

# Laboratory Electrocoagulation using Carbon Electrodes and Comparative Coagulation Studies

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**Abstract**—Chemical coagulation is commonly used in raw water and wastewater treatment plants for the destabilisation of pollutants so that they can be removed in the subsequent segregation processes. But in the past decade or so, the technology of electrocoagulation has been recommended for the treatment of raw waters and wastewaters in many countries. With this technology, ions which are produced on the electrodes via electrolysis take part in the purification process of water. In addition to this main reaction, certain side reactions take place in the electrolysis setup cell, such as hydrogen bubble formation and the consequential reduction of pH. In this research, basic laboratory setup of electrocoagulation has been demonstrated, investigating the applications of electrocoagulation in lake water and wastewater from various local sources. For this research, carbon (graphite) electrodes have been used rather than iron and aluminium which are otherwise commonly used, and hence the results, merits and demerits have been discussed. Also the results of electrocoagulation have been compared with more conventional laboratory coagulation processes.

**Keywords**—*electrocoagulation; wastewater treatment; electrolysis; carbon electrodes; chemical coagulation*

## I. INTRODUCTION

There has been a deluge of demand for new water treatment technologies recently as the world's population is increasing and major fresh water sources are being polluted. This is either due to the lack of proper funding by the government or dearth of appropriate know-how for water purification. Since industries play a major part in the development of these countries, these limited water sources are being consumed at a very high rate. Moreover, industries have to acquiesce to lower quality raw water as a higher proportion of fresh water is required for human consumption at a municipal and a domestic level. Wastewater treatment technologies used in both municipal and industrial applications have to be further developed. Chemical coagulation and flocculation are important traditionally used water purification methods and are common as a part of most water purification systems all around the world for the removal of pollutants [1]. Being chemical processes, their main function is to enhance particle separation in the subsequent processes. In order to understand destabilisation of particles by coagulants and

flocculants, it is crucial to understand the mechanisms which stabilise particles in aqueous solutions. The most commonly used coagulants are usually salts of higher valence cations (Aluminium ( $Al^{3+}$ ) or Iron ( $Fe^{3+}$ )), such as sulphates and chlorides. Some examples of coagulants are Aluminium Sulphate ( $Al_2(SO_4)_3 \cdot 14H_2O$ ) [2]. Polyaluminium Chloride ( $Al(OH)_x(Cl)_y$ ) and Ferric Chloride ( $FeCl_3$ ) [3]. Hydrolysis products are formed in these metal salts in the water depending on the chemical properties of water. Metal cations and hydroxides destabilise colloid pollutants in water by reducing repulsion forces between the colloids and by entrapping particles in the sludge.

As an advanced alternative to chemical coagulation, electrocoagulation (EC) has been suggested in pollutant removal from raw water and wastewater. From earlier studies, electrocoagulation may prove to be not only feasible and environmentally-friendly, but also technically and economically superior to conventional technology like chemical precipitation [4]. Metal cations are released into water through dissolving metal electrodes and the flocculated material can be removed from the water by beneficial side reactions [5]. However, there are some detrimental side reactions also, such as deposition of metal salts on the electrode surface, which may cause deterioration of removal efficiency in the long run and hence an increase in the maintenance costs. As in the case of chemical coagulation with metal salts, aluminium or iron cations and hydroxides are the active compounds in electrocoagulation. Chemical coagulation and electrocoagulation have fundamentally similar destabilisation reactions. Hence it is clear that electrocoagulation has a lot of scope and has the capability to remove a large range of pollutants under a variety of conditions ranging from: suspended solids [6], heavy metals [7], petroleum products [8], colour from dye-containing solutions [9], aquatic humus [10] and defluoridation of water [11].

## II. ELECTROCOAGULATION

A colloid is a microscopic particle, with finely divided solids that remain dispersed in a liquid for a long time, necessarily having at least one dimension in the range of 1 nm to 10  $\mu\text{m}$ . The combined surface area of colloids in dispersions is large due to their small size and therefore surface properties play an important role in their characteristics [5]. Colloids are said to be stable in aqueous solutions when their aggregation or sedimentation is so slow that they make virtually stable dispersions. This is important when considering raw water or wastewater treatments because these particles cannot be removed by sedimentation in a reasonable period of time.

The first electrocoagulation plant was built in London in 1889 for the treatment of municipal sewage [13]. Matesson et al. (1995) describe an 'Electronic coagulator', a device of the 1940's, which electrochemically dissolved aluminium (from the anode) into the solution reacting this with the hydroxyl ion from the cathode to form aluminium hydroxide [12]. In spite of some promising results, the success of this technology has been finite due to long reaction time and disadvantageous side reactions. However, due to the demand of alternate water treatment methods in the recent years, there has been renewed scientific, economic and environmental interest in the electrocoagulation technology.

Stability (or instability) of colloids in water is a balance between the repulsive electrostatic force which is due to overlapping double layers and attractive London-van der Waals force which in turn is due to permanent/temporary dipoles [5]. The theory of Derjaguin-Landau Verwey-Overbeek (DLVO) estimates these energies of attraction and repulsion [12]. When electricity is passed, ions go through the solution and these basically act as counter-ions for the charged contaminants. And hence, the electrostatic particles coagulate.

### A. Side Reactions

In addition to ion production, other electrochemical reactions can also take place in the system:

- Hydrogen formation at the cathodes, shown by frothing around the positive electrode.
- Decrease of pH due to the formation of hydrogen ions.
- Negative electrode disintegrates because it is the sacrificial electrode.

## III. OBJECTIVES

The following are the objectives of this experiment.

- To study the efficiency of carbon electrodes.
- To study the effect of the variation of voltage, V in the efficiency of electrocoagulation.
- To study the difference between electrocoagulation and chemical electrocoagulation and do comparative studies, with respect to the concentration of contaminants removed.

- To see the change in pH of the water undergoing electrolysis, and hence its effect in the purification of water.

## IV. SETUP

### A. Electrodes used

Electrodes which produce coagulants into water are made from either iron or aluminium. In this research, carbon electrodes have been used for producing ions. This has a very prominent effect on the system, since graphite electrodes don't give any coagulant, but gives only ions for the destabilization of the dissolved contaminants.

Although carbon materials used in electrochemistry share some of the electronic properties of metals, their structures and chemistry differ dramatically from all metallic electrodes. The graphite structure consists of ideally infinite sheets of 'graphene'. The carbon atoms in graphite, stacked like parallel sheets of chicken wire, are all  $sp^2$  hybridized. Graphite electrodes are used for the following reasons [14]:

- 1) Easy availability of different conducting allotropes, especially graphite which was for this experiment taken from battery cells.
- 2) The strong covalent bonds within carbon materials and to a variety of surface modifiers.
- 3) Low cost, especially of batteries with graphite electrodes. Metal electrodes, namely aluminium, iron, titanium etc. are relatively very expensive.
- 4) Easy availability of batteries in all departmental stores and supermarkets
- 5) Good thermal and electrochemical stability.
- 6) Good fluid permeability.
- 7) They are chemically inert and they have very good electrical conductivity.
- 8) Wide potential window.

### B. Construction of the Electrocoagulation cell

Electrocoagulation systems are typically constructed of plate electrodes and water flows through the space between the electrodes. There are several methods how electrodes can be arranged in the electrocoagulation setup. Flow between the electrodes can follow a vertical or horizontal direction. Broadly the setup of electrodes can be classified as monopolar or bipolar [15].

As shown in Fig. 1, all anodes are connected to each other and similarly all cathodes are also connected to each other in monopolar systems. In the bipolar systems the outermost electrodes are connected to a power source and current passes through the other electrodes, thus polarising them. The side of the electrode facing the anode is negatively polarised and vice versa on the other side facing the cathode.

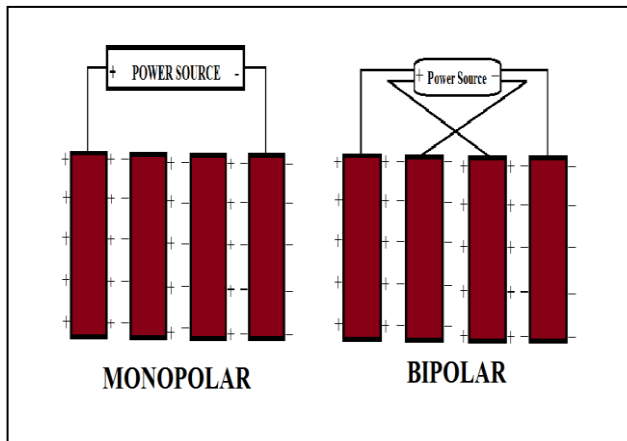


Fig. 1. Pictorial Representation of Arrangement of electrodes

### C. Collection of Water Sample

1) Lake water these days are being polluted in a number of ways ranging from pollution, tourist activities, unregistered and ungoverned encroachment. The VIT Lake in Vellore, India is an artificial lake, which was dug out in the year 2010. Due to its stagnant nature, inorganic particles such as sand, grit, metal particles, ceramics etc and animals such as protozoa, insects, arthropods, small fish etc are present in the lake water. Samples were taken from the lake and relevant water quality parameters were measured like turbidity and pH before and after the electrocoagulation tests.

2) Another sample was taken from the influent tank of the waste water treatment plant located in the faculty quarters of VIT University. The major source of contamination here is human and domestic waste. The waste was first passed through a low grade filter paper to remove all possible large solid wastes.

## V. EXPERIMENTATION

### A. Electrocoagulation

This was performed in a trough of capacity 750ml which was used to test sample water using carbon (graphite) electrodes from batteries. GI sheet was used as support for the electrodes insulated by tape so that the current does not pass into the sheet. Three voltages, namely 12V, 24V and 36V were obtained by connecting battery eliminators in parallel. Experimentation was done in two phases, first of which was lake water. Lake water samples of initial turbidity 11NTU were collected from the VIT Lake. Second phase included testing of sewage water from a waste water treatment plant. Water samples of initial turbidity of 100-170 NTU were collected from the treatment plant of the faculty residential complex of VIT University. Each batch was separately kept, for lake water and for domestic waste water, for exactly 45 minutes each without adding any external coagulant. After the flocs settled down, turbidity of the water was measured using a nephelometer.

### B. Jar test

Jar tests were done for both samples with the same amount of water (750ml) which was used for electrocoagulation to compare the results obtained. Alum was used as a coagulant, which was prepared by adding 10g of alum powder ( $Al_2[SO_4]_3 \cdot 16H_2O$ ) in one litre of water. This makes the concentration 10mg/ml.

### C. pH tests

pH tests were done before and after the batches to find out the change in acidity of the water.

## VI. RESULTS AND DISCUSSION

Two parameters of testing were used, namely turbidity and pH.

### A. Turbidity

Table 1 shows the results of the turbidity tests done before and after the lake water and wastewater batches.

TABLE I. TURBIDITY TEST

Voltage/Method	Initial (NTU)	Final (NTU)	Difference (NTU)	Percentage of Reduction (%)
<b>Lakewater</b>				
12V	11	6	5	45.45
24V	11	3	8	72.72
36V	11	5	6	54.54
Jar Test	11	4	7	63.63
<b>Wastewater</b>				
12V	170	161	9	5.29
24V	170	134	36	21.17
36V	104	94	10	9.61
Jar Test	134	96	38	28.35

Fig. 2 depicts a graph which has been plotted between the Voltage/Method of Testing and the Percentage of Reduction which is defined as the ratio of the difference between final and initial turbidity divided by the initial turbidity. It can be noted from the graph that the reduction capability in electrocoagulation is maximum when the voltage is 24V than when it is 12V or 36V. But also, it can be seen that Jar Test or chemical coagulation is also a very effective method.

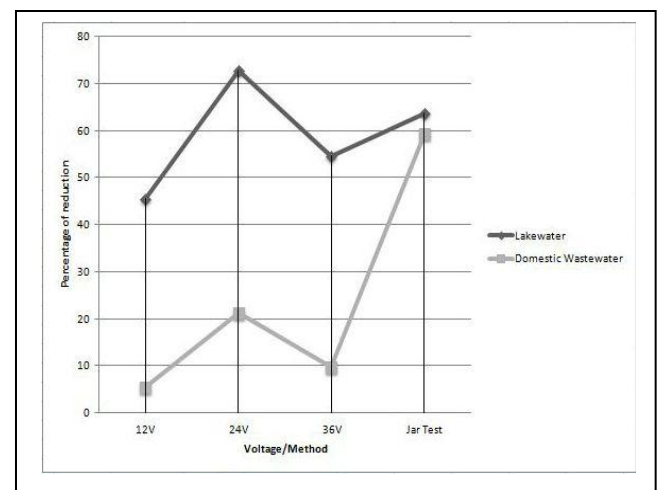


Fig. 2. Turbidity Tests

### B. pH

When electrocoagulation is done, due to the reactions involved,  $H^+$  ions are formed. Due to this, the pH of the solution comes down.

TABLE II. pH TESTS

LAKE	INITIAL PH	FINAL PH
12V	7.5	6.2
24V	7.5	6
36V	7.5	5.9
SEWAGE		
12V	7.05	6.91
24V	7.05	6.81
36V	7.05	6.7

It is noted that the highest acidic levels are found in the water treated under 36V.

### VII. CONCLUSION

We can draw the following conclusions from the experiments done

- 24V is the optimum voltage for 0.75-1 litre of water. The large scale treatment according to this basis requires further and extensive tests.
- A combination of alum dosage and electrocoagulation is the best method of coagulation of particles. Electrocoagulation reduces the amount of alum used and the amount of sludge produced at the end of the experiment.
- Moreover, the quality of sludge in normal chemical coagulation is not fit for immediate disposal as it contains chemicals and traces of other metals due to the mixing of the coagulant and the ions in the water.
- The increase in the pH of water after treatment is directly proportional to the voltage applied. This proves that high voltage is another drawback neutralization of charges is best accommodated in alkaline medium.

### VIII. FUTURE ASPECTS

- Mechanical stirrers can be installed in the batch setup of the cell. This serves as a flocculator for the flocs formed and hence will give better results.
- Varying voltages and pH levels from 3 to 10 can be used to check the various changes in the model.
- A larger scale model can be setup to check the workability of a scaled up model, and the optimum voltage in that case.
- Cost analysis of alum added in chemical coagulation versus electricity used up in electrocoagulation. This

is a major factor in the large scale application of electrocoagulation.

### IX. REFERENCES

- [1] P. Holt, G. Barton and C. Mitchell, "Electrocoagulation as a Wastewater treatment," Proc., The third Annual Australian Environmental Engineering Research Event, Caslemair, Victoria, pp. 41-46, November 1999.
- [2] K.A. Parmar, S. Prajapati, R. Patel, and Y. Dabhi, "Effective use of ferrous sulfate and alum as a coagulant in treatment of dairy industry wastewater," ARPJ Journal of Engineering and Applied Sciences, vol. 6, pp. 42-45, September 2011.
- [3] H.A. Aziz, S. Alias, F. Assari, and M.N. Adlan, "The use of alum, ferric chloride and ferrous sulphate as coagulants in removing suspended solids, colour and COD from semi-aerobic landfill leachate at controlled pH," Waste Management & Research, vol. 25, pp. 556-565, December 2007.
- [4] J. Rodriguez, S. Stopic, G. Krause, and B. Friedrich, "Feasibility Assessment of Electrocoagulation towards a New Sustainable Wastewater Treatment," Environmental Science and Pollution Research, vol. 14(7), pp. 477-482, 2007.
- [5] M. Vepsalainen, "Electrocoagulation in the treatment of industrial waters and waste waters," Ph.D. Thesis: VTT Science, Lappeenranta University of Technology, Finland, November 2012.
- [6] M.J. Matteson, R.L. Dobson, R.W. Glenn, N.S. Kukunoor, W.H. Waits and E.J. Clayfield, "Electrocoagulation and separation of aqueous suspensions of ultrafine particles," Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 104, pp. 101-109, November 1995.
- [7] V.D. Osipenko and P.I. Pogorelyi, "Electrocoagulation neutralization of chromium containing effluent," Metallurgist, vol. 21(9) pp. 628-630, September 1977.
- [8] V.V. Amosov and A.G. Zil'brtman, "Experience in local treatment of wastewaters from petrochemical production," Chemistry and Technology of Fuels and Oils, vol. 12(11-12), pp. 850-852, 1976.
- [9] J.-S. Do and M.-L. Chen, "Decolourization of dye-containing solutions by electrocoagulation," Journal of Applied Electrochemistry, vol. 24, pp. 785-790, August 1994.
- [10] N. Mameri, A.R. Yeddou, H. Lounici, D. Belhocine, H. Grib, and B. Bariou, "Defluoridation of septentrional Sahara Water of North Africa by electrocoagulation process using bipolar aluminium electrodes," Water Research, vol. 32(5), pp. 1604-1612, March 1998.
- [11] E. Bazrafshan, K.A. Ownagh, and A.H. Maahvi, "Application of Electrocoagulation process using iron and Aluminium Electrodes for Fluoride Removal from Aqueous Environment," E- Journal of Chemistry, vol. 9(4), pp. 2297-2308, 2012.
- [12] H.K. Christenson, "DLVO (Derjaguin-Landau-Verwey-Overbeek) theory and solvation forces between mica surfaces in polar and hydrogen-bonding liquids," Journal of the Chemical Society, Faraday Transactions 1: Physical Chemistry in Condensed Phases, vol. 80(7), pp. 1933-1946, 1984.
- [13] E.A. Vik, D.A. Carlson, A.S. Eikun, and E.T. Gjessing, "Electrocoagulation of potable water," Water Research, vol. 18(11), pp. 1355-1360, 1984.
- [14] E.O. Vilar, N.L. de Freitas, F.R. de Lirio, and F.B. de Sousa, "Study Of The Electrical Conductivity Of Graphite Felt Employed As A Porous Electrode," Brazilian Journal of Chemical Engineering, vol. 15, pp. 295-302, September 1998.
- [15] E. Zoulias, E. Varkaraki, Lymberopoulos, C.N. Christodoulou, and G.N. Karagiorgis, "A Review on Water Electrolysis; Report on Project: Cluster Pilot Project for the Integration of Renewable Energy Sources into European Energy Sectors Using Hydrogen," Centre for Renewable Energy Sources (CRES), Pikermi, Greece, 2006.