



A comparative study for turbidity removal by electrocoagulation and chemical coagulation

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Comparative study between electrocoagulation (EC) and chemical coagulation (CC) was done to assess the relative performance of turbidity removal in batch mode. The single parameter studies were carried out to assess the effect of pH, volume, initial turbidity and coagulant dose on turbidity removal by both EC and CC. It was observed that for equivalent dose of aluminum, EC (90.3% removal) performed better than CC (77.67% removal). It was found that during EC, turbidity removal increased when charge loading was increased. It was the first time reported in this study that for a constant charge loading the turbidity removal was decreased when current density was increased.

Keywords: Electrocoagulation, chemical coagulation, turbidity, charge loading, current density.

Introduction

Drinking water is becoming increasingly precious day by day. The developing countries are facing huge financial burden to supply adequate amount potable water to everyone. Furthermore, different water-bodies are being constantly polluted by different natural industrial discharges. Natural waters drawn from different surface water sources contain a wide variety of pollutant parameters among those suspended and colloidal particles are the commonest which is responsible for turbidity in surface water^{1,2}.

The problems associated by colloidal impurities includes: (i) shielding of microbes and reduce disinfection inefficiency^{3,4}, (ii) development of bacteria and anaerobic condition inside the deep filter bed^{5,6}, (iii) clogging of filter and backwash head loss⁷⁻⁹ thereby required a large amount of treated water for backwashing^{10,11}, (iv) handling of large amount of sludge^{12,13}.

Chemical coagulation involves the interaction of particulate and/or colloids with a destabilizing agent^{12,14}. The purpose of coagulation is to neutralize the surface charges of colloid particles and formation of heavy gelatinous particles by adding a chemical coagulant (mostly aluminum or iron salt), producing salts of heavy hydroxides. These heavy flocs

further entangles with other particles during flocculation (Orthokinetic flocculation) and sedimentation (differential settling) as well¹⁵⁻¹⁷. Additionally, the hydroxide precipitations are influenced the enmeshment between colloidal particles can be in a growing in size and proceed into sweep coagulation¹⁸. The purpose of flocculation is to aggregate these particles into large sizes that will settle quickly^{19,20}. The presence of polymeric species can also lead to the formation of bigger particles through interaction of different active groups of the polymer chains with different colloidal particles as bridge flocculation. Anyway, the primary mechanisms of coagulation in each case will depend on the type of species formed in the system during the dosing of the coagulant reagents²¹.

Electrocoagulation (EC) is a process where coagulants (aluminum, iron) are dosed by anodic dissolution of electrode materials by application of direct current potential. The effect of electrocoagulation process in reduction of turbidity of water depends on charge loading^{16,22}. All the negatively charged particles, especially the colloids and bacteria have an affinity to Al^{3+} ions, causing their removals by coagulation-flocculation and sedimentation^{23,24}. During the last few decades, EC assisted coagulation that can compete with the conventional chemical coagulation (CC) process for the treat-

ment of water polluted with colloids or macromolecules or in the treatment of emulsions are in wide application²⁵.

Commonly, conventional water treatment technique is used to remove turbidity and partially for microbial contamination to make surface water potable^{26,27}. The characteristics of raw water influence various treatment methods available for making water safe and appealing to the consumers²⁸. However, electrocoagulation has never become accepted as a conventional water treatment technology because of electrode passivation. Now the recent technical developments combined with a growing need for small-scale distributed water treatment facilities have led to a reconsideration of electrocoagulation system. The process of EC is easily operated by simple equipment for the dosing of coagulant in experiment and the sludge generation is quite less than other conventional counterpart²⁹. The associated anions are not produced in EC like chemical coagulation and easy to maintain the environmental friendly compatibility^{30–32}. The electrocoagulation process exhibits lower operational costs for low and intermediary doses of coagulant compared with conventional coagulation with aluminum polychloride (PACl)³³. Thus, the cost of the electrocoagulation process compares favorably with that of conventional coagulation for small coagulant demands³⁴ and the effective workability may partially replacement of the chemical coagulation³⁵.

Though electrocoagulation is widely used for wastewater treatment, the systematic study on different EC process variables is still not rigorously studied for potable water. In this paper, the effect of different factors namely pH, contact time, applied current, volume of sample, initial turbidity, dose of coagulant and current density was studied to get a preliminary idea for the case of electrocoagulation. The comparative study between EC and CC is carried out for the removal of turbidity.

Materials and methods

(A) Reagents:

Bentonite clay ($\text{Al}_2\text{H}_2\text{Na}_2\text{O}_{13}\text{Si}_4$) was procured from local suppliers to prepare water samples of different turbidity (NTU). Commercial aluminum sheet (0.3 cm thick) was purchased and cut in to pieces to make electrode arrangement. Sodium chloride (NaCl, Marck) @ 20 mg/L was added to

increase the electrical conductivity of the samples. Aluminum sulphate ($\text{Al}_2(\text{SO}_4)_3 \cdot 16\text{H}_2\text{O}$, 98.9% pure), sodium hydroxide (NaOH), hydrochloric acid (HCl) were bought from Merck, Germany (Darmstadt).

(B) Electrocoagulation setup:

Electrocoagulation was done by a 32V AC-DC converter (PSD3005, Scientific Mes-Technik Pvt. Ltd., India). The batch electrocoagulation experiments were carried out in the laboratory in 2 liters capacity Borosil glass Jar with magnetic stirrer. Aluminum (Al) plates were used as electrodes to dose Al as coagulant during EC. The active area of the electrodes was maintained at 8 cm×6 cm. Electrocoagulation (EC) and chemical coagulation (CC) experiments were done parallel to get relative performance of the two processes. For coagulant dosing, aluminum plates were used as anode and cathode both. The electrode gap was maintained at 5 mm. Chemical coagulation was done by dosing alum solution having equivalent amount of aluminum during EC process. The pH of the solution was measured by a pH meter (WTW, Germany). The pH of synthetic water was maintained by 1 (N) HCl or NaOH. Turbidity of water was measured by a Nephelometer (Testing Instrument, Kolkata, India). During electrocoagulation stirring was carried out at a speed of 500 rpm, followed by 20 min of flocculation and 30 min of sedimentation. The samples were then filtered through 30 cm sand filter of effective size (D10) 0.3 mm and co-efficient of uniformity (Cu) of 1.714. A schematic diagram of the set-up is given in Fig. 1.

(C) Experimental studies:

(i) Study of variation of pH:

Six different runs were made in batch mode with six numbers of bentonite solutions having same turbidity to each sample. These experiments were done with different initial pH level of 2, 4, 6, 8, 10 and 12 respectively. The contact time, applied current, volume of water, initial turbidity level of samples was maintained at 1 min, 0.15 A, 1000 mL and 150 NTU respectively. Chemical coagulations were carried out by maintaining equivalent amount of aluminum concentration as obtained during EC and was calculated by Faraday's law which is equals to 20 mg/L of alum (98.9% assay). The final turbidity removal was reported against equilibrium pH.

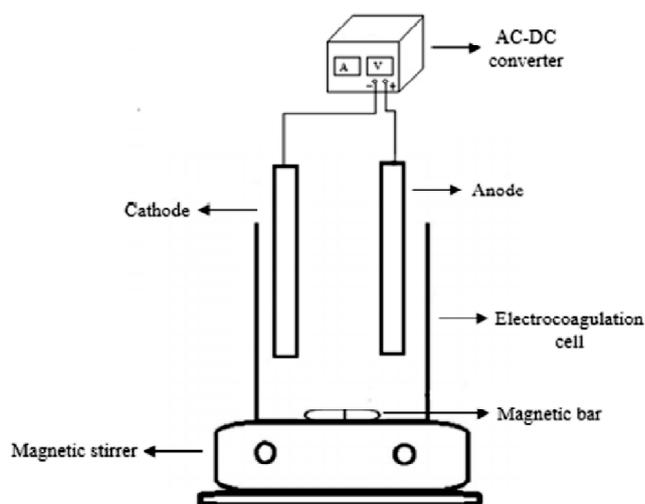


Fig. 1. Schematic diagram of experimental set-up for electrocoagulation system.

The decreasing pH in CC is controlled by the 1 (N) sodium hydroxide (NaOH) solution.

(ii) Effect of volume:

The effect of variation of volume on turbidity removal by both EC and CC was done at three different volumes. The volume of water was varied from 0.5 L, 1.0 L and 1.5 L respectively. The pH, contact time, applied current, initial turbidity level of samples were maintained at 7, 1.5 min, 0.15 A and 150 NTU respectively. An equivalent alum dose of 30 mg/L was applied for chemical coagulation.

(iii) Effect of turbidity:

The variation of initial turbidity of water was carried out for both for EC and CC. The initial turbidity of water was varied from 50, 100, 150, 200 and 250 NTU respectively. The pH, contact time, applied current, volume of water of samples were maintained at 7, 1.5 min, 0.15 A and 1000 mL respectively. The equivalent dose of alum was 30 mg/L for CC.

(iv) Effect of coagulant dose (varying time):

The effect of dose of coagulant on turbidity removal was carried out for both EC and CC. Six samples having turbidity 150 NTU were prepared for each run. The dose of coagulant was determined from Faraday's law of electrolysis as given below: $m = itM/zF$, where, m = weight of coagulant (g), i = applied current (mA), t = time (s), M = molecular weight (g.

mol^{-1}), z = valency of metal, F = Faraday's constant (96485.33 C.mol⁻¹). The dose of coagulant (as Al³⁺) was varied by operating the DC converter unit over different time intervals at constant current (0.15 A). The EC operating time was varied to get an aluminum dose of 0.08, 0.42, 0.84, 1.26, 1.68, 2.10 mg/L over the constant current of 0.15 A. The equivalent amount of aluminum was dosed during CC by dissolving Alum (98.9% pure, Merck) and the turbidity removal by CC and EC was compared. The corresponding alum doses obtained were 10, 20, 30, 40, 50, 60 mg/L respectively. The pH and volume of samples were maintained at a value of 7 and 1.0 L respectively.

(v) Effect of current density:

Current density is an important parameter in EC study. Care should be exercised that during study of current density, charge loading did not vary. The effect of current density was varied by varying the surface area of the electrode. The different current densities studied were: 250.00, 125.00, 83.33, 62.50, 50.00, 41.67, and 35.71 A/m². Thus, the dose of coagulant was fixed and only current density was varied. The pH, turbidity, contact time, applied current, volume of samples was maintained at 7, 150 NTU, 1.5 min, 0.15 A and 1.0 L respectively. Thus, the study corresponds to a constant charge loading of 13.5 C/L (0.15 A×1.5×60 s).

Results and discussion

(A) Effect of pH:

The turbidity removal is strongly depended on the variation of pH in the solution. Fig. 2 showed the equilibrium pH vs turbidity removal for both the cases of EC and CC. The maximum removal of turbidity was 97.6% at a pH 7.1 by EC and 81.67% at a pH 6.88 by CC respectively. In EC the anodic dissolution of aluminum produced aluminum hydroxide [Al(OH)₃]. But for the CC, alum [Al₂(SO₄)₃·6H₂O] dissolved into solution and produce aluminum hydroxide [Al(OH)₃]. Due to electrochemical activity anode released Al³⁺ ions, those neutralized the negative charge of turbid particles. Parallely, OH⁻ is released from cathode and maintained the desirable alkalinity level in solution for better flocculation. But for the case of CC the Al₂(SO₄)₃ dissolved in solution and produced weak alkali aluminum hydroxide [Al(OH)₃] and strong sulfuric acid (H₂SO₄). This strong acid tries to reduce the alkalinity of the solution and flocculation efficiency was reduced.

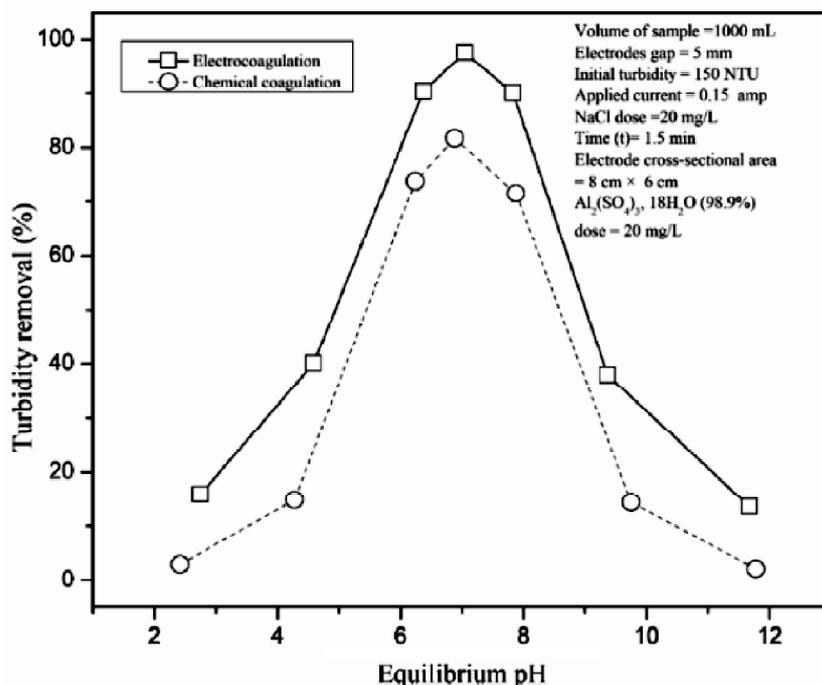


Fig. 2. Effect of pH.

Due to electrochemical reactivity EC shows higher turbidity removal than CC for equivalent dosing of alum^{17,22,24}. Similar results are reported by other researchers^{16,19,20}. In case of further increase of pH beyond a pH value about 7.5, the removal decreases because of formation of negative aluminum species $[\text{Al}(\text{OH})_4^-]$, which increases the repulsive force between colloidal particles and the negatively charged aluminum species.

(B) Effect of volume of water:

The effect of volume on turbidity removal is shown in Fig. 3 for both cases of EC and CC. It is clear from experiment that both the cases of EC and CC the turbidity removal is inversely dependent on the changes of volume of water samples. That is due to the fact that for a particular charge loading when the volume of solution is increased the coagulant dose is decreased proportionally and turbidity removal is decreased subsequently. Due to insufficient coagulant dose the floc formation rate reduces and eventually shows less removal of turbidity^{36,37}.

(C) Effect of coagulant dose:

The effect of coagulant dose was studied at constant

current of 0.15 A over varying time. The effect of coagulant dose on turbidity removal is shown in Fig. 4. It is clear that during EC, with the increase of coagulant dose the rate of turbidity removal is increased rapidly and continues up to an optimum dose of 1.258 mg/L of aluminium. Further increase of coagulant doses, the turbidity removal is decreased may be due to charge reversal or due to higher amount of OH⁻ formation at the cathode and formation of $\text{Al}(\text{OH})_4^-$.

However, in case of CC the removal seems to be increased slowly over a wide coagulant dose. Due to addition of more alum, H₂SO₄ is released which renders floc formation difficult and shows tangible increment over turbidity removal. This phenomenon was observed because after removal of certain colloidal matters the solution got neutralized and the lack of negative charge particles, the turbidity removal rate decreased^{34,35}.

(D) Effect of current density (A/m²):

Current density may be defined as the amount of current passing per unit of the electrode area ($i = I/a$, where 'a' = active electrode area, cm²). Thus, the effect of the parameter can be studied either by varying current (I) or by varying

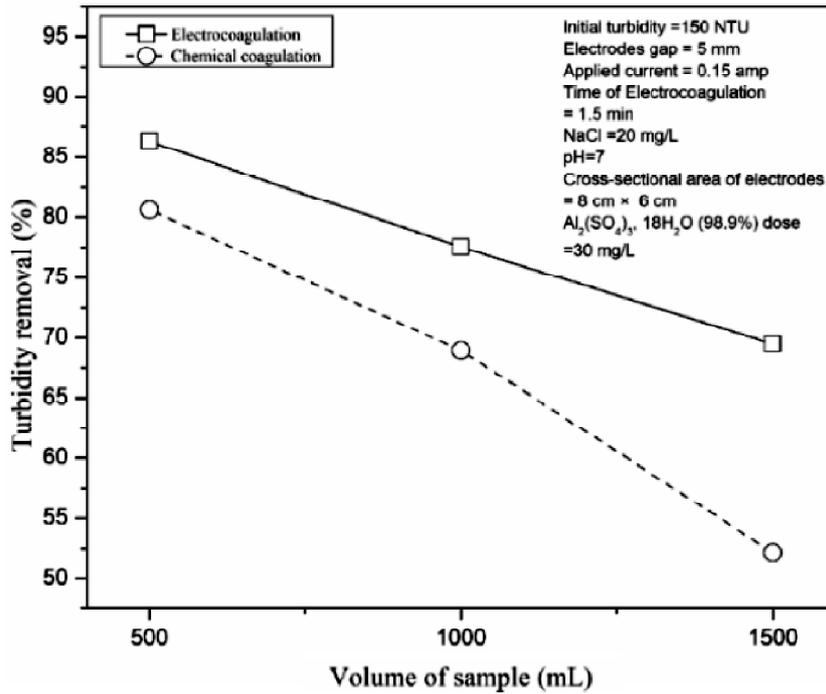


Fig. 3. Effect of volume of water.

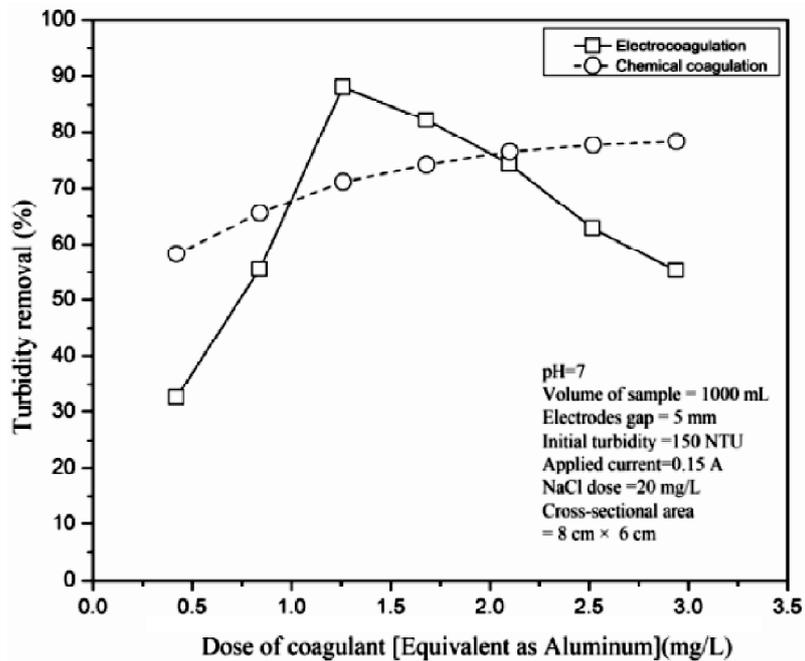


Fig. 4. Effect of coagulant dose.

electrode area 'a'. Again, when current is varied care must be taken that charge loading is not varied. Thus, in this study

the effect of current density was studied in two different modes namely: (1) keeping effective electrode area fixed at (8 cm ×

6 cm) and varying the current strength without varying the charge loading i.e. at constant charge loading and (2) with varying the electrode area at constant charge loading. In first case, the value of current varied from 0.1, 0.2, 0.3, 0.4, 0.5, 0.6 and 0.7 A respectively and the charge loading was kept constant at 13.5 C/L. The corresponding effect of current density on turbidity removal is shown in Fig. 5. It is clear that with increasing the current density, turbidity removal is decreased. However, most of the authors reported positive effect of current density^{24,34}. This is apparently due to the effect that during investigation of current density, charge loading was varied and was ignored^{38,39}.

From another perspective of the study the effect of current density was studied by varying the electrode area while charge loading was kept constant at a value of 13.5 C/L. This was achieved by a constant current value of 0.15 amp over 1.5 min time interval through different electrode area. The same trend (i.e. less removal over higher current density) is also observed in second case. However, when the current densities were varied by changing the electrode area, apparently higher potential was required to maintain a constant current of 0.15 A. To keep a constant current of 0.15 A

through varying electrode area, the voltages were changed to 54.8, 50.2, 44.6, 38.8, 31.1, 24.6, 19.8 volt respectively. A plot of the corresponding potential vs current density is given in Fig. 6.

The lower removal of turbidity at higher current densities for a constant charge loading is due to the fact that with increased current densities, electrode potentials also increased. Thus, when the electrode potential continued to increase beyond the standard potential of the electrode material (1.662 volt for aluminium), some other side reactions (water splitting, deposition of other metals at cathode etc.) might also occurred. These side reactions reduce the current efficiency to produce equivalent amount of aluminium from anode that could have been obtained according to Faraday's law and subsequently showed lower turbidity removal. Fig. 6 corroborates the same electrochemical principle for turbidity removal⁴⁰.

This phenomenon influenced a portion of energy in EC is decapitated with the increasing of current density. For this reason, the loss of dose of coagulant is decreased and eventually the turbidity removal also decreased with the raising current density⁴⁰. Therefore, it can be emphasized that the

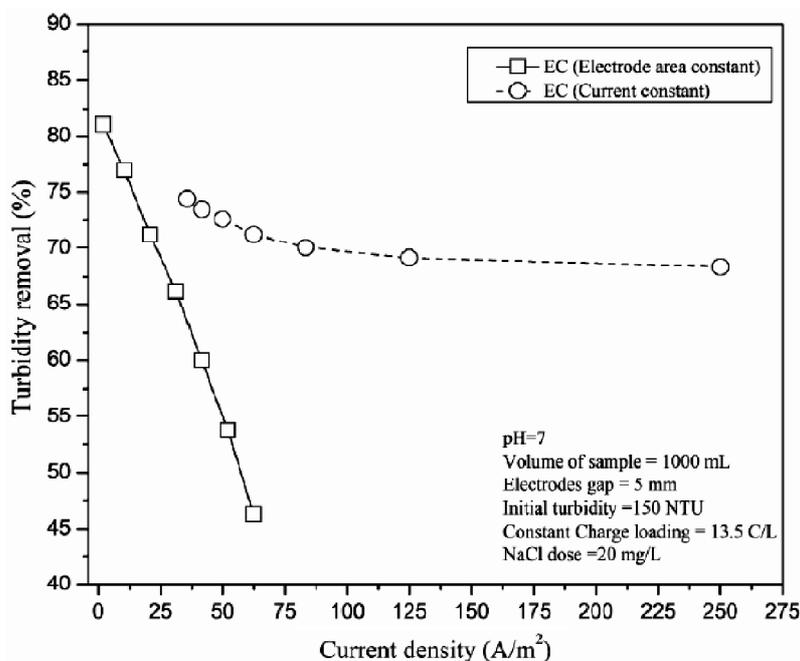


Fig. 5. Relation between current density (A/m²).

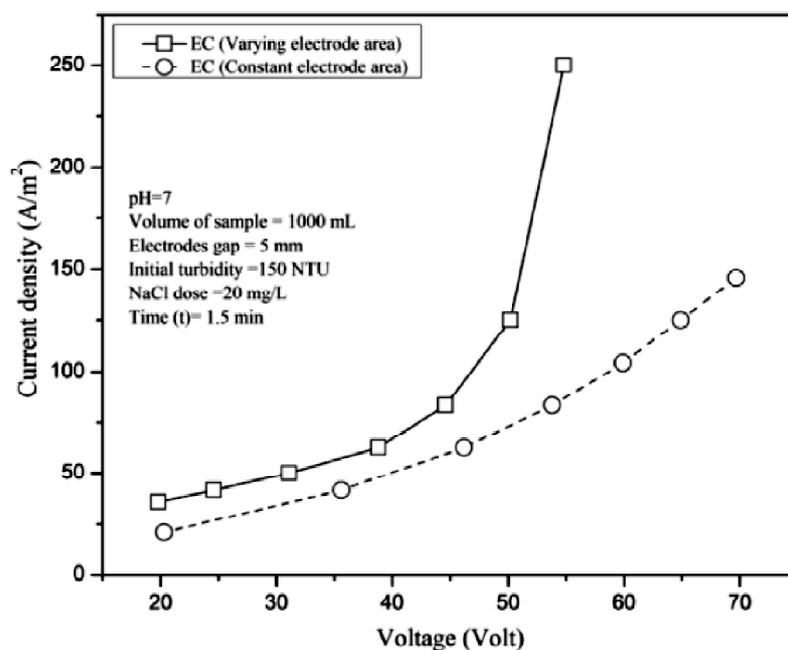


Fig. 6. Relation between voltage vs current density.

over voltage beyond the ORP of anodic electrode material during EC influence the metal (aluminum) precipitation⁴⁰.

Conclusion

In this study effect of pH, current density, charge loading, turbidity, and volume of sample has been studied on the performance of turbidity removal by EC system. A comparative study with respect to chemical coagulation by alum revealed that for equivalent amount of aluminum dose, EC gave more removal and requires no alkalinity adjustment. Initially, the effect of the factors has been studied by considering one factor at a time. It is found that pure curvature effect of pH is the most important factor in controlling the turbidity removal. It was also evident that turbidity removal increased with current processing time. Most researchers reported that turbidity removal was increased with increasing the current density. However, in this study it was the first time reported that with increasing the current density turbidity removal was decreased for a constant charge loading. This contradictory report is due to the fact that, the other researchers reported the effect of current density, while varying the charge density also. So, effect of current density is to be studied in such a way that charge loading was not varied.

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