Korean J. Chem. Eng., **25**(6), 1326-1330 (2008)

Comparison of electrocoagulation and chemical coagulation with fiber filters for water treatment

Young Man Cho*,†, Gi Weon Ji*, Pyeong Jong Yoo*, Chang Weon Kim, and Ki Baek Han*****

*Water Quality Research of Busan Water Authority, Kimhae, Gyeongnam 621-813, Korea
**Department of Environment Engineering, Pusan National University, Busan 609-735, Korea
***nanoENTech Co., LTd., Gyeongnam 626-220, Korea
(*Received 15 January 2007 • accepted 12 April 2008*)

Abstract−A combined electrocoagulation(EC)-fiber filter system has been presented as a new technology for water treatment. The objective of this study was to evaluate the feasibility of applying an aluminum EC-fiber filter for water treatment. We compared the water treatment efficiency of the chemical coagulation (CC)-fiber filter and EC-fiber filter. A comparison of the EC and CC processes reveals that EC significantly outperformed CC when the water to be filtered using fiber filters was pretreated with aluminum. For particle size less than 6 μm, the removal efficiency was 66%, 43% for EC and CC, respectively, and the average removal efficiency of the total organic carbon (TOC) was 50%, 65% for CC and EC. Therefore, EC reduced the amount of aluminum utilized by 25%, and the effluent turbidity improved by approximately 0.11 NTU to 0.19 NTU. Also, the average log removal value (LRV) for heterotrophic plate count (HPC) was 2.5 and 1.9 for EC and CC. respectively. Therefore, the aluminum used for EC proved to be excellent for pretreating the water to be filtered by a fiber filter.

Key words: Electrocoagulation, Chemical Coagulation, Electrocoagulation Reactor, Fiber Filter

INTRODUCTION

The need for a drinking water supply with good quality and economic plant management gives impetus to efficiency improvement of a conventional water treatment plant. Generally, a filtration process is used in drinking water treatment when the source is surface water. Sand filtration is one of the most important processes in conventional drinking water treatment. But the sand filter operates with low filtration velocities, and thus it requires a large installation.

During the last 3-4 years, a filter using polyamide fiber has been developed in Korea. Compared with a conventional rapid sand filter, this filter has over 20 times higher filtration velocity. The polyamide fiber has over twice the specific surface area when compared with sand [1]. This process might apply not only for drinking water treatment but also wastewater treatment process [2]. The efficiency with which this process removes the contaminants in raw water may be improved by using a coagulant. Usually, chemical coagulation (CC) is performed by using an iron or aluminum salt.

EC has been recognized as an alternative to the CC. The coagulant in EC is generated by dissolution of a sacrificial anode such as Fe and Al. It has a wide application field and it can also be effective for complicated wastewater which contains heavy metals, oils, and bacteria [3]. Recently, it has also been used in the removal of turbidity, color, algae and microorganisms in water treatment [4].

The typical benefit of the EC process is that no liquid chemical is added; alkalinity is not consumed and pH adjustment is not needed. Additionally, compared with CC, the EC process requires less dosage and produces less sludge [5]. The space required for EC is less than CC because EC does not require chemical storage, dilution, and rapid mixing [6].

In this study, aluminum sulfate was used as the chemical coagulant. The amount of aluminum dissolved or deposited is dependent on the quantity of electricity passed through the electrolytic solution. A simple relationship between current density and the amount of substances dissolved can be derived from Faraday's law as shown Eq. (1) [7].

$$w=\frac{M}{2F} \tag{1}$$

where M is the molecular weight of aluminum, I is the current density (A/cm^2), t is the time, z is the number of electrons involved in the oxidation, and F is Faraday's constant.

The objective of this study was to evaluate the feasibility of applying an aluminum EC-fiber filter for water treatment. We compared the water treatment efficiency of the CC-fiber filter and EC-fiber filter. This is the first research on EC pretreatment for fiber filter.

MATERIALS AND METHODS

1. Experimental Equipment and Methods

The experimental equipment was installed at the Busan Water Quality Institute. Influent water was collected from the Nakdong River. The experimental period was from December, 2005 until August, 2006. The flow of the influent water was 120 m^3/day, and its turbidity was from 13.5 NTU (Nephelometric Turbidity Unit) to 235 NTU. The average turbidity of the Nakdong River is 15 NTU on a normal day, but it is sometimes a few hundred NTU (Max. 1,000 NTU) more after heavy rainfall.

The experimental equipment was comprised of EC reactor, coagulant equipment, and fiber filters. A schematic of the experimen-

†To whom correspondence should be addressed.
E-mail: cho1221@metro.busan.kr

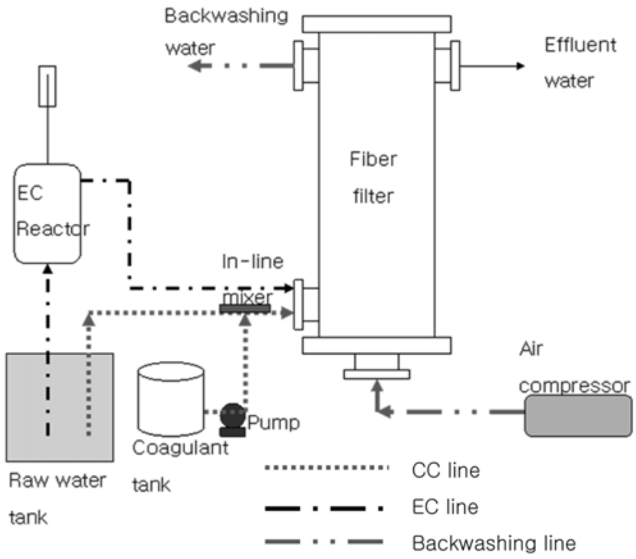

Fig. 1. Schematic diagram of experimental setup.

Table 1. Characteristics of fiber filter and EC reactor

Classification		Characteristics
EC reactor	Reactor	Material: Acrylic 310 mm (W)×20 mm (L)×800 mm (H)
	DC rectifier	Current 100 A, Voltage 60 V
	Electrode	Diameter 100 mm, 400 mm (H), Al (2EA)
Fiber filter	Filter velocity	160 m/Hr
	Fiber	Diameter 200 mm, 1,000 mm (H)
	Air compressor	10 kg/cm^2

Table 2. Summary of analytical instruments

Item	Instrument
Al(lll)	Inductively coupled plasma-atomic emission spectrometer (ICP)
Turbidity	HACH 2100AN
TOC	SHIMADZU TOC-V
Particle size	ACCUSIZER Particle sizing systems 770 A

tal setup is shown in Fig. 1. The process of water treatment by using the EC-fiber filter is indicated by a black line (influent→EC reactor→fiber filter), and a dotted line (influent→in-line mixer→fiber filter) indicates the process of water treatment by using the CC-fiber filter. The characteristics of the EC reactor and fiber filter are listed in Table 1.

The chemical coagulant was polyorganic aluminum magnesium sulfate (PSO-M: 7% Al_2O_3), and it was directly injected into the inlet pipe of the fiber filter by using the in-line injection method. Coagulation occurs within the inlet pipe by the high filtration velocity, and both the phenomena of floc growth and floc retention are generated inside the filter.

The aluminum electrode of the EC reactor was cylindrical, and it rotated to clean the electrode's surface. The quantity of aluminum dissolved is the most important variable regulating the coagulation efficiency of EC. The experiment result showed that the experimental and theoretical amounts of dissolved aluminum were almost the same (slope=1.052, R^2=0.985). Therefore, the quantity of aluminum utilized in the EC reactor was the theoretical quantity.

The method of experimentation was to compare the test item's removal efficiency between CC and EC based on influent turbidity. The test items were turbidity, particle counts, total organic carbon (TOC), and heterotrophic plate count (HPC).

2. Analytical Methods

The quantity of aluminum dissolved was measured with an inductively coupled plasma-atomic emission spectrometer (ICP) and compared to a theoretical quantity.

A carbon analyzer with an infrared detection system is used to measure TOC (total organic carbon). The larger the carbon or organic content, the more oxygen is consumed. A high organic content means an increase in the growth of microorganisms which contribute to the depletion of oxygen supplies [8].

The pour plate method was used to estimate the number of heterotrophic bacteria in water. This test can provide useful information about water quality [8]. The pour plate method uses plate count agar to confirm a typical number. Each sample is incubated at 35 °C for 48 h [9].

The HPC removal in this experiment is expressed as a log reduction value (LRV) calculated by using the permeate (CP) and initial level (CF) for the HPC. The measurement method of HPC was the pour plate method, which is simple to perform and can accommodate volumes of sample [10].

LRV=log removal value=log(CP/CF) [11].

RESULTS AND DISCUSSION

1. The Removal Efficiency of Turbidity

Turbidity may indicate the presence of microbes. Fig. 2 shows the efficiency of turbidity elimination according to influent turbidity for both CC and EC. The efficiency of turbidity elimination was from 97% to 99.7% by CC and from 97.8% to 99.8% by EC. Furthermore, as shown in Fig. 2, achieving a high efficiency of turbidity elimination by EC requires much fewer aluminum ions than CC. Using EC reduced the amount of aluminum utilized by 25%. The effluent turbidity by the CC process was from 0.41 NTU to 0.65 NTU and that by EC was from 0.30 NTU to 0.48 NTU. Treatment by EC improved the efficiency of turbidity elimination by approximately from 0.1% to 0.8%.

The cause for the improvement in the effluent turbidity and the utilization of fewer aluminum ions by the EC process was the use of electrolytically produced aluminum. It neutralizes the charge of colloidal particles, thus enhancing their coagulation rate [12]. In addition, ions and particles are removed through deposition or sorption onto the surface of metallic oxides and hydroxides formed by precipitation of the electrolytically produced aluminum ions [12]. Electrooxidation, surface complexation, electrostatic attraction, and chemical modification occur in the EC reactor [13]. The particles causing the turbidity are efficiently removed by the above-mentioned reactions.

2. The Removal Efficiency of Particles

Fig. 3 shows the effects of particle size on the efficiency with which particles are removed by EC and CC. Fig. 3(a) shows the

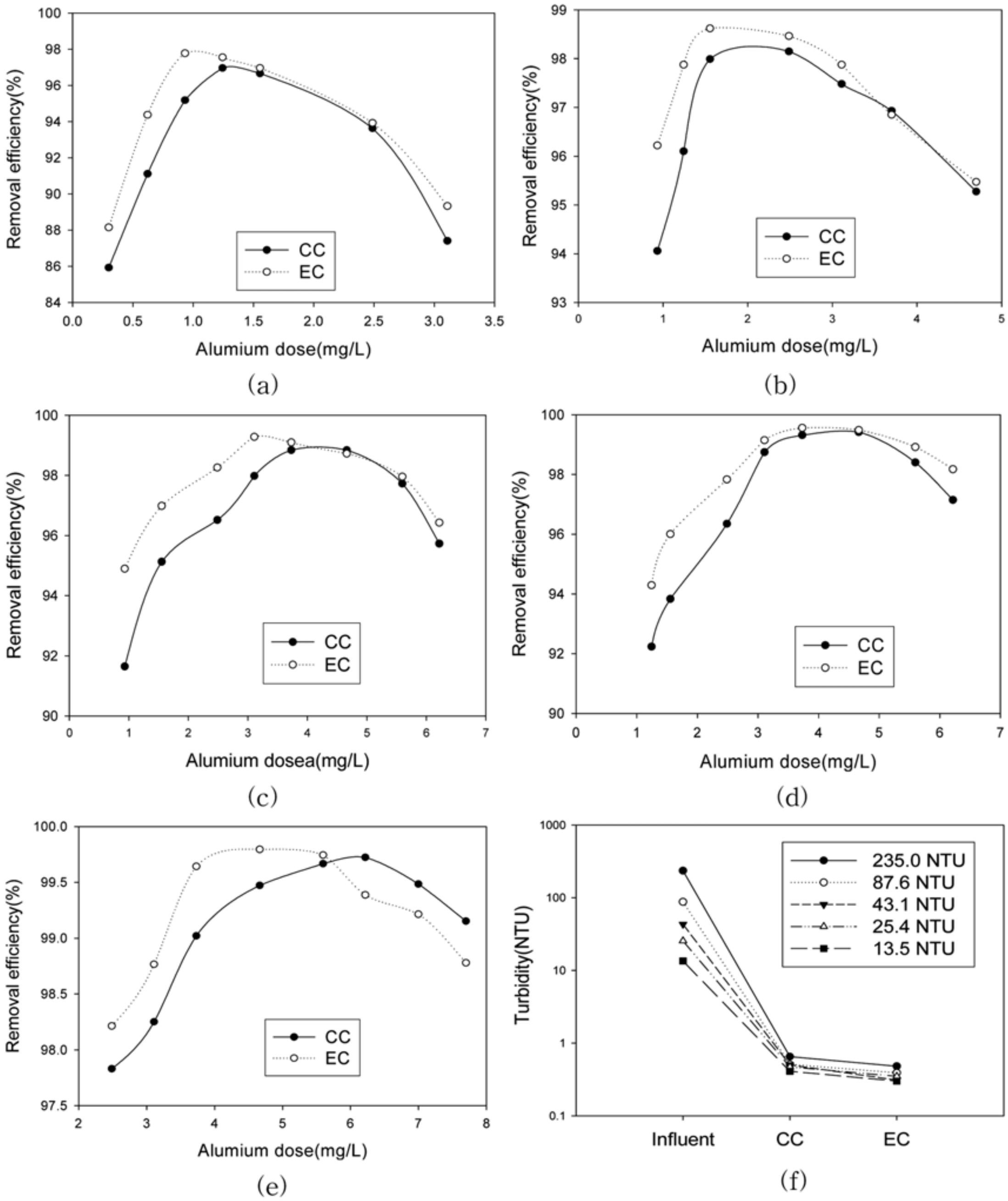

Fig. 2. Comparison of turbidity elimination by the EC and CC processes as a function of the aluminum dose at influent turbidities of (a) 13.5 NTU, (b) 24.5 NTU, (c) 43.1 NTU, (d) 87.6 NTU, and (e) 235.0 NTU. (f) effluent turbidity following EC and CC.

efficiency of particle removal from influent turbidity of 13.5 NTU. Most particles that were 1 to 3 μm in size were removed, and the particle removal efficiency by CC was approximately 40%, while that by EC was approximately 70%. On the other hand, more than 90% of particles larger than 4 μm were removed by CC and EC. Fig. 3(b) shows the efficiency of particle removal from influent turbidity of 25.4 NTU. Most of the particles that were removed were smaller than 8 μm. The removed percentage of 1 to 3 μm particles was negative by CC and approximately 50% were removed by EC. Moreover, approximately 40% of particles sized 3 to 4 μm were removed by CC and approximately 70% were removed by EC. Approximately 70% of particles sized 4 to 6 μm were removed by CC and approximately 90% were removed by EC.

Fig. 3(c) shows the efficiency of particle removal from influent turbidity of 43.1 NTU. Most particles were smaller than 10 μm. The removed percentage of 1 to 3 μm particles was negative by CC and approximately 23% were removed by EC. Moreover 4% of particles sized 3 to 4 μm were removed by CC and approximately 65% were removed by EC. Fig. 3(d) shows the efficiency of particle removal from influent turbidity of 87.6 NTU. The removed percentage of 1 to 3 μm particles was negative by CC and approximately 17% were removed by EC. Fig. 3(e) shows the efficiency of particle removal from influent turbidity of 235 NTU. Most of the particles were 10 μm or larger. The removed percentage of 1 to 3 μm

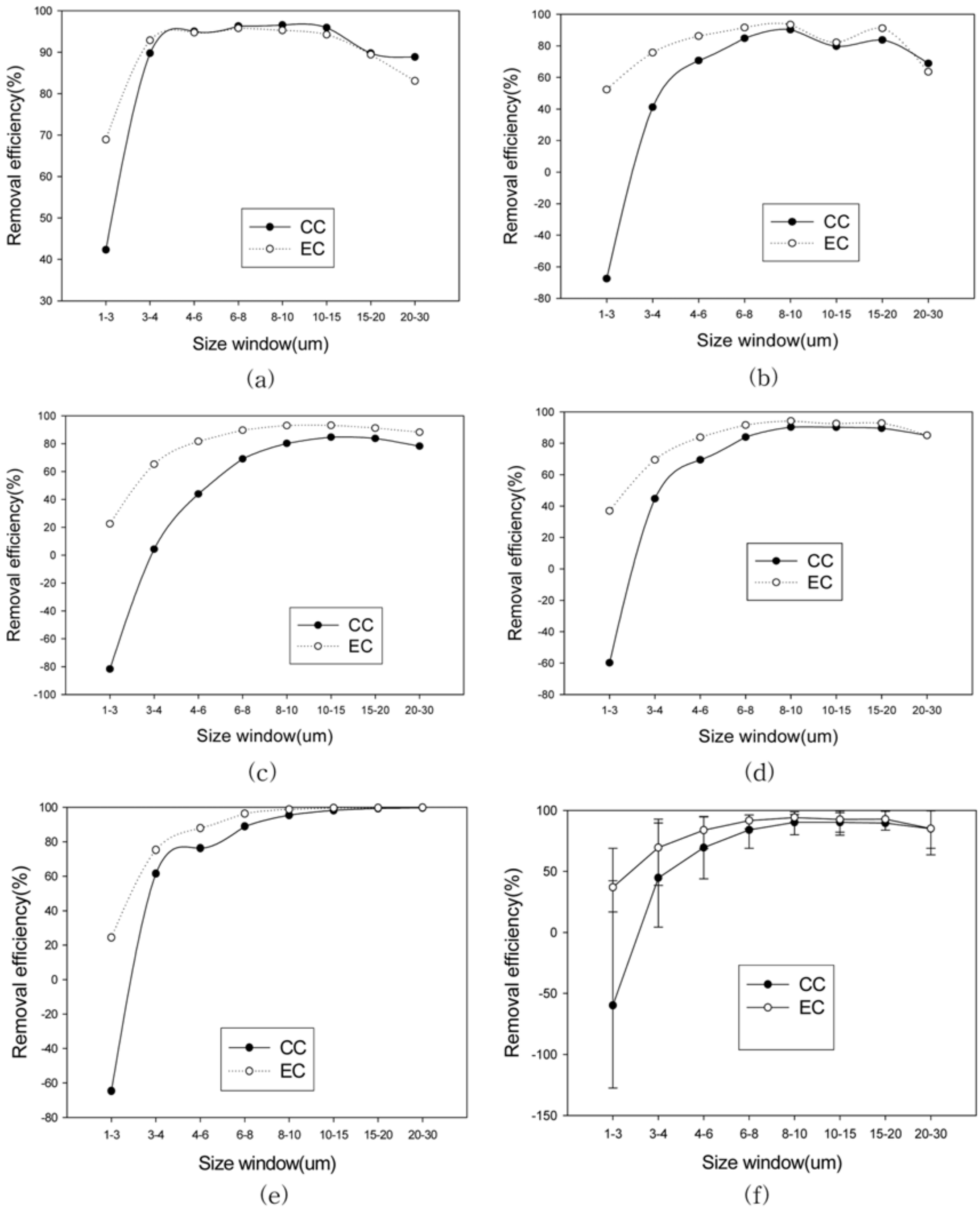

Fig. 3. Comparison of the particle removal efficiency of the EC and CC processes for influent turbidity of (a) 13.5 NTU, (b) 24.5 NTU, (c) 43.1 NTU, (d) 87.6 NTU, and (e) 235.0 NTU. (f) maximum and minimum removal efficiency.

particles was negative by CC and approximately 24% were removed by EC.

Fig. 3(f) shows the maximum and minimum particle removal efficiencies. The average removal efficiency of particles larger than 8 μm was over 90% by CC. This was almost similar to that by EC. An average of 84% of particles sized 4 to 6 μm were removed by CC and an average of 92% were removed by EC. An average of 45% of particles sized 3 to 4 μm were removed by CC and an average of 70% were removed by EC. The removed percentage of 1 to 3 μm particles was negative by CC and an average of 37% were removed by EC. The reason why a higher number of 1 to 3 μm sized particles were removed by CC was presumed to be due to the breaking of particles sized more than 10 μm by the turbulent flow of the water during the process.

It can be concluded that the efficiency with which particles smaller than 8 μm are removed was higher by EC than by CC. This may be because the colloid particles in the water are reduced to small organic and inorganic particles at the cathode during EC. The particles may have then been removed after being adsorbed by the coagulants that are produced during EC.

3. The Removal Efficiency of TOC

The removal efficiency of the EC and CC processes was deter-

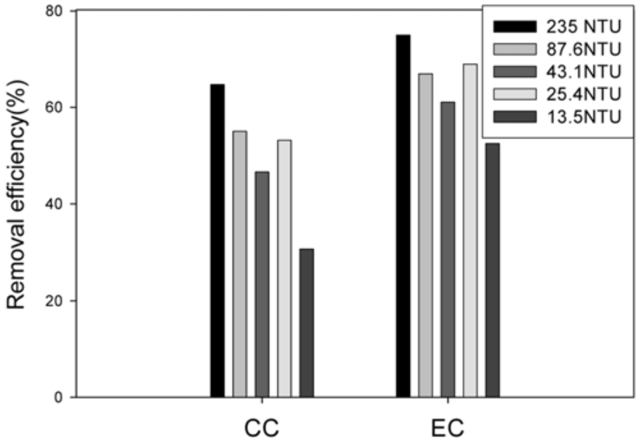

Fig. 4. TOC removal efficiency of CC and EC process.

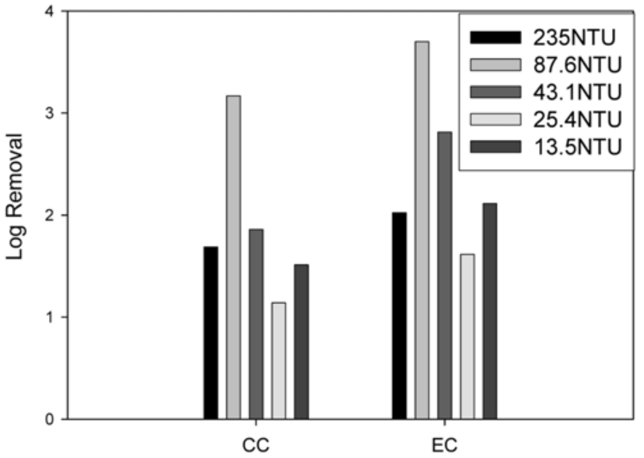

Fig. 5. HPC removal efficiency of CC and EC process.

mined based on the TOC as shown in Fig. 4. The TOC was estimated to determine the removal efficiency of organics by these processes. The TOC in influent water was between 3.048 and 8.412 mg/L. After CC, the TOC ranged from 2.111 to 2.965 mg/L, and after EC, it ranged between 1.447 to 2.104 mg/L. The average removal efficiency of TOC was 50%, 65% for CC and EC. The reason for the higher removal efficiency by EC is the presence of intermediate oxidation products such as oxygen, ozone, hydrogen peroxide, and free residual chorine during the EC process [14]. The TOC can be oxidized by these oxidants.

4. The Removal Efficiency of HPC

The HPC population in tap water may include some opportunistic bacterial pathogens. Fig. 5 shows the HPC removal efficiencies of the CC and EC processes based on the log removal value (LRV). The HPC of the influent water was 650 CFU/ml at 13.5 NTU and 20,000 CFU/ml at 235 NTU. As the influent turbidity increased, the HPC also increased. After CC treatment, the HPC was from 20 to 410 CFU/ml, and after EC treatment, it was from 5 to 190 CFU/ml. The LRV for HPC was from 1.1 to 3.2 (average: 1.9) for CC and from 1.6 to 3.7 (average 2.6) for EC. The bacteria could be removed along with particles sized 10 μm or smaller. Thus, EC had higher removal efficiency as compared to CC because particles sized less than 10 μm were removed better by EC than by CC.

Also, HPC removal by the EC-fiber filter was predominantly due to both the adsorption of the negatively charged HPC onto the positively charged aluminum flocs and the subsequent removal of the flocs by the fiber filter.

CONCLUSIONS

A combined EC-fiber filter system was applied for water treatment, and its performance was investigated in this experiment. The results can be summarized as follows:

A comparison of the EC and CC processes reveals that EC significantly outperformed CC when the water to be filtered using fiber filters was pretreated with aluminum. For particles sized less than 6 μm, the removal efficiency was 66%, 43% for EC and CC, respectively, and the average removal efficiency of the TOC was 50%, 65% for CC and EC. Therefore, EC reduced the amount of aluminum utilized by 25%, and the efficiency of turbidity removal improved by approximately from 0.1% to 0.8%. Also, the average LRV for HPC was 2.5, 1.9 for EC and CC, respectively.

Therefore, the aluminum used for EC proved to be excellent for pretreating the water to be filtered by a fiber filter. Furthermore, the EC process was proposed and its economical efficiency was subsequently verified by additional experiments that evaluated the operating parameters and stability of this process.

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