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Preliminary investigation of electrocoagulation as a substitute for chemical coagulation

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Abstract Recently electrocoagulation has been considered as one of the promising coagulation processes and was increasingly used as a substitute for chemical coagulation in many water treatment fields. However, there have not been many fundamental studies performed on it. In this research, a preliminary investigation was carried out to verify the effectiveness of the electrocoagulation compared with conventional chemical coagulation through a set of batch experiments. Turbidity removal efficiencies, using various aluminium dosages and at different water pH values, were investigated. In addition, the zeta potential was studied to develop understanding of particle characteristic after applying both electrocoagulation and chemical coagulation. It can be concluded from the results that electrocoagulation is more efficient than chemical coagulation in turbidity removal.

Keywords Chemical coagulation; electrocoagulation; particle size; turbidity removal; zeta potential

Introduction

Coagulation using chemical coagulants is one of the most essential processes in conventional drinking water treatment. However, chemical coagulation (CC) has some inherent problems in cost, maintenance and sludge production. CC needs proper chemical handling and effective rapid mixing.

Recently, electrocoagulation (EC) has been suggested as an alternative to conventional coagulation (Mills, 2000). Colloid-destabilizing agents that effect charge neutralization are produced by electrolysis in EC. Normally, aluminium anodes are used to produce aluminium cations that have the same effect as the addition of alum salts. This process can be characterized by reduced sludge production, no requirement for chemical handling and ease of operation, and has been applied efficiently to various kinds of water treatments (Rajeshwar and Ibanez, 1997). Therefore, if the EC can replace the conventional CC, the process efficiency would increase with little modification of present structures in water treatment plants and many problems caused by CC also would be solved.

However, there has not been sufficient study on the fundamental aspects of the EC process. The objectives of this study are: (1) to compare the turbidity removal efficiency of EC and CC; (2) to investigate the mechanism inducing changes in zeta potential; and (3) to verify the effectiveness of EC.

Materials and methods

A square acrylic 2L jar (10.5 × 10.5 × 22 cm) was used as the reactor during the investigation. Samples of treated water were collected from a port located 10 cm above the bottom of the jar. Tap water mixed with kaolin was used to prepare influent with the characteristics shown in Table 1.

The experimental set-up is illustrated in Figure 1. The testing procedures followed the standard jar test, which consists of rapid mixing (30 seconds), flocculation (15 minutes), and sedimentation (30 minutes). The EC experiment was similar except that the coagulant addition and rapid mixing were replaced by electrolysis of aluminium. The aluminium

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Table 1 Characteristics of raw water used for batch test

Composition	Turbidity (NTU)	Temperature (°C)	pH	Alkalinity (mg/L as $CaCO_3$)	Conductivity (mS/cm at 25°C)
Tap water 1 L + kaolin 6 mg	8–10	15–18	6.8–7.3	35	0.196

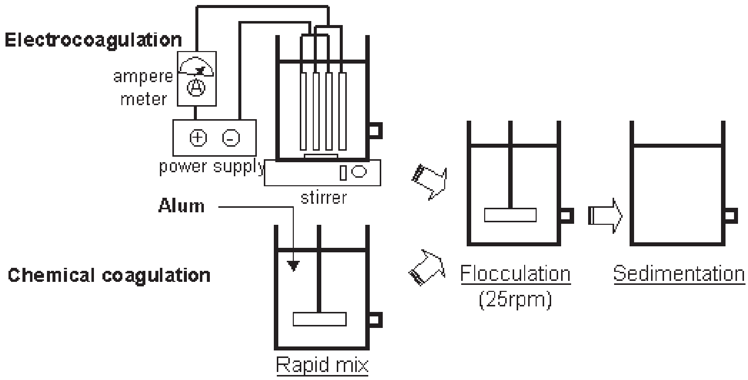

Figure 1 The experimental set-up

sources for EC are two pairs of aluminium plates with the dimensions of 8 × 16cm, while alum, $Al_2(SO_4)_3 \cdot 14{\sim}18H_2O$ was added for CC.

The zeta potential was measured at the highest removal efficiency obtained from pre-experiment optimizing removal efficiency. Zeta potential was measured just after electrolysis and rapid mix for EC and CC respectively, using a DELSA 440 SX (Beckman & Coulter, USA). The Delsa 440 SX utilizes laser light, four photodiodes, and four 256-channel autocorrelators to detect zeta potential differences by electrophoretic mobility measurement. The turbidity was measured using a turbidimeter (2100P, Hach, USA).

Results and discussion

Effect of aluminium dosage

Turbidity removal efficiencies using various dosage of aluminium in EC and CC are compared. Dissolved aluminium dosage during EC can be easily calculated based on the relationship between the one theoretically calculated from Faraday's law and the one experimentally measured, which showed that the current efficiency is approximately 130% (Song, 2001). As shown in Figure 2, EC results in better turbidity removal efficiency than the CC for all aluminium dosages. Approximately 5% higher removal efficiency is obtained in EC using the same aluminium dosage. It can be understood that for the same removal efficiency EC needs less aluminium dosage and consequently produces less sludge. This would have a positive implication on reducing operational costs, especially for those related to sludge handling and disposal.

The main reaction for turbidity removal in EC can be explored, from the design and operation diagram for alum coagulation (Amirtharajah and Mills, 1982). The dosage of aluminium needed to get the highest removal efficiency is 4 mg/L of aluminium, that is –3.73 as log|Al| mol/L, which is similar to that used for both processes in the current study. This value is within the optimum sweep domain with neutral pH for raw water. Therefore, the main mechanism to remove particles is sweep flocculation for both EC and CC investigated in this study.

Effect of pH

The pH of raw water is a very significant factor in coagulation, as the pH decides the form of aluminium hydroxide. In this research, experiments were performed to investigate the

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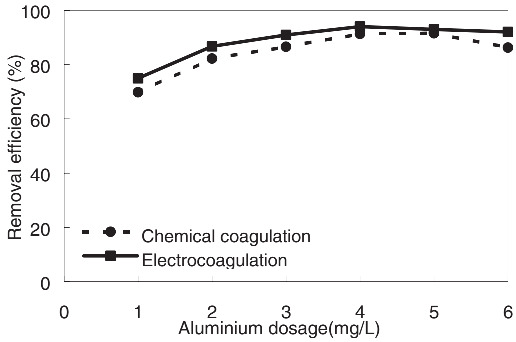

Figure 2 Effect of aluminium dosage on the removal efficiency

effect of initial pH on turbidity removal efficiency. Figure 3 indicates similar trends for both EC and CC. The shape of removal efficiency appears to be parabolic with various pH, where low and high pH both produce low removal efficiency. The highest removal efficiency was obtained at pH 8. The value is not so different for both processes, which is approximately 90% removal efficiency. However, apart from the optimum pH range, EC showed higher removal efficiency (by 20–30%) from pH 5–pH 11, thus less sensitive to initial influent pH compared with CC.

These phenomena can be more explained by considering effluent pH after reactions. The final pH shifts to neutral in EC (as shown in Figure 4) while that in CC usually decreases after reaction, because OH^- ions are consumed to form aluminium hydroxide. The pH increase in EC was discovered in past research, however, the pH decrease in the alkaline region was reported only recently by Chen *et al*. (2000) who stated that EC plays a role of neutralization. These results can be understood as follows: (1) in the acid, the main reaction to increase the pH is hydrogen evolution and formation of OH^- from the cathode (Vik *et al*., 1984); (2) in the alkaline, reactions shown in the following Eqs (1)–(3), may happen to satisfy the chemical equilibrium to decrease the pH (Chen *et al*., 2000).

$$Al^{3+} + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \quad (1)$$

$$Cl_2 + H_2O \rightarrow HOCl + H^+ + Cl^- \quad (2)$$

$$HOCl \rightarrow OCl^- + H^+ \quad (3)$$

The characteristics of particles (zeta potential)

Zeta potential represents the electric condition of particles. Most of the particles in water

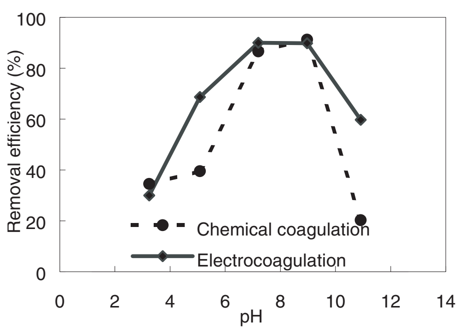

Figure 3 Effect of pH on turbidity removal efficiency

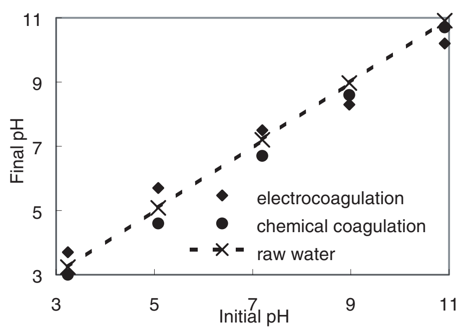

Figure 4 Changes in pH after reaction

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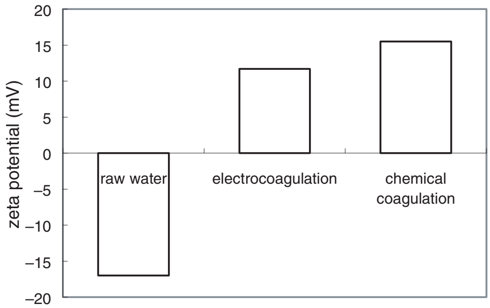

Figure 5 The zeta potential after electrolysis and rapid mix respectively

are negatively charged and similar charges prevent aggregation through electrostatic repulsion. It is recommended that the particles charge in the range of –10 mV to +10 mV to provide proper coagulation condition with respect to charge, should be maintained. Therefore, the study of particles charged through zeta potential measurement is needed for both EC and CC.

The measured zeta potential after electrolysis and chemical injection is shown in Figure 5 for the case of the highest removal efficiency (previously shown in Figure 2), using 4 mg/L aluminium. The zeta potential of raw water was –17mV and it shifted to positive values after both processes with no distinguishing difference. The zeta potentials before flocculation were 11.7 mV and 15.5 mV for EC and CC, respectively, which almost agree with the recommended values as mentioned earlier.

Conclusions

In this research, a preliminary investigation was carried out to verify the effectiveness of the EC compared with conventional CC through a set of batch experiments. Turbidity removal efficiencies using various aluminium dosages and changing influent pH were measured and particle characteristics as zeta potential under the highest removal efficiency was investigated. Less aluminium dosage was needed to get the same removal efficiency in EC, which is related to chemical cost and sludge production. In addition, EC was less sensitive to pH and produced a better removal efficiency than CC. Zeta potential showed similar results as for both, which almost agree with the recommended values. It can be concluded from the results that EC is more efficient than CC in turbidity removal from experiments, while further study should be performed to give a clear explanation for differences between EC and CC.

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