl) solution as a filter aid. The changed configuration helps to get higher output of filtered water but results in lower turbidity removal. This limitation is addressed by using PACl as filter aid. The study was carried out by installing a pilot scale model at Ichalkaranji municipal water treatment plant. Results demonstrated the higher turbidity removal, extended filter run, and low head loss as compare to conventional rapid sand filter.

2. MATERIAL AND METHODS

2.1. Following methodology was adopted for the study

I. The sand media of desired effective size and uniformity coefficient was prepared by sieving the washed and sun-dried stock sand available at Ichalkaranji WTP. The coefficient of uniformity of sand used was kept as 1.2 and effective size was 0.85mm. Along with this the filter media with conventional configuration was also prepared having effective size 0.5 mm and coefficient of uniformity 1.7.

II. A pilot scale model of filter was constructed using two glass columns with an inside dimension of 0.15m X 0.15m along with associated piping and valves for proper control on filtration rate. The pump of 0.5 HP was used for back washing. As the size of the filter column was kept as 15 cm the wall effect was eliminated [D/d=150/0.85=176, which should be more than 60]. The depth of the media was kept 75cm which is almost equal to the depth of the media practiced in conventional filtration process. This was helpful in maintaining expected porosity by eliminating thickness effect. These parameters were helpful in modeling more realistic conditions.

a. The pilot model was installed at Ichalkaranji water treatment plant, where the clarified water was used for the performance evaluation of alum aided modified filter media. As the raw water used by most of the plants in India is river water and it contains humic substances which are responsible for reduction in particle capture by porous medium filter, same water is used for the performance evaluation. This has helped the study to be more realistic. The filters were challenged by the water having turbidity in the range of 8 to 15 NTU. The pH of water was in between 7.2 to 7.4 while the temperature was around 20\(^\circ\)C.
i. The filter column was aided with the different dosages of PACl solution. The dosages were provided by adding the solution of PACl from top surface of column. One column was kept as control while the second was experimental column which was provided by the dose of PACl solution. The doses were prepared by preparing the PACl solution of 5% strength. Different dosages provided are mentioned in table 1.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Dose to experimental column of size 0.15m X 0.15m</th>
<th>Dose in gm per m² of filter area</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>500 mg/lit</td>
<td>44.44</td>
</tr>
<tr>
<td>02</td>
<td>450 mg/lit</td>
<td>40.00</td>
</tr>
<tr>
<td>03</td>
<td>400 mg/lit</td>
<td>35.55</td>
</tr>
<tr>
<td>04</td>
<td>350 mg/lit</td>
<td>31.00</td>
</tr>
</tbody>
</table>

ii. The comparison between the conventional filter and modified filter with PACl aid was made on the basis of turbidity of filtrate produced, ripening period, length of filter run and backwashing requirements.
ii. The particle count was assumed to be varying as per the turbidity. IS 10500-2012 (revised edition) was used for acceptance criterion of turbidity which was assumed to be 5 NTU.\textsuperscript{[20]}

3. RESULTS AND DISCUSSIONS
Following are the observations recorded while pilot plant study. The prominent observations are evident in graphs. Graphs below clearly demonstrate that the use of PACl as filter aid with coarser and more uniform media was much better performance as compare to conventional filter media.

3.1. Residual turbidity and filter run profiles:
Figure 3 to 6 represent the residual turbidity and total filter run observed during the experimental study. The residual turbidity of output water was found varying as the turbidity of input water. The performance of PACl aided filter column was much more stable as compare to untreated conventional filter column.

![Figure 3](image-url)

**Figure 3** Comparison of conventional RSF and modified RSF with PACl dose of 44.44gm/m$^2$
Figure 4 Comparison of conventional RSF and modified RSF with PACl dose of 40.00gm/m²

![Graph showing turbidity and time for different conditions](image1)

Figure 5 Comparison of conventional RSF and modified RSF with PACl dose of 35.55gm/m²

![Graph showing turbidity and time for different conditions](image2)

Figure 6 Comparison of conventional RSF and modified RSF with PACl dose of 31gm/m²

![Graph showing turbidity and time for different conditions](image3)

3.2. Rate of filtration/flow rate profiles:

Figure 7 to 10 represent rate of filtration or flow rate observed during the experimental study. The experimental column i.e. the column having the media of 0.85mm effective size and coefficient of uniformity as 1.2 has clearly high rate of filtration during the complete filter run. The length of filter run also was much more as compare to conventional filter column.
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**Figure 7** Flow rate Comparison of conventional RSF and modified RSF with PACl dose of 44.44gm/m²

**Figure 8** Flow rate Comparison of conventional RSF and modified RSF with PACl dose of 40 gm/m²
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**Figure 9** Flow rate Comparison of conventional RSF and modified RSF with PACl dose of 35.55 gm/m²

![Graph showing flow rate comparison](image)

**Figure 10** Flow rate Comparison of conventional RSF and modified RSF with PACl dose of 30 gm/m²

**Table 2** Summary of results obtained:

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Dose of PACl in gm/m²</th>
<th>Ripening period in min.</th>
<th>Filter run in min.</th>
<th>Total water filtered in one cycle in lit.</th>
<th>Remark on quality in terms of turbidity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Experimental</td>
<td>% reduction</td>
<td>Control</td>
<td>Experimental</td>
</tr>
<tr>
<td>01</td>
<td>44.4</td>
<td>23</td>
<td>8</td>
<td>405</td>
<td>495</td>
</tr>
<tr>
<td>02</td>
<td>40.0</td>
<td>21</td>
<td>8</td>
<td>420</td>
<td>565</td>
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<tr>
<td>03</td>
<td>35.5</td>
<td>18</td>
<td>9</td>
<td>420</td>
<td>570</td>
</tr>
<tr>
<td>04</td>
<td>31.0</td>
<td>18</td>
<td>10</td>
<td>405</td>
<td>560</td>
</tr>
</tbody>
</table>

Using polymer dose as filter aid, results in increased turbidity causing particle removal. The media of higher effective size and low coefficient of uniformity permits better utilization of the entire media depth of the filter bed. The primarily polymers as a filter aid produces aggregate flocs that will be large enough to be captured and strong enough to be able to withstand shear forces within the filter bed voids. Floc growth is the result of inter-particle collisions created by agitation. The value in having a strong floc to aid in the filtration of water has been recognized for years. Other benefits to the use of polymer as a filter aid can include increased filtration rates and longer filter run. The addition of a small amount of polymer after the end of a backwash cycle has resulted in reduction the duration and turbidity peak of the ripening period when a filter first comes online after backwashing. The use of filter polymer created an additional ‘working zone’ within the filter where effective particle removal took place. The working layer was characterized by saturation with particulate deposit above it and a relatively clean layer below it.

The study underlined the fact that the use of filter polymer can potentially allow a coarser media to be used and permit greater fluctuations in filtration rate without the risk of sub-standard performance of the filter. Rather for given filter configuration i.e. coefficient of
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uniformity around 1.2 and effective size around 0.85 the filtrate quality was far better throughout the filter run with higher rate of filtration.

As we increase the dose of PACl as filter aid the quality of filtered ware is improving on the other hand it also results in reduction in filter run. But because of coarser media the overall filtration rate still remains much higher as compared to conventional filter media.

4. CONCLUSION
From the study made to evaluate the effect of PACl aided RSF with higher effective size and lower coefficient of uniformity, (coefficient of uniformity around 1.2 and effective size around 0.85mm) following conclusions were made PACl aided rapid sand filter with higher effective size and lower coefficient of uniformity works much better than conventional rapid sand filter. Small addition of PACl in the form of filter aid results in higher operating filtration cycle as compare to conventional rapid sand filter. Because of changed configuration, high filtration rate was possible which results in increase in total volume of water filtered with better filtrate quality.

5. ACKNOWLEDGMENT
The author wants to acknowledge the support provided by the Hydraulic engineer, Ichalkaranji Municipal Corporation for permitting the study to carry out in their premise of water treatment plant.

REFERENCES


