PERFORMANCE EVALUATION OF ELECTROCOAGULATION REACTOR FOR THE TREATMENT OF DISTILLERY WASTEWATER

A

PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree

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Under the supervision

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STUDENT'S DECLARATION

We hereby declare that the work presented in the Project report entitled **"Performance Evaluation of Electrocoagulation Reactor for the treatment of Distillery Wastewater"** submitted for partial fulfilment 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 our work carried out under the supervision of **Mr. Anirban Dhulia.** This work has not been submitted elsewhere for the reward of any other degree/diploma. We are fully responsible for the contents of our project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"Performance Evaluation of Electrocoagulation Reactor for treatment of Distillery Wastewater"** in partial fulfilment 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 **Prikshit Gupta (151638), Harish Chander (151625)** and **Vedansh Garg (151676)** during a period from August 2018 to May 2019 under the supervision of **Mr. Anirban Dhulia** & Environment Laboratory assistant Mr. Amar Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement is correct to the best of our knowledge.

Date: …………………

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ABSTRACT

In the recent times, numerous studies have been conducted on electrocoagulation process, yet it is a different area of study. Nearly all of the research work laid emphasis on the treatment of various wastewaters that we come across in our daily lives like household, agricultural and industrial wastewater for the reduction of pollution caused by them. It also gives us an idea of how the process works, the effect of electrode materials and various operating conditions and the design of the reactor. Electrocoagulation has a certain number of merits as well as demerits as indicated in the literature, it still has been used for over a hundred years for treating polluted water. The reactor employed for treatment comprised of sheets of acrylic. The electrodes used were made from aluminium and iron. The process has been found effective in the treatment of different varieties of wastewater including water below the ground surface. The objective of the present study is to inspect the outcomes of the various operational parameters like electrode material, inter electrode distance and electrolysis time on COD, BOD, turbidity and TSS removal on the treatment of distillery wastewater.

Thus it can be concluded that EC process is productive for treating distillery wastewater which showed highest of COD removal of 83.65%; 75% turbidity removal; 83.36% BOD removal and 83.23% of TSS reduction.

Keywords: Electrocoagulation, Electrode materials, Operating conditions, COD, BOD, Turbidity

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND SYMBOLS

EC-	Electrocoagulation
COD -	Chemical Oxygen Demand
BOD -	Biological Oxygen Demand
TSS -	Total Suspended Solids
Al -	Aluminium
Fe -	Iron
Cl -	Chlorine
STP-	Sewage Treatment Plant

CHAPTER 1

INTRODUCTION

In the present times, the scarcity of safe consumable water is a well-known issue. To cope with this, it is very important to safeguard our natural water bodies and sources. For this it becomes very important to keep an eye on various factors responsible for this like population explosion, more and more movement of people to cities, the reduction in forest cover and changing weather patterns inclusive of global warming. As a result of increase in water contamination, the living creatures inside the water bodies also face various problems like decrease in oxygen level. Hence there is a need to bring up such technologies that prove efficient in the reduction of such contaminations from wastewater while ensuring environmental safety as well.

Electrocoagulation process can play a significant role in dealing with wastewater related problems. During the method, the current across the electrodes causes coagulant production through the oxidation of the anode. A number of coagulant species like hydroxide precipitates and other metal species are formed due to the metal ions hydrolysis produced due to the electrolytic oxidation of the anode depending on the pH conditions Due to the numerous benefits on aluminium and iron like their non-toxic nature, easy availability they are generally used as electrodes. It is possible that the anode and cathode are comprised of identical metal but electric integration takes place only at anode. Electrocoagulation can be carried out in batch mode or continuous mode as per the requirement. The applications of the process have been lately explored by Kabdash *et al.*, [4-5]. In the 19th century, England made use of electrocoagulation in drinking water treatment plants [6]. At late 30's, chemical coagulation had taken its place with the aid of biological remedies to put an end on suspended contaminants in wastewater. The primary cause came out to be high working value, mainly the charge of power. After the 90's Mollah *et al.*, [7] the circumstances have taken a turn due to the citation of various merits as indicated in review. EC affords additionally different issues like management of sludge, however chemical coagulation should also cope with it. Generally, sludge disposal should be similar as the characteristics of EC sludge and that of chemical coagulation are similar. Conversely a selected difficulty of this process is the lack of comprehensive evaluations of EC modelling.

1.1 OBJECTIVES OF THE STUDY

The aim of the research was to assess the workability of EC process to treat distillery wastewater. The objectives are indicated as under:

1. To design, construct batch and continuous electrocoagulation reactor for distillery wastewater treatment.

2. To investigate the impact of different operating parameters like:

   a) Effect of inter electrode distance

   b) Effect of electrolysis time

3. To study the efficiency of different electrodes (aluminium and iron) for treatment of distillery wastewater in various combinations as mentioned below:

   a) Al-Al electrode   b) Fe-Fe electrode

CHAPTER – 2

LITERATURE REVIEW

2.1 HISTORICAL DEVELOPMENT

Electrocoagulation process was first anticipated by Vik *et al.,* narrating a STP in London where electrochemical treatment was being done by combining household wastewater with brine. In 1909 (in US), J.T. Harries got a license for the handling of wastewater by utilising electrolysis through the use of conciliatory aluminium and iron anodes [1]. Matteson *et al.* [2] characterized the 'Electronic Coagulator', that disintegrated Al from anode to the arrangement that responds with the generation of hydroxyl ions at the cathode and leads to formation of hydroxide of aluminium. These flocculated hydroxides purified the contaminated water by flocculating and coagulating the suspended solids. In Britain in 1956[2], an identical manner was employed where electrodes of iron have been employed to cope with dirty river water. Thereon, a huge variety wastewater came up into light. Electrocoagulation was used to get rid of suspended particles [2]; heavy metals [3]; petroleum items [4]; colour from dye-containing solution [5]; aquatic humus [1]; fluorine in water [6]; and city wastewater [7].

2.2 THEORETICAL BACKGROUND OF ELECTROCOAGULATION PROCESS

Electrocoagulation merges diverse tools which may be electrochemical (anodic disintegration), chemical (pH change, redox response) and physical (coagulation, flotation). Those may be sequential or parallel. They are outlined in Fig 1. which shows the interactions among the mechanisms of EC procedure.

2.3 ELECTROCOAGULATION MECHANISMS

Electrocoagulation involves the creation of coagulant species by electro dissolution of anode normally iron or aluminium by usage of electric current passed through the electrodes.

Chemical reactions are outlined as under:

• At anode, oxidation of metal into cations take place;

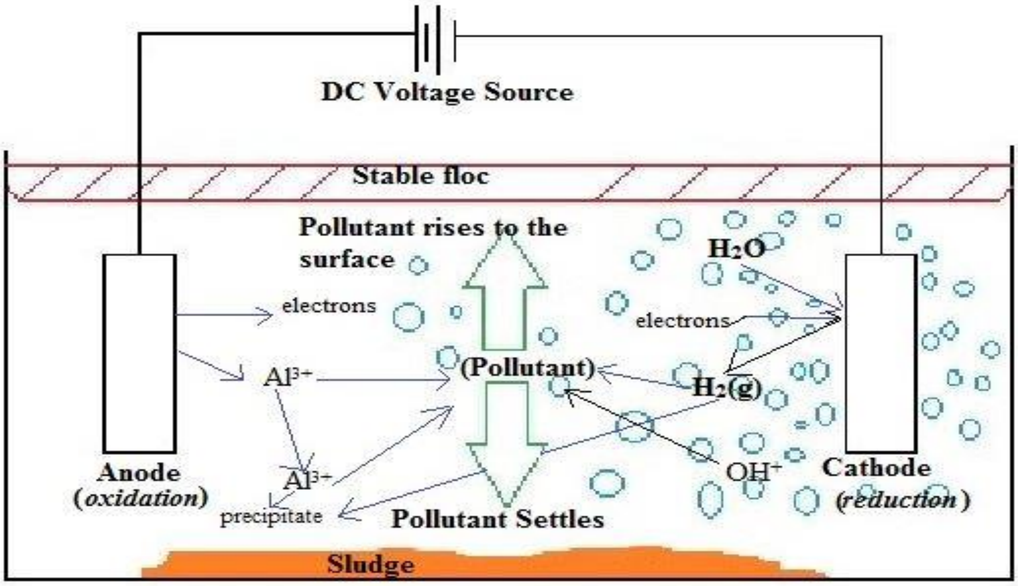

Figure 2.1: Interactions Occurring within Electrocoagulation Reactor

$$M \rightarrow M^{Z+} + Ze^{-} \quad (1)$$

In eq. (1), Z denotes the numerical value of electrons that are passed to the anodic disintegration system consistent with the mole of metal. Secondary reactions may arise in case of high anode potential [9, 10]. Oxidation of water can take place leading to the formation of hydronium ion and oxygen and Cl^{-} can oxidized into Cl_2 existence of chloride ions. Since Cl_2 is a robust oxidant, it can accord to the oxidation of disintegrated natural mixes or may prompt ClOH generation which likewise acts as an oxidizer [11].

$$2H_2O \rightarrow O_2 + 4H^{+} + 4e^{-} \quad (2)$$

$$2Cl^{-} \rightarrow Cl_2 + 2e^{-} \quad (3)$$

$$Cl_2 + H_2O \rightarrow ClOH + Cl^{-} + H^{+} \quad (4)$$

• At the cathode: reduction of water takes place into hydroxyl ions and H_2

$$3H_2O + 3e^{-} \rightarrow 3/2\ H_2 + 3OH^{-} \quad (5)$$

The measure of metal broken down by anodic oxidization can be determined by the utilization of Faraday's law. In this way, the mass m of the metal is an element of hydraulic retention time t and of current flow I:

$$m = (\phi It/ZF)\ M \quad (6)$$

In eq. (6) F denotes Faraday's constant and M is the weight of the materials used in the making of electrodes. Faraday's law ($\phi = 1$) is applicable only when each and every electron takes part only in the process of metal-disintegration at anode. In Eq. (6) Z indicates the valence number of ions of the substance.

2.3.1 SPECIFICITY OF AL ELECTRODES

For aluminium as Z=3, only half oxidation reaction occurs between Al^{3+}/ Al which follows Eq. (1). In accordance with the acid/base reactions (Eq. (9) - (12)) and Al^{3+} concentration [10] other monomeric species are also generated due to the regular hydrolysis of Al^{3+} ions as

$$Al^{3+} + H_2O \rightarrow Al(OH)^{2+} + H^+ \quad (9)$$

$$Al(OH)^{2+} + H_2O \rightarrow Al(OH)_2^+ + H^+ \quad (10)$$

$$Al(OH)_2^+ + H_2O \rightarrow Al(OH)_3 + H^+ \quad (11)$$

$$Al(OH)_3 + H_2O \rightarrow Al(OH)_4^- + H^+ \quad (12)$$

Generally, if the pH is below 4 then aluminate cations triumph and if pH is above 10 then aluminate cations triumph otherwise the indissoluble $Al(OH)_3$ prevails. The development of polymeric species is additionally represented. At cathode, the acidity of aluminium accord for the development of hydroxyl ions, initiating a buffer effect resulting in final pH in the range of 7 to 8 which varies from traditional chemical coagulation by utilizing aluminium salts. Consequently, polymeric and monomeric species initiates the production of amorphous $Al(OH)_3$ "sweep flocs" having huge surface regions that are valuable for a quick dissolvable natural mixes and trapping of colloidal particles [12-14].

$$nAl(OH)_3 \rightarrow Al_n(OH)_{3n} \quad (13)$$

Due to a purely chemical attack of aluminium under acid or alkaline conditions, secondary reactions can also occur at the electrodes:

$$2Al + 6H^+ \rightarrow 2Al^{3+} + 3H_2 \quad (14)$$

$$2Al + 6H_2O + 2OH^- \rightarrow 2Al(OH)_4^- + 3H_2 \quad (15)$$

The effect is such that the amount of broken down Al discharged during electrocoagulation surpasses the normal fixation as anticipated by the Faraday's law. So, the value of faradic yield is above 100 % and can extend up to 200 % [10].

Due to the increase in cell voltage and energy intake, cathode becomes passive. It is one of the important issues of EC. One way of reducing this passivation is the improvement of the current inversion frequency. The other way is to add NaCl to encourage pitting corrosion by a chemical interaction between Al^{3+} in the oxide cross section and Cl^{-} that is adsorbed on the aluminium oxide film. Two methods are responsible for the extent of chemical corrosion of soluble aluminium anodes [15]:

• The development and formation of a non-resistant layer of aluminium-oxide;

• The accompanying incomplete devastation of the above layer by pitting.

The factors that decide the extent of pitting corrosion include initial pH, character and concentration of electrolyte. The beneficial outcome of anions on inert layer of aluminium-oxide in decreasing order is [16]: Cl^{-}, Br^{-}, I^{-}, F^{-}, ClO_4^{-}, OH^{-}, SO_4^{2-}.

2.3.2 SPECIFICITY OF IRON ELECTRODES

Since oxidation of anode drives either to formation of ferric or ferrous cations, therefore the reactions occurring at iron electrodes are generally more complex than with that of aluminium,

$$Fe \rightarrow Fe^{2+} + 2e^{-} \quad (17)$$

$$Fe \rightarrow Fe^{3+} + 3e^{-} \quad (18)$$

Based on the concentration of ferric ion and pH, formation of monomeric and polymeric species takes place due to the hydrolysis of ferrous and ferric ions in water. In spite of certain vagueness in different papers on the procedures of Iron EC, ongoing investigations conclude that oxidation taking place at anode discharges Fe^{2+} as it has been demonstrated that the disintegration rate of Fe^{3+} is insignificant [17-18]. pH and the concentration of dissolved oxygen determine the extent of oxidation of Fe^{2+} ions to Fe^{3+} ions. If the medium is acidic then Fe^{2+} cations takes enough time in accordance with dissolved oxygen Eq. (19) and if the medium is neutral or alkaline then Fe^{2+} gets rapidly altered into $Fe(OH)_3$ Eq.(20) and is swiftly broken down dissolved oxygen into iron (III) hydroxide Eq. (21).

$$Fe^{2+} + O_2 + 2H_2O \rightarrow Fe^{3+} + 4OH^{-} \quad (19)$$

$$Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2 \quad (20)$$

$$4Fe(OH)_2 + O_2 + 2H_2O \rightarrow 4Fe(OH)_3 \quad (21)$$

When the pH values are low, clarifications are almost identical as stated for Al: in the existence of ionic compounds corrosion is likely to occur at each electrode. Because of the presence of secondary reactions close to the anode, alongside oxygen development when pH is high, the dissolution performance drops beneath the values given by Faraday's law. In case of alkaline medium, oxidation of iron guides to Fe (III) formation through Eq. (18). As a result, there is a decline in the iron concentration as Fe (III) generation requires 3 electrons against 2 required for Fe (II) and hence, a much higher current is needed to reach the same iron concentration [17-18]. Precipitates of amorphous $Fe(OH)_3$ are formed from different monomeric and polymeric species which are desirable for a fast adsorption of soluble organic mixes [19-20]. There are two other variations with aluminium electrodes. The first one being that the buffer impact outlined for Fe is fragile as compared to Al. The other distinction is the unsatisfactory EC performance can be attributed to the soluble nature of Fe^{2+} and subsequently not fit for proficient colloid destabilization with the guide of $Fe(OH)_3$. Thus an effective activity of Fe-EC calls for at least one of the underlying enhancement techniques for the Fe^{3+} generation:

(a) circulating air through water to enlarge the dissolved oxygen content and increase oxidation of Fe^{2+};

(b) raising the pH up to 7.5 or more to increase Fe^{2+} oxidation rate;

(c) presenting an elective oxidant, for example, chlorine which can be generated through the oxidization of the chloride ions that are there in the waste water at the iron anode [21]. From there on, oxidation of ferrous occurs in the mass arrangement:

$$Cl_2 + H_2O \rightarrow ClOH + Cl^{-} + H^{+} \quad (22)$$

$$2Fe^{2+} + 2HOCl \rightarrow 2Fe^{3+} + 2OH^{-} + Cl_2 \quad (23)$$

This process is not proficient until the wastewater to be treated carries over 600 mg Cl^{-}/L, by considering the current used up by oxidation of Cl^{-} ions.

(d) to accomplish complete oxidation of Fe^{2+} by escalating the residence time

Iron offers two extra points of interest over aluminium: iron being non-toxic can be used for consumable water.

2.4 PARAMETERS INFLUENCING THE ELECTOCOAGULATION PROCESS

The different factors influencing the adequacy of electrocoagulation are identified with the operating conditions, for example voltage, current flow and retention time, wastewater attributes which are alkalinity, pH, conductivity and the arrangement of the electrodes of the EC reactor.

2.4.1 EFFECT OF THE CURRENT DENSITY

Current (I) is a major factor which influences electrocoagulation. EC is commonly organized as a part of current density described as the proportion of current over the surface area S of electrode. Current conservation can be imposed by the continuity equation between the two terminals, current can differentiate between terminals where

$$I = i_A.S_A = i_C.S_C \tag{24}$$

As per Faraday's law, at anode the current density demonstrates the dosage of the chemical coagulant and at cathode the development of H_2. The density of air bubble impacts the structure hydrodynamics, which impacts the change in mass between pollutant particles, coagulant and gas miniaturized scale bubbles, and in the long run it coordinates the collision rate of coagulated particles. Current density likewise impacts hydrolysed species of metal through pH advancement amid EC process as a component of alkalinity of water. Accordingly, the current, make a dynamic physical/synthetic condition that checks the flocculation/coagulation mechanism and supports the electro movement of particles and charged colloids [22].

Because of the linkage of electric current needed for Electrocoagulation with the electric flow and potential, EC can be operated either through the galvanostatic mode or potentiostatic mode. EC process is executed only by changing the current connected by electrodes for the galvanostatic mode while for the potentiostatic mode, the connected voltage of cell is differed as an element of measure of coagulant which is to be discharged in the reactor. The potentiostatic mode isn't regularly utilized for EC and is generally utilized for various electrochemical methods, for example, electro-oxidation and electro-reduction while sacrificial anodes and cathodes are not utilized [23-24].

2.4.2 EFFECT OF WATER PH AND ALKALINITY

pH is a major characteristic which impacts the accomplishment of EC, particularly the coagulation methods as it administers the hydrolysed species of metal produced in responsive media and impacts the predominant process of EC [25]. An examination of the evolution of Al and Fe from the hydrolysis of the relating cations controlled by methods for thermodynamic stability equilibrium is earliest to get to the base of how pH adds to deal with the EC process. Coagulation and adsorption especially rely on pH. The adsorption of charged solvent monomeric species on different hydroxide molecules explains the apparent charge of the Al or Fe extracts. Talking about their superficial charge, the chemistry between the pH-subordinate coagulant species and their surrounding pollution particles might be identified with electrostatic interchange. A point by point assessment pondering these components (double layer pressure, balance and charge neutralization) has been accounted for by utilizing Jimenez *et al.*, [18] for aluminium and iron EC process so one can amplify the decrease of various pollution causing particles as an element of the hydrolysed steel species.

Zongo [22] considered the speciation of aluminium and iron with the objective to set up the major diagrams of relating hydroxides and also to review a piece of unsolvable hydroxides as a component of pH taking into account monomeric species only. Thus, for Al electrodes, it is seen that the quantity of insoluble aluminium hydroxide increments strongly as the pH increments from 4.5 to 7 to the disservice of aluminium hydroxide particles and the turnaround is valid for a pH from 7 to 10, while formless hydroxide of metal is missing over the last recorded value of pH. For iron cathode, with pH extending from 4 to 7, the amount of insoluble iron hydroxide radically increases. Iron hydroxide ions are missing on the major diagram at this last pH.

It is incredibly critical that after Electrocoagulation the increment for the acidic influent yet can diminish for alkaline effluent because of the buffering effect of EC. This increment of pH in acidic medium is because of the increase of hydrogen at cathode and the decrement of pH is expected because of the generation of precipitates of hydroxide that discharge hydrogen ion at the anode and the optional responses which incorporate oxidation of water and creation of chlorine. This demonstrates the EC buffering effect that demonstrations further to alkalinity of water. Due of the advancement of aluminate anions at a high pH level, this impact is high with aluminium anodes [11]. The bicarbonate alkalinity is represented to increase possibly the pollutants expulsion productivity [26] moreover it permits to get rid of the hardness by precipitation of $CaCO_3$ [27].

2.4.3 EFFECT OF GEOMETRY OF THE CELL AND DESIGN OF ELECTRODES

The EC reactor is specifically built up of electrodes that are enclosed in specific area. The electrodes are composed in a non-conductive tank in which wastewater is treated.

2.4.4 ARRANGEMENT OF ELECTRODES

EC procedure is impacted by the electrode system by electrodes arrangement and distance between the various electrodes. Arrangement of electrodes can be fundamentally made out of an anode and a cathode or can be made out of numerous anodes and cathodes unpredictably placed in EC cell.

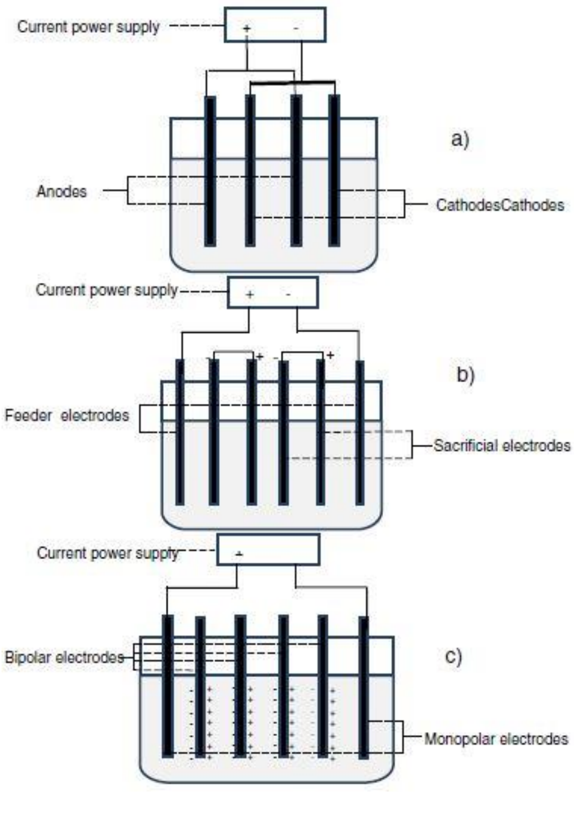

Figure 2.2: Monopolar electrode in a) electrodes in parallel connections; b)electrodes in series connections; c) bipolar connection of electrodes in series

The complex cathodes system can be categorized as monopolar electrodes and bipolar electrodes

• Monopolar electrodes arranged in parallel association (MP-P) are shown in Fig. 2.a. In this geometry the anode and cathode are connected alternatively at the equivalent anodic or cathodic potential, individually. Every arrangement of anode/cathode match to a little electrolytic cell having a similar voltage. The EC reactor is made thus, of parallel electrolytic cells because of which every electrolytic cell has current of additive nature.

• Monopolar electrodes arranged in series arrangement (MP-S) are depicted in Fig. 2. b. Every pair of inward conciliatory electrodes is internally related with the other having no common connection with the other two outer terminals. For these circumstances, the electric flow experienced by every one of the electrodes is equivalent, while the overall voltage is the entire of voltage in every single electrolytic cell.

• Bipolar electrode arranged in series (BP-S) includes two external electrodes that are connected with a DC power supply and also to the sacrificial electrode arranged in between the two external electrodes (Fig 2.c). External electrodes are monopolar while the internal are bipolar. The sides of bipolar terminals act at the same time as an anode and a cathode and are not connected internally. So due to the oppositely charged nature of bipolar terminals, the positive side suffers from disintegration of anode and the cathodic responses takes place at the negative side.

As a rule, monopolar electrode requires a high current and low voltage while the bipolar electrode work with a comparatively high voltage and a low density of electrical current. This is hard to assume what electrode course of action is effective than the other taking into account just EC yield given that it is already demonstrated that similarly BP-S could show a high EC effectiveness. Considering the proportion adequacy cost, monopolar cathodes may appear to be fascinating but in a large portion of the cases this sort of electrodes shows a higher reduction of pollutant with lesser power utilization, understanding that bipolar anode always uses a high amount of power. This outstanding mode which is easy to deal with, requires low support cost amid task, consequently the effect of maintenance cost on in general activity cost ought to similarly be considered to pick accurate electrode mode. Other than the outstanding rectangular electrode, there are some other geometrical figures, for example, circular, tube shaped. Cathodes are settled either vertically or a level plane in EC cell.

2.4.5 EFFECT OF INTER ELECTRODE DISTANCE

As the separation among electrodes expands, the IR-drop increases. Henceforth, as the separation between electrode diminishes the power utilization diminishes. As the gap between electrodes reduces, all of the electrochemically created gas bubbles result in violent hydrodynamics, which leads to an unreasonable mass exchange like a high rate of reaction among the coagulant species and pollution content. Additionally, between electrode separation portrays the HRT between the anode and the cathode for a reliable structure and the treatment time for the reactor to obtain the desired EC efficiency. For a perplexing electrode course of action, the distance between the two electrodes determines that how many electrodes have to be placed in a EC reactor. [28].

2.4.6 EC REACTOR DESIGN

EC reactor arrangement is of extraordinary significance as it impacts the general operations of the EC procedure by its impact on the working settling qualities. EC reactors are arranged dependent on some basic norms, for the most part the working mode and the attainment of the predetermined goals, EC reactor design can be organized relying upon three noteworthy qualifications as shown by literature survey [6]. The first is whether a reactor is placed as a batch or a persistent framework, for example the feed mode. For a firm structure, EC reactors are perpetually nourished in waste water and set for work in those conditions, while the assignment is finished with a fixed quantity of wastewater for every cycle of treatment in a batch procedure. The second treatment is the strategy used to isolate the amassed pollutants. The last is the structure of the electrodes arrangement that describes the dispersion of electric current in the cell: normal EC cells are investigated by Mollah et al., and have undergone very little modification in the ongoing decade. Basically, cells that have rectangular arrangement still overpower, as rectangular anodes can be used, and the generally perceived structure for regular use is the open vertical-plate cell, as a rule pursued by a pioneer. This suggests that the reactor is open from the top, which helps to keep submerged contacts aside and make upkeep more straightforward; similarly, vertical anodes and cathodes are divided in parallel; any vertical length extent can be utilized, making scale-up basic, yet support is empowered by qualities less than 2. In case of current inversion, the symmetry of the anode-cathode terminals diminishes support, explicitly interestingly with tube shaped EC cells [7].

Alongside the arrangement of the electrode and their separation, EC reactor setup impacts electrocoagulation through the volume of the reactor that intercedes to describe electrode region/volume proportion (A/V). Electrode A/V proportion is the primary parameter in plant structure that grants making EC full-scale gear from research centre analyses by keeping the equivalent between electrode separate while utilizing terminal plates. The average scope of electrode A/V proportion moves from 15 m^2/m^3 to 45 m^2/m^3 [28]. At the point when the A/V proportion is expanded both the time of treatment and the ideal current thickness diminishes. Exactly when the terminal zone is sufficiently high, the huge parameter is the present fixation I/V. When this parameter is joined by the current and flow thickness and the electrode area/volume proportion it allows portrayal of convergence of coagulants discharged in water at a given treatment time under cluster circumstances. Under constant framework, the volume of the reactor licenses characterizing the habitation time for a given stream of wastewater and as such the discharged coagulant amount can be reasoned.

$$C = (M/ZF)\ (I/V)\ t$$

here C and V are the hypothetical concentrations of metallic cations (g/m^3) and the volume of the EC gadget (m^3), respectively. The standard geometry of reactor, for instance cubic, cylindrical marginally influences EC execution, except for a non-conventional moulded EC reactor also called electrochemically determined carrier reactor. Essadki et al., [29] considered the decolourization of material colour wastewater by EC flotation in an outside circle airdrop reactor, by and large used to do substance and biochemical oxidations. Using ideal current density and electrode position it ended up conceivable to 80% COD removal and shading from the material colour wastewater. This shows the primary occupation of the EC reactor geometry is identified with hydrodynamic and mixing properties [29].

2.4.7 EFFECT OF WATER CONDUCTIVITY

The current density productivity is based solidly on the ionic nature of wastewater and conductivity. With expanding electrolytic conductivity, the current density efficiency increments because of the decline of ohmic opposition of wastewater. The HRT needed to accomplish a given evacuation yield also diminishes due to conductivity. Thus, the vitality use is diminished. Electrolytic conductivity is being enhanced by the use of NaCl. Chloride anions plays an important role in the decrease of the unfortunate impacts of different anions to side-line the interaction from the calcium carbonate in hard water that can prompt a protecting layer on the outside of the terminals. For incredibly high value of current density, chloride anions can in like manner be oxidized to dynamic chlorine frames, for example, hypochlorite anions, which can oxidize natural organic compounds [9] and ferrous ions [21] or add to wastewater cleansing. To make sure an ordinary activity of EC in treating waste water, it is proposed that 20% of the anions present should be of chlorine. [16].

Moreover, many restrictions are imposed on conductivity increment in waste water treatment generally in drinking water treatment. For the treatment of waste water, other than an auxiliary contamination made by an expansion of conductivity, some measures to be pursued relying upon if the wastewater being treated is offered either for reuse or to be gushed out in biological system. Conductivity increment amid the treatment of drinking water by EC is confined according to the set standards that restricts the greatest chloride concentrations in industrial discharge outflow at 250 mg/L [30].

Table2.1: Summary of Studies related to Electrocoagulation

S. No	**Title**	**Journal Name (Year)**	**Author**	**Methodology**	**Conclusion**
1	Sequential Treatment of Food Industry Wastewater by Electro-Fenton and Electrocoagulation Processes	International Journal of Electrochemical Science (2018)	Gizem Basaran Dindas, Yasemin Caliskan, Emin Ender Celebi1, Mesut Tekbas1, Nihal	Batch electrochemical reactor which made-up of polypropylene (PP) with a capacity of 1 L and the working volume of the effluent was 0.5 L was used. EF process was	The most effective and economic degradation were observed in the 120 min EF using 5 mA/cm^2 pulsed current density and then 180 min EC using 15 mA/cm^2 of current density. Results of tandem

			Bektas, H.Cengiz Yatmaz1	initially performed to govern the amount of released iron ions into the solution by different time intervals using 5 mA/cm^2 current density.	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).
2	Benefits of Electrocoagulation for the Treatment of Wastewater: Removal of Fe and Mn metals, oil and grease and COD: three case studies	International Journal of Applied Engineering Research (2018)	Warren. Reategui-Romero, Lisveth.V. Flores-Del Pino, Jose. Guerrero-Guevara, Josue. Castro-Torres, Luis. M. Rea-Marcos, Maria. E. King Santos, Ricardo. Yuli-Posadas	The reactor was made of plexiglass with a capacity of 5 L, with seven Fe electrodes arranged vertically with a spacing of 0.03 m and dimensions of 0 224 m x 0.133 m. The reactor worked with four cathodes (0.238 m^2) and three anodes (0.179 m^2). The analyses were carried out in the Minsur S.A laboratory for pH measurement, turbidity and spectrophotometer, the emissions used	Electrocoagulation was evaluated as a possible technique for the reduction of pollutants from wastewater. The metals were removed with an efficiency greater than 99 %, while the oils and fats and phenols reached 59 and 32 % respectively. A special case was the removal of COD, since the treated effluent was a mixture of effluents from various industrial sectors, reaching 39 %.

				for Fe and Mn were 372 nm and 403.1 nm respectively.	
3	Applying Response Surface Methodology for Optimizing the Treatment of Swine Slaughterhouse Wastewater by Electrocoagulation	Polish Journal of Environmental Studies (2018)	Ha Manh Bui	A plexiglass reactor of greatest volume limit of 5 L was utilized in the EC experiment. Four Fe electrodes were joined in parallel and were put in the reactor with a functioning zone of 19.6 cm^2. The terminals were associated with a flexible DC control supply (220 V, 30 A).	The quadratic models for COD removal productivity were eminent at very lower likelihood esteem and high coefficient of assurance. Ideal conditions for COD evacuation were set up at 130 A/m^2 current thickness, 9.5 min electrolysis time, and introductory pH 8.5.
4	Electro-oxidation and characterisation of Ni foam electrodes for removing boron	Chemosphere (2017)	Danis Kartikaningsih, Yao-Hui Huang, Yu-Jen Shih	A bunch reactor, made of Pyrex glass with measurements of 12 cm × 10 cm × 8 cm, was utilized Nickel froth as cathode and anode in four sets (compelling zone = 8 cm × 10 cm × 10 cm) were orchestrated at 1 cm	Removal efficiency was expanded at pH 8-9, and diminished as the pH expanded past that go. At specific beginning possibilities (0.5 - 0.8 V versus Hg/HgO), the miniaturized scale granular nickel oxide that was made on the outside of the

				interims and associated with a DC control supply.	nickel metal substrate relied upon pH, as controlled by cyclic voltammetry.
5	Characterization of a new cartridge type electrocoagulation reactor (CTECR) using a three-dimensional steel wool anode	Journal of Electroanalytical Chemistry (2016)	Ainhoa Lopez, David Valero, Leticia Garcıa-Cruz, Alfonso Seaz, Vicente Garcıa-Garcıa, Eduardo Exposito, Vicente Montiel	Another Cartridge type reactor for electrocoagulation is tried. Electrocoagulation is performed utilizing 3D terminals made of steel fleece anodes. Expulsion of material colour Remazol Red RB 133 is utilized as test response.	The total framework incorporates the Cartridge Type Electrocoagulation Reactor (CTECR) and its lodging. The living arrangement time dispersion (RTD) was utilized as apparatus to think about the stream conduct of the electrolyte inside the reactor. The new reactor has been effectively utilized in the expulsion of a material colour (Remazol Red RB 133) working in persistent method of activity, where the shading end rate comes to 99 %.
6	Electrocoagulation of bio-filtrated	Chemosphere (2016)	Oumar Dia , Patrick	EC tests were completed in a cylinder reactor in	The impacts of current densities, kind of anode (Al vs

	landfill leachate: Fractionation of organic matter and influence of anode materials		Drogui , Gerardo Buelna , Rino Dube , Ben Salah Ihsen	distribution mode having a cluster limit of 1.5 L. An outside empty barrel made of hardened steel filled in as cathode, and a full chamber pole was utilized as a conciliatory anode. The anodic terminals were either aluminium or iron. The terminal surfaces in contact with the influent were 476 and 1130 cm^2 for the anode and the cathode individually	Fe), and treatment time on the execution of COD evacuation were researched. The best COD evacuation exhibitions were recorded at a present thickness going somewhere in the range of 8.0 and 10 mA cm^{-2} amid 20 min. of treatment time. At these circumstances, 70 % and 65 % of COD were evacuated utilizing aluminium and iron cathodes, individually.
7	Electrocoagulation Process by Using Aluminium and Stainless Steel as Electrodes to treat the Total	Procedia Chemistry (2016)	Mohd Khairul Nizam Mahmad, Mohd Remy Rozainy M.A.Z, Ismail Abustan	The pH of the solution was taken utilizing pH meter and noted. The terminals were clipped at anode stand. Every association in the circuit was finished by wire association with terminal	The distinctive electrodes have diverse adequacy in evacuating all out Chromium, shading and turbidity, depends on the sorts of cathodes. In light of the outcome, can be reasoned that Aluminium anodes

	Chromium, Colour and Turbidity		and Norlia Baharun	positive and negative to DC control supply, anodes, voltmeter and ammeter. The anodes were drenched in an electrolyte arrangement.	are best suited for evacuation of turbidity and shading. Tempered steel cathodes is best for expulsion absolute Chromium.
8	Electrocoagulation: an electrochemical process for water clarification	Journal of Electrochemical Science and Engineering (2016)	Eva Fekete, Bela Lengyel, Tamas Cserfalvi, Tamas Pajkossy	A non-thermostatic rectangular-channel flow-through cell, containing vertically placed parallel-plate electrodes (height 10 cm, width 5 cm, inter-electrode distance 0.2 cm). A peristaltic pump with a flow rate of 1 - 16 L/h and range of 0.3-4 mL/s was used for continuous operation.	As a result of these experiments with oil-in-water type emulsions with about 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.

9	Treatment of Distillery wastewater by electrocoagulation using Aluminium electrodes	International Journal of Modern Trends in Engineering and Research (2015)	Kaustubh S Sasane, Sandip R Korke	The electrolyte cell (20 cm x 10 cm x 15 cm) is made up from the of Plexiglas acrylic material having 1.5 L net ability to treat the electrolyte, the anode, pH meter, thermometer and the attractive stirrer with hot plate. The anode and cathode with surface territory of 0.2 cm^2 were made up from the aluminium compound with Zinc.	The COD, Chlorides, Sulphates, Total hardness and Turbidity removal efficiency were increased by maintaining the optimum voltage supplied to the electrode, HRT and the maintaining optimum charge density within the volume of electrolyte.
10	Investigation of electrocoagulation reactor design, parameters effect on the removal of cadmium from synthetic	Arabian Journal of Chemistry (2015)	Khaled Brahmi, Wided Bouguerra, Bechir Hamrouni, Elimame Elaloui, Mouna Loungou, Zied Tlili	The EC cell comprised of 1 L round and hollow Plexiglas container, having wooden spread assisting the arrangement of parallel aluminium sheets utilized as conciliatory cathodes. The anodes utilized in	Cadmium removal was accomplished for a inter electrode separation of 0.5 cm, in monopolar mode, mixing rate of 350 rev min^{-1}, surface-region to volume proportion (S/V) of 13.6 m^{-1}, and at a temperature of 50^0C.

	and phosphate industrial wastewater			here were shaped using two rectangular aluminium plates (250 mm × 80 mm × 2 mm). The all out inundated territory of every cathode was dynamic (95 mm * 90 mm * 4 mm) S= 68 cm^2.	
11	Optimization of colour and COD removal from livestock wastewater by electrocoagulation process: Application of Box–Behnken design (BBD)	Journal of Industrial and Engineering Chemistry (2015)	Bong-yul Tak, Bong-sik Tak, Young-ju Kim, Yong-jin Park, Young-hun Yoon,Gil-ho Min	Domesticated animal's wastewater; Tests were led in a EC cell which had a capacity of 1 L. The cell was produced using 8 mm straightforward Plexiglas with the components of 80 mm × 80 mm × 10 mm furnished with four terminals: two anodes and two cathodes with the element of 50 mm × 60 mm × 3 mm, made of plate of	Prudent working situations and evacuation efficiencies were observed having pH of 8, flow thickness of 30 mA/cm^2, NaCl grouping of 1 g/L, and 94.2 % (Y1) and 93 % (Y2), individually.

				aluminium. The all out viable terminal zone was $100cm^2$.	
12	Reduction of pollutants and disinfection of industrial wastewater by an integrated system of copper electrocoagulation and electrochemically generated hydrogen peroxide.	Journal of Environmental Science and Health, (2015)	Carlos E. Barrera Diaza, Bernardo A. Frontana Uribea, Gabriela Roa-Moralesa and Bryan W.Bilyeu	Industrial wastewater; A cluster electrochemical reactor: The reactor consisted of 2 parallel monopolar copper terminals. Every cathode was 9.0 cm by 7.0 cm having a surface territory of 63 cm^2.The complete surface of anode was 75 cm^2. An immediate current power source provided the framework with 1 A, relating to current thickness of 15.3 mA/cm^2.	The copper electrocoagulation alone diminishes COD by 56 % at pH 2.8 in 30 minutes, yet the joined framework lessens COD by 78 %, BOD_5 by 83 %, and shading by 98 % under similar conditions. The flocculation of colloidal particles occurred and 84 % decrease in turbidity and 99 % decrease in all out solids was watched.
13	Removal of zinc ions from synthetic and industrial	Desalination and Water Treatment (2014)	Khaled Brahmi, Wided Bouguerra, Bechir Hamrouni	Industrial wastewater; The electrolytic cell comprises of a 1L glass container. Two rectangular	Ideal circumstances for zinc evacuation were observed at a pH estimation of 7, a present thickness of 7.35 mA cm^{-2}, a

	wastewater by electrocoagulation using aluminium electrodes		and Mouna Loungou	aluminium plate terminal of size 250 mm x 80 mm x 2 mm were utilized in parallel. The anode– cathode separate (ACD) was fluctuated from 5 mm to 20 mm.	between anode capability of 5 V, an EC time of 30 min., a conductivity of 5.3 mS cm^{-1}, and
14	Investigation of electrocoagulation reactor design parameters effect on the removal of cadmium from synthetic and phosphate industrial wastewater	Arabian Journal of Chemistry (2014)	B. Khaled, B. Wided, H. Bechir, A. Limam, L. Mouna, Z. Tlili,	Synthetic and phosphate mechanical wastewater; The EC cell was comprised of 1L barrel shaped Plexiglas measuring utensil. The cathodes utilized were shaped by two rectangular aluminium plates (250 mm x 80 mm x 2 mm). The all out drenched region of every cathode was dynamic (85 mm x 80 mm x 2 mm) S = 68 cm^2. The anode-cathode separating	The best cadmium removal was accomplished for a anode separation of 0.5 cm, monopolar association mode, mixing velocity of 300 rev min-1and surface-region to-volume proportion (S/V) of 13.6 m-1, with a temperature of 50 C°. The study showed that the parameters that impact the operating expense are the cathode arrangement, between terminal separation and S/V proportion.

				was shifted from 5 mm to 20 mm.	
15	Chromium ions (Cr^{6+}&Cr^{3+}) removal from synthetic wastewater by electrocoagulation using vertical expanded Fe anode	Journal of Electroanalytical Chemistry (2014)	T.M. Zewail, N.S. Yousef	It comprised predominantly of two litres plexi-glass tube shaped holder of 14 cm measurement and tallness 24 cm, the electrical circuits and the cell. The cell comprised of two concentric iron tube shaped cathodes. The external terminal consisted a strong iron cathode of 12.5 cm distance across and 23 cm stature which was bolstered on the compartment divider. The internal cathode consisted of an extended round and hollow iron of 11.5 cm width and stature of 26 cm.	The examination uncovered that as present thickness increments, % Cr^{3+} expulsion marginally increments, though % Cr^{6+} evacuation somewhat diminishes. As NaCl fixation increments, % Cr^{6+} evacuation increments steadily, while % Cr^{3+} expulsion increments up to 1 g/L and diminishes past this esteem. Most extreme % Cr^{6+} evacuation happens at pH 4.5, while greatest % Cr^{3+} expulsion happens at pH 8.

				The hole between the cathode and anode was kept 0.5 cm.	
16	Electrocoagulation Process Coupled with Advance Oxidation Techniques to Treatment of Dairy Industry Wastewater	International Journal of Electrochemical Science (2014)	Ana L. Torres-Sanchez, Sandra J. Lopez-Cervera, Catalina de la Rosa, Maria Maldonado-Vega, Maria Maldonado-Santoyo, Juan M. Peralta-Hernández	Ice cream wastewater; The reactor consisted of Pyrex Becher glass, having 2 aluminium anodes and 3 iron cathodes that are connected with a BK Precision power supply (model 1900) connected in bipolar mode. The overall area of electrodes in contact with the solution was 160 cm^2. Tests were performed with a current density of 5 mA/cm^2.	Electrocoagulation is productive and ready to accomplish a COD expulsion of 40% at a present thickness (j) of 5 mA/cm^2, the expansion of a Fenton procedure to the EC further builds the treatment proficiency near 25 % in at a proportion 1:1 H_2O_2/Fe^{2+}. At the point when utilized in mix with ozone limited time framework further contributes an extra 30 % COD expulsion.
17	Elimination of Pb^{2+} through electrocoagulation: Applicabilit	Journal of Electroanalytical Chemistry (2014)	Maria M.S.G. Eiband, Kamelia C. de A. Trindade,	EC tests were done utilizing a solitary compartment electrolytic stream cell outfitted with parallel plate	The test consequences of EC demonstrated that the exhibitions of the procedure marginally rely upon the

	y of adsorptive stripping voltammetry for monitoring the lead concentration during its elimination		Kelvin Gama, Jailson Vieira de Melo, Carlos A. Martinez-Huitle, Sergio Ferro	anodes. Round about Al terminals were utilized, with an ostensible surface region of 63.5 cm^2. The between terminal hole was 15 mm. .	connected current; a total evacuation of the poison is gotten in all cases, anyway with various treatment times for (90, 75 and 45) min for 0.25, 0.5 and 0.75 A of current, individually.
18	A comparative study of chemical precipitation and electrocoagulation for treatment of coal acid drainage wastewater	Journal of Environmental Chemical Engineering (2013)	M.S.Oncel, A. Muhcu, E.Demirbas, M. Kobya	Wastewater: Coal mine seepage wastewater; The EC was done in bunch mode utilizing vertically situated iron cathodes with measurements of 50 mm × 73 mm × 3 mm in a 1 L Plexiglas reactor (120 mm × 110 mm × 110 mm) at a steady temperature of 200C.	The ideal pH for evacuation of the vast majority of substantial metals from waste water by the compound precipitation utilizing sodium hydroxide is 8 aside from Sr, Ca and B (pH 10 or higher). Results from the EC procedure demonstrated that the evacuation of metals is expanded with expanding current thickness and working time.

19	Arsenic removal from groundwater using iron electrocoagulation: Effect of charge dosage rate	Journal of Environmental Science and Health, Part A: (2013)	Susan Amrose, Ashok Gadgil, Venkat Srinivasan ,Kristin Kowolik, Marc Muller, Jessica Huang and Robert Kostecki	Groundwater test; A 3-L seat scale cluster reactor contained an iron wire anode (measurement 0.18 cm) situated over a copper work cathode confined by a polyvinylidene fluoride hydrophilic layer.	EC utilizing iron cathodes may lessen arsenic underneath 10 µg/L in manufactured groundwater and in genuine groundwater. Charge measurements rate affects both expulsion limit and time of treatment and is a suitable parameter for keeping up execution when scaling to various dynamic territories and capacities.
20	Comparative study of electrode material (iron, aluminium and stainless steel) for treatment of textile industry wastewater	International Journal of Environmental Sciences (2013)	Akanksha, Roopashree G. B, Lokesh K. S.	Textile wastewater; The materials utilized in this examination are iron cathode, aluminium anode and tempered steel terminal. There are six monopolar terminals, three anodes and three cathodes of a	The outcome shows that electro-coagulation is exceptionally productive and had the capacity to accomplish shading expulsion (99.46 %) at 14 V in 80 min and COD evacuation (90.12 %) in 80 minutes at a

				similar measurement (5 cm× 5cm× 1mm). Anodes were associated with the positive and negative terminals of the DC control supply.	capability of 8 V within the sight of iron terminal. The expulsion of colour and COD by aluminium and treated steel terminals were accomplished at higher voltages.
21	Application of Electrocoagulation Process for Dairy Wastewater Treatment	Journal of Chemistry (2013)	Edris Bazrafsha, Hossein Moein,Ferdos Kord Mostafapour,Shima Nakhaie	Dairy wastewater; A bipolar group reactor, with six aluminium cathode associated in parallel was utilized for the investigation. The inner size of the cell was 15 cm × 15 cm × 25 cm with a working volume of 2000 cm^3. The capacity (V) of the arrangement of each clump was 2 L. The dynamic zone of every terminal (plate) was 14 cm × 20 cm with an absolute region	The expulsion proficiency of COD, BOD_5, and TSS expanded with expanding the connected voltage and the response time. The outcomes were productive and ready to accomplish 98.84 % COD evacuation, 97.95 % BOD5 expulsion, 97.75 % TSS evacuation, and > 99.9 % bacterial pointers at 60 V amid 60 min.

				of 280 cm^2. Between terminal separation was 2 cm.	
22	Enhanced removal of Methylene Blue by electrocoagulation using iron electrodes	Egyptian Journal of Petroleum (2013)	Mohamed S. Mahmoud, Joseph Y. Farah , Taha E. Farrag	The EC unit comprises of a 2 L electrochemical cell with iron anodes. The elements of the cathodes are 0.04 × 0.08 m and bury anodes separate was 0.02 m. The present thickness was kept up steady at 8 mA/cm^2.	The ideal electrolysis was for 10 – 20 min at a present thickness of 8 mA/cm^2, and the ideal centralization of the electrolyte was observed to be 2 wt. % at the colour fixation of 50 mg/L. The usage of an electro-attractive field upgraded the colour evacuation because of the instigated movement of paramagnetic particles inside the arrangement.
23	Electrocoagulation of heavy metals containing model wastewater using	Separation and Purification Technology (2012)	Bassam Al Aji , Yusuf Yavuz , A. Savas Koparal	Trials were made by utilizing a round and hollow glass cell of capacity 500 mL on an attractive stirrer. 6 iron plates were introduced vertically with the help of a spacer to	EC proved useful to eradicate heavy metals in model wastewater with preliminary concentration of 250 mg/L for every metal. As per pH results, EC treatment

	monopolar iron electrodes			guarantee fixed separation and drenched to a 4 cm profundity, were utilized as terminals in monopolar way in the investigations. The complete drenched zone of the anode and cathode terminals was 100 cm^2. The between cathode separate was 0.3 cm.	was easier at higher pH. At energy consumption of 49 kWh/m^3 and current density of 25 mA/cm^2, above removal of 96% was reached for all metals except Mn for which removal was 72.6 %.
24	Study of an electrocoagulation (EC) unit for the treatment of industrial effluent of Ouagadougou, Burkina Faso	Advances in Applied Science Research (2012)	Inoussa Zongo, Belkacem Merzouk, Kalifa Palm, Joseph Weth, Amadou Hamamaiga, Jean-Pierre Leclerc, Francois Lapicque	pH estimations are done by a pH meter Consort C931 model having a glass cathode containing an answer of 4 M KCl fixation. The estimation of the convergence of broke down metal is finished by taking an amount of the profluent after homogenization of	The treatment delivers about 480 m^3 yr-1 of slop after pressure utilizing channel press and 216 T of dry issue containing chromium and iron hydroxides, natural and inorganic toxins.

				the emanating gathered.	
25	Domestic Wastewater Treatment by Electrocoagulation with Fe-Fe Electrodes	International Journal of Engineering Trends and Technology (2012)	C. Sarala	Domestic waste water; In current investigation iron terminals are utilized and the example is made to keep running at various interims of time i.e., 5 min., 10 min., and 20 minutes and distinctive current flows through the example(0.12 A, 0.25 A, 0.36 A).	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.
26	Application of Electrocoagulation Process Using Iron and Aluminium Electrodes for Fluoride Removal from Aqueous	E-Journal of Chemistry (2012)	Edris Bazrafshan, Kamal Aldin Ownagh1, and Amir Hossein Mahvi	Analyses were done in a bipolar clump reactor, having four Aluminium and Iron anode associated in parallel. Just the external cathodes were associated with the power source. The inside measurements of the cell were 10 cm × 13 cm × 12 cm	The best removal limits of fluoride were accomplished at electrical potential of 40V. Furthermore, the expansion of electrical potential, in the scope of 10-40 V, improved the rate of treatment. Additionally, correlation of fluoride evacuation proficiency

	Environment			(width × length ×profundity) with a compelling capacity of 1000 cm^3. The volume of the arrangement of each group was 1.0 L. The dynamic zone of every terminal was 10 × 10 cm. The separation between anodes was of 1.5 cm.	demonstrated that expulsion productivity is comparable with aluminium and iron cathodes.
27	The efficiency of electrocoagulation process using aluminium electrodes in removal of hardness from water	Iranian Journal of Environmental Health Science & Engineering (2009)	M. Malakootian, N.Yousefi	The investigation was led by utilizing a pilot plant with 6 aluminium terminals, 15 mm separated from one another. Pilot types of gear incorporated a power source, six business aluminium terminals with measurements of 10 × 10 cm and a glass supply with the productive volume of 1.3 Electrodes	The effectiveness of the framework in different pH, time and voltages interims were studied. Results indicated the productivity of 95.6 % for electrocoagulation procedure in evacuation of hardness. The impact of electric potential and pH was directly related to hardness expulsion.

				were associated as monopolar.	
28	Treatment of the textile wastewater by combined electrocoagulation	Chemosphere (2006)	O.T. Can, M. Koby, E. Demirbas, M. Bayramoglu	Textile wastewater; The electrocoagulator was built up of plexiglass with the components of 65 × 65 × 110 mm at steady blending velocity of 200 rpm. It consisted, two anodes and two cathodes of similar measurements and four monopolar terminals. Both aluminium cathodes and anodes were produced using plates with measurements of 46 × 55 × 3 mm. The complete powerful anode zone was 78 cm2, and the separation between terminals was 11 mm.	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 aluminium provided, by starting expansion and electrochemical age.

CHAPTER-3

MATERIALS AND METHODS

Electrocoagulation reactor is used for the treatment of distillery wastewater and the principle of electrocoagulation were used for treatment of the wastewater. Iron and aluminium electrodes were used as cathodes and anodes. Various parameters were used in the treatment process and their removal efficiency were calculated during the experimental work.

3.1 EXPERIMENTAL SETUP

3.1.1 REACTOR DESIGN

The reactor that was employed for treatment comprised of sheets of acrylic having thickness 0.5 cm. A rectangular shaped reactor was used and has measurements of 20 cm × 15 cm × 8 cm and has 2 litres net capacity. Inlet valve is located at 2 cm beneath the reactor's top surface and outlet valve is located at 2 cm above reactor's base. Eight sheets of electrode having measurements as 9 cm × 5 cm and 0.3 cm of thickness were used. Electrode materials used were of two types i.e. aluminium and iron. The separation between the electrodes was alterable up to minimal separation of 0.5cm. The Electrocoagulation system was linked with a DC supply of capacity 0-10 A and 0-30 V.

3.2 WASTEWATER SAMPLE

The samples of distillery wastewater were gathered from a brewery "Green Valley Cider Private limited" which is located in Shoghi, Shimla in the state of Himachal Pradesh. The industry produces vinegar, cider and wine with the use of apples. Proper fermentation of the apple fruits results in the formation of vinegar, cider and wine. The distillery wastewater of these enterprises for the most part have higher COD, BOD, turbidity and TSS content. Wastewater in such industries comes from ablution action of the huge containers utilized in cleaning of the brew house and many other things. Plastic containers with a capacity of 5 litres were used for the collection of wastewater through equalisation tank of the industry. The resulted wastewater was examined for COD, pH, BOD, total suspended solids, turbidity and conductivity.

3.3 REACTOR OPERATION

Experimental operations were performed in two phases. In first phase, the reactor was fed with a voltage of 20V and was treated for time interval of 0-15 minutes, 15-30 minutes and 30-45 minutes. All the testes were performed and removal efficiency were determined. In the second phase the reactor was fed with a voltage of 30V and was treated again for time interval of 0-15 minutes, 15-30 minutes & 30-45 minutes.

3.4 ANALYTICAL TECHNIQUES

A couple of physical and chemical analysis was done on the wastewater samples. The parameters picked for investigation included: Turbidity, pH, conductivity, Total Suspended Solids (TSS), BOD and COD.

Standard Methods were used for the estimation of TSS and COD (APHA,2005). pH paper was used for computing the pH. Turbidity has been determined with the use of a Turbidity Meter (LABTRONICS MODEL NO. 33). Deluxe Conductivity Meter (MODEL NO. LT-26) was used to determine the conductivity.

CHAPTER-4

RESULTS & DISCUSSION

4.1 CHARACTERISTICS OF DISTILLERY WASTEWATER

The waste water samples used for conducting the experiments were taken from the Distillation industry which generates cider, vinegar and wine from apple fruit. For every sample collected, the physiochemical properties differed a little. This was due to the different volumes of the batch production by the industry. The waste water was characterised for each sample that was collected. The outcomes demonstrated that the concentrations of COD, turbidity and TSS showed an up marked limits than prescribed limits. The pH of the wastewater was nearly neutral. The outcomes demonstrated that the waste water produced within the industry should be treated prior to its release to the environment. The characteristics of the distillery wastewater are shown in the ***Table 4.1***.

Table 4.1: Composition of distillery wastewater

Composition	Value
Ph	3.5
Cl content	587.33 mg/l
TS	2900 mg/l
TSS	650 mg/l
COD	20160 mg/l
Turbidity	156 NTU
Conductivity	1.072 (m. mho/cm)

4.2 ELECTROCOAGULATION EXPERIMENTS RESULTS

The point of this investigation has been to inspect the effects of inter electrode separation and the electrode material. Current density was taken constant to 25 mA/cm^2 to perform the experiments. The norms for deciding the effects of electrocoagulation for these operational parameters were based on these parameters: efficiencies of removal of COD, turbidity, BOD and TSS. The outcomes revealed that for a spacing of 0.5 cm between the electrodes, maximum removal efficiencies were achieved.

.4.2.1 EFFECT OF ELECTRODE MATERIAL

The results from the experiments demonstrated that for a separation of 0.5 cm between the electrodes, the maximum COD removal was obtained i.e. 83.65 % after 45 min of electrocoagulation by using aluminium for both the cathode and the anode. The removal efficiency of turbidity, BOD and total suspended solids for these parameters were 75 %, 83.36 % and 82.23 % respectively.

While using iron for both the anode and the cathode for 0.5 cm inter electrode spacing, the maximum removal for COD i.e. 78.68 % was achieved after 45 min of electrocoagulation. The turbidity, BOD and TSS removal were 74.28 %, 79.80 % and 81.75 % respectively. The graphs comparing the electrode materials i.e. anode and cathode for the percent removal of COD, turbidity, BOD and TSS for electrode distance of 0.5 cm are shown in fig.4.1,4.2,4.3 and 4.4.

From the above results, it can be concluded that aluminium is more effective electrode material.

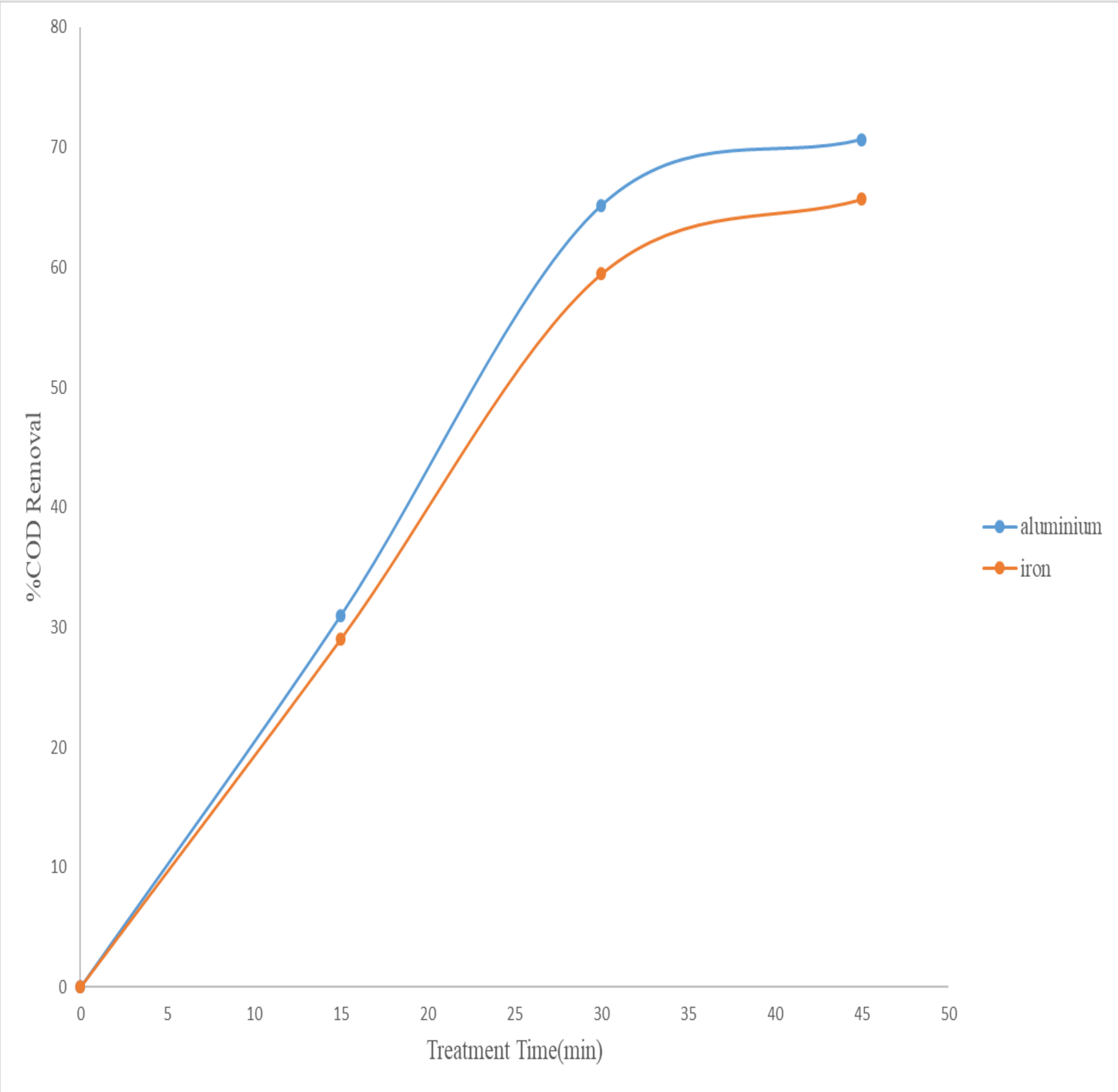

Fig. 4.1. COD removal comparison of electrode materials with spacing of 0.5cm

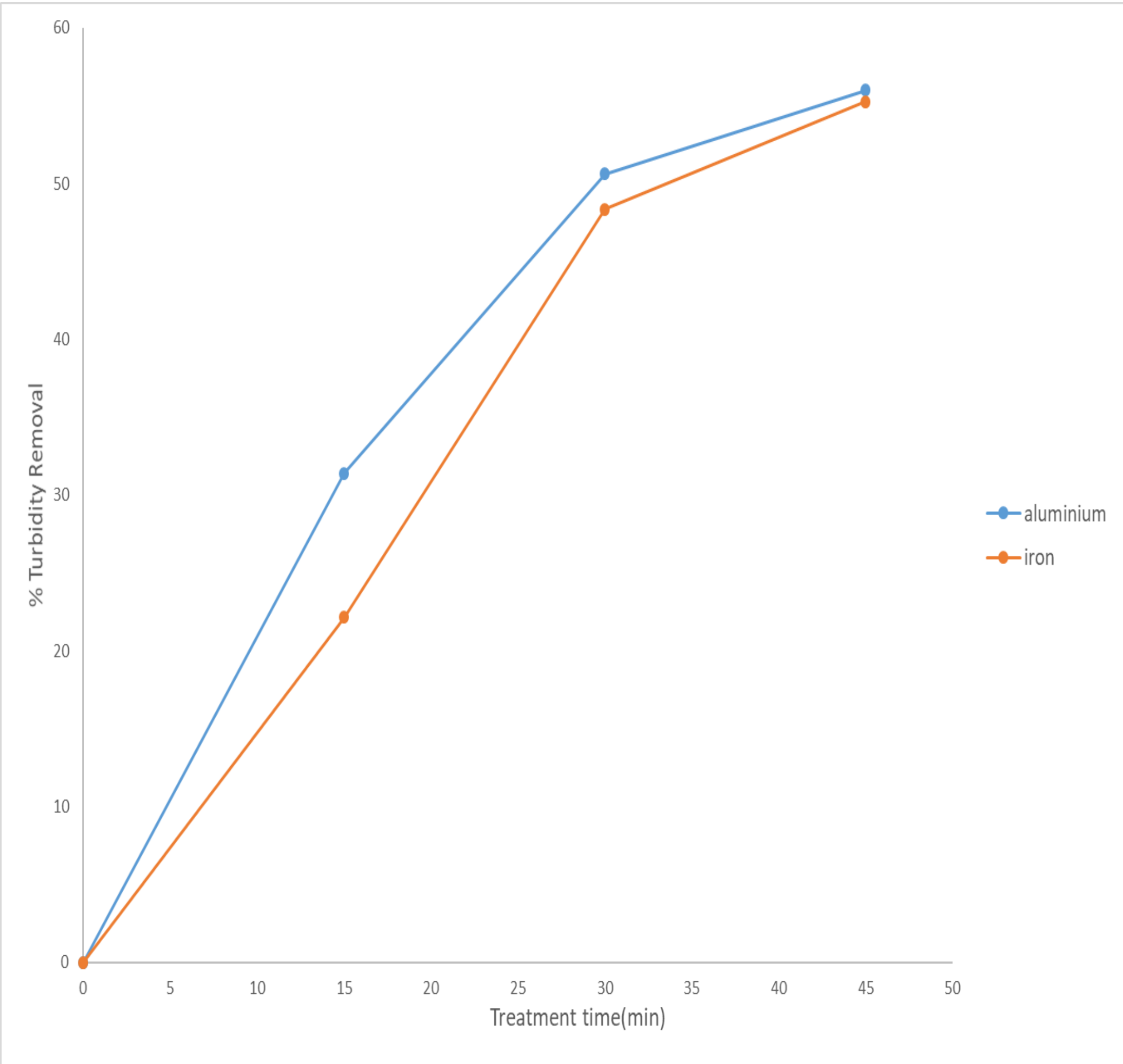

Fig. 4.2. Turbidity removal comparison of electrode materials with spacing of 0.5cm

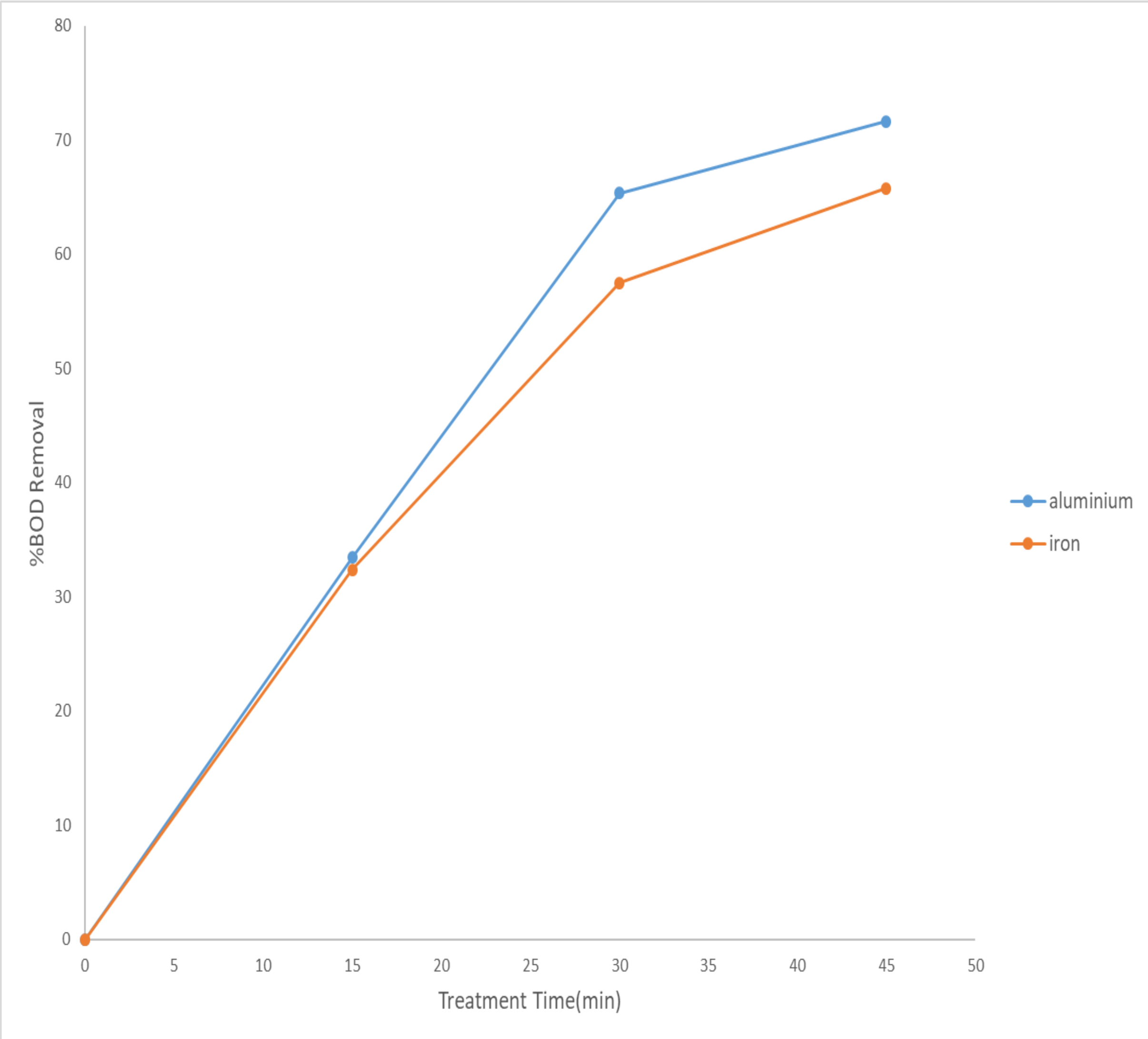

Fig. 4.3. BOD removal comparison of electrode materials with spacing of 0.5cm

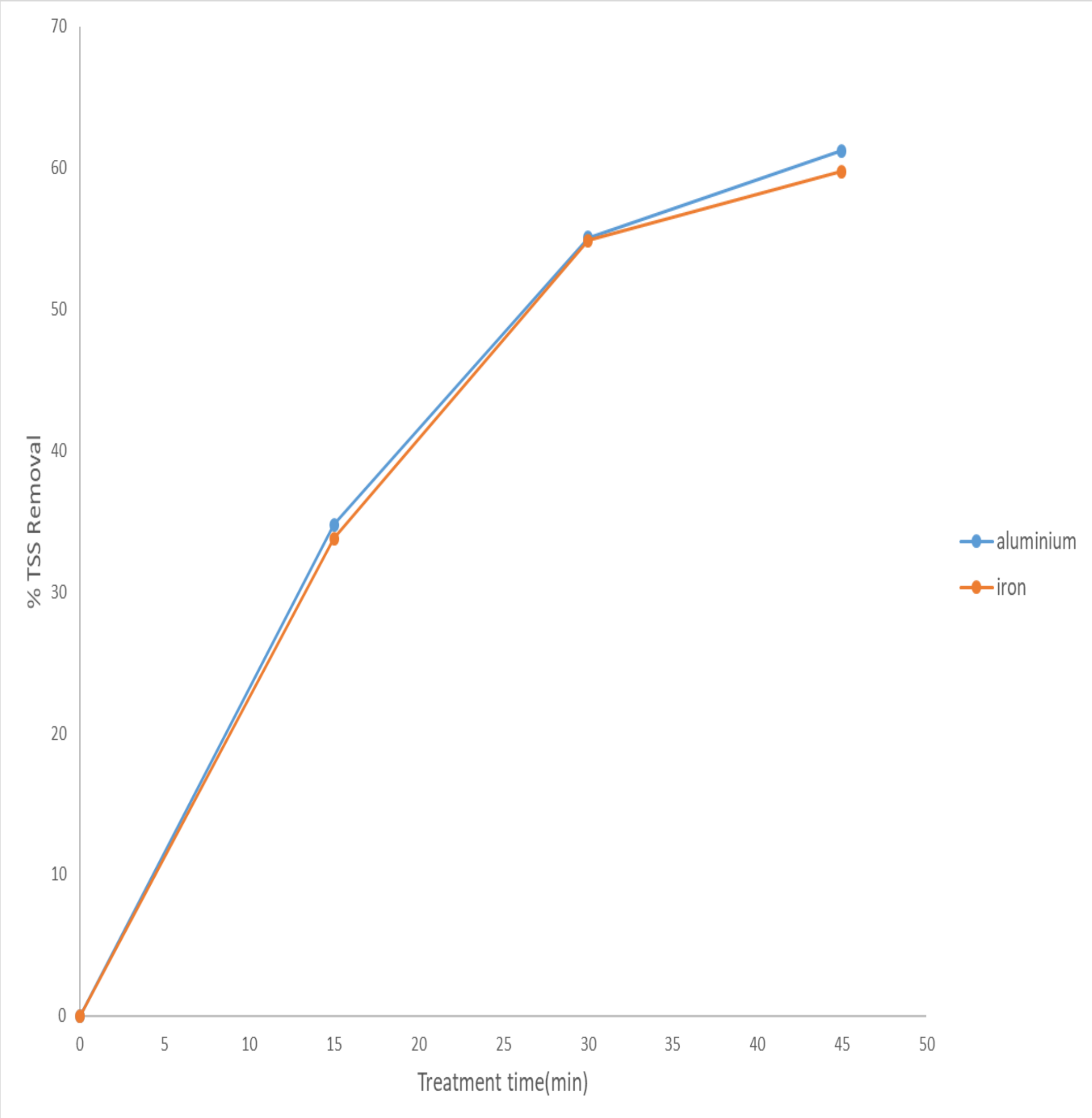

Fig. 4.4. TSS removal comparison of electrode materials with spacing of 0.5cm

4.2.2 EFFECT OF INTER ELECTRODE DISTANCE

An inter electrode separation of 0.5 cm and 1 cm were taken to notice the outcomes of inter electrode spacing for the elimination of BOD, turbidity, TSS and COD. When aluminium was used at both the terminals, the COD removals were found to be 83.65 % and 77.33 % when the separation between electrodes was 0.5 cm and 1 cm respectively. The results demonstrated that the decline in rates of removals happened in practically all the tests. The internal resistance of the cell has a role in it. With the decrease in electrode separation there is a decline in internal resistance of the cell resulting in greater passage of electric current within the electrodes leading into high coagulant production which ultimately leads to increased removals.

The contrast in the COD removals, turbidity, BOD and total suspended solids with different electrode spacings are shown in the Fig. 4.5, 4.6, 4.7, 4.7, 4.8, 4.9, 4.10, 4.11 and 4.12.

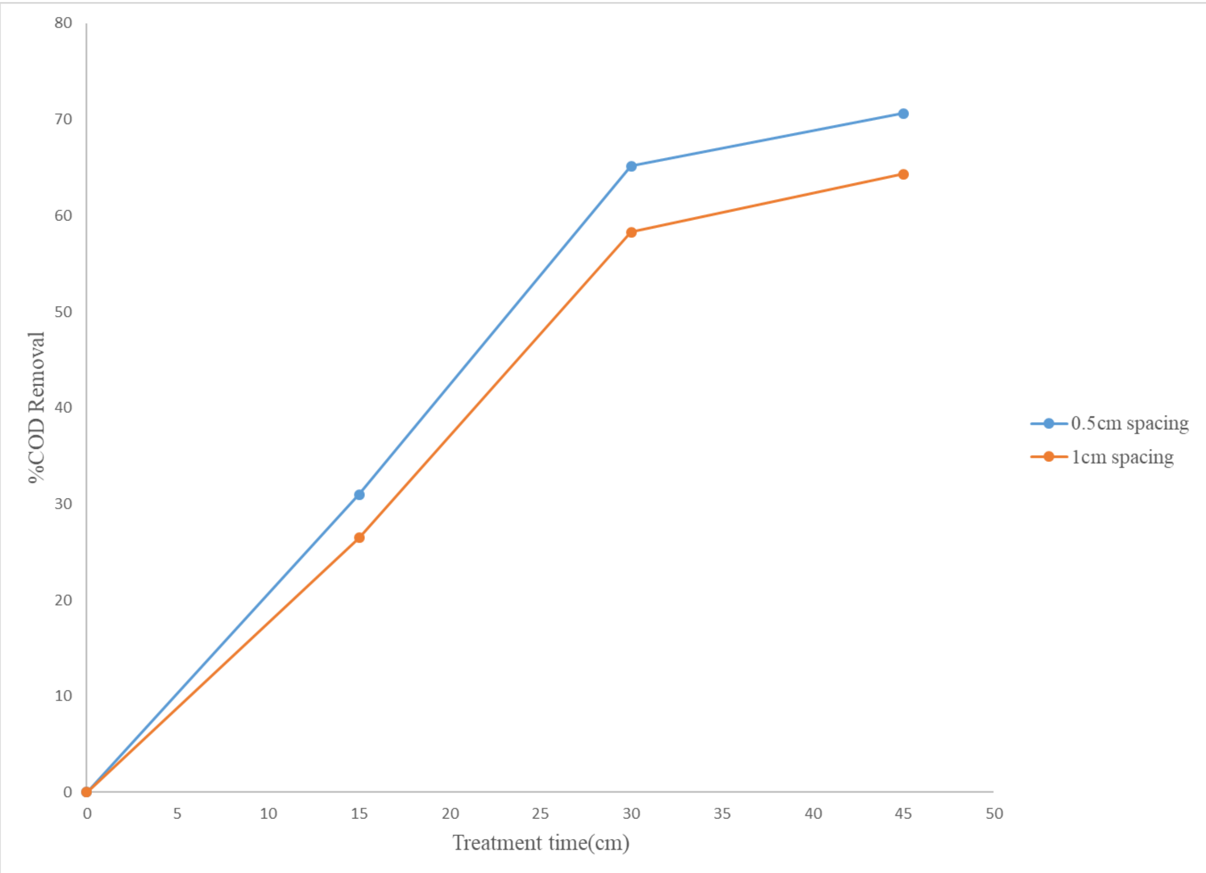

Fig. 4.5. COD removal comparison of different electrodes spacing using Al-Al electrodes (anode- cathode)

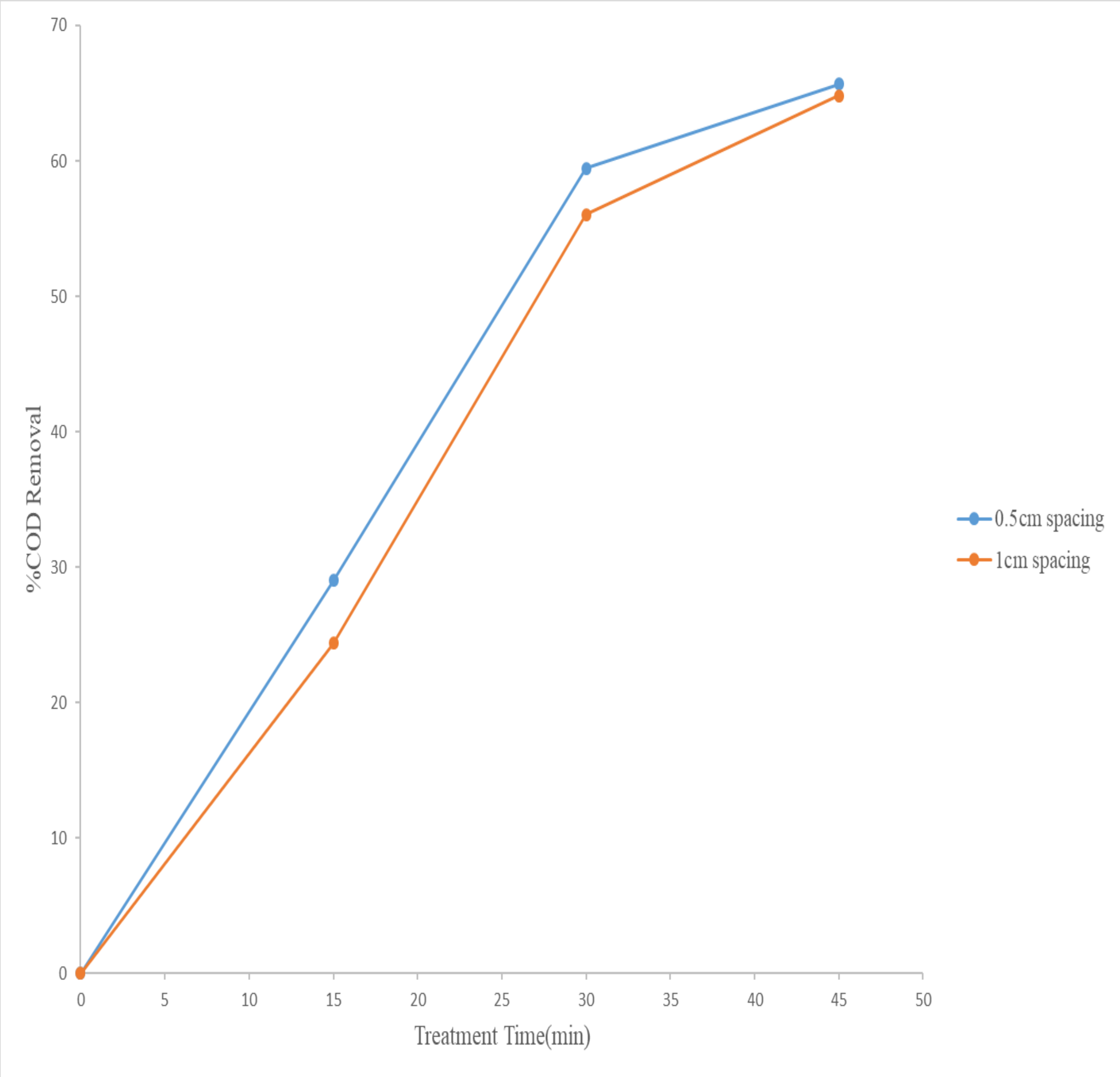

Fig. 4.6. COD removal comparison of different electrodes spacing using Fe-Fe electrodes (anode- cathode)

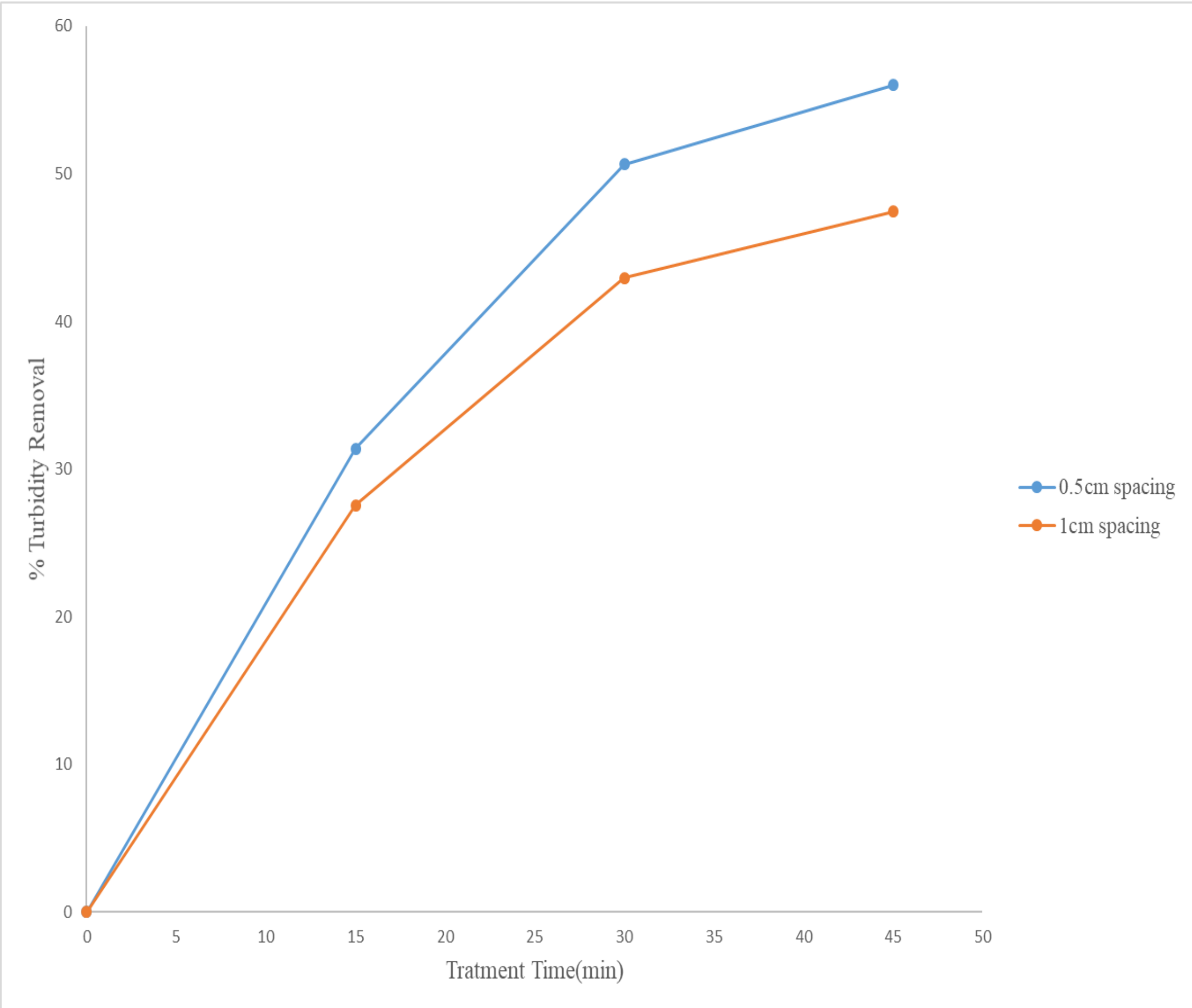

Fig. 4.7. Turbidity removal comparison of different electrodes spacing using Al-Al electrodes (anode- cathode)

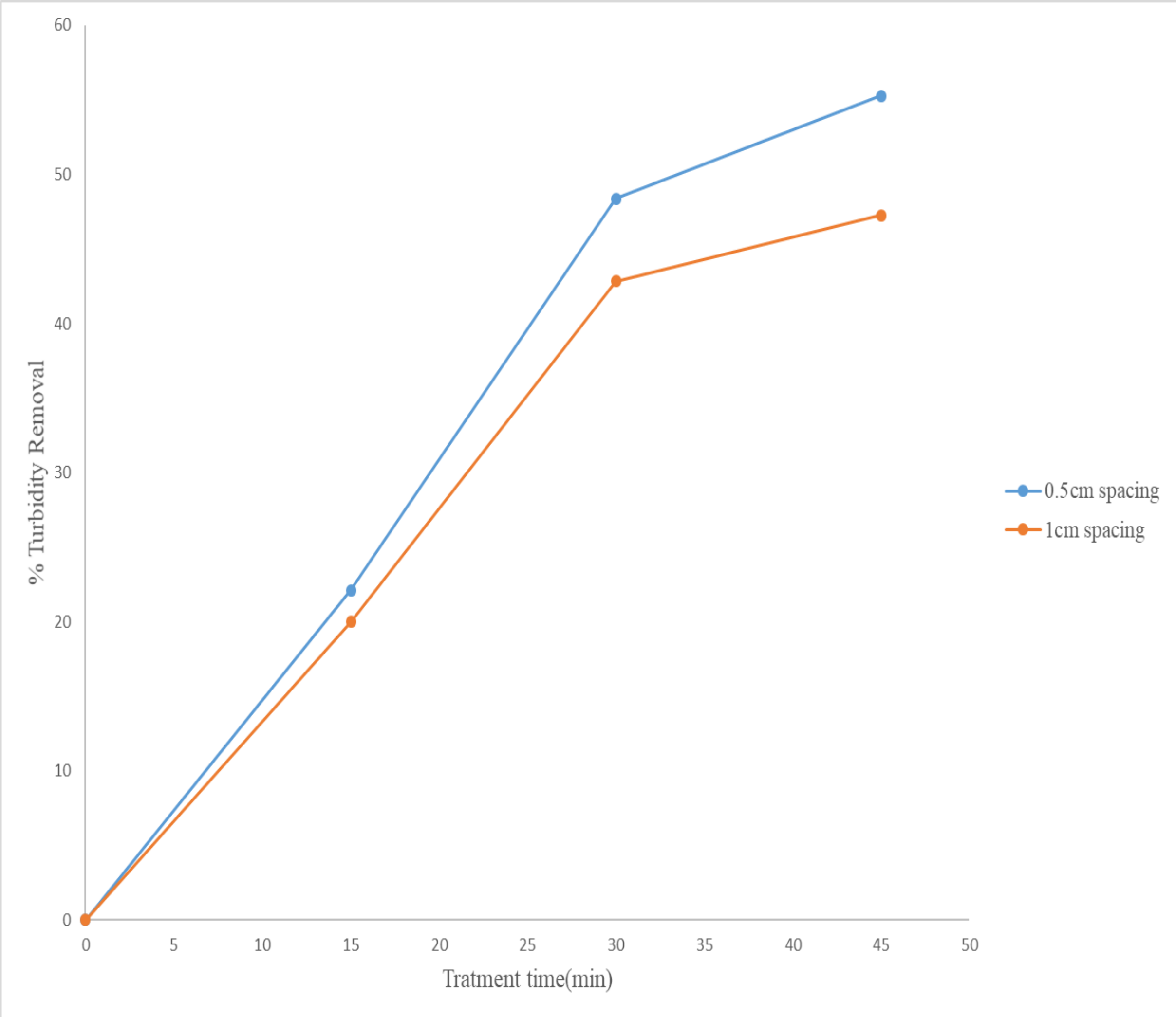

Fig. 4.8. Turbidity removal comparison of different electrodes spacing using Fe-Fe electrodes (anode- cathode)

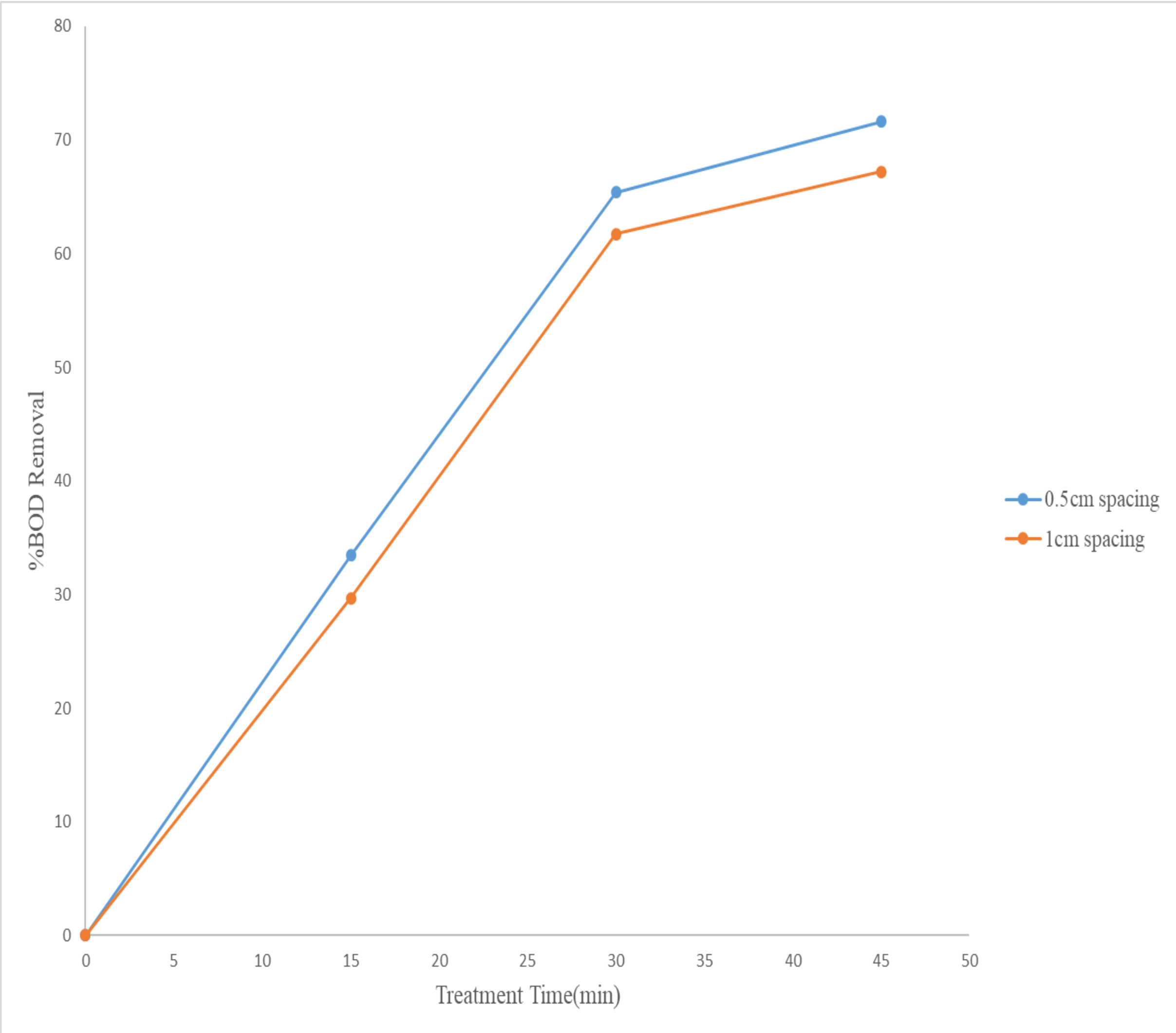

Fig. 4.9. BOD removal comparison of different electrodes spacing using Al-Al electrodes (anode- cathode)

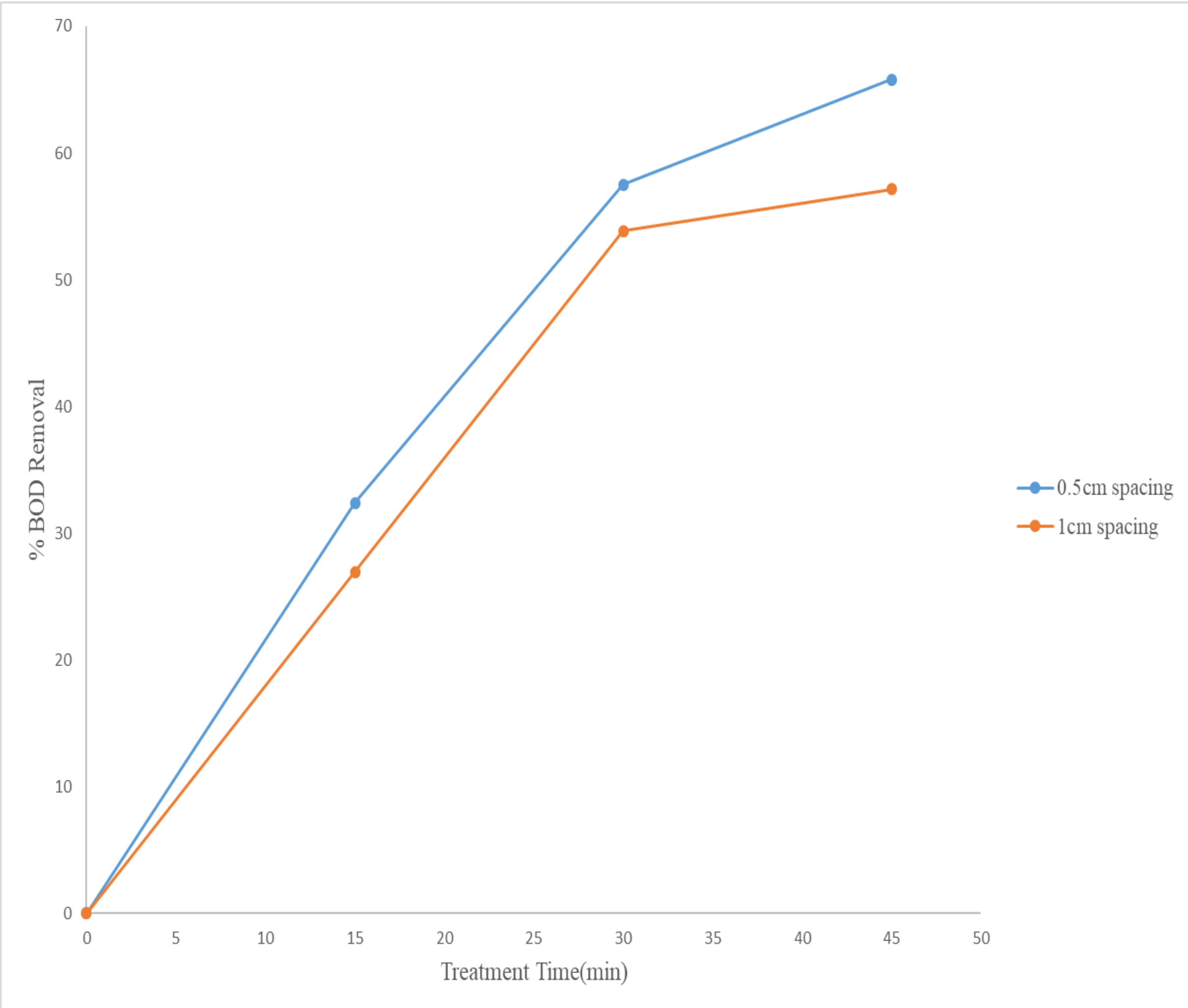

Fig. 4.10. BOD removal comparison of different electrodes spacing using Fe-Fe electrodes (anode- cathode)

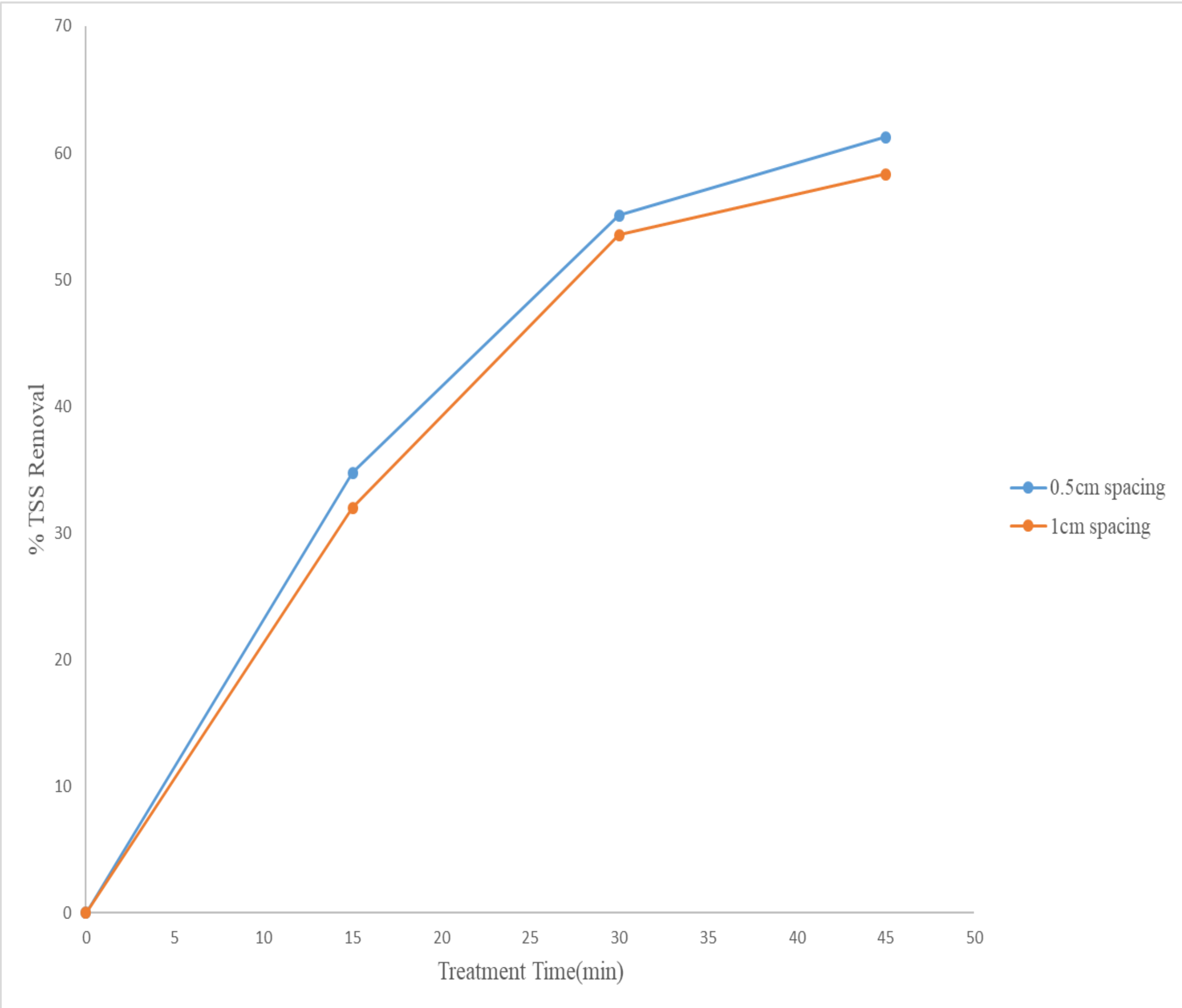

Fig. 4.11. TSS removal comparison of different electrodes spacing using Al-Al electrodes (anode- cathode)

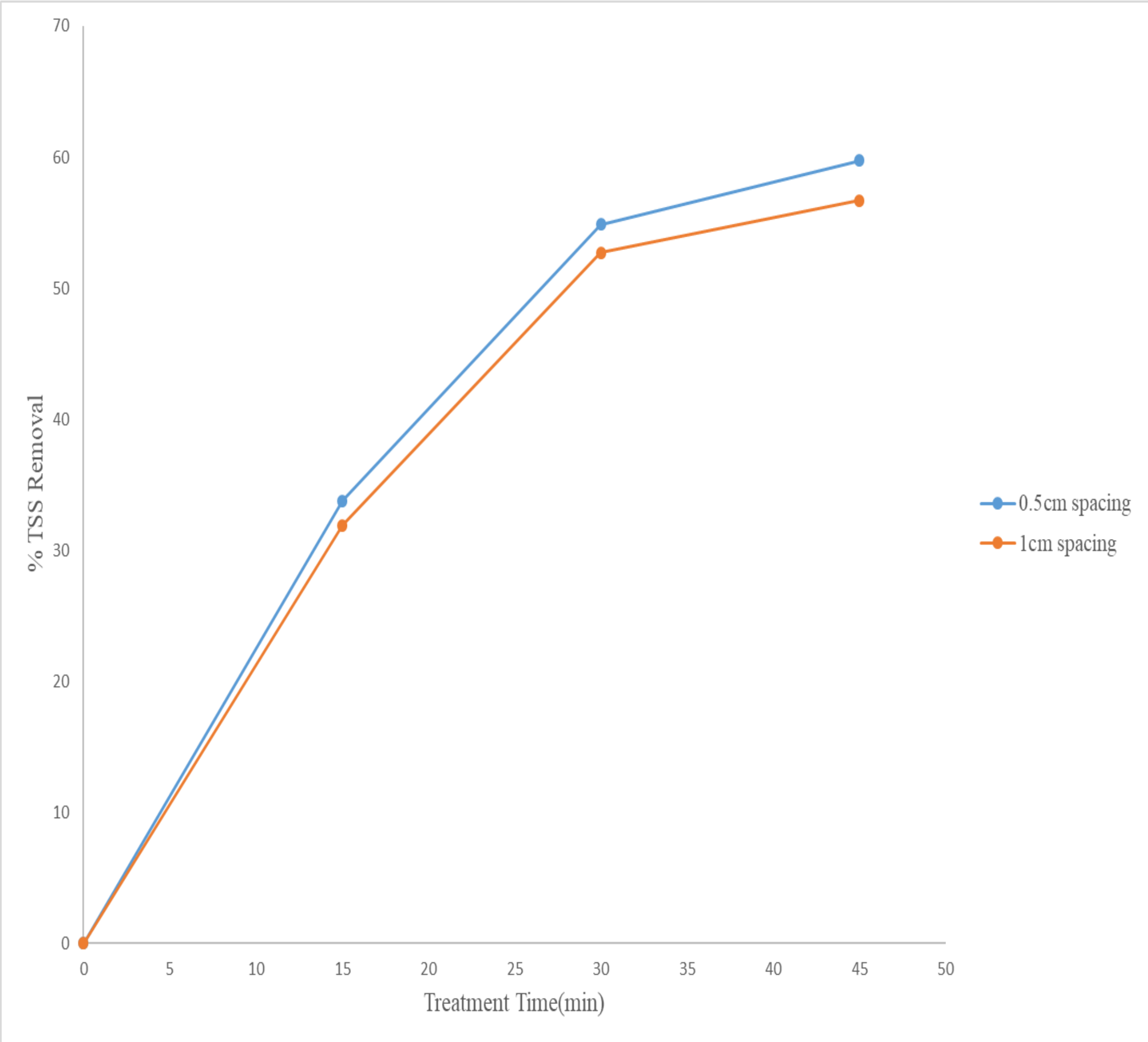

Fig. 4.12. TSS removal comparison of different electrodes spacing using Fe-Fe electrodes (anode- cathode)

4.2.3 EFFECT OF ELECTROLYSIS TIME

The time for which electrolysis is carried out is a significant specification as it impacts the productivity of treatment of the electrochemical technique. To investigate the impact of electrolysis time on the removal efficiency, experiments were done. It is noticed that with the increase in the electrolysis time, the removal of BOD, COD, conductivity, turbidity and TSS increases.

CHAPTER-5

CONCLUSIONS

5.1 CONCLUSIONS

Electrocoagulation is a productive process to treat distillery wastewater having high concentration of COD, BOD and TSS. For this purpose, the investigation was done for the treatment of distillery wastewater by using the electrocoagulation technique. Iron and aluminium electrodes were used and were tested for their efficiencies concerning COD, turbidity, BOD and TSS. As the electrode material changed the efficiency also changed. Aluminium electrode was observed to be more coherent than iron electrode in removal. The results from various experiments demonstrated that for treating distillery wastewater through electrocoagulation, the electrode spacing plays significant role. As the inter electrode distance was decreased, the removal efficiency was found to increase. The ideal value of electrode separation was observed to be 0.5 cm. Thus, it can be concluded that electrocoagulation is productive for treating waste water which showed highest of COD removal of 83.65 %, 75 % turbidity removal, 83.36 % BOD removal and 83.23 % of total suspended solids reduction.

5.2 SUGGESTIONS FOR FUTURE SCOPE

In the current research, analysis was done for the samples that were taken out and the sedimentation time was provided. The use of agitation technique was not done due to which well mixing of coagulants did not occur as agitation performs in the conventional chemical and flocculator systems.

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APPENDIX A

TABLE OF RESULTS

TABLE A.1. ALUMINIUM AS BOTH ANODE AND CATHODE

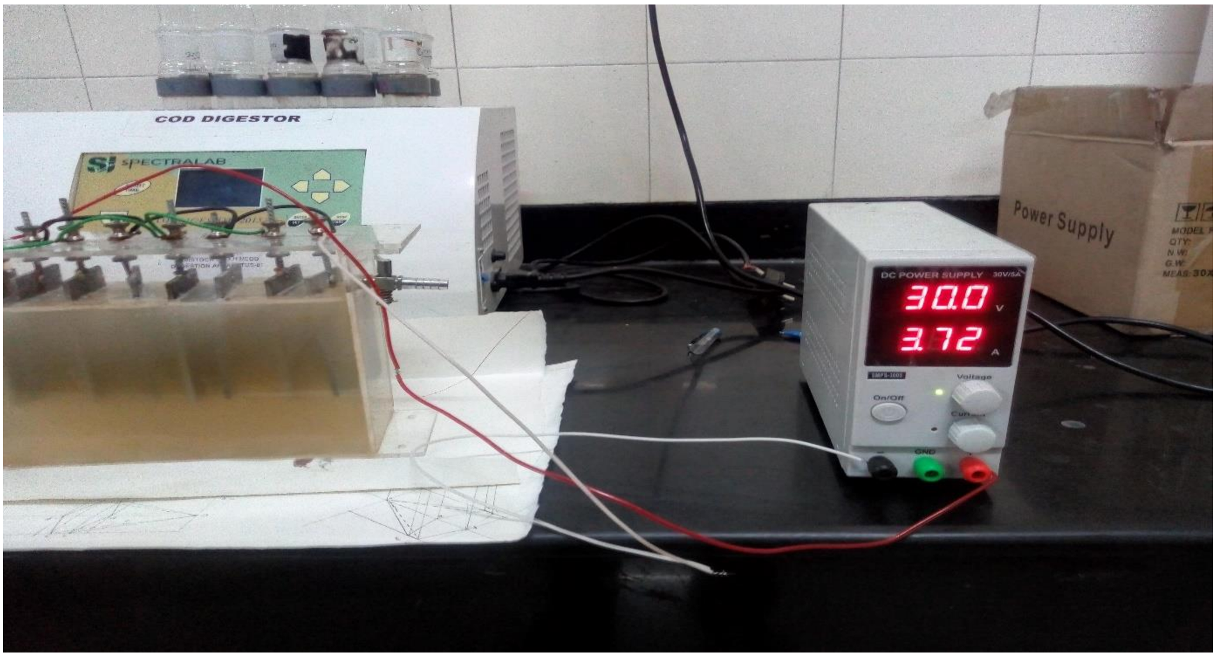
Electrode Spacing (cm)	Time (min.)	pH	COD (mg/L)	Conductivity (m.mho/cm)	Turbidity (NTU)	BOD (mg/L)	TSS (mg/L)
0.5	**0**	**3.5**	**20160**	**1.212**	**156**	**5423**	**650**
	15	**4.0**	**13727**	**1.131**	**107**	**3610**	**424**
	30	**4.3**	**7023**	**1.076**	**77**	**1877**	**292**
	45	**4.8**	**5916**	**0.838**	**68**	**1538**	**252**
1	**0**	**3.5**	**20160**	**1.212**	**156**	**5423**	**650**
	15	**3.8**	**14816**	**1.198**	**113**	**3812**	**442**
	30	**4.0**	**8412**	**1.110**	**89**	**2076**	**302**
	45	**4.3**	**7194**	**0.997**	**82**	**1779**	**271**

TABLE A.2. IRON AS BOTH ANODE AND CATHODE

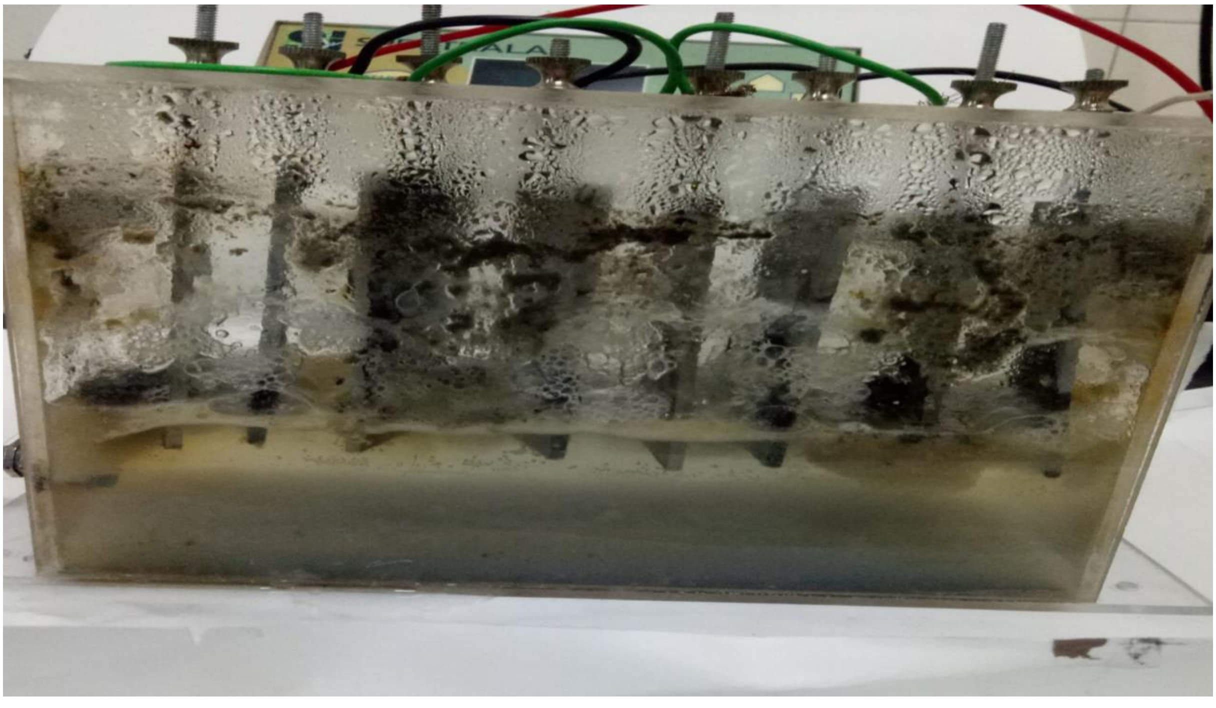
Electrode Spacing (cm)	Time (min.)	pH	COD (mg/L)	Conductivity (m.mho/cm)	Turbidity (NTU)	BOD (mg/L)	TSS (mg/L)
0.5	0	3.8	18420	1.114	140	4912	592
	15	4.3	13096	1.101	109	3321	392
	30	4.5	7468	0.972	72	2087	267
	45	4.8	6321	0.845	62	1679	238
1	0	3.8	18420	1.114	140	4912	592
	15	4.0	13922	1.107	112	3587	403
	30	4.3	8096	0.990	80	2266	280
	45	4.5	6484	0.899	74	2105	256

APPENDIX B

PHOTOGRAPHS



Photograph B.1. Electrocoagulation Reactor with DC power supply



Photograph B.2. Electrocoagulation Reactor after treatment of distillery wastewater