JIMMA UNIVERSITY

SCHOOL OF POST GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

ENVIRONMENTAL ENGINEERING CHAIR

Investigation of Integrated Sono-direct and Sono-alternative Current Electro Coagulation process for the treatment of Domestic wastewater

This Thesis submitted to the School of Post Graduate Studies of Jimma University in partial fulfillment of the requirements for the degree of Master of Science in Environmental Engineering.

BY

LELISA REGEA MENGISTU

July, 2021

Jimma, Ethiopia

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LELISA REGEA MENGISTU

Main Advisor: Dr. Zerihun Asmelash

Co-advisor: Mr Chali Dereje (MSc)

July, 2021

Jimma, Ethiopia

DECLARATION

I declare that this research entitled Investigation of Integrated sono-direct current and sono-alternative current electrocoagulation process for the treatment of domestic wastewater is my original work and has not been submitted as a requirement for the award of any degree in Jimma University or elsewhere.

LELISA REGEA MENGISTU	________________	______________________
NAME	SIGNATURE	DATE

As research Adviser, I hereby certify that I have read and evaluated this thesis paper prepared under my guidance, by Lelisa Regea Mengistu entitled "Integrated sono-direct current and sono-alternative current electrocoagulation process for the treatment of domestic wastewater. And recommend and would be accepted as a fulfilling requirement for the Degree Master of Science in Environmental Engineering.

Main Advisor: Dr. Zerihun Asmelash (PhD)	______________________
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Co advisor: Mr. Chali Dereje (MSc)	______________________
Name	Signature

ABSTRACT

Integrated sono-alternative and direct current Electrocoagulation process is simple technology needed in the treatment of domestic wastewater only by applying electric current with sacrificial electrode. The main objective of this study was to analyze the influence of Integrated Sono-Alternative and Direct –current on electrocoagulation process in terms of percent COD, percent color and percent turbidity removal from domestic *wastewater. Furthermore; this study was conducted to explore and to capture the application of Sono Alternative and Direct current electrocoagulation process in terms of percent color removal efficiency by UV spectrophotometer, percent Turbidity removal efficiency by turbidometery and percent COD removal efficiency by COD digester and using chemical that may use for the determination of COD removal along with electrical energy consumption. The data obtained from the laboratory were analyzed by using Response Surface Methodology (RSM). The percentage of COD, color and turbidity removal was about 82.6%, 97.5 and 95.28% respectively with Direct – Current Electrocoagulation (DCE),For Alternating–Current Electrocoagulation (ACE), it was 86.58%, 98.3% and 96.2%, respectively and COD ,color and turbidity removal were about 88.6%, 98.7 and 98.27 %with sono-direct current (SDCE) and 92.5%, 99.9% and 99.76%, with sono alternative current(SACE), at the optimal experimental condition of COD – 960 mg/L, initial wastewater pH – 6.8, current density – 0.4 A/dm2, inter–electrode spacing – 1 cm, combination of electrode – Al/Al, and treatment time 1 hr. The ACE and SACE wer more successful in eliminating %COD, % color and %turbidity with less electrical energy consumption than DCE and SDCE process In DCE and SDCE, the formation of an impermeable oxide layer on the cathode and the occurrence of corrosion on the anode due to oxidation have decreased the efficiency of this process compared to the ACE and SDCE process. As a result, experimental findings have shown that with less electrical energy usage and process efficiency, the ACE and SACE could be a more promising solution to removing pollutants from wastewater and domestic effluent than the DCE and SDCE method.*

Keywords: *Alternative current, Direct current Electrolyte, Integrated sono electrocoagulation, University wastewater*

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ACRONOMYS

AC	Alternative Current
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CCD	Central composite Design
DC	Direct current
EC	Electrocoagulation
FAS	Ferrous ammonium sulphate
IR	Infrar radiation
JUEEL	Jimma university Environmental Engineering Laboratory
Jit	Jimma Institute of Technology
JU	Jimma University
RSM	Response Surface Methodology
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
SACE	Sono alternative Current Electrocoagulation
SDCE	Sono direct Current Electrocoagulation
SPSS	Statistical Package for Social Science

CHAPTER ONE

1 INTRODUCTION

Water, a natural resource, is essential for the existence of life. Although water is present in abundance, only a limited amount of usable water is available. Water and energy are the major challenges for the 21st century. Water also plays a central part in irrigated agriculture, for drinking, in industries, factories, construction and influences the health of many ecosystems. Wastewater is the spent water after used from a different area like homes, commercial establishments, industries, public institutions, and similar entities have used their waters for various purposes. Water quality is a crucial problem, particularly for third world countries, because of increased pollution from point and non-point sources. The domestic wastewater prevails as one of the world's leading source of pollution (Tchamango *et al.*,2020). Domestic effluent is a dark brown liquid with high levels of chemical oxygen demand (COD) and biological oxygen demand (BOD) due to the presence of large quantities of organic substances, including proteins, polyphenols, organic acids and polysaccharides. Untreated wastewater from the Domestic waste water can lead to a high degree of soil pollution and water contamination (Cerqueira, S. et al. 2014). As a result, domestic wastewater has also been seen as a barrier in traditional treatment systems. Electrocoagulation and electro flotation is the promising method based on electrochemical technology (Chaturvedi, 2013). There has been a growing interest in seeking creative ways to efficiently extract toxins from water, soil and air in recent years (Martı and Ferro, 2006). The discharge of untreated domestic effluent, however, could lead to significant water contamination in both surface and ground water and a possible increase in the concentration of these contaminants could pose a serious threat to plants and animals, the environment and humans (Eyvaz, 2016). Experiments for the treatment of domestic waste water containing various impurities was performed in this research (Nippatla and Philip, 2019).

EC is one of the electrochemical process using sacrificial soluble iron (Fe) and/or aluminum (Al) as anodes and/or cathodes, in which anodic oxidation process release metal ions (Fe^{2+} or Fe^{3+} Al^{3+}).The mechanism of electrocoagulation process is discussed below

Anode Reaction

$M \longrightarrow Mn+ \ + \ ne^-$…… …………………………………………………………....(1)

Cathode Reaction

$nH_2O + ne^- \longrightarrow n/2H_2 + {}_nOH^-$………………………………………………..(2)

The overall reaction

${}_Mn+ + nH_2O \longrightarrow M(OH)_n + nH^+$……………………………………………….(3)

In the overall reaction M (OH) $_n$ formed were used up as a coagulant in system. This may be Aluminum hydroxide or Iron hydroxide depending on the electrode we used in the technique.

$Fe(s) \longrightarrow Fe^{2+(}aq) +2e-$ ………………………………………………………….(4)

Cathode reaction

$2H_2O (l) + 2e^- \longrightarrow H_2 (g) + 2OH^-(aq)$ ………………………………………….…. (5)

Overall reaction

$Fe + 2H_2O \longrightarrow Fe (OH)_2(s) + H_2 (g)$ …………………………………………...(6)

When aluminum is used as an electrode material, the reactions are as follows

Anodic reaction

$Al (s) \longrightarrow Al^{3+} (aq) + 3e^-$ ……………………………………………………….. (7)

Cathode reaction

$3H_2O (l) + 3e- \longrightarrow 3/2H_2O (g) + 3OH^-$ ……………………………………………. (8)

Overall reaction

$Al^{3+} (aq) +3H_2O (l) \longrightarrow Al (OH)_3 (s) + 3H+ (aq)$ ………………………………. ..(9)

Electrocoagulation process described in the figure below

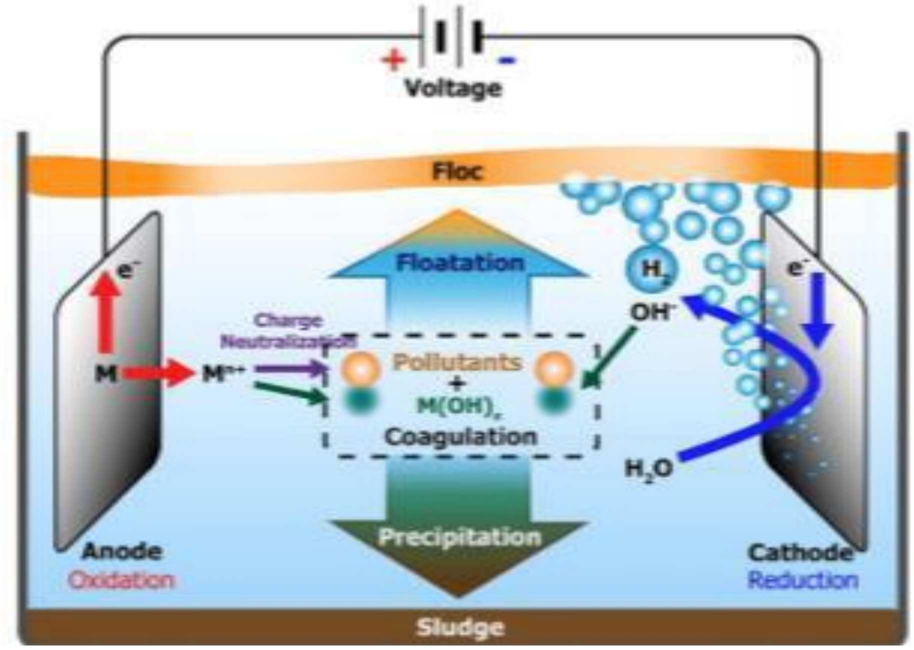


Figure 1.1 Electrocoagulation Process

EC process has its own advantages and disadvantages (Mollah *et al.*, 2004)

Compared to other traditional methods, the main advantages of the EC process are simple experimental set-up and operation, less treatment time, no addition of chemicals, faster flock sedimentation and less sludge development, high efficiency in the removal of pollutants with lower use of electrical energy (Asaitham, P. et al. 2020) . Direct current is widely used in the EC process for the treatment of various wastewaters. The major disadvantages of the Direct –Current Electrocoagulation (DCE) process, however, are the inevitable formation of an impermeable oxide layer on the cathode and the formation of corrosion on the anode due to oxidation; which prevents the active current transport between anode and cathode. In order to avoid the disadvantage of the DCE process with cathode passivation, either anode or cathode may occasionally be substituted with each other in direct current mode operation, or the Alternating Current Electrocoagulation (ACE) process may be preferred

1.1 Background

Electrocoagulation has been called associate chemistry development since the last century (Wan, 2010).It has been used antecedently for treating varied styles of waste product (Wan, 2010). Since 1970, Electrocoagulation method has become progressively well liked round the world for the treatment of commercial waste product containing significant metals (Mohora, E.et al. 2019). Electrocoagulation method offers a substantial potential for removing soluble ionic species from wastewater, significantly significant metals (Wan, 2010).

Different chemical science processes like chemical activity and reverse diffusion of biological natural action, adsorption, thermolysis and biological processes of designed wetlands and different rising technologies like advanced oxidization processes and membrane technology have presently been adopted for the treatment of domestic waste product (Alimohammadi, M.et al 2019). The chemical science methodology isn't efficient, needs chemicals being overused, and creates vital amounts of sludge. At identical time, high dilution is required by the biological treatment methodology and it's a slow and long procedure.

Ultra-sonication (US) is transmitted to the material by waves compressing its molecules and stretching them. The cavitation bubbles are generated when the negative pressure is large enough to disturb the distance between the liquid molecules (Dizge,A. *et al.*, 2018). Very high temperatures and pressures can be generated by the collapse of these bubbles and these conditions may cause the water molecules inside the cavitation bubbles to break down. The sonolytic cleavage of water molecules therefore produces reactive OH percent radicals that are non-selective oxidants in waste water for organic pollutants (Dizge,A. *et al.*, 2018)

This method improves the production of radical ultrasound, so greater reaction rate and pollutant degradation can be achieved and high pollutant removal efficiency can be achieved when combined.

1.2 Statement of the Problems

The issues caused by discharging of liquid waste product to the setting imparts high concentration of material body, COD toxic shock and cytotoxic chemicals found in it and it would like appropriate treatment before discharging to the water body. A correct treatment technology that is well tested and applied is needed to discharge this waste product to water bodies. Otherwise, it will have an effect on the setting and human life (Bhagawan *et al.*, 2018).

Sono-Electrocoagulation is becoming a promising wastewater treatment technology- appearing with substantial reduction of chemical cost and significant reduction of sludge production. Sono-electrocoagulation (SEC) have a high application potential, principally derived from the high reactivity and low property of the hydroxyl group radicals.

Direct current and Alternative current electrocoagulation treatment technology have been distinctly studied and their corresponding treatment efficiency and limitations are well identified under different settings. However, integrated Sono-direct current and sono-alternative current electrocoagulation potential is not yet well investigated. For present study integrated Sono-direct current and sono-alternative current electrocoagulation is investigated under Jimma University setting.

1.3 Objective of the research

1.3.1 General objective

- The main objective of this study is to investigate the effect of integrated sono direct current (SDC) and Sono-alternating current (SAC) electro coagulation process to treat wastewater generated from Jimma University (JU) student cafeteria.

1.3.2 Specific Objective

- To identify the characteristics of wastewater generated from Jimma University (JU) student cafeteria ;
- To determine the removal efficiency of COD, color and Turbidity ;
- To Compare DCE and ACE with SDCE and SACE electrocoagulation process for treatment of domestic wastewater that generated from Jimma University (JU)
- To identify factors affecting sono- electrocoagulation process on removal efficiency such as COD, Color, and turbidity ; and

1.4 Research Questions

During the study different questions were answered that include:

1. What are the characteristics of wastewater generated from Jimma University (JU) student cafeteria?
2. How to determine the removal efficiency of COD, color and Turbidity?
3. Which one is more efficient among DC, AC, SDC and SAC electrocoagulation process to treat domestic wastewater?
4. What are the factors that affecting sono-electrocoagulation process on removal efficiency such as COD, Color and turbidity?

1.5 Significance of the Study

This study was conducted to University, student and Jimma community benefit. It was a significant endeavor in domestic wastewater treatment that generated from Jimma University by integrated sono-direct and integrated sono-alternative current electro coagulation. Also helps to improve the efficiency of integrated sono-direct and integrated sono-alternative current electro coagulation to remove pollutants from wastewater. Domestic wastewater treatment was the great demand for the need and for more effective acceptance before disposal. More over the university were helpful to manage the waste generation and apply wastewater treatment technology. It also serve as feature reference for researchers on the subject of integrated sono-direct current and integrated sono-alternative current electro coagulation and corporate institutions. Integrated sono electrocoagulation technology is more preferable compared to other technologies since the process needs only electric current, which is an environmental friendly.

1.6 Scope of the study

The scope of this study is to determine the difference in effluent quality of the domestic waste water that generated from Jimma University (JU) student cafeteria before and after treatment through the integrated sono Alternative and Direct current (AC/DC) electro-coagulation process and also to determine the removal efficiency of Color, COD, Turbidity. To identify factors affecting son-electrocoagulation process on removal efficiency such as pH, electric density.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Introduction

The demand for drinking water quality is increasing globally and environmental laws concerning sewer water discharge are getting progressively tight. Several developing countries have issues in managing their domestic sewer water. Untreated institutional sewer water might build a retardant of environmental deterioration in rivers, lakes and different public water bodies. It's been increasing significantly over the past decade. the most sources of pollution area unit domestic wastewater (Va *et al.*, 2018).Therefore, this research was to know the quality of domestic wastewater generated.

2.2 Physicochemical characteristics of Waste water

2.2.1 Turbidity

The presence of suspended particles of different diameters, ranging from very tiny colloidal particles to large flocks, which spread and absorb electromagnetic radiation in the IR and VIS ranges, induces water turbidity. Particles in surface waters can be of both mineral and organic origin, but organic suspended matter is typically observed in effluent treatment plants (Mucha, 2016).

2.2.2 Total solids (TS)

When referring to any substance suspended or dissolved in water or waste water that can be physically separated either by filtration or by evaporation, the term solids is commonly used. It is possible to classify solids as either filterable or non-filterable. Either settleable or non-settleable solids can be filterable. Solids can be categorized as organic or inorganic as well. Complete Solids is the term applied to the residue of the substance remaining in the vessel after a sample has been evaporated and subsequently dried at a given temperature in an oven (Baxter, 2017a)

2.2.3 Total dissolved solids (TDS)

The term total dissolved solids refer to materials that are completely dissolved in water. These solids are filterable in nature. It is defined as residue upon evaporation of filterable sample. The term total suspended solids can be referred to materials which are not dissolved in water and are non-filterable in nature. TDS values ranged within 385.3 to 531.4mg/L (Baxter, 2017b).

2.2.4 Electrical Conductivity (EC)

EC samples of the raw and processed waste water for domestic wastewater selected were carried out with the help of a salinometer. It is known as residue upon non-filterable sample evaporation on a filter paper. The electrical conductivity depends on temperature. With increasing temperature of liquids, the motion of ions increase which leads to increase in conductivity (Prieto *et al.*, 2001)

2.2.5 Chemical oxygen demand (COD)

In order to indirectly confirm organic compounds in water, the chemical gas demand is wide used. Chemical gas demand (COD) could be a live of the capability of water to consume gas throughout the decomposition of organic matter gift in an exceedingly effluent sample. COD measurements square measure ordinarily created on samples of wastewaters or of natural waters contaminated by domestic or industrial wastes. It’s expressed in milligrams per litre (mg/L), indicating the gas mass absorbed per litre of resolution. COD is that the calculation of the number of gas absorbed in water for waste material chemical reaction. underneath explicit conditions, COD specifies the number of gas required to oxidize the organic matter in an exceedingly sample of water or waste water (Khan and Shahid, 2011).

2.2.6 Color determination

Removal of the color from waste water has been studied because of its toxic effect to living organisms as well as to the environmental pollution. Absorbance measurements were performed to determine color removal efficiency. Color was assayed at 420 nm on a UV spectrophotometer and calibrated against deionized water (Dizge, A., *et al.*, 2018).

2.2.7 Major contents (impurities) of domestic wastewater

Since the domestic wastewater is one of the main water users and produces a significant volume of waste water containing high concentrations of organic matter, nutrients, suspended matter and highly acidic wastewater, domestic wastewater produce very high pollution load wastewater.

pH, temperature, turbidity and electrical conductivity, BOD5, COD, TDS and TSS are essential components in domestic waste water (Tekle *et al.*, 2015)

2.3 Waste water treatment methods

Treatment systems may be based on traditional technologies, including physical, biological and chemical approaches, depending on the form and quality of agro-industrial waste. In addition to classical methods, advanced technologies such as membrane separation processes, reverse osmosis, ultrafiltration, Sono electro coagulation and advanced oxidation processes, which are increasingly being introduced, can also be used to pick a treatment method based on the self-purification ability of streams, acceptable levels of pollutants in water bodies and the economic interests of industries (Amor *et al.*, 2019). The traditional methods of water treatment allowing small organic molecules to be extracted are adsorption, biological treatment, nan filtration, AOPs, such as photo catalysis and photo degradation of the EO, US, Fenton process, zonation, persulphate oxidation, radiolysis (Electrodes, 2016). The dumping of waste water into the rivers has a detrimental effect on the quality of water supplies and endangers human and animal life (Aghdam, K et al 2015). Therefore, it has become important to establish more efficient water purification treatment methods and/or improve the operation of current methods. Sono Electrocoagulation is very crucial to optimize the removal efficiency of pollutants.

2.4 Electro coagulation (EC) process of wastewater treatment.

Electrocoagulation (EC) is one of the important technologies that combine the advantages of conventional coagulation, flotation, and adsorption in water and wastewater treatment. Electrocoagulation is an inexpensive method for the treatment of different industrial effluents and the removal of a broad variety of waste water contaminants (Asaithambi *et al.*, 2016). One of the most interesting electrochemical technologies for the treatment of different wastewaters is electrocoagulation (EC) technique (Yahiaoui, 2018). Process depends on dissolution of the anode electrode. Oxidation reactions take place on anode while reduction reactions occur on cathode (Dizge, A *et al.*, 2018). The process of electrocoagulation (EC) has received a great deal of attention for the treatment of different forms of wastewater, such as domestic waste and paper, distillery, organic fertilizer, petrochemical, pharmaceutical, automotive industry, potentially toxic metals, tannery metal plating wastewater, rice mill effluent, model Wastewater humic acid removal real industrial wastewater landfill leachate by using sono alternative and Direct current electrocoagulation process

2.4.1 Alternative and Direct current (AC/DC) electro coagulation Process of waste water treatment methods

The key innovation of this study is to increase the synergistic effect of the combined alternative current (AC) and direct current (DC)electrocoagulation process for further color reduction, turbidity and COD removal (Dizge, A. *et al.* 2018). Combined ultrasound and electrocoagulation (Farooq *et al.*, 2002) of direct and alternative current electrocoagulation to remove COD, Color and Turbidity. AC/DC Electrocoagulation method has been examined for other effluents and demonstrated successful results (Aghdam, K. *et al* 2015) and (Afsharnia *et al.*, 2018).A few research studies on the treatment of pulp and paper waste water using electrocoagulation have been published (Aghdam, K. *et al* 2015). In view of these fascinating aspects, the use of ultrasound is a technologically advanced application of oxidation in effluent treatment to speed up the degradation of liquid-phase pollutants (Picchio *et al.*, 2020). The effect of AC/DC electrolysis parameters and other generic parameters as stated earlier with the hybrid weather combination of Fe-Al, Al-Al or Fe-Fe electrodes where be conducted during experiments to track optimum operating conditions (Xu *et al.*, 2017). Usually, in EC processes, direct current (DC) is used, which inherently contributes to increased anode consumption due to oxidation. In this work, it was shown that the use of an alternating current (AC) field minimizes the consumption of electrodes (Weisbart *et al.*, 2020). The use of an alternating current (AC) field has been shown to reduce electrode consumption in this research (Butler *et al.*, 2011). Surface Methodology (RSM) was used to optimize the impact of experimental color removal (CR) conditions, removal of COD and turbidity removal (Access, 2014). In practice, in an electrocoagulation process, direct current (DC) is used. The adoption of alternating current (AC) in electrocoagulation processes has decreased these drawbacks of DC (Vasudevan, 2011). In an electrocoagulation process, the use of alternating current provides an alternative to traditional electrocoagulation methods where direct current is used (Vasudevan, 2011). Investigating the layout of electrodes and evaluating the effects of alternating current (AC) and direct current (DC) on the phase of electrocoagulation (EC) carried out in a batch reactor (Taylor *et al.*, 2017).

The cyclic energization between the anode-cathode in the alternating current (AC) system is believed to simulate manual polarity reversal (Cerqueira, S. *et al*,2014). The alternative and direct current treatment for domestic waste water in these analysis new forms of pair electrodes (simultaneously applying Aluminum and aluminum electrodes) were examined. For the improved oxidation of organic compounds, a combination of the Alternative Current (AC) and Direct Current (DC) electro coagulation method was developed (Babuponnusami and Muthukumar, 2012). An impermeable oxide layer may form on the cathode when direct current (DC) is used in electrocoagulation processes and corrosion of the anode may occur due to oxidation. This prevents efficient current transfer between the anode and the cathode, thereby reducing the efficiency of the electrocoagulation process. By adopting alternating current, these drawbacks of DC were minimized by (AC) (Vasudevan *et al.*, 2011). Recent research has shown that electrochemistry provides an enticing alternative to the conventional waste-water treatment methods mentioned above. Electrocoagulation, based on the electrochemical processing of destabilizing agents that eliminate pollutants by charge neutralization, has been used as one of these techniques for water or waste water treatment (Vasudevan *et al.*, 2011). In this research, the treatment of real domestic waste water was investigated using electrode plating in the AC and DC electrocoagulation processes. To achieve the optimum removal of COD, turbidity and color, electrolysis time, pH and voltage were chosen as variable parameters (Aghdam, K et. al, 2015).

2.5 Ultrasound technology (US) to wastewater treatment

Ultrasound technology is non-selective and is also appropriate for the application of industrial waste water treatment (Electrodes, 2016). It does not require chemicals to be applied to the treatment process and can easily be automated. Ultra-sonication alone, however, is often unable to achieve full organic pollutant mineralization and has low degradation rates. Ultrasound is combined with other treatment methods in order to provide synergetic effects and better degradation efficiency of organic pollutants.

2.6 Sono-electrocoagulation (SEC) of wastewater

The combinations of treatment processes are one of the hot topics in environmental engineering. Especially, the highly-polluted wastewater can be treated effectively using combined processes.

Sono-electrocoagulation process was successfully applied for the removal of COD, Color, and turbidity (Shah,T. *et al.*, 2018). The institutional waste water was processed by a Sono-electrocoagulation reactor to test the efficiency of the Sono-electrocoagulation process (Afsharnia *et al.*, 2018). Ultrasound (US) and electrochemical (EC) techniques consist of the sono-electrochemical (SEC) phase. This method improves the output of ultrasound radicals, so higher reaction rates and pollutant degradation can be achieved (Dizge,A., *et al.*, 2018). By employing the ultrasonic waves with the EC process, the OH radicals are generated in wastewater which favor the subsequent oxidation of pollutants (Shah, T. *et al*, 2018). In sonication process, the energy of sound is applied to stimulate particles in samples for different aims. Ultrasound generates localized microenvironments with high-energy in a medium, based on the frequency (Afsharnia *et al.*, 2018).Sono electrocoagulation is a reliable, quick and cost-effective method of treating institutional wastewater (Qian *et al.*, 2018). Theoretical aspects of power ultrasound in this study include the effects on mass transport and electrode surface cleaning, experimental considerations on the application of ultrasound to electrocoagulation experiments and the use of power ultrasound in electrochemical pollutant degradation, including direct and alternative current electrocoagulation. All organic water contaminants can be broken down into two categories of scale. The first group involves polymers with a particle size of around 10 - 100 nm. Heterogeneous blending of polymers with water (colloidal solutions). Removal of organic water contaminants of high molecular weight normally accomplished by their coagulation, flocculation, flotation, electro flotation electrocoagulation as well as micro and ultrafiltration(Electrodes, 2016). Tiny organic molecules with a mean size of 1 to 10 nm, forming a homogeneous mixture of water or molecular solution, constitute the second group. In addition, clear treated waste water will be created with full color removal, turbidity removal and COD removal, suggesting the application of sono-electrocoagulation for institutional wastewater treatment.

2.7 Integration of Sono-Direct current and Sono-Alternative current Electrocoagulation Process for domestic wastewater treatment

Integration of Sono-Alternative and Direct current Electrocoagulation Process is to optimize the removal efficiency of dependent parameters by combining electro coagulation and Ultrasound using AC/DC method. The impacts of SAC/SDC, current density, pulse duration, electrode distance and electrolysis period on the removal efficiencies of COD, turbidity and color was studied by using Al-Al electrode and simulated wastewater. Integrated processes have been intensively studied in recent years to improve the performance of wastewater treatment (Dizge, A *et al.*, 2018). The effects of various parameters, including electrolysis time, voltage and pH, on reducing the demand for chemical oxygen (COD), turbidity and color in institutional waste water was investigated in this study and as anode and cathode, aluminum was used. In particular, the amount of published literature on alternative and direct current applications for electrocoagulation appears to have risen significantly over the last few years. Electrocoagulation is the mechanism by which suspended, emulsified or dissolved pollutants are destabilized in an aqueous medium by adding electric current into the medium (Aghdam, K et al, 2015).

An electrocoagulation reactor may, in its simplest form, consist of an electrolytic cell with one anode and one cathode. Conductive metal plates are generally referred to as 'sacrificial electrodes' and can be constructed of the same or varying materials (anode and cathode). The effects of various voltages on COD, turbidity and color removal w studied(Aghdam, K et al, 2015). The impacts of alternating current and direct current electrocoagulation time, initial pH, initial COD removal performance, color and turbidity and current density and other factors on the removal rate was investigated in this experiment (Xu *et al.*, 2019). The electrode surface was polished with sandpaper before each experiment and then rinsed with dilute HCl solution (0.1 M).The effect of alternating current (AC) and direct current (DC) with sonication on COD, turbidity and color removal was investigated.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Study Setting/Area

Jimma is the biggest town in the southwestern Ethiopia. It is located at 345 kilometers away from Addis Ababa with a geographic location of 6^{0}40’0”to 7^{0} 40’0” N latitude and 36^{0} 60’0” E to 37^{0}30’0” longitudes. The town occupies a total area of nearly 4623 hectares, of which about 26% is a residential area. Jimma has a warm and humid climate with daily average temperature of 20 ^{0}C and mean annual rainfall varying between 1450 and 1800 millimeter (Abebaw and Ayenew, 2006).

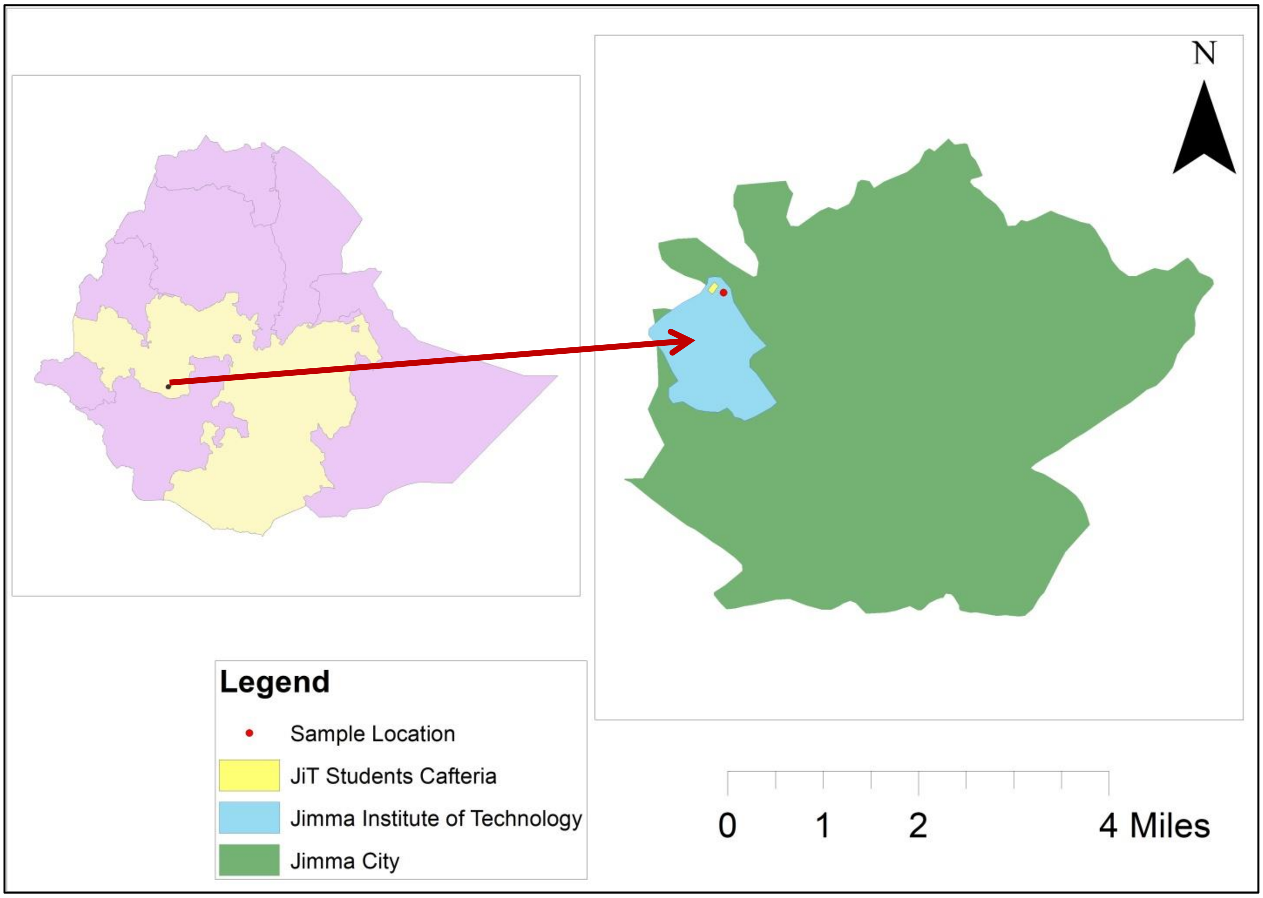


Figure 3.1.Location of Jimma University Institute of Technology by GIS

3.2 Study Period

To perform the study in deep and reliable way, the study period is for six months from January 1st2021 to June 30th2021.

3.3 Study Design

The study was performed through experiment in Laboratory by using sono-direct and sono-alternative current electrocoagulation of sacrificial parallel electrode and analyzed using RSM (Design Expert 11) is used for optimization by Central Composite Design and Excel software. The schematic setup of Electrocoagulation process is simple and easy to understand.

3.4 Experimental procedure

All tests were performed in laboratory at normal temperature. Tests were performed in batch reactor such that one liter of waste water sample was taken in glass beaker for one electrode combination. Aluminum Aluminum electrodes are used up for this EC process with a weight of 30.70g as well as dimensions of 13cm x 6cm x 1cm length, width and thickness respectively. Copper wires were connected to DC/AC power source and at one end the wires are connected to electrodes by electrical clips. Then the power was supplied and the result was conducted at different affecting parameters.

3.5 Materials

Batch Reactor (DC/AC electrocoagulation cell),DC/AC power supply, Ultrasonic (US) ,Parallel Electrode (Iron and Aluminum),Magnetic Stirrer**,** Copper Wires, Magnetic Bar Stirrer**,** Electrical Clips**,** Local available chip woods (Holding electrodes),turbidometry ,kits, Spectrophotometry, wash bottle

3.6 Experimental set-up

Fig. 3.2 illustrates the DCE and ACE process arrangement used for the treatment of domestic wastewater effluent and Fig 3.3 illustrates the SDCE and SACE process arrangement used for the treatment of domestic wastewater effluent.

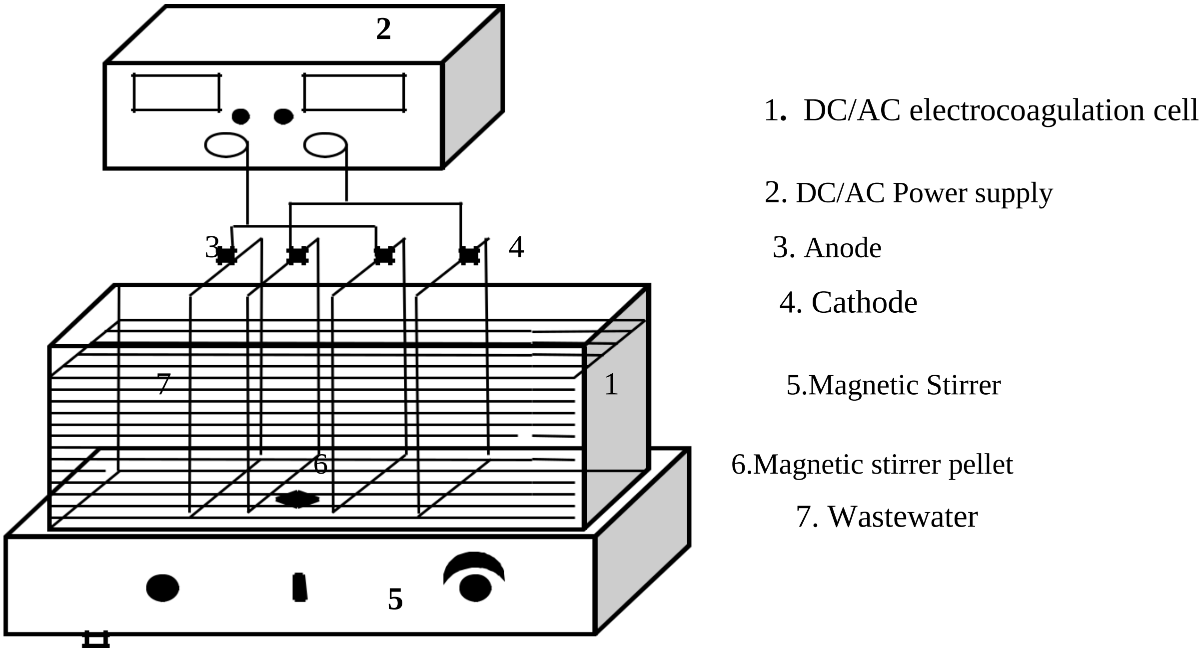


Figure 3.2 Schematic diagram of Electrocoagulation process (Asaithambi, P. et al.(2020).

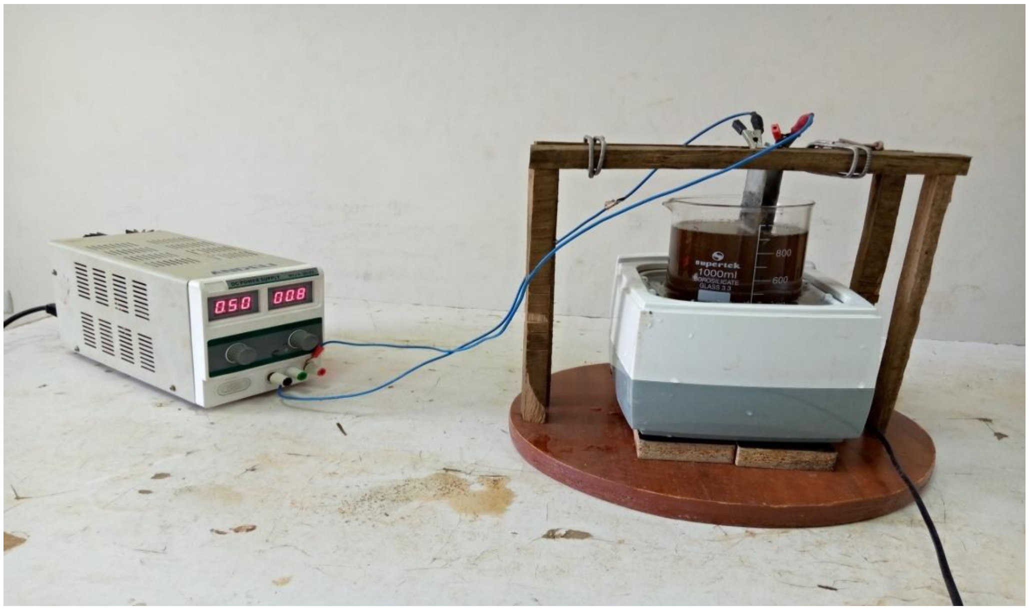


Figure 3.3. Real setup of Sono-Electrocoagulation process

3.7 Sample Size and Sampling Procedures

3.7.1 Sample Size

The size of the sample is based on the requirement of the level of precision needed for the analysis in laboratory. The rotatable experimental plan was performed with the three independent variables at three coded levels (-1, 0, +1). Actual values are original values that given to different factors and code values are also given for the levels of factors (Sharma and Simsek, 2020). For the more accurate and precise result, appropriate data sampling obtained. In this research, the CCD model with three factors was applied to optimize the parameters. The experimental design was based on two-level full factorial design to which central and star points were also added. The total number of experiments (N) can be calculated by:

$$N = N_a^n + N_o + N_c = (2^3+6+6) = (8+6+6=20) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

where, N number of runs, “n” is number of factors, N_a represents the number of two-level experiments in a full factorial design or replicates of factorial points (2^3=8), N_0 is the number of replications in the central point (6 replications) for evaluation of net error, and N_c denotes the number of replicates of axial (star) points (2*3=6) by using alpha = 2 fourteen (8+6 = 14) factorial points and 6 replicates of central point in the total 20 experimental runs were provided by software for single process. That means (20 by using DC and 20 by using AC) and also by integrating with ultrasonic (20 by using SDC and 20 by using SAC) totally (20*4=80) running was done. Six center point of the design to evaluate the pure error and consequently the lack of fit. Lack of fit test was performed to assess the fit of the final model. The experimental results were analyzed using RSM algorithm and were fitted to the predictive quadratic polynomial Equation. Second-order model equation for prediction of the optimal conditions can be expressed by the following equation:

$$Y_i = \beta_0 + \sum_{i=1}^{4} \beta_i \,.\, X_i + \sum_{i\leq j}^{4} \sum_{j}^{4} \beta_{ij} . X_i . X_j + \sum_{i=1}^{4} \beta_{ii} \,.\, X_i^2 + e \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

where Y_i, is the response variable, β_0 is the model (regression) constant, β_i is the linear terms, β_{ii} are the squared terms (second-order), βij is the interaction terms, X_i and X_j are independent

Exactly the sample required for the experiment was eighty liters of waste water since the preferred method combination of four methods, for each combination twenty liters of waste water was selected based on RSM (Design Expert 11) combination.

3.7.2 Sampling Procedure

The sampling procedure was performed in the correct way by considering different factors that may affect the sample. Wastewater was taken from different places in order to obtain the accurate result. The maximum holding time is kept in and performed based on the WHO/UNEP 2004 standard protocol and laboratory manuals.

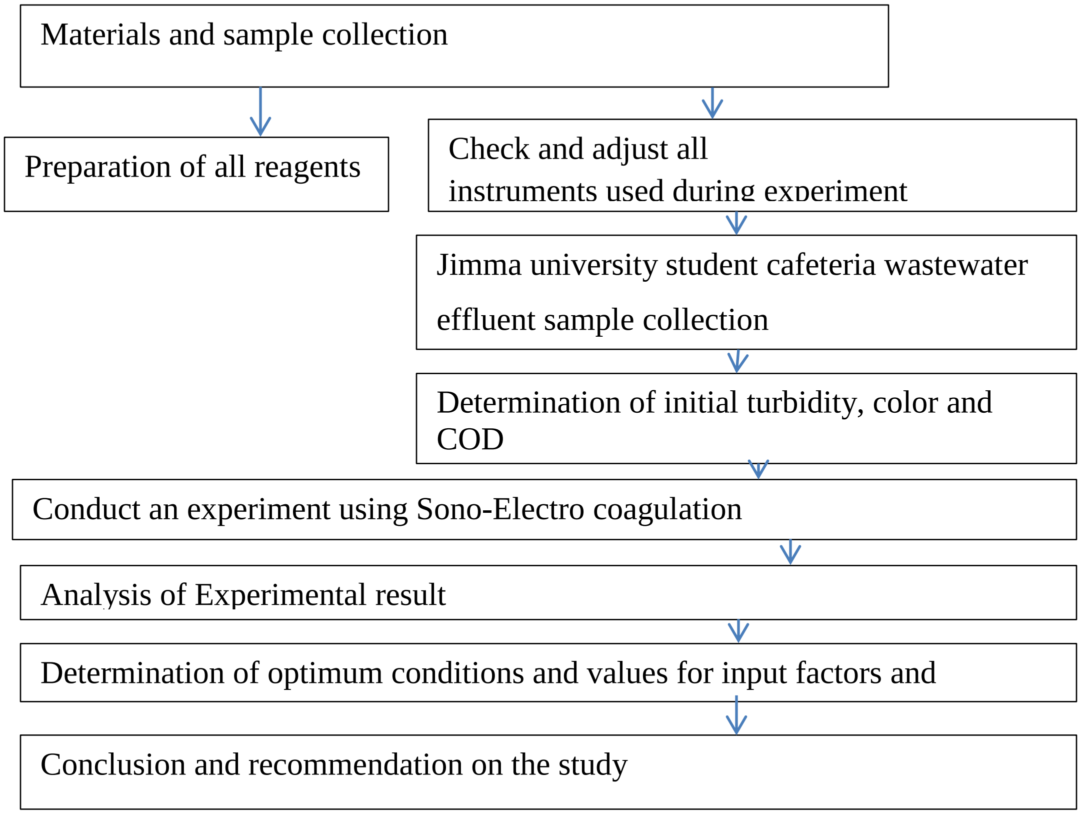


Figure 3.4 Flow chart of Sampling Procedure

3.7.3 Dependent Variable

COD, turbidity and color are dependent variables used for the evaluation of the efficiency or the Performance of the wastewater treatment technology.

3.7.4 Independent Variables

Independent variables are operating parameters like: time, pH and electric density are controlling variables

3.8 Sample Collection Process

The study sample collection process begins with the looking for available literatures related to Sono-Direct current and Sono-Alternative current electrocoagulation process especially for Jimma University (JU) student cafeteria wastewater treatment. Then the materials needed for this process was prepared as much as possible with minimum cost. In this study grap/hand sampling technique were used to take samples from Jimma University student cafeteria processing effluent sample point by direct filling of the container. Clean Plastic containers (polyethylene terephthalate (PET) were used for sample collection after cleaned with detergent, rinsed with tap water, soaked in 10% of concentrate nitric acid and rinsed with deionized water. Finally the collected sample was transported in to JUEE laboratory and preserved in a refrigerator at 4°C in order to minimize the chance of their characteristics changes until analysis were done. .

3.9 Reagent Preparation

Based on the independent variables reagent preparation is mandatory before experimental investigation, data processing and analysis. Especially this preparation of reagent is for the determination of COD that can be determined by titration

1. Reagent for COD
   a) Principles

The organic matter present in sample gets oxidized completely by potassium dichromate ($K_2Cr_2O_7$) in the presence of Sulphuric Acid (H_2SO_4), Silver Sulphate ($AgSO_4$) and Mercury Sulphate ($HgSO_4$) to produce CO_2 and H_2O. The sample is refluxed with a known amount of Potassium Dichromate ($K_2Cr_2O_7$) in the Sulphuric Acid medium and the excess Potassium Dichromate ($K_2Cr_2O_7$) is determined by titration against Ferrous Ammonium Sulphate, using Ferroin as an indicator.

3.9.1 Materials and Chemicals Required for COD

I. **Apparatus Required:** COD Digester, Burette & Burette stand, Kits(Tubes), 250 mL conical flask (Erlenmeyer Flask), Pipettes, Wash Bottle

II. **Chemicals Required for COD:** Potassium Dichromate, Sulfuric Acid, Ferrous Ammonium Sulphate, Silver Sulphate, Mercury Sulphate, Ferroin indicator and Organic free distilled water

III. **Procedure**

a. **Preparation of Standard Potassium Dichromate Reagent - Digestion Solution**

First accurately 4.913 g of Potassium Dichromate is measured and dried at 103 ^{O}C for 2 - 4 hours and transferred to a beaker (‘Method 410 . 3 : Chemical Oxygen Demand (Titrimetric , High Level for Saline Waters) by Titration TITLE ’:, 1978). Then exactly 33.3g of Mercuric Sulphate was weighted and added to the same beaker. After that 167 mL of concentrated Sulphuric Acid was measured using clean dry measuring cylinder and transferred to the beaker. The contents are dissolved and cooled to room temperature. 1000 mL standard measuring flask was taken and a funnel was placed over it. Carefully the contents were transferred to the 1000 mL standard flask and made up to 1000 mL using distilled water. Hence, this was the standard Potassium Dichromate solution used for digestion

b. **Sulphuric Acid Reagent - Catalyst Solution**

For the preparation of Sulphuric Acid reagent, 5.5 g of Silver Sulphate crystals were accurately weighted to a dry clean 1000 mL beaker. To this carefully about 500 mL of concentrated Sulphuric Acid was added and allowed to stand for 24 hours (so that the Silver Sulphate crystals dissolved completely) .

c. **Standard Ferrous Ammonium Sulphate solution** …($Fe(NH_4)_2(SO_4)_2.6H_2O$

Accurately 39.2g of Ferrous Ammonium Sulphate crystals were Weighted and dissolved in distilled water. Then 1000 mL standard measuring flask was taken and a funnel was placed over it. Carefully the contents were transferred to the 1000 mL standard flask and made up to 1000 mL marked using distilled water.

IV. Testing of sample

- 2.5 ml of sample and 2.5 ml of distilled water was taken into different kit (tube)
- 1.5.ml of Potassium Dichromate was added to both tubes
- 3.5 ml of Sulphuric Acid was carefully added to both tubes
- Tightly both tubes are closed and kept in open COD digester for two hours at 150 ^{o}C.
- After two hours tubes were cooled to room temperature and the contents are transferred to conical flask.
- Then the burette was filled with FAS solution.
- Then 2-3 drops of Ferroin indicator was added to sample in conical flask
- The contents were titrated for both blank and sample until the color was changed to grey to reddish brown and COD was calculated based on the value titrated.

3.10 Data Processing and Analysis

Data processing and analysis was done through laboratory based on the sample obtained from selected place and optimized using RSM (Design Expert11). Waste water parameters like color, COD and turbidity was determined in laboratory analysis from the sample taken by integrated sono AC/DC electrocoagulation process. Finally, data was processed and analyzed through calculation and RSM (Design Expert11) software was used for optimization to check the feasibility of integrated sono AC/DC electrocoagulation process.

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Characteristic of wastewater

The effluent was obtained from the institutional wastewater located in Oromia, Jimma University. The water quality parameters such as color – dark brown, odor – burnt sugar, COD – 960 mg/L, wastewater pH – 6.8 were analyzed for the institutional effluent.

Table 4.1 Characteristic of domestic wastewater before treatment

No	Parameters	Quantity	Unit
1	pH	6.8	-
2	color	3	-
3	turbidity	116	NTU
4	COD	960	mg/L

4.2 Removal Efficiency of COD, Color and Turbidity

The removal efficiency (%) was measured based on COD, color and turbidity of domestic effluent before and after the integrated SDCE and SACE process.

The Eqs. (14),(15) and (16) were used to determine the percentage of COD, percentage of color and percentage of turbidity removal efficiency.

$$COD = \frac{Vblank - Vsample}{Vsampletaken} * N * 8 * 1000 \quad \ldots\ldots(12)$$

Where, V_{blank} – Volume of FAS used for Blank

V_{sample} – Volume of FAS used for sample solution

N – Normality of FAS

$$NormalityofFAS = \frac{WeightofFASusedinFASsolutionpreparation}{EquivalentweightofFAS} = \frac{39.2}{392} = 0.1N \quad \ldots\ldots(13)$$

COD reoval $(\%) = \frac{Ci-Ct}{Ci} * 100$ ……………………………………………………….(14)

Where: Ci =COD before treatment

Ct =COD after treatment

Color reoval $(\%) = \frac{Ai-At}{Ai} * 100$……………………………………………..………..(15)

Where:

Ai – Initial absorbance

At –Absorbance after treatment.

Turbidity removal (%) = $\frac{Ti-Tf}{Ti} * 100$ ……………………………………………..(16)

Where: Ti – Initial turbidity and

T_f-turbidity after treatment (in NTU)

4.3 Comparison of DCE and ACE with SDCE and SACE process

Experiments were conducted to compare the DCE, ACE SDCE and SACE process using the domestic waste water and analyzed for the removal of percentage color percentage turbidity and percentage COD .The operating conditions like: COD – 960 mg/L, wastewater pH – 6.8, current density – 0.50 A, inter-electrode spacing – 1 cm, combination of electrode – Al/Al, and reaction time – 1 h were used and the results are schematically shown in Fig. 4.1. It is evident from Fig. 4.1 that percentage color, percentage turbidity and percentage COD removing institutional wastewater was higher in the ACE than in DCE process and higher in the integrated SACE than integrated SDCE. In the case of ACE and SACE, the production of sludge and formation of the impermeable layer was lower than that of the DCE and SDCE process. Thus, when comparing the DCE with ACE and integrated SDCE with integrated SACE process for removal of percentage color percentage turbidity and percentage COD from domestic wastewater, the ACE method was more suitable than using the DCE process and integrated SACE method was more suitable than using integrated SDCE process. Results are obtained from sample taken and performed in laboratory based on different parameters. Totally eighty running and for each twenty running was conducted.

Eighty experiments was done in the laboratory and from eighty liters of wastewater sample twenty experiments were performed for Direct current , twenty were performed for Alternative current, twenty for sono direct current and twenty for sono-alternative current. In those all experiments absorbance of Color, COD and Turbidity were determined by considering different parameters like; pH, Current Density and Reaction time. All Laboratory results are tabulated under appendices in annex one that consists of factors affecting parameters and absorbance of color at 420 nm wavelength, COD titrated at each treatment interval and turbidity.

4.3.1 Al-Al electrode combination

In this experiment two Aluminum electrodes were combined parallel by considering different factors (Science, 2018, Kuokkanen *et al.*, 2013, Apaydin and Kurt, 2009) for the removal efficiencies of Color, COD and Turbidity respectively.

4.4 Effect of Sono-Direct Current and Sono-Alternating current electrocoagulation (SAC/SDC)

Usually direct current (DC) is used in an electrocoagulation processes. In this case, an impermeable oxide layer may form on the cathode as well as corrosion formation on the anode due to oxidation. These prevent the effective current transport between the anode and cathode, so the efficiency of electrocoagulation processes declines (Vasudevan and Lakshmi, 2012). These disadvantages of DC have been overcome by adopting alternating current (AC) in electrocoagulation processes ,Vasudevan and Lakshmi, 2012).

Table 4.2 Input Data and removal percentage by DC electro coagulation

Run	Factor1	Factor 2	Factor 3	Response 1	Response 2	Response 3
	A:pH	B:Current (A)	C:Time (minute)	COD removal efficiency (%)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	75.33	92.56	91.23
2	5	0.4	40	78.5.	94.93	92.72
3	9	0.5	50	70.21	91.03	89.59
4	3	0.5	50	82.66	97.53	95.28
5	9	0.4	40	69.33	88.93	88.84
6	5	0.4	40	78.60	95.25	92.56
7	7	0.4	40	75.15	91.34	90.12
8	9	0.5	30	68.92	86.32	88.73
9	3	0.5	30	80.23	96.83	95.32

10	5	0.4	40	79.87	95.15	92.50
11	3	0.3	30	76.23	94.66	94.23
12	7	0.4	20	71.28	85.43	89.73
13	5	0.2	40	73.82	91.69	90.57
14	7	0.4	40	74.80	91.36	90.23
15	9	0.3	30	69.25	83.45	87.53
16	7	0.4	40	75.18	91.55	90.53
17	3	0.3	50	79.21	95.26	94.56
18	9	0.4	40	69.33	88.16	88.96
19	5	0.5	50	79.32	95.78	92.81
20	3	0.3	40	78.63	94.83	94.29

In table 4.2, factors like pH, electric current, and reaction time were considered with different ranges. Similarly, the removal efficiency for Color, Turbidity and COD were determined. Hence, using Al-Al electrode consumption by DC electro coagulation the removal efficiency up to 97.5% of Color, 95.281% of turbidity and 82.6667% of COD respectively.

Table 4.3 Input Data and removal percentage by AC electro coagulation

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
	A:pH	B:Current (A)	C:Time (minute)	COD removal efficiency (%)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	79.62	93.96	92.51
2	5	0.4	40	84.69	95.93	93.72
3	9	0.5	50	78.43	92.54	90.15
4	3	0.5	50	86.58	98.35	96.12
5	9	0.4	40	75.36	89.65	89.84
6	5	0.3	30	82.36	94.65	93.56
7	7	0.4	40	79.31	92.55	91.13
8	9	0.5	30	75.69	90.58	89.75
9	3	0.5	30	83.52	96.25	96.17
10	5	0.4	40	82.69	95.94	93.50
11	3	0.3	30	81.65	95.68	95.25
12	7	0.4	20	75.36	89.35	91.28
13	5	0.2	40	79.23	92.58	89.19
14	7	0.4	40	79.32	92.68	91.82
15	9	0.3	30	75.25	87.54	89.32
16	7	0.4	40	79.29	92.38	91.54
17	3	0.3	50	82.36	96.23	94.95
18	9	0.4	40	75.36	90.56	89.90
19	5	0.5	50	85.56	96.95	93.81
20	3	0.3	40	83.25	95.68	94.18

In the table 4.3, factors like pH, electric current and reaction time were considered with different ranges just like that of table 4.2. Similarly the removal efficiency for Color, Turbidity and COD were determined by considering all those factors. Hence, using AC electrocoagulation the removal efficiency up to 98.352% of Color, 96.125% of Turbidity, 86.58% of COD.

Table 4.4 Input Data and removal percentage by SDC electro coagulation

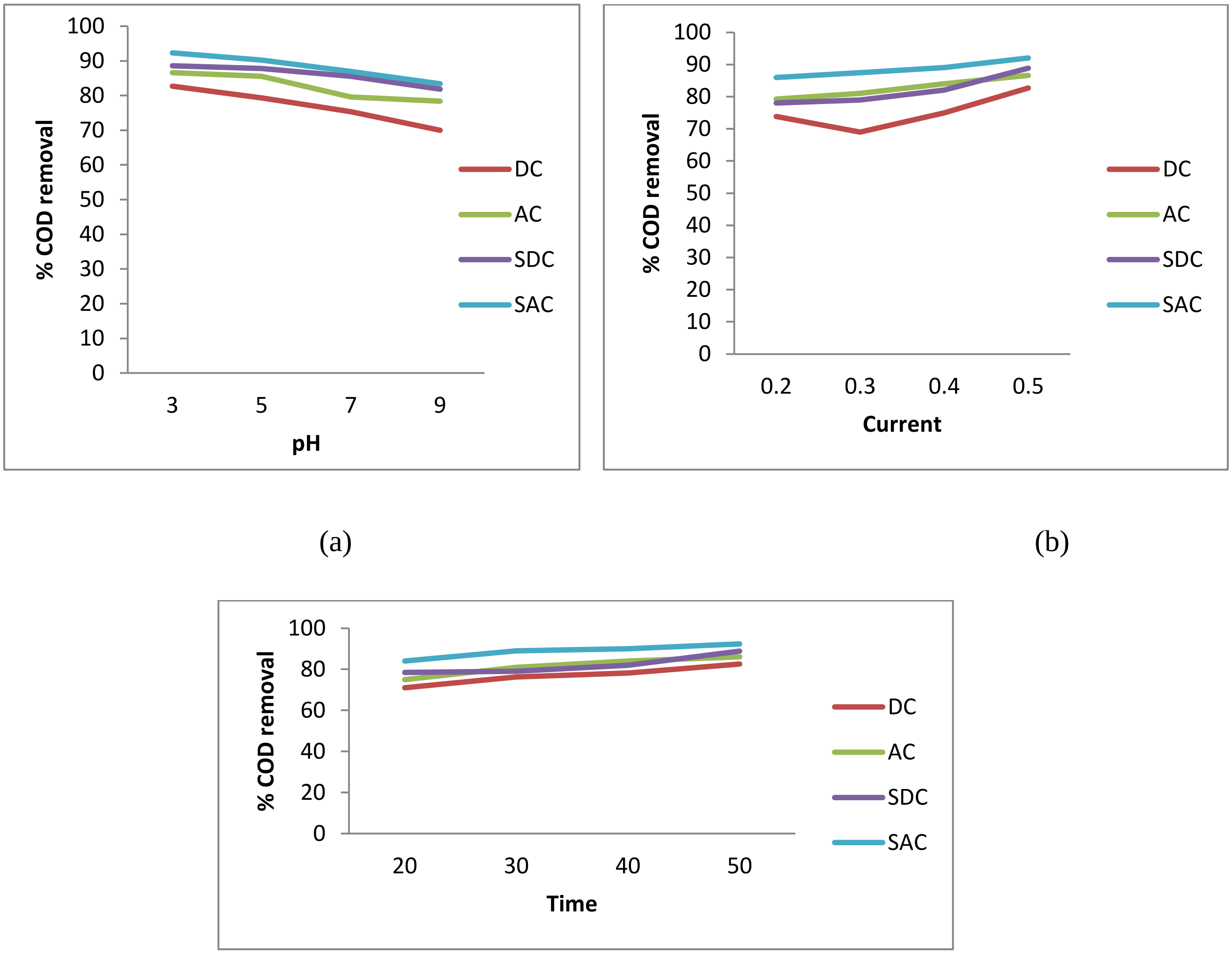
Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
	A:pH	B:Current (A)	C:Time (minute)	COD removal efficiency (%)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	85.54	94.83	93.6
2	5	0.4	40	86.69	97.19	95.23
3	9	0.5	50	81.87	92.59	91.59
4	*3*	*0.5*	*50*	*88.58*	*98.55*	*98.27*
5	9	0.4	40	78.38	93.25	90.59
6	5	0.4	40	86.72	96.94	92.55
7	7	0.4	40	82.38	94.96	92.17
8	9	0.5	30	79.26	91.57	90.53
9	3	0.5	30	86.52	97.39	96.83
10	5	0.4	40	86.84	96.82	92.62
11	3	0.3	30	84.25	95.85	95.63
12	7	0.4	20	78.56	92.45	91.73
13	5	0.2	40	78.54	91.45	91.93
14	7	0.4	40	82.48	94.93	92.18
15	9	0.3	30	79.26	90.78	89.87
16	7	0.4	40	82.57	94.88	92.16
17	3	0.3	50	84.36	97.46	95.29
18	9	0.4	40	80.98	92.87	91.22
19	5	0.5	50	87.21	96.89	94.56
20	3	0.3	40	83.25	96.91	95.26

In the table 4.4, factors like pH, electric current and reaction time were considered with different ranges just like that of table 4.3. Similarly the removal efficiency for Color, Turbidity and COD were determined by considering all those factors. Hence, using SDC electrocoagulation the removal efficiency up to *98.55*% of Color, *98.27*% of Turbidity, *88.581* % of COD

Table 4.5 Input Data and removal percentage by SAC electro coagulation

Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2	Response 3
	A:pH	B:Current (A)	C:Time (minute)	COD removal efficiency (%)	Color removal efficiency (%)	Turbidity removal efficiency (%)
1	7	0.4	60	86.98	94.40	94.26
2	5	0.4	40	89.51	97.17	96.55
3	9	0.5	50	83.43	93.35	91.83
4	3	0.5	50	92.35	99.95	99.76
5	9	0.4	40	82.91	92.25	91.02
6	5	0.4	40	89.42	97.17	96.53
7	7	0.4	40	86.93	93.22	93.76
8	9	0.5	30	82.24	92.09	91.35
9	3	0.5	30	91.52	97.91	97.94
10	5	0.4	40	89.52	97.16	96.46
11	3	0.3	30	89.78	96.59	95.83
12	7	0.4	20	84.52	92.90	91.94
13	5	0.2	40	86.82	96.33	94.45
14	7	0.4	40	86.72	94.57	93.65
15	9	0.3	30	81.25	90.81	90.14
16	7	0.4	40	86.52	93.83	93.75
17	3	0.3	50	89.87	97.88	97.52
18	9	0.4	40	82.98	91.92	91.81
19	5	0.5	50	90.22	98.65	96.73
20	3	0.3	40	90.15	97.76	96.31

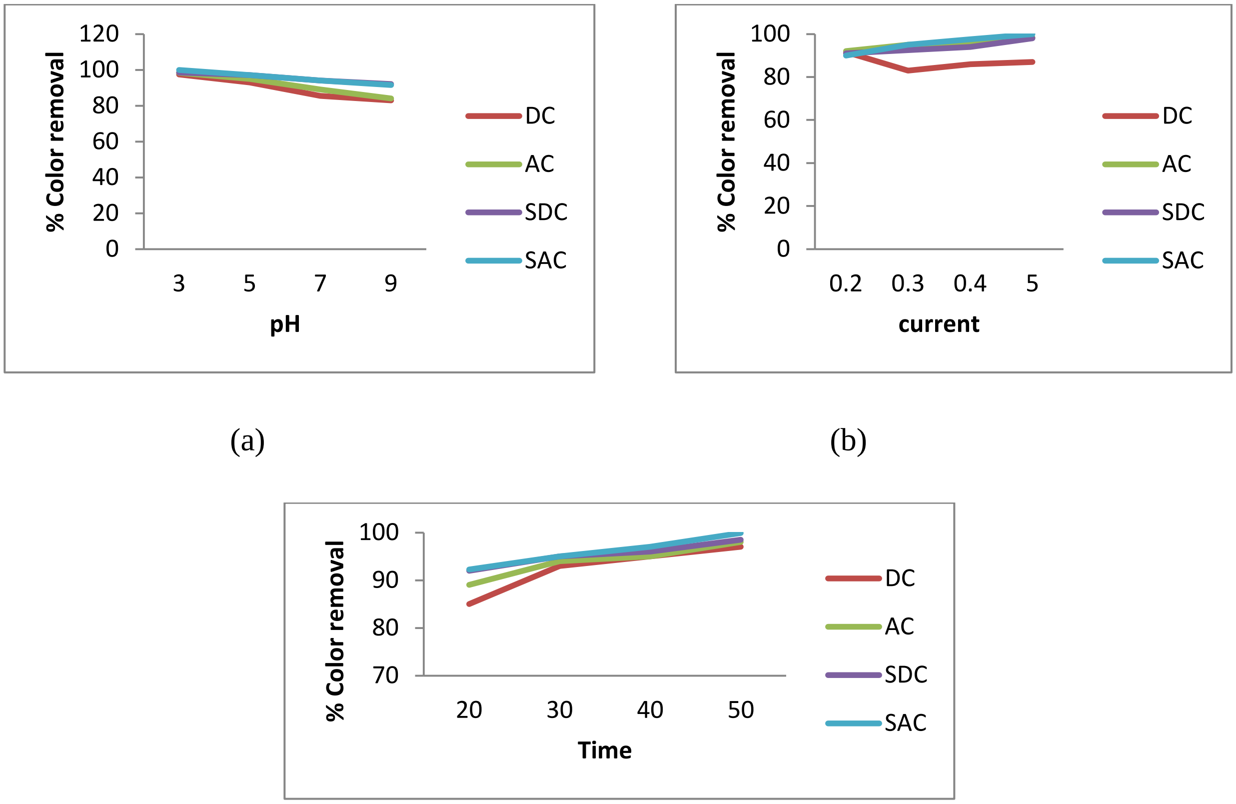
In the table 4.5, factors like pH, electric current and reaction time were considered with different ranges. Similarly the removal efficiency for Color, Turbidity and COD were determined by considering all those factors. Hence, using SAC electrocoagulation the removal efficiency up to 99.952% of Color, 99.76% of Turbidity, 92.35% of COD. Furthermore, the removal efficiency of COD, Color and Turbidity are clearly explained in the figure 4.1 with respect to different factors.



(a) (b)

(c)

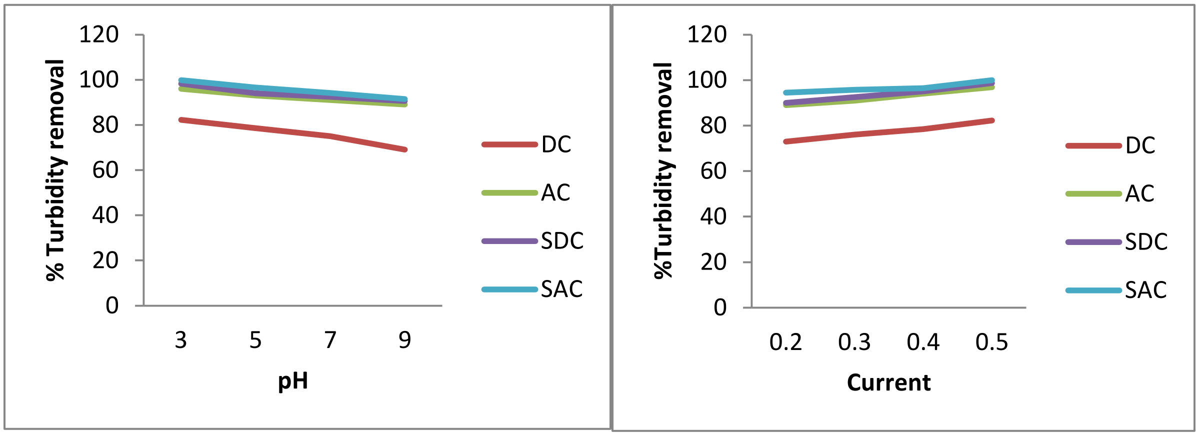
Figure 4.1 COD Removal efficiency versus different factors (a), (b) and (c), using Al-Al electrode



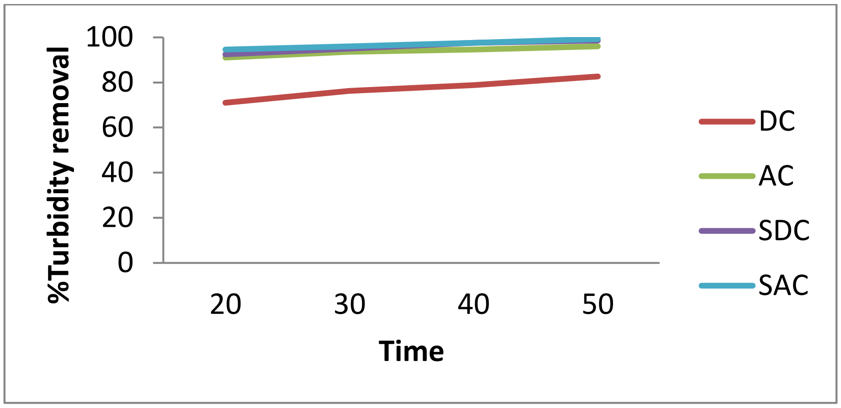
(a) (b)

(c)

Figure 4.2 Color Removal efficiency versus different factors (a), (b) and (c), using Al-Al electrode



(a) (b)



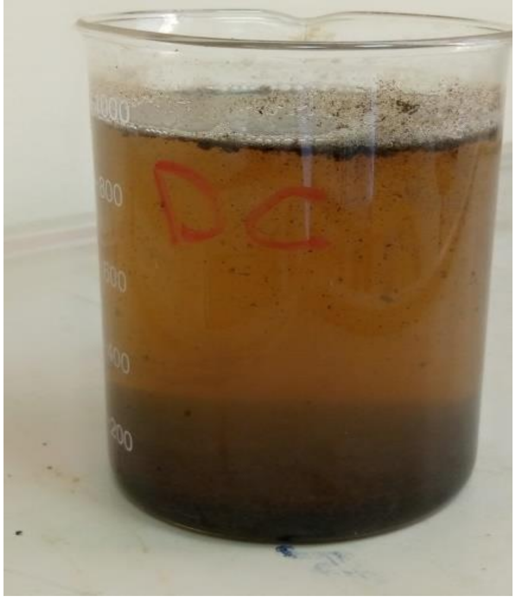
(C)

Figure 4.3 Turbidity Removal efficiency versus different factors (a), (b) and (c), using Al-Al electrode

4.5 Some Laboratory Illustrations of Sono-Direct current and Sono-Alternative Electrocoagulation (SACE/SDCE) By Aluminum electrode

During Electrocoagulation system, there are a number of processes takes place whatever types of electrodes used up. Especially, the formation of flocs on the upper part of the electrocoagulation cell due to the formation of Hydrogen gas and formation of small quantity of sludge at the bottom of electrocoagulation cell.

a) Before treatment



b) After Treatment by DC

C) After treatment By AC D) After treatment By SAC

4.6 Factors Affecting Sono-Electrocoagulation

Electrocoagulation is clearly defined in introduction part such that the process of only applying electric current for the treatment of wastewater without using any coagulant. However, the treatment of waste water by electrocoagulation process can be done by considering different factors. In this paper pH, Current Density and Reaction Time considered as a factors to treat the waste water from Jimma University.

a) **pH**

Initial pH (pH_0) exhibits a significant impact on the (SDC and SAC) electro coagulation process. There are different allowable concentrations of hydroxyl radicals and different forms of aluminum hydroxide complexes under the condition of various pH solutions. Under the acidic conditions (pH < 5), the most favorable species are $Al(OH)^{2+,}$ $Al(OH)^{+}_{2}$, and $Al(OH)^{2-}$, which easily reacts with H_2O_2 to produce ·OH (Kong *et al.*, 2020). There is the maximum concentration of Al^{2+} at pH 3 solution and more ·OH is generated through the reaction of $H_2O_{2.}$

In this experiment, the sample regulated the pH by using sulphuric acid solution and sodium hydroxide to pH 3-9. These ranges will give the data about how acidic pH, neutral pH and bases pH will affect the electrocoagulation efficiency in the removal of COD, Color and

Turbidity by DC,AC,SDC and SAC respectively that contain in the samples (Prasetyaningrum *et al.*, 2019). For all pH COD, Color and turbidity is decreased; but with a maximal reduction recorded at pH 3 (82.7%) and (97.5%) and (95.281) respectively. (Taylor, 2008) by Direct current electrocoagulation, (86.58%), (98.352%),(96.1255%) by Alternative current electrocoagulation and (88.585), (98.55%), (98.27%) by sono direct current and (92.35%),(99.952%),(99.76%)by Sono-Alternative current respectively.

b) **Current**

It is the amount of electric current in Ampere applied to waste water taken during electrocoagulation process. By varying the value of electric current applied to the sample with different parameters the removal efficiency also varies. Increasing the current in Ampere increases the removal efficiency of pollutants. Higher removal value of pollutants is observed while gradual increment of electric current applied. With the increase of current density from 0.2 A to 0.5A removal efficiency also increases (Prasetyaningrum *et al.*, 2019). This is due to the higher amount of ions produced on the electrodes promoting destabilization of the pollutant molecules.

c) **Reaction Time**

Reaction time is also another factor that affects electrocoagulation process. It is the time required to complete the reaction process of sample taken by electrocoagulation. According to this activity the reaction time is one hour in which the removal efficiency checked at different minute’s interval using the initial value as a base line. In this paper the laboratory result shows one hour reaction time is somewhat enough to remove pollutants. Increase the reaction time increase the removal efficiency of pollutants from wastewater (Singh and Awasthi, 2017).

4.7 Optimization with Response surface methodology (Design Expert11)

The RSM is a mathematical and statistical technique that is useful for the optimization of chemical reactions and industrial processes and is commonly used for experimental designs (Abu *et al.*, 2014). Response Surface Methodology is a particular set of mathematical and statistical methods that includes experimental design, model fitting and validation as well as condition optimization. The aim of RSM (Design Expert11) is to optimize response of interest which is influenced by numerous variables. Response surface methodology (Design Expert11) is a useful statistical method for the optimization of chemical reactions and/or industrial processes and widely used for experimental design

4.7.1 Optimization of Operating Parameters by DC Electrocoagulation

Table 4.6 ANOVA for the percentage of COD Removal quadratic model by DC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	358.33	9	39.81	93.12	< 0.0001	significant
A-pH	177.14	1	177.14	414.32	< 0.0001	
B-I	2.25	1	2.25	5.27	0.0446	
C-Time	9.57	1	9.57	22.39	0.0008	
AB	4.22	1	4.22	9.88	0.0104	
AC	1.20	1	1.20	2.81	0.01245	
BC	0.0175	1	0.0175	0.0410	0.00843	
A^2	10.03	1	10.03	23.45	0.0007	
B^2	3.78	1	3.78	8.84	0.0140	
C^2	5.45	1	5.45	12.75	0.0051	
Residual	4.28	10	0.4275			
Lack of Fit	3.06	5	0.6124	2.52	0.1663	not significant
Pure Error	1.21	5	0.2427			
Cor Total	362.61	19				

According to Table 4.6 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. In this case A, B, C, AB, A^2, B^2, C^2 are significant model terms. The quadratic model regression equation for COD removal is obtained by RSM (DesignExpert11) given below.

COD removal (%) = 75.0595 -4.2886 A + 0.613219B + 0.900932C -0.555552AB - 0.27277AC-0.0509426BC-0.749057A^2-0.56374B^2-0.456059 C^2………………….. (17)

Table 4.7 ANOVA for the percentage of Color Removal quadratic model by DC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	293.15	9	32.57	159.92	< 0.0001	significant
A-pH	97.07	1	97.07	476.60	< 0.0001	
B-I	9.27	1	9.27	45.52	< 0.0001	
C-Time	36.67	1	36.67	180.06	< 0.0001	
AB	0.0036	1	0.0036	0.0176	0.0089	
AC	9.38	1	9.38	46.07	< 0.0001	
BC	0.0223	1	0.0223	0.1096	0.00747	
A^2	1.92	1	1.92	9.45	0.0118	
B^2	0.3382	1	0.3382	1.66	0.02266	
C^2	12.89	1	12.89	63.29	< 0.0001	
Residual	2.04	10	0.2037			
Lack of Fit	1.65	5	0.3306	4.31	0.0674	not significant
Pure Error	0.3837	5	0.0767			
Cor Total	295.19	19				

According to Table 4.7 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant In this case A, B, C, AC, A^2, C^2 are significant model terms.

The quadratic model regression equation for Color removal is obtained by RSM (Design Expert11) given below:

Color Removal (%) = 91.7706 -3.1747A + 1.24384B + 1.76354 C + 0.0161826 AB + 0.762029 AC -0.0574674BC -0.328139 A^2 -0.168592B^2 -0.701383 C^2…………………………….. (18)

Table 4.8 ANOVA for the percentage of Turbidity Removal quadratic model by DC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	106.14	9	11.79	525.26	< 0.0001	significant
A-pH	31.93	1	31.93	1422.11	< 0.0001	
B-I	1.47	1	1.47	65.43	< 0.0001	
C-Time	1.59	1	1.59	70.83	< 0.0001	
AB	0.0474	1	0.0474	2.11	0.01769	
AC	0.1898	1	0.1898	8.45	0.0156	
BC	0.0084	1	0.0084	0.3721	0.05555	
A^2	1.07	1	1.07	47.75	< 0.0001	

B^2	0.8383	1	0.8383	37.34	0.0001	
C^2	0.0051	1	0.0051	0.2290	0.03425	
Residual	0.2245	10	0.0225			
Lack of Fit	0.1175	5	0.0235	1.10	0.4604	not significant
Pure Error	0.1070	5	0.0214			
Cor Total	106.36	19				

According to Table 4.8 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. . In this case A, B, C, AC, A^2, B^2 are significant model terms. The quadratic model regression equation for Turbidity removal is obtained by RSM (DesignExpert11) given below

Turbidity Removal (%) $=90.4002 -1.82076\,A + 0.495112\,B + 0.367234C + 0.0588338AB + 0.10836AC -0.035158BC + 0.244952A^2 -0.265446B^2 + 0.0140078C^2$…………………… (19)

Table 4.9 Sequential Model Sum of Squares and Model Summary Statistics for COD by DC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.132E+05	1	1.132E+05			
Linear vs Mean	326.77	3	108.92	48.63	< 0.0001	
2FI vs Linear	11.06	3	3.69	1.93	0.1740	
Quadratic vs 2FI	**20.50**	**3**	**6.83**	**15.98**	**0.0004**	**Suggested**
Cubic vs Quadratic	3.06	5	0.6124	2.52	0.1663	Aliased
Residual	1.21	5	0.2427			
Total	1.136E+05	20	5677.58			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	1.50	0.9012	0.8826	0.8555	52.38	
2FI	1.38	0.9317	0.9001	0.6946	110.75	
Quadratic	**0.6539**	**0.9882**	**0.9776**	**0.8982**	**36.91**	**Suggested**
Cubic	0.4926	0.9967	0.9873			Aliased

Table 4.10 Sequential Model Sum of Squares and Model Summary Statistics for Color by DC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.695E+05	1	1.695E+05			
Linear vs Mean	267.25	3	89.08	51.03	< 0.0001	
2FI vs Linear	11.38	3	3.79	2.98	0.0706	
Quadratic vs	**14.52**	**3**	**4.84**	**23.76**	**< 0.0001**	**Suggested**

2FI						
Cubic vs Quadratic	1.65	5	0.3306	4.31	0.0674	Aliased
Residual	0.3837	5	0.0767			
Total	1.698E+05	20	8488.73			

Model Summary Statistics

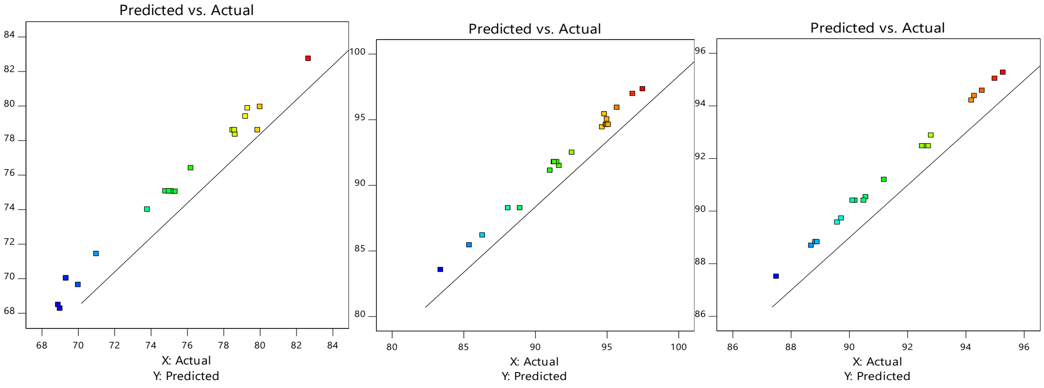
Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	1.32	0.9054	0.8876	0.8388	47.60	
2FI	1.13	0.9439	0.9180	0.8093	56.30	
Quadratic	**0.4513**	**0.9931**	**0.9869**	**0.9013**	**29.15**	**Suggested**
Cubic	0.2770	0.9987	0.9951			Aliased

Table 4.11 Sequential Model Sum of Squares and Model Summary Statistics for Turbidity by DC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.674E+05	1	1.674E+05			
Linear vs Mean	104.17	3	34.72	253.54	< 0.0001	
2FI vs Linear	0.3577	3	0.1192	0.8453	0.4933	
Quadratic vs 2FI	**1.61**	**3**	**0.5364**	**23.89**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	0.1175	5	0.0235	1.10	0.4604	Aliased
Residual	0.1070	5	0.0214			
Total	1.675E+05	20	8375.62			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	0.3701	0.9794	0.9755	0.9637	3.86	
2FI	0.3756	0.9828	0.9748	0.9529	5.01	
Quadratic	**0.1498**	**0.9979**	**0.9960**	**0.9876**	**1.32**	**Suggested**
Cubic	0.1463	0.9990	0.9962			Aliased

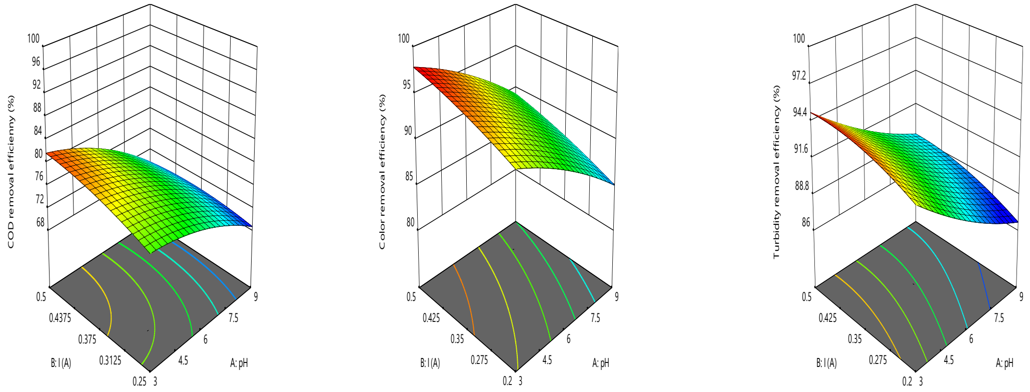


(a) COD removal (%) (b) Color removal (%) (c) Turbidity removal (%)

Figure 4.4 Plot for relationship between experimental and predicted value for color, turbidity nd COD by DC electrocoagulation

The comparison between the experimental and predicted value from the model is expressed in the above figure. It was observed that the model predictions matched the experimental values and the data points lay close to the diagonal line indicated above. This indicate the analysis of variance of regression model was highly significant (P<0.0001).

4.7.2 Interactions of Different parameters and Responses by DC



(a) COD removal (%) (b) Color removal (%) Turbidity removal (%)

Figure 4.5.Three dimensional response surface graphs for COD (a) ,Color (b), Turbidity (c), versus pH and current for DCE**.**

4.7.3 Optimization of Operating Parameters AC Electrocoagulation

Table 4.12 ANOVA for the percentage of COD Removal quadratic model by AC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	238.38	9	26.49	23.44	< 0.0001	significant
A-pH	116.06	1	116.06	102.73	< 0.0001	
B-I	11.28	1	11.28	9.98	0.0102	
C-Time	6.28	1	6.28	5.56	0.0401	
AB	0.0125	1	0.0125	0.0111	0.9184	
AC	0.2537	1	0.2537	0.2246	0.6457	
BC	8.11	1	8.11	7.18	0.0231	
A^2	7.05	1	7.05	6.24	0.0316	
B^2	0.0262	1	0.0262	0.0232	0.8820	
C^2	7.74	1	7.74	6.85	0.0257	
Residual	11.30	10	1.13			
Lack of Fit	9.29	6	1.55	3.08	0.1478	not significant
Pure Error	2.01	4	0.5023			
Cor Total	249.68	19				

According to Table 4.12 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. In this case A, B, C, BC, A^2, C^2 are significant model terms. The quadratic model regression equation for COD removal is obtained by RSM (DesignExpert11) given below

COD removal (%) = 79.9591 -3.48698 A + 1.37078B + 0.710239 C -0.0300148AB -0.124931 AC + 1.03489BC -0.627884 A^2 -0.0475851 B^2 -0.553833C^2………………………………..(20)

Table 4.13 ANOVA for the percentage of color Removal quadratic model by AC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	157.95	9	17.55	38.12	< 0.0001	significant
A-pH	66.16	1	66.16	143.72	< 0.0001	
B-I	10.97	1	10.97	23.83	0.0006	
C-Time	9.64	1	9.64	20.93	0.0010	
AB	1.56	1	1.56	3.39	0.0953	
AC	0.2414	1	0.2414	0.5243	0.4856	
BC	1.36	1	1.36	2.96	0.1162	
A^2	1.68	1	1.68	3.65	0.0850	

B²	0.2012	1	0.2012	0.4370	0.5235	
C²	2.26	1	2.26	4.90	0.0513	
Residual	4.60	10	0.4604			
Lack of Fit	4.15	6	0.6911	6.05	0.0516	not significant
Pure Error	0.4572	4	0.1143			
Cor Total	162.55	19				

According to Table 4.13 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. In this case A, B, C are significant model terms. The quadratic model regression equation for Turbidity removal is obtained by RSM (DesignExpert11) given below

Color Removal (%) = $93.0331-2.63278A + 1.35219B + 0.879572C + 0.335682\ AB + 0.121849\ AC + 0.424108\ BC-0.306784\ A^2-0.131826\ B^2-0.298931C^2$……………………………….. (21)

Table 4.14 ANOVA for the percentage of Turbidity Removal quadratic model by AC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	98.79	9	10.98	45.05	< 0.0001	significant
A-pH	30.08	1	30.08	123.46	< 0.0001	
B-I	1.25	1	1.25	5.15	0.0467	
C-Time	0.1542	1	0.1542	0.6329	0.4448	
AB	0.1096	1	0.1096	0.4498	0.5176	
AC	0.1830	1	0.1830	0.7511	0.4064	
BC	0.4206	1	0.4206	1.73	0.0182	
A²	1.23	1	1.23	5.03	0.0488	
B²	6.79	1	6.79	27.85	0.0004	
C²	0.5161	1	0.5161	2.12	0.1762	
Residual	2.44	10	0.2437			
Lack of Fit	2.18	6	0.3636	5.71	0.0569	not significant
Pure Error	0.2549	4	0.0637			
Cor Total	101.23	19				

According to Table 4.14 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. In this case A, B, A², B² are significant model terms. The quadratic model regression equation for Turbidity removal is obtained by RSM (DesignExpert11) given below

Turbidity Removal (%) = $91.5619-1.77523\ A + 0.457193\ B + 0.111264\ C-0.0889244AB + 0.1061AC + 0.235679\ BC + 0.261887\ A^2 -0.765569\ B^2 + 0.143006\ C^2$……………………..(22)

Table 4.15 Sequential Model Sum of Squares and Model Summary Statistics for COD by AC

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	Prob>F
Mean vs Total	1.288E+05	1	1.288E+05			
Linear vs Mean	**215.93**	**3**	**71.98**	**34.12**	**< 0.0001**	**Suggested**
2FI vs Linear	9.31	3	3.10	1.65	0.2261	
Quadratic vs 2FI	**13.14**	**3**	**4.38**	**3.88**	**0.0448**	**Suggested**
Cubic vs Quadratic	9.29	6	1.55	3.08	0.1478	Aliased
Residual	2.01	4	0.5023			
Total	1.290E+05	20	6450.64			

Model Summary Statistics

Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	Prob>F
Linear	**1.45**	**0.8648**	**0.8395**	**0.7883**	**52.86**	**Suggested**
2FI	1.37	0.9021	0.8569	0.7437	64.00	
Quadratic	**1.06**	**0.9548**	**0.9140**	**0.4612**	**134.52**	**Suggested**
Cubic	0.7087	0.9920	0.9618		*	Aliased

Table 4.16 Sequential Model Sum of Squares and Model Summary Statistics for Color by AC

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**	Prob>F
Mean vs Total	1.749E+05	1	1.749E+05			
Linear vs Mean	**151.29**	**3**	**50.43**	**71.63**	**< 0.0001**	**Suggested**
2FI vs Linear	2.89	3	0.9640	1.50	0.2618	
Quadratic vs 2FI	3.77	3	1.26	2.73	0.0999	
Cubic vs Quadratic	4.15	6	0.6911	6.05	0.0516	Aliased
Residual	0.4572	4	0.1143			
Total	1.750E+05	20	8751.35			

Model Summary Statistics

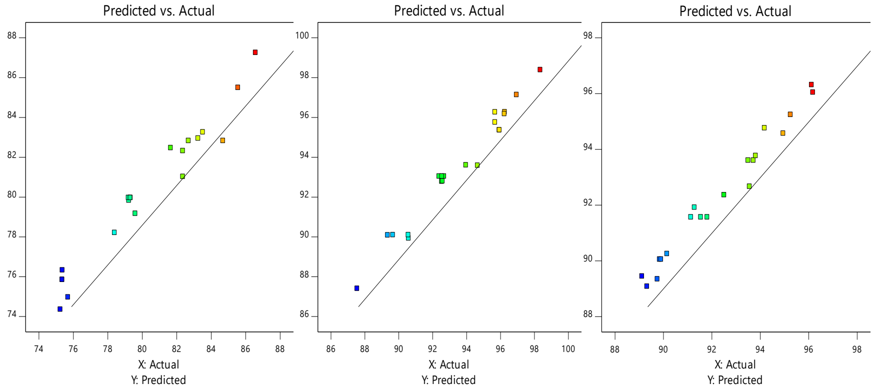
Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	Prob>F
Linear	**0.8391**	**0.9307**	**0.9177**	**0.8893**	**17.99**	**Suggested**
2FI	0.8025	0.9485	0.9247	0.8439	25.38	
Quadratic	0.6785	0.9717	0.9462	0.8032	32.00	
Cubic	0.3381	0.9972	0.9866		*	Aliased

Table 4.17 Sequential Model Sum of Squares and Model Summary Statistics for Turbidity by AC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.707E+05	1	1.707E+05			
Linear vs Mean	90.03	3	30.01	42.88	< 0.0001	
2FI vs Linear	0.8703	3	0.2901	0.3652	0.7793	
Quadratic vs 2FI	**7.89**	**3**	**2.63**	**10.80**	**0.0018**	**Suggested**
Cubic vs Quadratic	2.18	6	0.3636	5.71	0.0569	Aliased
Residual	0.2549	4	0.0637			
Total	1.708 E+05	20	8539.96			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	0.8366	0.8894	0.8686	0.7828	21.99	
2FI	0.8913	0.8980	0.8509	0.6709	33.31	
Quadratic	**0.4936**	**0.9759**	**0.9543**	**0.6451**	**35.93**	**Suggested**
Cubic	0.2524	0.9975	0.9880		*	Aliased

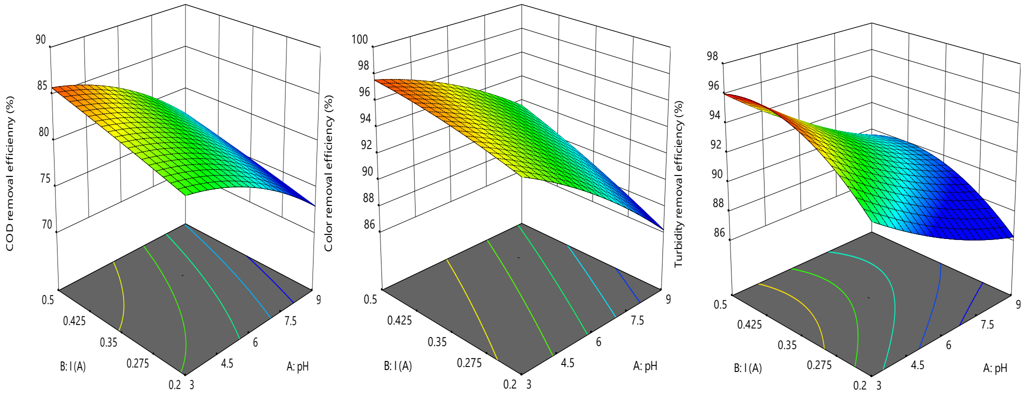


a)COD removal (%) b) Color removal (%) (C) Turbidity removal (%)

Figure 4.6 Plot for relationship between experimental and predicted value for COD, color and Turbidity for ACE

The comparison between the experimental and predicted value from the model is expressed in the above figure. It was observed that the model predictions matched the experimental values and the data points lay close to the diagonal line indicated above. This indicate the analysis of variance of regression model was highly significant (P<0.0001).

4.7.4 Interactions of Different parameters and Responses for ACE



a) COD removal (%) b) Color removal (%) c) Turbidity removal (%)

Figure 4.7.Three dimensional response surface graphs for COD (a), Color (b), Turbidity (c), versus pH, time and current for ACE.

4.7.5 Optimization of Operating Parameters SDC Electrocoagulation

Table 4.18 ANOVA for the percentage of COD Removal quadratic model by SDC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	193.49	9	21.50	11.18	0.0004	significant
A-pH	63.58	1	63.58	33.06	0.0002	
B-I	7.60	1	7.60	3.95	0.0748	
C-Time	17.97	1	17.97	9.35	0.0121	
AB	2.72	1	2.72	1.42	0.0415	
AC	0.4300	1	0.4300	0.2237	0.0264	
BC	2.14	1	2.14	1.11	0.0162	
A^2	2.24	1	2.24	1.16	0.0063	
B^2	8.99	1	8.99	4.67	0.0559	
C^2	1.57	1	1.57	0.8166	0.3874	
Residual	19.23	10	1.92			
Lack of Fit	15.82	5	3.16	4.65	0.0585	not significant
Pure Error	3.40	5	0.6807			
Cor Total	212.72	19				

According to Table 4.18 the model is significant. That means all P values less than 0.0500 indicate the model terms are significant. In this case A, C are significant model terms.

The quadratic model regression equation for COD removal is obtained by RSM (DesignExpert11) given below

COD Removal (%) =83.3598 -2.56923A + 1.12626 B + 1.23451 C -0.446068 AB + 0.163127 AC + 0.562812 BC-0.353705 A^2 -0.869186 B^2 -0.24478 C^2……………..……………………….(23)

Table 4.19 ANOVA for the percentage of Color Removal quadratic model by SDC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	105.86	9	11.76	453.63	< 0.0001	significant
A-pH	35.64	1	35.64	1374.65	< 0.0001	
B-I	1.52	1	1.52	58.43	< 0.0001	
C-Time	4.17	1	4.17	160.92	< 0.0001	
AB	0.1387	1	0.1387	5.35	0.0433	
AC	0.0606	1	0.0606	2.34	0.1572	
BC	0.0125	1	0.0125	0.4837	0.5026	
A^2	0.0249	1	0.0249	0.9594	0.3504	
B^2	13.20	1	13.20	509.03	< 0.0001	
C^2	3.00	1	3.00	115.87	< 0.0001	
Residual	0.2593	10	0.0259			
Lack of Fit	0.1172	5	0.0234	0.8248	0.5811	not significant
Pure Error	0.1421	5	0.0284			
Cor Total	106.12	19				

According to Table 4.19 the model is significant. That means all P values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, B^2, C^2 are significant model terms.

The quadratic model regression equation for COD removal is obtained by RSM (DesignExpert11) given below

Color Removal (%) =95.026 -1.92375A + 0.502824B + 0.59484C-0.100644AB -0.0612501 AC -0.0430777BC-0.0373135 A^2 -1.05326B^2-0.338604 C^2……………………………….(24)

Table 4.20 ANOVA for the percentage of Turbidity Removal quadratic model by SDC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	101.18	9	11.24	25.01	< 0.0001	significant
A-pH	12.24	1	12.24	27.23	0.0004	
B-I	2.53	1	2.53	5.64	0.0390	
C-Time	6.61	1	6.61	14.71	0.0033	
AB	2.83	1	2.83	6.29	0.0311	
AC	0.1596	1	0.1596	0.3551	0.5645	
BC	0.3450	1	0.3450	0.7675	0.4015	
A^2	5.88	1	5.88	13.08	0.0047	
B^2	1.21	1	1.21	2.69	0.1321	
C^2	0.4787	1	0.4787	1.07	0.3264	
Residual	4.49	10	0.4494			
Lack of Fit	1.82	5	0.3648	0.6831	0.6570	not significant
Pure Error	2.67	5	0.5341			
Cor Total	105.67	19				

According to Table 4.13 the model is significant. That means all P values less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, A^2 are significant model terms.

The quadratic model regression equation for COD removal is obtained by RSM (DesignExpert11) given below

Turbidity Removal (%) = 91.8009-1.12714 A + 0.650306B + 0.748792C -0.454289 AB -0.0993755 AC-0.225915BC + 0.573586 A^2 -0.318724 B^2 -0.135157C^2………………..(25)

Table 4.21 Sequential Model Sum of Squares and Model Summary Statistics for COD by SDC

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Mean vs Total	1.386E+05	1	1.386E+05			
Linear vs Mean	169.73	3	56.58	21.06	< 0.0001	Suggested
2FI vs Linear	9.41	3	3.14	1.22	0.3434	
Quadratic vs 2FI	14.35	3	4.78	2.49	0.1202	
Cubic vs Quadratic	15.82	5	3.16	4.65	0.0585	Aliased
Residual	3.40	5	0.6807			
Total	1.388E+05	20	6940.79			

Model Summary Statistics

Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	**1.64**	**0.7979**	**0.7600**	**0.6790**	**68.29**	**Suggested**
2FI	1.61	0.8422	0.7693	0.3993	127.77	
Quadratic	1.39	0.9096	0.8283	0.1374	183.49	Prob>F
Cubic	0.8250	0.9840	0.9392		*	Aliased

Table 4.22 Sequential Model Sum of Squares and Model Summary Statistics for Color by SDC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.802E+05	1	1.802E+05			
Linear vs Mean	88.35	3	29.45	26.52	< 0.0001	
2FI vs Linear	1.14	3	0.3795	0.2967	0.8272	
Quadratic vs 2FI	**16.37**	**3**	**5.46**	**210.47**	**< 0.0001**	**Suggested**
Cubic vs Quadratic	0.1172	5	0.0234	0.8248	0.5811	Aliased
Residual	0.1421	5	0.0284			
Total	1.804E+05	20	9017.57			

Model Summary Statistics

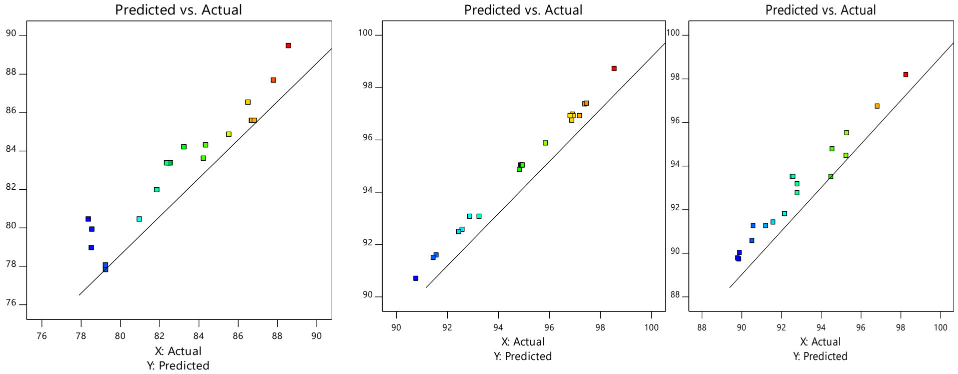
Source	Std. Dev.	R^2	Adjusted R^2	Predicted R^2	PRESS	Prob>F
Linear	1.05	0.8325	0.8011	0.7041	31.40	
2FI	1.13	0.8433	0.7709	0.2398	80.68	
Quadratic	**0.1610**	**0.9976**	**0.9954**	**0.9848**	**1.61**	**Suggested**
Cubic	0.1686	0.9987	0.9949		*	Aliased

Table 4.23 Sequential Model Sum of Squares and Model Summary Statistics for Turbidity by SDC

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.721E+05	1	1.721E+05			
Linear vs Mean	91.42	3	30.47	34.21	< 0.0001	
2FI vs Linear	2.67	3	0.8894	0.9979	0.4247	
Quadratic vs 2FI	**7.09**	**3**	**2.36**	**5.26**	**0.0195**	**Suggested**
Cubic vs Quadratic	1.82	5	0.3648	0.6831	0.6570	Aliased
Residual	2.67	5	0.5341			
Total	1.722E+05	20	8612.21			

Model Summary Statistics

Source	**Std. Dev.**	**R²**	**Adjusted R²**	**Predicted R²**	**PRESS**	Prob>F
Linear	0.9439	0.8651	0.8398	0.7666	24.67	
2FI	0.9440	0.8904	0.8398	0.6944	32.29	
Quadratic	**0.6704**	**0.9575**	**0.9192**	**0.8253**	**18.46**	**Suggested**
Cubic 0.7308 0.9747	0.9040			*	Aliased	

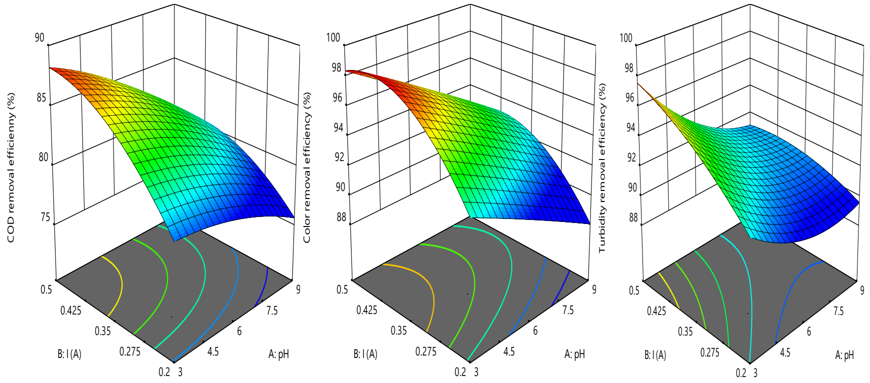


a) COD removal (%) b) Color removal (%) C) Turbidity removal (%)

Figure 4.8 Plot for relationship between experimental and predicted value for COD, color and Turbidity for SDCE

The comparison between the experimental and predicted value from the model is expressed in the above figure. It was observed that the model predictions matched the experimental values and the data points lay close to the diagonal line indicated above. This indicate the analysis of variance of regression model was highly significant (P<0.000)

4.7.6 Interactions of Different parameters and Responses for SDCE



a) COD removal (%) b) Color removal (%) C) Turbidity removal (%)

Figure 4.9.Three dimensional response surface graphs for COD (a) ,Color (b)and Turbidity (c) versus pH, time and current for SDCE

4.7.7 Optimization of Operating Parameters SAC Electrocoagulation

Table 4.24 ANOVA for the percentage of COD Removal quadratic model by SAC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	210.62	9	23.40	840.61	< 0.0001	significant
A-pH	104.63	1	104.63	3758.18	< 0.0001	
B-I	2.38	1	2.38	85.56	< 0.0001	
C-Time	3.68	1	3.68	132.25	< 0.0001	
AB	0.5132	1	0.5132	18.43	0.0016	
AC	0.3726	1	0.3726	13.39	0.0044	
BC	0.0243	1	0.0243	0.8742	0.0218	
A^2	4.00	1	4.00	143.59	< 0.0001	
B^2	0.8663	1	0.8663	31.12	0.0002	
C^2	1.52	1	1.52	54.42	< 0.0001	
Residual	0.2784	10	0.0278			
Lack of Fit	0.1855	5	0.0371	2.00	0.2332	not significant
Pure Error	0.0929	5	0.0186			
Cor Total	210.90	19				

According to Table 4.24 the model is significant. **P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, AC, A^2, B^2, C^2 are significant model terms. The quadratic model regression equation for COD removal is obtained by RSM (Design Expert11) given below:

COD Removal (%) = 86.6929 -3.29592 A + 0.630435B + 0.558774C -0.193618AB + 0.151853 AC + 0.0600054BC-0.473002A^2-0.269835B^2-0.240449C^2…………………………………..(26)

Table 4.25 ANOVA for the percentage of Color Removal quadratic model by SAC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	130.66	9	14.52	41.57	< 0.0001	significant
A-pH	58.72	1	58.72	168.16	< 0.0001	
B-I	4.77	1	4.77	13.67	0.0041	
C-Time	2.29	1	2.29	6.56	0.0283	
AB	0.0242	1	0.0242	0.0693	0.0277	
AC	0.5702	1	0.5702	1.63	0.0302	
BC	0.4768	1	0.4768	1.37	0.0397	
A^2	1.82	1	1.82	5.22	0.0454	
B^2	1.11	1	1.11	3.19	0.1043	
C^2	1.48	1	1.48	4.22	0.0669	
Residual	3.49	10	0.3492			
Lack of Fit	2.53	5	0.5057	2.62	0.1566	not significant
Pure Error	0.9634	5	0.1927			
Cor Total	134.15	19				

According to Table 4.25 the model is significant**. P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, A^2 are significant model terms.

The quadratic model regression equation for Color removal is obtained by RSM (Design Expert11) given below:

Color Removal (%) = 94.526 -2.46924A + 0.892367B + 0.44072 C + 0.0420437 AB -0.187845 AC + 0.265598 BC -0.319395 A^2 + 0.306116 B^2 + -0.237268 C^2…………………….. (27)

Table 4.26 ANOVA for the percentage of Turbidity Removal quadratic model by SAC electrocoagulation

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	132.49	9	14.72	90.98	< 0.0001	significant
A-pH	54.35	1	54.35	335.94	< 0.0001	
B-I	2.22	1	2.22	13.74	0.0041	
C-Time	3.37	1	3.37	20.86	0.0010	

AB	0.7803	1	0.7803	4.82	0.0528	
AC	0.3074	1	0.3074	1.90	0.0281	
BC	0.1197	1	0.1197	0.7400	0.0398	
A²	0.6196	1	0.6196	3.83	0.0788	
B²	0.0122	1	0.0122	0.0755	0.7891	
C²	1.25	1	1.25	7.72	0.0195	
Residual	1.62	10	0.1618			
Lack of Fit	1.30	5	0.2590	4.01	0.0767	not significant
Pure Error	0.3227	5	0.0645			
Cor Total	134.10	19				

According to Table 4.26 the model is significant **P-values** less than 0.0500 indicate model terms are significant. In this case A, B, C, C² are significant model terms. The quadratic model regression equation for Turbidity removal is obtained by RSM (Design Expert11) given below:

Turbidity Removal (%) = $93.9293-2.37556A + 0.609093B + 0.534959C-0.238754AB - 0.137921AC -0.133093BC-0.186216A^2-0.0320387B^2 + -0.21838\ C^2$……………….... (28)

Table 4.27 Sequential Model Sum of Squares and Model Summary Statistics for COD by SACE

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.520E+05	1	1.520E+05			
Linear vs Mean	201.69	3	67.23	116.83	< 0.0001	
2FI vs Linear	2.16	3	0.7216	1.33	0.3066	
Quadratic vs 2FI	6.76	3	2.25	80.99	< 0.0001	Suggested
Cubic vs Quadratic	0.1855	5	0.0371	2.00	0.2332	Aliased
Residual	0.0929	5	0.0186			
Total	1.522E+05	20	7611.62			

Model Summary Statistics

Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	Prob>F
Linear	0.7586	0.9563	0.9482	0.9358	13.53	
2FI	0.7360	0.9666	0.9512	0.7898	44.33	
Quadratic	0.1669	0.9987	0.9975	0.9742	5.44	Suggested
Cubic	0.1363	0.9996	0.9983		*	Aliased

Table 4.28 Sequential Model Sum of Squares and Model Summary Statistics for Color by SACE

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.816E+05	1	1.816E+05			
Linear vs Mean	125.98	3	41.99	82.21	< 0.0001	Suggested
2FI vs Linear	0.9072	3	0.3024	0.5411	0.6625	
Quadratic vs 2FI	3.77	3	1.26	3.60	0.0537	Suggested
Cubic vs Quadratic	2.53	5	0.5057	2.62	0.1566	Aliased
Residual	0.9634	5	0.1927			
Total	1.818E+05	20	9088.76			

Model Summary Statistics

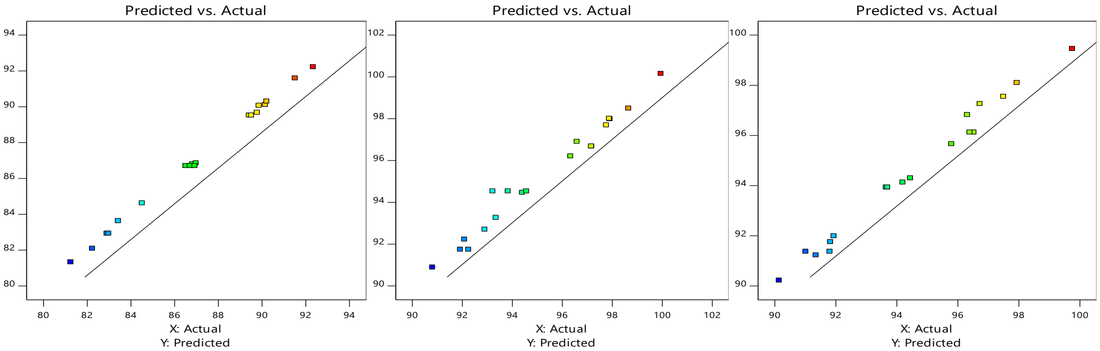
Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	Prob>F
Linear	0.7147	0.9391	0.9277	0.8958	13.97	Suggested
2FI	0.7476	0.9458	0.9208	0.8439	20.95	
Quadratic	0.5909	0.9740	0.9505	0.8879	15.04	Suggested
Cubic	0.4389	0.9928	0.9727		*	Aliased

Table 4.29 Sequential Model Sum of Squares and Model Summary Statistics for Turbidity by SACE

Source	Sum of Squares	df	Mean Square	F-value	p-value	Prob>F
Mean vs Total	1.788E+05	1	1.788E+05			
Linear vs Mean	129.01	3	43.00	135.12	< 0.0001	
2FI vs Linear	1.70	3	0.5679	2.18	0.1395	
Quadratic vs 2FI	1.77	3	0.5902	3.65	0.0521	Suggested
Cubic vs Quadratic	1.30	5	0.2590	4.01	0.0767	Aliased
Residual	0.3227	5	0.0645			
Total	1.790E+05	20	8949.15			

Model Summary Statistics

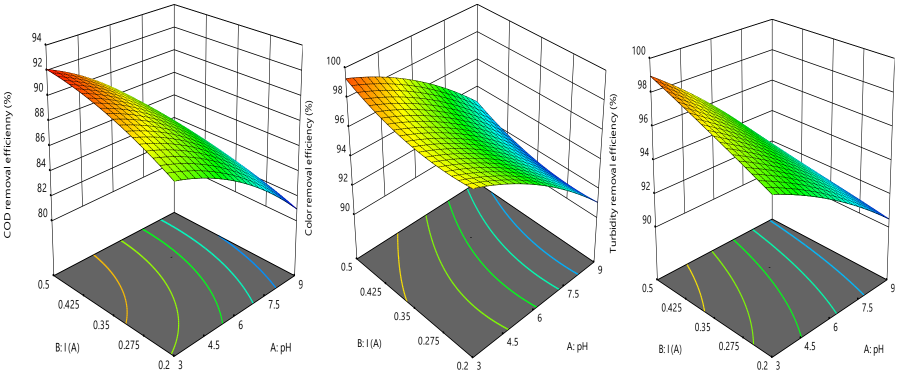
Source	Std. Dev.	R²	Adjusted R²	Predicted R²	PRESS	Prob>F
Linear	0.5642	0.9620	0.9549	0.9419	7.79	
2FI	0.5105	0.9747	0.9631	0.9120	11.80	
Quadratic	0.4022	0.9879	0.9771	0.8244	23.55	Suggested
Cubic	0.2541	0.9976	0.9909		*	Aliased



a) COD removal (%) b) Color removal (%) c) turbidity removal (%)

Figure 4.10.Plot for relationship between experimental and predicted value for, COD, color and turbidity for SACE

4.7.8 Interactions of Different parameters and Responses for SACE



a) COD removal (%) b) Color removal (%) C)Turbidity removal (%)

Figure 4.11.Three dimensional response surface graphs for COD (a),Color (b) and Turbidity (c) versus pH, time and current for SACE

4.8 Optimization of COD, Color and Turbidity by RSM

One of the main advantages of Response Surface Methodology by Central composite Design is to obtain the optimum conditions for the removal of pollutants based on the laboratory experiments.

The results were optimized using the regression equation of RSM (Design Expert 11) based on the Central Composite Design. In the optimization of pH (A), current (B), Time(C) were selected as within range and the responses such as COD, color and turbidity removal efficiency were maximized. For Direct current electrocoagulation the optimum value was obtained at pH 3, current 0.5A and time 50min. such that the optimum value of COD Color and turbidity were 82.6%,97.8% and 95.8%, respectively. Similarly for Alternative current electrocoagulation the optimum value was obtained at pH 3, current 0.5A, time 50 such that the optimum value of COD, Color and turbidity were 86.6%, 98.5% and 96.5% respectively.

For Sono-Direct current electrocoagulation the optimum value was obtained at pH 3, current 0.5A and time 50min. such that the optimum value of COD Color and turbidity were 88.5%,98.7% and 98.27%, respectively. Similarly for Sono-Alternative current electrocoagulation the optimum value was obtained at pH 3, current 0.5A, time 50 such that the optimum value of COD, Color and turbidity were 92.5%, 99.9% and 99.76% respectively.

CHAPTER FIVE

5 CONCLUSSIONS AND RECOMMENDATIONS

5.1 CONCLUSSIONS

The present research has demonstrated that the application of the DCE and ACE process to the treatment of Domestic wastewater. At the optimum experimental conditions, the % COD, color and % Turbidity removal were higher for the ACE than for the DCE process and SDCE than for SACE. The % COD removal Color removal and Turbidity removal from Domestic wastewater by means of an ACE and SACE method were influenced by the current density, initial pH of wastewater, and initial time. With ACE and SACE the production of sludge was lower and the recovery of water was very high than the DCE and SDCE process. An Electrocoagulation technology is one of the mentioned waste water treatment technology that is simple and easy to implement. It was observed that the integrated sono-Alternative and direct current electrocoagulation process treatment achieves a fast and effective removal of COD, color and turbidity. The treatment efficiency was found to be a function of the initial pH, inter electrode distance, applied current density and electrolysis time under the optimal values of the process parameters. During the laboratory activities different operating parameters are considered which affects the removal efficiency of pollutants by using Al electrodes. Those are pH having the values of 3, 5, 7 and 9, Electric current is 0.2A, 0.3A,0.4 A 0.5A, Distance between electrodes with ranges of 1cm, and reaction time of one hour is selected as a constant parameters. By using those all parameters for DCE, ACE, SDCE and SACE different value of removal efficiencies are obtained for COD Color, and turbidity. This indicates that using Alternative current electrocoagulation wastewater treatments have the ability to remove more pollutants than Direct current electro coagulation. And for optimization Sono-Alternative current electro coagulation wastewater treatments have the ability to remove more pollutants than Sono-Direct current electro coagulation.

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5.2 RECOMMENDATIONS

Electrocoagulation technology is a simple technology to use and implement for wastewater treatment. It was done by applying a source of energy power either from electric power or solar power depending on their availability.

However, there are a number of precautions needed during applying electrocoagulation for wastewater treatment.

- Since the source of energy is electric power, it may suddenly stop or may be off during the process, to cover this source like generator must be provided to minimize the effect of electric power.
- On another hand electrodes are the best material needed in electrocoagulation, during the process there is electrode dissolution and it must be replaced regularly for proper treatment.
- There some sludge produced during electrocoagulation technology applied for wastewater treatment.
- Laboratory safety should be applied in order to apply the technique.
- Hence, proper disposal area of sludge produced must be provided especially when the wastewater going to be treated is from Institution.

Generally, this treated water is not recommended for drinking. However it is used for irrigational purpose, toilet flushing other household purpose.

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APPENDICIES

Annex 1

All Lab Results

Table 4.1a: Experiment 1 &2for DCE

Date: 16/3/2021			Day: Tuesday		
System: Batch system			Experiment No: 1&2		
Effect of operating parameters					
pH: 3			Electrode material: Anode and Cathode: Al In-between electrode distance: 1cm		
Direct current electrocoagulation					
Current Ampere: 0.3A					
Reaction Time:1hr minute			Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)	Volts	Color Wavelength(nm)	Abs.	Turbidity(NTU)
1	0	-	420	3	116
2	20	2.8	420	0.103	4.9
3	40	2.8	420	0.202	4.87

Table 4.1b: Experiment 1&2 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.42	0.42	0.42	1.62	1.2	1.2	249
40	1.2	1.6	0.4	0.4	1.62	1.22	1.22	256

Table 4.2a: Experiment 3&4 for DCE

Date: 17/3/2021					Day: Wednesday			
System: Batch system					Experiment No: **3&4**			
				Effect of operating parameters				
pH: 3						Electrode material:		
Direct current electrocoagulation						Anode and Cathode: Al		
Current Ampere: 0.5A						In-between electrode distance: 1cm		
Reaction Time:1hr minute						Mode of Electrode Connection: Parallel		
Treatment	Time			Color				
Interval	(min.)	Volts		Wavelength(nm)		Abs.	Turbidity(NTU)	
1	30	2.9		420		0.39	4.7	
2	50	2.9		420		0.401	4.75	

Table 4.2b: Experiment 3&4 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
			Volume			down the	volume	(mg/L)
			down the burette(mL)			burette(mL)	(mL)	
30	0	0.42	0.42	0.42	1.62	1.2	1.2	249
50	1.2	1.6	0.4	0.4	1.62	1.22	1.22	256

Table 4.3a: Experiment 5 for DCE

Date: 18/3/2021			Day: Thursday			
System: Batch system			Experiment No: 5			
			Effect of operating parameters			
pH: 5				Electrode material:		
Direct current electrocoagulation						
				Anode and Cathode: Al		
Current Ampere: 0.2A				In-between electrode distance: 1cm		
Reaction Time:40 minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)		Color			
1	40	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
		2.1	420	0. 58	9.6	

Table 4.3b: Experiment 5 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.32	0.32	0.34	1.56	1.22	1.22	281

Table 4.4a: Experiment 6,7&8 for DCE

Date: 19/2021			Day: Friday			
System: Batch system			Experiment No: **6,7&8**			
			Effect of operating parameters			
pH: 5				Electrode material:		
Direct current electrocoagulation						
				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
Reaction Time:1 hr				Mode of Electrode Connection: Parallel		
Treatment interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	

1	20	3.7	420	0. 225	6.15	
2	40	3.7	420	0.15	5.58	
3	60	3.7	420	0.05	4.6	

Table 4.4b: Experiment 6,7&8 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	1.2	1.2	1.2	2.2	1	1	320
40	1	1.8	0.8	0.8	1.6	0.8	0.8	256
60	0.8	2	1.2	1.2	1.7	0.5	0.5	160

Table 4.5a: Experiment 9 for DCE

Date: 20/3/2021			Day: Saturday			
System: Batch system			Experiment No: 9			
			Effect of operating parameters			
pH: 5				Electrode material:		
Direct current electrocoagulation						
					Anode and Cathode: Al	
Current Ampere: 0.5A				In-between electrode distance: 1cm		
Reaction Time:50 minute				Mode of Electrode Connection: Parallel		
Treatment interval	Time		Color			
1	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
	50	2.7	420	0. 224	10.6	

Table 4.5b: Experiment 9 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	0	0.46	0.46	0.46	1.68	1.22	1.22	243

Table 4.6a: Experiment 10,11&12 for DCE

Date: 22/3/2021			Day: Monday			
System: Batch system			Experiment No: **10,11&12**			
			Effect of operating parameters			
pH: 7				Electrode material:		
Direct current electrocoagulation				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
Reaction Time:1hr minute				Mode of Electrode Connection: Parallel		
Treatmentinterval	Time (min.)	Volts	Color Wavelength(nm)	Abs.	Turbidity(NTU)	
1	20	3.7	420	0.706	10.6	
2	40	3.7	420	0.224	8.96	
3	60	3.7	420	0.172	6.1	

Table 4.6b: Experiment 10,11&12 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.65	0.65	0.65	1.85	1.2	1.2	176
40	1.2	1.97	0.77	0.77	2.3	1.54	1.54	246
60	1.54	2	0.46	0.46	1.6	1.2	1.2	236

Table 4.7a: Experiment 13 for DCE

Date: 23/3/2021			Day: Tuesday			
System: Batch system			Experiment No: 13			
			Effect of operating parameters			
pH: 9				Electrode material:		
Direct current electrocoagulation						
				Anode and Cathode: Al		
Current Ampere: 0.3A				In-between electrode distance: 1cm		
Reaction Time:30 minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)	Volts	Color Wavelength(nm)	Abs.	Turbidity(NTU)	
1	30	2	420	0.235	11.26	

Table 4.7b: Experiment 13 COD determination for DCE

	Sample			Blank				
Time	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
(min.)			Volume			down the	volume	(mg/L)
			down the			burette(mL)	(mL)	
			burette(mL)					
30	0	0.4	0.4	0.4	1.6	1.2	1.2	360

Table 4.8a: Experiment 14 for DCE

Date: 24/3/2021	Day: Wednesday					
System: Batch system	Experiment No: 14					
			Effect of operating parameters			
pH: 9					Electrode material:	
Direct current electrocoagulation					Anode and Cathode: Al	
Current Ampere: 0.4A					In-between electrode distance: 1cm	
Reaction Time:40 minute					Mode of Electrode Connection: Parallel	
Treatment Interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3	420	0.269	11.14	

Table 4.8b: Experiment 14 COD determination for DCE

	Sample			Blank				
Time	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
(min.)			Volume			down the	volume	(mg/L)
			down the			burette(mL)	(mL)	
			burette(mL)					
40	0	0.2	0.2	0.2	1.4	1.2	1.2	320

Table 4.9a: Experiment 15 for DCE

Date:25/3/2021	Day: Thursday					
System: Batch system	Experiment No: 15					
		Effect of operating parameters				
pH: 9			Electrode material:			
Direct current electrocoagulation				Anode and Cathode: Al		
Current Ampere: 0.5A			In-between electrode distance: 1cm			
ReactionTime:50minute			Mode of Electrode Connection: Parallel			
Treatment Interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	50	3.1	420	0.332	14.06	

Table 4.9b: Experiment 15 COD determination for DCE

	Sample			Blank				
Time	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
(min.)			Volume			down the	volume	(mg/L)
			down the			burette(mL)	(mL)	
			burette(mL)					
50	0	0.2	0.2	0.2	1.06	0.86	0.86	211

Table 4.10a: Experiment 16 for DCE

Date:26/3/2021			Day: Friday			
System: Batch system			Experiment No: 16			
		Effect of operating parameters				
pH: 7				Electrode material:		
Direct current electrocoagulation						
				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)	Volts	Color			
			Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.23	8.96	

Table 4.10 b: Experiment 16 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	1.97	0.75	0.75	2.3	1.55	1.55	246.2

Table 4.11a: Experiment 17 for DCE

Date:29/3/2021			Day: Monday			
System: Batch system			Experiment No: 17			
			Effect of operating parameters			
pH: 7				Electrode material:		
Direct current electrocoagulation						
					Anode and Cathode: Al	
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.231	8.9	

Table 4.11 b: Experiment 17 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.55	2.29	0.75	0.75	2.27	1.52	1.52	246.4

Table 4.12a: Experiment 18 for DCE

Date:30/3/2021			Day: Tuesday			
System: Batch system			Experiment No: 18			
		Effect of operating parameters				
pH: 7				Electrode material:		
Direct current electrocoagulation					Anode and Cathode: Al	
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.232	8.91	

Table 4.12 b: Experiment 18 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.52	2.28	0.76	0.76	2.26	1.51	1.51	240

Table 4.13 a: Experiment 19 for DCE

Date:1/4/2021			Day: Wednesday			
System: Batch system			Experiment No: 19			
			Effect of operating parameters			
pH: 7					Electrode material:	
Direct current electrocoagulation					Anode and Cathode: Al	
Current Ampere: 0.4A					In-between electrode distance: 1cm	
ReactionTime:40minute					Mode of Electrode Connection: Parallel	
Treatment Interval	Time (min.)	Volts	Color Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.232	8.92	

Table 4.13 b: Experiment 19 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.52	2.28	0.76	0.77	2.25	1.51	1.51	243

Table 4.14 a: Experiment 20 for DCE

Date:2/4/2021			Day: Wednesday			
System: Batch system			Experiment No: 20			
		Effect of operating parameters				
pH: 5			Electrode material:			
Direct current electrocoagulation						
				Anode and Cathode: Al		
Current Ampere: 0.4A			In-between electrode distance: 1cm			
ReactionTime:40minute			Mode of Electrode Connection: Parallel			
Treatment Interval	Time (min.)		Color			
		Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	2.6	420	0.152	6.15	

Table 4.14 b: Experiment 20 COD determination for DCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0.43	1	0.57	0.57	1.3	0.73	0.73	233.6

Table 5.1a: Experiment 1 &2 for ACE

Date: 3/4/2021	Day: Thursday
System: Batch system	Experiment No: **1 &2**
Effect of operating parameters	
pH: 3	Electrode material: Anode and cathode Al In-between electrode distance: 1cm
Alternative Current electrocoagulation	
Current Ampere: 0.3A	
Reaction Time:1hr minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	2.8	420	3	116
2	20	2.8	420	0.066	5.8
3	30	2.8	420	0.081	4.5

Table 5.1b: Experiment 1&2 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.89	0.89	0.89	2.09	1.2	1.2	99.2
30	1.2	2.08	0.88	0.88	2.08	1.2	1.2	102.4

Table 5.2a: Experiment 3&4 for ACE

Date: 4/4/2021			Day: Friday		
System: Batch system			Experiment No: **3&4**		
Effect of operating parameters					
pH: 3			Electrode material: Anode and cathode: Al In-between electrode distance: 1cm		
Alternative Current electrocoagulation					
Current Ampere: 0.5A					
Reaction Time:1hr minute			Mode of Electrode Connection: Parallel		

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	3.2	420	3	116
2	30	3.2	420	0.081	7.2
3	50	3.2	420	0.032	3.8

Table 5.2b: Experiment 3&4 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
30	0	0.89	0.89	0.89	2.09	1.2	1.2	99.2
50	1.2	2.1	0.9	0.9	2.1	1.2	1.2	96

Table 5.3a: Experiment 5 for ACE

Date: 7/4/2021	Day: Monday
System: Batch system	Experiment No: 5
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Alternative Current electrocoagulation	
Current Ampere: 0.2A	
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	1.6	420	0.075	4.34

Table 5.3b: Experiment 5 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.9	0.9	0.9	2.175	1.275	1.275	120

Table 5.4a: Experiment 6,7&8 for ACE

Date: 8/4/2021	Day: Tuesday
System: Batch system	Experiment No: **6,7&8**
Effect of operating parameters	
pH: 5	Electrode material:
Alternative Current electrocoagulation	Anode and cathode: Al
Current Ampere: 0.4A	In-between electrode distance: 1cm
Reaction Time:1hr	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	20	2.8	420	0.211	5
2	40	2.8	420	0.15	4.2
3	60	2.8	420	0.023	3.4

Table 5.4b: Experiment 6,7&8 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.92	0.92	0.92	1.4	0.48	0.48	153.6
40	0.48	1.08	0.6	0.6	1.12	0.52	0.52	128
60	0.52	1	0.48	0.48	0.8	0.52	0.52	102

Table 5.5a: Experiment 9 for ACE

Date: 9/4/2021	Day: Wednesday
System: Batch system	Experiment No: 9
Effect of operating parameters	
pH: 5	Electrode material:
Alternative Current electrocoagulation	Anode and cathode : Al
Current Ampere: 0.5A	In-between electrode distance: 1cm
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)	
			Wavelength(nm)	Abs.		
1	50	3.1	420	0.077	4.54	

Table 5.5b: Experiment 9 COD determination for AC

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	0	0.82	0.82	0.82	2.02	1.2	1.2	121

Table 5.6a: Experiment 10,11&12 for ACE

Date: 10/4/2021			Day: Thursday		
System: Batch system			Experiment No: **10,11&12**		
Effect of operating parameters					
pH: 7			Electrode material: Anode and cathode: Al		
Alternative Current electrocoagulation					
Current Ampere: 0.4A			In-between electrode distance: 1cm		
Reaction Time:1hr minute			Mode of Electrode Connection: Parallel		

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	20	2.1	420	0.168	6.8
2	40	2.1	420	0.106	4.46
3	60	2.1	420	0.093	4.4

Table 5.6b: Experiment 10,11&12 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.88	0.88	0.88	2.08	1.2	1.2	102
40	1.2	2.02	0.82	0.82	2.02	1.2	1.2	121
60	1.2	2.07	0.87	0.87	2.07	1.2	1.2	105.6

Table 5.7a: Experiment 13 for ACE

Date: 11/4/2021	Day: Friday
System: Batch system	Experiment No: 13
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Alternative Current electrocoagulation	
Current Ampere: 0.3A	
Reaction Time:30 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	30	2.1	420	0.09	7.76

Table 5.7b: Experiment 13 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
30	0	0.88	0.88	0.88	2.08	1.2	1.2	102.4

Table 5.8a: Experiment 14 for ACE

Date: 14/4/2021	Day: Monday
System: Batch system	Experiment No: 14
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Alternative Current electrocoagulation	
Current Ampere: 0.4A	
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color Wavelength(nm)	Abs.	Turbidity(NTU)
1	40	2.2	420	0.278	18.6

Table 5.8b: Experiment 14 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.7	0.7	0.7	1.9	1.2	1.2	160

Table 5.9a: Experiment 15 for ACE

Date: 15/4/2021	Day: Tuesday
System: Batch system	Experiment No: 15
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Alternative Current electrocoagulation	
Current Ampere: 0.5A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
2	50	2.4		0.111	5.66

Table 5.9b: Experiment 15 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	1.2	2.02	0.82	0.82	2.02	1.2	1.2	121.6

Table 5.10a: Experiment 16 for ACE

Date: 16/4/2021	Day: Wednesday
System: Batch system	Experiment No: **16**
Effect of operating parameters	
pH: 7	Electrode material: Anode and cathode: Al
Alternative Current electrocoagulation	
Current Ampere: 0.4A	In-between electrode distance: 1cm
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	2.1	420	0.105	4.45

Table 5.10b: Experiment 16 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.8	0.8	2	1	1.19	121.2

Table 5.11a: Experiment 17 for ACE

Date: 17/4/2021	Day: Thursday
System: Batch system	Experiment No: **17**
Effect of operating parameters	
pH: 7	Electrode material: Anode and cathode: Al
Alternative Current electrocoagulation	
Current Ampere: 0.4A	In-between electrode distance: 1cm
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	2.1	420	0.105	4.45

Table 5.11b: Experiment 17 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.8	0.8	2	1	1.19	121.2

Table 5.12a: Experiment 18 for ACE

Date: 18/4/2021	Day: Friday
System: Batch system	Experiment No: **18**
Effect of operating parameters	
pH: 7	Electrode material: Anode and cathode: Al
Alternative Current electrocoagulation	
Current Ampere: 0.4A	In-between electrode distance: 1cm
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	2.1	420	0.105	4.45

Table 5.12b: Experiment 18 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.8	0.8	2	1	1.19	121.2

Table 5.13a: Experiment 19 for ACE

Date:21/4/2021				Day: Monday		
System: Batch system				Experiment No: 19		
			Effect of operating parameters			
pH: 7				Electrode material:		
Alternative current				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)		Color			
		Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.106	4.47	

Table 5.13 b: Experiment 19 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.81	0.81	2	1.19	1.18	121.3

Table 5.13a: Experiment 19 for ACE

Date:22/4/2021		Day: Tuesday				
System: Batch system		Experiment No: 19				
		Effect of operating parameters				
pH: 7				Electrode material:		
Alternative current						
					Anode and Cathode: Al	
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)		Color			
		Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.106	4.47	

Table 5.13 b: Experiment 19 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.81	0.81	2	1.19	1.18	121.3

Table 5.14a: Experiment 20 for ACE

Date:23/4/2021			Day: Wednesday			
System: Batch system			Experiment No: 20			
		Effect of operating parameters				
pH: 5				Electrode material:		
Alternative current					Anode and Cathode: Al	
Current Ampere: 0.4A			In-between electrode distance: 1cm			
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)		Color			
		Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	3.1	420	0.106	4.47	

Table 5.14 b: Experiment 20 COD determination for ACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.2	2	0.81	0.81	2	1.19	1.18	121.3

Table 6.1a: Experiment 1&2 for SDCE

Date: 24/4/2021	Day: Thursday
System: Batch system	Experiment No: 1&2
Effect of operating parameters	
pH: 3	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.3A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	20	2.7	420	0.062	5.4
3	30	2.7	420	0.045	4.1

Table 6.1b: Experiment 1 &2 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.87	0.87	0.87	2.07	1.2	1.2	105.6
30	1.2	2.14	0.94	0.94	2.14	1.2	1.2	83.2

Table 6.2a: Experiment 3&4 for SDCE

Date: 25/4/2021	Day: Friday
System: Batch system	Experiment No: **3&4**
Effect of operating parameters	
pH: 3	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.5A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	20	2.4	420	0.092	5.6
3	30	2.4	420	0.072	4.5

Table 6.2b: Experiment 3&4 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.6	0.6	0.6	1.4	0.8	0.8	256
30	0.8	2	1.2	1.2	1.8	0.6	0.6	192

Table 6.3a: Experiment 5 for SDCE

Date: 28/4/2021	Day: Monday
System: Batch system	Experiment No: 5
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode: Al
Sono-direct Current electrocoagulation	
Current Ampere: 0.2A	In-between electrode distance: 1cm
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	40	2.3	420	0.07	4.82

Table 6.3b: Experiment 5 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.7	0.7	0.7	1.9	1.2	1.2	160

Table 6.4a: Experiment 6,7 &8 for SDCE

Date: 29/4/2021	Day: Tuesday
System: Batch system	Experiment No: **6,7&8**
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.5A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	20	2.6	420	0.76	5.9
3	40	2.6	420	0.076	4.7
4	60	2.6	420	0.05	3.8

Table 6.4b: Experiment 6,7&8 COD determination for SDCE

	Sample			Blank				
Time	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
(min.)			Volume			down the	volume	(mg/L)
			down the			burette(mL)	(mL)	
			burette(mL)					
20	0	0.6	0.4	0.4	1	0.6	0.6	64
40	0.6	1.6	0.8	0.8	1.2	0.4	0.4	128
60	0.8	0.8	0.8	0.8	1.4	0.6	0.6	192

Table 6.5a: Experiment 9 for SDCE

Date: 30/4/2021	Day: Wednesday
System: Batch system	Experiment No: 9
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.5A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	50	2.5	420	3	116

Table 6.5b: Experiment 9 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	0	0.6	0.4	0.4	1	0.6	0.6	64

Table 6.6a: Experiment 10,11&12 for SDCE

Date: 1/5/2021			Day: Thursday		
System: Batch system			Experiment No:**10,11&12**		
Effect of operating parameters					
pH: 7			Electrode material: Anode and cathode: Al		
Sono-direct Current electrocoagulation					
Current Ampere: 0.4A			In-between electrode distance: 1cm		
Reaction Time:1hr minute			Mode of Electrode Connection: Parallel		

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	20	2.4	420	0.125	5
3	40	2.4	420	0.073	4.8
4	60	2.4	420	0.048	4.65

Table 6.6b: Experiment 10,11&12 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.81	0.81	0.81	2.02	1.21	1.21	124
40	1.21	2.05	0.84	0.84	2.04	1.2	1.2	115.2
60	1.2	2.08	0.88	0.88	2.08	1.2	1.2	102.4

Table 6.7a: Experiment 13 for SDCE

Date: 2/5/2021	Day: Friday
System: Batch system	Experiment No:13
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.3A	
Reaction Time:30 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	30	2.2	420	0.082	5.8

Table 6.7b: Experiment 13 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
30	0	0.88	0.88	0.88	2.08	1.2	1.2	102.4

Table 6.8a: Experiment 14 for SDCE

Date: 5/5/2021	Day: Monday
System: Batch system	Experiment No:14
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-direct Current electrocoagulation	
Current Ampere: 0.4A	
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
2	40	2.5	420	0.09	6

Table 6.8b: Experiment 14 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.84	0.84	0.84	2.04	1.2	1.2	115.2

Table 6.9a: Experiment 15 for SDCE

Date: 6/5/2021	Day: Tuesday
System: Batch system	Experiment No:15
Effect of operating parameters	
pH: 9	Electrode material: Anode: Al
Sono-direct Current electrocoagulation	
Current Ampere: 0.5A	In-between electrode distance: 1cm
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	0	-	420	3	116
3	50	2.3		0.07	4.8

Table 6.9b: Experiment 15 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	1.2	2.09	0.89	0.89	2.09	1.2	1.2	99.2

Table 6.10a: Experiment 16 for SDCE

Date:7/5/2021			Day: Wednesday			
System: Batch system			Experiment No: 16			
			Effect of operating parameters			
pH: 7				Electrode material:		
Sono-direct current				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment	Time		Color			
Interval	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	2.1	420	0.074	4.81	

Table 6.10b: Experiment 16 COD determination for SDCE

	Sample			Blank				
Time	Initial	Final	FAS	Initial	Final	FAS Volume	FAS	COD
(min.)			Volume			down the	volume	(mg/L)
			down the			burette(mL)	(mL)	
			burette(mL)					
40	1.201	2.05	0.84	0.84	2.04	1.2	1.2	115.2

Table 6.11a: Experiment 17 for SDCE

Date:8/5/2021			Day: Thursday			
System: Batch system			Experiment No: 17			
		Effect of operating parameters				
pH: 7				Electrode material:		
Sono-direct current				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment	Time		Color			
Interval	(min.)	Volts	Wavelength(nm) Abs.		Turbidity(NTU)	
1	40	2.3	420	0.0732	4.82	

Table 6.11b: Experiment 17 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.201	2.05	0.84	0.84	2.04	1.2	1.2	115.1

Table 6.12a: Experiment 18 for SDCE

Date:9/5/2021				Day: Friday			
System: Batch system				Experiment No: 18			
			Effect of operating parameters				
pH: 7					Electrode material:		
Sono-direct current							
						Anode and Cathode: Al	
Current Ampere: 0.4A					In-between electrode distance: 1cm		
ReactionTime:40minute					Mode of Electrode Connection: Parallel		
Treatment Interval	Time		Color				
	(min.)	Volts	Wavelength(nm)		Abs.	Turbidity(NTU)	
1	40	2.3	420	0.072		4.804	

Table 6.12b: Experiment 18 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.201	2.05	0.84	0.84	2.04	1.2	1.2	115.3

Table 6.13a: Experiment 19 for SDCE

Date:12/5/2021			Day: Monday			
System: Batch system			Experiment No: 19h			
			Effect of operating parameters			
pH: 7				Electrode material:		
Sono-direct current						
					Anode and Cathode: Al	
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment	Time		Color			
Interval	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	2.2	420	0.073	4.805	

Table 6.13b: Experiment 19 COD determination for SDCE

	Sample			Blank				
Time (min)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	1.201	2.05	0.839	0.839	2.04	1.2	1.2	115.5

Table 6.14a: Experiment 20 for SDCE

Date:13/5/2021			Day: Tuesday			
System: Batch system			Experiment No: 20			
		Effect of operating parameters				
pH: 5				Electrode material:		
Sono-direct current						
				Anode and Cathode: Al		
Current Ampere: 0.4A				In-between electrode distance: 1cm		
ReactionTime:40minute				Mode of Electrode Connection: Parallel		
Treatment Interval	Time		Color			
	(min.)	Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40	2.3	420	0.07	4.82	

Table 6.14b: Experiment 20 COD determination for SDCE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.2	0.2	0.2	0.6	0.4	0.4	128

Table 7.1a: Experiment 1& 2 for SACE

Date: 14/5/2021	Day: Wednesday
System: Batch system	Experiment No: **1& 2**
Effect of operating parameters	
pH: 3	Electrode material:
Sono-alternative Current electrocoagulation	Anode and cathode: Al
Current Ampere: 0.3A	In-between electrode distance: 1cm
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	20	2.1	420	0.053	4.72
2	30	2.1	420	0.04	3.7

Table 7.1b: Experiment 1& 2 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.9	0.9	0.9	2.1	1.2	1.2	96
30	1.2	2.12	0.92	0.92	2.12	1.21	1.21	92.8

Table 7.2a: Experiment 3&4 for SACE

Date: 15/5/2021			Day: Thursday		
System: Batch system			Experiment No: **3&4**		
Effect of operating parameters					
pH: 3			Electrode material: Anode and cathode : Al		
Sono-alternative Current electrocoagulation					
Current Ampere: 0.5A			In-between electrode distance: 1cm		
Reaction Time:50 minute			Mode of Electrode Connection: Parallel		

Treatment Interval	Time (min.)	Volts	Color Wavelength(nm)	Color Abs.	Turbidity(NTU)
1	20	2.4	420	0.082	5.06
2	30	2.4	420	0.075	4.23

Table 7.2b: Experiment 3&4 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.75	0.75	0.75	1.95	1.2	1.2	144
30	1.2	1.7	0.5	0.5	1.2	0.7	0.7	224

Table 7.3a: Experiment 5 for SACE

Date: 16/5/2021	Day: Friday
System: Batch system	Experiment No:5
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.2A	
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	2.4	420	0.042	3.96

Table 7.3b: Experiment 5 COD determination for SACE

	Sample			Blank				
Time(min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.91	0.91	0.91	2.11	1.2	1.2	92.8

Table 7.4a: Experiment 6,7&8 for SACE

Date: 17/5/2021	Day: Saturday
System: Batch system	Experiment No:**6,7&8**
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.4A	
Reaction Time:1hr	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	20	2.5	420	0.064	4.4
2	40	2.5	420	0.058	4
3	60	2.5	420	0.048	3.4

Table 7.4b: Experiment 6,7&8 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.92	0.92	0.92	0.92	2.15	1.23	99.2
40	1.23	1.8	0.57	0.57	1.2	0.63	0.63	201
60	0.63	2	1.37	1.37	2.2	0.83	0.83	265.6

Table 7.5a: Experiment 9 for SACE

Date: 19/5/2021	Day: Monday
System: Batch system	Experiment No: 9
Effect of operating parameters	
pH: 5	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.5A	
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	50	-	420	0.053	4.2

Table 7.5b: Experiment 9 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	0	1	1	1	1.8	0.8	0.8	256

Table 7.6a: Experiment 10,11&12 for SACE

Date: 20/5/2021	Day: Tuesday
System: Batch system	Experiment No:**10,11&12**
Effect of operating parameters	
pH: 7	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.4A	
Reaction Time:1hr minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	20	2.2	420	0.105	4.84
2	40	2.2	420	0.064	4.4
3	60	2.2	420	0.045	4.2

Table 7.6b: Experiment 10,11 &12 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
20	0	0.87	0.87	0.87	2.09	1.22	1.22	112
40	1.22	2.11	0.89	0.89	2.11	1.2	1.2	99.2
60	1.2	2.1	0.9	0.9	2.1	1.2	1.2	96

Table 7.7a: Experiment 13 for SACE

Date: 21/5/2021	Day: Wednesday
System: Batch system	Experiment No:13
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode: Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.3A	
Reaction Time:30 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	30	2.4	420	0.079	5.32

Table 7.7b: Experiment 13 COD determination for SACE

	Sample			Blank				
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial	Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
30	0	0.98	0.98	0.98	2.2	1.22	1.22	76.8

Table 7.8a: Experiment 14 for SACE

Date: 22/5/2021	Day: Thursday
System: Batch system	Experiment No:14
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode : Al In-between electrode distance: 1cm
Sono-alternative Current electrocoagulation	
Current Ampere: 0.4A	
Reaction Time:40 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	40	2.4	420	0.064	4.4

Table 7.8b: Experiment 14 COD determination for SACE

	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.91	0.91	0.91		2.13	1.22	1.22	99.2

Table 7.9a: Experiment 15 for SACE

Date: 23/5/2021	Day: Friday
System: Batch system	Experiment No:15
Effect of operating parameters	
pH: 9	Electrode material: Anode and cathode: Al
Sono-alternative Current electrocoagulation	
Current Ampere: 0.5A	In-between electrode distance: 1cm
Reaction Time:50 minute	Mode of Electrode Connection: Parallel

Treatment Interval	Time (min.)	Volts	Color		Turbidity(NTU)
			Wavelength(nm)	Abs.	
1	50	2.4	420	0.064	4.16

Table 7.9b: Experiment 15 COD determination for SACE

	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
50	0	0.92	0.92	0.92		2.12	1.2	1.2	89.6

Table 7.10 a: Experiment 16 for SACE

Date:24/5/2021					Day: Saturday				
System: Batch system					Experiment No: 16				
				Effect of operating parameters					
pH: 7							Electrode material:		
Sono-alternative Current electrocoagulation									
								Anode and Cathode: Al	
Current Ampere: 0.4A							In-between electrode distance: 1cm		
ReactionTime:40minute							Mode of Electrode Connection: Parallel		
Treatment	Time			Color					
Interval	(min.)		Volts	Wavelength(nm)	Abs.			Turbidity(NTU)	
1	40		2.3	420	0.064			4.4	

Table 7.10b: Experiment 16COD determination for SACE

	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.89	0.89	0.89		1.2	0.3	0.3	99.2

Table 7.11 a: Experiment 17 for SACE

Date:26/5/2021					Day: Monday				
System: Batch system					Experiment No: 17				
				Effect of operating parameters					
pH: 7							Electrode material:		
Sono-alternative Current electrocoagulation								Anode and Cathode: Al	
Current Ampere: 0.4A							In-between electrode distance: 1cm		
ReactionTime:40minute							Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)			Color					
			Volts	Wavelength(nm)		Abs.		Turbidity(NTU)	
1	40		2.6	420	0.064			4.4	

Table 7.11 b: Experiment 17 COD determination for SACE

	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.89	0.89	0.9		1.2	0.31	0.31	99.3

Table 7.12 a: Experiment 18 for SACE

Date:27/5/2021				Day: Tuesday			
System: Batch system				Experiment No: 18			
				Effect of operating parameters			
pH: 7						Electrode material:	
Sono-alternative Current electrocoagulation						Anode and Cathode: Al	
Current Ampere: 0.4A						In-between electrode distance: 1cm	
ReactionTime:40minute						Mode of Electrode Connection: Parallel	
Treatment	Time			Color			
Interval	(min.)		Volts	Wavelength(nm)	Abs.	Turbidity(NTU)	
1	40		2.5	420	0.065	4.42	

Table 7.12 b: Experiment 18 COD determination for SACE

	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
40	0	0.89	0.89	0.9		1.22	0.32	0.32	102

Table 7.13 a: Experiment 19 for SACE

Date:28/5/2021					Day: Wednesday				
System: Batch system					Experiment No: 19				
				Effect of operating parameters					
pH: 7							Electrode material:		
Sono-alternative Current electrocoagulation									
								Anode and Cathode: Al	
Current Ampere: 0.4A							In-between electrode distance: 1cm		
ReactionTime:40minute							Mode of Electrode Connection: Parallel		
Treatment Interval	Time (min.)			Color					
			Volts	Wavelength(nm)		Abs.		Turbidity(NTU)	
1	40		2.5	420	0.0652			4.44	

Table 7.13 b: Experiment 19 COD determination for SACE

	Sample			Blank					
Time	Initial	Final	FAS	Initial		Final	FAS Volume	FAS	COD
(min.)			Volume				down the	volume	(mg/L)
			down the				burette(mL)	(mL)	
			burette(mL)						
40	0	0.91	0.91	0.91		1.21	0.31	0.31	99.2

Table 7.14 a: Experiment 20 for SACE

Date:29/5/2021					Day: Thursday				
System: Batch system					Experiment No: 20				
				Effect of operating parameters					
pH: 5							Electrode material:		
Sono-alternative Current electrocoagulation									
								Anode and Cathode: Al	
Current Ampere: 0.4A							In-between electrode distance: 1cm		
ReactionTime:40minute							Mode of Electrode Connection: Parallel		
Treatment	Time			Color					
Interval	(min.)		Volts	Wavelength(nm)	Abs.			Turbidity(NTU)	
1	40		2.6	420	0.064			4.4	

Table 7.14b: Experiment 20 COD determination for SACE

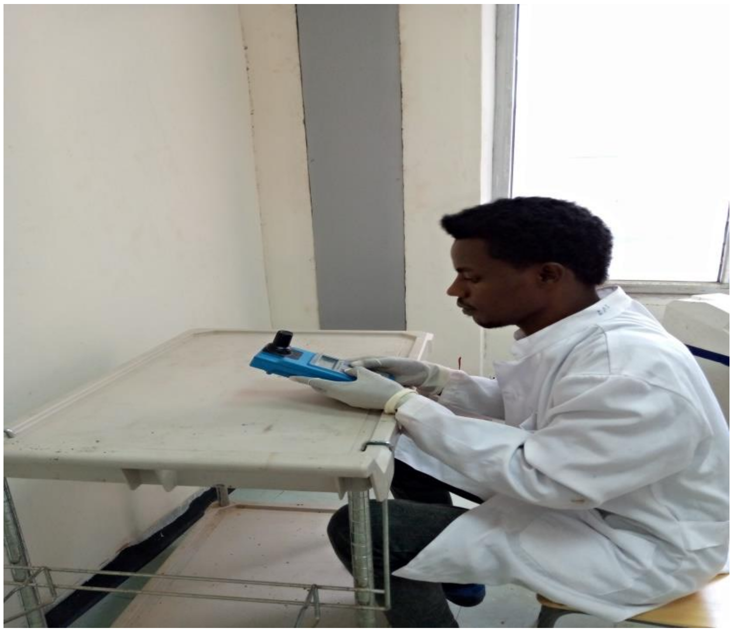
	Sample			Blank					
Time (min.)	Initial	Final	FAS Volume down the burette(mL)	Initial		Final	FAS Volume down the burette(mL)	FAS volume (mL)	COD (mg/L)
0	0.89	0.89	0.89	0.89		1.2	0.31	0.31	99.2

Annex 2

Some Figures Illustrate Lab activities.

a) During COD determination

b) During Color determination



C) During Turbidity determination