環境工学研究論文集・第31巻・1994 (Proc. of Environmental Engineering Research, Vol. 31, 1994)

(4) Removing Color and Turbidity from Secondary Wastewater Effluent by Direct Filtration in a Dual Media Filter

2階床直接ろ過による下水2次処理水の色度・濁度の除去

N'guessan Bi Tozan Michel*, H.Hozumi*, H.Yoshida*, M.Jarhen* and H.Iorois*
エンギッソン・ビ・トザン・ミッシェル、穂積 準、吉田 英樹、ジャルキン マナフ、五百蔵 浩史

ABSTRACT; Coagulant-assisted filtration through a dual-media filter, with pH adjusted to 5.5~6, gave an average effluent turbidity of less than 0.5 mg/L at a filtration rate of 120 m/day. The dual-media filter has a coarse medium bed at the upper part and a sand bed at the lower part. The removal efficiency was almost 100% for turbidity and 50~60% for color. Though 80% of the removed flocs were in the coarse medium, the head loss in that part was less than 20% that of the total head loss. The coagulant dosage of 4 mg Al^{3+}/L was the optimum for filtration.

Key words; color, turbidity, coagulant dosages, filter run length and head loss

1 INTRODUCTION

Direct filtration process has been used for low turbidity water in the field of both water, and wastewater treatment to remove the suspended solids as an economical alternative to conventional water treatment. The direct filtration process differs from the conventional sedimentation filtration system in that the total solids, both natural and added, must be stored in the filter. Suspended solids removed by granular-media filters generally are filtered at the surface of the media or are captured in the upper part of the filter bed. To prevent the fast build-up of the head loss, low-density coarse media is used above the sand bed to remove the coarse particle. Anthracite is usually used above the sand bed satisfactorily but the problem lies in the fact that 50~80% of the head loss occurs in the anthracite bed[1,2,3]. To further enhance the filter run length, a little head loss above the sand filter was needed. In the filter model proposed[4], filtration without coagulation at the rate of 120 m/day gave a run length that was five times that of the single-sand bed filter and 50% to 70% of the turbidity was removed in the coarse medium with a head loss that was up to 10% the head loss of the filter. Coagulation-assisted filtration without pH control removed a small fraction of the dissolved matters and 80% of the turbidity, but did not improve the turbidity effluent and shortened the filter run length.

The objectives of these studies were to investigate the effect of pH and coagulant dosages on the removal of both particulate, and dissolved matters. In this study, coagulation-assisted filtration with and without pH control was carried out. The performance of the dual-media filter was determined in terms of removal of turbidity and color, and filter run length.

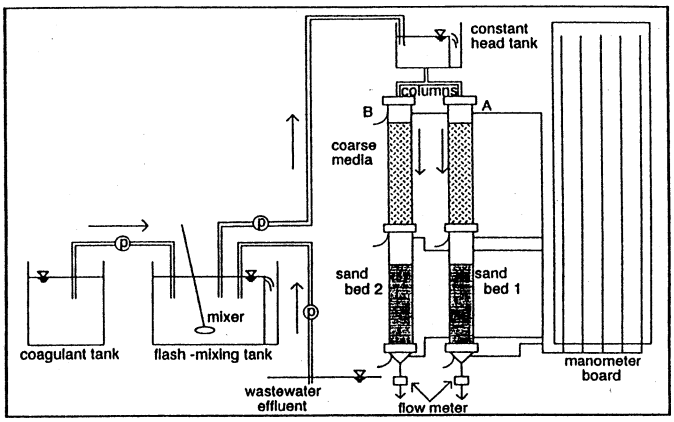

Fig1:Experimental Apparatus

*Depart.of Civil Engineering, Muroran Institute of Technology, Muroran 050, Japan
(室蘭工業大学、建設システ工学科)

2 EXPERIMENTAL APPARATUS and METHODS

2-1 Apparatus

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 valves and the manometer board. In both columns, a 90 cm coarse medium bed is housed in the upper part, and in the lower part a 60 cm sand bed is housed. The sand size range is 0.59~0.71 mm. The coarse medium consists of a hollow vinyl tube with an interior diameter of 2 mm, an exterior diameter of 4 mm, a length of 6 mm,and a density of 1.12 g/cm^3. The porosity of the coarse medium bed is 45%.

2-2 Methods

The raw water and the coagulant were vigorously mixed at 1450 to 1750 rpm in the flash-mixing 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 rate of 120 m/day and samples were taken hourly in order to have an average concentration. To monitor the filter clogging, the head losses through the filter were measured at different depths. Aluminum sulfate($Al_2(SO_4)_3.14\text{~}18H_2O$) was used as coagulant at the dosages of 2, 4, 6 and 8 mg Al^{3+}/L.

The pH value was adjusted to the desired value by hydrochloric acid. Hydrochloric acid was mixed with the coagulant.

After each experiment, the coarse medium was removed out of the column and washed to remove the flocs. The cleaning of the sand bed was made by backwashing.

The jar test experiments were carried out along with the filtration in order to determine the optimum conditions for coagulation of the wastewater effluent, i.e., the optimum pH for soluble matters and turbidity removal, and the smallest coagulant dosage that gave the highest removal efficiency. The size distribution was also drawn up. Color, turbidity, CODcr, Fe and humic substances were measured. Color was measured on the 0.45 μm filtrate and the pH was adjusted to 10 before it was done.

3 RESULTS AND DISCUSSIONS

3-1 Coagulation of the secondary wastewater effluent

The secondary effluent from the activated sludge treatment plant in Muroran city has the characteristics presented in **Table 1**. Turbidity of the secondary effluent ranges from 5 to 15 mg/L. The sediments obtained from the activated sludge by centrifugation consist of approximately 75% of organic matters and 25% of inorganic matters. Color of the secondary effluent ranges from 23 to 57 mg Pt/L and to 1 mg/L of humic substances corresponds 20 to 33 mg Pt/L of color. Soluble CODcr represents 65% to 75% of total CODcr.

Table-1:Characteristics of the secondary wastewater effluent

Items	Total (mg/L)	Soluble (mg/L)
Turbidity	5~15	
Color		23~57
NH4-N		18~33
Phosphate	0.6~1.0	0.4~0.8
CODcr	22~45	16~33
Fe3+	0.21~0.26	0.08~0.12
Humic subs.	1.1~1.7	
BOD5	8~11	
Alkalinity as CaCO3	11~13	
pH	7~8	

Previous experiments showed that the removal of turbidity and dissolved matters were optimum in the same pH range[4].

Fig. 2 shows the effect of pH on the coagulation of some dissolved matters. The coagulation of both, organic and inorganic matters is maximum in the pH range of 4 to 6. The curves of color, humic substances and Fe have the same form, and the same coagulation rate of 50% in the optimum pH range suggests that stable humic-Fe complexes exist in the effluent. Color in wastewater is mainly caused by the humic substances. Humic substances make up the major part of the refractory organic matters in natural waters and secondary wastewater effluents. Black and Chrisman[5] found in studies of colored streams, high dissolved COD and only trace amounts of BOD. These results suggested to them that the organic matters responsible for color are resistant to microbial decay. Shapiro[6] also observed that yellow organic acids extracted from colored waters resisted microbial attack. These compounds are the end products of aerobic biological processes.

In **Fig. 3**, the C/Co ratio is plotted against the coagulant dosages at pH value of 5.5. The coagulation of color, CODcr and turbidity increases with an increase in the coagulant dosages. At the coagulant dosage higher than 6 mg Al^{3+}/L, the removal efficiency of color and CODcr do not vary too much. CODcr removal of up to 25% was obtained against 60% for color. The difference in removal efficiency is due to the fact that COD consists of color and some organic matters that are not easily removed by alum coagulation.

Manka et al[7] found that total COD in the secondary effluent. from the activated sludge consists of 35% of humic substances, 23% of proteins, and 16% of ether extractables and anionic detergents each. Hall and Packam[8], Tambo and Kamei[9] found in their studies that low molecular-weight organic matters are not well removed by alum coagulation. Color coagulation of the secondary effluent is limited to the range of 60% to 70%. We may say the 30% to 40% of color that were not coagulated by alum had a low molecular-weight. At 4 mg Al^{3+}/L, 90% of the turbidity were removed and dosages higher than 4 mg Al^{3+}/L did not improve the turbidity removal.

Fig. 4 shows the size distribution of color for different dosages. At 2 mg Al^{3+}/L, 80% of the coagulated color flocs were larger than 5 μm against almost 100% for the dosages higher than 4 mg Al^{3+}/L. In **Fig. 5**, the residual color is plotted against the pH for the 0.45 μm filtrate and for the supernatant after a settling period of 30 minutes at the dosage of 6 mg Al^{3+}/L. In both cases, the coagulation is maximum in the pH range of 4 to 6. In the supernatant, the residual color is 55% against 50% in the 0.45 μm filtrate. The difference of 5% is equivalent to 10% of the amount of coagulated color flocs. Larger flocs were settled but only flocs slightly larger than 5 μm remained in solution.

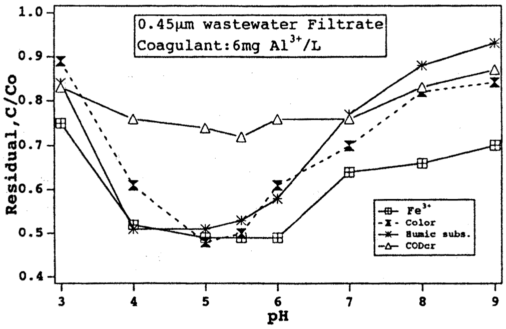

Fig 2:Effect of pH on wastewater content coagulation

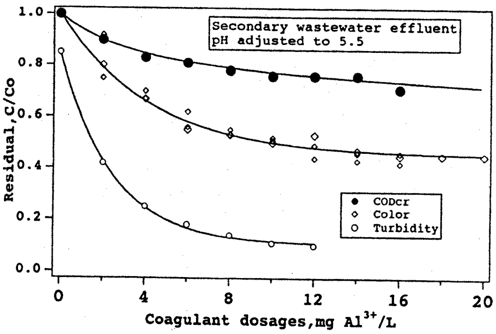

Fig 3 :Effect of coagulant dosages on the removal of effluent content

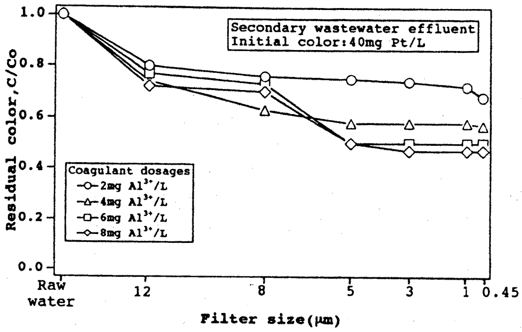

Fig 4:Color size distribution

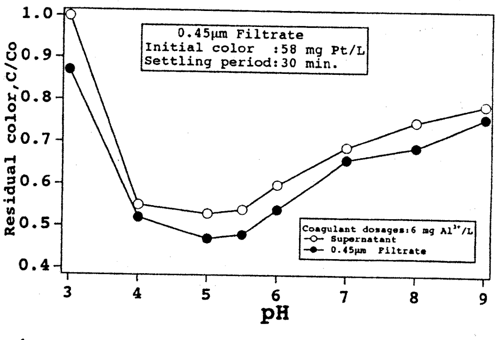

Fig 5:Effect of pH on color coagulation

3-2 Filtration

These experiments were carried out to investigate the effect of pH and coagulant dosages on the filter performance.

3-2-1 Effect of pH control

The results obtained in the jar test experiments showed that removal of dissolved matters and turbidity is pH-dependent. Though the optimum in the pH ranges between 4 and 6, these experiments were performed by adjusting the pH to 5.5. The pH was in the range of 5.5 to 6 because of the variation of water quality.

At the coagulant dosage of 4 mg Al^{3+}/L, the filter was run with pH adjusted to 5.5 and without pH control.

In **Fig. 6**, the variation of the turbidity with and without pH control is plotted at the dosage of 4 mg Al^{3+}/L. Without pH control, the average effluent turbidity was almost 2 mg/L, the removal efficiency was 75~85%, and 50~70% of the turbidity were removed in the coarse medium. When pH was controlled, the average effluent turbidity was 0.5 mg/L, the removal efficiency was 90~100% and 80% of the turbidity were removed in the coarse medium. When pH was controlled, the flocs had grown larger and were easily removed in the coarse medium and that improved the removal efficiency of the filter.

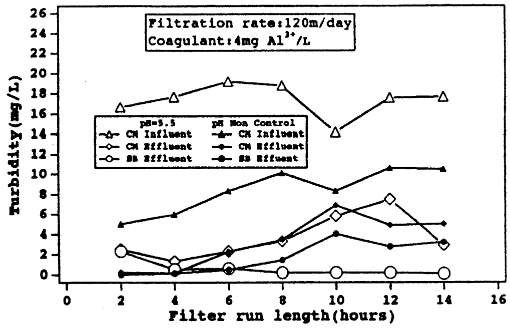

Fig 6:Variation of the turbidity during the filtration

In **Fig. 7-a and 7-b**, the variation of color during the filtration is plotted. Without pH control in **Fig. 7-a**, almost 25% of the color were coagulated in the flash-mixing tank and 80% of the coagulated color were removed in the dual-media filter. It is a matter of course that uncoagulated (soluble) color can not be removed in the filter. The filter removal efficiency was 20% for the color itself and 80% for the coagulated color. With pH control in **Fig. 7-b**, the coagulation rate (the ratio of the concentration of the coagulated color to that of the initial color in the influent) improved from 25% to 50~60%. Almost 100% of the coagulated color were removed in the filter because the effluent color was the same as that of the 0.45 μm filtrate of the coagulated water. The control of pH enhanced the coagulation rate 2 times and the removal efficiency for the color itself 2.5~3 times.

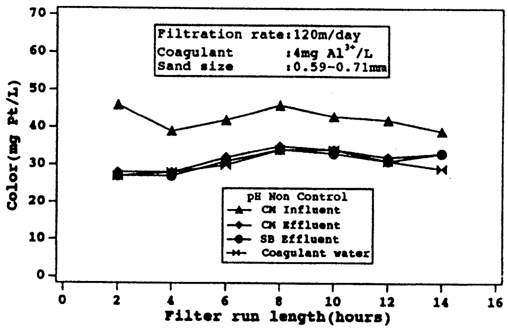

Fig 7-a:Variation of the color during the filtration without pH control

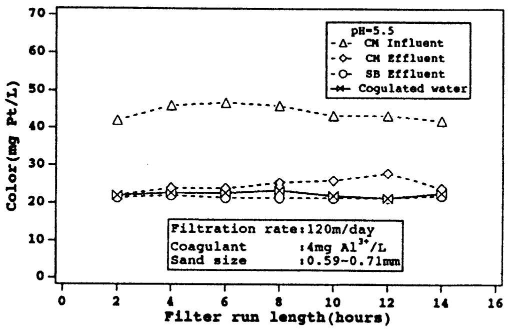

Fig 7-b:Variation of the color during the filtration with pH control

Fig. 8 shows the build-up of the head loss in the dual-media filter. When pH was controlled, the head loss increased in the coarse medium and decreased in the sand bed because the flocs had grown larger and were easily removed in the coarse medium. With 80% of removal efficiency for the turbidity, the head loss in the coarse medium was less than 20% that of the filter. When pH was not controlled, more than 90% of the head loss occurred in the sand bed.

The run length in both cases was 14 hours but when pH was controlled, the color removal increased from 20% to 50~60% and the average effluent turbidity decreased from 2 mg/L to less than 0.5 mg/L.

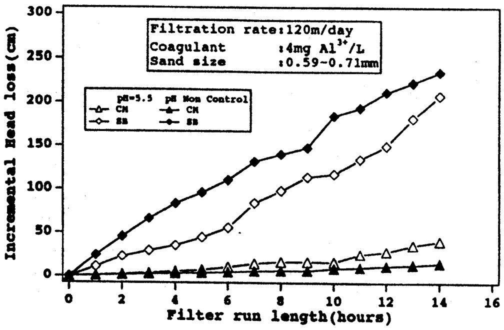

Fig 8:Build-up of the head loss during the filtration

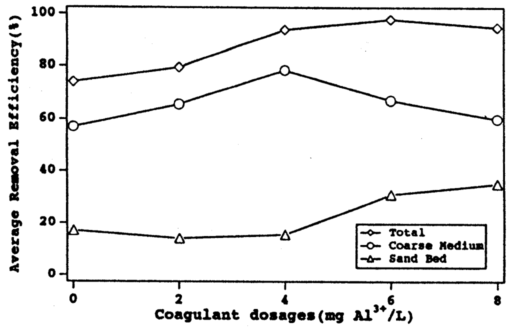

Fig 9:Effect of coagulant dosages on turbidity removal efficiency

3-2-2 Effect of coagulant dosages

The coagulant dosages of 2, 4, 6 and 8 mg Al^{3+}/L with pH adjusted to 5.5 were used to investigate their effect on the filter performance.

Fig. 9 shows the removal efficiency of the turbidity versus the coagulant dosage. Without coagulation, 75% of the turbidity was removed in the filter and the average effluent turbidity was of 2 mg/L. At the dosage of 2 mg Al^{3+}/L, the average turbidity effluent was 2 mg/L and the average removal efficiency was of 80%. The dosages of 4, 6 and 8 mg Al^{3+}/L gave an average effluent turbidity of 0.5 mg/L and a removal efficiency of 90% to 100%. In the coarse medium, almost 80% of the turbidity were removed at the dosage of 4 mg Al^{3+}/L against an average of 70% for 6 and 8 mg Al^{3+}/L.

In **Fig. 10**, the average removal efficiency of the coagulated color is plotted versus the coagulant dosages. Without coagulation, color was not removed in the filter because color was measured on the 0.45 μm filtrate. In the filter, almost 100% of the coagulated color were removed at the dosages of 4, 6 and 8 mg Al^{3+}/L against 85% at 2 mg Al^{3+}/L. The removal efficiency in the coarse medium was 4 times higher than that of the sand bed.

Fig 11 shows the effect of coagulant dosages on filter coefficient in the coarse medium. The filter coefficient was calculated from the first-order differential equation proposed by IWASAKI[4].

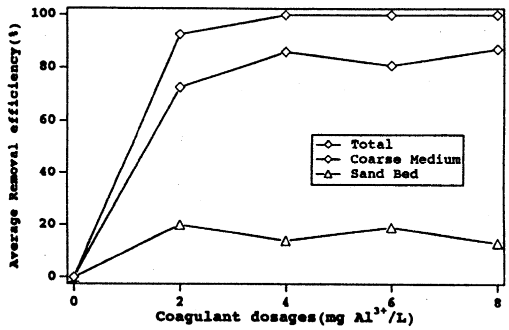

Fig 10:Effect of coagulant dosages on color flocs removal efficiency

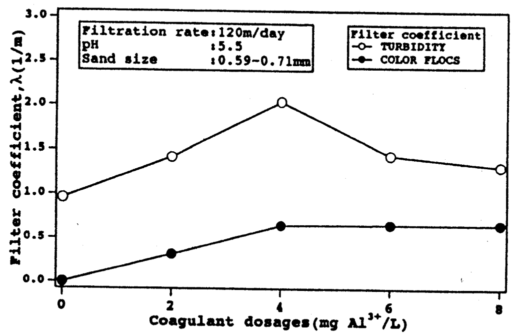

Fig 11:Effect of coagulant dosages on filter coefficient

The filter coefficient for turbidity is 3 to 4 times that of color. For coagulated color, at 4 mg Al^{3+}/L and higher dosages, the filter coefficient is constant because 80~85% of the coagulated color were removed in the coarse medium. However, for turbidity, the filter coefficient increased with an increase in the coagulant dosages, reached the maximum at 4 mg Al^{3+}/L and then decreased. As shown in **Fig. 3**, dosages higher than 4 mg Al^{3+}/L did not improve turbidity removal. Dosages higher than 4 mg Al^{3+}/L may be considered as overdose that led to the breakage of the coagulated flocs.

In **Fig. 12**, the filter run is plotted against the coagulant dosages. The increase in the coagulant dosages shortened the filter run length.

The dosages of 4, 6 and 8 mg Al^{3+}/L gave an average effluent turbidity of less than 0.5 mg/L and an average removal efficiency of almost 100%. At 4 mg Al^{3+}/L and higher dosages, 4 mg Al^{3+}/L gave the longest filter run. At the dosages of 6 and 8 mg Al^{3+}/L, the head loss in the coarse medium was less than 10% that of the filter but in the case of 4 mg Al^{3+}/L, the head loss ranged between 15% and 20%. As shown in **Fig. 9**, 20% of the turbidity was removed in the sand bed at the dosage of 4 mg Al^{3+}/L against 30% at 6 and 8 mg Al^{3+}/L. The head loss grew faster at 6 and 8 mg Al^{3+}/L and as a consequence, the filter run was shorter.

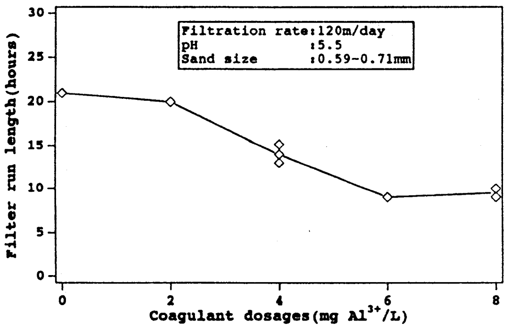

Fig 12:Variation of the filter run length with the coagulant dosages

Fig. 13 shows the distribution of the incremental head loss across the sand bed. ΔH/H represents the ratio of the incremental head loss due to the arrested flocs across any depth of the sand bed at any filtration time to that across the whole depth of the sand bed at the end of filter run. Filtration at 4 mg Al^{3+}/L is illustrated here. During the first hours of the filtration, the distribution of the head loss across the sand bed was almost the same but with time, the top layers accumulated the majority of the head loss. During the first 4 hours of the filter run, the flocs were mainly removed in the top 5 cm. From the 5th hour until the 12th hour, flocs were removed in the top 15 cm. From the 12th until the end of the filter run, flocs were removed in the top 25 cm of the sand bed.

At the end of the filter run, for 4 mg Al^{3+}/L as well as for 6 and 8 mg Al^{3+}/L, 90% of the head loss occurred in the top 35 cm of the sand bed. The top 5 cm accumulated 40% to 60% of the head loss followed by the 5~15 cm layer with 20%.

To enhance the filter run length, a better distribution of the head loss across the sand bed was needed.

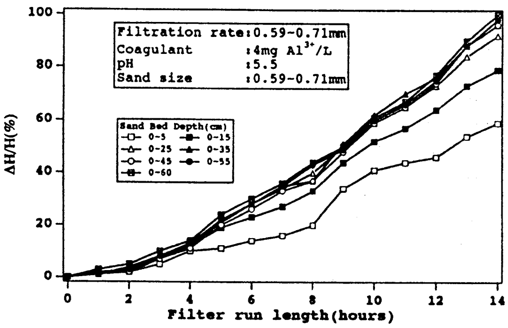

Fig 13:Distribution of the head loss across the sand bed

4 CONCLUSIONS

The following conclusions have been drawn:

1- Coagulation-assisted filtration with pH control improved turbidity and especially color of the filter effluent in comparison with no control of pH.

2- Almost 100% of the flocs that grew larger than 5 μm were removed in the filter.

3- The filter effluent quality was improved with an increase in the coagulant dosages, but was not improved at a certain dosage and over. The filter run length was shortened as coagulant dosages increased. Therefore, the smallest dosage that gave the longest run length with the same highest effluent quality was the optimum for filtration.

4- With the secondary effluent in this study, the dosage of 4 mg Al^{3+}/L was the optimum and the removal efficiency was almost 100% for turbidity and 50~60% for color.
5- At the optimum dosage of 4 mg Al^{3+}/L, 90% of the head loss in the sand bed occured in the upper part of 35 cm and 40~60% of that in the top 5 cm.
6- A better distribution of the head loss across the sand bed will lengthen the filter run. The following points should be considered:
- Flocculation stage before the filters to produce larger flocs that can be easily removed in the coarse medium bed.
- Coagulant aid to strengthen the flocs in order to prevent breakthrough in the coarse medium bed.
- A coarser sand size that allows a better distribution of the head loss and gives a good turbidity effluent.

References

1-T.Ueda and O.Shinohara: Basical Study On the Mechanisms of Multi-Media Filtration. *J.JWWA, vol 44, No 489, June 1975.*

2-J.Tsuchikawa, S.Semba and K.Shirai: Experimental Study On the Rate In the Rapid Filtration of Secondary Effluent. *J.JWWA, vol 22, No 253, June 1985.*

3-J.K.Edzwald, W.C.Becker and S.J.Tambini: Organics, Polymers, and Performance in Direct Filtration. *J.Envir. Engineering, ASCE, vol 113, No 1, February 1987.*

4-N.B.Tozan Michel, H.Hozumi, H.Yoshida and H.Ueda: Direct Filtration of Secondary Waste Water Effluent by a Dual Media Filter. *Proc. of Env.Engr.Research, vol 30, 1993. p267~273.*

5-A.P.Black and R.F.Christman: Chemical Characteristics of Fulvic Acids. *J.AWWA, July 1963.*

6- Shapiro J.: Chemical and Biological Studies on the Yellow Organic Acids of Lake Water. *Limnol.Oceanog., 2:161,1957.*

7-J.Manka, M.Rebhun, A.Mandelbaum and A.Bortinger: Charaterization of Organics in Secondary Effluents. *Environmental Science and Technology, vol 8, No 12, November 1974.*

8-E.S.Hall and R.F.Packam: Coagulation of Organic Color with Hydrolizing Coagulant. *J.AWWA, 55:9:1149, September 1965.*

9-N.Tambo, T.Kamei and H.Itoh: Evaluation of Extent of Humic-Substance Removal by Coagulation. Aquatic Humic Substances: Influence on Fate and Treatment of Pollutants. *I.H.Suffet and Patrick MacCarthy,Editors. American Chemical Society.*