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(28) Direct Filtration of Secondary Waste Water Effluent by a Dual Media Filter
2階床ろ層による下水2次処理水の直接ろ過

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ABSTRACT; A dual-media filter with a coarse medium at the upper part and a sand bed at the lower part has been proposed for the direct filtration of secondary waste water effluent from an activated sludge treatment plant. Filtration without coagulation gave, for the model proposed, a filter run length five times that of the single sand bed filter at the rate of 120 m/day. Laboratory experiments were carried out to evaluate the optimum values of pH and aluminum dosage that gave a color removal of up to 70%. Coagulant-assisted filtration without pH control gave a color removal of up to 40%. The filter performance was measured in terms of (1)filter run length and (2)removal of color, COD and phosphate.

KEYWORDS; Head loss, turbidity, color, COD, phosphate

1 INTRODUCTION

The secondary effluent from the activated sludge treatment plant in Muroran city has the characteristics presented in **Table 1**. Laboratory experiments were done in order to find the optimum pH and aluminum dosage for the highest color removal. The direct filtration process was carried out with and without coagulation. Coagulant-assisted filtration was performed with the dosage of 1, 2 and 4 mg Al^{3+}/L but without pH control. The pH of the effluent ranges between 6.5 and 7.

Direct filtration with a single sand bed or a multi-media filter has been used during the past 30 years for water treatment and recently for secondary waste water effluent with low turbidity (i.e. less than 10 mg/L). The problem encountered in the direct filtration process with a single sand bed medium is the fast build-up of head loss which shortens the filter run length. To prevent this phenomenon, anthracite is usually used above the sand in the multi-media filter but more than 80% of the total head loss occurs in the anthracite layer[1,2]. A small head loss in the layer above the sand will lengthen the filter run. A dual media filter[3] with coarse medium in the upper part and sand in the lower part has been proposed.

Table 1: Characteritics of the waste water effluent

Items	Concentration (mg/L)
Turbidity	4~15
Apparent Color	70~150
Color	23~51
NH4-N	19~33
Total Phosphate	0.6~1.0
Phosphate	0.4~0.8
CODcr	22~67
pH	7~8

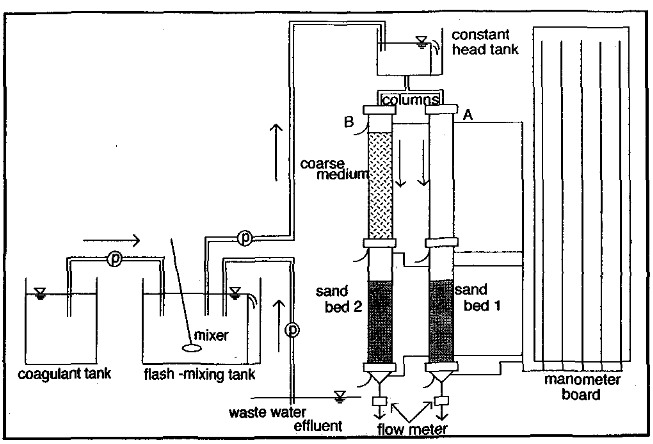

Fig1:Experimental Apparatus

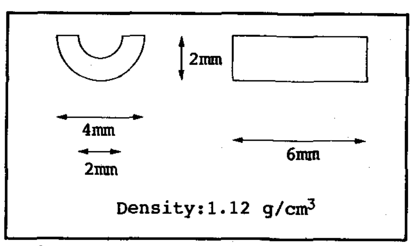

Fig 2:Structure of the Coarse Medium

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The objective of this study is to investigate the dual-media filter performance in terms of filter run length, head loss and removal of turbidity, color, COD and phosphate.

2 EXPERIMENTAL APPARATUS AND METHODS

As shown in **Fig 1**, the experimental apparatus consists of a feeding system, a constant head tank, two 7.5 cm interior diameter columns (A and B), the downstream valves and a water manometer board. The sampling ports and the water manometers are located at the same level. In the lower parts of both columns, an identical 60 cm sand bed is housed and in column B, a 90 cm coarse medium (**Fig 2**) bed is housed in the upper part. The coarse medium consists of a 6 mm long semi-cylindrical vinyl tube with a 2 mm interior diameter, 4 mm exterior diameter and a density of 1.12 g/cm^3. The porosity of the coarse medium filter bed is 45% and the sand size ranges from 0.59 mm to 0.71 mm. The experiment ends when the total head loss of 330 cm is reached or when the filtration rate is no longer constant.

2.1 Jar test

The samples were filtered through a 0.45 µm membrane filter prior to use in order to remove any trace of non dissolved material except for the sample used in **Fig 3**. A height-beaker jar-tester was used and the experiments were performed with 500 ml beakers. A period of 5 minutes was allowed for rapid mixing at 120 rpm, followed by 30 minutes of flocculation at 50 rpm and 30 minutes of sedimentation. Then, the supernatant water was sampled and divided in two parts. One part was immediately filtered and the pH of the other part was first adjusted to 10 and then filtered. The pH is adjusted to 10 in order to hydrolyze the aluminum-color complexes. At the pH value of 10 and depending on the coagulant dosage, the sample recovers its initial color concentration with a dispersion ranging between 4% and 6%.

Before filtration, the membrane filter was washed with 100 ml of distilled water. During these experiments, the coagulant was first added, then, depending on each case, hydrochloric acid(HCl, 1N and 0.1N) and/or sodium hydroxide (NaOH, 1N and 0.1N) was added for pH correction. Aluminum Sulfate ($Al_2(SO_4)_3.18H_2O$) was used as coagulant.

2.2 Filtration procedure

The waste water effluent was used as raw water. The raw water and the coagulant were vigorously mixed at 1450 to 1750 rpm in the coagulation tank before the head tank was fed. The hydraulic retention time of the coagulation tank was 3 minutes. The filtration experiments were performed at constant rates of 120, 240, 360 and 480 meters per day and the flow was manually controlled by continuous adjustment of the downstream valves. Samples were taken hourly in order to have an average solution and the head loss through the filter was measured by means of the water manometers. These experiments were carried out without pH control.

After each experiment, the filter was back washed at the flow rate up to 8 L/min for the single sand bed and 3 L/min for the dual media filter.

2.3 Analysis

The color was measured by the spectrophotometer at the wavelength of 420 nm with a 5 cm-cell and the concentration was calculated from the following formula:

Color = 133.5 Absorbance/cm .

The turbidity was measured by the turbidimeter.

The COD content was evaluated by the method of the dichromate potassium.

3 RESULTS AND DISCUSSIONS

3.1 Coagulation in the jar test experiment

The waste water effluent was coagulated in the jar test experiment and the effect of pH on turbidity, color and COD removal were plotted in **Fig 3**, **Fig 4** and **Fig 5**. These results show that the turbidity, color, COD and phosphate removal is pH-dependent. The optimum pH values for the removal of the three first items range between 5 and 6. In waste water effluent, the suspended solids consist of organic and inorganic matters and their presence influence the pH values for optimum removal of the dissolved compounds.

According to Hall and Packman[4)], the optimum pH values for color(fulvic acid) and turbidity(clay suspension) removal are 5.5 and 7, respectively. However Semmens and Field[5)], in their studies on the coagulation of Mississippi river water found that the optimum pH for organics removal and turbidity are similar. Narkis and Rebhun[6)]

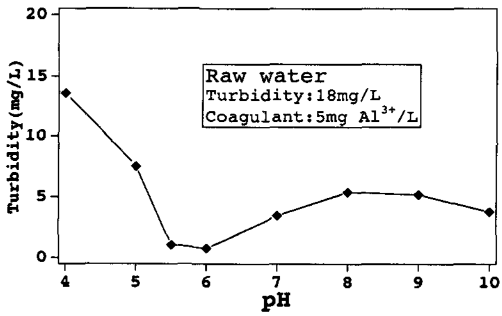

Fig 3:Effect of pH on turbidity removal

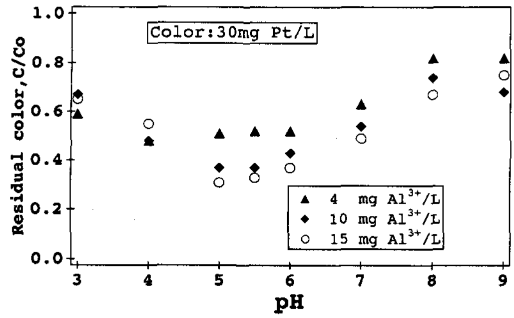

Fig 4:Effect of pH on color removal

found that, when a cationic polyelectrolyte is added to clay or an organo-clay complex suspension dispersed in humate or fulvate solution, it reacts first with the free organic acids because of the latter's relatively high mobility and charge density. The same authors observed the same tendency with the secondary waste water effluent from the trickling filter and found that the optimum pH for color and turbidity removal are the same[7]. Turbidity removal without dissolved organic compounds was investigated. Suspended solids from the secondary effluent were separated by centrifugation and then, "resuspended" in the tap water. The result is plotted in **Fig 7**. The optimum pH for turbidity removal ranges from 5 to 7. The formation of the settleable precipitate of aluminum-color complexes in the pH range of 5 to 6 combined with its enmeshment with turbidity compounds may have shifted the optimum pH for turbidity removal to the range of 5 to 6 in **Fig 3**.

In **Fig 5**, only 35% of COD are removed at the coagulant dosage of 10 mg Al^{3+}/L.

Though the optimum pH for phosphate removal has been found to range between 5.5 and 6.5[8], more than 90% of the phosphate are removed in the pH range of 5 to 8. The low concentration of dissolved phosphate compounds, compared with the coagulant dosage of 4 mg Al^{3+}/L, may have widened the optimum pH range.

Though the optimum pH ranges between 5 and 6, the pH of 5.5 was chosen for the experiment in **Fig 7**. This figure shows the color removal at the optimum pH of 5.5 for different coagulant dosages. The residual color decreases with an increase in the coagulant dosage. For coagulant dosages more than 6 mg Al^{3+}/L, removal of up to 70% was obtained. 30% of the precipitated aluminum-color complexes have a floc size smaller than 0.45 μm. 90% of the 70% of the color removed occurs after a sedimentation of 30

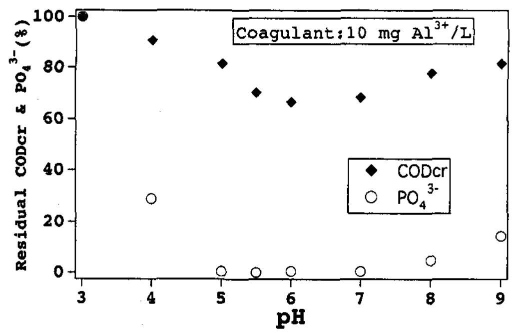

Fig 5:Effect of pH on CODcr and phosphate removal

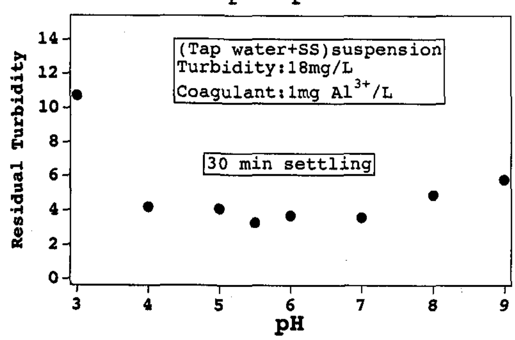

Fig 6:Effect of pH on turbidity removal

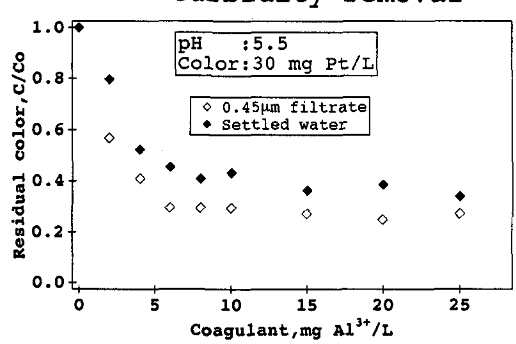

Fig 7:Effect of coagulant dosage on color removal

3.2 Filtration without coagulation

The experiment without the coagulation was carried out in order to investigate the performance of the dual filter at the filtration rate of 120 m/day.

The variation of the turbidity is plotted in **Fig 8**. Both single sand bed and dual media filters have an average removal efficiency of 80%. The average turbidity in the effluent is 2 mg/L. 50% to 70% of the turbidity removed in the dual-media are in the coarse medium whereas 10% to 30% are in the sand bed. The amount of deposited solid in the coarse medium is three times as much as that of sand bed 2 for the same run time of 23 hours.

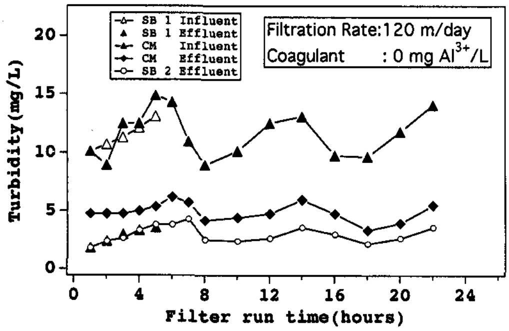

Fig 8:Variation of the turbidity during the filtration

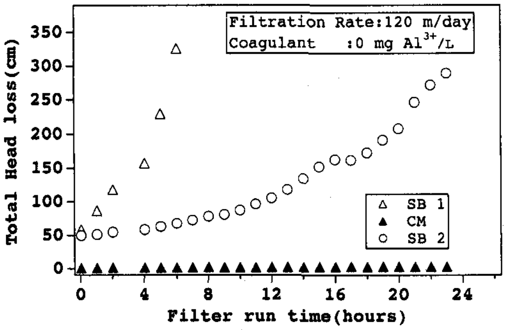

Fig 9:Variation of the head loss during the filtration

Fig 9 and **Fig 10** show the build-up of the head loss. For a total head loss of 300 cm in **Fig 9**, the run time in the single sand bed filter is 5 hours whereas it is 23 hours in the dual-media filter. The run time in the dual-media filter is five times as long as that of the single sand bed. The total head loss in the coarse medium is only 10 cm whereas it is 290 cm for sand bed 2. The head loss in the coarse medium represents only 2% of the total head loss in the filter.

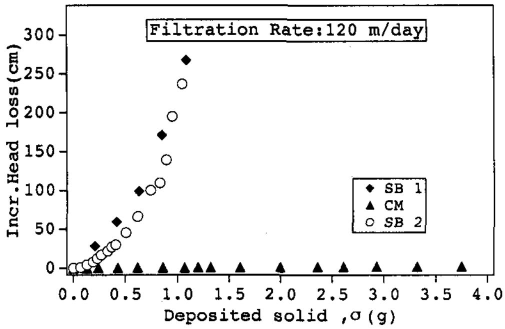

Fig 10:Build-up of the incremental head loss with the deposited solid

Fig 10 shows the build-up of the incremental head loss(difference between the head loss from the beginning of the filter run and the head loss at any given time) with the deposited solid for both sand beds 1 & 2 and the coarse medium during the filtration. For the same amount of 1 gram, the coarse medium has an incremental head loss of 3 cm against 255 cm for both sand beds. The coarse medium has a high removal efficiency with a small incremental head loss. Compared with the amount of solid removed, the head loss in the coarse medium is by far smaller than that of the anthracite bed filter. An anthracite bed filter has an incremental head loss which is 50% of that of the sand bed[1,2).

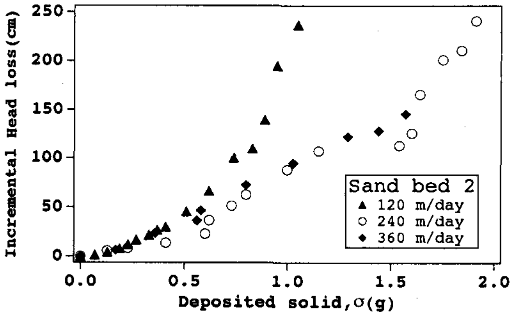

Fig 11:Variation of the incremental head loss with the deposited solid

The head loss build-up is related to the deposited solid and the clogging patterns. From the curves shown in **Fig 10**, the form of the curves show that the clogging pattern for both sand beds 1 & 2 is almost the same. **Fig 11** shows the build-up of the head loss in sand bed 2 at three different filtration rates. The pattern of the filter clogging in sand bed 2 is almost the same for the filtration rate of 240 m/day and 360 m/day. When solids are partly removed on the surface and partly in the depth of the filter, the head loss generated is characteristic of surface head losses[9]. The fast build-up of the head loss encountered in the case of 120 m/day is due to the accumulation of solids in the upper part of the filter. The porosity of the filter in the upper part decreases and consequently the head loss increases. For an amount of 1 gram of deposited solid, the head loss at the rate of 120 m/day is almost twice as much as that of the case of 240 m/day and 360 m/day. With higher rates, the surface is partially caked because the solids are carried deeper into the sand bed. The head loss in this case is only controlled by the deep filtration. At the filtration rates of 240 m/day and 360 m/day, the filter clogging occurs deeper in the filter bed. We will talk about surface filtration for 120 m/day and deep filtration for 240m/day and 360 m/day.

With a kaolin suspension as an influent, some experiments were carried out to evaluate λ, the filter coefficient, of the coarse medium. **Fig 12** shows the relation between ln(C/Co) and the filter depth for different filter runs. The semi-logarithmic plot is approximately represented by a straight line. The filter coefficient of the coarse medium is taken as a constant because it does not depend on the amount of kaolin removed. It may be calculated by the first-order differential equation proposed by IWASAKI[10]:

$$dC/dZ = -\lambda C$$

C = turbidity(mg/L)

Z = filter depth(m)

λ = filter coefficient(1/m)

Integrated over the depth, it becomes:

$$C/Co = \exp(-\lambda Z)$$

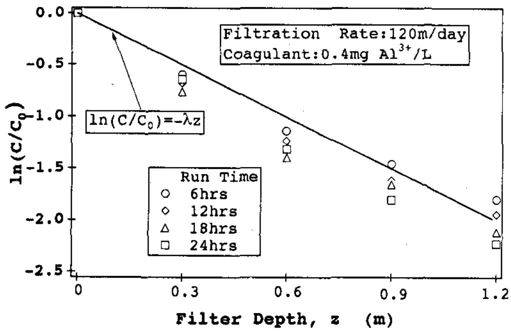

Fig 12:Variation of ln(C/Co) with the filter depth

From **Fig 13**, we see that 40% of the CODcr is removed in the filter. This percentage represents the particles larger than 5 μm in the size distribution in **Fig 14**. We may say that the particles larger than 5 μm are removed in the filter.

3.3 Coagulant-assisted filtration

In these experiments, coagulant dosages of 1, 2 and 4 mg Al^{3+}/L were used in order to investigate the turbidity, color, COD and phosphate removal. The case of 4 mg Al^{3+}/L was used to illustrate the results. **Fig 15** shows the hourly variation of the turbidity during the filtration. The turbidity removal was almost 80% and this rate was the same as the case without coagulant. In both cases, the average turbidity effluent of 2 mg/L was almost the same as that of the residual turbidity in the pH range of 5 to 6 in **Fig 3**. **Fig 16** shows the build-up of the head loss in sand bed 2 for the filter with and without coagulation at the rate of 120 m/day. For the incremental head loss of 250 cm(i.e the end of the filter run), the amount of deposited solid in sand bed 2 is 0.6 gram in the case of coagulant-assisted filtration whereas it is 1 gram in the case of filtration without coagulation. The forms of the curves show that only the clogging are different because we observed in **Fig 8 & 15** that the average turbidity effluent in both cases were almost the same. In Fig 11, we talk about surface filtration for the filtration rate of 120 m/day without coagulation. When coagulant is added, larger flocs of flocculated colloids and agglomerated small particles are mostly removed at the surface and the most upper layer of the sand bed. Consequently, the head loss built up faster. That was the reason why the filter run length was shorter when the coagulant was added.

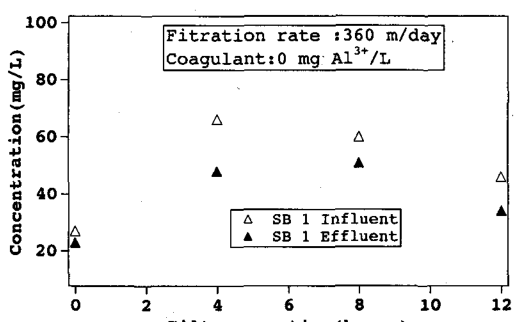

Fig 13:Variation of the CODcr during the filtration

The filter run time was 14 hours whereas in the case without coagulation, it is 23 hours. The coagulation does not improve the turbidity removal but shortens the filter run time.

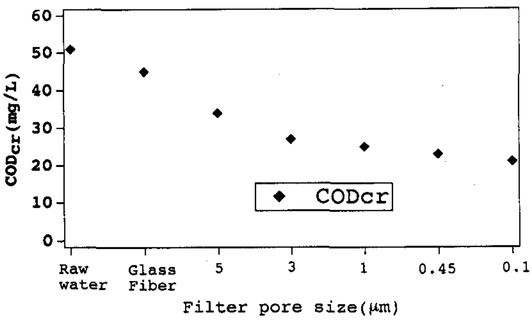

Fig 14:CODcr size distribution

Color size distribution in **Fig 17** shows that 20% (11 mg Pt/L) of the color reacted with the coagulant and gave a turbidity of 1 mg/L. The flocs produced were larger than 5 μm. 11% of the color has a size larger than 5 μm. We may say that the particles larger than 5 μm are removed in the filter.

In **Fig 18**, the hourly variation of the residual color during the filtration is plotted. Hourly samples of the waste water effluent and the coagulated water were also taken in order to evaluate the color to be removed i.e. the coagulated particles. At the coagulant dosage of 4 mg Al^{3+}/L, 25% of the color(0.45 μm filtration) was coagulated compared with 50% in the jar test experiment. As explained above, these experiments were carried out without pH control. 10% of the color was removed in the dual-media filter. This value represents 40% of the 25% of color coagulated in the tank. In order to improve the dual media filter efficiency, a coagulant aid was needed to agglomerate the small particles which were not removed into large flocs.

The secondary waste water had a very low phosphate content. As in the jar test experiment, 90% of the phosphate was coagulated(0.45 μm filtration) in the coagulation tank. From **Fig 19**, 60% to 80% of the phosphate was removed in the filter.These values represent 70% to 90% of the phosphate coagulated in the tank.

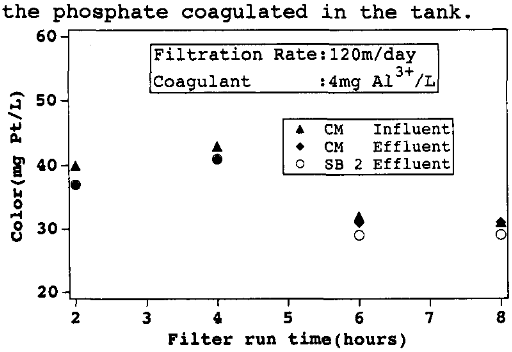

Fig 18:Variation of the color during the filtration

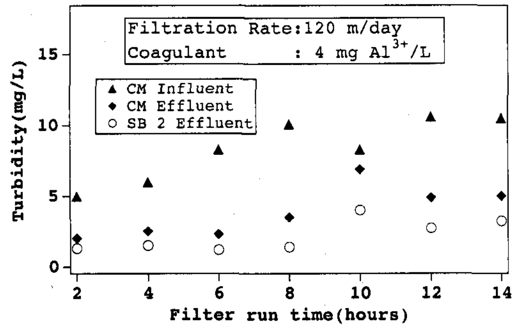

Fig 15:Variation of the turbidity during the filtration

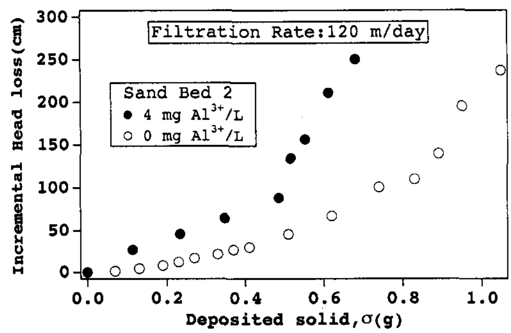

Fig 16:Build-up of the head loss in the sand bed 2 for two cases

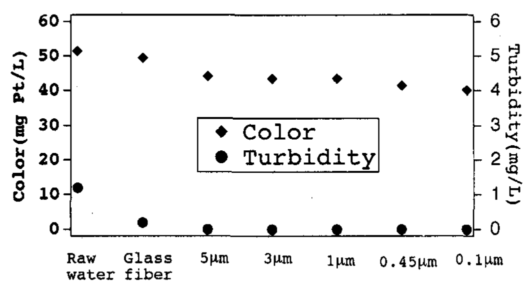

Fig 17:Color size distribution

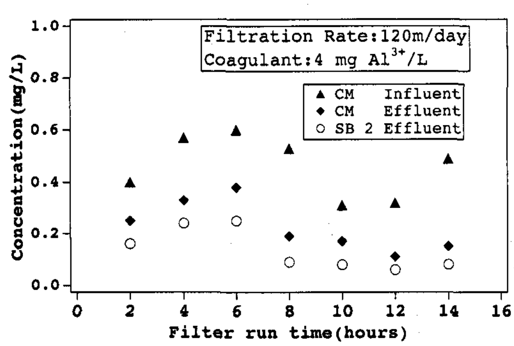

Fig 19:Phosphate removal in the dual-media filter

4 CONCLUSIONS

From these studies, the following conclusions have been drawn:

1- The coarse medium is efficient in removing the turbidity with a small head loss. At the filtration rate of 120 m/day and without coagulation, the dual media filter has lengthened the filter run time to five times that of the single sand bed.

2-The coagulant does not improve the turbidity removal but removes the color and phosphate.

3-The turbidity, color and COD removal is pH-dependent and the optimum pH values for coagulation range between 5 and 6. Color removal of 70% (0.45 µm filtrate) occurs in the jar test experiment. The particles larger than 5 µm are removed in the filter. The use of a coagulant aid will improve the color and COD removal in the dual-media filter.

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