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Removal of algae and turbidity by floating-media and sand filtration

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ABSTRACT

In Korea, almost every water treatment plant suffers from seasonal problem due to high concentrations of algae and turbidity, which result from eutrophication and heavy rainfall. To relieve this problem, experimental investigation was performed to test the applicability of floating-media (FM) and sand (SM) filtration as a preliminary water treatment for the algae and turbidity removal. Experimental results using artificial algae water showed that different morphology of algae as well as filtration velocity affect the removal efficiency. From the experiments using natural river water, it was concluded that algae removal is more affected by the depth of FM than that of SM. But turbidity was removed more effectively with deeper SM depth. Both algae and turbidity removals were affected by filtration velocity. The filtration system removed more total phosphorous (TP), total nitrogen (TN), turbidity, chlorophyll-a (Chl-a) and COD_{cr} than dissolved organic carbon (DOC) and UV_{254}. The removals of TP, TN, turbidity, Chl-a, and COD_{cr} were more than 30% but those of DOC and UV_{254} were less than 20%.

Keywords: Algae; Turbidity; Floating-media filtration; Sand filtration; Filtration velocity

1. Introduction

Surface water has typically been used as a source of drinking water in Korea. However, with the decreasing quality of surface water, almost every water treatment plant in Korea has a problem in producing the drinking water. High concentration of algae and turbidity in surface water has been reported as one of the most serious problems, which results in early filter blockage, odour or taste in water treatment plants [1–3]. From February to April, high algae concentration such as 600–32,000 cells/mL was detected in drinking water sources. During the period, numerous complaints were reported on bad odour and taste originating from the high concentration of algae [4]. Activated carbon and pre-chlorination can be used for the treatment of the odor and taste [5,6], but no useful treatment or research result can be used for the filter blockage due to the algae. In Korea, a dominant algal species varies seasonally but *Diatoms* and *Cyanobacteria* are dominant in April and green algae in autumn [1]. The main species of algae in

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Korea are *Microsystis, Synedra, Asterionella, Cyclotella* and *Stephanodiscus.* In particular, the *Synedra*'s bloom sometimes cause the load of filtration surface to increase suddenly which results in the shortening of filtration duration from 24 to 48 h up to 4 h in water treatment plants [3].

Korea has a seasonal heavy rainfall which results in high turbidity in water resources. The high turbidity continues for several months and comes into water treatment plants. The fine particles that are a cause material of the high turbidity have a electric repulsive force. That is the reason that water treatment plant cannot remove effectively the high turbid water by sedimentation [7].

The technology for the algae and turbidity removal has focused on mostly following treatment chain: pre-oxidation, coagulation and flocculation, and dissolved air flotation or sedimentation, followed by granular media filtration [8]. Pre-treatment, using oxidants such as ozone, chlorine, potassium permanganate and potassium ferrate, has been shown in many instances to improve algae removal as a result of algal inactivation [9–12]. However, there are a number of drawbacks to pre-oxidation. Disinfection by-products can form when using chlorine or chlorine dioxide, specifically trihalomethanes [9,13,14]. Irrespective of oxidant utilized, overdosing cannot only induce cell lysis, releasing undesirable toxins or taste and odour compounds, but also degrade extracellular organic matter (EOM) to the extent that compounds with interfering properties including mono and dicarboxylic acids and glycaric acid are formed [15].

On the other hand, direct filtration has recently been developed as a pressure from cost and energy constraints for the rapid development of economical and energy-efficient treatment technology [16,17]. The primary potential advantage of direct filtration is a reduction in the capital cost of the treatment facility as a result of elimination of the settling basins and elimination or significant reduction in the flocculation tank. Other benefits include a reduction in chemical dosages, resulting in decreased sludge production and less maintenance. Ngo et al. have developed a combined system of dual-media (floating-media (FM) and sand (SM)) filter with the concept of using FM as a flocculator and prefilter and SM as a subsequently polishing filter [18,19]. Henderson et al. have also reported that direct filtration appears to be the removal process most susceptible to variations in algal functionality [8].

The objective of the present study was to clearly quantify, compare and evaluate the removal characteristics of a filtration system utilizing FM and SM under several operational conditions such as media depth, combination of media and filtration velocity. To achieve the removal efficiencies of three different filter configurations using two separate measures, chlorophyll-a (Chl-a) and turbidity reduction, were measured and reported for both FM and SM. Additional parameters such as COD_{cr}, dissolved organic carbon (DOC), UV_{254}, total phosphorous (TP) and total nitrogen (TN) were also measured to further understand the behavior of the filtration system.

2. Materials and methods

2.1. Filtration system

The filtration system used in experiments is shown in Fig. 1. Raw water was pumped from 50 L of influent tank into a constant head tank, after which it was fed into filtration column at a constant velocity. Overflow from the constant head tank was sent back to the influent tank and headloss development in the filtration column was monitored by a manometer. In all filtrations, the headloss developed within a negligible range less than 3 cm for 60-min operation.

The filtration system was composed of two kinds of filter mediaFM and SM. The FM were expandable polystylene bead which diameter, porosity, density and specific surface area were 2–3 mm, 0.33, 25 kg/m^3 and 2,000 m^2/m^3, respectively. SM was provided from a municipal water treatment plant. Specific gravity, uniformity and SiO_2 composition were 2.62, 1.37, and 90.8%, respectively. Maximum, minimum and effective sizes were 1.8, 0.7, and 1.0 mm, respectively.

The filtration system was operated at two different modes—dual-media and mono-media. At the operation of dual-media mode, the filter was packed with both FM and SM. But the filter at mono-media mode was

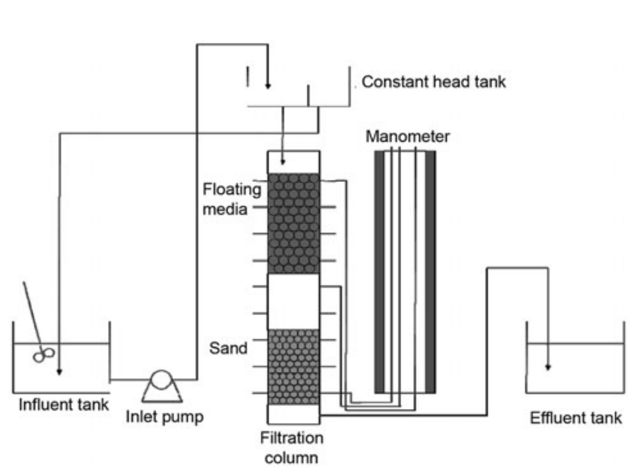

Fig. 1. Apparatus of filtration system.

packed with only FM or SM. Various depths of media at both modes were tested to investigate the effect of media on the removal. The specific depths of each media will be mentioned in each experimental result.

2.2. Raw water

The experiments were carried out with two different kinds of raw waterartificial algae water and natural river water. The artificial algae water was prepared with tap water spiked with pure-cultured algae until a specific concentration of Chl-a was achieved. Three species of algae (*Anabaena cylindrical* (*AC*), *Microcystis viridis* (*MV*), and *Microcystis aeruginosa* (*MA*)) were cultured in axenic BG-11 medium at 25℃ under fluorescent light (1000 lx, 12-h light/12-h dark). The BG-11 medium was composed of 1.5 g/L $NaNO_3$, 40 mg/L.

K_2HPO_4, 75 mg/L $MgSO_4{\cdot}7H_2O$, 36 mg/L $CaCl_2{\cdot}2H_2O$, 6.0 mg/L Citric acid, 6.0 mg/L Ferric ammonium citrate, 1.0 mg/L $EDTANa_2$, 20 mg/L $NaCO_3$, 2.86 mg/L H_3BO_3, 1.86 mg/L $MnCl_2{\cdot}4H_2O$, 0.22 mg/L $ZnSO_4{\cdot}7H_2O$, 0.39 mg/L $Na_2MoO_4{\cdot}2H_2O$, 0.08 mg/L $CuSO_4{\cdot}5H_2O$ and 0.05 mg/L $Co(NO_3)_2{\cdot}6H_2O$. It was controlled at pH 7.0 before autoclaving by adding either 0.1 M NaOH or 0.1 M HCl solution. The algae were cultured for 10 days until the cell concentration reached about 104–105 cells/Land then diluted about 10 times before each experiment. The algal concentration of influent was kept at a constant value for every filtration.

The natural river water was collected from Nakdong -river and used directly. It was taken 20 times (200 L per each time) from early January to mid-March. The properties of the raw water were analyzed before each experiment and are shown in Table 1.

2.3. Analytical methods

Water samples were taken from three points—influent tank, middle and bottom of the filtration column—after 5, 10, 20, 30, 40, 50 and 60-min operation for the quality analysis. Sample from influent tank was for the analysis of raw water. Sample from the middle of the filtration column was effluent filtered through FM only. Sample from the bottom was effluent filtered through both FM and SM. Analytical methods used in this study are presented in Table 2.

Table 1
Properties of natural river-water

pH	6.7	~7.7
Turbidity (NTU)	8.2	~19.8
Chl-a (ug/L)	46	~144
DOC (mg/L)	2.1	~3.8
UV_{254} (cm^{-1})	0.056	~0.086
Zeta-P (mV)	−9.8	~−12.7
CODcr (mg/L)	26.2	26.2
TN (mg/L)	3.6	3.6
TP (mg/L)	0.25	0.25

Table 2
Analytical methods used in this study

Items	Analytical methods
pH	pH meter (DMS model DP-880M)
Turbidity	HACH 2100N Turbidimeter
Chl-a	Trichromatic method
DOC	TOC analyzer (Shimadzu TOC 5000)
UV_{254}	UV-VIS Spectrophotometer (Kontron model Uvikon 930)
Zeta-Potential	Malvern Zetasizer 2000
$TCOD_{cr}$	Reactor digestion method (HACH)
TN	Reactor digestion method (HACH)
TP	Acid persulfate digestion method (HACH)
Cell counting	Microscopic observation (Reverse, Olympus CK 2)

3. Results and discussion

3.1. Artificial algae water

The effect of algae species on the filtration was first investigated with three different species of pure-cultured algae. The algae used in the experiments (*AC, MV* and *MA*) often appear in Nakdong-River at summer and make a serious problem to near water treatment plants.

3.1.1. Removal characteristics of algae

The operational mode in this study was dual -media with 20 cm of FM and 20 cm of SM. It was operated at a constant filtration velocity of 76 m/d for 60 min. Fig. 2 shows the removals of the three algae. The figure consists of the removal rates by FM (R_f) and SM (R_s) of the three algae. The value of R_f was obtained from counting the cell numbers of raw water and FM effluent. The value of R_s was calculated from the cell numbers of FM effluent and SM effluent, which means that the influent into SM was the effluent from the FM.

From the figure, different tendency can be shown in R_f and R_s. In the case of *AC*, R_f was high in the beginning but R_s was high later. This means that the removal of *AC* was dominantly carried out by the SM

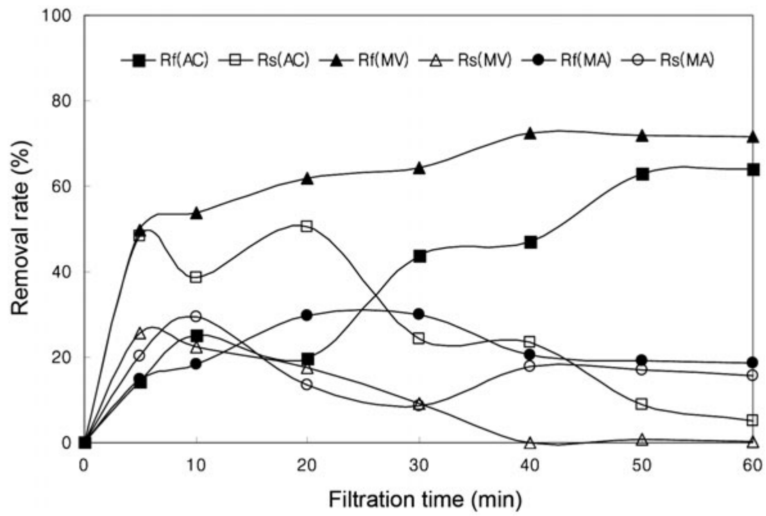

Fig. 2. Removal rate of three algae with filtration time (initial cell number: 8.29×10^4 cells/ml).'

for early 20 min, but the removal by the FM was dominant afterwards. In particular, the removal was done almost by only the FM after 50 min filtration. Unlike the removal of *AC*, *MV* was dominantly removed by FM from the beginning. The removal was done only by the FM after 40 min during which the removal by the SM was almost zero. The removal of *MA* was also slightly different from the others. The FM and the SM removed almost same amount of the algae for 60 min filtration.

The data of Fig. 2 were rearranged in Table 3 to examine the function of the FM in algae removal. The table shows average total removal rate (R_t), average R_f , and R_f/R_t. The R_t was obtained from adding R_f to R_s. Average R_t was 68.1, 74.1, and 39.1% for *AC*, *MV*, and *MA*, respectively. These different removals of three algae might come from their different morphology. The key algal characteristics impacting on water treatment processes have been reported to be morphology, motility, surface charge, cell density and, the EOM composition and concentration. Based on a number of reports, Henderson et al. have also concluded that the specific algae character affecting the removal is morphology [8]. It is reported that *AC* is filamentous-like and *MV* is agglomerated-shape. *MA* is reported to be individual sphere-like. The results imply that the agglomerated-shaped algae like *MV* can be removed relatively easily by the filtration. The ratios (R_f/R_t) were 64, 86, and 55% for *AC*, *MV*, and *MA*, respectively. All the values are more than 50%, which implies that the role of the FM was more than that of the SM in the removal of algae.

Table 3
Average algae removal for 60 min filtration

	AC	*MV*	*MA*
Average R_t (%)	68.1	74.1	39.1
Average R_f (%)	43.8	63.7	21.7
R_f/R_t (%)	64.0	86.0	55.0

3.1.2. Removal characteristics of various filtration velocities

This study was conducted with mono-media filter as well as dual-media filter. The dual-media filter was packed with both 20 cm of FM and 10 cm of SM. The mono-media filter was packed with only 20 cm of FM or 10 cm of SM. Filtration velocities tested were 23, 45, 68, and 113 m/d. *MA* was used in the experiments.

Fig. 3 shows removal characteristics of the various velocities. As shown in the figures, the removals were almost constant with time but reduced as the velocity increased. The removal in particular reduced sharply as the velocity increased from 68 to 113 m/d. This result was similar to what were reported by several other researchers who found that at low filtration velocity, FM filtration provided excellent total suspended solids (TSS) removal but was considerably reduced at higher filtration velocity [16,18,20]. Steicke et al. have reported the experimental results with downflow with floaging-media and downflow with sand that TSS removal reduced 80–31% as velocity increased 8.8–32 m/h [20]. It can also be found from the comparison of Fig. 3(b) and (c) that the removal-

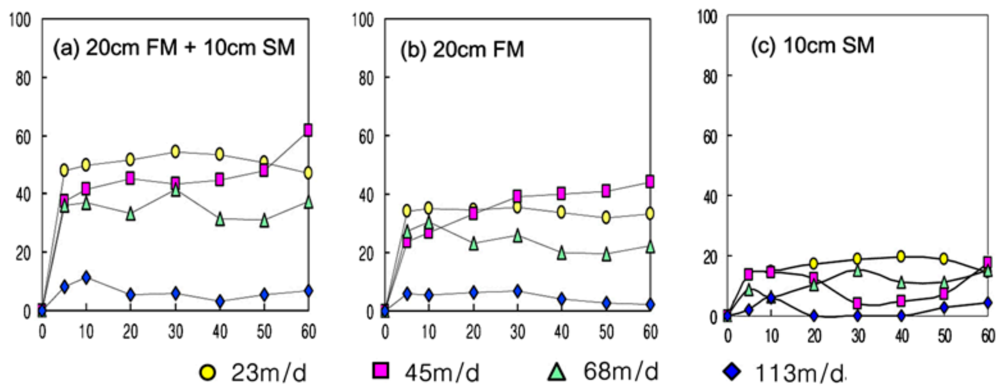

Fig. 3. Removal of *MA* at various filtration velocities (initial cell number: 4.52×10^4 cells/ml).

decrease with velocity-increase in 20 cm FM was more significant than in 10 cm SM. This implies that the removal by FM can be said to be more sensitive to the variation of velocity than that by SM.

3.2. Natural river water

Natural river water collected from Nakdong River was used as raw water to examine the filtration characteristics in various operational conditions such as filter media, media depth, and filtration velocity.

3.2.1. Removal characteristics of various filtration depths

This study was performed with three different depths of filters. Total depth of the FM and SM was fixed at 100 cm, but the depth of each media was changed. The depths of the FM and SM were varied to 80:20, 50:50, and 20:80 cm. Filtered samples were taken after 5, 10, 20, 30, 40, 50 and 60-min operation for the removal analysis of turbidity and Chl-a. Filtration velocity was fixed at 36 m/d.

Fig. 4(a) and (b) shows the removals of turbidity and Chl-a. Fig. 4(a) shows that R_f was higher than R_s when FM/SM was 80: 20 cm. R_f was almost equal to R_s when FM:SM was 50:50 cm and R_s was higher than R_f when FM/SM was 20:80 cm. This implies that more turbidity was removed by the deeper media. Average removals of turbidity were 34, 40, and 43% for 80:20, 50:50, and 20:80 cm, respectively. This means that deeper sand removed slightly more turbidity.

Fig. 4(b) shows that R_f was higher than R_s in all depths. This implies that Chl-a was removed mostly by FM despite of depth's variation. Average removals of Chl-a were 48, 37, and 20% for 80:20, 50:50, and 20:80 cm, respectively. It is said from the result that the removal of algae was significantly related with the depth of FM.

3.2.2. Removal characteristics of various filtration velocities

The filter used in the experiments was packed with the depth of FM/SM as 80:20 cm. Filtration velocities tested were 23, 45, 68, and 113 m/d.

Fig. 5(a) and (b) shows the removals of turbidity and Chl-a at the different velocity with filtration time. The removal of turbidity decreased as the velocity increased, but the removal of Chl-a was not affected by the variation of velocity. Average removals of turbidity were 37.2, 30.1, 22.8, and 20.4% for the velocity of 23, 45, 68, and 113 m/d, respectively. On the other hand, average removals of Chl-a were 37.3, 31.7, 33.7, and 35.1% for the velocity of 23, 45, 68, and 113 m/d, respectively.

3.3. Water treatment by floating- media and sand filtration

From the experimental results, the optimal condition of the filtration was selected as 72 m/d for filtration velocity and 80:20 cm for the depth of FM/SM. The ability of the filter in water treatment was tested from the operation at this condition. COD_{cr}, TN, TP, DOC, and UV_{254} including turbidity and Chl-a were analyzed for the test. Raw water was Nakdong River water. The filtration was operated for 60 min, and sample was taken from the influent and the effluent every 10 min. Average values of the removal are shown in Table 4.

By the FM and SM filtration, TP, TN, turbidity, Chl-a, and COD_{cr} were relatively more removed than DOC and UV_{254}. The removals of TP, TN, turbidity, Chl-a, and COD_{cr} were more than 30% but those of

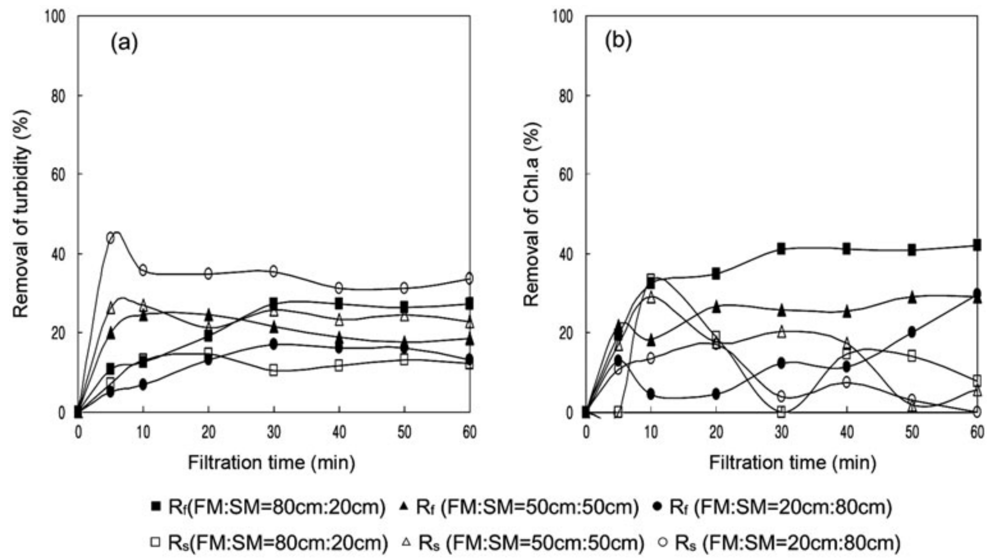

Fig. 4. Removal of (a) Turbidity and (b) Chl-a by various depths of dual media.

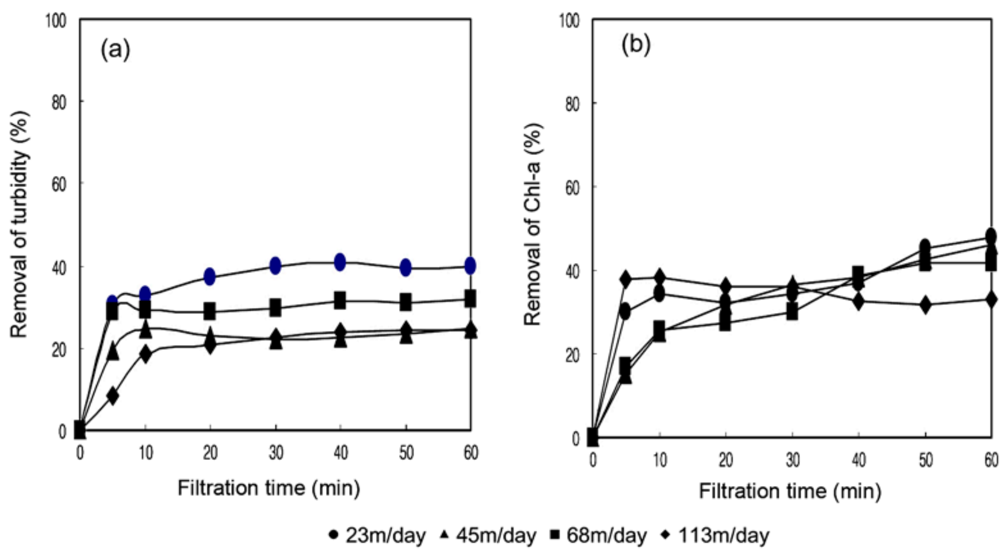

Fig. 5. Removal of (a) Turbidity and (b) Chl-a at the different velocity.

Table 4
Water treatment by 60-min operation of dual-media filter

	Turbidity	Chl.a	DOC	UV_{254}	COD_{cr}	TN	TP
Average removal (%)	37.0	33.1	16.3	4.7	27.5	33.3	48.0

DOC and UV_{254} were less than 20%. It might be because suspended solid, turbidity or algae could be relatively easily removed by the filtration, which resulted in the removal of phosphorus, nitrogen, and COD. Ngo et al. have reported from experimental study with FM and SM filtration system that the removals of TN and TP were 33.2 and 37.1% without any coagulant addition although TSS removal was more than 65%. They could accomplish the both removal efficiencies more than 70% with 50 mg/L alum addition [18,21]. Membrane filtration without coagulation pretreatment has also been reported significantly low removal like 37.9 and 9.52% for UV_{254} and DOC, with more than 95% turbidity removal [22]. Therefore, filtration alone cannot remove effectively the soluble materials such as DOC and UV_{254}. Therefore, this filtration system can be combined with coagulation for the removal of these soluble materials.

4. Conclusions

In this study, the following conclusions could be drawn according to the experimental results.

(1) From the experimental result with artificial algae water, different algae showed different removal characteristics. It might be resulted from the different morphology of the algae. Average removals of *AC, MV* ,and *MA* were 68.1, 74.1, and 39.1%, respectively. FM played more important role than SM in the removal of algae. The increase of filtration velocity caused the decrease of the algae removal.

(2) The experiments with natural river water showed that turbidity removal depended slightly more on SM depth, but algae removal significantly depended on FM depth. Average removals of turbidity were 34, 40, and 43% for 80:20, 50:50, and 20:80 cm of the FM to SM, respectively. Average removals of Chl-a were 48, 37, and 20% for 80:20, 50:50, and 20:80 cm, respectively. The removal of Chl-a was not affected by the variation of velocity, although the removal of turbidity decreased as the velocity increased.

(3) By FM and SM filtration TP, TN, turbidity, Chl-a, and COD_{cr} were relatively more removed than DOC and UV_{254}. The removals of TP, TN, turbidity, Chl-a, and COD_{cr} were more than 30% but those of DOC and UV_{254} were less than 20%.

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