Review of Studies on Hardness Removal by Electrocoagulation

Kumbhare Pooja

P. G. Student in Environmental Engineering, Department of Civil Engineering,
Walchand College of Engineering.
Sangli, Maharashtra, India

Dr. V. D. Salkar
Associate Professor, Department of Civil Engineering,
Walchand College of Engineering.
Sangli, Maharashtra, India

Abstract
Water is an important resource for the survival of life. The inadequate availability of surface water makes people depend on ground water for fulfilling their needs. However, ground water is generally too hard to satisfy the requirements for domestic as well as industrial applications. Removal of hardness involves various techniques such as lime soda process, ion exchange, reverse osmosis, nano-filtration, distillation, and, evaporation etc. These techniques have individual problems such as high annual operating cost, sediment formation on membrane, sludge disposalproblem etc.Electrocoagulation (EC) is being explored as modern and cost-effective technology to cope up with the growing demand of high water quality at consumer end. This review study focuses onvarious literature that has been dedicated to utilizing electrocoagulation for water treatment. This review attempts to highlight the main achievement in the area and outline the advantages of EC process to broaden its range of application.

Keywords: Groundwater treatment, Hardness removal, Electrocoagulation, Continuous process, batch process.

Introduction

Water is one of the basic needs for human being and the essential element for the development of any area. Groundwater is one of the most valuable resources. The inadequate availability of surface water makes people depend on ground water resources to fulfill their needs. Ground water is the major source of water supply for drinking purposes in most parts of India. [1, 2].

Groundwater forms an important source of fresh water supply throughout the world, as it is not only essential for the lives of animals and plants, but also occupies a unique position in industries. Groundwater is a source of drinking water for at least 50% of the world population. Groundwater gets polluted as a result of human activities including extensive use of pesticides, herbicides and fertilizers, leaking fuel and chemical tanks, industrial chemical spills, drainage of house hold chemicals and badly managed landfills etc. Due to the pollution, safe drinking water scarcity is becoming a significant problem throughout the world.

Among the various problems water hardness creates a lot of problem for life and industry. There are various techniques for the removal of water hardness, such as using chemical substances, ion exchange resins, reverse osmosis and nano-filtration. Applying each of these techniques has some problem such as increased sludge, permanent water hardness, annual high operating cost, sediment deposition on membrane which requires an effluent post treatment and disposal of residual sludge. In recent years, strict environmental regulations have called for new processes for efficient and adequate treatment of waters with relatively low operating costs. [7]

At this point, the electrocoagulation (EC) process has attracted a great deal of attention in treating water due to its versatility and environmental compatibility. This method is characterized by simple equipment, easy operation, a shortened reactive retention period, a reduction or absence of equipment for adding chemicals, and decreased amount of precipitate or sludge which sediments rapidly. EC has been proved to be an efficient method for the treatment of water. It was tested successfully for treating river water, ground water, drinking water, and waste water such as municipal wastewater, textile wastewater, poultry manure wastewater, landfill leachate etc. So, in the present study attempts are made to evaluate efficacy of EC for hardness removal.[3].

Electrocoagulation (EC) mechanism

It involves dissolution of metal from the anode with simultaneous formation of hydroxyl ions and hydrogen gas occurring at the cathode. Highly charged cations destabilize any colloidal particles by the formation of polyvalent polyhydroxide complexes. These complexes have high adsorption properties, forming aggregates with pollutants. Evolution of hydrogen gas aids in mixing and hence flocculation. Once the floc is generated, the electrolytic gas creates a flotation effect removing the pollutants to the floc - foam layer at the liquid surface. There are a variety of ways in which species can interact in solution:

1. Migration to an oppositely charged electrode (electrophoresis) and aggregation due to charge neutralization.
2. The cation or hydroxyl ion (OH-) forms a precipitate with the pollutant
3. The metallic cation interacts with OH- to form a hydroxide, which has high adsorption properties thus bonding to the pollutant (bridge coagulation
4. The hydroxides form larger lattice-like structures and sweeps through the water (sweep coagulation).
5. Oxidation of pollutants to less toxic species.
6. . Removal by electroflotation and adhesion to bubbles.

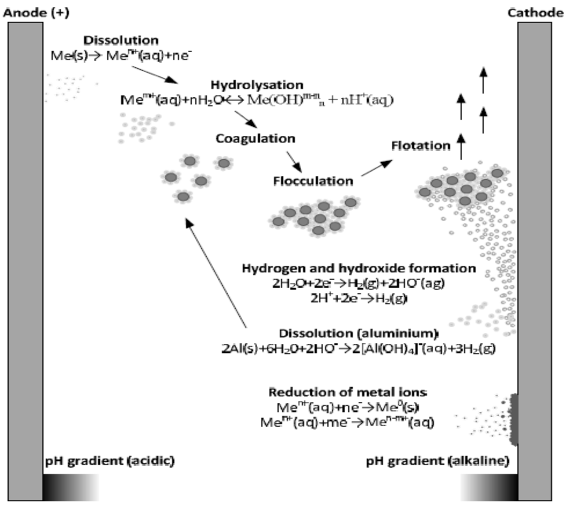

Figure 1: Main Mechanism of EC
(Source: Rahmani et al.,(2008))

Previous works

Malakootian et al., (2009)studied the Efficiency of Electrocoagulation Process Using Aluminum Electrodes in Removal of Hardness from Water**.** In this study, efficiency of EC in removal of water hardness under different condition was investigated. Effects of operating parameters for the EC process such as electrode type (Al), initial pH (5.3 - 10.1), electric potential (5 - 20 V), electrode spacing (0.5 - 3cm) and operating time (0 - 60 min.) were evaluated for optimumoperating conditions. Ground water of Kerman (southeast of Iran) was used in the experiments. Electrodes were connected as monopolar and batch process was adopted. In order to achieve desired pH, sulfuric acid (1N) or NaOH (1N) were used. The highest removal efficiencies for hardness removal obtained forAluminum (Al) electrodes at the optimum conditions (20 V, 60min. and pH 10.1, spacing 1 cm) was 95.6% .The effect of the electric potential, pH, electrode spacing on the performance of the electrocoagulation was studied and significant effect of the pH on the performance of the Electrocoagulation was noticed

Mansoorian et al., (2010) conducted study on "Performance Evaluation of Electrocoagulation Process Using Iron-rod Electrodes for Removing Hardness from Drinking Water". The purpose of this study was to investigate the efficiency of EC process in removal of water hardness through iron-rod electrodes in different circumstances. In this study Experimental water sample was taken from waterdistribution network of Anar City located in northwestern part of Kerman Province, Iran. Effects of operating parameters for the EC process such as electrode type (Fe), initial pH (3 - 10), electric potential (6 - 24 V), electrode spacing (2cm) and operating time (0 - 60 min.) were evaluated for optimum operating conditions using batch process. The pH of sample was adjusted using sulfuric acid and sodium hydroxide. The maximum efficiency of hardness removal was obtained in pH 10.0, voltage of 12 V and reaction time of 60 min is 97.4%.

Khairi et al., (2011) has worked on Hardness Removal from Drinking Water Using Electrochemical Cell. In this work the tap water taken from Aljadriya municipal water network-Baghdad. A parallel plate electrochemical cell was constructed using two graphite electrodes as anode and three aluminum electrodes as cathodes; batch process was adopted in this study. Operating parameters for the EC process such as electrode type (Al and graphite), initial pH (7 - 8), electric potential (10 - 28.5 V), electrode spacing (2- 4 cm) and operating time (0 - 60 min.) were evaluated for optimum operating conditions using batch process. Removal efficiency of 85% was obtained at pH of 7.5and electrical voltage of 28.5V with detention time of 60 minutes. The effect of electric potential, electrode spacing and electric power consumption on hardness removal by electrocoagulation was studied.

Brahmi et al., **(2013)** have worked on "Use of Electrocoagulation with Aluminum Electrodes in Tunisian Phosphate Mining Process Water". The aim of this study was to evaluate electrocoagulation using (Al) electrodes for removal of non-carbonate hardness in phosphate mining process water. Effects of operating parameters for the EC process such as electrode type (Al), initial pH (3 - 10), current density (7.4 - 22.2 mA/cm^2), electrode spacing (1-4cm) and operating time (0 - 60 min.) were evaluated for optimum operating conditions using batch process. Examination of process parameters identified optimal conditions for hardness removal at pH 7, a current density of 22.2 mA/cm^2, an inter-electrode distance of 2 cm and operating time of 30 min with removal efficiency of 83.8%. Effect of various operating parameters such as conductivity, current density, and operating time was investigated.

Saravanan et al., (2014) studied Removal of Total Hardness by Electrocoagulation Process. The purpose of this study was to investigate the efficiency of EC process in removal of water hardness through aluminum electrodes. Groundwater was taken from Jaffna peninsula, which is in Shri Lanka, having

International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 10, Number 1 (2017)
© International Research Publication House http://www.irphouse.com

hardness of 883mg/lit. Effects of operating parameters for the EC process such as electrode type (Al), initial pH (7 - 10), electric potential (5 - 20 V), electrode spacing (1cm) and operating time (0 - 60 min.) were evaluated for optimum operating conditions using batch process. The maximum removal efficiency of 60 % was obtained at pH (7.38), operating time of 60min. and voltage (20 V). Effect of various operating parameters was studied and amount of residual aluminum in the water after electrocoagulation process was investigated.

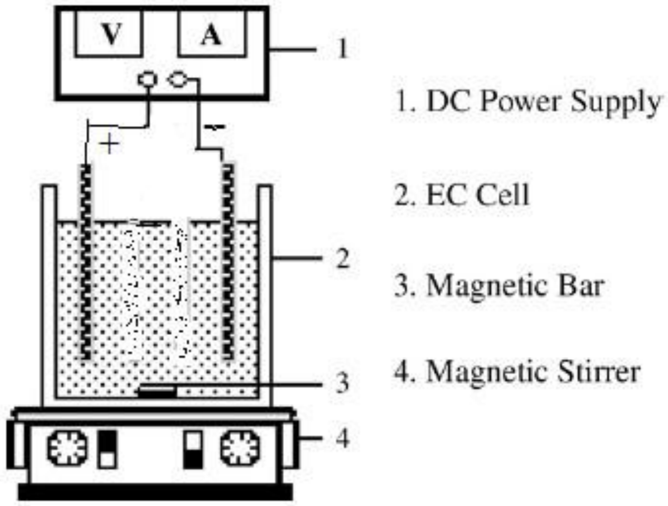

Figure 2. Bench scale EC reactor (batch process) (Source: Saravanan et al., (2014))

Zhao et al., **(2014)** conducted study on "Hardness, COD and Turbidity Removals from Produced Water by Electrocoagulation Pretreatment Prior to Reverse Osmosis Membranes". Produced water comes as a byproduct during recovery of natural gas and crude oil from onshore and offshore production operation, it is a mixture of organic and inorganic material (oil and grease, metal ion large amount of hardness etc.) .The aim of this study was to refine the hardness removal (together with chemical oxygen demand (COD) and turbidity) from the produced water by a pilot-scale electrocoagulation (EC) system to mitigate the scaling and fouling of Reverse Osmosis (RO) membrane. Effects of initial pH, current density and electrolysis time on pollutant removal were investigated. Operating parameters such as pH (3.64-10.36), current density (1.82-9.29 mA/cm^2) and electrolysis time (13.2-46.8 min.) Were investigated to find out optimum condition using batch process. The refined operating conditions were pH of 7.36, current density of 5.90 mA/cm^2, and reaction time of 30.94 min to maximize the hardness removal at 85.81%, COD at66.64%, and turbidity at 93.80%.

Sharma et al., **(2016)** have worked on "Ground Water Assessment and Its Electro Chemical Treatment". In this study, groundwater quality assessment and its electrochemical treatment was carried in Dwarka district, Delhi. Water samples were collected and analyzed to find out its suitability for drinking purpose. Different parameters such as pH, electrical conductivity, total dissolved solids (TDS), total hardness, nickel, chromium were analyzed. They collected and analyzed 26 samples of the ground water from the bore wells in Dwarka and nearby areas. Effects of operating parameters for the EC process such as electrode type (Al), initial pH (7.16-7.38), electric current (0.5-0.75Amp),) and operating time (0 - 150 min.) with initial hardness of water 3900 mg/lit were evaluated for optimum operating conditions using batch process. The maximum removal efficiency was obtained at pH (7.36), current (0.75Amp) and operating time of 150 min. was 58.97%. The effect of current density on hardness removal by electrocoagulation from groundwater was studied and it was noticed that both hardness removal was affected by current density and time intervals.

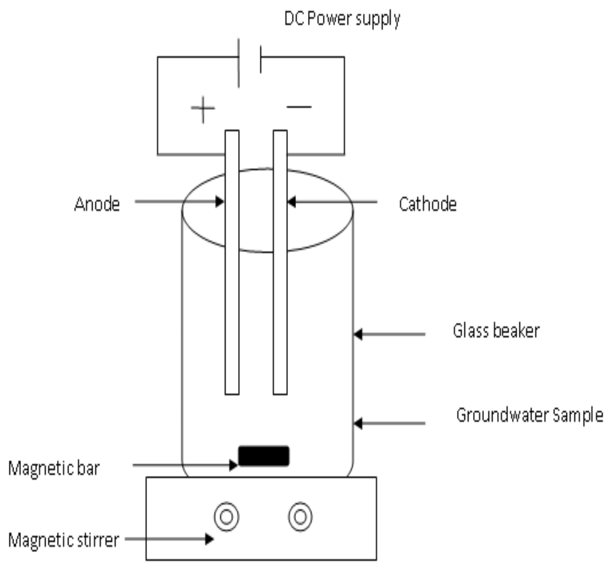

Figure 3. Schematic Diagram of Electrocoagulation Cell (Source: Sharma et al., (2016))

Conclusions

- As the conventional wastewater treatment system is lacking in the treatment processes new alternatives for the treatment of water and wastewater at its source of generation are emerging.
- At this point, the electrocoagulation (EC) process has attracted a great deal of attention in treating water due to its versatility and environmental compatibility.
- Research on various application of EC has been conducted worldwide to treat water, waste water, heavy metals and the range of feasible application of EC is expanding due to its high removal efficiency of various pollutants.
- Most of the authors conducted their EC studies using small laboratory scale reactor in batch mode. Optimal treatment current was found to be in range of 20-80 mA/cm2 in most of studies.
- In the studies discussed above EC has been found to be feasible, economical in treatment of various types of water, waste water and heavy metals with promising result due to this the interest on EC is seems to be rise.

Table 1. Other Previous Studies Related to Hardness Removal

Reference	Water sample	Current density (mA/cm^2)	Cell voltage (V)	Electrode material & electrode connection	Mode	Distance between electrodes (cm)	Treatment efficiency
Malakootian. M. and N.Yousefi, (2009)	Tap water	22.4	20	Al/Al plate Monopolar	Batch	1	80.6%
Daneshvar et al., (2010)	Brackish water hardness	22	20	Fe/Fe plate Monopolar	continuous	0.5	90.6%
Agostinho et al., (2010)	Ground water	36	25	Steel/Al plate Monopolar	Batch	1	80%
Sanfan and Qinlai (2013)	Brackish water: hardness	30	23	Al/Fe plate Monopolar	Batch	1	80%
Gnusin et al (2013)	Ground water	50	30	Steel/Al plate Monopolar	Batch	1	80.5%

Table 2. Recent Applications of EC in the Treatment of Wastewater

Reference	Waste Water sample	Current density (mA/cm^2)	Cell voltage (V)	Electrode & Electrode Connection	Mode	Electrode Spacing (cm)	Treatment efficiency
Kongjao et al., (2008)	Tannary waste water	22.4	20	Fe / Fe plates monopolar	Batch	0.5	COD- 95% BOD-96%
Zodi et al., (2010)	Textile wastewater	80	35	Al / Al plates monopolar	Batch	0.2	COD- 70% TS – 50%
Hanafi et al., (2010)	Olive mill waste water	250	-	Al / Al plates monopolar	Batch	0.3	COD-84% Color- 92%
Kushwaha et al., (2010)	Dairy waste water	270	-	Fe / Fe plates monopolar	Batch	0.1	COD –70% TS - 48 %
Valero et al., (2010)	Almond industry wastewater	50	-	Al/Fe plate Monopolar	Batch	0.1	COD –81% BOD_5 80%
Maghanga et al., (2011)	Tea factory wastewater	45	-	Steel plate Monopolar	Batch	0.5	COD- 91% BOD- 84%
Ubale and Salkar (2017)	Textile wastewater	60	35	Al / Al plates Mono-polar	Continuous	1	COD-93.3%

Table 3. Recent Applications of EC in the Treatmnt of Water Containing Heavy Metals

Reference	Water Sample	Current Density (mA/cm^2)	Cell Voltage (V)	Electrode & Electrode Connection	Mode	Electrode Spacing (cm)	Efficiency
Kobya et al. (2010)	Contaminated groundwater (As)	25	-	Al/Fe plate Monopolar	Batch	1.3	95%
Ghosh et al., (2011)	Contaminated drinking water (Fe)	22.4	22	Al / Al plates monopolar	Batch	0.5	92%
Vasudevan et al.,(2011)	Drinking water containing (boron)	22	20	Steel plate Monopolar	Batch	0.5	70%
Behbahani et al. (2012)	Water containing (fluoride)	21.1	-	Al / Al plates monopolar	Batch	0.3	95%
Bhatti et al., (2013)	Water containing (copper)	22	20	Al / Al plates monopolar	Batch	1.5	81%

References

[1] Malakootian M. and Yousefi N., (2009), "Efficiency of Electrocoagulation Process Using Aluminum 1 [1] Electrode in Removal of Hardness from Water." *Desalination*, 6, 131-136.

[2] Mansoorian H., Malakootian M. and Moosazadeh M., (2010), "Performance Evaluation of Electrocoagulation Process Using Iron Electrode for Removing Hardness from Drinking Water." *Desalination*, 255, 67-71.

[3] Khairi K., Ghazi N. and Mohammed A., (2011), "Hardness Removal from Drinking Water Using Electrochemical Cell." *Egg. & Tech. Journal*, 33 (1), 78- 88

[4] Brahmi K., Bouguerra W., Hamza B., Zied T. and Mouna L., (2013), "Use of Electrocoagulation with Aluminum Electrodes to Hardness in Tunisian Phosphate Mining Process Water*." Indian Journal of Environmental Protection*, 34(7), 529-533

[5] Saravanan S. and Thushyanth M., (2014), "Removal of Total Hardness by Electrocoagulation Process." *Desalination*, 59(3), 355-367.

[6] Zhao S., Haiyan F., Guohe H., and Guanhui C., (2014), "Hardness, COD and turbidity Removal from Produced Water by Electrocoagulation pretreatment prior to Reverse Osmosis Membrane." *Desalination*, 344, 454-462

[7] Sharma S. and Acharya S., (2016), "Ground Water Assessment and its Electro chemical treatment." *4th International Conference on Recent Innovations in Science Engineering and Management*, 77-85

[8] M. Kobya, F. Ulu, U. Gebologl Oncel, "Treatment of Potable Water Containing Low Concentration of Arsenic with Electrocoagulation: Dif- ferent Connection Modes and Fe-Al Electrodes," *Se- paration and Purification Technology*, Vol. 77,

[9] E. Butler, Y.-T. Hung, R. Y.-L. Yeh and M. S. Al Ahmad, "Electrocoagulation in Wastewater Treatment," Water, Vol. 3, No. 2, 2011, pp. 495-525.

[10] S. Zodi, O. Potier, F. Lapicque and J. Leclerc, "Treatment of the Textile Wastewaters by Electrocoagulation: Effect of Operating Parameters on the Sludge Settling Characteristics," *Separation and Purification Technology*, Vol. 69, No. 1, 2009, pp. 29-36.

[11] G. Chen, "Electrochemical Technologies in Wastewater Treatment," *Separation and Purification Technology*, Vol. 38, No. 1, 2004, pp. 11-41.

[12] Brahmi K, Bouguerra W, Hamrouni B, Elaloui E, Loungou M, Tlili Z(2015) Investigation of electrocoagulation reactor design parameterseffect on the removal of cadmium from synthetic and phosphate industrial wastewater.

[13] Kumar PR, Choudhary S, Khilar KC, Mahajan SP (2015) Removal of arsenic from water by electro coagulation. *Chemosphere55*:1245–1252.

[14] R. M. Makdisi, "Tannery Wastes Definition, Risk Assess- ment and Cleanup Options, Berkeley, California," *Journal of Hazardous Materials*, Vol. 29, No. 1, 1991, pp. 79-96.

[15] L. Szpyrkowicz, S. N. Kaul and R. N. Neti, "TanneryWastewater Treatment by Electro-Oxidation Couple a Biological Process*," Journal of Applied Electrochemistry*, Vol. 35, No. 4, 2005, pp. 381-390

[16] Ubale M. A. and Dr. Salkar V. D., "Experimental study on electrocoagulation of textile wastewater by continuous horizontal flow through aluminum baffles". *Korean J. Chem. Eng.*, In press (2017)