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The effect of some variables on the removal of synthetic bentonite suspension in water by electrocoagulation using turbidity measurements

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Abstract. Electrocoagulation can be considered as a simple and an efficient method for treating both wastewater and water. In this work, a synthetic bentonite suspension water was treated using this technique to reduce turbidity caused by solid particles pollutants. This process was carried out in a batch glass reactor of 1000 ml operated with aluminium electrodes with and without agitation. The removal efficiency as a turbidity removal procedure has been examined using bentonite clay as a turbidity source. The effects of some parameters such as contact time, and electrolyte concentration on the removal efficiency were investigated and compared. The mixing effect over the range (0-800 rpm) on the removal efficiency was also evaluated. The process was found to achieve excellent turbidity removal with mild mixing (550 rpm). In addition, the effect of using Ultrasonic as a mixing source has also been studied. The lowest residual turbidity was found to be 1.0 NTU for the samples with initial turbidities of 500 NTU. Similar final turbidity of 1.0 NTU was obtained after 25 min with initial turbidity of 200 NTU. This was obtained at a current of 750 mA, a contact time of 60 min, and a calculated dissolved aluminium concentration of 10 mg/l.

1. Introduction

Electrochemical treatment of turbid water is an effective method of increasing the clarity and purity of water. The electrocoagulation (EC) process has been recently employed in separating suspended solids materials in water and wastewaters. This method functions in a series of steps which start with breaking down forces that stabilize charged particles found in water or wastewater. This allows inter-particle collision to occur to generate what is known as flocs [1].

The chemistry of this process has been utilized from the subject of electricity. The electricity explains the performance of charged particles given their attraction/repulsion affinities. The suspended solids have negative charge in water and they inclined to stabilize and repel each other when they get closer to each other that are because of their charge surface similarity [2].

The EC process intends to destabilize these negative charged particles. Appropriate application of the process takes into consideration satisfactory empathetic of certain interaction parameters. These comprise of the source of the charge, composition of the charge, particle size, particle shape, and density of the suspended particles. EC starts usually with the dissolution of Al or Fe as hydroxides in the wastewater. Thus these metal hydroxides are used as coagulants material. Electro-addition of coagulants material with opposite charges is the first approach to destabilize the particles' charge. They are added to water and wastewater to neutralize the negative charge of suspended particles. Upon neutralization, the suspended solid particles try to stick together in order to form slightly larger particles. Furthermore, mixing is preferred here to scatter the coagulant and encourage particle collision. It is later followed by the "flocculation process" where gentle mixing increases the particle size from micro flocs to visible suspended solids. Particles are thus bounded together to produce larger macro flocs. Finally, a floating process is proceeding due to the formation of bubbles of hydrogen and oxygen gas on the electrodes. This process moves up most of the flocs to the top of the water and separates them [3].

Bentonite was designated to represent clays which are often found in the oil industry drilling mud. Bentonite behaves as hydrophobic colloids in water. These compounds involve flat sheets of alternating layers of silicon oxides and aluminum oxides, held together by ionic attraction for cations sandwiched between the sheets. In water solutions, aluminum (+3) or silicon (+4) can be replaced with sodium (+1), potassium (+1), or ammonium (+1) ions resulting in an overall negative charge of the particle. This charge is responsible for the electric repulsion of bentonite particles and, thus, of the stability of the colloidal suspension [4].

Most previous studies show that mixing could cause an increase in the removal efficiency of the pollutants. However, it has not been clear on this subject. Studies of Sitorus et al. [5] showed a proportional relation in the range (10-200 rpm) whereas Eskibalci et al. [6] revealed a reduction in turbidity with increasing mixing speed up to 360 rpm, yet an increase happened after that speed up to 700 rpm. On the other hand, Ilhan et al. [7] has proposed that mixing is not good for the EC process where they showed a decrease in COD removal efficiency with increasing mixing. Derayat et al. [8] investigated the EC treatment of surface water showing that turbidity rate increased with increasing mixing rate and they preferred low mixing rate.

In this paper, the mixing parameter besides basic other parameters such as initial concentration, pH and adding NaCl salt have been studied to elucidate their effect on the EC process using turbidity measurements.

2. Materials and Methods

Detail description of the experimental system can be found elsewhere [9]. A photograph for the experimental set up is given in Figure 1. In this study, the EC reactor (Pyrex glass beaker) with active volume of 1000 ml was used. Two home-made circular metal electrodes were Ø95mm×2 mm, and operative area for coagulation was 235 cm2. Commercially available power supply with 220v AC input voltage and 0~16v output voltage was used. The anode and cathode electrodes were fixed horizontally paralleled (9 mm distance) in the bottom of the reactor, and then 800 ml of wastewater was poured into the reactor. Samples of treated water-clay were synthetically prepared in the lab using mixer blender. The bentonite suspension is prepared using fresh tap water. This suspension is then succumbed to a strong mixing to obtain a well homogenization. Later, bentonite suspension samples after EC were submitted to sedimentation for 5 min before aspiration for their analyses. Hanna Multimeter (model HI-9828)- Multisensor probes was used to monitor changes in conductivity, TDS, pH and temperature. The electrolytic cell was equipped with a magnetic stirrer (BOECO MSH-300N, 50-1250RPM) in order to keep the electrolyte well mixed. Ultrasonic bath (frequency of 40 kHz and power of 50W SilverCrest model, China) was used in some experiments. Turbidity was determined by using Microprocessor Turbidity Meter, Model HI93703, HANNA instruments where samples of the liquid were taken periodically and analyzed using standard procedure.

Figure 1. The EC experimental setup.

3. Results and Discussion

This study was part of series of experiments carried out in our labs to investigate the treatment of various water and wastewater pollutants using EC technique [9]. In the current work, pollutant was chosen as suspended bentonite water. Thus, the purpose of this investigation was to evaluate the effect of various factors including mixing with magnetic stirrer/ or ultrasonic waves on the treatment efficiency of EC process. Turbidity removal kinetics was investigated by varying the values of time, initial concentration, added NaCl salt, pH, applied voltage and mixing parameters. In this research, turbidity measurements were utilized as a measure of the bentonite concentration in the tap water.

The effect of time was studied at constant applied voltage of 10v, mixing speed of 400rpm and initial concentration of 100NTU. Figure 2 illustrates the turbidity as a function of operating time. It is clearly seen that the operating time has an important effect on the turbidity removal.

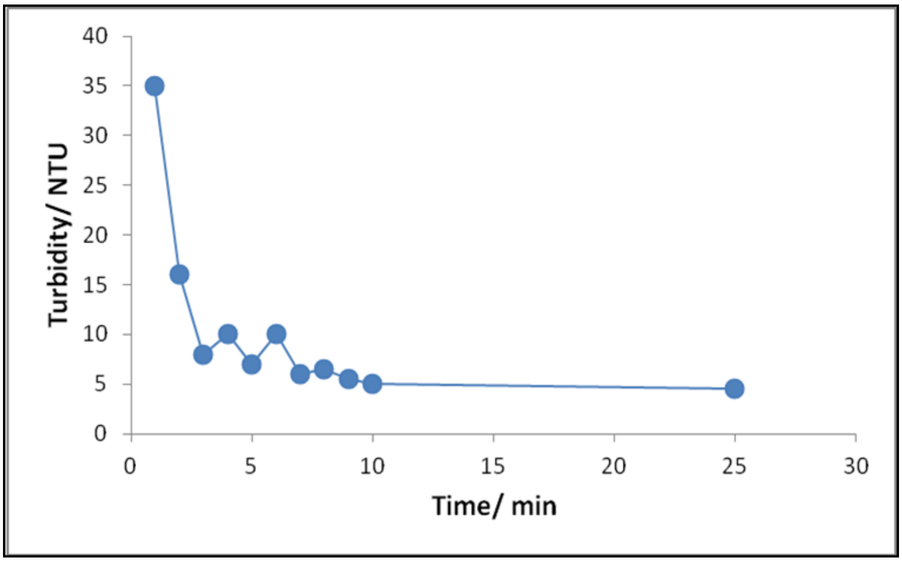

Figure 2. The change in turbidity with operating time during the EC process.

During the period of 10 min time, the turbidity has been dropped from 100 NTU to 5 NTU with an efficiency of 95%. Figure 2 also indicates that the EC process encompasses of two stages that are destabilization and aggregation, the first stage is fast, whereas the second stage is relatively slow. To explain that, Faraday's law stated that the current time of passing raises the applied electricity to the electro-cell. This may lead to more ions of aluminum to be liberated at the anode electrode. These positive charges of these ions would neutralize the negatively charged particle droplets. This effect would improve the split-up of the particle droplets and thus they float on the water surface. Alternatively, more bubbles (conceivably H_2) would be created at the cathode by increasing the operating time. These bubbles would drive the produced flocs upwards by "bouncy force", thus increasing the removal efficiency and decreasing turbidity of the water (improving separation).

On the other hand, and in order to explore the effect of the operating time and pH value, the initial pH value was taken at 9. Figure 3 shows the reduction of turbidity with the operating time at initial pH of 9. pH parameter is a vital factor influencing the treatment performance of EC process. The pH of the solution varies little during electrolysis, as shown in Figure 4. It is the result of several reactions occurring in the synthetic solution : hydrolysis reaction of Al^{3+}, formation of hypochlorous acid from chlorine (existing in municipal water) reduced to the anode, etching of the electrodes by the Cl^- and OH^- ions and formation of the OH^- ions to the cathode. It may be the reason behind the decrease in pH was due to the hydrolysis and the formation of the hypochlorous acid.

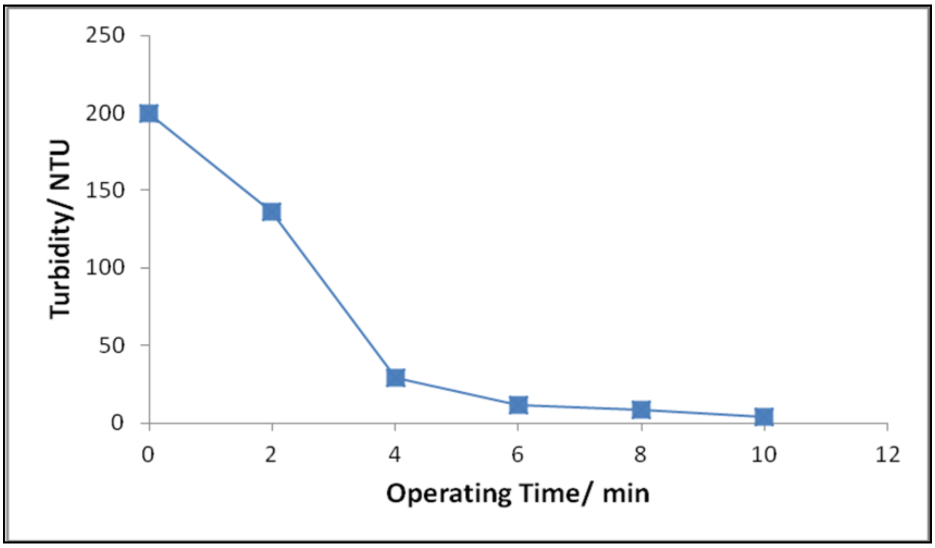

Figure 3. Turbidity change with operating time. (pH=9, I= 500-800mA, V= 10v, Ci=200NTU)

Figure 4 shows the change trend of pH with time for the EC process where a clear small reduction in pH was found from 8.2 to approximate 7.5 over a period of 10 min.

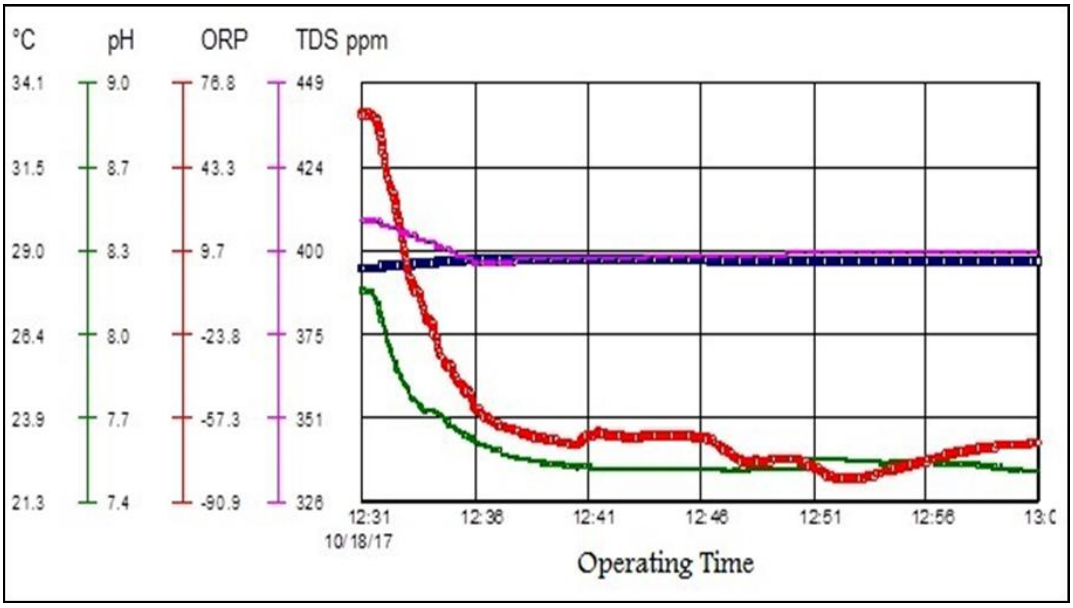

Figure 4. The change of pH with a long period of operating time of EC process.

In figure 5, other experiments were carried out to evaluate the effect of increasing initial concentration on final turbidity. Increasing turbidity of more than 400 NTU would reduce separation efficiency as expected. Since the formation amounts of the coagulant are insufficient, and the voltage to achieve the same removal efficiency as concentration is lowered.

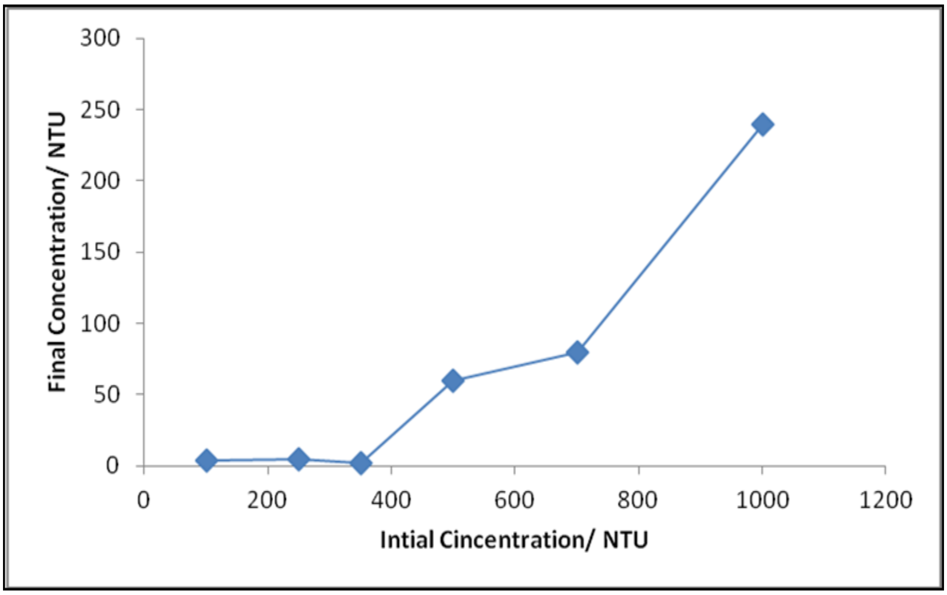

Figure 5. variation of initial concentration with final concentration. (Time= 5min, V= 10v, Speed= 400rpm,I= 400-1000mA)

The outcome of NaCl concentration on the EC separation of clays from water was plotted in Figure 6.

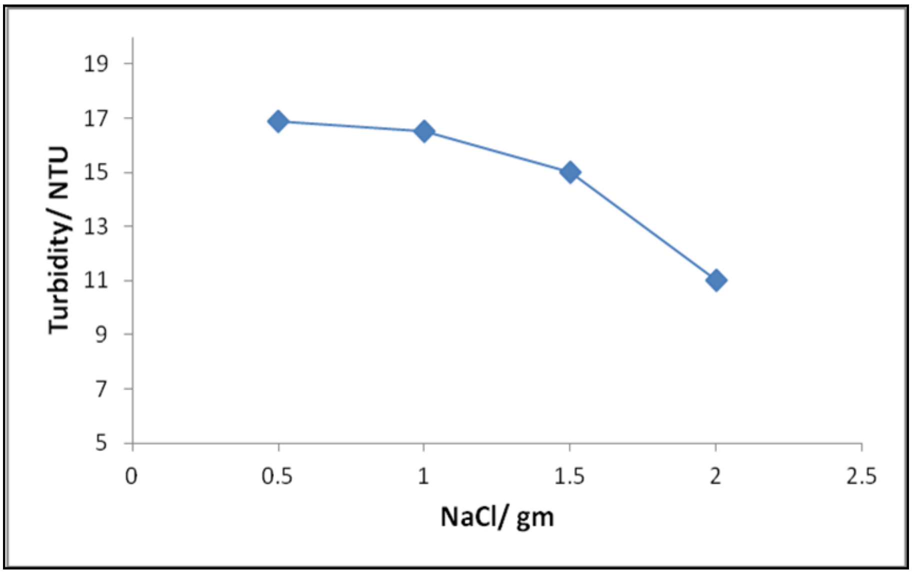

Figure 6. The effect of adding NaCl on the removal efficiency of bentonite suspension waste. (Ci= 100 NTU, V= 4v, Time= 5min, mixing speed= 400rpm)

From this figure it can be seen that increasing NaCl concentration leads to reduce turbidity with decreasing in treatment time that is required to achieve the highest removal percent. The presence of NaCl causes the formation of Na^+ ions and Cl^- ions. Accordingly, presenting NaCl salt to the water would increase the conductivity of the solution and decrease the portion of the applied potential that is spent to overwhelm the resistance of the solution. Consequently, it raises the fraction of the applied potential engaged to the EC process. The same results of sodium chloride effect were reported by [10].

Figure 7 also shows the change of turbidity removal with NaCl added at moderate mixing. Results show higher efficiency removal at shorter time compared to the study without adding any salt. However, the difference was reduced at longer operating time.

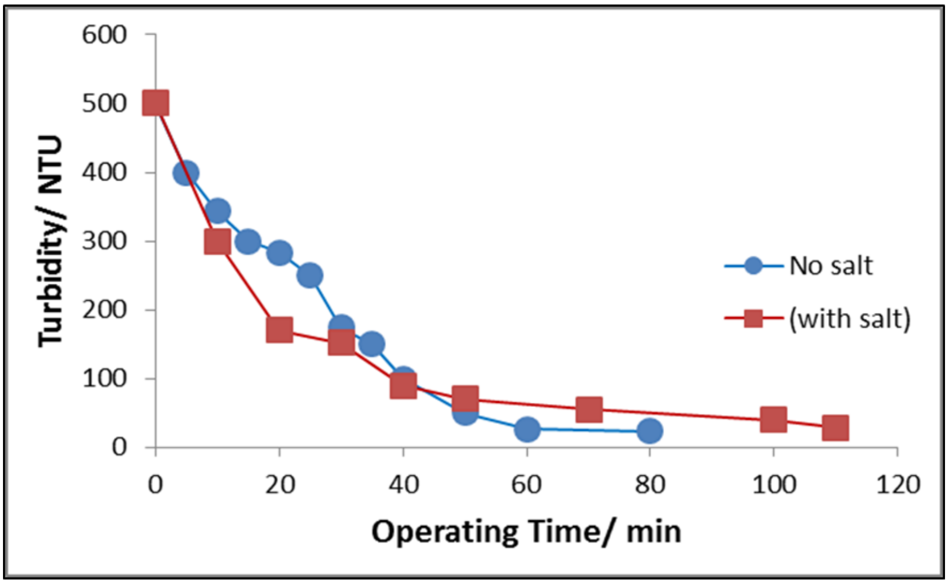

Figure 7. Comparison results of the EC process with and without adding NaCl.

The mixing speed has also been studied in this work to determine its effect on the interaction of ions and molecules in suspension with particles. Mixed solution would produce a distressed of ions placement and some inadequately electricity consumption. The most effective interaction rate may produce a suspension and may also increase coagulation efficiency considerably. When the mixing speed and operating time exceed certain restrictions, the produced flocs might be fragmented. This also reduces the efficiency of coagulation. In order to conclude the optimum stirring speed (0-800 rpm) for the EC experiments in the absence of NaCl, the other parameters namely current density, operating time, and pH were all retained constant.

The result of agitating speed on the EC is revealed in Figure 8. The turbidity of the suspension at a stirring speed of 550 rpm dropped from 100 NTU to 10 NTU level with a 90% removal efficiency. With mixing speeds over 600 rpm, it was determined that turbidity values started to increase again in parallel with the disintegration of formed flocs. Therefore, 500 rpm was chosen to be the optimum mixing speed for this study.

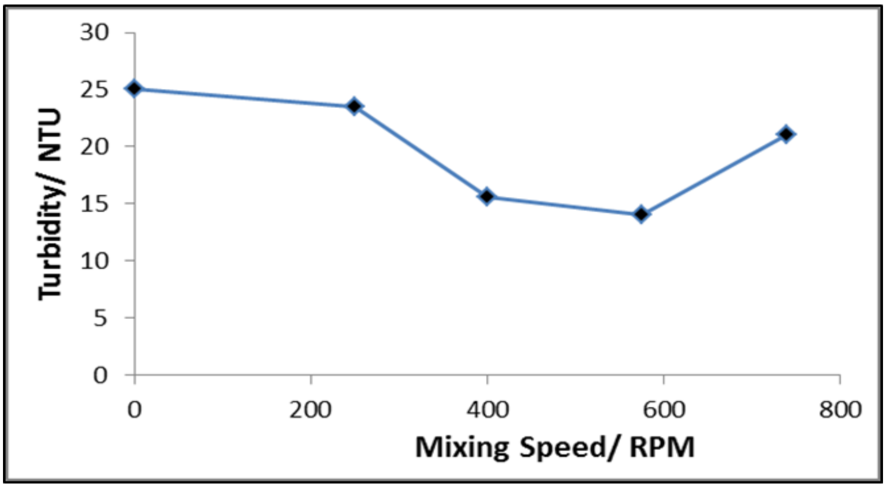

Figure 8. The change in turbidity with the mixing speed of the magnetic stirrer (voltage=15v, Ci= 110NTU, time= 5min, Ø=10cm,electrodes distance= 9mm).

Figure 9 has shown that changing applied voltage (10v and 16v) has not changed Turbidity considerably. However, it seems lower voltage was preferred.

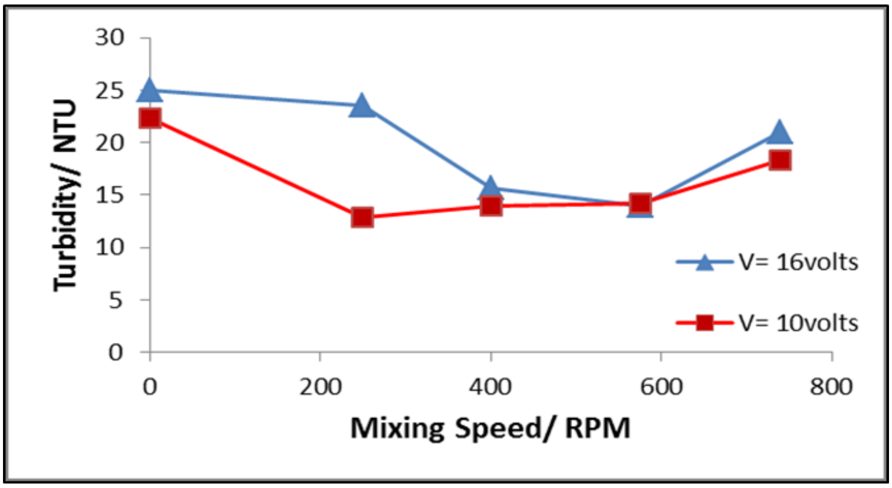

Figure 9. The change in turbidity with mixing speed using magnetic stirrer at two different applied voltages.(Ci=110NTU, Mixing speed=250NTU, 0.5gm NaCl)

The key cause behind this result is the fact that mixing operation influences the mobility of ions in water (negatively charged ions towards the anode and positively charged ions towards the cathode). Considering the fact that mixing may cause the break-up of flocks, mixing is not always recommended to be a good choice for EC treatment, especially at higher speed (above 600 rpm). Taking into consideration these points, it was established that low to medium mixing should be included in EC treatment process to obtain the best removal efficiencies and to maintain the system working. Thus, another experiment was carried out with adding NaCl and using the optimum mixing condition of 500 rpm. This case has provided approximately 98% efficiency.

With increasing mixing rate, flocs in solution are formed and sedimentation gets easier. The results display that the removal efficiency of study turbidity rate parameter increased with increasing mixing rate. For the prevention of flocs break and the release of metal is better using moderate mixing rate. Similar results of investigating the effect of mixing rate on removal efficiency was found by Modirshahla *et al.* [11].

Figure 10 represents the comparison of current consumption with and without mixing.

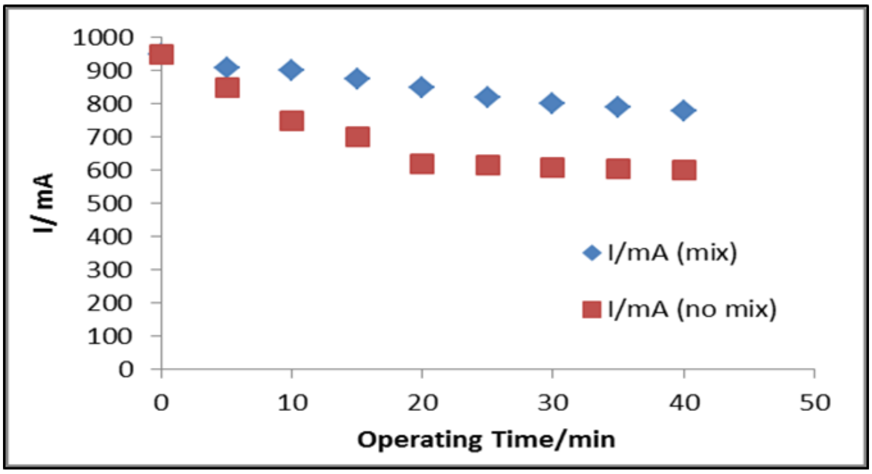

Figure 10. The change in current density with operating time during the EC process for both mixing and no mixing process.

It can be seen clearly that the current required with mixing is higher compared with no mixing. The reason behind that is lying in the process of making the solution more conductive in mixing process thus the amount of energy consumed is higher.

Furthermore, comparison results of using agitating mixing by magnetic stirrer and when the process carried out with no mixing (the mixer turned off) were done. Data demonstrate an affected reduction in removal efficiency without mixing, this reached to about 50% at about 15 min operating time. Mixing is important due to the fact that this process improved conductivity and thus the current density was increased [8]. With lower to moderate mixing, flocs were formed which led to facilitate sedimentation as stated previously.

To evaluate the effect of Ultrasonic Waves on the EC processes, a number of experiments were carried out using bentonite suspended water and zinc wastewater [15] (for comparison). The results are presented in figures 11 and 12.

The results in figure 11 illustrate a serious deterioration in the wastewater turbidity. Similar results have been reported from other researchers [5]. On the other hand, other researchers proposed a positive impact using combined ultrasonic-electrocoagulation technique [9,12]. Ultrasonic-EC technique was proposed by Chu Jinyn *et al.* [13] to treat the car-washing wastewater. They reported the COD removal efficiency by ultrasound-EC technique to be better than the conventional EC. They also proposed a mechanism to clarify the reason behind the enhancement in the efficiency. In addition, He *et al.* [14] concluded that ultrasonic tool may improve the EC work by eliminating the passive film of Reactive Blue 19 that produced on the surface of the electrode during EC process. They proposed a mechanism showing that the passive film could be detached from the sacrificial electrode under the effect of ultrasound causing to generate more coagulant metals and thus reducing the size of the metal hydroxide which in turn adsorbs more contamination in wastewater.

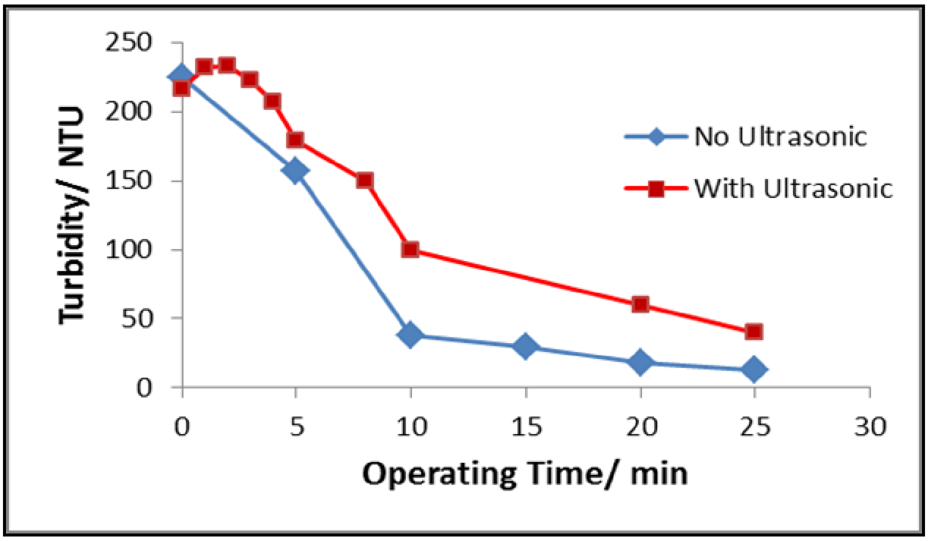

Figure 11. Changing of removal efficiency with operating time for EC of bentonite wastewater (comparison Results).

On the other hand, the situation was different for the zinc pollutant where the removal efficiency was found to improve. A comparison was made between the treatment with and without Ultrasonic in figure 12 [15]. The same results of positive ultrasonic effects were reported elsewhere [16].

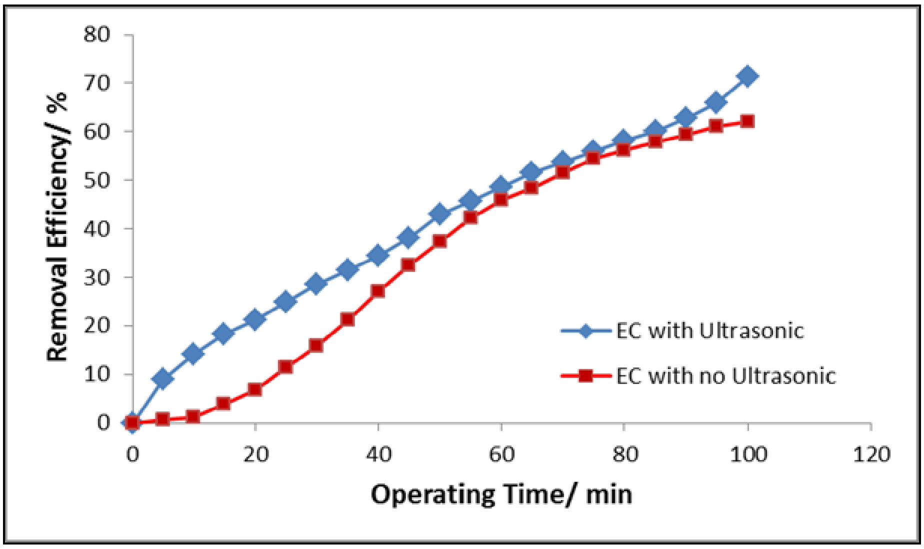

Figure 12. Changing of removal efficiency with operating time for EC of Zn wastewater (comparison Results) [9]

4 Conclusions

In this study, the efficiency of the EC process applied to the treatment of bentonite suspended water was investigated. It was observed that the EC treatment achieved a fast and effective removal of solid particles turbidity. During the operating time, two steps are eminent, the most important of which is related to the removal of the turbidity. During this process, there is the creation of flocs, a quantity of which is moved to the free surface by the bubbles generated in the surrounding area of the surface of the electrodes. The turbidity is removed by adsorption on the $Al(OH)_3$ flocs. In this step, the electrochemical kinetics is fast and increases when the initial electrical conductivity of the solution increases. The treatment efficiency was found to be a function of the NaCl electrolyte dose, mixing process using magnetic stirrer and operating time under the optimal values of the process parameters. The results showed removal efficiencies of 95% turbidity at moderate mixing speed of 500 rpm. This technique thus seems to be a promising alternative for the treatment of clay particles suspensions wastewater under low to moderate mixing.

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