Optimizing Electrocoagulation of Drinking Water for Turbidity Removal in a Batch Reactor

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Abstract. The aim of this study was to evaluate the effects of various operating parameters such as initial pH, applied voltage (V), inter-electrode distance (d), and initial pollutant concentration (C_0) on turbidity removal using electrocoagulation (EC). Synthetic turbid water was used for conducting batch experiments. Voltage was applied across a single pair of mild steel (MS) electrodes immersed in 1 L solution for 2 hours and then allowed to settle for one hour. The results showed that turbidity removal efficiency increased with increase in applied voltage from 50% at 5 V to 99% at 25 V. Maximum removal efficiency of 99% was observed at an optimum inter-electrode distance of 2 cm. In this study, initial pH <7 resulted in a final pH of 7 while initial pH >7 also resulted in a final pH of 7 to 8. Maximum removal efficiencies of 98-99% were observed at pH 7 to 8. Increase in initial pollutant concentrations resulted in a decrease in removal efficiency from 98% at 100 NTU to 78% at 500 NTU.

KEYWORDS: Electrocoagulation, Drinking Water, Turbidity, pH, Applied Voltage

1. Introduction

One of the major problems faced by the present world is accessibility to safe and clean drinking water. According to World Health Organization (WHO), nearly 1.1 billion people do not have access to any drinking water[1]. Thus, with an exponentially increasing population, better and more economical water management strategies including treatment methods have become the need of the hour. One such sustainable water treatment method is electrocoagulation (EC) which has the potential for treating a wide-spectrum of contaminants in drinking water.

Electrocoagulation (EC) is an electro-chemical process where current is passed through an aqueous solution and across electrodes resulting in the production of metal ions *in situ*. These metal ions form oxides and poly-oxyhydroxide complexes, which act as coagulants and can remove a variety of contaminants present in water. Mechanisms for contaminant removal include coagulation, electro-oxidation, electro-flotation, precipitation, adsorption and settling. Due to the multiple processes that occur simultaneously in a single unit, EC has proved to be highly effective in removing a wide-range of contaminants from drinking water.

Conventional chemical coagulation (CCC), which is used routinely in drinking water treatment, was compared with EC[2,3]. Some of the major advantages of EC compared to CCC are higher removal efficiencies, and the ability to remove a variety of contaminants due to the multiple processes that occur in an EC unit. EC was found to be extremely effective in the removal of contaminants that are present in reduced form such as As(III) due to its ability to oxidize and then coagulate the contaminant[4].

The objectives of this study were to determine the optimum operating conditions for turbidity removal from synthetic drinking water. Clay (reagent grade kaolinite) was added to water for generating turbidity.

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Four major operating parameters were evaluated: applied voltage, initial pH, inter-electrode distance and initial turbidity concentrations.

2. Materials and Methods

2.1. EC batch reactor and experimental setup

A 1 L glass beaker was used as the EC cell with a synthetically prepared sample solution of reagent-grade kaolinite ($Al_2Si_2O_2(OH)_4$) in double-distilled water. Two mild steel (MS) electrodes of size 17.5 cm x 2.5 cm x 0.75 cm were used with an immersion depth of about 12.5 cm in the water, shown in Dolo and Goel, 2010[5]. This beaker was supported on a magnetic stirrer to keep its contents mixed. Current was passed through the reactor for 2 hours and the solution was allowed to settle for 1 hour. The supernatant was sampled at regular time intervals (0, 5, 10, 15, 30, 45, 60, 120, 180 minutes) for pH, turbidity and conductivity. The supernatant (10 to 15 mL) above the settled floc was removed after 180 minutes and filtered using cellulose nitrate filter paper of 47 mm diameter with a nominal pore size of 0.45 μm (Whatman India Ltd.). An external DC power supply was used for applying a constant voltage across the cell during the course of an experiment.

Four operating parameters were varied for each controlled experiment: applied voltage from 5 to 25 V, initial pH from 5 to 11, inter-electrode distance from 1 to 4 cm and initial turbidity concentration from 100 NTU and 500 NTU. A set of baseline conditions was defined initially at which each individual operating parameter was then varied and turbidity removal evaluated. The baseline conditions were defined as 2 cm inter-electrode distance, 20 V, initial pH 7 and initial concentration of 100 NTU.

2.2. Synthetic drinking water

A synthetic drinking water solution was prepared for all experiments by adding kaolinite to double-distilled water. Reagent grade kaolinite [$Al_2Si_2O_2(OH)_4$] was used to generate a solution with consistent turbidity to simulate turbid raw water sources. 10 mg of kaolinite was added to 1000 L distilled water, which resulted in turbidity of 80 - 100 NTU. This falls in the range of usual murky waters, which have turbidity between 85 NTU to 110 NTU.

3. Results and Discussion

3.1. Effect of Applied Voltage

Experiments were performed at five different voltages: 5, 10, 15, 20 and 25 V. Turbidity removal increased with increase in EC time and increase in applied voltage. The rapid increase in removal efficiency at 180 minutes is due to removal during settling and due to filtration through a 0.45 μm filter.

Turbidity removals after passive settling of the solution and after applying 5 V were nearly same. Increasing the applied voltage from 5 to 25 V resulted in an increase in removal efficiency from 47.36 to 99%. These results are summarized in **Table 1**. All these experiments were performed at an initial concentration of 100 NTU, an initial pH of around 6.9 - 7.1 and an inter-electrode distance of 2 cm. As the voltage increased, the electrode weight utilized or dissolved also increased. As shown in **Table 1**, it is evident that the final pH remained almost the same as the initial pH (around 7), regardless of the applied voltage.

3.2 Effect of Electrode Spacing

Different electrode spacing or inter-electrode distances resulted in significant differences in removal efficiencies. The highest removal efficiency was observed at 2 cm inter-electrode distance **(Figure 1).** There was no significant change in pH for different electrode spacing. Removal efficiencies varied from 98% at a distance of 2 cm to 80% at 4 cm. The weight of the electrodes utilized or dissolved was maximum at 1 cm inter-electrode distance [1.3 g] and minimum at 4 cm distance [0.8 g].

These results are similar to those observed in various other studies where the optimum inter-electrode distances were found to be 2 cm for removal of lead and 2.5 cm for removal of cadmium and copper in studies with laminate steel electrodes[6]. In parametric studies with distillery wastewater[7] and biodigester effluent[8], the optimum electrode spacing was found to be 1 cm. Another parametric study for removal of

arsenic and chromium found the optimum electrode spacing to be 1.4 cm[9]. Kumar et al., [2009][10] found that 2 cm was optimum for removal of COD from biodigester effluent.

3.3   Effect of Initial pH

Initial pH is an important parameter influencing removal efficiencies. Experiments were conducted for initial pH values ranging from 5 to 11 and the results are shown in **Figure 2.** A few important observations were:

a. As shown in **Figure 2**, maximum or optimum removal efficiency was observed at pH 8. Removal efficiencies were lower at all other pHs.

b. It was also observed that the final pH of the solution ranged from 7 to 8 for any given initial pH and is shown in **Figure 3**. This highlights one of the major advantages of electrocoagulation versus conventional coagulation (CCC). In CCC, the pH of the solution generally decreases after addition of coagulant (depending on the alkalinity of the water) and neutralization is required to bring the pH of treated water to an acceptable level. However, in electrocoagulation when the influent pH is acidic, the treated solution pH value rises, and when the influent pH is alkaline, the effluent pH drops. These results are similar to those found by Chen et al., 2000[12] when treating restaurant wastewater with EC.

c. Another important observation was the visible generation of bubbles at pH $\geq$ 9 indicating an increase in gas production with initial pH. Bubble generation was observed only at the cathode in all these experiments.

3.4   Effect of Initial Concentration

Initial concentration (C_0) was an important factor in determining removal efficiency. When the initial turbidity was increased, the final turbidity also increased with a resultant decrease in removal efficiency. Increase in initial concentration from 100 NTU to 500 NTU resulted in a decrease in removal efficiency from 98% to 78%. **Figure 4** shows the decrease in removal efficiency with increase in initial concentration.

Reports in the literature regarding the effect of initial concentration can be put in two categories:

a. Increase in initial concentrations lead to a *decrease* in removal efficiency as in our study and many others[3,13,9].

b. Increase in initial concentrations lead to an *increase* in removal efficiency as in the following studies[5,6,14].

4. Conclusions

Turbidity removal was evaluated in an electrocoagulation (EC) batch reactor where coagulation was followed by flocculation, and settling. The supernatant was filtered after removal from the reactor. Factors evaluated in this study included applied voltage, initial concentration, initial pH, and inter-electrode distance. Temperature and conductivity were also monitored in each experiment.

Applied Voltage (V): Five experiments were conducted and removal efficiencies increased from 50% to 99% as applied voltages were increased from 5 to 25 Volts.

Initial pH: Initial pH was a very important factor in determining removal efficiency. The optimum initial pH for turbidity removal was 8 and resulted in removal efficiency of 99%. Another interesting aspect of the effect of initial pH was its impact on the final pH after EC treatment. For all initial pHs tested between 5 and 11, the final pH ranged between 7 and 8 indicating that the process tends towards neutral pH under all conditions. Bubbles were observed at pH $\geq$ 9 indicating an increase in gas production with initial pH.

Electrode Spacing: Electrode spacing affected removal efficiency substantially. At higher spacing, the conductivity of the solution decreased and so did the removal efficiency. At 2 cm spacing, maximum removal efficiency of 99% was observed

Initial Concentration (C_0): Removal efficiencies were also affected by the initial concentrations. As initial concentrations were increased from 100 NTU to 500 NTU, removal efficiencies decreased from 99% to 80%.

These results suggest that maximum removal efficiencies can be obtained with EC by optimizing the operating conditions of applied voltage, initial concentration, pH and inter-electrode distance.

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Table 1: Removal efficiencies and final pH for different applied voltages for turbidity removal by EC. Initial conditions in all experiments were Co = 100 NTU, Experimental Time = 180 min, Initial pH= 7

Voltage (V)	Initial pH	Final pH	Final Turbidity (NTU)	Removal efficiency (%)
5	6.97	7	50	47.36
10	7	7.03	30	58
15	6.95	7.02	17	82.1
20	6.99	7	2	98
25	7	7.2	1	99

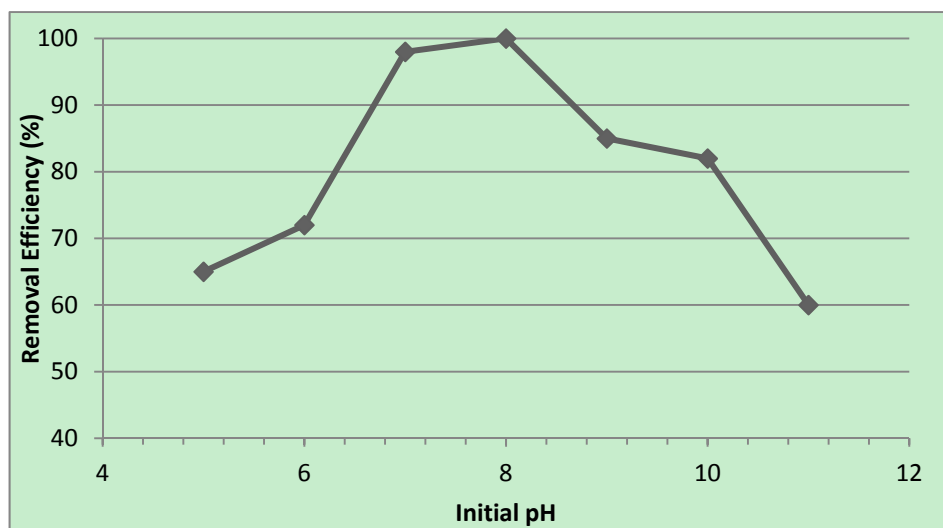Fig. 1: Removal efficiencies at the end of each experiment with different inter-electrode distances.

Fig. 2: Removal efficiencies for different initial pH values. Initial conditions were Co= 100 NTU, Voltage = 20 V, Inter-Electrode distance= 2 cm
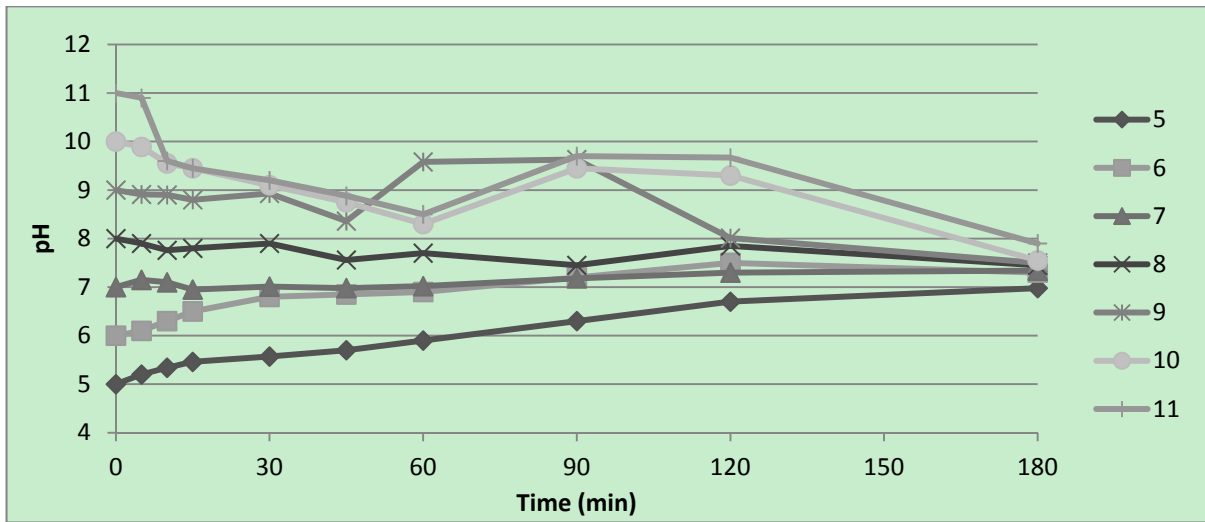
Fig. 3: Change in pH values for different values of initial pH. Initial conditions were C0 = 100 NTU, Voltage = 20 V, Inter-electrode distance = 2 cm
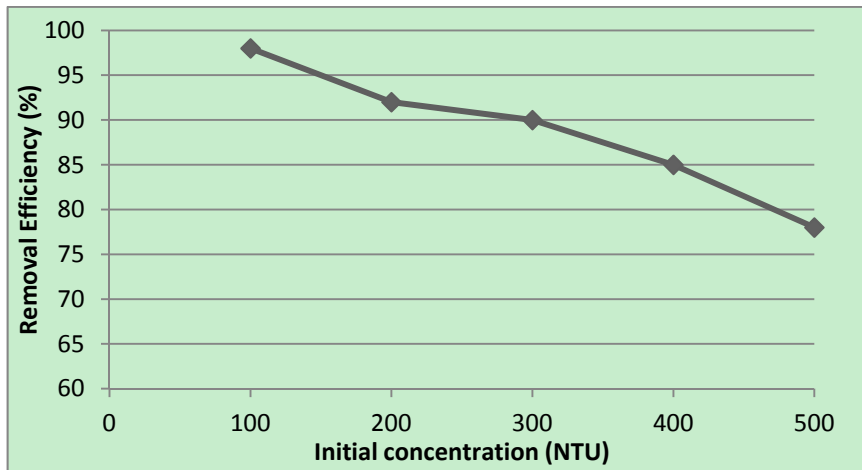

Fig. 4: Removal efficiencies for different initial turbidity concentrations