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## Practical Paper

# Flexible fibre filter: potential for algae removal

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## ABSTRACT

When algae is present in surface water it becomes an important issue in the production of drinking water, causing problems such as the interruption of coagulation and sedimentation processes and blockage of the filter. Dissolved air flotation is generally considered to be the most effective process available for the removal of algae from surface water. In this research, an evaluation is carried out on the effectiveness of an innovative fibre filter as an alternative method for algae removal. The fibre filter has been known as an effective particle separator through flexible polyamide fibres. This filter might apply for production of drinking water as well as for tertiary treatment of wastewater. The removal of particles can reduce the turbidity of the surface water and simultaneously remove microorganisms such as algae. The experiments were performed with a field-scale filter installed close to the Nak-dong River. An improvement was achieved in the removal efficiency through the in-line injection of a coagulant (PAC: 11% as $Al_2O_3$). With a low optimum coagulant dosage of $1\,mg\,l^{-1}$, the filter was able to achieve 90% algae removal with an effluent turbidity of less than 1 NTU when operated at a high velocity of $120\,m\,h^{-1}$.


**Key words** | algae, coagulant, fibre filter, filtration velocity, in-line injection method

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## INTRODUCTION

The release of contaminants from industrial and agricultural activities increases the concentration of nutrients in surface water (and aquifers) resulting in eutrophication. The most common indicator of eutrophication is the presence of algae. Algae are unicellular, generally non-motile plants ranging in size from 5 to 100 μm. The dominant type of algae found in Korean rivers is blue-green algae such as *Microcystis*, which appear from the beginning of summer through to autumn. They have a tendency to float and are therefore difficult to remove by sedimentation. For this reason, dissolved air flotation (DAF) is usually needed to remove algae from surface water.

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This study focuses on the flexible fibre filter for the separation of algae from surface water. BenAim *et al.* (2004) demonstrated the effectiveness of this filter for the tertiary treatment of effluents. The fibre media within the filter have a high surface area, ranging from 1.5 to 6 times larger than other typical sand media. Because of the large porosity of the packing media, this filter can operate at a high filtration velocity of up to $2{,}400\,m^3/m^2$/day. More recent results have proved that, with the addition of an in-line injection of poly aluminium chloride (PAC) (11% as $Al_2O_3$), the fibre filter can efficiently remove particles from surface water (Lee *et al.* 2006*a*,*b*). In the case of drinking water production, the removal of particles can reduce the turbidity of the surface water and simultaneously remove microorganisms such as bacteria and algae. The purpose of this research is to evaluate the feasibility of the fibre filter in terms of its application in the removal of algae from surface water. In order to determine the optimal operational condition for the filter, an examination of algae and particle removal was carried out at different coagulant dosages.

## MATERIALS AND METHODS

### Field-scale fibre filter plant

For the purposes of this experiment, a field-scale fibre filter with an internal diameter of 650 mm and a height of 1,500 mm was installed in a water treatment plant (see Figure 1). Polyamide (nylon) fibres of 30 μm diameter were used as the filter media. The packing density of the fibre was 80 kg m$^{-3}$, while the porosity was 93%. The filter media were packed parallel to the vertical axis of the filter and the U-shaped bundles of fibres were fixed to a perforated plate at the bottom of the filter. The fibre media were flexible against the flow since they were not fixed at the top of the filter. This method was also convenient for detaching the particles by the process of backwashing as well as for lowering the pressure in the filter during a run. The filtration direction was axial up-flow. The influent entered the inflow pipe at the side of the lower region of the filter. The fluid passed through the bundles of fibres, and was then collected into a perforated tube that was installed inside the filter. A peristaltic pump was used to directly inject the coagulants to the feed pipe through a static mixer. For the backwashing process, air and water were injected at the bottom of the filter.

Nak-dong River water that was not pretreated was used as the filter influent water for the experiment. Although the raw water turbidity was over 100 NTU during the rainy season in the summer, the average turbidity of the water ranged from 8 to 15 NTU, and the chlorophyll-a concentration ranged from 5.4 to 67.3 μg l$^{-1}$ for the period of the field-scale filter run from September to November (Figure 2). The pH varied within the acceptable range for coagulation and the average pH was approximately 7.2.

### Operational conditions

Various dosages of coagulant were injected into the full-scale fibre filter in order to evaluate the dosage required to remove the algae. A filtration velocity of 80 m h$^{-1}$ was selected, which has been previously identified as the mid-range velocity suitable for drinking water production (Lee et al. 2006a). PAC (11% $Al_2O_3$) was used as a coagulant and the coagulant dosage was gradually increased from 1 to 3 mg l$^{-1}$. During the experiment, the results were compared with those obtained from a blank test where a coagulant was not used.

The filter backwashing process, based on the collapse-pulsing phenomenon documented by Amirtharajah (1993), was performed using water and an air intermittent injection.

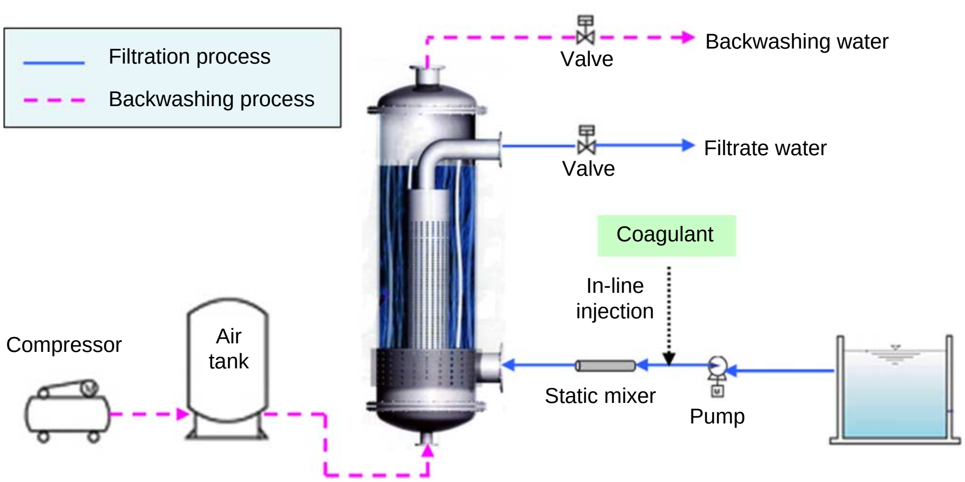


**Figure 1** | Schematic diagram of the pilot scale fibre filter plant.

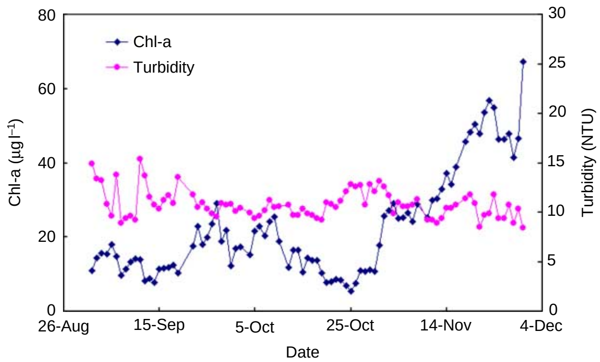


**Figure 2** | Chlorophyll-a concentration and turbidity of Nak-dong River water from September to November 2006 (source: Busan Water Authority, Korea).

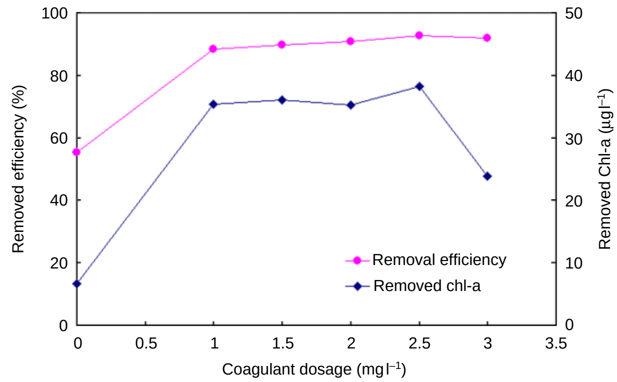


**Figure 3** | Chlorophyll-a removal according to coagulant dosage.

In this present study, water and air backwash are operated sequentially, where 7 seconds of air injection was followed by approximately 15 seconds of water injection. This sequence is repeated up to 14 times, with a total backwashing times of 5 minutes, 43 seconds, followed by a 35 seconds water-rinsing phase. The water flow rate for backwashing was equal to the influent flow rate. Before backwashing, an air tank was filled with air that was maintained at an inner pressure of 196 kPa. The air was then jetted into the filter when a solenoid valve was opened.

### Measurements

For filter run, influent and effluent flow rate were monitored by flowmeter (Krohne co. Ltd, Swiss). At the same time, the pressure in the filter was measured by a digital pressure gauge. Using an on-line turbidimeter (HF Scientific, inc.) and a turbidity meter (HACH 2100N), the turbidity of influent and effluent was measured at intervals of 1 minute. The concentration of algae was evaluated by analysing the chlorophyll-a concentration based on standard methods. Particle analysis was performed using a particle sizing system (Model 770 Accusizer, USA).

## RESULTS AND DISCUSSION

### Influence of the coagulant dosage on algae removal

Figure 3 shows the variation of algae removal efficiency of the filter according to the different dosages of coagulant. The concentration of chlorophyll-a in the raw water ranged from 12.03 to 41.18 $\mu g\,l^{-1}$. Without a coagulant, the removal efficiency of algae was approximately 60%. In contrast, the removal efficiency increased by more than 90% at each coagulant dosage with the injection of the coagulant. The best result was obtained with a coagulant dosage of 2.5 $mg\,l^{-1}$ of PAC. However, each increase in the dosage of the coagulant only marginally affected the removal efficiency. This implies that the fibre filter can sufficiently capture algae particles with a low dosage of at least 1 $mg\,l^{-1}$. When the dosage of coagulant was increased from 2.5 to 3 $mg\,l^{-1}$, the removal of chlorophyll-a by the filter decreased from 38.2 to 23.9 $\mu g\,l^{-1}$.

### Comparison between algae removal and particle capture

While the chlorophyll-a measurement was being conducted, a particle counter was used for the determination of the particle size distribution (PSD) in the raw water and the filtrate. Figure 4 shows results obtained from the influent and the effluent of the filter. It can be seen that the raw water has a well-defined peak in the distribution at about 8 μm. Without a coagulant, the removal efficiency of small particles (less than 10 μm) was not sufficient. In this case, the retention efficiency of small particles less than 3 μm appears to be negative. This could be due to the detachment of those particles that were initially retained (Bai & Tien 1997). In contrast, the coagulant injection improved the removal efficiency of fine particles for all particle sizes. The coagulant injection improves not only the algae removal but also the removal of all the particles by the fibre filter.

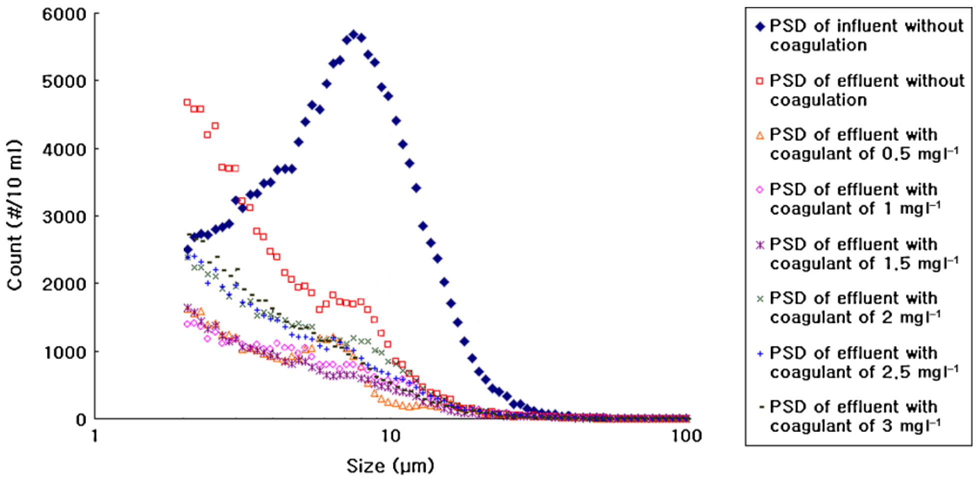


**Figure 4** | Particle size distribution (after 45 minutes of filtration) in the influent and the effluent at different coagulant dosages.

A total particle count (TPC) in the influent and the effluent of the filter was determined at 15-minute intervals (Figure 5). With no coagulant, the filter captured approximately 70,000 particles. When the coagulant was injected into the filter, the TPC of removed particles increased significantly. With 1 $mg\,l^{-1}$ of PAC, the number of removed particles increased from 70,000 to 120,000. When 2 $mg\,l^{-1}$ or more coagulant was used, the number of particles captured by the filter decreased after a 30 minute filter run.

Figure 6 shows the effect of the coagulant dosage on the removal of suspended solids. The concentration of suspended solids in the influent ranged from 7.2 to 11.6 $mg\,l^{-1}$. When coagulant was not added, the removal of the suspended solids was poor. However, removal efficiency was improved with the injection of the coagulant. These results are similar to those obtained from testing for the removal of algae, as shown in Figure 3.

## Influence of the filtration velocity

The removal of algae was observed when the filtration velocity was increased from 60 $m\,h^{-1}$ to 120 $m\,h^{-1}$ while using a coagulant dose of 1 $mg\,l^{-1}$. Figure 7 summarizes the results obtained. In all conditions, an efficiency of about 85% was achieved, regardless of filtration velocity. The influence of the

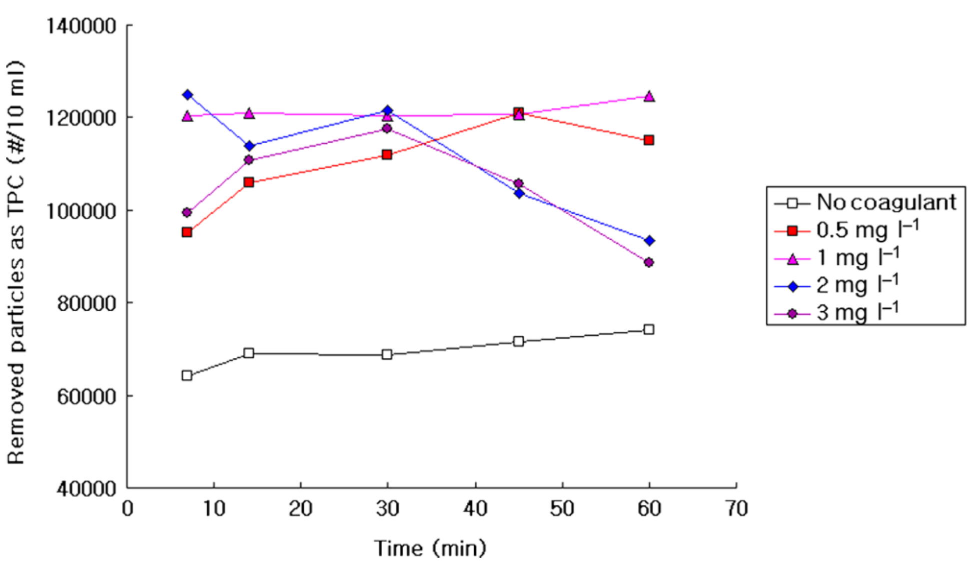


**Figure 5** | Quantity of removed particles with time at different dosages of coagulant, expressed as total particle count (TPC).

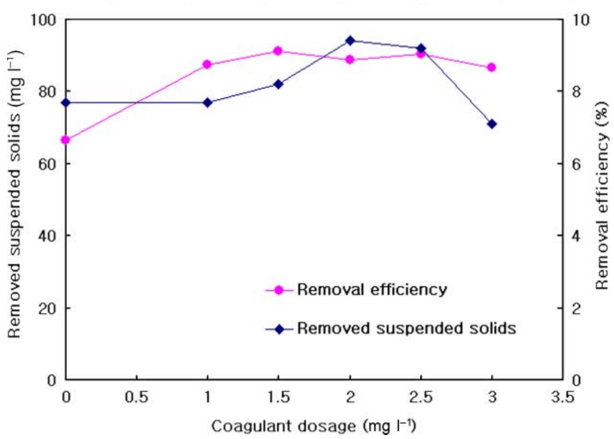


**Figure 6** | Effect of coagulant dosage on the removal of suspended solids.

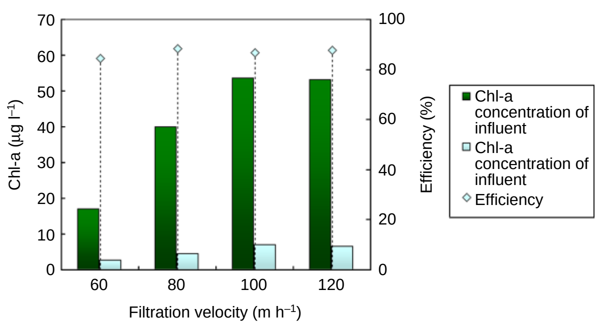


**Figure 7** | Chlorophyll-a removal depending on filtration velocity.

filtration velocity is marginal since a high efficiency of algae removal could be achieved when the 3FM filter was operated at a velocity of $120\,m\,h^{-1}$. For a velocity of $120\,m\,h^{-1}$, the residence time in the filter is less than 1 minute. The flexible fibre filter therefore appears to be an effective tool for treating surface water in the presence of algae.

## CONCLUSIONS

The performance of the flexible fibre filter is enhanced by the in-line injection of a PAC coagulant. With only a low dosage of coagulant ($1\,mg\,l^{-1}$), this filter can efficiently remove algae as well as particles that are larger than 2 μm. Despite a very high filtration velocity of $120\,m\,h^{-1}$, the flexible fibre media was able to remove more than 85% of the algae. The flexible fibre filter therefore appears to be an effective tool for treating surface water in the presence of algae. It is more compact than a flotation cell (smaller residence time and online coagulation), consumes less energy and less coagulant is required than in effective air flotation, since the formation of large flocs is not required for on-line direct filtration.

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## REFERENCES

Amirtharajah, A. 1993 Optimum backwashing of filters with air scour: a review. *Water Sci. Technol.* **27**(10), 195–211.

Bai, R. & Tien, C. 1997 Particle detachment in deep bed filtration. *J. Colloid Surf.* **186**, 307–317.

BenAim, R., Han, K. B., Woo, H. J., Marteil, P., Im, J. H., Kim, C. W. & Hwang, M. H. 2004 An innovative deep bed filter for the tertiary treatment of wastewater. *9th World Filtration Congress*, 18–22 April 2004, New Orleans, USA.

Lee, J. J., Jung, M. K., Im, J. H., BenAim, R., Lee, S. H., Kim, C. W., Oh, J. E. & Woo, H. J. 2006*a* Enhancing flexible fiber filter performance using in-line coagulation. *Water Sci. Technol.* **53**(7), 59–66.

Lee, J. J., Im, J. H., BenAim, R., Han, K. B. & Kim, C. W. 2006*b* Using innovative fiber filter and in-line coagulation for surface water treatment. *IWA World Water Congress*, 10–14 September 2006, Beijing, China.

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