Wastewater Treatment Using Electrocoagulation

Rakhi M.S.

Assistant Professor, Division of safety and fire Engineering, School of Engineering,
Cochin University of Science and Technology, Kerala, India.

ABSTRACT

There are various techniques for the removal of water hardness each with its special advantages and disadvantages. The electrochemical or electrocoagulation method due to its simplicity has gained great attention and is used for the removal of various ions and organic matters. The present study aimed to investigate the efficiency of this technique in the removal of water hardness under different conditions. This experimental study was performed using a pilot plant. The applied pilot was comprised of a reservoir containing aluminum sheet electrodes. The electrodes were connected as monopolar and power supply was used for supplying direct electrical current. Sample water of hardness 370 ppm was used in the experiments. The efficiency of the system in three different pH, current and time intervals were determined. Results showed an efficiency of 95.6% for electrocoagulation technique in hardness removal. pH and current had a direct effect on hardness removal in a way that the highest efficiency rate was obtained in pH=10, the potential difference of 28 volts, current of 3 ampere and detention time of 60 minutes. Considering the obtained efficiency in the present study, the electrocoagulation technique may be suggested as an effective alternative technique in hardness removal.

Keywords: Electrocoagulation, Hardness removal, Aluminium sheet electrodes, Detention time, Electrochemical methods.

1. Introduction

Water hardness creates a lot of problems for life and industry. Except for calcium and magnesium, iron, manganese and strontium, and some other metals can cause water hardness too, but their amount in comparison to the amount of calcium and magnesium can be ignored.

Considering the problems of water hardness, its removal is essential. There are various techniques for the removal of water hardness, such as using chemical substances and ion exchange resins. Applying each of these techniques has undesirable effects on the quality of product water. In the process of ion exchange, sodium concentration of water increases that is harmful to patients with hypertension or cardiovascular diseases who have to consume sodium limit diet.

Ion exchange processes cannot be applied for the removal of water hardness in large water treatment plants. Using lime for softening causes an increase in permanent water hardness. On the other hand, a great amount of produced sludge causes clogging of filters and water distribution systems. Using these appliances requires skill and addition of a specified amount of lime and sodium carbonate to the system. In the process of liming, coagulants such as alum or ferric chloride are used to increase the weight of insoluble particles and consequently sedimentation velocity.

This technique in addition to its economic cost has desirable health effects such as increasing the risk of Alzheimer's disease, moreover, lime increases water pH. To improve the efficiency of chlorine in the process of disinfection, water pH after hardness removal should be decreased to <7.8 and this requires an increase in acid consumption. Coagulants in addition to increasing the amount of sludge production, increase the total solids in the effluents. The Adsorption process is also used for hardness removal. This process due to adsorbent loss during the process and the necessity of backwashing has also gained less attention. The use of membranes has the problem of

scaling and frequent membrane fouling. The electrochemical or electrocoagulation process due to its simplicity has gained great attention and is used in the removal of various ions and organic matters. This process includes a cell with a metal anode (mostly iron and aluminium) and uses direct electrical current. This process has three stages

1. Coagulants forming due to anode electrical oxidation.

2. Destabilizing pollutants and suspended substances and emulsion breaking.

3. Combining instable particles to form a floc.

Destabilization mechanisms in this process include electrical double-layer compression, adsorption and charge neutralization, enmeshment in a precipitate and inter-particle bridging.

If in this process M is considered as an anode, the following reactions will occur:

In Anode

$M_{(s)} \rightarrow M_{(aq)}^{n+} + ne^-$

$2H_2O + 2e^- \rightarrow 4H^+ + O_2 + 4e^-$

In Cathode

$M_{(aq)}^{n+} + ne^- \rightarrow M_{(s)}$

$2H_2O + 2e^- \rightarrow H_{2(g)} + 2OH$
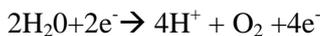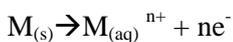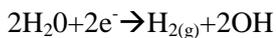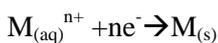
If iron and aluminium electrodes are used, Fe^{+3} and aluminium are produced. These metal ions after reaction with hydroxyl ions will produce metal hydroxides or poly-hydroxides. For instance, aluminium in water produces $Al(H_2O)_6^{3+}$, $Al(H_2O)_5OH^{2+}$, $Al(H_2O)4OH^{1+}$ or monomer or polymer strains of $Al(OH)^{2+}$, $Al_2(OH)_2^{4+}$, $Al_6(OH)_{15}^{3+}$, $Al_{13}(OH)_{34}^{5+}$. These compounds increase the elimination efficiency. The final compound of the eliminated matter by this process depends on parameters such as electrode type of matter, electrode shape. In recent decades, three - dimensional electrodes have been used (instead of two dimensional) that are suitable for the treatment of low concentration pollutants. In this process because of hydrogen release from cathode and oxygen release from the anode, flotation takes place. Moreover, the adsorption rate of produced hydroxides by this process is 100 times as much as hydroxides produced through chemical processes and they do not produce secondary pollutants. In addition to the above reactions, the following reactions may also occur in cathode in high acidity conditions:

$HCO_3 + OH^+ \rightarrow CO_3^{2-} + H_2O$

$CO_3^{2-} + Ca^{2+} \rightarrow CaCO_3$

$CO_3^{2-} + Mg^{2+} \rightarrow MgCO_3$
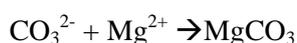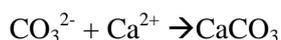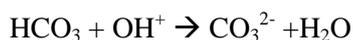
Calcium carbonate and magnesium carbonate are settled on the cathode. Usually, underground water contains a high concentration of hardness, nitrate, and fluoride either naturally or by agricultural activities and it seems that electrocoagulation process is suitable for removal of these matters. The study aimed to investigate the capability of electrocoagulation process in the removal of water hardness as an alternative technique and to determine the optimum pH and electrical potential.

2. Materials and methods

2.1 Experimental setup

1. 1- liter beaker.

2. Aluminium electrode-(200x30x10) mm.

3. DC power supply (voltage:-10 – 30V, current:-5 - 10 A).

4. 1 ammeter and 1 vo1tmeter.

Electrocoagulation consists of a pair of parallel metal plate electrodes separated by few millimeters with a low voltage applied at high current densities. The current flowing between the electrodes destabilizes the electrical charges which maintain suspensions of particles.eg clay, hydrocarbons. The process uses electricity and sacrificial plates to combine with contaminants in a waste stream, producing insoluble oxides and hydroxides - flocs - that are easily separated from the clear water. The hydrocarbons and insoluble compounds coalesce into larger compounds and float on the top. Reactions at the electrodes produce very fine H_2 and O_2 gas bubbles and highly chemically reactive radicles, these productions of gases do a good job as aerating the sample which indeed increases the efficiency.
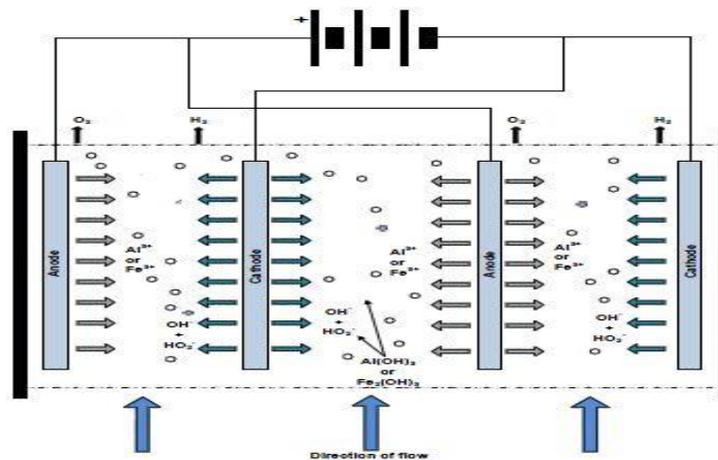
2.2 Procedure

The study was conducted by using a pilot plant with 6 aluminium electrodes, 5mm apart from each other. Pilot equipment included a power source (alternative to the direct current converter), six commercial aluminium electrodes with dimensions of 10×10 cm and a glass reservoir with an efficient volume of 1.0L. Electrodes were connected as monopolar. The hardness rate was determined by EDTA titrimetric method. To achieve the desired pH, sulfuric acid (1N) or NaOH (1N) were used pH rate was determined by the universal indicator. Water samples were prepared by adding MgSO4 salt for hardness and NaCl for proper conductivity. The total hardness of the water was 370 mg/L, as calcium carbonate. The prepared solutions with adjusted pH were injected into the reactor and sampling from the reactor was done at different time intervals of 20 minutes. After passage from filter paper, pH, total hardness and calcium hardness was measured. To determine the effect of current on process efficiency in this study, the efficiency of hardness removal in different electric currents of 1, 2 and 3 amps and pH of 3, 7 and 10 and time intervals of 20, 40 and 60 minutes were determined.

3. Results and Discussions

Figs 1, 2, and 3 represent the percent of total hardness and calcium hardness removal in different pH, electrical potential and time intervals. As it is seen, removal efficiency in pH=5.3, the electrical potential of 20 v and 60 minutes has been 47% (Fig. 1). In pH=7.2 the removal efficiency has increased and the maximum efficiency in this pH and in electrical potential of 20v and time 60 minutes has been 80.6% (Fig. 2). In pH=10.1, the highest removal efficiency was 95.6% that has been achieved in a potential difference of 20v and time 60 minutes (fig. 3).
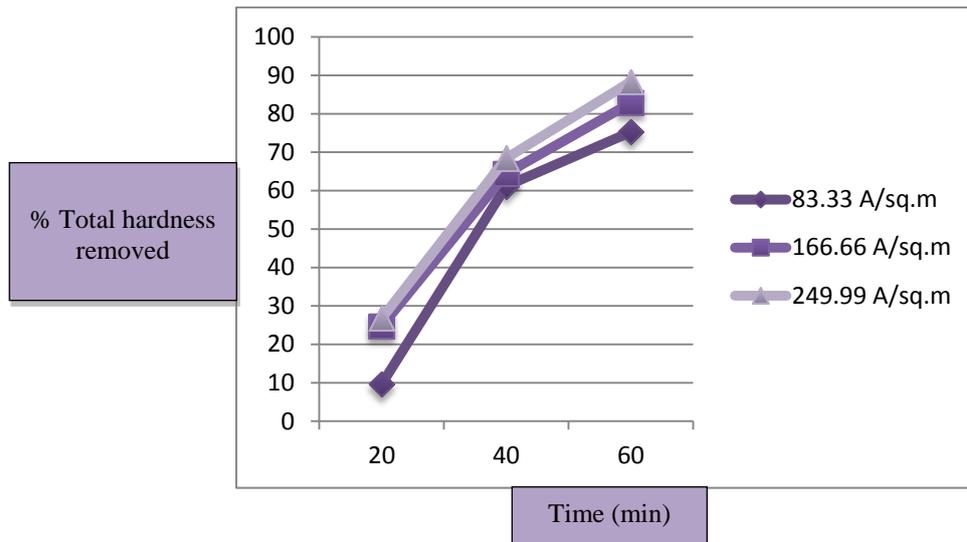

Fig.1. % total hardness VS time graph-1($_p$H-9)

The graph shown above is a plot between the percent of total hardness removed **vs** time for 3 different current flux (per electrode).
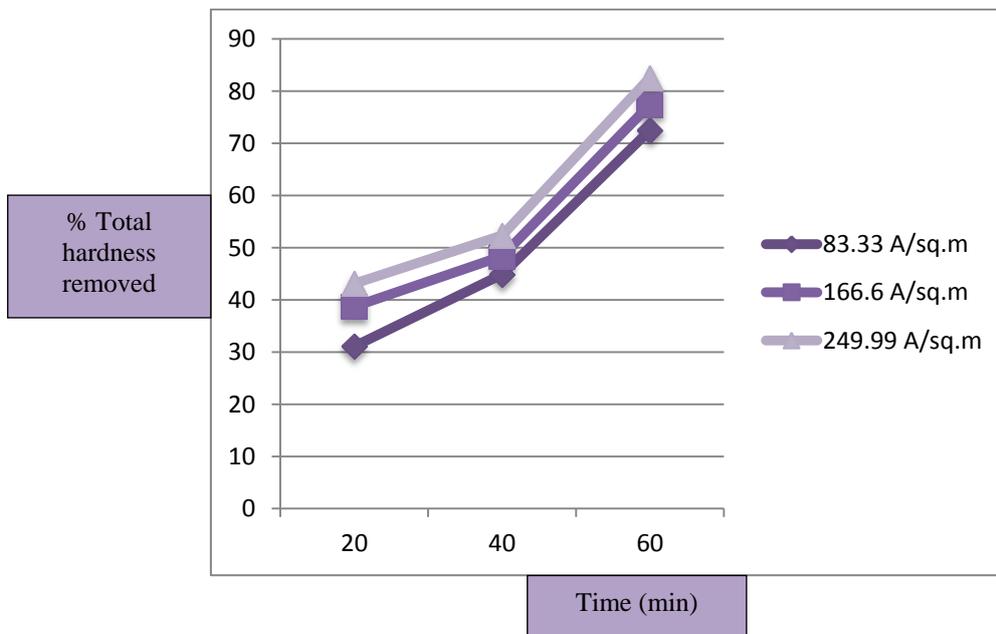

Fig.2. % total hardness VS time graph-1($_p$H-7)

The $_p$H maintained here for this sample is 9 which shows that it is basic, which is one of the parameters that change for I A the flux passing through one electrode is 83.88A/m^{2}similarly for 3A and 4A is 166.66A/m^2 and 249.9A/m^2 respectively. Now let us calculate the percentage of hardness removed between the interval of 20 min to 40 min. On

calibrating the following result was obtained:-For the flux of 83.88A/m^2 the efficiency of hardness removed between the interval of 20 min and 40 min is 51% and for the flux of 166.66A/m^2 and 249.9A/m^2 efficiency is 41% and 43% respectively. For the flux of 83.88A/m^2 the efficiency of hardness removed between the interval of 20 min and 40 min is 14% and for the flux of 166.66A/m^2 and 249.9A/m^2, the efficiency is 8% and 10% respectively.
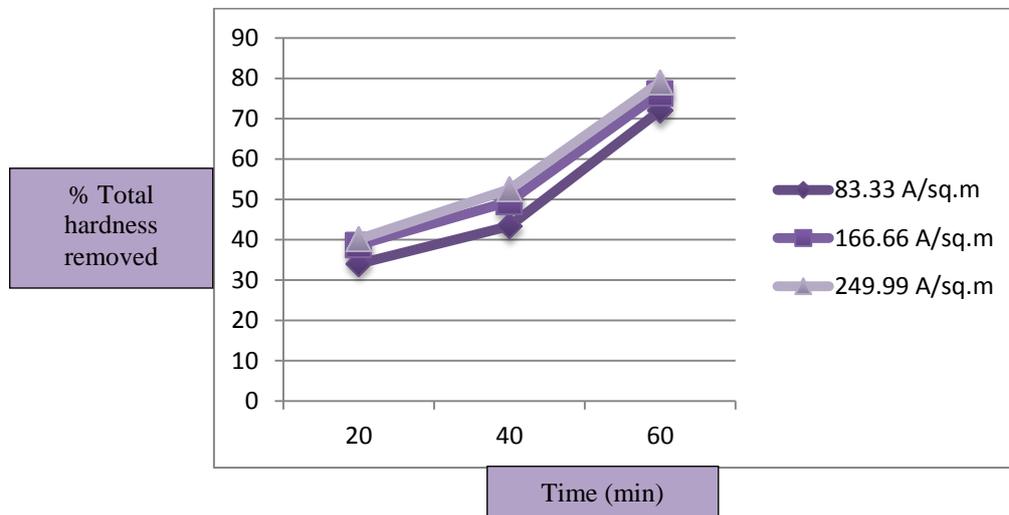

Fig.3. % total hardness VS time graph-1($_P$H-5)

For the flux of 83.88A/m^2 the efficiency of hardness removed between the interval of 20 min and 40 is 10% and for the flux of 166.66A/m^2 and 249.9A/m^2, the efficiency is 10% and 12% respectively.

3.1 Observations from graph

The quantitative analysis of efficiency in hardness removed by electrocoagulation for the basic medium is greater than that of the acidic and neutral medium.

For flux of 83.33A/m^2 and $_P$H 9, the efficiency is 51% (time -20 min to 40 min)

For flux of 83.33A/m^2 and $_P$H 7, the efficiency is 14% (time -20 min to 40 min)

For flux of 83.33A/m^2 and $_P$H 5, the efficiency is 10% (time -20 min to 40 min)

So this result clearly shows that the basic medium is the best suitable medium for electrocoagulation.

3.1.1 Effects of pH

With pH increase, the rate of hardness removal increase since the effect of pH on coagulants depends on the produced reactions on different conditions.

In neutral conditions:

$3Al_{(s)} + 8H_2O_{(1)} \rightarrow Al(OH)_{2(s)} + 2Al(OH)_3 + 4H_{2(g)}$

In acid conditions:

$2Al_{(s)} + 6H_2O_{(1)} \rightarrow O_{2(g)} + 4H_{2(g)} + Al(OH)_{2(s)}$

In alkali conditions:

$2Al_{(s)} + 6H_2O \rightarrow 2Al(OH)_{3(s)} + 3H_2O_{(1)}$

Here, Al (OH)$_3$ and Al (OH)$_2$ settle while, H$_2$ moves upward and causes flotation. As reactions show, in acidity condition Al (OH)$_2$ and alkali condition Al (OH)$_3$ are produced. Since Al (OH)$_3$ has higher weight and density, it settles faster and has higher efficiency. Therefore, it acts better in enmeshment in a precipitate. This fact has also been confirmed by Ghernaout in his study in 2008 on Escherichia coli removal from surface water by electrocoagulation method. Hence, based on the results of the present study and previous studies the electrocoagulation process can act as a pH moderator.

With pH increase, the rate of hardness removal increase since the effect of pH on coagulants depends on the produced reactions on different conditions.

In neutral conditions:

$$3Al_{(s)} + 8H_2O_{(1)} \rightarrow Al (OH)_{2(s)} + 2Al (OH)_3 + 4H_{2 (g)}$$

In acid conditions:

$$2Al_{(s)} + 6H_2O_{(1)} \rightarrow O_{2 (g)} + 4H_{2 (g)} + Al (OH)_{2(s)}$$

In alkali conditions:

$$2Al_{(s)} + 6H_2O \rightarrow 2Al (OH)_{3(s)} + 3H_2O_{(1)}$$

Here, Al (OH)$_3$ and Al (OH)$_2$ settle while, H$_2$ moves upward and causes flotation. As reactions show, in acidity condition Al (OH)$_2$ and alkali condition Al (OH)$_3$ are produced. Since Al (OH)$_3$ has higher weight and density, it settles faster and has higher efficiency. Therefore, it acts better in enmeshment in a precipitate. This fact has also been confirmed by Ghernaout in his study in 2008 on Escherichia coli removal from surface water by electrocoagulation method. Hence, based on the results of the present study and previous studies the electrocoagulation process can act as a pH moderator.

3.1.2 The effect of electric current

With an increase in electrical current, the efficiency of hardness removal increases. In high voltages, the size and growth rate of produced flocs increase and this, in turn, affects the efficiency of the process. By electric current increase the amount of oxidized aluminium increases and consequently hydroxide flocs with the high adsorption rate increase and this leads to an increase in the efficiency of hardness removal. On the other hand, by electrical current increase, the density of bubbles increases while their size decreases.

Since the effective surface and retention time of larger bubbles are less comparing to small ones, so density increase and bubble size decrease the flotation efficiency increases. Of course, sometimes surfactants are used to decrease the surface tension of solutions and consequently the size of bubbles. With a decrease in electrical current, the required time for achieving similar efficiencies increases. These findings are in line with the results of Ranta Kumar et al study in 2004 about arsenic removal by electrocoagulation method and the results of Bazrafshan et al study in 2007 about the capability of electrocoagulation method with aluminium electrodes in Cr^{6+} removal. Generally, the electrical potential of 28v is required for achieving the desired efficiency. Of course, the electrical conductivity of electrodes affects also efficiency. The rate of electrical conductivity has a direct relation with the distance of

electrodes. With increasing electrodes distance, electricity consumption increases that lead to an increase in removal efficiency.

3.1.3 The effect of retention time

An increase in retention time in the case of constant potential difference and pH, increases the efficiency of hardness removal and this is because of precipitation of flocs that cause the removal of hardness particles. Also, in this process the rate of mixing, affects efficiency since this mixing causes flocs growth and decreases retention time (Kim *et al*., 2005). The results show that most of the hardness has been removed at the beginning of the process and this has also been found by Kumar et al in their study about the efficiency of Arsenic removal, Chaudhary et al (2003) and Bazrafshan et al (2007) in their studies on Cr+6 removal by electrocoagulation process.

4. Conclusion

The results of the present study and other related studies show that the electrocoagulation process in comparison to other techniques has some important advantages such as simple equipment, convenient operation, lower retention time, decrease or no need for using chemical matters, rapid sedimentation of produced flocs and less sludge production. On the other hand it seems that the electrocoagulation process cannot be applied for removal of water hardness in large water treatment plants.

Declarations

Source of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing financial, professional and personal interests.

Consent to participate

Not Applicable

Consent for publication

We declare that we consented for the publication of this research work.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

References

[1] online:webhttp://www.kaselco.com/electrocoagulation/basics-of-electrocoagulation.html;22 th November.

[2] M. Malakootian, N.Yousefi "The efficiency of electrocoagulation process using aluminum electrodes in removal of hardness from water" *Iran. J. Environ. Health. Sci. Eng., 2009, Vol. 6, No. 2, pp. 131-136.*

[3] *Peter Holt, Geoffrey Barton and Cynthia Mitchell" electrocoagulation as a wastewater treatment" The Third Annual Australian Environmental Engineering Research Event. 23-26 November Castlemaine, Victoria.*

[4] Abbes, I. B., Bayoudh, S., M., Baklouti,(2008). The removal of hardness of water using sulfonated waste plastic, Desalination, 222: 81–86.

[5] APHA /AWWA /WEF, (1999). "Standard methods for examination of water and wastewater", 20 th ed, Washington DC, American Public Health Association Publication, 2340.

[6] Bazrafshan, E et al,(2008) . performance evaluation of electrocoagulation process for removal of chromium (VI)from synthetic chromium solutions using iron and aluminum electrodes, Turkish J.Eng .Env Sci, 32:59-66.

[7] Bazrafshan, E., Mahvi ,A.H., Nasseri, S., Shaighi, M., (2007). performance evaluation of electrocoagulation process for diazinon removal from aqueous environment by using iron electrodes, Iran. J. Environ. Health. Sci. Eng., 2(4):127-132.

[8] C.Y., Hua, S.L., Loa, W.H., Kuan ,(2003) . Effects of co-existing anions on fluoride removal in electro coagulation (EC) process using aluminum electrodes , Water Research ,37 (18): 4513–4523

[9] Chaudhary, A., Goswami, n., Grimes, N., (2003). Electrolytic removal of hexavalent chromium from aqueous solution, Journal of chemical technology and Biotechnology, 78 (8): 877 – 883.

[10] Daida ,P., (2005). Removal of arsenic from water by electro coagulation using Al – Al , Fe – Fe electrode pair systems and characterization of by product , UMI Microform , 1– 68.

[11] Doula, K.M.K., (2006). Removal of Mn^{2+} ions from drinking water by using Clinoptilolite and a Clinoptilolite–Fe oxide system, Water Research,40 (17):3167 – 3176.