Journal of Engineering and Applied Sciences 13 (1): 97-104, 2018
ISSN: 1816-949X

Enhancing Turbidity Removal using Electrocoagulation Method

Mohammad Abid Muslim Altufaily and Zahraa Ahmed Abedalaama
University of Babylon, Hillah, Iraq

Abstract: This study aims to investigate removal of turbidity from waste water using electrocoagulation method. Two electrocoagulation reactors with a new configuration were used in this study. One of them with aluminum electrodes and the other with iron electrodes. The effects of several parameters such as initial pH, detention time initial turbidity, current density, electrode surface area and conductivity on the removal efficiency were studied. Experimental results revealed that the removal efficiency of turbidity using aluminum and iron electrodes increased with the increase of every parameter stated except for the initial turbidity. It was found that the optimum conditions for aluminum and iron electrodes were: initial turbidity of 100 NTU, current density of 4 A/m^2, electrode surface area of 1.3 m^2, conductivity of 2200 μS/cm and initial pH of 7 and 9 for aluminum and iron electrodes, respectively. The results showed that within 70 min of detention time and at the optimum conditions, the maximum removal efficiency of turbidity was 98.82 and 97.15% for aluminum and iron electrodes, respectively. At the optimum conditions, it was found that the energy consumption for turbidity removal using aluminum and iron electrodes was 0.621 and 0.362 $kW.h/m^3$, respectively.

Key words: Electrocoagulation, iron electrode, aluminum electrode, turbidity, removal efficiency, experimental results

INTRODUCTION

One of the major challenges facing mankind today is providing clean water to a vast majority of the population around the world. Rivers, canals, lakes and other water bodies are constantly polluted due to indiscriminate discharge of industrial effluents as well as other anthropogenic activities and natural processes (Mollah *et al*., 2001).

The presence of particulate materials such as algae, clays, silts, sand organic particles and soluble substances in water often causes it to get turbid or colored. Turbidity is one of the principal physical characteristics of water; excessive turbidity or cloudiness in water is aesthetically unappealing and may also represent a health concerns as it can provide food and shelter for pathogens. If not removed; turbidity can promote re-growth of pathogens in the distribution system; leading to waterborne disease outbreaks which have caused significant cases of gastroenteritis (DeZuane, 1997).

The conventional method for the removal of turbidity consists of adding metal salts (aluminum, iron, etc.), destabilization of colloidal particles (which is called coagulation), followed by flocculation, sedimentation, filtration and disinfection. This method of treatment has certain drawbacks like handling large quantities of chemicals, proper assessment of requirements, feeding of chemicals and production of large volume of sludge causing disposal problem and loss of water (Paul, 1996; Mills, 2000). During recent decades, research on electricity applied directly in water treatment has progressed well making it an attractive method for coagulation or clarification of water, usually known as the electrocoagulation/electrochemical method (Kobya *et al*., 2003). Electrocoagulation is a complex process involving chemical and physical mechanisms operating simultaneously to remove pollutants from waste waters. When sacrificial electrodes are used, metal ions are produced (*in situ*) resulting in the removal of pollutants. The process takes place in three successive stages: formation of coagulants by the oxidation of the sacrificial anode, destabilization of the pollutants, particulate suspension and emulsion breaking, aggregation of the destabilized phases and formation of flocs (Mollah *et al*., 2004). These flocs can be easily separated either by gravity settling or by electroflotation where the evolved hydrogen gas bubbles at the cathode would enhance flocs growth and their separation by flotation (Elsayed *et al*., 2013). Aluminum or iron is usually used as electrodes and their cations are generated by the dissolution of sacrificial anodes upon the application of direct current. The metal ions generated are hydrolyzed to produce metal hydroxide ions (Bensadok *et al*., 2008). When a DC electric field is applied, the following electrolysis reactions are expected in the vicinity of the aluminum electrodes (Ghosh *et al*., 2008):

Corresponding Author: Mohammad Abid Muslim Altufaily, University of Babylon, Hillah, Iraq

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^-$$

$$3H_2O + 3e^- \rightarrow 3/2H_{2(g)} + 3OH^-_{(aq)}$$

Then, Al^{3+} ion and OH^- ions react to generate $Al(OH)_3$

$$Al^{3+}_{(aq)} + 3H_2O \rightarrow Al(OH)_3 + 3H^+_{(aq)}$$

A similar mechanism has been proposed for the case of iron electrodes (Zaroual *et al*., 2006):

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$$

$$2H_2O + 2e^- \rightarrow H_{2(g)} + 2OH^-_{(aq)}$$

$$Fe^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_2$$

$$Fe^{2+}_{(aq)} + 5H_2O + 1/2O_2 \rightarrow 2Fe(OH)_3 + 4H^+_{(aq)}$$

The formation of gelatinous compounds, $Fe(OH)_3$ and $Al(OH)_3$ is responsible for removal of pollutants by adsorption/complexation process. Many researchers have been focused on performance of electrocoagulation process in water and waste water treatment. Paul (1996) had treated river water of various turbidities in an electrolytic cell. Robinson showed that the water with turbidities in the range of 197 NTU and 400 NTU can be reduced by the process of electrocoagulation to <0.5 NTU. Rahmani (2008) investigated removal of turbidity from raw water using electrocoagulation under different voltage rates with three types of electrodes. Giwa *et al*. (2012) studied the factors that affect the energy consumption and removal efficiency of electrocoagulation process used for removal of turbidity from petrochemical waste water. Mansoorian *et al*. (2016) examined the efficiency of continuous electrocoagulation process in the treatment of spent filter backwash water.

The objective of the present research is to investigate the performance of continuous electrocoagulation process using two electrocoagulation reactors with a new configuration (large electrode surface area) to remove turbidity. One of the reactors with aluminum electrodes and the other with iron electrodes. Several parameters such as initial pH, detention time (t) initial Turbidity (TD_o), Current Density (CD), electrode surface Area (As) and conductivity (k) were investigated in term of turbidity removal.

MATERIALS AND METHODS

Experimental setup: Figure 1 shows a schematic diagram of the pilot plant used in this study. It consists mainly of a rectangular electrocoagulation reactor made of glass and a power supply. The dimensions of the reactor are 65 cm height 30 cm length 30 cm width and 5 mm wall thickness. Two electrocoagulation reactors with a new configuration were used in the present study. One of them with aluminum electrodes with 99.43% purity and other with iron electrodes with 99.573% purity. Six vertical and concentric cylinders with diameters of 21.5, 18.5, 15.5, 12.5, 9.5, 6.5 cm are connected together to act as a single cathode. The anode also consists of six vertical and concentric cylinders with diameters of 20, 17, 14, 11, 8, 5 cm also connected together. All the cylinders are perforated, the diameter of each hole is 5 mm and the distance between the holes is 4 cm. The height of all cylinders is 30 cm; the concentric gap between electrodes is 0.75 cm and the thickness of all cylinders is 1 mm, Fig. 2. The effective surface area is 1.3 m^2 and the anode surface area to effective reactor volume ratio As/V is 27.7 m^2/m^3. Before each run, the cathode is placed in the electrocoagulation reactor, then the anode cylinders are inserted between the cathode cylinders. The anode and cathode are attached to a power source by using a copper wire. The electrical current was supplied by a power supply type Dazheng with range of 0-5 A and 0-30 V. During the experiments, the waste water flows through the perforated electrodes this leads to waste water turbulence inside the reactor which leads to better mixing and increasing mass transfer, thus, leading to increased removal of contaminants (Fig. 1 and 2).

Chemicals: The study was carried out on a synthetic turbid water using kaolinite clay. The kaolinite clay was sieved and the fractions below 75 μm mesh was used in this study. Turbid water with certain levels of turbidity was prepared by mixing a certain weight of kaolinite in a known volume of tap water. The initial pH of the waste water was adjusted to the required value using HCl or NaOH solutions. For conductivity adjustment, NaCl salt was added to the waste water.

Procedures and analysis: Prior to starting each run, the electrodes were washed carefully with diluted HCl to remove the oxide layer from the surface and then rinsed with water before dipping in the electrocoagulation reactor to remove any solids accumulated on the surfaces. The experiments were carried out by introducing the waste water into the storage tank. The waste water was pumped by centrifugal pump from the storage tank to the electrocoagulation reactor and the desired flow rate was achieved by adjusting the valve in the feed pipe. The DC power supply was switched on as soon as the waste water fills the electrocoagulation reactor. The desired current was achieved easily by manipulating the dial for control of current in the power supply. To monitor the

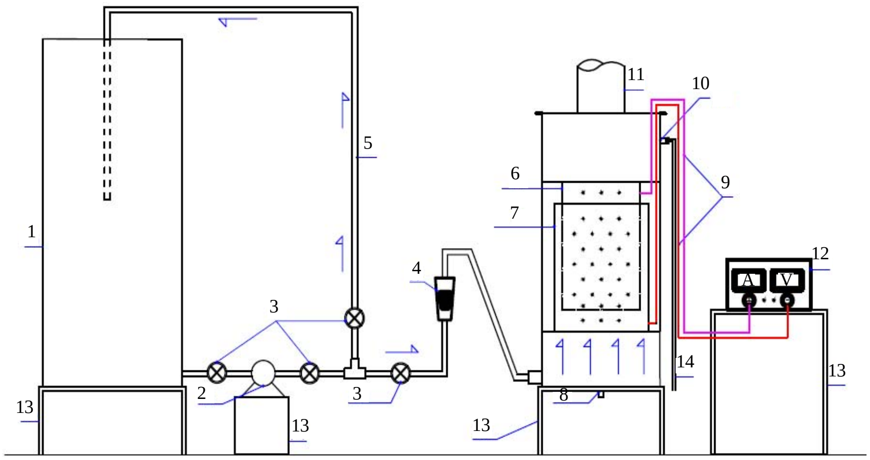

Fig. 1: The pilot plant used in the study: 1) Storage tank; 2) Pump; 3) Gate valve; 4) Rotameter; 5) The return pipe; 6) Anode electrode; 7) Cathode electrode; 8) Drain valve; 9) Wires; 10) Effluent valve (sampling port); 11) Pipe for gaseous by-product vent; 12) Power supply; 13) Stand and (14) Tube to drainage hole

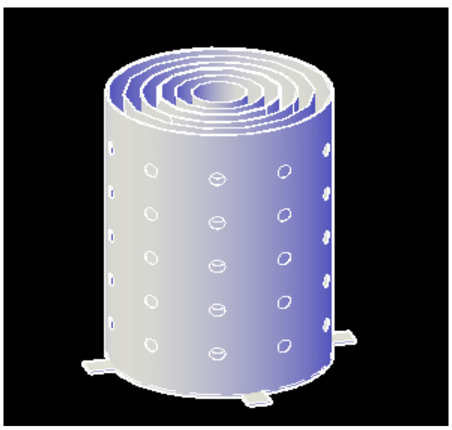

Fig. 2: Schematic diagram of the electrode used in the study

progress of turbidity removal process, samples were collected from the reactor at 10 min intervals and allowed to be settle for 30 min and then analyzed by using (Turbidimeter). The removal efficiency (R%) was determined using the following equation:

$$R(\%) = \left[\frac{(C_o - C)}{C_o}\right] \times 100\ (\%)$$

where, C_o and C are the initial and final turbidity, respectively. The Energy consumption (E) was calculated as follows (Ghosh *et al.*, 2011):

$$E = \frac{IVt}{Vol.}$$

Where:

E = The energy consumption (kWh/m^3)
I = The current (A)
V = The Voltage (V)
t = The detention time (h)
Vol. = The volume of solution (m^3)

RESULTS AND DISCUSSION

Effect of initial pH and detention time: This parameter (pH) significantly influences the performance of electrocoagulation process as it governs the speciation of metal hydroxides. To investigate the effect of initial pH on turbidity removal, a series of experiments were conducted using synthetic waste waters with different initial pH values 3, 5, 7, 9 and 11. While the other parameters were kept constant.

Figure 3 shows that, turbidity removal efficiency using (Al) electrodes increased as the initial pH increased from 3-5 to reach its maximum value at pH 7 and then, declined with further increase of pH. This change of turbidity removal with the initial pH is mainly attributed to the predominant species of aluminum where in pH = 7, the majority of aluminum coagulants were formed, especially $Al(OH)_3$ which has a minimum solubility at this pH (Fagnekar and Mane, 2015).

Figure 4 shows that, turbidity removal efficiency using (Fe) electrodes increased as the initial pH increased from 3-7 to reach its maximum value at pH 9. Then, the removal efficiency decreased as the initial pH increased to 11. This result is discussed as follows, iron dissolves as Fe^{+2} which is a poor coagulant compared to Fe^{+3} due to higher solubility of its hydroxides. If the pH is alkaline and

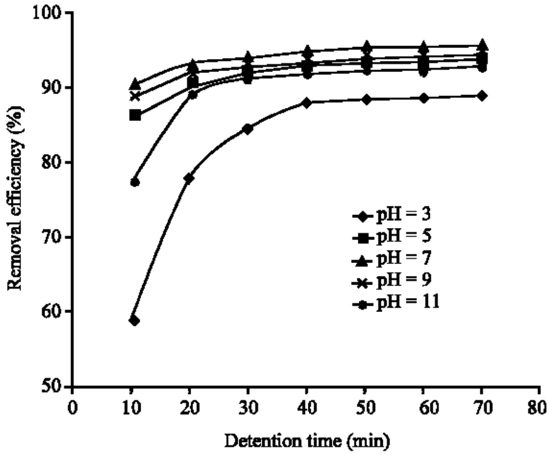

Fig. 3: Effect of initial pH on turbidity removal efficiency using aluminum electrodes (TDo = 200 NTU, CD = 4 A/m^2, Q = 40 L/h, As =1.3 m^2, k =1100 μS/cm)

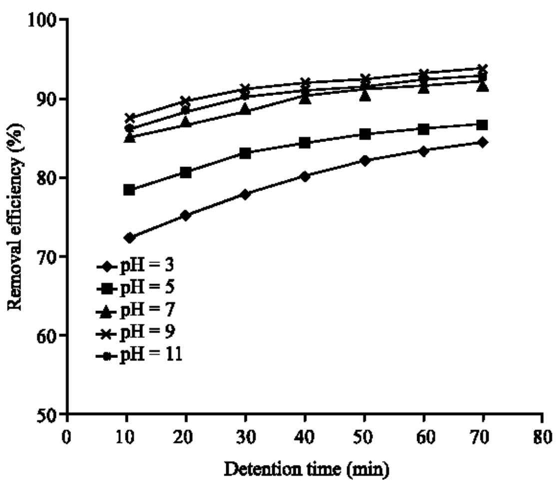

Fig. 4: Effect of initial pH on turbidity removal efficiency using iron electrodes (TDo = 200 NTU, CD = 4 A/m^2, Q = 40 L/h, As = 1.3 m^2, k = 1100 μS/cm)

there are oxidants such as oxygen, present in sufficient concentration, Fe^{+2} is oxidized in bulk solution to Fe^{+3} which is a good coagulant, hence, increase the removal efficiency (Vepsalainen, 2012).

Figure 3 and 4 also show that the removal efficiency for both electrodes increased as the detention time increased. A fast increase in the removal efficiency was occurred in the first 10 min and then a slight increase was observed as the detention time increased from 10-70 min. The removal efficiency depends directly on the concentration of metal ions (Al^{+3} and Fe^{+3}) produced on the electrodes. Based on Faraday's law increasing the

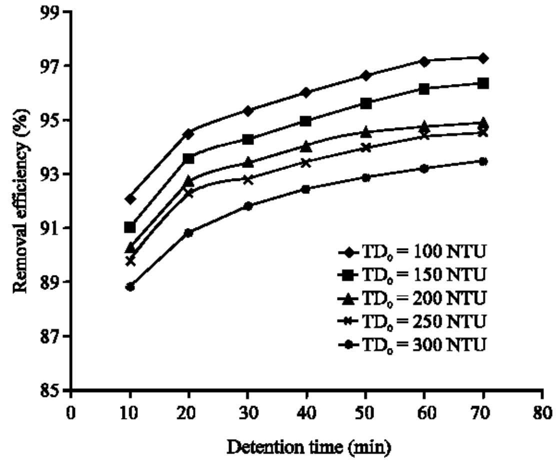

Fig. 5: Effect of initial turbidity on turbidity removal efficiency using aluminum electrodes (pH = 7, CD = 4 A/m^2, Q = 40 L/h, As = 1.3 m^2, k =1100 μS/cm)

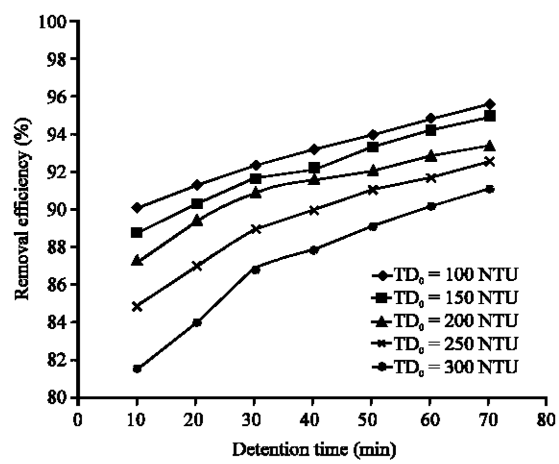

Fig. 6: Effect of initial turbidity on turbidity removal efficiency using iron electrodes (pH = 9, CD = 4 A/m^2, Q = 40 L/h, As = 1.3 m^2, k = 1100 μS/cm)

detention time leads to an increase in both the concentration of metal ions and the accumulation of hydroxide flocs. After 70 min detention time, the maximum removal efficiency using (Al) electrodes was found to be 95.54% at pH 7 while the maximum removal efficiency using (Fe) electrodes was found to be 93.43% at pH 9.

Effect of initial turbidity: The influence of initial turbidity on the removal efficiency was examined using synthetic waste waters with initial turbidity of 100, 150, 200, 250 and 300 NTU. The other operating parameters were kept constant. Figure 5 and 6 show that the removal efficiency of turbidity for both aluminum and iron electrodes decreased with increasing initial turbidity from 100-300 NTU. This result is explained as follows, constant amounts of aluminum or iron ions are dissolved from the anode at the same detention time and current density (according to Faraday's law) this means constant amounts of coagulants are produced in the electrocoagulation reactor for all initial turbidity values and the active surface area for these coagulants becomes totally saturated with molecules of pollutants with no more active surface left to capture further molecules at high initial concentrations (Hashim *et al.*, 2017). After 70 min and at initial turbidity of 100 NTU, the maximum removal efficiency was found to be 98.13 and 95.79% using aluminum and iron electrodes, respectively.

Effect of current density: Current density is one of the main important parameters which influences electrocoagulation process. According to Faraday's law, CD highly influences the dosage of coagulants and hence, the removal efficiency. Current density also influences the generation rate of bubbles:

$$X = \frac{ItM}{ZF}$$

Where:

- X = The released coagulants from the anode (g)
- I = The applied current (A)
- t = Detention time (sec)
- M = The Molecular weight of electrode metal (g/mol)
- Z = The number of electrons and F is Farada's constant (96487 C/mol)

The effects of different current densities 0.77, 1.54, 2.31, 3.1 and 4 A/m^2 on the removal efficiency were studied. The other parameters were kept constant.

The variation of turbidity removal efficiency with the studied current densities is shown in Fig. 7 and 8. It is well noted that turbidity removal efficiency increased noticeably when the current density increased from 0.77 4 A/m^2. It was found that after 70 min of detention time and at 4 A/m^2, the maximum removal efficiency was 98.13 and 95.79% for (Al) and (Fe) electrodes, respectively. The increase in the removal efficiency with increasing current density is attributed to the increase of the electrophoretic motion under the applied electrical field; beside to the increase of the dissolved coagulants (according to Faraday's law). The increase of both electrophoretic motion and the dissolved coagulants will enhance charge neutralization of pollutant particles which improve their removal. In addition as current density increases hydrogen bubble generation rate increases and

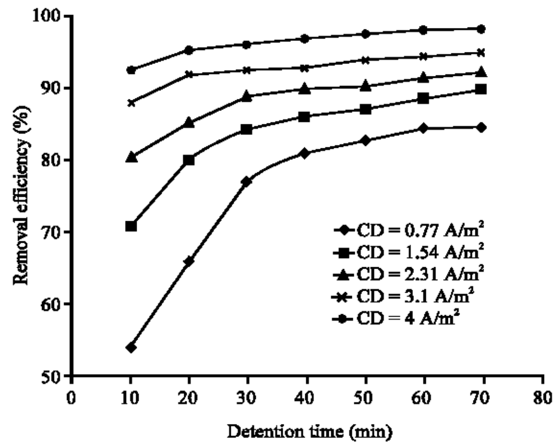

Fig. 7: Effect of current density on turbidity removal efficiency using aluminum electrodes (pH = 7, TD_0 = 100 NTU, Q = 40 L/h, As = 1.3 m^2, k = 1100 μS/cm)

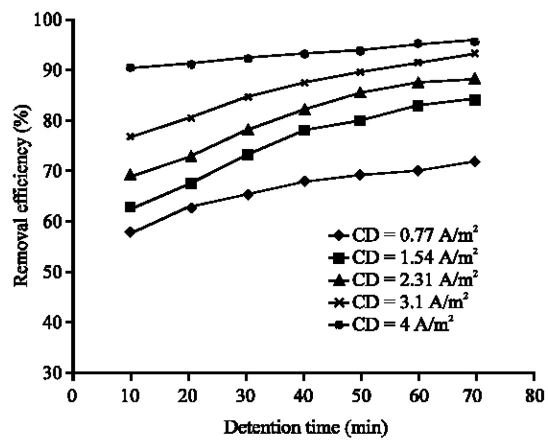

Fig. 8: Effect of current density on turbidity removal efficiency using iron electrodes (pH = 9, TD_0 = 100 NTU, Q = 40 L/h, As = 1.3 m^2, k = 1100 μS/cm)

bubble size decreases. The generated bubbles improve the mixing of Al^{+3} and Fe^{+3} hydroxides with pollutant molecules which could improve floc formation and their subsequent flotation (Chopra and Sharma, 2013; Merzouk *et al.*, 2009).

Effect of electrode surface area: Electrodes with three different surface areas 1.3, 0.6333 and 0.1828 m^2 were used to investigate the influence of electrode surface area. The surface area of 0.6333 m^2 was obtained by removing the two outer cylinders from the electrode while the surface area of 0.1828 m^2 was obtained by removing the four outer cylinders from he electrode. The other operating parameters were kept constant. As shown in Fig. 9 and 10,

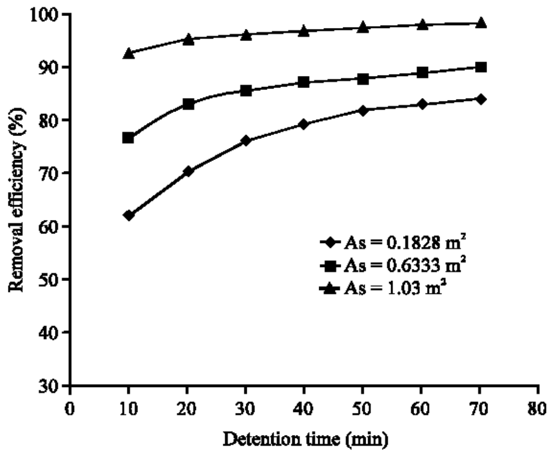

Fig. 9: Effect of electrode surface area on turbidity removal efficiency using aluminum electrodes (pH = 7, TD_0 = 100 NTU, CD = 4 A/m^2, Q = 40 L/h, k = 1100 μS/cm)

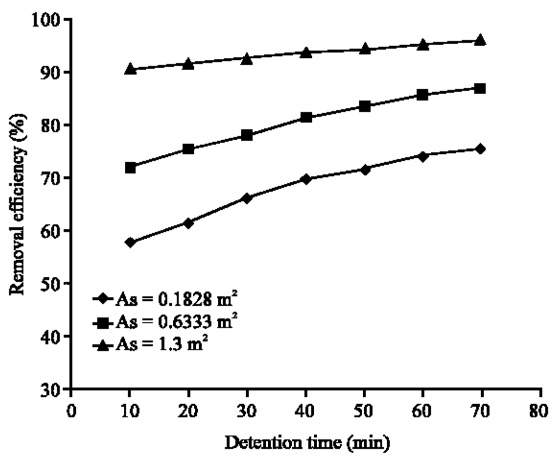

Fig. 10: Effect of electrode surface area on turbidity removal efficiency using iron electrodes (pH = 9, TD_0 = 100 NTU, CD = 4 A/m^2, Q = 40 L/h, k = 1100 μS/cm)

the removal efficiency of turbidity increased as the electrode surface area increased from 0.1828-1.3 m^2. After 70 min and at 1.3 m^2, the maximum removal efficiency was found to be 98.13 and 95.79% for aluminum and iron electrodes, respectively. The increase in the removal efficiency with increasing electrode surface area is due to the fact that, greater electrode surface area produces larger quantities of cations and anions from the anode and cathode which means greater quantities of aluminum or iron ions and greater number of (OH-). The greater electrode surface area increases the rate of floc's formation which in turn increases the removal efficiency.

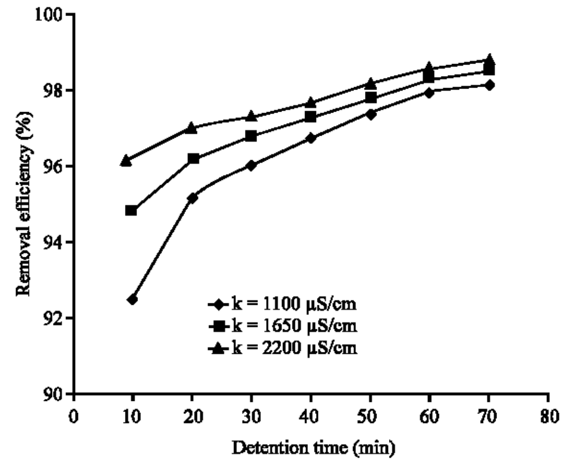

Fig. 11: Effect of conductivity on turbidity removal efficiency using aluminum electrodes (pH = 7, Td_0 = 100 NTU, CD = 4 A/m^2, Q = 40 L/h, As = 1.3 m^2)

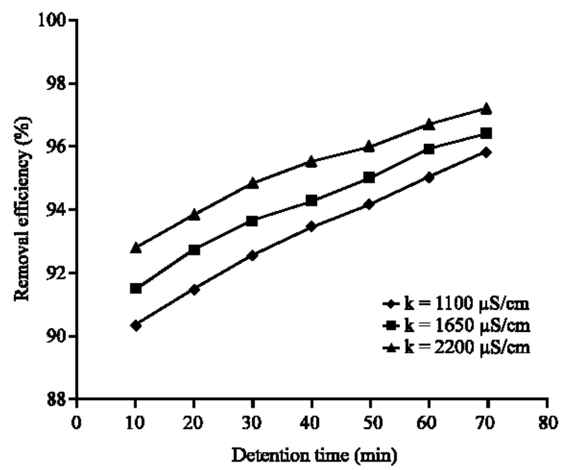

Fig. 12: Effect of conductivity on turbidity removal efficiency using iron electrodes (pH = 9, TD_0 = 100 NTU, CD = 4 A/m^2, Q = 40 L/h, As = 1.3 m^2)

Also, the increase in electrode surface area enhances the distribution of the coagulant in the reactor which enhances the removal efficiency (El-Ashtoukhy *et al*., 2016).

Effect of conductivity: To have a better understanding of the effect of conductivity on the removal efficiency, solutions with three different values of conductivity 1100, 1650 and 2200 μS/cm were used. Figure 11 and 12 show that the removal efficiency of turbidity using both Al and Fe electrodes increased slightly with increasing conductivity. For instance, after 70 min of detention time, the removal efficiency of turbidity using Al and Fe electrodes increased from 98.13-98.82% and from 95.79-97.15%, respectively when the conductivity increased from 1100-2200 μS/cm. These results are explained as follows increasing conductivity using NaCl, means increasing NaCl concentration which enhances the removal efficiency because the antipassive Cl^- ions can destroy the passive oxide layer that formed on the surface of the anode and hence increase the anodic dissolution rate of metal. Also, chloride anions could significantly reduce the adverse effects of other anions such as HCO_3^- and SO_4^{-2}. Indeed, the existence of carbonate anion would lead to the precipitation of Ca^{2+} ion. These can form an insulating layer on the surface of the cathode which could increase the ohmic resistance of the electrochemical cell (El-Ashtoukhy *et al*., 2016).

In addition increasing conductivity by addition of NaCl reduces the voltage at constant current due to the decrease of the ohmic resistance of the solution and hence energy consumption will be decreased. It is noted that after 70 min, the energy consumption decreased from 1.036-0.621 kW.h/m^3 and from 0.699-0.362 kW.h/m^3 for (Al) and (Fe) electrodes, respectively when the conductivity increased from 1100-2200 μS/cm.

CONCLUSION

The present research has investigated the removal of turbidity from synthetic waste water in a continuous electrocoagulation system. Two electrocoagulation reactors with a new configuration were used in the study. One of the reactors with aluminum electrodes and the other with iron electrodes. The new electrocoagulation reactor was proven to be efficient and economic as it reduced the energy consumption and enhanced mixing and mass transfer inside the reactor which reduced the need for external stirring device which requires extra power to work. The obtained results showed that the removal efficiency using Al and Fe electrodes is directly proportional to CD as conductivity and detention time. Contrarily, removal efficiency is reversely proportional to the initial turbidity. From the experimental results it was found that aluminum electrode is superior to iron in removal of turbidity with maximum efficiency of 98.82 and 97.15% for (Al) and (Fe) electrodes, respectively at the optimum conditions. The results also showed that fast increase in the removal efficiency was occurred in the first 10 min. Energy consumption is a very important economical parameter. The results showed that as the conductivity increased, energy consumption decreased. It was found that iron electrodes consumed less energy than aluminum electrodes with energy consumption of 0.621 and 0.362 kW.h/m^3 for aluminum and iron electrodes, respectively.

REFERENCES

Bensadok, K.S., S. Benammar, F. Lapicque and G. Nezzal, 2008. Electrocoagulation of cutting oil emulsions using Aluminium plate electrodes. J. Hazard. Mater., 152: 423-430.

Chopra, A.K. and A.K. Sharma, 2013. Removal of turbidity, COD and BOD from secondarily treated sewage water by electrolytic treatment. Appl. Water Sci., 3: 125-132.

DeZuane, J., 1997. Handbook of Drinking Water Quality. 2nd Edn., John Wiley & Sons, New York, USA., Pages: 565þ.

El-Ashtoukhy, E.S., A.A. Mobarak and Y.O. Fouad, 2016. Decolourization of reactive blue 19 dye effluents by electrocoagulation in a batch recycle new electrochemical reactor. Intl. J. Electrochem. Sci., 11: 1883-1897.

Elsayed, E.M., T.M. Zewail and A.A. Zaatout, 2013. Particulate solids removal from synthetic and real turbid water and waste water by electro coagulation using vertical expanded al anode. J. Chem. Eng. Process Technol., 4: 177-183.

Fagnekar, N.A. and S. Mane, 2015. Removal of turbidity using electrocoagulation. Intl J. Res. Eng. Technol., 1: 537-543.

Ghosh, D., C.R. Medhi and M.K. Purkait, 2008. Treatment of fluoride containing drinking water by electrocoagulation using monopolar and bipolar electrode connections. Chemosphere, 73: 1393-1400.

Ghosh, D., C.R. Medhi and M.K. Purkait, 2011. Techno-economic analysis for the electrocoagulation of fluoride-contaminated drinking water. Toxicol. Environ. Chem., 93: 424-437.

Giwa, S.O., S. Ertunc, M. Alpbaz and H. Hapoglu, 2012. Electrocoagulation treatment of turbid petrochemical waste water. Int. J. Adv. Sci. Technol., 5: 26-32.

Hashim, K.S., A. Shaw, R. Al-Khaddar, M.O. Pedrola and D. Phipps, 2017. Iron removal, energy consumption and operating cost of electrocoagulation of drinking water using a new flow column reactor. J. Environ. Manage., 189: 98-108.

Kobya, M., O.T. Can and M. Bayramoglu, 2003. Treatment of textile waste waters by electrocoagulation using iron and aluminum electrodes. J. Hazad. Mater., 100: 163-178.

Mansoorian, H.J., M. Ansari, E. Ahmadi and G. Majidi, 2016. Assessment of a continuous electrocoagulation on turbidity removal from spent filter backwash water. Arch. Hyg. Sci., 5: 102-110.

Merzouk, B., B. Gourich, A. Sekki, K. Madani and M. Chibane, 2009. Removal turbidity and separation of heavy metals using electrocoagulation-electroflotation technique: A case study. J. Hazard. Mater., 164: 215-222.

Mills, D., 2000. A new process for electrocoagulation. Am. Water Work Assoc. J., 92: 34-43.

Mollah, M.Y., P. Morkovsky, J.A. Gomes, M. Kesmez and J. Parga *et al*., 2004. Fundamentals, present and future perspectives of electrocoagulation. J. Hazard. Mater., 114: 199-210.

Mollah, M.Y.A., R. Schennach, J.R. Parga and D.L. Cocke, 2001. Electrocoagulation (EC)-science and applications. J. Hazard. Mater., 84: 29-41.

Paul, A.B., 1996. Electrolytic treatment of turbid water in package plant. Proceedings of the 22nd WEDC Conference on Reaching theUnreached, Challenges for the 21st Century, September 9-13, 1996, WEDC, New Delhi, India, pp: 286-288.

Rahmani, A.R., 2008. Removal of water turbidity by the electrocoagulation method. J. Res. Health Sci., 8: 18-24.

Vepsalainen, M., 2012. Electrocoagulation in the Treatment of Industrial Waters and Waste waters. VTT Technical Research Centre of Finland, Espoo, Finland, ISBN:9789513879402,.

Zaroual, Z., M. Azzi, N. Saib and E. Chainet, 2006. Contribution to the study of electrocoagulation mechanism in basic textile effluent. J. Hazard. Mater., 131: 73-78.