ELECTROCOAGULATION: TREATMENT OF INDUSTRIAL WASTEWATER

A

PROJECT REPORT

Submitted in fulfillment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

Of

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(MAY – 2020)

STUDENT'S DECLARATION

I hereby declare that the work presented in the Project report titled **"ELECTROCOAGULATION: TREATMENT OF INDUSTRIAL WASTEWATER"** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Rajiv Ganguly and Mr. Anirban Dhulia**. This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"ELECTROCOAGULATION: TREATMENT OF INDUSTRIAL WASTEWATER"** in fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Anish Kapil (161649), Nishant Thakur (161651), Yash Goyal (161696)** during a period from August, 2019 to May, 2020 under the supervision of **Dr. Rajiv Ganguly and Mr. Anirban Dhulia,** Department of Civil Engineering, Jaypee University of Information Technology,Waknaghat.

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PREFACE AND ACKNOWLEDGEMENT

For the last twelve months, (August 2019 - June 2020) we were enrolled for a research project titled “ELECTROCOAGULATION: TREATMENT OF INDUSTRIAL WASTEWATER”. We worked on various aspects during our tenure. Through this project, we did not only gain a lot of knowledge and exposure but most importantly, we also had a great chance to sharpen our skills in real time working environment.

We are really indebted to **Dr. Rajiv Ganguly and Mr. Anirban Dhulia** for giving us a chance to work on this research model. Also, we are grateful to **Prof. Ashok Kumar Gupta**, Head of the Civil Engineering Department for his invaluable time and instructions. We would like to express our gratitude to **Mr. Amar Kumar** for his enthusiastic encouragements, who helped us in our research project. Last but not the least we would like to thank the Civil Department for introducing us to this great opportunity in which we developed ourselves academically, professionally and socially.

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ABSTRACT

The process of electrocoagulation (EC) has been the subject of several reviews over the past decade and remains a very active research area. Most of the works published deal with applications for drinking water treatment and urban, industrial or agricultural wastewater to improve the simultaneous reduction of soluble and colloidal pollution. This often involve contributions to theoretical knowledge, electrode materials, working conditions, architecture of reactors and also techno-economic research. Our main aim in this study was to test industrial waste water and check the efficiency of electrocoagulation for the parameters such as pH, TDS, Turbidity, Conductivity, COD. Testing was done for 10-20-30 minutes by the Electrocoagulation reactor. The results contain various relationships between the parameters using graphical representation. This report presents a comprehensive review of electrocoagulation and its efficiency over other conventional techniques. Present study focuses on the feasibility of Electrocoagulation (EC) treatment on pharmaceutical wastewater (PW).

Keywords: Electrocoagulation, electrode materials, pH, COD, Turbidity, TDS, Conductivity, pharmaceutical wastewater.

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LIST OF ACRONYMS AND ABBREVIATIONS

EC	Electrocoagulation
PW	Pharmaceutical Wastewater
COD	Chemical oxygen demand
BOD	Biological oxygen demand
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
TS	Total Solids
NTU	Nephelometric Turbidity Unit

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Throughout the years, raising growth, increasing industrialization, developing agriculture and rising living standards have driven water demand up (WHO, 2012). Collection and reuse of industrial wastewater is one of the successful approaches to the water shortage issue. This includes the methods and procedures used to handle wastewater generated as a by-product of industrial or commercial operation. The handled municipal wastewater (or effluent) can be collected or discharged to a sanitary sewer or surface water in the area following treatment, ensuring that the residual water supply stays unpolluted. Access to clean drinking water is currently minimal, and adversely affect marine environments and sustainable freshwater supply. Therefore, effective technologies and methods to treat and handle wastewater ought to be created, efficiency preserved and large-scale volumes increased whilst maintaining environmental safety and sustainability, for municipal, industrial and agricultural wastewater. Highly effective, reliable drinking water systems are therefore required to tackle threats raised by environmental pollution, such as the occurrence of high concentrations of nitrate or fluoride complexes.

Processing and reuse of industrial wastewater is one of the successful approaches to the water shortage issue. This includes the methods and procedures used to handle wastewater generated as a by-product of industrial or commercial operation. The processed chemical wastewater (or effluent) can be collected or released to a sanitary sewer or surface water in the area after treatment, ensuring that the residual water supply stays unpolluted.

In a complex variety of environments, cost-effective approaches are required to manage a wide spectrum of wastewater contaminants. Compared to conventional methods of treatment, electrocoagulation provides an alternative for reasonably sized and resilient diagnosis wherein sacrificial metal anodes initiate electrochemical processes which provide active metal cations for coagulation and flocculation (Hakizimana, and Naja, J. 2017). The inherent advantage of electrocoagulation is that no coagulants are to be added to the wastewater and therefore, upon treatment, the salinity of the water does not increase. Electrocoagulation is a complex process involving a multitude of mechanisms for removing pollutants which operate synergistically (Kabdasli and Tunay. 2012). While several articles have emerged in the modern years, the absence of a systemic and comprehensive strategy has contributed to the construction of multiple treatment centers without taking into consideration the complexities of the environment and process management mechanisms. Given that electrocoagulation is assumed to be an enigmatic, promising treatment technology and a cost-effective solution for sustainable water management and planning, a broader perspective into the contaminant removal mechanisms involved, kinetic prototyping and reactor design will be increasingly important. In this paper, industrial wastewater electrocoagulation applications were reviewed with special emphasis on the major reaction mechanisms involved in those applications, taking into account the above-mentioned facts. Evaluation was based on sector-specific pollutant specifications as well as operating costs including solid waste management, sacrificial electrode materials and demands for electric power.

The traditional physiochemical method used to handle runoff by the distillery units was chemical coagulation, flocculation, adsorption, etc. Such therapies have disadvantages such as restricted capacity of disposal, high administrative expenses, repairs and include a long processing period that eventually reduces the average phase duration of diagnosis. To address the drawback and downside of the traditional treatment unit; modern safe system focused on the electrochemistry and named electrocoagulation may be used (Hakizimana, J. N., Gourich, 2017). The EC cycle should be used for the drinking water and wastewater management.

1.2 ELECTROCOAGULATION MECHANISM

- The coagulant species are produced in situ during the EC process. Electro degradation of a sacrificial anode, typically in iron or aluminum, through the application of electrical current through metal electrodes.

- Chemical reactions can be encapsulated as shown in **Figure 1.1**
  Metal is oxidized into cations at the anode.

  At the cathode: reducing water to hydrogen gas and hydroxyl anions.

$$M \rightarrow M^{Z+} + Ze^- \quad (1.1)$$

$$3H_2O + 3e^- \rightarrow \frac{3}{2}H_2 + 3OH^- \quad (1.2)$$

Where,

M = Metal ion

Z = no. of electrons

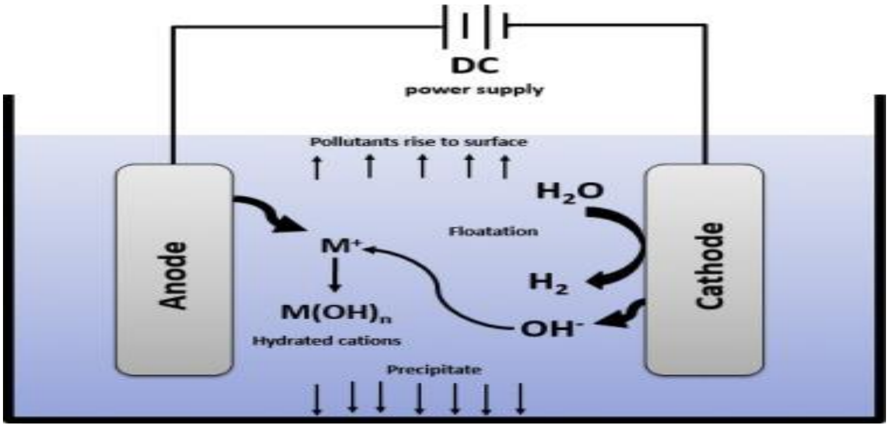


Figure 1.1 Electrocoagulation Mechanism **(Mohammed & Youssef, 2017)**

1.3 PARAMETERS EFFECTING ELECTROCOAGULATION

1.3.1 EFFECT OF CURRENT

Current (I) is a key EC parameter often designed as a function of current density defined as the current-to-electrode surface area S ratio. The continuity equation imposes current preservation here between anode and the cathode, as well as the current density between electrodes may differ (Oncel, M.S., Muhcu, 2013). However, very large current values may have an adverse impact on the EC performance (**Figure 1.2)**. For example, secondary reactions may occur primarily, and overdosing may invert the colloid charge and scatter it, causing a reduction in coagulant efficiency and a reduce in electrode lifetime (Brahmi & Loungou 2015).

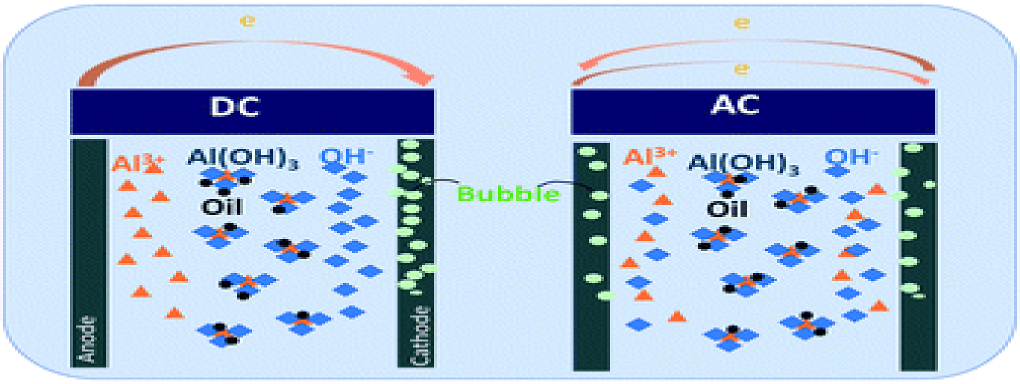


Figure 1.2: Effect of current **(Oncel, M.S., Muhcu, 2013)**

1.3.2 EFFECT OF WATER pH AND ALKALINITY

pH is another main factor influencing EC efficiency, in particular the coagulation mechanism, because it regulates hydrolyzed metal species produced in reactive media and influences the prevailing EC mechanisms (Khaled & Zied 2019). The pH especially depends on adsorption and coagulation. The superficial load of the precipitates of Al or Fe can be explained by the adsorption on their respective hydroxide precipitates of the charged soluble monomeric species (Khaled & Zied 2019). It should be noted that effluent pH would increase for acidic influence after EC treatment but can decrease for alkaline effluent, which is due to the EC buffering effect. The increase in pH in acidic medium is due to the evolution of hydrogen in the cathode while the decrease in pH is primarily due to the formation of hydroxide precipitates releasing H+ cations in the vicinity of the anode and secondary reactions such as water oxidation and chlorine production and its hydrolysis (Brahmi & Loungou 2015). This illustrates EC's buffering power, which works in addition to the alkalinity of water. This impact is especially strong due to the creation of high pH aluminate anions with Al electrodes. A pH scale is shown in **Figure 1.3.**

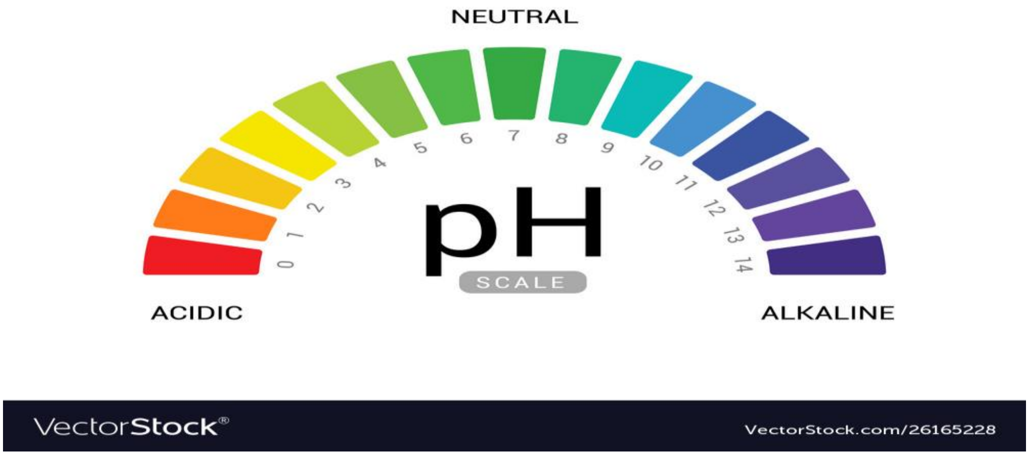


Figure 1.3: pH scale **(Oncel, M.S., Muhcu, 2013)**

1.3.3 ELECTRODES ARRANGEMENT:

Electrode device may influence the EC cycle via the arrangement of electrodes and the inter-electrode space. The arrangement of electrodes may either clearly consist of an anode and a cathode, or be made of several anodes and cathodes complexly settled in EC cells.

The arrangement of complex electrodes can be ranked in monopolar and bipolar electrodes.

i. Monopolar electrodes are defined as being in parallel contact (MP-P). It relates to an electrode arrangement consisting, respectively, of cathodes and anodes placed alternatively at the same anodic or cathodic potential **(Figure 1.4)**. Growing cathode / anode pair corresponds to a tiny electrolyte cell where the voltage is the same. Hence, the reactor consists of two parallel electrolyte cells. The current of each electrolyte cell is also additive (Kabdasli and Tunay. 2012).

ii. In each pair of internal sacrificial electrodes, monopolar electrodes in series connections (MP-S) are defined as being internally linked to each other, and have no interconnections with the two outer electrodes **(Figure 1.5)**. For this situation, the electric current going through all the electrodes is the same, while in each human electrolytic cell, the global voltage is the sum of the voltage (Kabdasli and Tunay. 2012).

iii. Two outer electrodes linked to the electrical power supply and the sacrificial electrodes situated between the two outer electrodes constitute the bipolar electrode in sequence contacts (BP-S). Exterior electrodes are monopolar, and the inner electrodes are bipolar **(Figure 1.6)**. The bipolar electrodes are not intertwined, and each of their sides functions as an anode and a cathode concurrently. It ensures opposite sides of each bipolar electrode are balanced together; the anodic breakdown happens on the positive side whereas the negative side becomes susceptible to cathodic reactions (Kabdasli and Tunay. 2012).

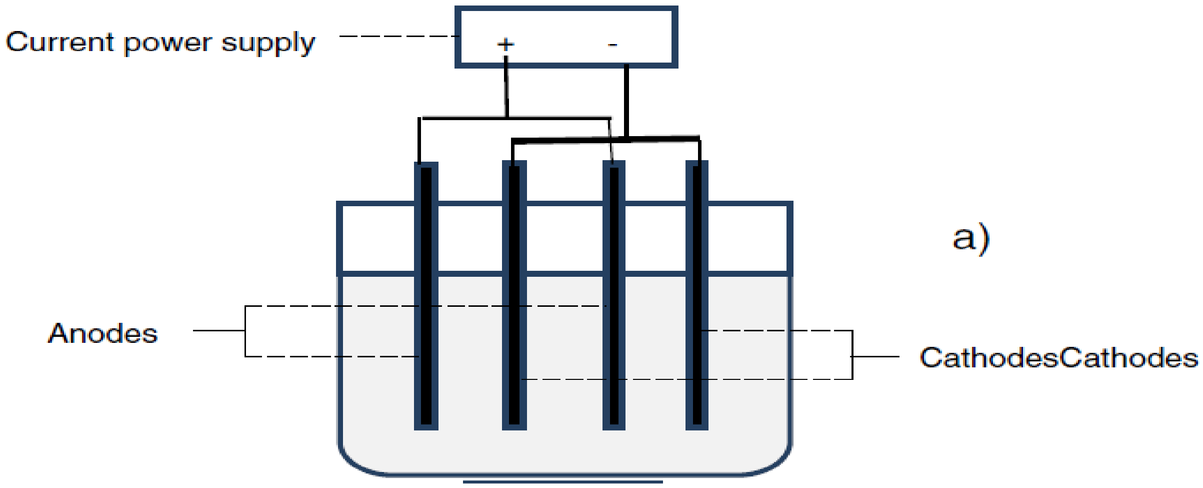


Figure 1.4 Monopolar Electrode in parallel connection **(Mohammed & Youssef, 2017)**

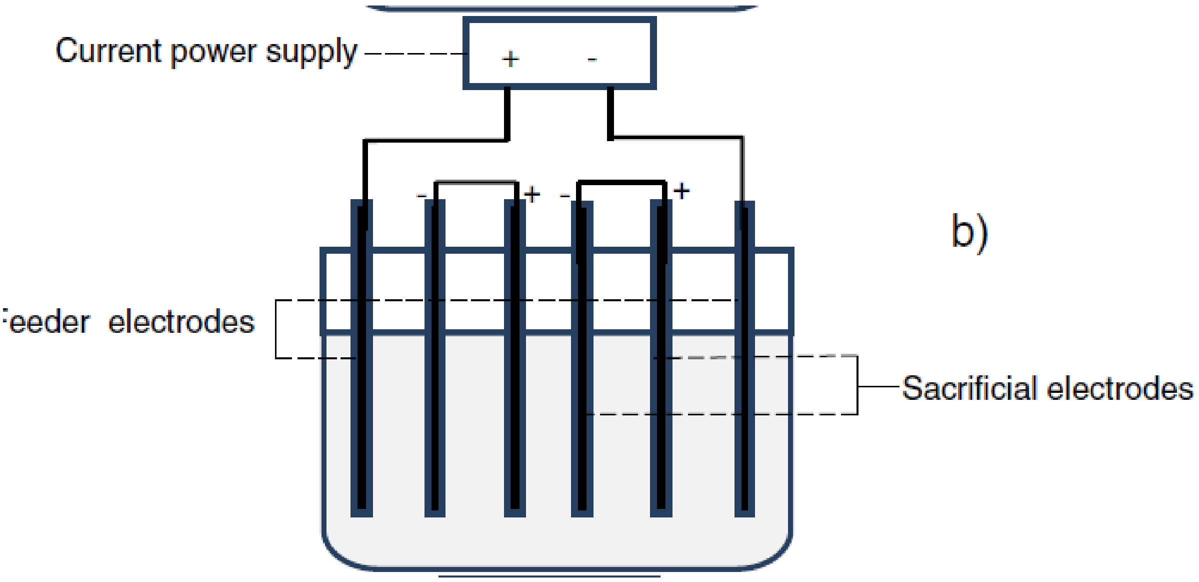


Figure 1.5 Monopolar electrode in series connection **(Mohammed & Youssef, 2017)**

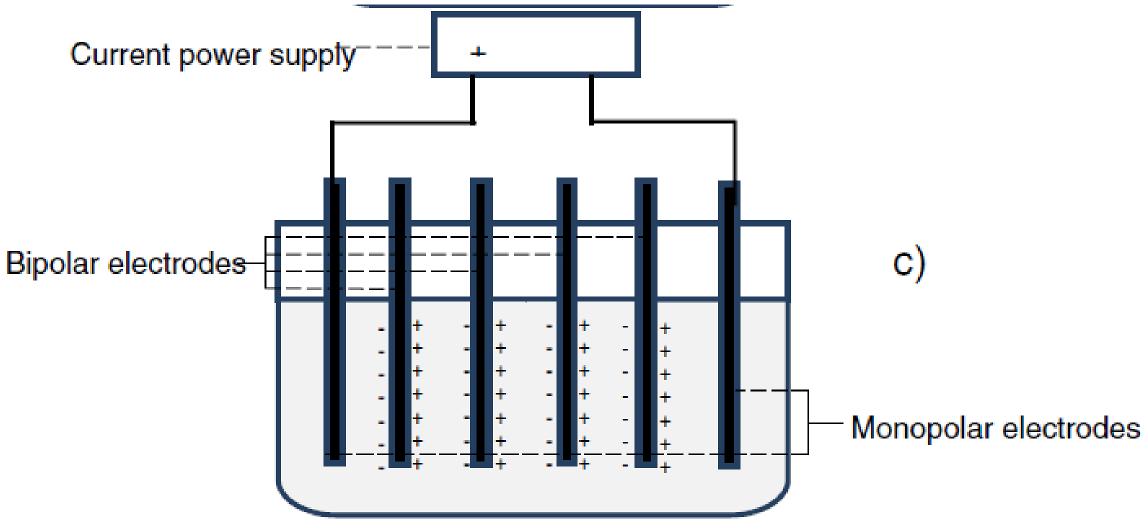


Figure 1.6 Bipolar electrode in series connection **(Mohammed & Youssef, 2017)**

1.3.4 EFFECT OF INTER-ELECTRODE DISTANCE:

The Internal resistance (IR)-drop decreases with rising the gap between the electrodes. Thus, with reducing the distance between electrodes, energy usage decreases. When the gap between the electrodes decreases (Oncel, M.S., Muhcu, 2013), further electrochemically produced gas bubbles create turbulent hydrodynamics, resulting in a strong mass transfer and a strong rate of reaction between the coagulant species and contaminants (Amrose, S., Gadgial, 2013). Additionally, the inter-electrode distance determines the residence period for a continuous device between the anode and the cathode and the treatment time for a batch reactor to obtain a satisfactory EC output (Oncel, M.S., Muhcu, 2013). Inter-electrode spacing as shown in **Figure 1.7** often specifies the number of electrodes to be positioned in the electrocoagulation cell, until its volume is specified, for a complex electrode structure.

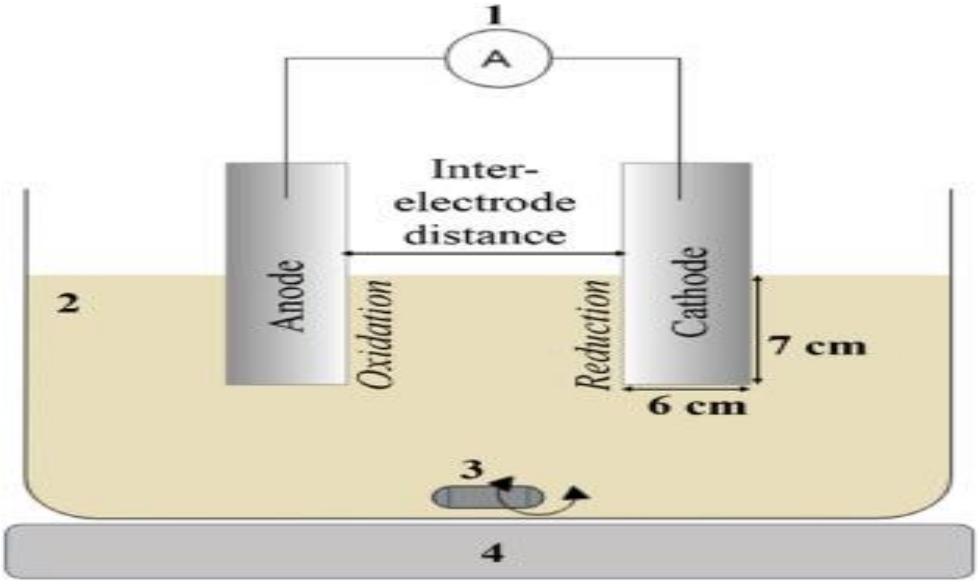


Figure 1.7: Effect on inter- electrode distance **(Amrose, S., Gadgial, 2013)**

1.3.5 EFFECT OF WATER CONDUCTIVITY:

The present performance of density is highly dependent on water / wastewater conductivity and ionic strength. Thanks to the reduction in ohmic water / wastewater resistance, the present density output improves with improved electrolytic conductivity (Brahmi & Loungou 2015). Conductivity also reduces the treatment time needed to achieve a given removal yield (Barrera-Diaz, C.E. and Bilyeu, 2015). Consequently, the energy demand (UI) is reduced.

NaCl is frequently used to significantly boost the electrolytic conductivity. Chloride anions often help in minimizing the harmful effects of other anions to avoid accumulation of calcium carbonate in hard water which may create an insulating coating on the electrode surface. Chloride anions may even be oxidized to active chlorine types, such as hypochlorite anions, and may oxidize organic compounds and ferrous ions, which lead to water / wastewater disinfection, with quite large current density (Hakizimana, and Naja, J. 2017). Chloride anions may even be oxidized to active chlorine types, such as hypochlorite anions, and may oxidize organic compounds and ferrous ions, which lead to water / wastewater disinfection, with quite large current density. Typical conductivity pattern is shown in **Figure 1.8**

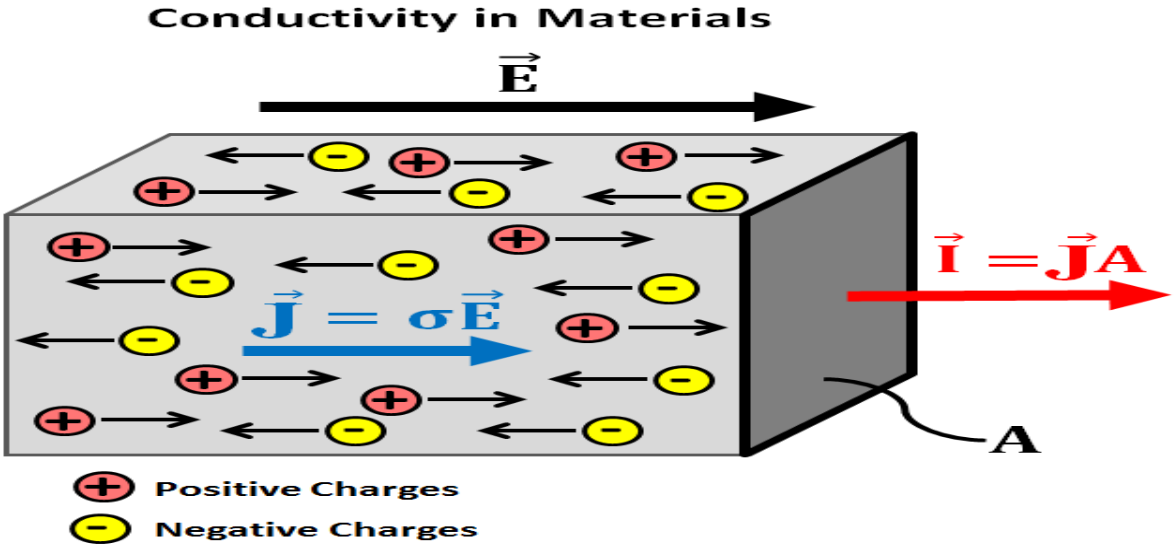


Figure 1.8: Conductivity pattern in materials yield **(Barrera-Diaz, C.E. and Bilyeu, 2015)**

1.4 NEED OF THE STUDY:

i. Has been performed on small scales but not on large scale.
ii. Less researched topic.
iii. Efficiencies greater than conventional methods.
iv. Can be used to treat wastewater.
v. Solve water crisis.
vi. Less time consuming.

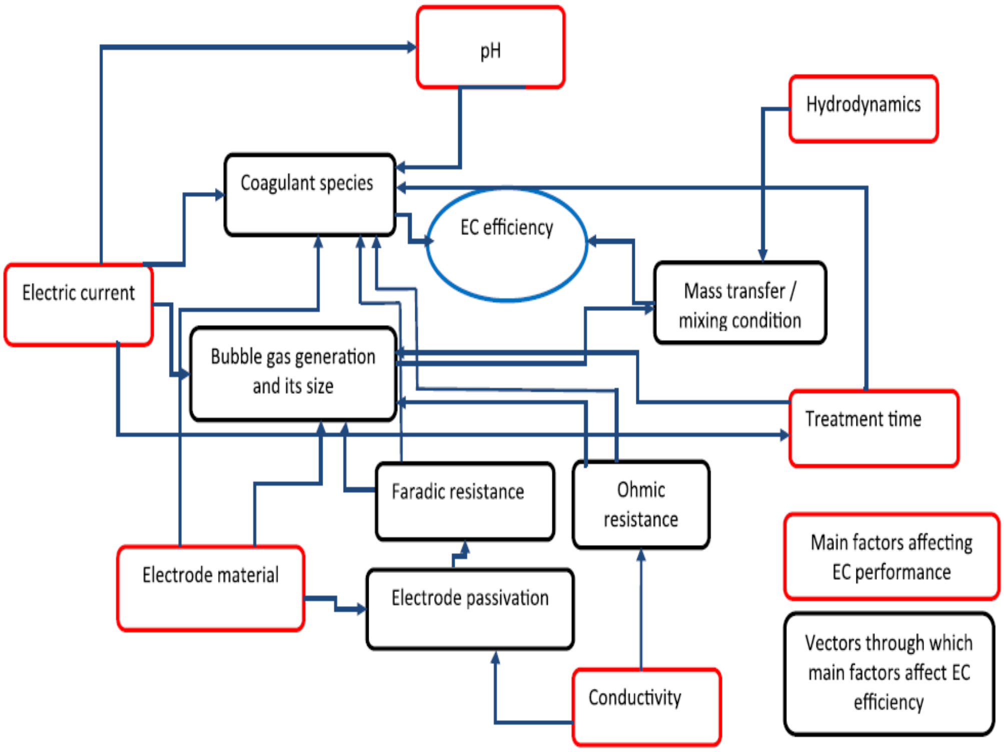


Figure 1.9 Main factors that affects EC process **(Mohammed & Youssef, 2017)**

1.5 OBJECTIVES OF THE STUDY:

The main objectives of the study are:

i. To study the response of EC reactor for the operational and process parameters of industrial wastewater.

ii. To develop a process remodel for the different operational and process parameters considered for industrial wastewater.

CHAPTER 2

LITERATURE REVIEW

2.1 ELECTROCOAGULATION PROCESS

The fundamental idea of the EC cycle derives from the term "electrolysis," implying that with the aid of energy, objects fall apart. (Chen *et al.*, 2005; Arslan *et al.*, 2009; Can et al., 2010; Cerqueira *et al.*, 2009). This step takes place with electrolyte assistance to boost the aqueous medium 's conductivity (transferring the ions between the two electrodes). The positive ions pass to the cathode as the electrical current is applied and the negative ions to the anode. The anions are oxidized at the electrodes and the cations are reduced as shown in **Figure 2.1**. It is found that, since it contains the potential mechanisms such as electrocoagulation (EC), electro floatation (EF) and electrooxidation (EO), the electrochemical mechanism is rather complex. Relatively little attempt has been made to better understand the fundamental dynamics of the processes and their reaction to the optimum parameters in rendering the technique quick and cheap (Brahmi & Loungou 2015). In other terms, EC is the method of destabilizing suspended, emulsified or dissolved pollutants by injecting an electrical current by parallel metal electrodes linked in monopoly or dipolar mode into the aqueous medium (Brahmi & Loungou 2015). The conductive metal electrodes are generally called "sacrificial electrodes". The cathodes and sacrificial anodes may be of the same or separate materials.

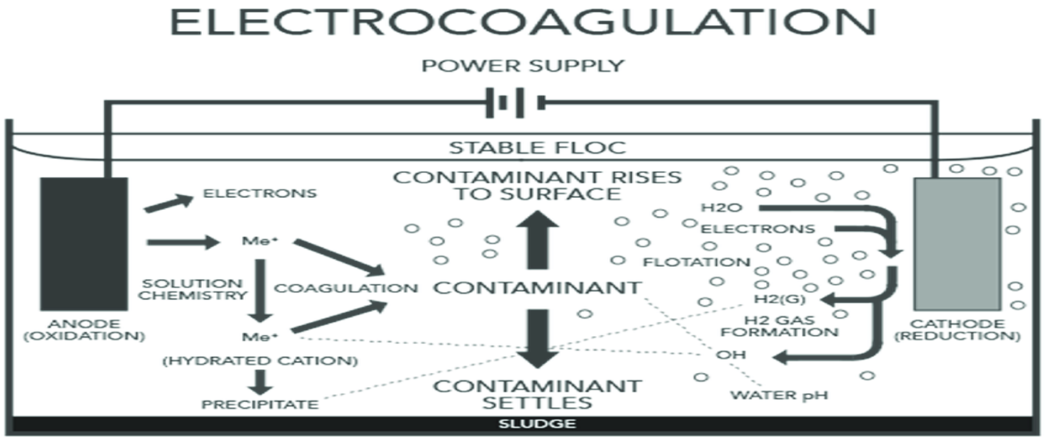


Figure 2.1 Electrocoagulation reaction **(Kabdasli and Tunay. 2012)**

The general electrochemical reactions may be the following with metal M as anode:

At the anode:

$M_{(s)} \rightarrow M_{(aq)}^{n+} + ne^{-}$ (1.3)

$2H_2O_{(l)} \rightarrow 4H_{+(aq)} + O_{2(g)} + 4e^{-}$ (1.4)

At the cathode:

$M_{(aq)}n^{+} + ne^{-} \rightarrow M_{(s)}$ (1.5)

$2H_2O_{\ (l)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-}$ (1.6)

Where,

M = Metal ion
n = no of electron

The two most widely utilized electrodes are Aluminum and Iron. Metal ions are divided off and disperse into liquid media according to Faradays law. Replenishable metal plates such as Fe and Al are commonly used for the release of metal ions as sacrificial electrodes to facilitate coagulation. Depending on the substance to be processed and the pollutants to be extracted, electrodes may be of copper, graphite, stainless steel or other materials. The emitted ions neutralize particle charges and so start coagulation. These ions detach the molecules by chemical reaction and precipitation or by mixing colloidal compounds, which can be separated by flotation afterwards. (Khaled & Zied 2019). The metal ions appear to form metal oxides, serving as EC attractants and destabilizing the molecules. Although the amount of electrical current needed depends with the volume of pollutants to be handled, the processing of the molecules involves the availability of sufficient, though not excess, electrical current. (Chitra *et al.*, 2008; Edris *et al.*, 2012) Excess current absorbs more electrical power and stimulates the consumption rate of electrodes which results in increased operational costs. Consequently, the correct selection of the electrode content is of utmost importance and is one of the considerations that defines the EC process's operating expense. Temperature and pressure affect less on the operation. For an effective EC method, optimizing all of these operating parameters is critical.

As the amount of electrical current needed correlates with the volume of pollutants to be handled, the processing of heavy metals needs the provision of sufficient but not excess electrical current. (Chitra *et al.,* 2008; Edris *et al*., 2012) Excess current utilizes more electrical power and accelerates the rate of consumption of electrodes which results in increased operational costs. The correct selection of the electrode content is therefore of utmost importance, and is one of the factors deciding the operational costs of the EC cycle (Hakizimana, and Naja, J. 2017). Hence the right collection of the electrode material is of paramount importance and is one of the variables that decide the EC cycle's running costs (Hakizimana, and Naja, J. 2017).

2.2 SUMMARY AND RESEARCH GAP

Brahmi *et. al.*,2019 conducted a study on removal of cadmium from synthetic and industrial wastewater using an EC reactor. He used aluminum as the main sacrificial anode with the electrode bars spaced at distance of 5 mm with a speed maintained at 300 rev/min at temperature of 50^0C. A complete removal of cadmium was observed after test duration of 5 minutes.

The next study done by Gizem *et. al.*, 2018 focused on high resistance food industry wastewater, treated with electroFenton (EF) and electrocoagulation (EC) process was applied sequentially to remove total organic carbon (TOC) from wastewater. Then, EC process to finalize the linear care phase was also carried out. Optimum reaction time was initially investigated for EF process then the ideal current density value was determined for EC process with iron plate electrodes.

Chafi *et. al.,* 2017 researched on theoretical understanding, electrode materials, operating conditions, reactor design and even techno-economic analysis. This paper presents a comprehensive review on its development and design, outlooks for future research and developments are suggested.

Ainhoa *et. al.,* 2017 studied a modern cylindrical configuration electrocoagulation reactor utilizing a three-dimensional anode in steel wool. The Electrocoagulation reactor design is directly connected to a filter tube, which is changed to accommodate the electrodes. The new reactor has been efficiently used to extract a textile dye (Remazol Red RB 133) that works in a continuous mode where the colour removal rate is 99%.

Drogui *et. al.*, 2017 conducted a report on the handling of biological residuals from landfill leachate pretreated using an aerated bio-filter device. The results of existing densities, anode size (Aluminum versus iron), and treatment period on COD removal efficiency have been studied. Such findings showed that EC is an effective and productive method for the management of residual organic refractory matter from a landfill leachate previously handled by a biological system.

Huang *et. al.*, 2017 analyzed Electrocoagulation (EC) tested utilizing metallic Ni foam as electrodes to extract boron from a solution. The electrolytic parameters were pH (4-12), current density (0.6-2.5 mA cm-2), and boron initial (10-100 mg L-1) concentration. Experimental findings showed maximization of percentage removal at pH 8-9, and significantly reduced as the pH increased beyond that range.

Bo Yang *et. al.*, 2016 studied the Electrocoagulation (EC) technique used to examine the removal efficiency of fairly high concentration aqueous perfluoroalkyl acids (PFAAs) as a simulation of wastewater from the organic fluorine industry. The study of removal efficiency for PFAAs with various lengths of carbon chain after EC and the characteristic of zeta potential on Fe flocs suggested that electrostatic adsorption was primarily responsible for the iron hydroxide flocs PFAAs sorption.

Khairul *et. al.*, 2016 involved in the study of the removal by electrocoagulation of Total Chromium, Color and Turbidity contaminations from landfill leachate. This project focused on leachate landfill as an electrolyte solution from Pulau Burung, Nibong Tebal, Penang. It can be inferred on the basis of the outcome that aluminum electrodes are better for eliminating turbidity and light. Electrodes made of Stainless Steel are best for removing Total Chromium. The initial pH also provides the major impact of heavy metal removal, and the highest voltages make the heavy metal removal stronger.

Fekete *et. al.*, 2016 examined the key characteristics of the process highlighted in the illustration of oily wastewater washing. From the results of small-scale tests, the architecture parameters of a 1 m 3 / h wastewater cleaning device are determined.

Barrera-Díaz *et. al.*, 2015 conducted a study to assess the effect of copper electrocoagulation and hydrogen peroxide on COD, color, turbidity and bacterial activity in wastewater mixed industry. Copper electrocoagulation by itself reduces COD by 56% at pH 2.8 in 30 min, but the combined system decreases COD by 78%, biochemical oxygen demand (BOD5) by 81%, and color by 97% under same conditions.

Brahmi *et. al.*, 2015 researched the efficiency of zinc ion removal electro-coagulation utilizing aluminum electrodes. Optimum zinc removal conditions were observed at pH value 7, current density 7.35 mA cm−2, inter-electrode potential 5 V, conductivity 5.3 mS cm−1, and EC duration 30 min. With a very small power usage of 1.02 kW h m−3 for an initial pH above 5, the removal performance of zinc exceeded 100 percent in the first 5 min of operation. This approach offers important industrial uses, in the light of these findings.

Bong-yul Tak *et. al.*, 2015 focused on electrocoagulation (EC) processes using Al electrodes to remove color and COD from livestock wastewater. Economic operating conditions and efficiencies for removal were discovered to be pH 8, current density 30 mA / cm2, electrolysis time 30 min and NaCl concentration 1 g / L, and 95.2% (Y1) and 93% (Y2), respectively.

Roopashree *et. al.*, 2014 conducted a study to analyze the method of electrocoagulation using iron, aluminum and stainless-steel electrodes to treat wastewater in batch reactor in the textile industry. The result showed that electrocoagulation was very effective and was able to accomplish color removal (99.46 percent) in 80 min at 14V and COD removal (90.12 percent) in 80 min at 8V in iron electrode presence.

Zewail *et. al.*, 2014 analyzed the performance of an innovative batch cell design in electrocoagulation removing chromium ions (Cr6 + & Cr3 +) from synthetic wastewater solutions. Calculations of power consumption show that 10.98 kW h / kg (1.09 kW h / m3) is required under optimal conditions for Cr3 + removal by Electrocoagulation (EC) whereas 16.14 kW h / kg (2) is required under optimal conditions for Cr6 + removal by Electrocoagulation (EC).

Maria *et. al.*, 2014 investigated the collaborative approach for the identification and remediation of Pb2 + bacteria in aqueous setting. The Pb2 + process of electrocoagulation (EC) was analyzed using an electrolytic flow cell fitted with Al sacrificial electrodes and working under galvanostatic conditions (using 0.25, 0.5 and 0.75 A currents).

M.S.Oncel *et. al.*, 2013 Designed a comprehensive laboratory-scale distinction of chemical precipitation and electrocoagulation (EC) for the removal of heavy metals such as Fe, Al, Ca, Mg, Mn, Zn, Si, Sr, B, Pb , Cr and As from coal mine wastewater runoff (CMDW). Except for Ca, Sr and B (pH 10 or higher), the optimum pH for removal of most heavy metals from CMDW by chemical precipitation using sodium hydroxide was 8.

A study done by Gadgil *et. al.*, 2013 discovered iron electrodes may reduce arsenic below 10 μg / L in synthetic groundwater in Bangladesh and in natural groundwater in Bangladesh and Cambodia, thus researching the effects of frequently ignored operational parameters such as load dosage levels. Although the emphasis was on creating a functional tool, the findings indicated that As [III] is largely oxidized via a chemical pathway and does not depend on anode processes.

Mahmoud *et. al.*, 2013 studied the improvement of removal of Methylene Blue dye using an electromagnetic field during the electrocoagulation cycle. For the application of an electromagnetic field, the power consumption required to remove the dye was reduced by 45 per cent.

Al Aji *et. al.*, 2013 evaluated the efficiency of batch electrocoagulation (EC) using monopolar-configured iron electrodes for synchronized removal of copper (Cu), nickel (Ni), zinc (Zn) and manganese (Mn) from model wastewater. The efficiency of batch electrocoagulation (EC) utilizing monopolar-configured iron electrodes for simultaneous removal of copper (Cu), nickel (Ni), zinc (Zn) and manganese (Mn) from a wastewater platform.

A study performed by Ciblak *et. al.*, 2012 saw that by controlling the physicochemical conditions of an electrochemical redox system, the performance of electrochemical remediation methods could be optimised. The study showed that the use of iron anodes in divided or mixed electrolytes could achieve a highly reduced environment, and the pH and redox potential could be optimized using appropriate current and polarity reversals.

Kabdaşlı *et. al.*, 2012 evaluated result based on sector-specific pollutant parameters as well as operating costs including solid waste management, sacrificial electrode materials and demands for electrical energy.

C. Sarala *et. al.*, 2012 conducted the present study to investigate the applicability of the Domestic Wastewater Treatment Electrocoagulation Technique at JNTU Hyderabad. It confirmed that the 20-minute batch operating at 0.25A has optimum removal efficiency of Chemical Oxygen Demand, Total Dissolved Solids, pH, color, chlorides, etc.

Malakootian *et. al.*, 2009 investigated the utility extracting water hardness under various conditions. This experimental study was carried out through a pilot plant Tests revealed a 95.6 per cent efficiency of hardness reduction for electrocoagulation technique. pH and electrical potential had a direct effect on the removal of hardness in such a way that pH=10.1, potential 20-volt difference and detention time of 60 minutes had the highest efficiency rate.

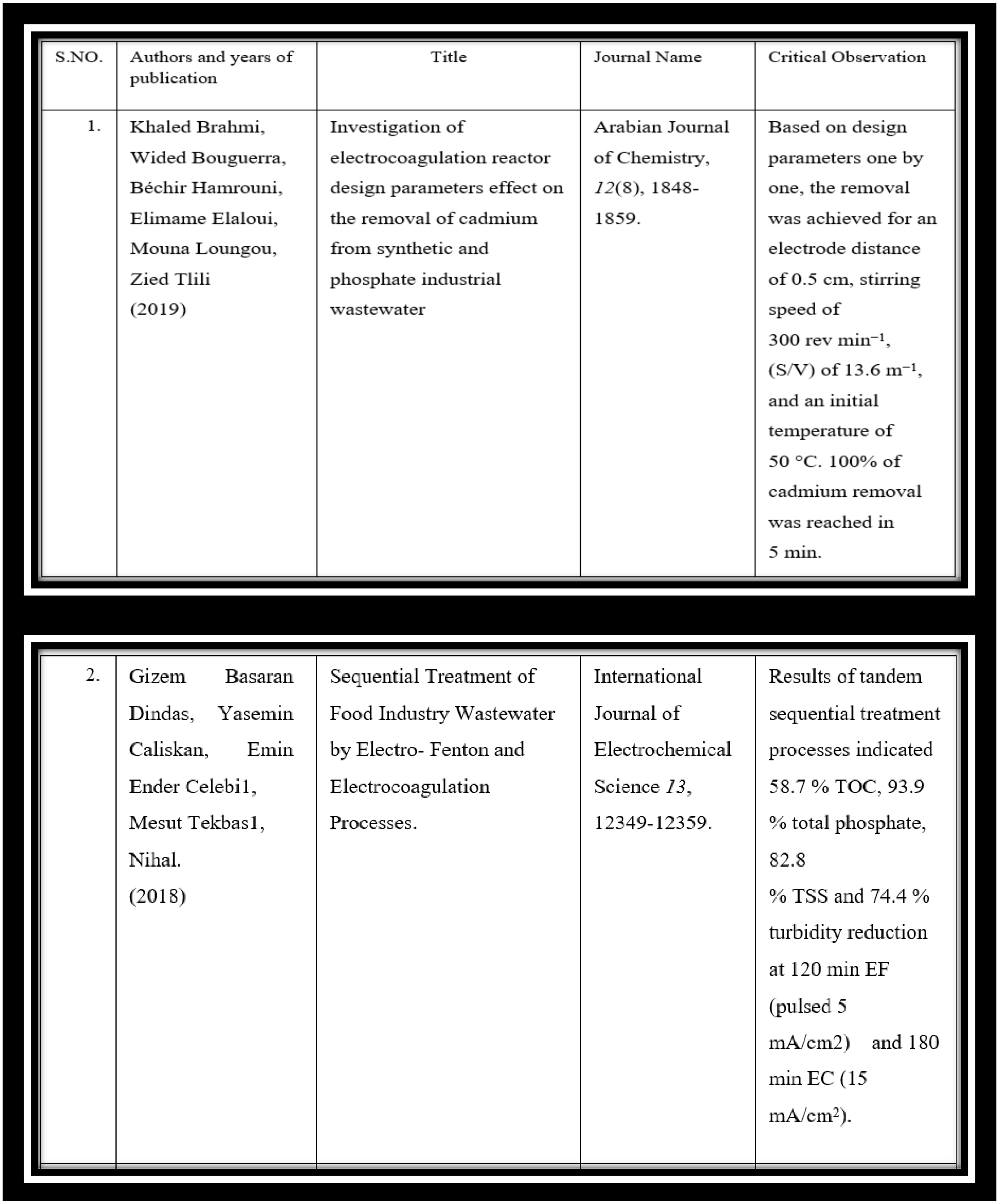
M. Koby *et. al.*, 2006 was to investigate the effect of the initial addition of a chemical coagulant such as polyaluminum chloride (PAC) or alum on the efficiency of COD removal of EC textile wastewater treatment. There was also a comparative analysis of operating costs and it was found that with the same operating cost per COD mass removed, CEC performance was 80 percent, compared to 23 percent with EC in 5 min of operation.

P Ratna Kumar *et. al.*, 2004 reviewed electrocoagulation (EC) as the arsenite [As (III)] control process and arsenate [As(V)] separation from water. The comparison revealed that EC has better efficiency for removal of As (III), whereas removal of As(V) by both processes was almost the same. EC's removal mechanism of As (III) appears to be As (III) to As(V) oxidation, and subsequent removal by adsorption / complexation with metal.

As is well known, although different treatment methods are conventionally used, electrocoagulation is considered an environmentally friendly and economically viable process used in this study. A detailed review of the earlier work carried out by different investigators on the conventional electrocoagulation process and its response to various operational parameters, chemical coagulation and hybrid electrocoagulation process was thus conducted and reported in this chapter in order to establish the methodology in meeting the objectives.

From the comprehensive analysis carried out, it was found that not several studies on extracting heavy metals in waste water using EC have been published. Only few works have been carried out to identify the strategy to improve removal efficiency with less electrolysis time and to apply current according to the knowledge of the author. Very few authors performed continuous flow academic research in the treatment of industrial wastewater. This means no in depth has been done. The studies on the influence of design parameters were found very scarce from the availability of literature. It was also recognized that the energy and electrode usage often decrease while there is a rise in the reaction time and the applied current, which also boosts the rate. This was a motivation and inspiration to take up this study to develop a novel electrode (Al electrode and Fe electrode) to improve the EC reactor's efficiency.

2.3 SUMMARY TABLE

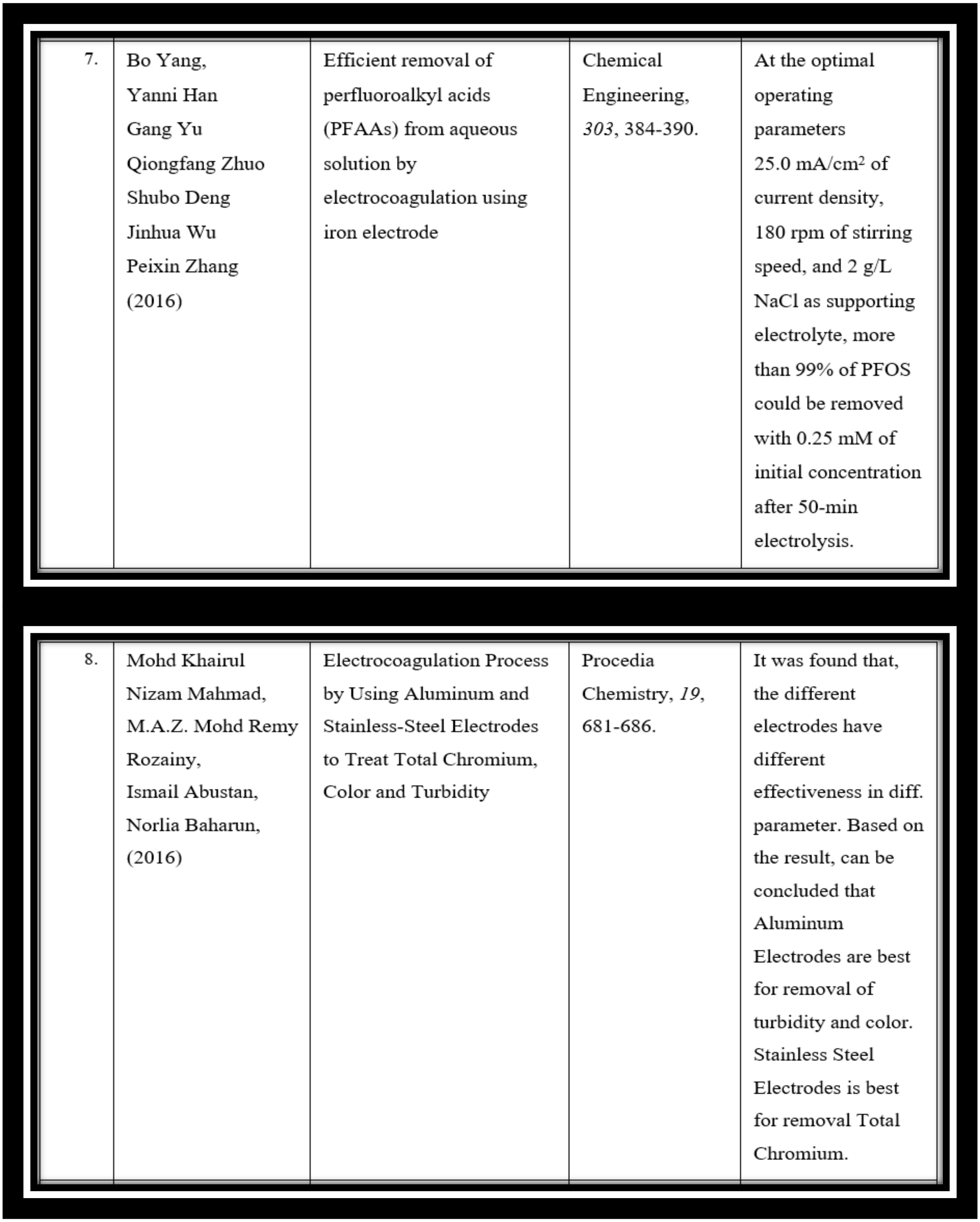


S.NO.	Authors and years of publication	Title	Journal Name	Critical Observation
1.	Khaled Brahmi, Wided Bouguerra, Béchir Hamrouni, Elimame Elaloui, Mouna Loungou, Zied Tlili (2019)	Investigation of electrocoagulation reactor design parameters effect on the removal of cadmium from synthetic and phosphate industrial wastewater	Arabian Journal of Chemistry, *12*(8), 1848-1859.	Based on design parameters one by one, the removal was achieved for an electrode distance of 0.5 cm, stirring speed of 300 rev min^{-1}, (S/V) of 13.6 m^{-1}, and an initial temperature of 50 °C. 100% of cadmium removal was reached in 5 min.
2.	Gizem Basaran Dindas, Yasemin Caliskan, Emin Ender Celebi1, Mesut Tekbas1, Nihal. (2018)	Sequential Treatment of Food Industry Wastewater by Electro- Fenton and Electrocoagulation Processes.	International Journal of Electrochemical Science *13*, 12349-12359.	Results of tandem sequential treatment processes indicated 58.7 % TOC, 93.9 % total phosphate, 82.8 % TSS and 74.4 % turbidity reduction at 120 min EF (pulsed 5 mA/cm2) and 180 min EC (15 mA/cm^2).

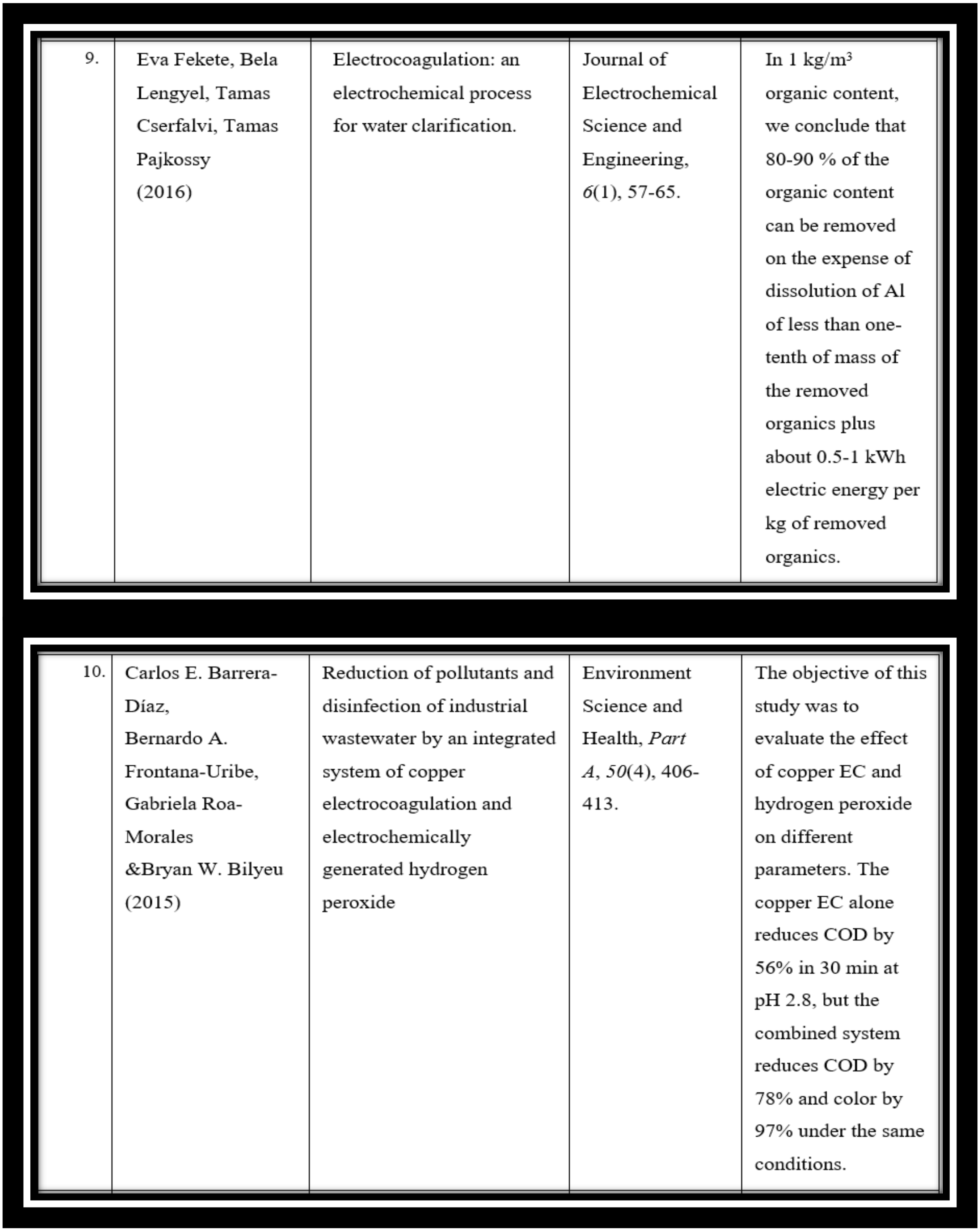
3.	Ainhoa López, David Valero, Vicente, García-García, Eduardo Expósito, Vicente Montiel (2017)	Characterization of a new cartridge type electrocoagulation reactor (CTECR) using a three-dimensional steel wool anode.	Electroanalytical Chemistry, *793*, 93-98.	In this a new EC reactor with cylindrical geometry using steel wool anode has been developed. The new reactor has been successfully used in the removal of a textile dye, where the color elimination rate reaches 99%.
4.	Mohammed Chafi, Youssef Stiriba, Christophe Vial, Patrick Drogui, Jamal Naja (2017)	Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches.	Desalination, 404, 1-21	Electrocoagulation process (EC) has been the subject of several reviews in the last decade, and is still a very active area of research. This paper presents a comprehensive review on models for reactor development and design.

5.	Oumar Dia, Patrick Drogui, Gerardo Buelna, Rino Dubé, Ben Salah Ihsen, (2017)	Electrocoagulation of bio-filtrated landfill leachate: Fractionation of organic matter and influence of anode materials.	Chemosphere, *168*, 1136-1141.	The effects of current densities, type of anode on the performance of COD removal were investigated. The best COD removal performances were recorded at a current density ranging between 8.0 and 10 mA cm^{-2} during 20 min of treatment time.

6.	Danis Kartikaningsih, Yao-Hui Huang, Yu-Jen Shih, (2017)	Electro-oxidation and characterization of nickel foam electrode for removing boron.	Chemosphere, *166*, 184-191.	The optimal conditions under which 99.2% of boron was removed from treated wastewater with 10 mg L^{-1}-B, leaving less than 0.1 mg L^{-1}-B in the electrolyte, were pH 8 and 1.25 mA cm^{-2} for 120 min.

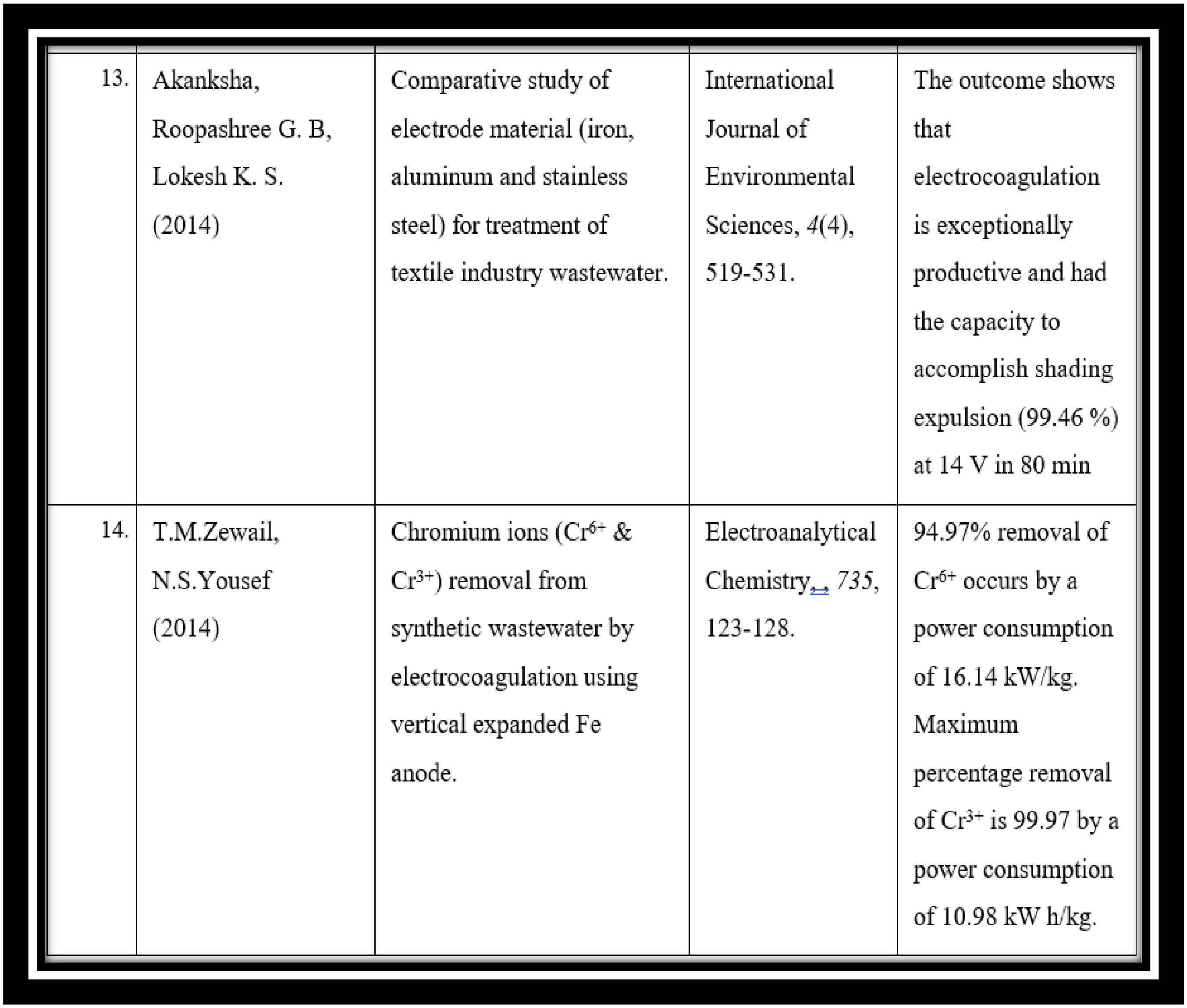


7.	Bo Yang, Yanni Han Gang Yu Qiongfang Zhuo Shubo Deng Jinhua Wu Peixin Zhang (2016)	Efficient removal of perfluoroalkyl acids (PFAAs) from aqueous solution by electrocoagulation using iron electrode	Chemical Engineering, *303*, 384-390.	At the optimal operating parameters 25.0 mA/cm^2 of current density, 180 rpm of stirring speed, and 2 g/L NaCl as supporting electrolyte, more than 99% of PFOS could be removed with 0.25 mM of initial concentration after 50-min electrolysis.
8.	Mohd Khairul Nizam Mahmad, M.A.Z. Mohd Remy Rozainy, Ismail Abustan, Norlia Baharun, (2016)	Electrocoagulation Process by Using Aluminum and Stainless-Steel Electrodes to Treat Total Chromium, Color and Turbidity	Procedia Chemistry, *19*, 681-686.	It was found that, the different electrodes have different effectiveness in diff. parameter. Based on the result, can be concluded that Aluminum Electrodes are best for removal of turbidity and color. Stainless Steel Electrodes is best for removal Total Chromium.

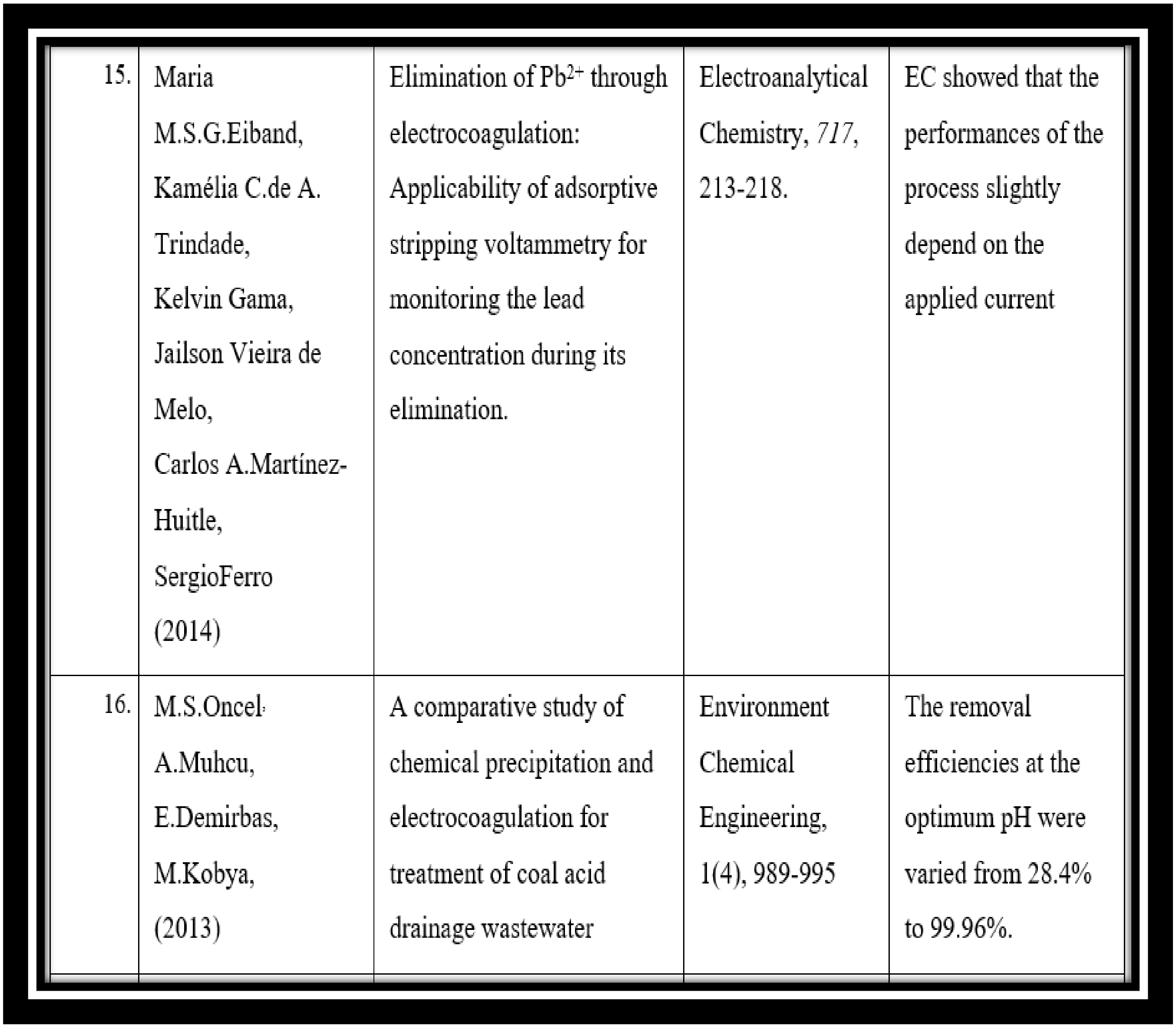


9.	Eva Fekete, Bela Lengyel, Tamas Cserfalvi, Tamas Pajkossy (2016)	Electrocoagulation: an electrochemical process for water clarification.	Journal of Electrochemical Science and Engineering, *6*(1), 57-65.	In 1 kg/m^3 organic content, we conclude that 80-90 % of the organic content can be removed on the expense of dissolution of Al of less than one-tenth of mass of the removed organics plus about 0.5-1 kWh electric energy per kg of removed organics.
10.	Carlos E. Barrera-Díaz, Bernardo A. Frontana-Uribe, Gabriela Roa-Morales &Bryan W. Bilyeu (2015)	Reduction of pollutants and disinfection of industrial wastewater by an integrated system of copper electrocoagulation and electrochemically generated hydrogen peroxide	Environment Science and Health, *Part A*, *50*(4), 406-413.	The objective of this study was to evaluate the effect of copper EC and hydrogen peroxide on different parameters. The copper EC alone reduces COD by 56% in 30 min at pH 2.8, but the combined system reduces COD by 78% and color by 97% under the same conditions.

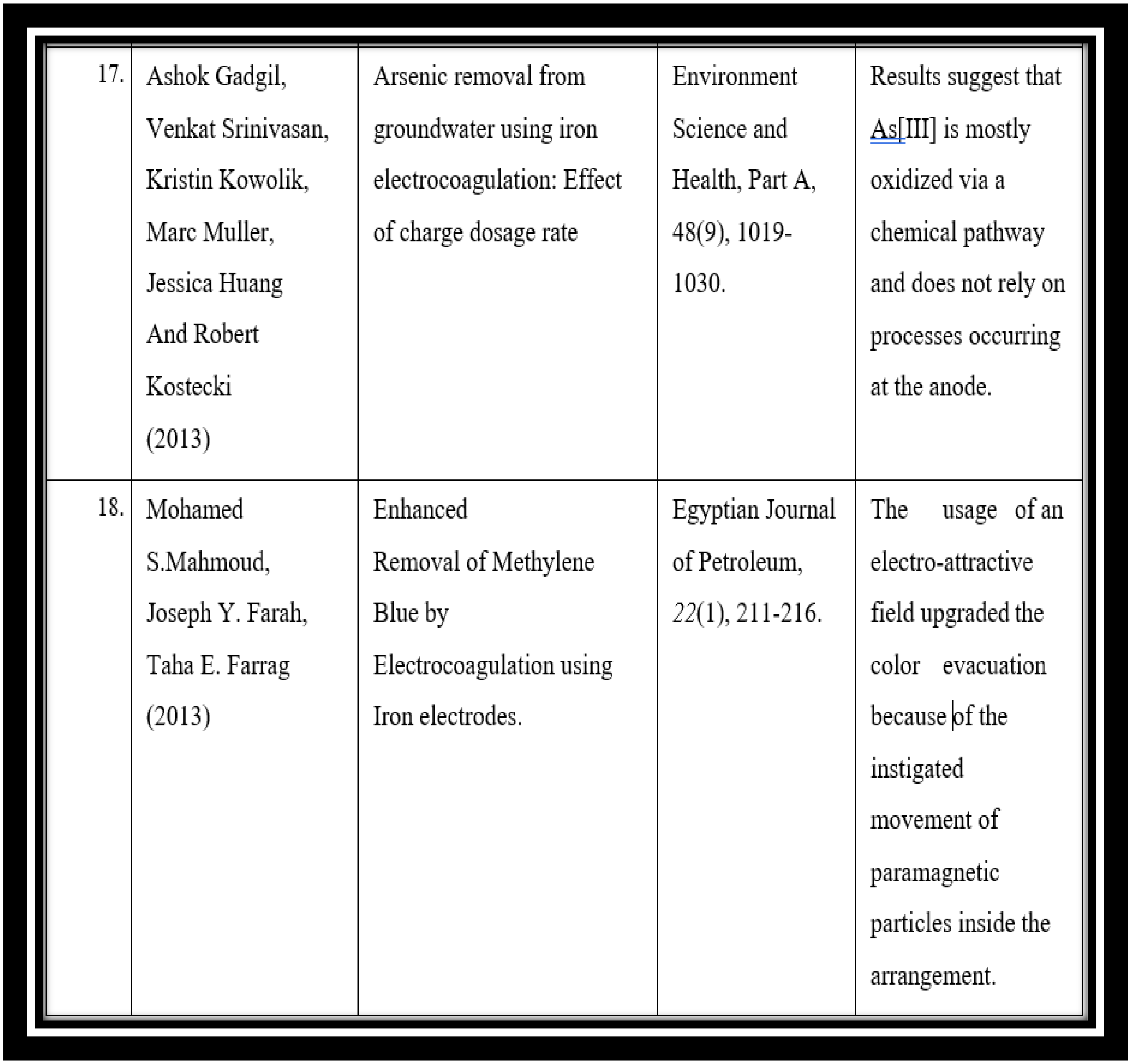
11.	Khaled Brahmi, Wided Bouguerra, Béchir Hamrouni , And Mouna Loungou (2015)	Removal of zinc ions from synthetic and industrial Tunisian wastewater by electrocoagulation using aluminum electrodes	Desalination and Water Treatment, *56*(10), 2689-2698.	Optimum conditions for zinc removal were found at a pH value of 7, a current density of 7.35 mA cm^{-2}, a conductivity of 5.3 mS cm^{-1}, and an EC time of 30 min with a removal percentage up to 98.96
12.	Bong-yul Tak, Bong-sik Tak, Young-ju Kim, Yong-jin Park, Young- hun Yoon,Gil-ho Min. (2015)	Optimization of color and COD removal from livestock wastewater by electrocoagulation process: Application of Box– Behnken design (BBD).	Journal of Industrial and Engineering Chemistry, *28*, 307-315.	Prudent working Situations and Evacuation efficiencies were observed having pH of 8, flow thickness of 30 mA/cm2, NaCl grouping of 1 g/L, and 94.2 % (Y1) and 93 % (Y2), individually.



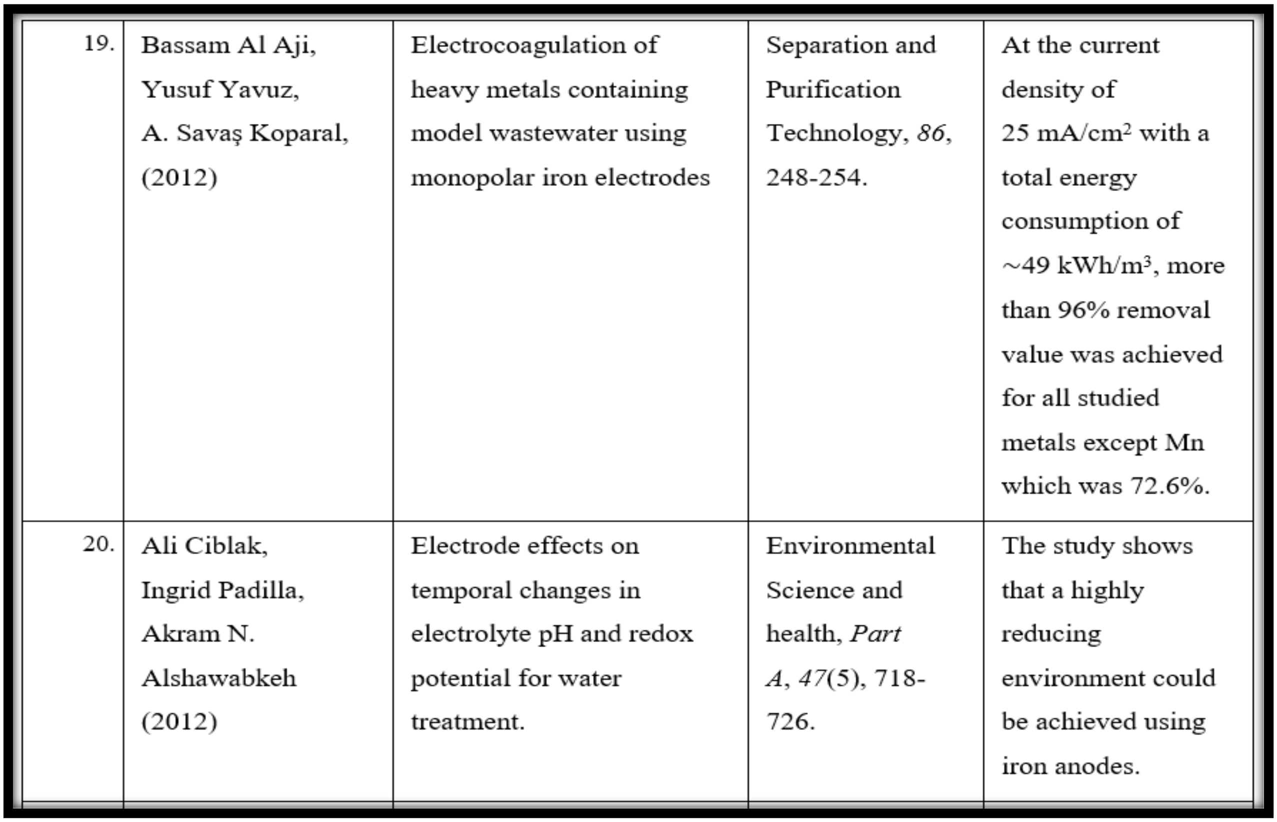
13.	Akanksha, Roopashree G. B, Lokesh K. S. (2014)	Comparative study of electrode material (iron, aluminum and stainless steel) for treatment of textile industry wastewater.	International Journal of Environmental Sciences, *4*(4), 519-531.	The outcome shows that electrocoagulation is exceptionally productive and had the capacity to accomplish shading expulsion (99.46 %) at 14 V in 80 min
14.	T.M.Zewail, N.S.Yousef (2014)	Chromium ions (Cr^{6+} & Cr^{3+}) removal from synthetic wastewater by electrocoagulation using vertical expanded Fe anode.	Electroanalytical Chemistry, *735*, 123-128.	94.97% removal of Cr^{6+} occurs by a power consumption of 16.14 kW/kg. Maximum percentage removal of Cr^{3+} is 99.97 by a power consumption of 10.98 kW h/kg.



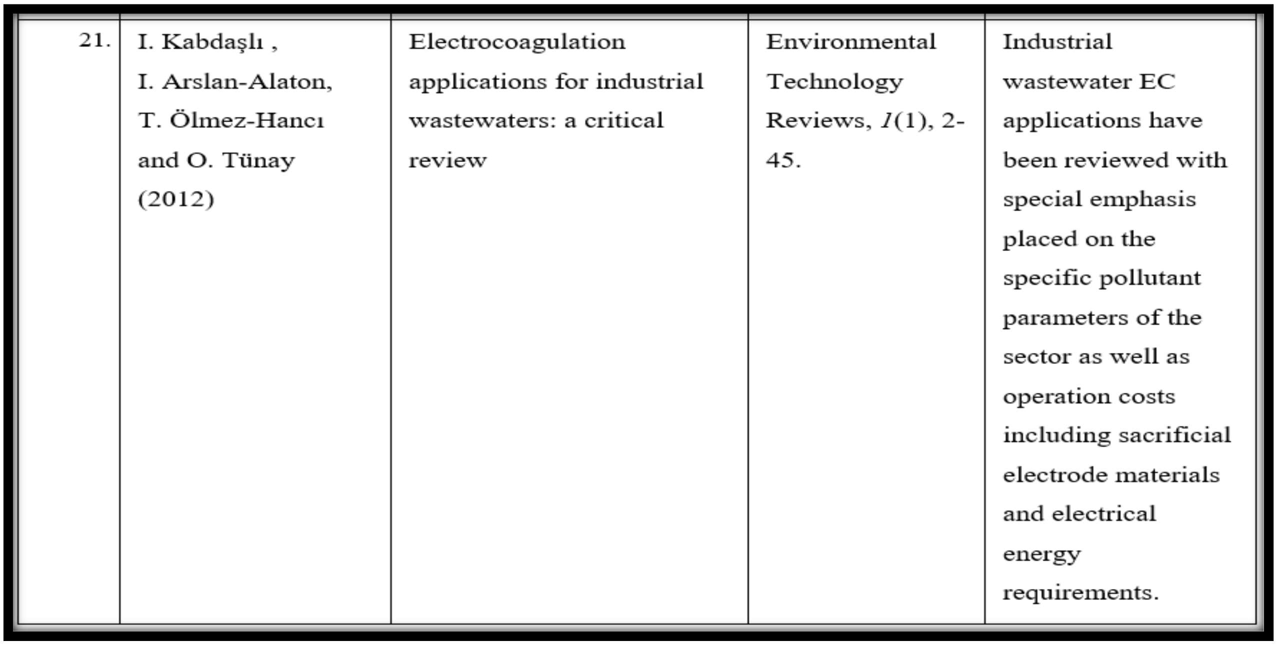
15.	Maria M.S.G.Eiband, Kamélia C.de A. Trindade, Kelvin Gama, Jailson Vieira de Melo, Carlos A.Martínez-Huitle, SergioFerro (2014)	Elimination of Pb^{2+} through electrocoagulation: Applicability of adsorptive stripping voltammetry for monitoring the lead concentration during its elimination.	Electroanalytical Chemistry, *717*, 213-218.	EC showed that the performances of the process slightly depend on the applied current
16.	M.S.Oncel, A.Muhcu, E.Demirbas, M.Kobya, (2013)	A comparative study of chemical precipitation and electrocoagulation for treatment of coal acid drainage wastewater	Environment Chemical Engineering, 1(4), 989-995	The removal efficiencies at the optimum pH were varied from 28.4% to 99.96%.



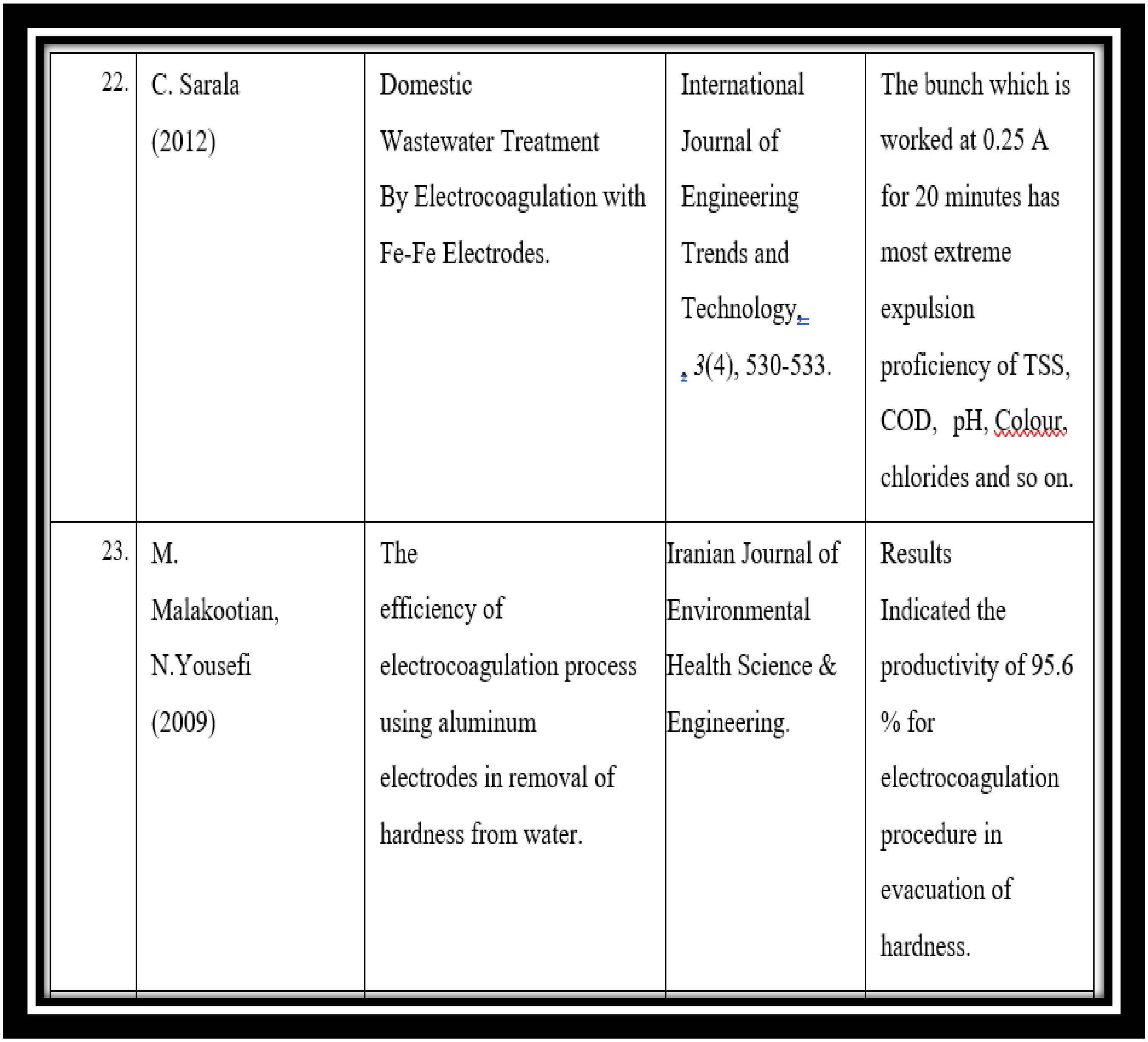
17.	Ashok Gadgil, Venkat Srinivasan, Kristin Kowolik, Marc Muller, Jessica Huang And Robert Kostecki (2013)	Arsenic removal from groundwater using iron electrocoagulation: Effect of charge dosage rate	Environment Science and Health, Part A, 48(9), 1019-1030.	Results suggest that As[III] is mostly oxidized via a chemical pathway and does not rely on processes occurring at the anode.
18.	Mohamed S.Mahmoud, Joseph Y. Farah, Taha E. Farrag (2013)	Enhanced Removal of Methylene Blue by Electrocoagulation using Iron electrodes.	Egyptian Journal of Petroleum, *22*(1), 211-216.	The usage of an electro-attractive field upgraded the color evacuation because of the instigated movement of paramagnetic particles inside the arrangement.



19.	Bassam Al Aji, Yusuf Yavuz, A. Savaş Koparal, (2012)	Electrocoagulation of heavy metals containing model wastewater using monopolar iron electrodes	Separation and Purification Technology, *86*, 248-254.	At the current density of 25 mA/cm^2 with a total energy consumption of ~49 kWh/m^3, more than 96% removal value was achieved for all studied metals except Mn which was 72.6%.
20.	Ali Ciblak, Ingrid Padilla, Akram N. Alshawabkeh (2012)	Electrode effects on temporal changes in electrolyte pH and redox potential for water treatment.	Environmental Science and health, *Part A*, *47*(5), 718-726.	The study shows that a highly reducing environment could be achieved using iron anodes.



21.	I. Kabdaşlı , I. Arslan-Alaton, T. Ölmez-Hancı and O. Tünay (2012)	Electrocoagulation applications for industrial wastewaters: a critical review	Environmental Technology Reviews, *1*(1), 2-45.	Industrial wastewater EC applications have been reviewed with special emphasis placed on the specific pollutant parameters of the sector as well as operation costs including sacrificial electrode materials and electrical energy requirements.



22.	C. Sarala (2012)	Domestic Wastewater Treatment By Electrocoagulation with Fe-Fe Electrodes.	International Journal of Engineering Trends and Technology, , *3*(4), 530-533.	The bunch which is worked at 0.25 A for 20 minutes has most extreme expulsion proficiency of TSS, COD, pH, Colour, chlorides and so on.
23.	M. Malakootian, N.Yousefi (2009)	The efficiency of electrocoagulation process using aluminum electrodes in removal of hardness from water.	Iranian Journal of Environmental Health Science & Engineering.	Results Indicated the productivity of 95.6 % for electrocoagulation procedure in evacuation of hardness.

24.	O.T. Can, M. Koby, E.Demirbas, M.Bayramoglu (2006)	Treatment of the textile wastewater by combined electrocoagulation.	Chemosphere, *62*(2), 181-187.	The two salts displayed a similar act in compound coagulation, but in consolidated electrocoagulation, PAC upgraded the COD evacuation rate and productivity, contingent upon the measure of the all-out aluminum provided, by starting expansion and electrochemical age.

25.	P Ratna Kumar, Sanjeev Chaudhari, Kartic C Khilar, (2004)	Removal of arsenic from water by electrocoagulation	Chemosphere, *55*(9), 1245-1252.	Arsenic removal obtained was highest with iron electrodes. It was observed that higher current density achieved rapid arsenic removal.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Pharmaceutical companies list among the world's leading industries. Though the output of such industries is focused on plants, the production method still uses synthetic chemicals. The pharmaceutical companies contain a substantial amount of high-resistance wastewater. It cannot be immediately released into the sea water, because it putrefies very easily. Pharmaceutical waste is a complex component of alkaloids, plant extracts, and toxic solutes which make a contribution to pollution of the environment (Can & Bayramoglu, 2006). Untreated disposal of chemical contaminants into the natural ecosystem poses environmental risks to current flora and fauna and thus effluent control is essential to the accumulation of toxins to the required levels until they are eventually released into the natural environments (Kumar& Mahajan, 2004). Therefore, a treatment technique is required which is simple to administer and can be readily adopted by the local manufacturing units. Latest work has shown that thanks to stringent environmental laws, electrochemical methods will offer a reasonable potential for avoiding and remedying emission problems (Kumar& Mahajan, 2004).

The process of electro-coagulation (EC) is a easy and effective system which has gained much interest for the treatment of different industrial wastewaters Compared to the conventional, the advantages of this approach are simple to operate, less retention time, relatively lower costs, no addition of chemicals, rapid sedimentation of electrogenerated flocks and less sludge production, and simple equipment is required. But the efficacy of these treatments varies for different types of wastewater. Therefore, it is important to research the effectiveness of electrocoagulation on a pharmaceutical wastewater before recommending it as a treatment method. Over the previous years, pollution disposal has been performed mainly using microbial processes. This work tries to study the feasibility of Electrocoagulation in Pharmaceutical Wastewater (PW).

3.2 SAMPLING OF PHARMACEUTICAL WASTEWATER

The wastewater used for the study was collected from Kudos pharmaceuticals Ltd. Shoghi. The experimental runs were conducted in the lab scale reactor and all the chemicals used were of analytical grade. The samples were taken from the equalization tank of the treatment unit after the skimming operation. The wastewater was stored at a temperature lower than 30^{o}C but above the freezing point of water. For the characterization of wastewater analysis were done for all samples collected as per standard methods. The range of values of characteristics of raw pharmaceutical wastewater (PW) is shown in the **Table 3.1**.

Table 3.1 Characteristics of Industrial Wastewater

Parameters	Unit	Range
pH		3.5-5.5
Chemical oxygen demand (COD)	mg\L	9500-15000
Biological oxygen demand (BOD)	mg\L	4250-6250
Total solids	mg\L	8300-12300
Turbidity	NTU	170-260
Conductivity	mS/cm	4.5-8.5

3.3 EXPERIMENTAL SETUP AND PROCEDURE

The dimensions of the reactor are 10*10*20 cm and its total capacity is 1 Litre. The electrodes used are made of Aluminium and Iron and their width is 0.6 cm. Total number of electrodes is 7 out of which 4 are made of aluminium and 3 are of iron as shown in **Table 3.2** The power supply used is a variable supply with maximum output of 250V and 3 Ampere. The aforementioned voltage and current were adopted as we wanted flexibility in the range and wanted to test at various values to get the maximum efficiency. As it was mentioned in the literature review, (Kabdasli and Tunay. 2012), we tried to perform our testing at 25V and current of 1-3 Ampere.

The testing was divided into three phases of 10, 20 and 30 min respectively. Various parameters such as pH, TDS, COD, Turbidity and conductivity will be checked in the three phases. After all the data collection **(Table 3.3)**, statistical modelling and efficiency of the EC process will be checked and verified.

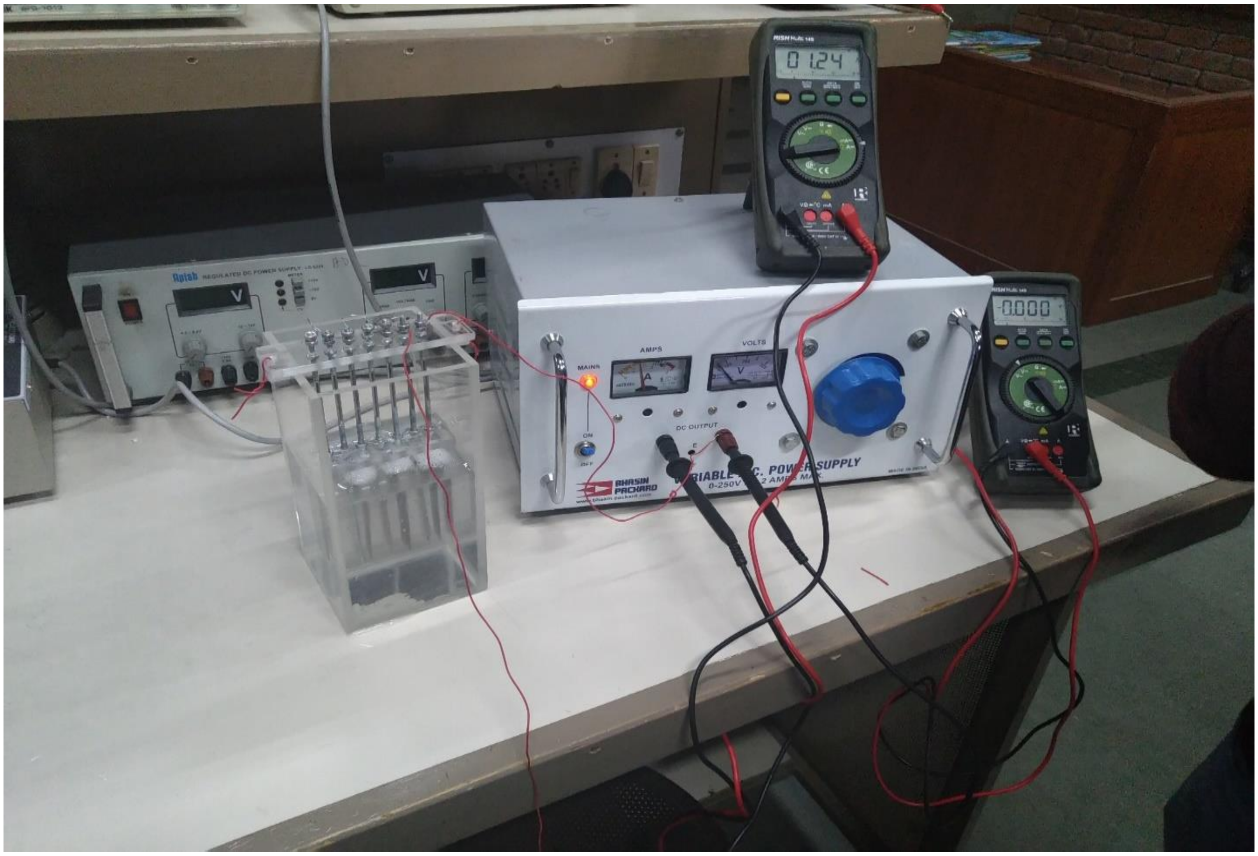


Fig 3.1: Pictorial depiction of EC reactor

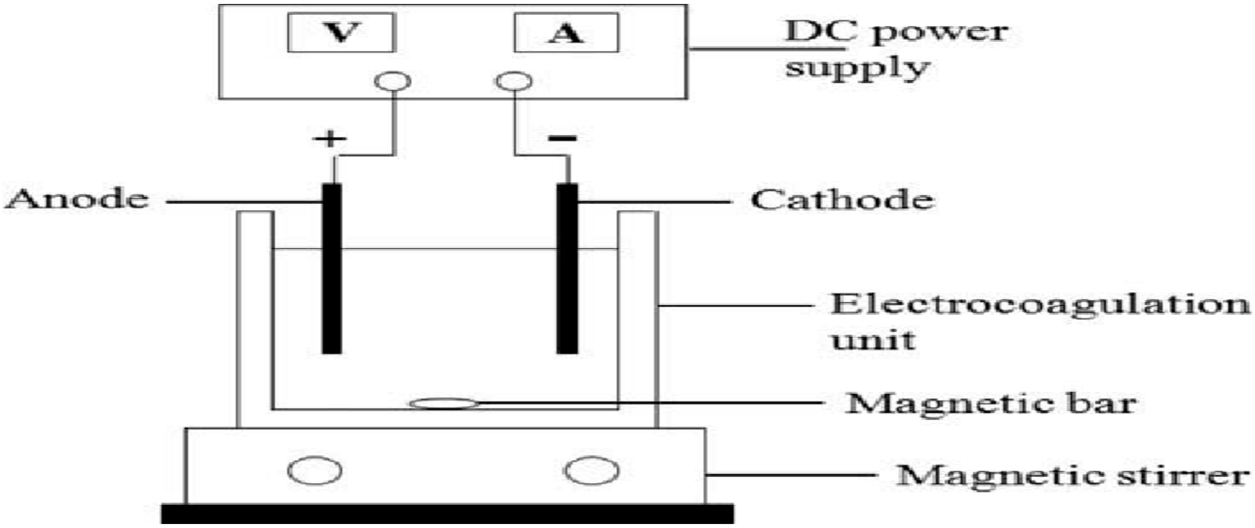


Fig 3.2: Line Diagram of EC reactor

Table3.2 Specifications of EC reactor

No. of anodes	No. of cathodes	Side gap(cm)	Internal Gap(cm)
1	1	3	2.6
2	2	2	1.06
3	2	1.3	1.3
4	3	0.6	0.6

3.4 ANALYTICAL METHODS

The analytical methods adopted for testing are shown in **Table 3.3.**

Table 3.3 Analytical methods for testing

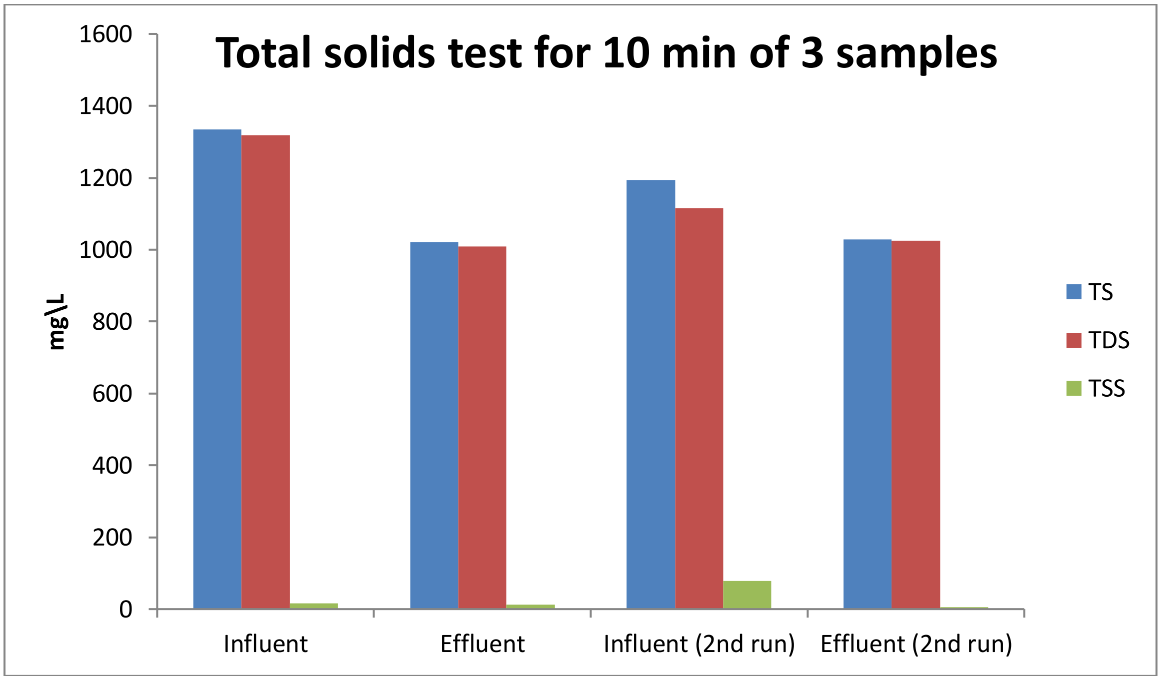
Parameter	Instrument
pH	pH meter
COD	COD Digester
Turbidity	Turbidity meter
TDS	Filter paper
Conductivity	Conductivity meter

CHAPTER 4

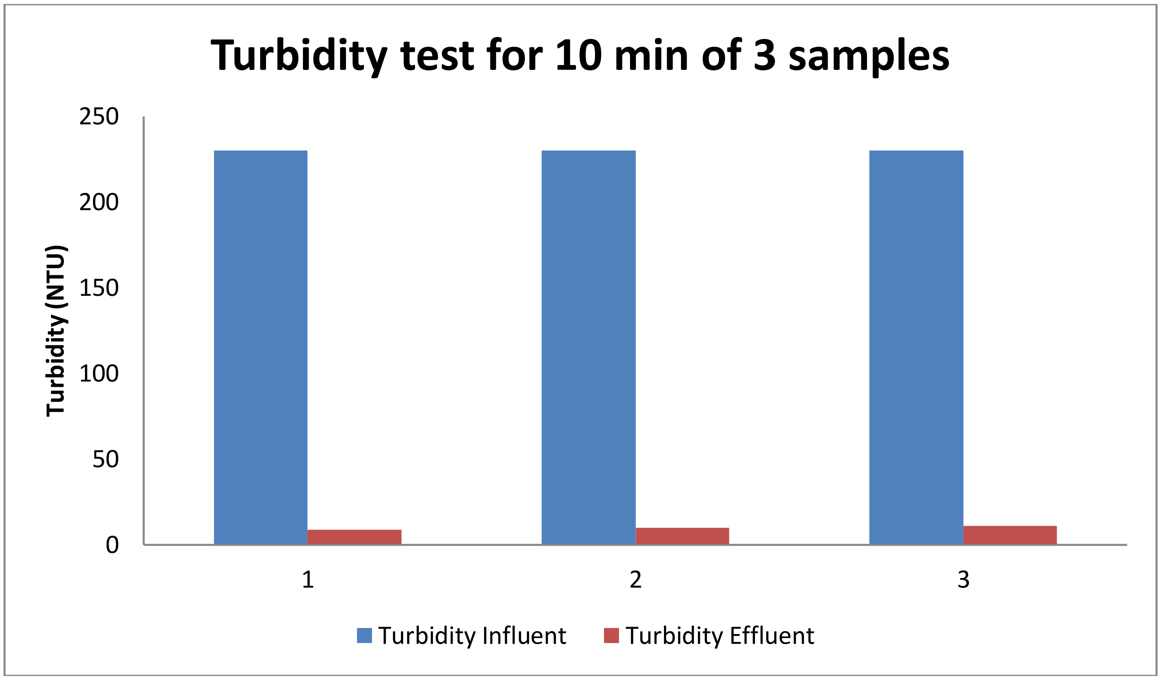
RESULTS AND DISCUSSION

4.1 PRELIMINARY TESTING (10 MINS)

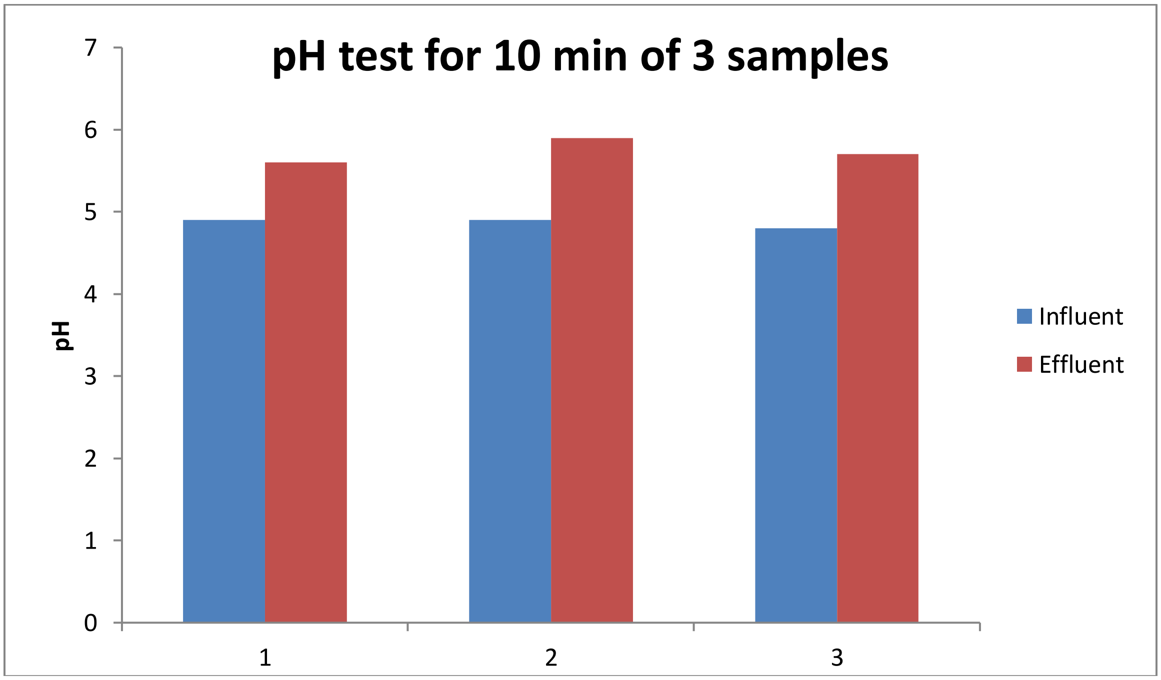
Effect on pH, TDS, Turbidity, Conductivity: The reactor was operated for 10 min in the preliminary stage and the initial voltage was 25V and current was around 2.5-3A. The testing was done for 10mins in the first phase for which the graphical representation for all the parameters is shown below.



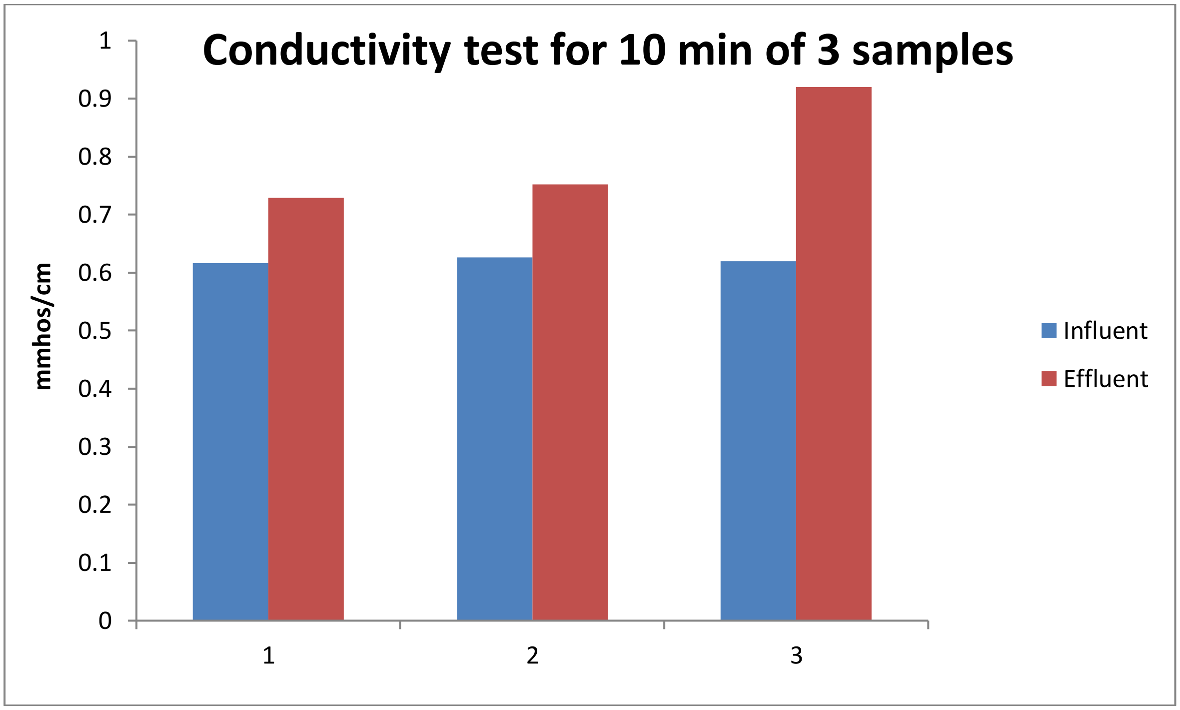
After the first phase testing of pharmaceutical samples for 10 min, it was found that some number of total solids was removed and the removal efficiency was 23.4%. This was due to the electricity used which precipitated the dissolved and suspended solids and hence decreased the total solids concentration.



The results of the first phase testing showed that turbidity was removed to a great extent and the removal efficiency was 95.6%. This was because the total solids concentration decreased due to the EC process.



pH levels were increased after 10 min testing and became 6.5 which is very close to neutral pH. The increase of pH in acidic medium is due to hydrogen evolution at the cathode while the decrease of pH is due firstly to the formation of hydroxide precipitates that release H+ cations at the anode surrounding and the secondary reactions such as water oxidation and chlorine production and its hydrolysis (Oncel, M.S., Muhcu, 2013).



Conductivity also increased after the first phase due to the formation of metal ions and dissolution of the ions. There was seen a 30% increase in conductivity for the first phase testing.

SUMMARY TABLE FOR PRELIMINIARY TESTING (10 MINS)

Parameters	**Removal Efficiency**
Total solids	23.4%
Turbidity	95.6%
Conductivity	30%

4.2 OPTIMUM TIME

In the second phase testing was done for 20 and 30 mins which proved to be less significant as the results were not within the prescribed limits due to the dissolution of electrode ions. This resulted in higher conductivity, TDS TSS and TS values. So, in this phase of testing we got to know that optimum time lies within 30 mins.

After three trial test runs for 10, 20 and 30 mins, we got to know that the optimum time (residence time) of operation is 7 mins. The required voltage and current varies from 20-25V and 1-2A current. The efficiency at this time was the maximum for the parameters taken into consideration. The parameters such as pH, turbidity, TS, TDS, TSS were analyzed and had efficiencies greater than 80%. This was because minimal or no dissolution of electrodes was occurring at this time contributing to high values of removal efficiencies.

4.3 EFFECT OF pH

pH is responsible for hydrolyzation of metal species which are generated in reactive media therefore pH is one the main factor in affecting the performance of EC. Many studies show how pH affects in relation with thermodynamic equilibrium. Properties like coagulation and adsorption mainly depends on pH. The Al or Fe precipitates can be explained by the adsorption of the charged soluble monomeric species on their respective hydroxide precipitates. In respect of these superficial charge, relation between coagulant species depend on pH and its neighboring pollutants can be found by electrostatic interactions. Nernst equation is used to find the importance of EC performance by thermodynamics associated with electrochemistry (Khaled & Zied 2019).

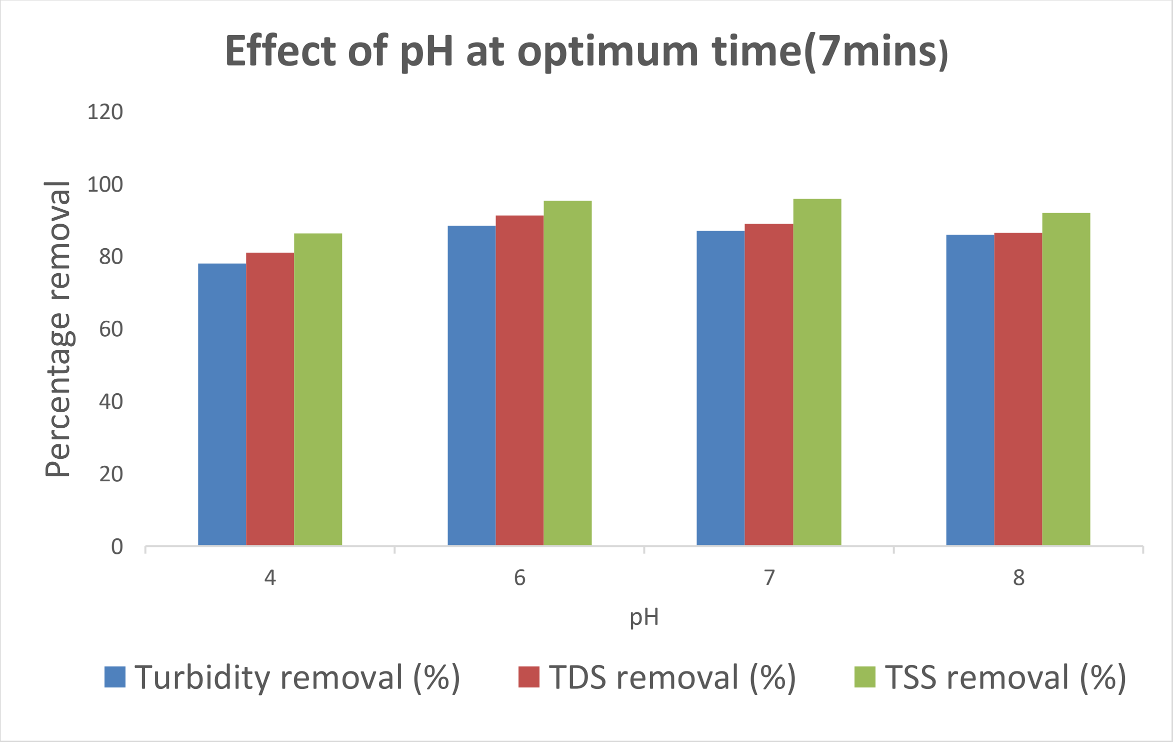
A study done by Zongo about the Al and Fe speciation with aim to establish the predominance of corresponding hydroxides as a function of pH considering only monomeric species. It has been observed that there is a sharp increase in aluminum hydroxide with increase in pH from 4.5 to 7. Similarly, it has been observed that amount of insoluble iron hydroxide sharply increases with increase in pH from 4.5 to 7.

From the above studies, we can say that due to buffering effect of EC, the pH of effluent would increase after EC for acidic medium and can decrease for alkaline medium. Hydrogen evolution at the cathode leads to increase in pH in acidic medium and formation of hydroxide precipitates that releases H+ cations at anode leads to decrease in ph. This buffering effect of EC is high in case if Al electrode due to formation of aluminate ions.

It also has been observed that bicarbonate alkalinity is also efficient in pollution removal activity. According to other studies, it has also been observed that maximum turbidity removal occurs at pH around 8. pH affects the sample as shown in **Table 4.1**

Table 4.1 pH range and its effect

pH range	**Effect**
2-3	Cationic species Al^{3+} and Al $(OH)_2^+$ predominate
4-9	Reaction between Al^{3+} and OH^- to form Al $(OH)_2^+$ and Al $(OH)_2^{2+}$
>8	Formation of Al $(OH)_4^-$

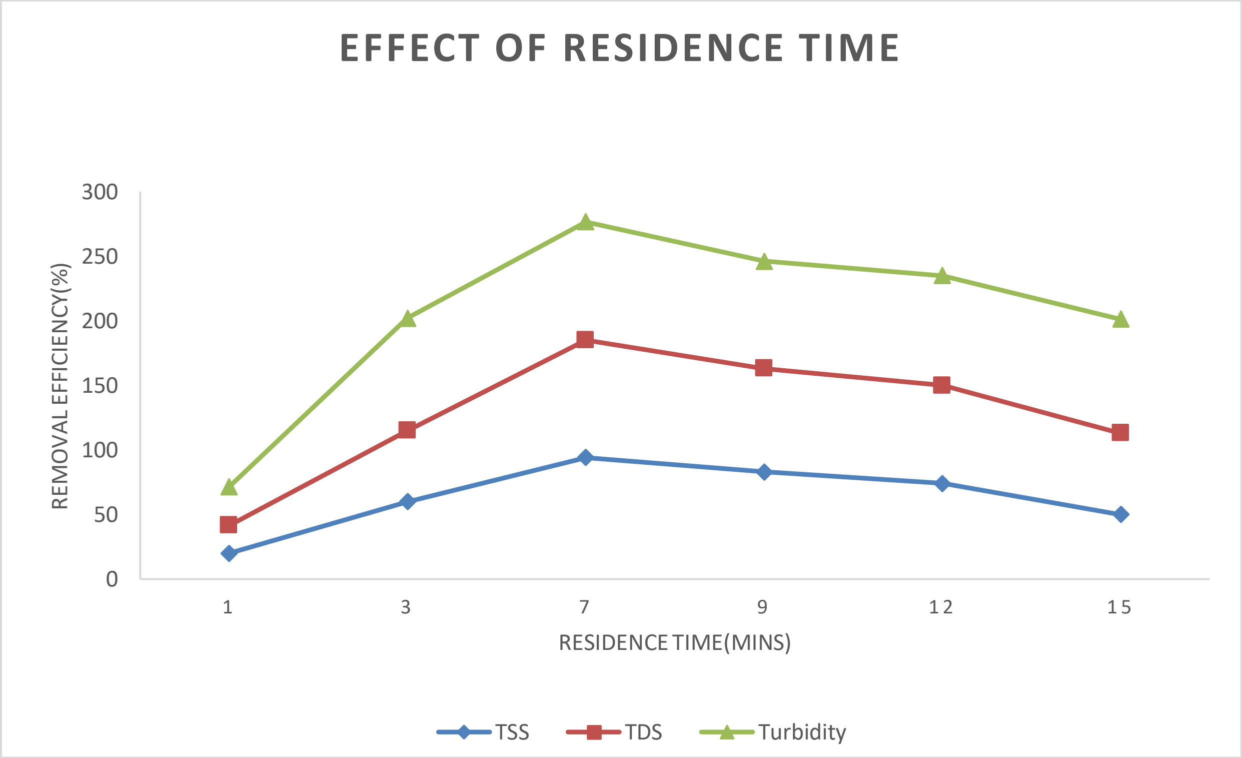


pH is one of the most important parameters in electrocoagulation process and has been researched upon widely. To study the effect of pH, electrolysis time, inter electrode distance were kept at 7 mins and 0.6 cm respectively. The experiments were conducted at various pH levels which are shown below in the graphical representation. It was also observed that electrolysis is effective in suspended solids removal. Electro-coagulation provided TSS removal efficiency above 85% in acidic, neutral and basic ranges. In the lower pH range the slight decrease in TSS removal is due to the lack of proper floc formation (Can & Bayramoglu, 2006).

Turbidity and suspended solids increase after the process because of hydroxide formation. The abatement of suspended solids contained in EC treated effluent after 60 min settling was 13 % at 50A/m2 higher suspended removal yields were obtained with iron electrodes ranging from 47.9% at 50 A/m2 to 60.6% at 200 A/m2. After 60 min settling the avg suspended solids reached little less value. This is due to the presence of larger flocs present in the sample. Nevertheless, there is no suspended solid in the first centimeters of the surface and the liquid is clear, that means easy initial separation of the suspended solids. The remaining bigger flocs containing the hydrogen easily settle upon smooth agitation. The removal efficiency of suspended solids and turbidity by treatment with aluminum electrode is much more effective for acidic pH 5 as the liquid pH after EC was equal to 7.02(Salim & Potier, 2009). Because Al $(OH)_3$ predominates for pH near 7 and that amorphous al hydroxides exhibit min solubility for pH ranging from 6.5 and 7.8 it can be concluded that the highest removal rates are achievable. Nevertheless, for pH 9, EC was measured at 7.41 the clear liquid over sludge still had an appreciable suspended solid content although the separation was faster and resulted in a thinner sludge layer the clear liquid was not perfectly treated. On the contrary higher settling efficiency was observed at neutral and alkaline pH when EC was conducted with Fe electrode. The best results corresponding to the best suspended solid and turbidity removal yields were obtained with pH 7. Also, for higher time period the suspended solids obtained were less which shows that the rate of suspended solid removal yield increases with increase in treatment period and that better results can be obtained with Fe electrodes than with al electrodes. Once again, the Suspended solid is mainly due to the presence of larger flocs containing hydrogen bubbles that can easily be removed.

4.4 EFFECT OF RESIDENCE TIME

The time for which electrolysis is carried out is a significant feature as it impacts the productivity of treatment of the electrochemical technique in this experiment, and effects turbidity, TSS, TDS removal efficiency. This was performed at constant current of 1A, electrode distance of 0.6cm. The graph below shows the change of turbidity and TDS removal efficiencies as a function of residence time.



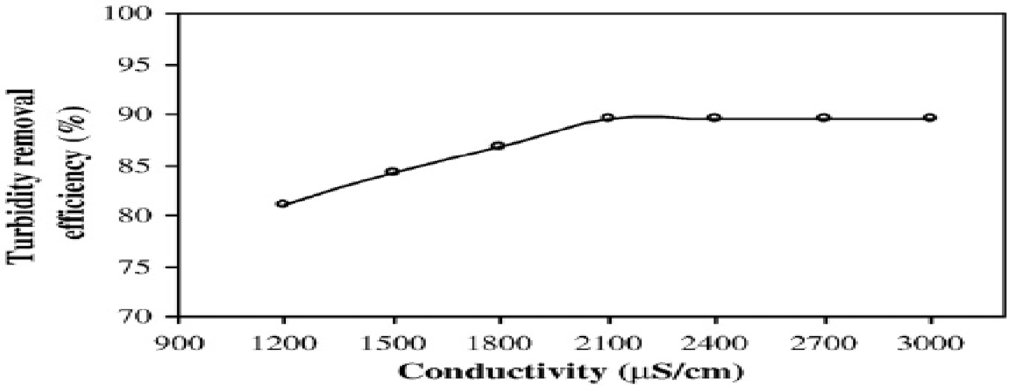
It is pretty evident that the removal efficiency at 7 mins is the highest for all the parameters. The turbidity increases from 30% to 91.5 % at optimum time. The values of TDS and TSS at residence time of 7 mins are 91 and 94 respectively. In this process electro coagulation process, there are two stages: The first is destabilization and collection of particles which takes place in a short period. The second which includes precipitation of particles takes a longer time. It is clear that Fe2+ formed at the electrode is responsible for destabilizing the negative particles in water. The quantity of Fe2+ irons is small at the beginning in the EC reactor so Fe3+ is not enough to precipitate all colloids from water. So, the efficiency of removing turbidity, TDS and TSS is low at small residence times.

4.5 EFFECT ON CONDUCTIVITY

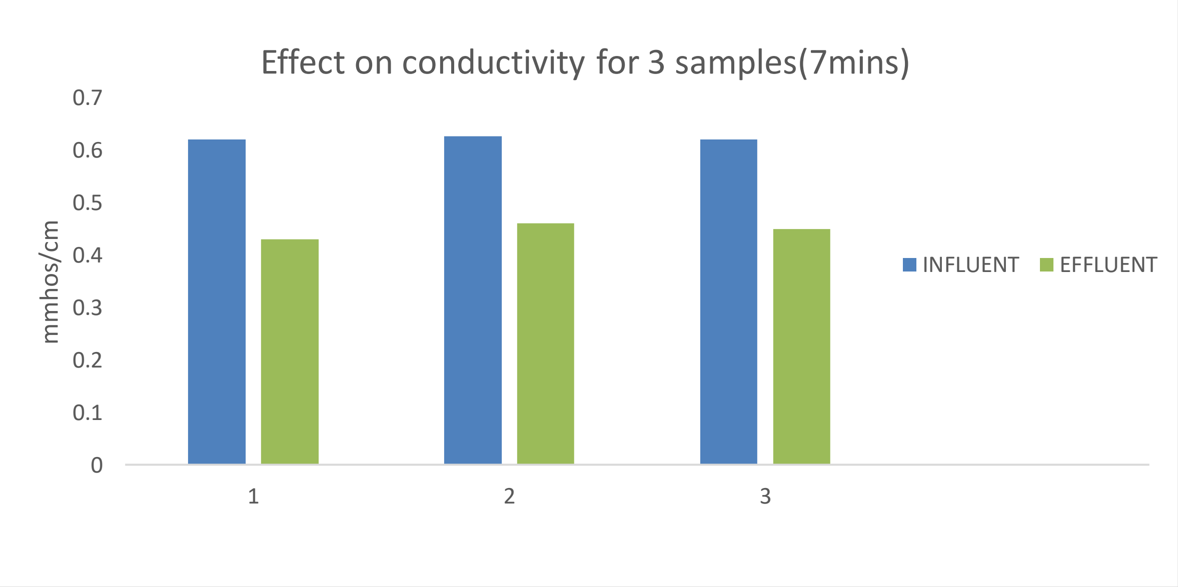
Conductivity and ionic strength play an important role in current density. Increase in electrolytic conductivity leads to increase in current density efficiency, this happens due to decrease of ohmic resistance of waste water. To achieve particular removal yield, conductivity also decreases the treatment time. On the other hand, energy consumption is also reduced (Khaled & Zied 2019).

To increase the electrolytic conductivity, NaCl is widely used. To avoid the precipitation of calcium carbonate in hard water, chloride ions take part in reduction of adverse effect of other ions. At very high current density there is oxidation of chloride ions to active chlorine forms take place. Further they can oxidize organic compounds which contribute to disinfection in wastewater. Many studies show that atleast 20% of ions present should be Cl^- for normal working of EC operations (Salim & Potier, 2009).

In treatment of wastewater with EC operations, there can be formation of secondary pollutants due to conductivity. So, we have to follow some norms which are the deciding factors of whether treated wastewater will be reused or flow out to ecosystem. This is not in the case of treatment of drinking water by EC operations due to various other factors.
Conductivity plays an important role in removal of turbidity. As shown in the graph we can have a relation between conductivity and turbidity (Salim & Potier, 2009).



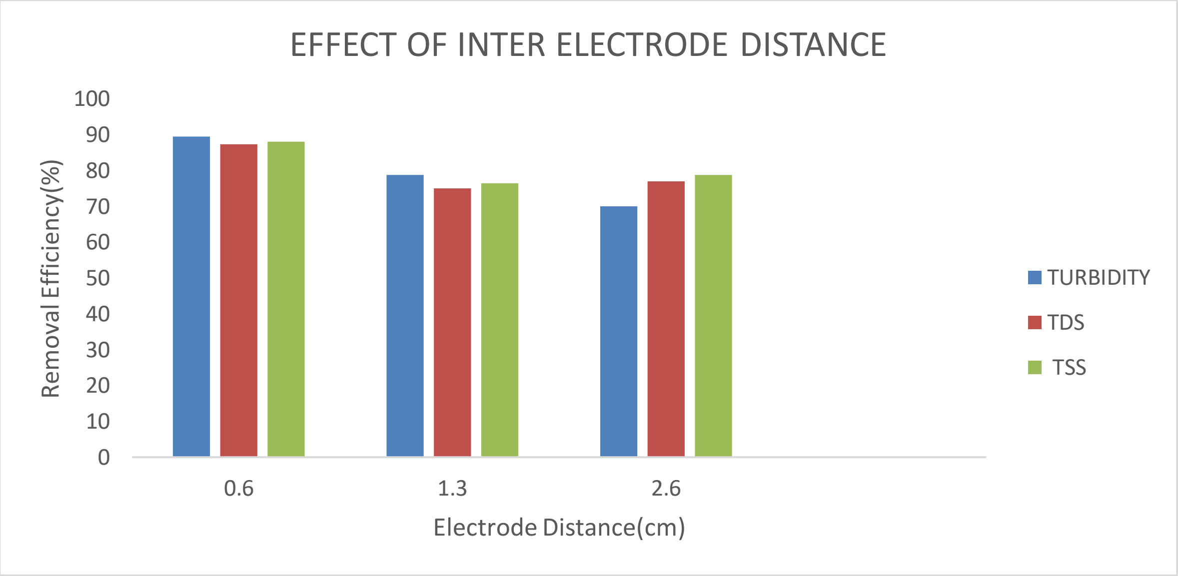
Initially for the preliminary testing of conductivity, a significant rise of 30% was observed which was not comparable with the conventional results. This was due to the dissolution of electrode ions and formation of metal ions. Then conducting various trial and test runs we got to know that at optimum time i.e. 7 mins the conductivity was coming to be decreasing as per the literature review (Salim & Potier, 2009). It was mentioned that the maximum conductivity value ranges from 5- 8mins of residence time, when voltage is 25V and current is 1A. This meant that the residence time selected was right as other results were also coming under the prescribed limits. A graph shown below shows us the drop in conductivity



The results from the graph clearly shows a drop in the conductivity value. Taking an average of the three samples, a significant decline of 35.69% in the conductivity of the three samples was witnessed.

4.6 EFFECT OF INTER ELECTRODE DISTANCE

In the reactor setup, three electrode gap arrangements are provided i.e. 0.6 cm, 1cm and 1.3 cm, 2.6cm. To study the effect of inter electrode distance on the treatment efficiency trials were conducted varying the electrode gap and keeping other factors constant. Following graph shows the effect of the same.



As it can be seen from the graph the maximum removal efficiency is coming at 0.6 cm electrode distance. For turbidity, a removal efficiency of 89.5% was witnessed. For TDS and TSS a similar efficiency of 87.4 % and 88% were seen which were the highest. For other two configurations i.e. 1.3cm & 2.6cm all the removal efficiencies were coming low as compared to the former configuration.

Electrocoagulation is a efficient method for handling industrial wastewater that has a large COD, BOD, and TDS content. To this purpose, the study was carried out using electrocoagulation for the management of pharmaceutical wastewater. Iron and aluminum electrodes were used and were tested for their efficiencies concerning, turbidity, conductivity, TDS, TSS. The performance often improved as the substrate for the electrodes shifted. Aluminum electrode was found to be more cohesive in removal than iron electrode. Results from different studies showed that electrode spacing plays a significant role in the treatment of pharmaceutical wastewater by electrocoagulation.

CHAPTER-5

CONCLUSION

From the results of the preliminary testing of 10 mins we got to know that after EC process, all the parameters were affected to a great extent. We saw an increase in pH from the acidic zone to neutral zone. Turbidity of the industrial wastewater also decreased drastically and the removal efficiency was 95.6%. TS concentrations were also decreased and the removal efficiency was 23.4%. Conductivity of the wastewater increased (around 30%) due the formation of ions.

- Optimum time was decided to be 7 mins and effect of turbidity, TDS TSS and conductivity was examined in depth. The following results were obtained:
- A significant decline of 35.69% in the conductivity of the three samples was witnessed.
- The turbidity increases from 30% to 91.5 % at optimum time. The values of TDS and TSS at residence time of 7 mins are 91% and 94% respectively.
- The maximum removal efficiency was coming at 0.6 cm of electrode distance which was 89.5%, 87.4%, 88% etc. for turbidity, TDS and TSS respectively.

5.1SCOPE FOR FUTURE STUDY

- The sludge produced after the EC cycle can contain dissolved metals and require special attention.

- Financial modeling / feasibility of EC treatments will be appropriate to understand the economic side of this treatment.

5.2 RECCOMENDATIONS

- After doing a vigorous research on the EC process, one thing was evident that this practice is not used on a large scale and the preconceived notions of its cost.

- The initial cost is 0-4% more but the lifetime operational cost is 45-55% less which makes it more economical for a long-term use.

- There are metal electrodes used in the EC process which requires to be changed after sometime. Incorporating some other materials such as non-metallic electrodes like carbon, graphite can be more successful as less dissolution of ions will be there.

- A process needs to be invented to remove the skimming layer from the wastewater which is treated. Adoption of skimming tanks, screening processes can be useful in it.

- Addition of an electrolyte can fasten the EC process to a great extent and help in faster coagulation and treatment process.

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APPENDIX- A (TABLE OF RESULTS)

Table A-1 Results of total solids(10mins)

S.no.	Influent (mg/L)			Effluent (mg/L)		
	Total	**Dissolved**	**Suspended**	**Total**	**Dissolved**	**Suspended**
1	1335	1319	16	1022	1009	13
2	1193	1115	78	1029	1024	5

Table A-2: Results of pH (10 mins)

S.no.	Influent	Effluent
1.	4.9	5.6
2.	4.9	5.9
3.	4.8	5.7

Table A-3: Results of turbidity (10 mins)

S.no	Influent (NTU)	Effluent (NTU)
1	230	9
2	230	10
3	230	11

Table A-4: Effect on conductivity(10mins)

S.no.	Influent (mmho/cm)	Effluent (mmho/cm)
1	0.616	0.729
2	0.626	0.752
3	0.620	0.920

Table A-5: Effect of pH

pH	Turbidity removal (%)	TDS removal (%)	TSS removal (%)
4	78	81	86.3
6	88.4	91.3	95.4
7	87	89	95.8
8	86	86.6	92

Table A-6: Effect of residence time

Residence time (mins)	TSS removal efficiency (%)	TDS removal efficiency (%)	Turbidity removal efficiency (%)
3	80.75	83	87
7	94	91	91.5
9	90	89	90.5
12	91.5	90.25	89.4
15	89.5	88.5	88.17

Table A-7: Effect on conductivity (7mins)

S.no.	Influent (mmho/cm)	Effluent (mmho/cm)
1	0.620	0.43
2	0.627	0.46
3	0.620	0.45

Table A-8: Effect of electrode distance

Electrode distance(cm)	Turbidity removal efficiency (%)	TDS removal efficiency (%)	TSS removal efficiency (%)
0.6	89.5	87.4	88
1.3	78.7	75	76.5
2.6	70.1	77	78.8

APPENDIX- B (PHOTOGRAPHS)

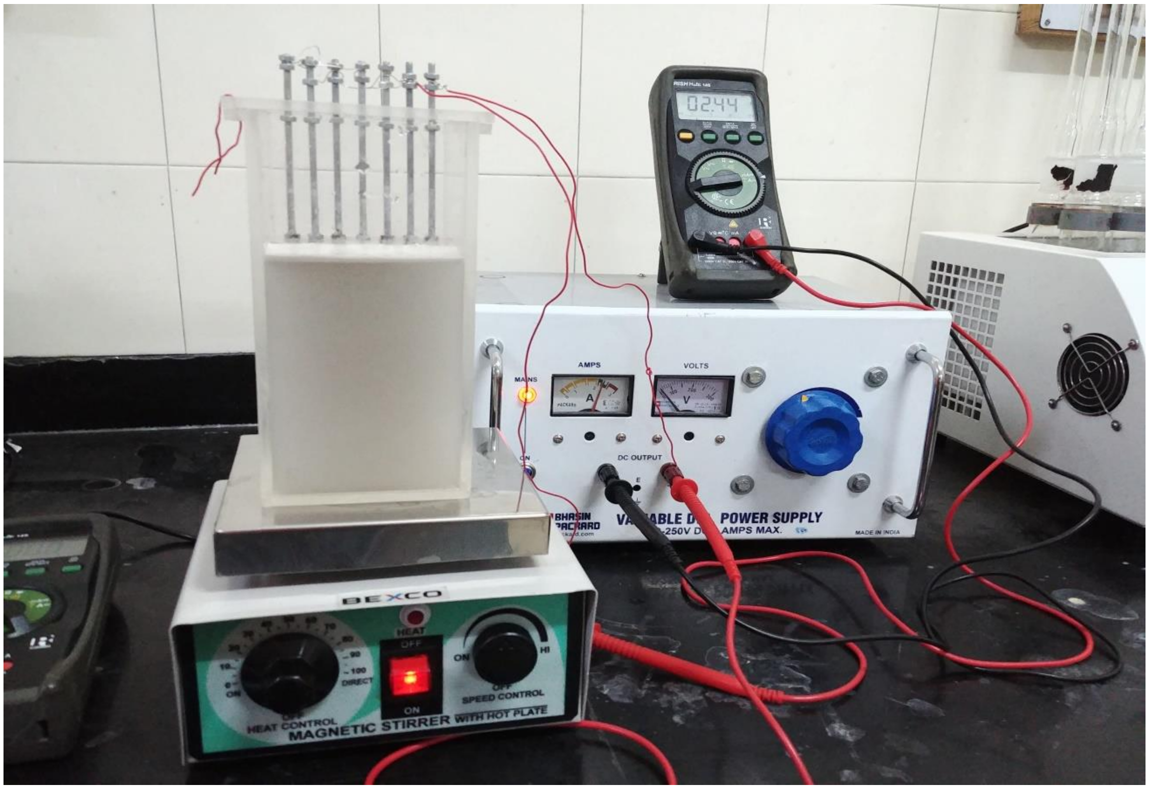

Figure B-1 Working of EC reactor

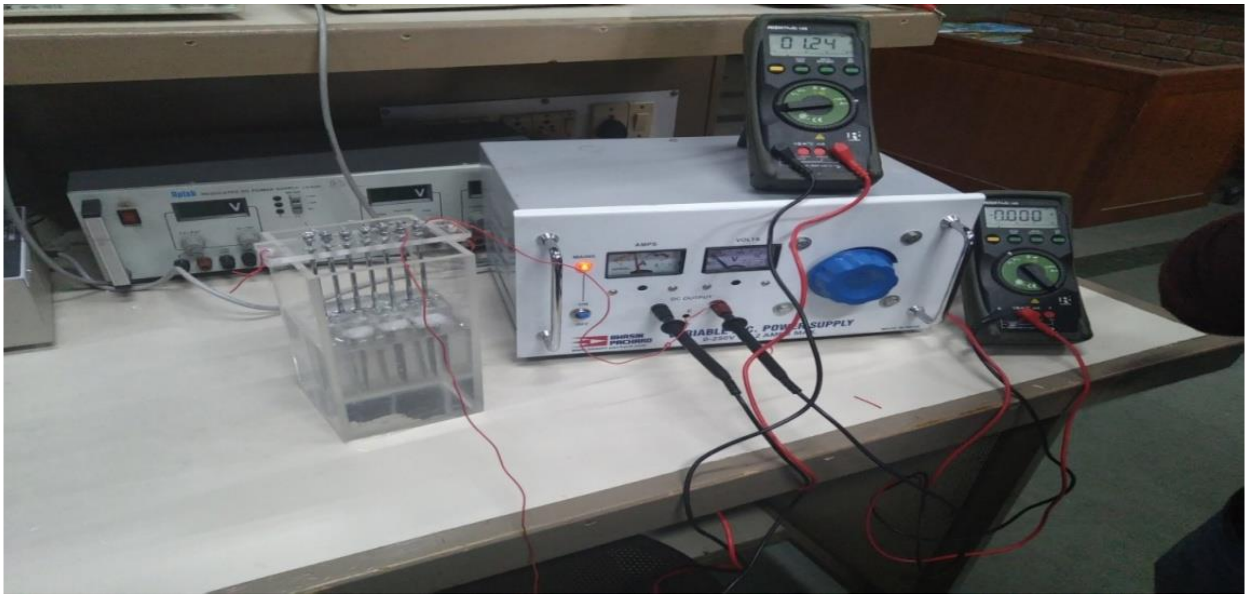

Figure B-2 Experimental Setup of EC reactor

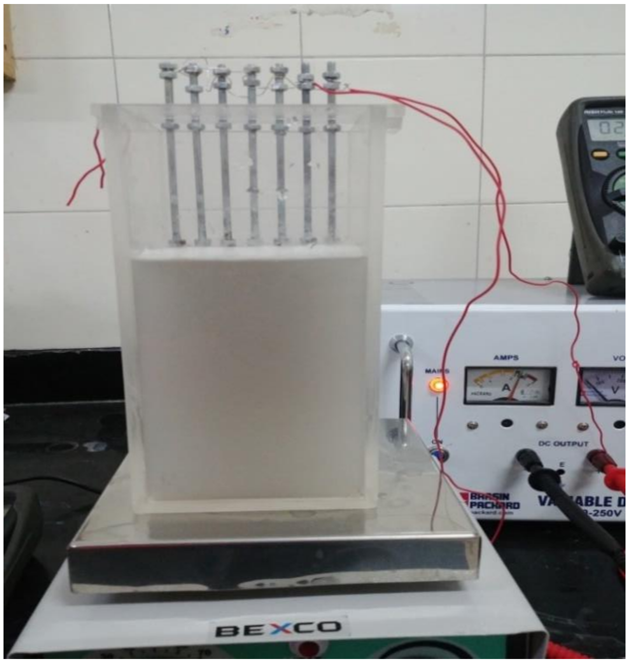

Figure B-3 In between of EC process

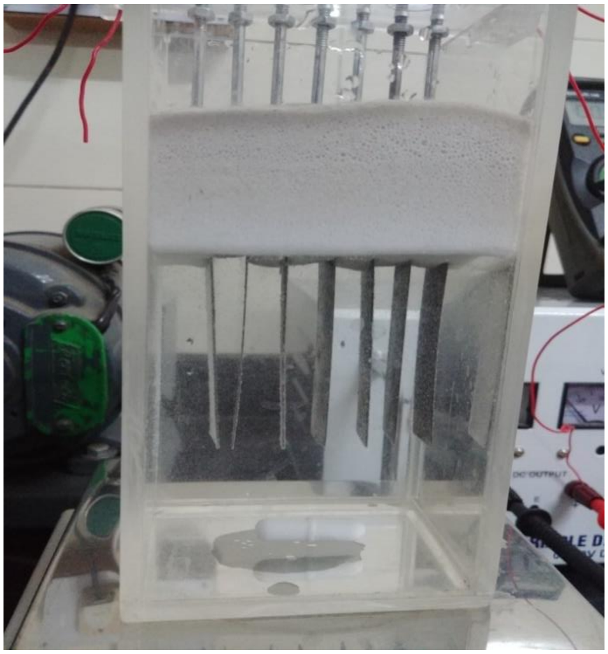

Figure B-4 After EC of Industrial wastewater

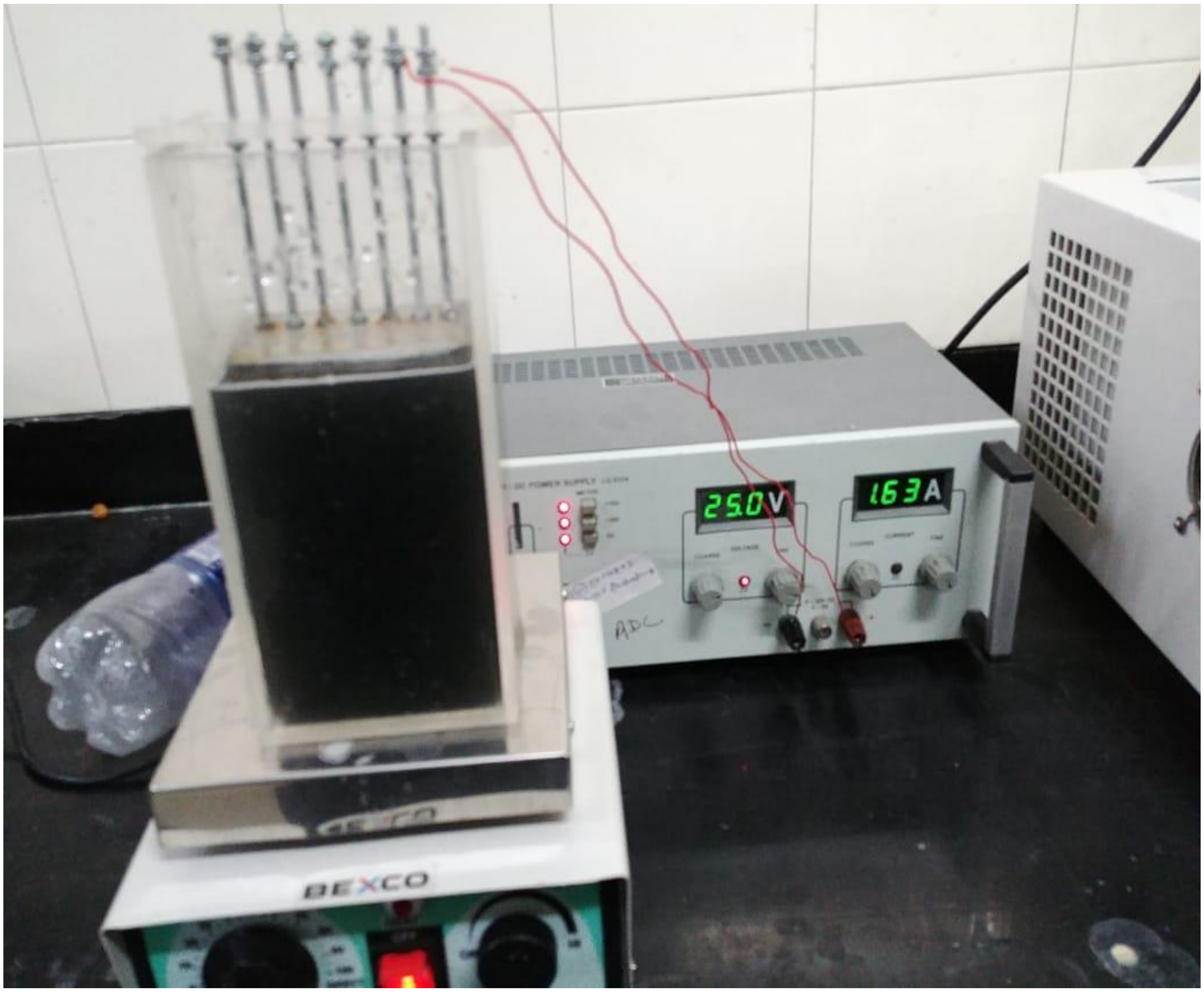

Figure B-5: Industrial Wastewater before EC (7mins)

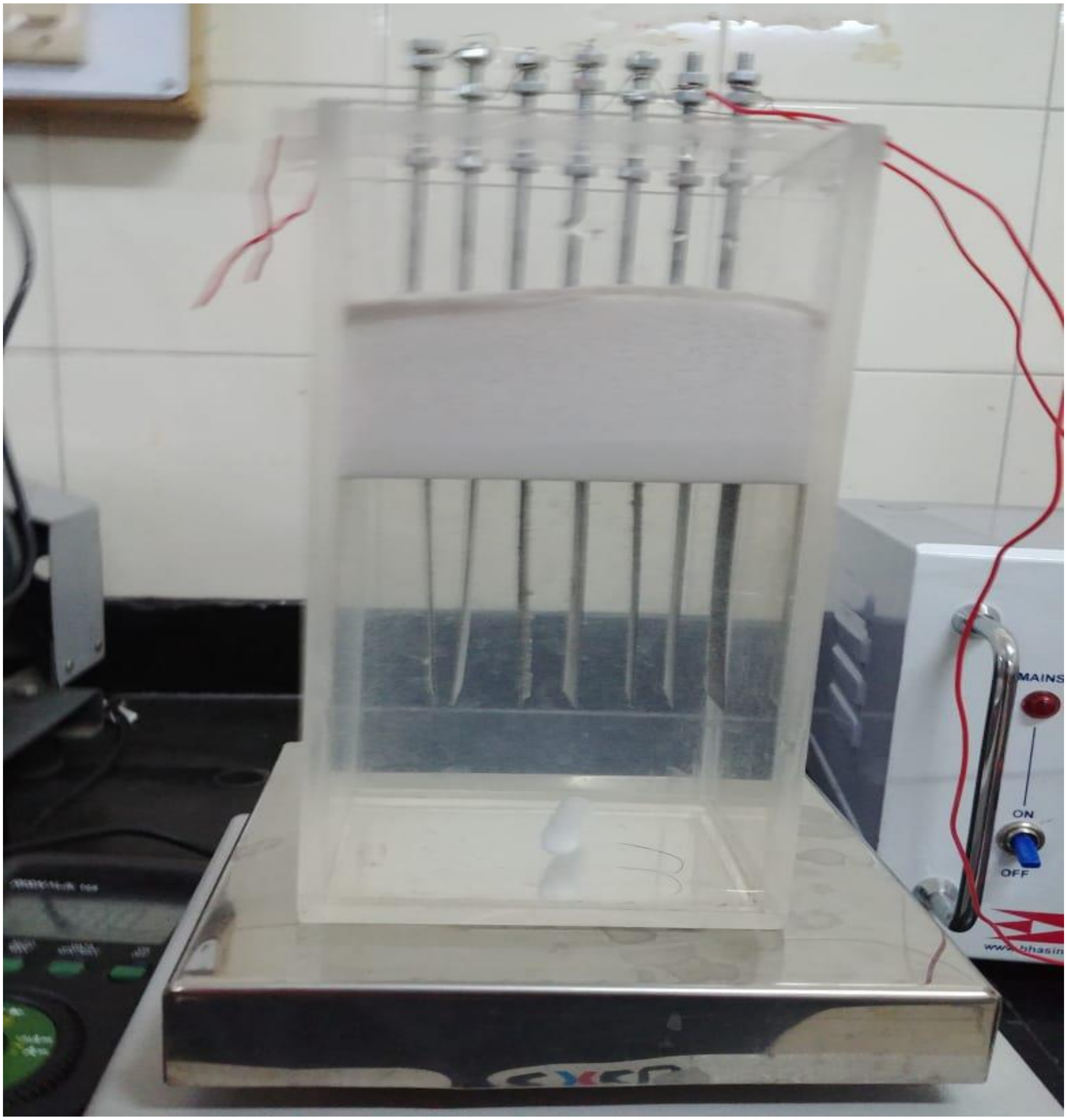

Figure B-6: Industrial Wastewater after EC (7 mins)

Figure B-7: TDS meter showing TDS

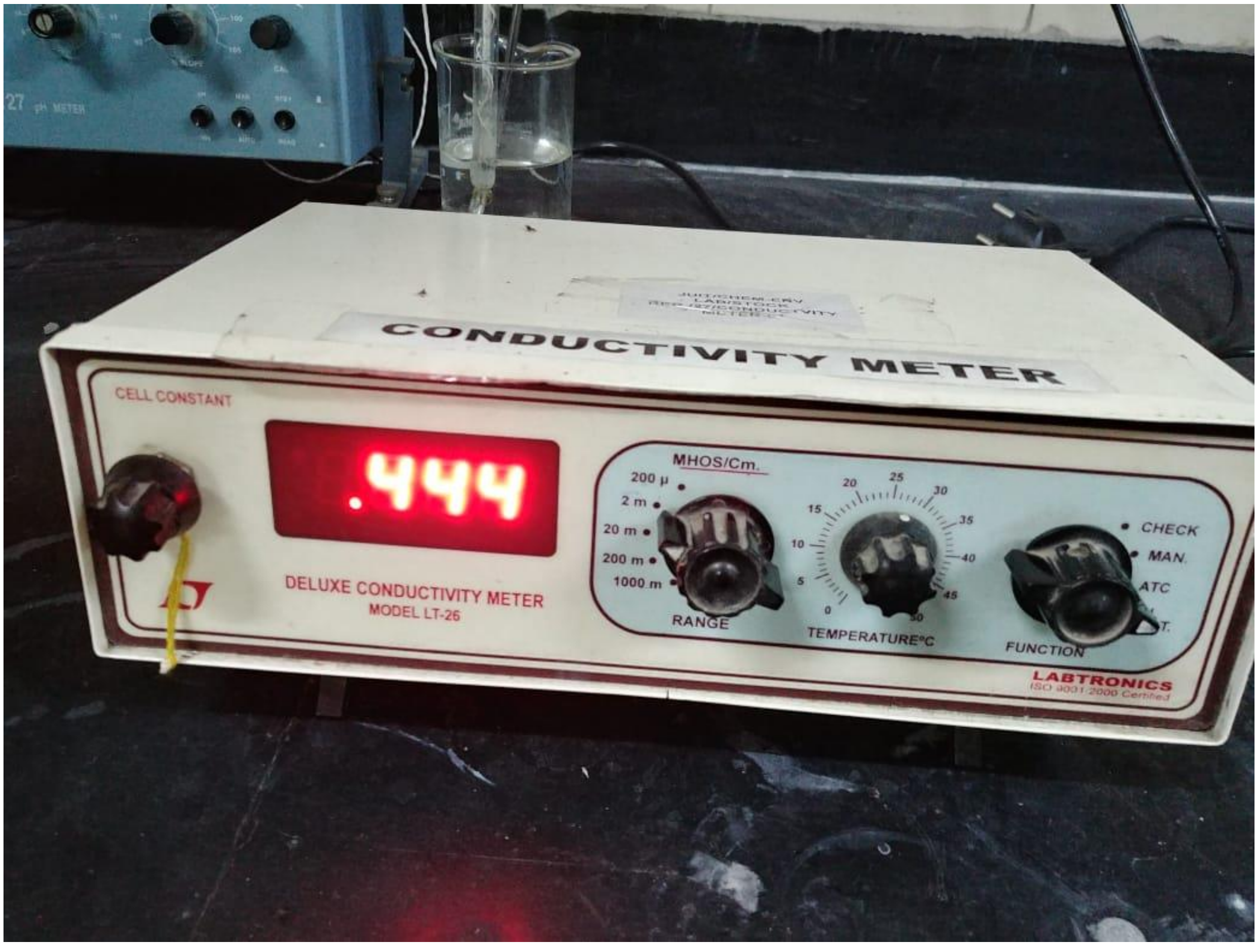

Figure B-7: Conductivity meter showing conductivity

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