ISLAMIC UNIVERSITY OF TECHNOLOGY

DHAKA, BANGLADESH

ORGANIZATION OF ISLAMIC COOPERATION

B.Sc. (Civil & Environmental Engineering) Thesis on "Industrial Dye Wastewater Treatment by Electrocoagulation"

Authored by

Md. Al Farabe
Student ID: 170051050

Md. Ashraful Haque
Student ID: 170051074

Nafis Islam
Student ID: 170051078

Kazi Taimur Shabib
Student ID: 170051086

Supervised by
Dr. Amimul Ahsan
Assistant Professor
Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)
Boardbazar, Gazipur, Bangladesh.

Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)

May 2022

DECLARATION

We hereby declare that the thesis under the supervision of Dr. Amimul Ahsan entitled "Industrial Dye Wastewater Treatment by Electrocoagulation", has been performed by us and this work has not been submitted elsewhere for reward of any degree or diploma (except for publication).

22 May, 2022

Farabe

Md. Al Farabe
Student ID: 170051050

Ashraful

Md. Ashraful Haque
Student ID: 170051074

Nafis Islam
Student ID: 170051078

Taimur

Kazi Taimur Shabib
Student ID: 170051086

DR. AMIMUL AHSAN
Assistant Professor,
Department of Civil and Environmental Engineering (CEE)
Islamic University of Technology (IUT)
Boardbazar, Gazipur, Bangladesh.

APPROVAL

This is to certify that the thesis submitted by Md. Al Farabe (170051050), Md. Ashraful Haque (170051074), Nafis Islam (170051078), and Kazi Taimur Shabib (170051086) have been found as satisfactory and accepted as partial fulfillment of the requirement for the Degree Bachelor of Science in Civil & Environmental Engineering has been approved for the Bachelor of Science Degree in Civil and Environmental Engineering.

SUPERVISOR

_____

DR. AMIMUL AHSAN

Assistant Professor,

Department of Civil and Environmental Engineering (CEE)

Islamic University of Technology (IUT)- OIC,

Boardbazar, Gazipur, Bangladesh.

DEDICATION

We dedicate this thesis work to our loving parents. We also express our heartfelt gratitude to our respected supervisor Dr. Amimul Ahsan.

ACKNOWLEDGEMENT

First and foremost, we express our heartfelt gratitude to Almighty Allah. We are truly blessed to have had the opportunity to conduct this type of research and the people and events that have taken part in my life to make this research possible. Thank you for being so gracious with these things, Almighty. We have been given more blessings than we deserve, and I intend to share our abundance with the rest of the world.

We'd also like to thank our family, particularly our parents, for always believing in us and showing unwavering love and support. They have made self-sacrifices for the sake of their children's advancement and prosperity, and they have served as the embodiment of love in my life.

We must express our humble gratitude to our respected supervisor Prof. Dr. Amimul Ahsan, Assistant Professor, Department of Civil and Environmental Engineering (CEE), Islamic University of Technology (IUT), for his generosity and kindness. His extensive research knowledge influenced us to carry out this project. His unending patience, knowledgeable advice, reading many inferior drafts and correcting them in all circumstances have helped us reach this point.

We want to thank all the staff members for their sincere cooperation.

ABSTRACT

Wastewater is not only one of the leading causes of permanent environmental damage, but it also contributes to the depletion of freshwater reserves on the planet, posing a major threat to future generations. Many industrial operations use a lot of freshwaters, dumped as wastewater. This wastewater must be treated adequately to decrease or eliminate pollutants and attain the purity level needed for re-use in industrial processes to ensure sustainability. Industrial wastewater contains a high concentration of organic pollutants that are active agents in water pollution. This research was conducted to remove various contaminants from industrial wastewater using electrolysis. Electrolysis is a very effective wastewater treatment method for removing contaminants and creating hydrogen gas as a revenue stream to compensate for operating costs. The removal efficiency of these treatments for chemical oxygen demand (COD), total suspended solids (TSSs), color, and turbidity from industrial wastewater was investigated using a simple electrolytic reactor at different electric current densities (CDs) and retention times (RTs). Our experiment observed that the highest removal efficiency for the parameters COD, TSS, turbidity, and color was obtained for 50V electricity and 4 hours RT, and the values are 73.92%, 91.67%, 73.63%, and 92.86%, respectively. It was also observed that as CD and RT increased, so did the removal efficiency of COD, TSS, turbidity, and color. Before the treatment, COD, TSS, turbidity, and color values for raw wastewater were 69 mg/L, 12 mg/L, 3.11 NTU, and 168 PT-Co, respectively. And after the electrocoagulation, COD, TSS, turbidity, and color values decreased to 18 mg/L, 1 mg/L, 0.82 NTU, and 12 PT-Co, respectively, for 50V electricity and 4 hours RT. However, as CD and RT levels increased, the parameters like pH, DO, salinity, TDS, and electrical conductivity (EC) also increased. It was noticed that the change in turbidity is proportional to the change in TSS. A linear and proportional relationship between EC and TDS was also observed in this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 General

Water contamination is a major issue that puts our health at risk. Unsafe water kills more people every year than all forms of violence combined. Meanwhile, our sources of drinkable water are limited. We only have access to only 1% of the world's freshwater. Without intervention, the situation will worsen by 2050, when global freshwater demand is anticipated to be one-third more than it is currently.

Water contamination can come from a variety of places. Waterways are mostly contaminated by chemicals and heavy metals from industrial and municipal wastes. These contaminants are toxic to aquatic life. These toxins reduce an organism's lifespan and ability to reproduce. When chemicals are dissolved or suspended in water, such as during the use of water in an industrial production process or cleaning activities related to that process, industrial wastewater is created. The purpose of industrial wastewater treatment is to remove dissolved or suspended pollutants. The easiest strategy to create an effective and economical industrial wastewater treatment technique is to understand how compounds dissolve or suspend in water and then deduce probable chemical or physical activities that would reverse those processes.

Almost every industry generates wastewater. In recent years, there has been a tendency toward reducing such production or recycling treated wastewater in the manufacturing process. By reorganizing their manufacturing processes, some businesses have been able to decrease or eliminate pollution. Industrial wastewater comes from a variety of sources, including battery manufacturing, electric power plants, food processing, iron and steel production, mines and quarries, nuclear power, oil and gas extraction, organic chemicals production, petroleum refining and petrochemicals, pulp and paper production, smelters, textile mills, industrial oil contamination, water treatment, and wood preservation. Some treatment methods include electrolysis, brine treatment, solids removal (e.g., chemical precipitation, filtering), oils and grease removal, biodegradable organics removal, other organics removal, and acids and alkalis and toxic compounds removal.

Electrolysis is a typical wastewater treatment option that has been widely studied for a variety of wastewater types due to its adaptability, ease of setup, small footprint, and eco-friendly nature. The primary aspects that define the process pollutant removal mechanism, as well as the operational variables that are critical to electrolysis and the fundamental link between electrolysis and classical chemical coagulation, have all been investigated. As a result, more research into process parameter optimization and modeling is needed for industrial scale-up of electrolysis. Due to its overall low footprint need, environmental sustainability, and tremendous potential for continuous operation without requiring major supervision, the electrolysis technology certainly stands out as the future of wastewater treatment.

1.2 Background

Electrolysis is a method of decomposing ionic compounds into their constituent components by sending electricity through them in liquid form. A chemical change caused by transmitting electricity through a substance can also be defined. Both oxidation and reduction occur concurrently at the anode and cathode, respectively, in this chemical reaction. To achieve successful electrolysis, some essential components are required. Electrodes, an electrolyte solution, and an external power source, preferably with a partition such as a salt bridge or an ion-exchange membrane, are among them. Martinus Van Marum, a Dutch scientist, was the first to effectively use electrolysis in 1785. It was used to remove zinc, antimony, and tin from their respective salts. He was, however, unaware that he was employing electrolysis at the time. William Nicholson and Anthony Carlisle discovered how electrolysis works fifteen years later, in 1800. (Ashworth, 2015). In 1817, Johan August Arfwedson discovered that some of his samples included an additional element, lithium. However, due to time constraints, he was unable to separate them. William Thomas Brande successfully isolated lithium from the aforementioned substances using electrolysis in 1821. In 1823, he improved the technique by electrolyzing lithium chloride and potassium chloride to produce lithium and lithium hydroxide (Helmenstine, 2018). Michael Faraday established two laws of electrolysis while working as an assistant to Humphry Davy ("The History of Electrochemistry", 2019). When Paul Émile Lecoq de Boisbaudran conducted electrolysis on gallium hydroxide in November of 1875, he discovered gallium.

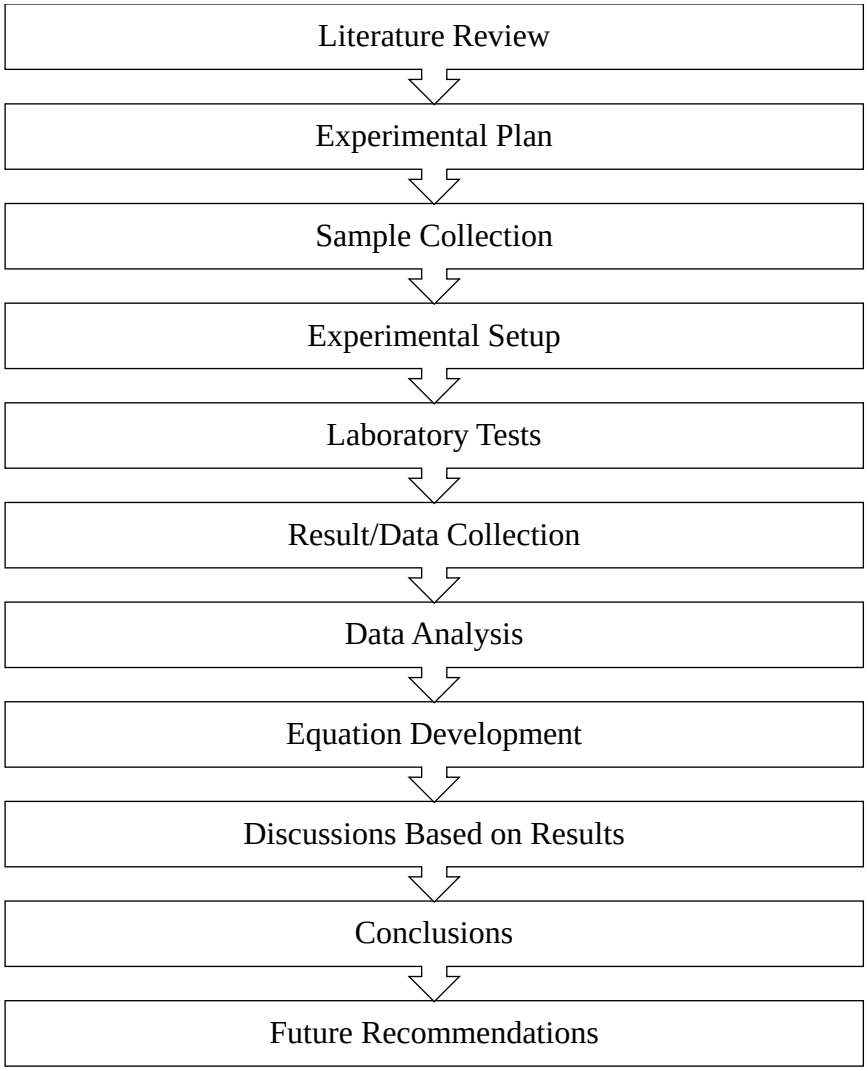
3.4 milligrams of gallium were produced as a result of this experiment. In December of the same year, he presented his discovery of gallium to the Academie des Sciences in Paris (Marshall et al., 2002).

1.3 Objectives of the Study

The study's objectives are to verify previous studies' claims and treat wastewater more efficiently. This paper presents the formulation of generalized equations for the predictions of efficiency of pollutants removal from wastewater based on an experimental investigation to develop a simple mathematical model. Here, in this study, we have to measure the parameters of the wastewater before and after electrolysis, calculate the removal efficiency (RE) for each parameter, and make the relation between the removal efficiency (RE) and retention time (RT) at a specific voltage. The mathematical relationship will help us to estimate the better removal of each parameter at different electric densities in the future.

1. To determine the characteristics of raw industrial dyewater wastewater.
2. To understand the variation of removal of different parameters.
3. To determine the effects of various voltages and retention time on pollutants removal from industrial dyewater wastewater by electrocoagulation.
4. To develop the relationship between TSS & Turbidity and EC & TDS.
5. To understand the relationships between the retention time and deposition.

1.4 Research Flow Diagram



1.5 Outline of Thesis

Chapter 1 thoroughly covers the study's background and aims. It also shows the research flow diagram and the outline of the study. Chapter 2 discusses the electrolysis of wastewater using different types of electrodes and electrolytic treatments based on literature reviews. It also discusses the significance and effectiveness of electrolysis based on findings of recent research. Chapter 3 presents information on the development of the method used to conduct the electrolysis and the laboratory experiments in this study. In addition, it shows the development of mathematical equations of removal efficiency,

electric voltage, and retention time. Chapter 4 presents the results of the tests performed on the wastewater after electrolysis at different retention times. It also shows the relationship between removal efficiency, voltage, and retention time for different parameters. Chapter 5 summarizes the conclusions reached due to this study's findings and makes recommendations for further research.

CHAPTER 2: LITERATURE REVIEW

2.1 General

This chapter will discuss and expand upon the efficiency of electrolytic systems in the treatment of wastewater and the processes, functions, and conditions that result in such efficiency. It will elaborate on electrolysis as a significant wastewater treatment process and its implementations on an industrial scale. The efficiency of electrolysis on the parameters of wastewater will also be discussed.

2.2 Electrolysis in Water Treatment

Electrolytic treatment of wastewater involves utilizing electrical energy to remove all solid wastes from wastewater. This is achieved through an electrochemical reaction, the nature of which depends on the type of wastes present in the wastewater as well as the electrodes used in the process. There are different electrolytic methods done through various devices and apparatus. A significant advantage of using electrolysis treatment is that it does not require any special reagents or chemicals or costly apparatus. It has a very low impact on the environment if renewable energy sources are used (Zoulias et al., 2004). It also produces extremely little sludge that dissipates very efficiently (Bayramoglu et al., 2006).

Multiple studies have been carried out on electrolysis using iron, steel, aluminium etc., as electrodes. These studies have focused on removing chemical pollutants, heavy metals, and other solid wastes from different wastewater samples collected from different locations. Electrolysis has been proven to be effective on different types of polluted water such as poultry wastewater (Bayramoglu et al., 2006), laundry wastewater (Wang et al., 2009) and industrial wastewater (Mahmoud and Hoadley, 2012). The electrodes best suited for electrochemical wastewater treatment are generally Aluminum (Al), Iron (Fe), steel and

graphite (Kumar et al., 2011). Electrolysis has been effective in the treatment of fly ash leachate (Tao et al. 2014). (Kabuk et al., 2014) investigated the use of electrocoagulation to remove pollutants from leachate. Fernandes et al. (2014) carried out another study which involved a combination of the electrocoagulation process (ECP) and Anodic Oxidation (AO). The reasoning behind this combination was to increase the biodegradability of leachate obtained from landfills. Electrolysis is also among several novel technologies studied to remove phosphorus (P) from manure and runoff (Liang, 2011; Cho et al., 2010).

However, all these tests and experiments have been conducted on a laboratory scale and performances of the same processes multiple times under different conditions, whether laboratory or industrial scale, will require much more time, effort, and data. Generally, mathematical modeling study aids in reducing the need to conduct numerous experiments. The availability of a good set of preliminary experimental data can help a mathematical model replicate different experimental conditions successfully. The parameters of the different conditions include BOD, COD, TSS, TDS, color, turbidity, odor etc. These vary depending on both external and internal factors.

2.3 Efficiency of Electrolytic Treatment

Electrochemical treatment has yielded promising results in treating wastewater due to its high effectiveness, lower costs and labour requirements and faster output of results (Feng et al., 2003). Treatment of wastewater through different electrolytic processes has been very effective. Multiple varied methods of electrolytic treatments have been adopted to remove different types of solid wastes from different types of wastewater. Electrocoagulation is a process where destabilised agents (Al, Fe etc.) are produced electrochemically to neutralise electric charge to remove pollutants. This process has proved to be highly effective in removing contaminants from water, has produced less sludge, requires no chemical use and is easy to operate (Rajeshwar et al., 1997).

Aluminum plates can be used as electrodes to produce Al^{3+} ions by connecting the plates to a low power supply, which will produce Al^{3+} ions, which will attract all the negatively charged particles, therefore causing their coagulation and sedimentation (Matteson et al., 1995; Chen et al., 2000). Electro-flotation (EF) is another method used

for separating substances. Here, electrically generated minuscule gas bubbles of hydrogen and oxygen interact with pollutant particles causing them to coagulate and float on the surface of the water body (Raju, 1984).

An investigation was undertaken by Kabuk et al. (2014), where an electrocoagulation process was used to remove pollutants from leachate. Removal efficiencies thus achieved were 60.5%, 92.4%, 60.8%, 28.3%, and 28.9% for COD, total suspended solids (TSS), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and ammonia nitrogen, respectively. Fernandes et al. (2014) used a combined method of electrocoagulation process (ECP) and Anodic Oxidation (AO) to increase the biodegradability of leachate from landfills. Complete removal of chromium was achieved through ECP, alongside partial zinc removal. In the AO process that followed, removal of the remaining zinc was also achieved. Zailani et al. (2018) investigated the pollutant removal efficiency of an electrocoagulation technique, where an aluminum electrode was used. The technique was used for removing pollutants from leachate. It was reported that an application of a current density of 200 A/m^2 under optimum conditions and a pH value of 4.0 for a duration of 20 minutes resulted in a 60% removal of COD, 37% removal of ammonia, 94% removal of color, 88% removal of turbidity and 89% removal of suspended solids. (Zailani et al.,2018)

A low-cost process investigated by Ahsan et al. (2014), used activated carbon filtration alongside electrolysis to treat leachate. The process resulted in 75.6%, 57%, 72%, and 83.1% removal efficiencies of BOD, COD, TDS, and TSS. The entire process had a retention time of 4 hours and a current of 7 V. The removal efficiencies, however, increased for all the mentioned pollutants simultaneously once filtration with activated carbon was applied after electrolysis was completed. COD removal efficiency increased from 7.5% to 38. 5% at 3 V and from 31.1% to 49.5% at 5 V, while under the same conditions, BOD removal efficiency increased from 54.6% to 61.5% at 3 V and from 66.4% to 70.5% at 5 V. (Ahsan et al., 2014)

The effects of pH, NaCl and electrode distance on the efficiency of electrolysis in treating BOD, COD, TDS, TSS, turbidity, salinity, zinc (Zn) and manganese (Mn) have been investigated by Erabee et al. (2017). A most efficient condition was reported: an electric potential of 60 V, a retention time of 120 minutes, and a 5% NaCl solution using aluminum (Al) as the anode and iron (Fe) as the cathode kept 3 cm apart. Under optimum conditions, 94% COD removal and a 93% Mn removal were achieved. Sousa et al. (2019)

investigated the effectiveness of electrolysis and photo-assisted electrolysis in the presence of chloride in removing TOC, COD, BOD, pH, chlorides, color, conductivity, and turbidity from dairy waste. More than 90% of TOC and COD were removed through only electrolysis (with chloride), and more than 95% of TOC AND COD were removed through photo-assisted electrolysis (with chloride). The effect of current density, coagulant concentration, oil concentration, flotation time, and other such operating parameters on the performance of the EF cell was investigated by Mansur and Chalbi (Ben Mansur et al., 2006). A 99.5% maximum change in the percentage of oil removal was observed, with a flotation time of 40 minutes, an initial oil concentration of 1000 mg dm^3, a current density of 120 $A/m^{2,}$ and 3.5% NaCl by wt with an additional 30 mg dm^3 coagulants. (Ben Mansur et al., 2006)

All the studies on the efficiency of electrolysis in wastewater treatment mentioned so far are based purely on experiments carried out in a laboratory. As mentioned earlier, the implementation of these processes on an industrial scale will require the development of mathematical models based on the investigated processes. There have been a few mathematical modeling studies that have been successful in conducting such experiments successively with satisfactory results. A three-parameter optimization that utilizes the response surface method to put forward the best conditions for treating pollutants such as COD, TSS, TKN, TOC, and ammonia-nitrogen was used by Kabuk et al. (2014).

A second-order full polynomial model was proposed eventually, which can replicate the optimization studies' results. A simulation model was developed by Curteanu et al. (2011), which predicts the efficiency of algae removal from water through electrolysis by using neural networks. The problem with this model is that it is a neural network model. Neural network models are black-box type models and therefore incapable of immediately providing output based on the particular input. A physically-based numerical model was developed by Gößling et al. (2018) for predicting the behavior of a PEMEC (Proton Exchange Membrane Electrolysis Cell) depending on certain conditions such as current density, cell temperature, and parameters specific to the cell (electrical resistance of the cell, thickness, and conductivity of the membrane). This particular method needs to be calibrated to a specific electrolyzer and the measured polarization curve of the said electrolyzer. Such complex calibration is essential due to the production processes of the components as well as the individual materials. (Gößling et al., 2018)

2.4 Significance and Effectiveness of Electrolysis Treatment methods

Many different methods of electrolysis treatment have been tried and tested, with some being successful and others not so much. However, the fact remains that electrolysis remains one of the best ways to acquire clean water, something that is becoming scarcer by the year. It is perhaps the most important approach that has emerged to resolve problems of water contamination (Módenes et al., 2012; Chen, 2004). One of the reasons is the fact that in electrochemical processes, applying constant current results in the continuous generation of active reagents at the surface of the electrodes (Moussa et al., 2017). In electrocoagulation (EC), another electrochemical treatment technology, the cation coagulants of either iron or aluminum are generated by applying a direct current to the electrodes. Metal hydroxides produced during this process can act as coagulant/flocculant and therefore separate charged pollutants from the wastewater. This phenomenon is very useful for removing high amounts of chromium and organic matter present in tannery wastewater (Elabbas et al., 2016; Benhadji et al., 2011; Brillas et al., 2015). The same process can be used to remove heavy metals from other wastewater sources. (Elabbas et al., 2016; Benhadji et al., 2011; Brillas et al., 2015).

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter will include a summary of the experimental methods of the study. It will include the collection and preparation of wastewater, properties of the wastewater and the apparatus involved in the experiment, setup of the apparatus, preparation of samples, and the method of electrolysis used.

3.2 Wastewater Proportions and Case Study

The wastewater was collected from Dyeing mills, and the volume was 5L. During the experiment, four beakers were used. One beaker was used to test the water parameters of our Raw sample water which is dyeing water. Its volume was 400 ml. The other three beakers were used for electrolysis treatment for 1 hour, 2 hours, and 4 hours retention time. Each beaker had nearly 500 ml of wastewater.

Figure 3.1: Dye Wastewater Sample

3.3 Preparation of Materials and Apparatus

In order to carry out the case study properly, the materials and apparatus were prepared accordingly. This involved the standard procedures for laboratory equipment. This experiment required the standard materials needed for electrolysis, including beakers, electrodes and a stable power source. The wastewater and seawater needed for the experiment was collected beforehand and stored in a secure location. For electrodes, the materials used were steel rulers. The beakers must be large enough to accommodate the necessary volume of wastewater. For a power source, a laboratory DC power supply was used. Wires are used to connect the electrodes to the power supply and to the electrodes of the adjacent beakers.

3.3.1 Laboratory DC Power Supply

A laboratory DC power supply is a machine that gives an adjustable stabilized DC (direct current) output voltage between the specified range (e.g. 0 and 30 V DC). It includes an adjustable current limiter, which is used to limit the output current to the set maximum by decreasing the output voltage. This is important because it can prevent the electric circuit from being destroyed in case the output current exceeds the set value.

Figure 3.2: DC Power Supply

3.3.2 Multiparameter Meter

A multiparameter meter is a device, or an instrument used to measure multiple electrochemical parameters including, but not limited to, pH, conductivity, dissolved oxygen, salinity, temperature, and turbidity. Multiparameter meters are a crucial element in any kind of electrochemical measurement. Scientists across the globe rely on such instruments for acquiring accurate measurements of multiple different chemicals simultaneously.

The device cannot be used immediately and must be prepared first. The first step is to properly calibrate the meter. The order of calibration is temperature, specific electrical conductance, dissolved oxygen, pH, oxidation-reduction potential, turbidity, and ion-selective electrodes, followed by chlorophyll-fluorescence and other sensors. After the sample has been prepared, the multiparameter meter is used to take the readings of each parameter.

Figure 3.3: Multiparameter Meter

3.3.3 Spectrophotometer

A spectrophotometer is a device that measures the intensity of light beams at different wavelengths. To generate the analytical spectrum, a spectrophotometer employs a monochromator with a diffraction grating (which can be fixed or movable). In a spectrophotometer, a light source is shone into the monochromator, diffracted into a rainbow, and split into two beams, which are then scanned through the sample and reference solutions. Fractions of the incident wavelengths are either transmitted through or reflected from the sample and the reference. The photodetector device is then struck by the resulting beam of light and compares the relative intensities. Electronic circuits convert relative currents into linear transmission percentages and absorbance or concentration measurements.

Figure 3.4: Spectrophotometer

3.3.4 Turbidity Meter

A turbidity meter is used to measure the cloudiness or turbidity of a liquid caused by suspended solids in the sample. Sometimes also termed water clarity, turbidity is often used as a measure of the sanitary quality of water and often indicates that filters are not working properly.

Figure 3.5: Turbidity Meter

3.4 Wastewater and Seawater

The wastewater was collected from an industrial dyeing plant in Madhobdi. The wastewater is untreated effluent from the plant. Seawater was collected from Cox's Bazaar. After collecting, both were kept in a secure place to prevent any unwanted reactions.

3.5 Properties of Wastewater and Seawater

Unlike freshwater, seawater is naturally saline and slightly basic in nature. It also has some unique properties. The freezing point of seawater is slightly lower than freshwater. Due to the presence of multiple salts and other compounds, the density of seawater is somewhat higher than that of freshwater. The presence of salts also gives it a comparatively higher electrical conductivity.

Wastewater also has some specific characteristics. Different types of wastewater have different qualities. Some types have a higher concentration of inorganic matter, while others have more organic matter. The wastewater used in this experiment is effluent from a dyeing plant. Such wastewater contains dyes mixed with a variety of pollutants at various concentrations.

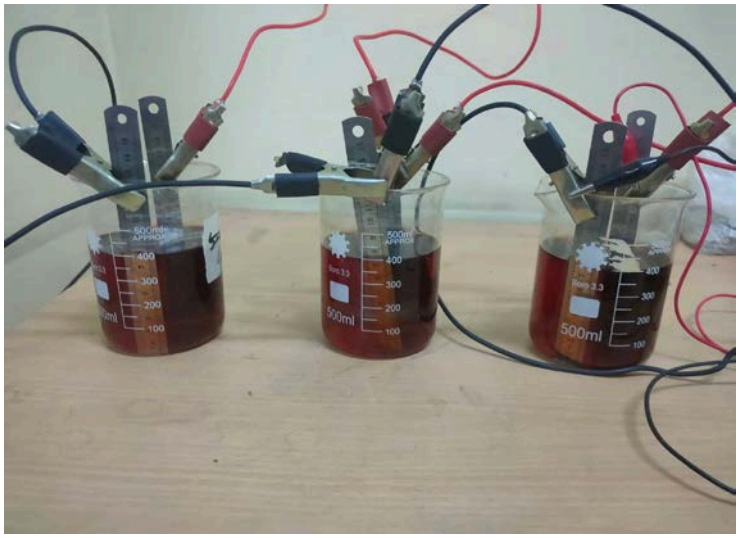
Usually, this effluent is treated before being discharged into the nearest waterbody. For the experiment, the effluent has been collected before undergoing any treatment procedures, so that the state of the effluent remains unaffected.

3.6 Experimental Setup

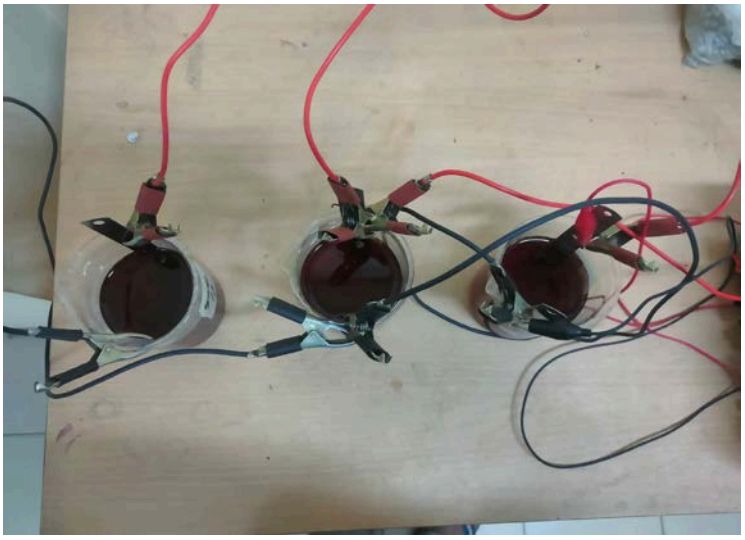
After the preparation of the necessary apparatus, the experiment was set up accordingly. Three beakers were used at a time. The wastewater was poured into the beakers. Two steel rulers (acting as electrodes) were placed in each beaker, being the anode and cathode, respectively. The three beakers will be connected in a series connection.

3.7 Sample Preparation

Each beaker is rinsed thoroughly with distilled water (and other cleaning agents if required), so that the wastewater does not have an adverse reaction to any traces of foreign substances. The beakers are filled with approximately 500 ml of wastewater. The rulers are placed at the two sides of each beaker, half-submerged in the wastewater. The electrodes of the first beaker are then connected to the DC power supply with the wires. The electrodes of the remaining two beakers are then connected to the electrodes of the first beaker in a series connection.



(a)

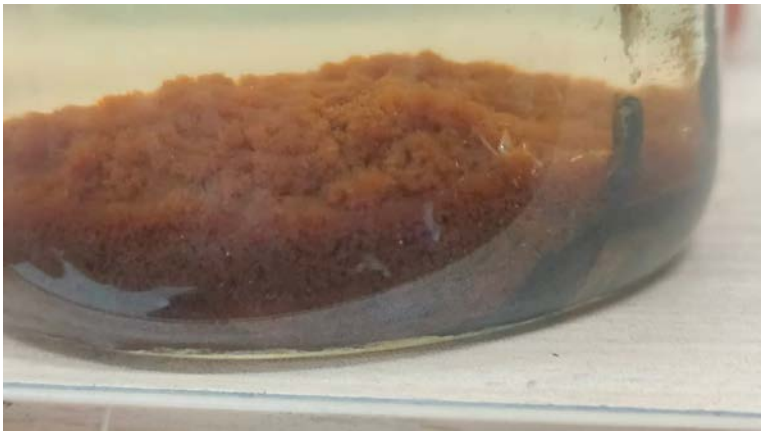


(b)

Figure 3.6: (a) Experimental Setup of Side View and (b) Experimental Setup of Top View

3.8 Scum and Cathode-Anode:

After treating the water, scum was measured, and it was also seen the cathode was decayed more severely than the anode due to the electrolysis process. The scum layer was formed in the cathode due to electrolysis.



(a)

(b)

Figure 3.7: Deposition of Scum (a) Side View and (b) Top View

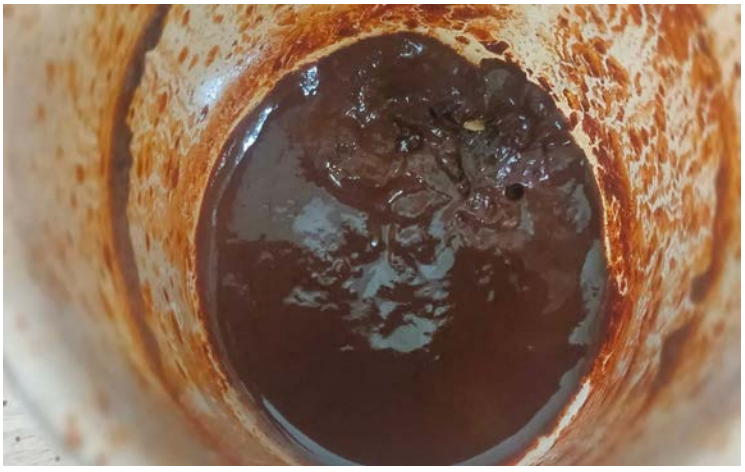


Figure 3.8: Scum Settlement at 60V

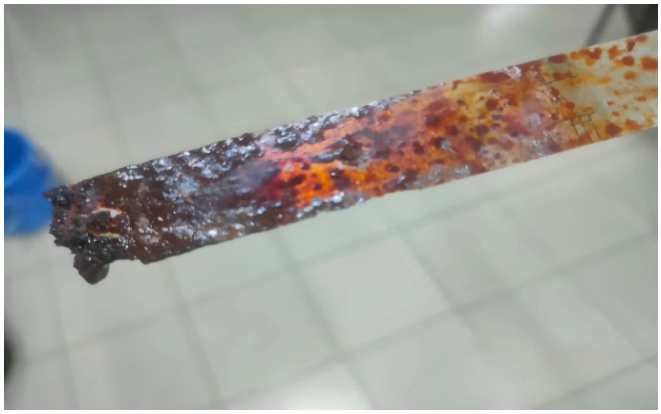


Figure 3.9: Cathode After Experiment

3.9 Testing

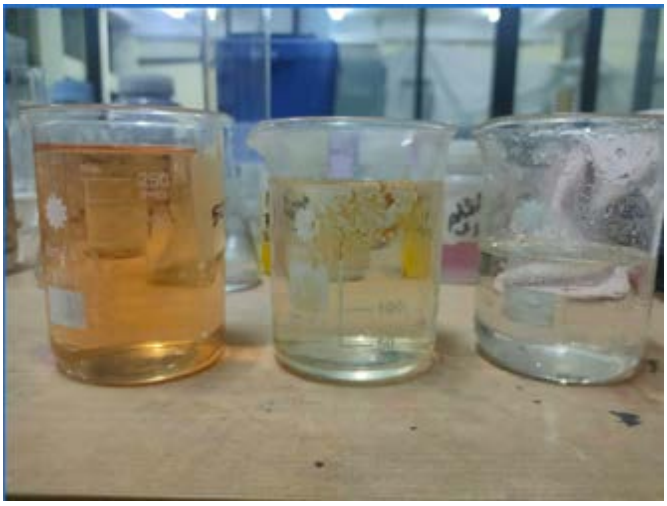
The power supply is switched on to start the electrolysis. The machine will be running continuously for 4 hours. Readings on each of the beakers are taken after intervals of 1, 2, and 4 hours, respectively. At each interval, the following tests are run on the wastewater to record the changes:

- Turbidity
- pH test
- DO (Dissolved Oxygen)
- COD (Chemical Oxygen Demand)
- TDS (Total Dissolved Solids)
- TSS (Total Suspended Solids)
- Color test
- EC (Electroconductivity)
- Salinity test

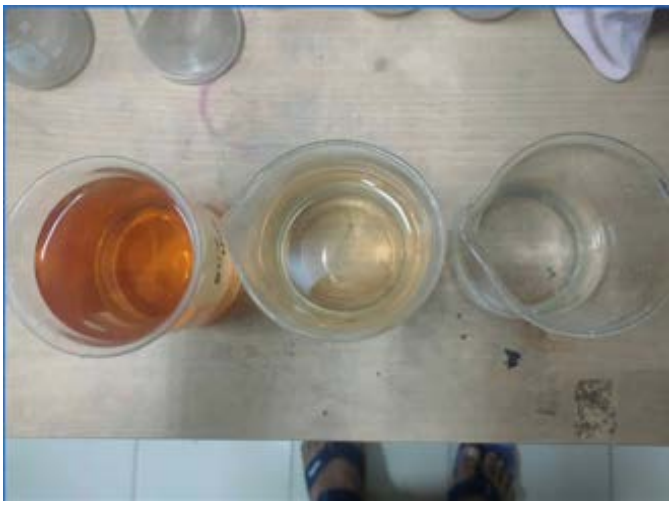
Figure 3.10: Testing of Samples

3.10 Before and After Case Study

It was seen that before the experiment, the color of the dyeing waster was yellowish, and it was cloudy due to turbidity. However, the color and the turbidity get clearer after the experiment, and after using filtration, the water gets very clear and uncloudy.



(a)



(b)

Figure 3.11: Visual Change After Treatment (a) Side View and (b) Top View

CHAPTER 4: RESULTS AND DISCUSSION

4.1 General

This chapter summarizes and discusses the results obtained throughout the investigation. The effects of varying voltages and retention times on wastewater are examined and discussed. The correlation between EC and Total Dissolved Solids (TDS) and Turbidity and TSS have also been discussed. Moreover, equations have been developed to construct a mathematical model for this electrocoagulation treatment process. We also compared the water characteristics among the treated water samples and the raw wastewater sample.

4.2 Wastewater and Treated Water Characteristics Analysis

Important water quality parameters such as pH, TDS, COD, EC, Salinity, DO, TSS, TDS, Color etc. were analyzed for the raw wastewater and the treated water samples. From the analysis, we can see the characteristics of the water samples before the treatment and after the treatment. For 30V, from Table 4.1, It was seen that as the retention time increased, the value of most of the parameters also increased. However, COD, Color, TSS and Turbidity decreases with RT. The height of the scum also increased with time, and no scum was noticed in the Raw Wastewater sample. But as our experiment proceeded with time and voltages, the scum heights eventually started to increase.

The raw dyewater was alkaline, cloudy, wine red colored having a higher value of COD, TSS, Turbidity, Color. On the other hand, after the electrolysis, the value of TSS, COD, Turbidity, and color decreased with higher value of voltages and retention time. The treated water remains more alkaline, more saline, having more electroconductivity and dissolved oxygen.

Table 4.1: Wastewater Characteristics Analysis (with 30V)

	Wastewater	RT (1 hr)	RT (2 hr)	RT (4 hr)
pH	8.56	8.82	8.83	8.85
TDS (mg/L)	837	995	1060	1081
EC (µS/cm)	1672	1972	2113	2129
Salinity (‰)	0.83	1	1.07	1.09
DO (mg/L)	7.23	7.25	7.28	7.42
Turbidity (NTU)	3.11	2.31	1.73	0.92
TSS (mg/L)	12	9	7	4
Color (PT-Co)	168	94	35	25
COD (mg/L)	69	66	47	40
Scum height (cm)	0	0.5	0.8	1.8

For 40V, we get a similar characteristic from the treated water sample in which COD, Color, TSS, and Turbidity decreases with RT and other parameters increase with RT in Table 4.2.

Table 4.2: Wastewater Characteristics Analysis (with 40V)

	Wastewater	RT (1 hr)	RT (2 hr)	RT (4 hr)
pH	8.56	8.72	9	9.06
TDS (mg/L)	837	919	990	1078
EC (µS/cm)	1672	1823	1967	2146
Salinity (‰)	0.83	0.92	1	1.09
DO (mg/L)	7.23	7.5	7.63	7.67
Turbidity (NTU)	3.11	2.45	1.83	0.94
TSS (mg/L)	12	10	6	5
Color (PT-Co)	168	93	49	20
COD (mg/L)	69	61	53	51
Sludge Height (cm)	0	0.9	1.3	1.5

For 50V, we also get a similar characteristic from treated water sample in which COD, Color, TSS and Turbidity decreases with RT and other parameters increased with RT as Table 4.3 shows.

Table 4.3: Wastewater Characteristics Analysis (with 50V)

	Wastewater	RT (1 hr)	RT (2 hr)	RT (4 hr)
pH	8.56	9.82	10	10.07
TDS (mg/L)	837	932	1036	1297
EC (µS/cm)	1672	1819	2032	2593
Salinity (‰)	0.83	0.92	1.03	1.33
DO (mg/L)	7.23	7.69	7.73	7.85
Turbidity (NTU)	3.11	1.8	1.63	0.82
TSS (mg/L)	12	7	3	1
Color (PT-Co)	168	129	48	12
COD (mg/L)	69	36	26	18
Sludge Height (cm)	0	0.8	1	2

4.3 Effects of Different Retention Time & Voltages

The effects of different voltages with different retention times are discussed here. It is well established that the removal efficiency (RE) also increases with the increase of voltages. In a similar pattern, with the increase of retention time (RT), the Removal Efficiency also increases. Removal efficiency is taken in percentage, and retention time is taken in hours (hr). Every equation's coefficient of determination was calculated as a measurement of how much variability of one element may be explained by its relationship to another related factor. This "goodness of fit" connection is expressed as a number between 0 and 1. Here, the closer the value to 1, the better the result.

As shown in Figure 4.1, with an increase in voltage, the Removal efficiency is relatively higher and keeps following an upward trendline in total suspended solids (TSS). The removal efficiency (RE) is on the y-axis and the retention time is on the X-axis. Similarly, with the increase in retention time (RT), the removal efficiency keeps increasing. We get three different logarithmic equations for three different voltages (30V, 40V, and 50V) and three retention times (1 hr, 2 hr, 4 hr). Using the constants of these equations, Figure 4.2 has been plotted where the x-axis represents voltage and the y-axis represents the constants/interceptions.

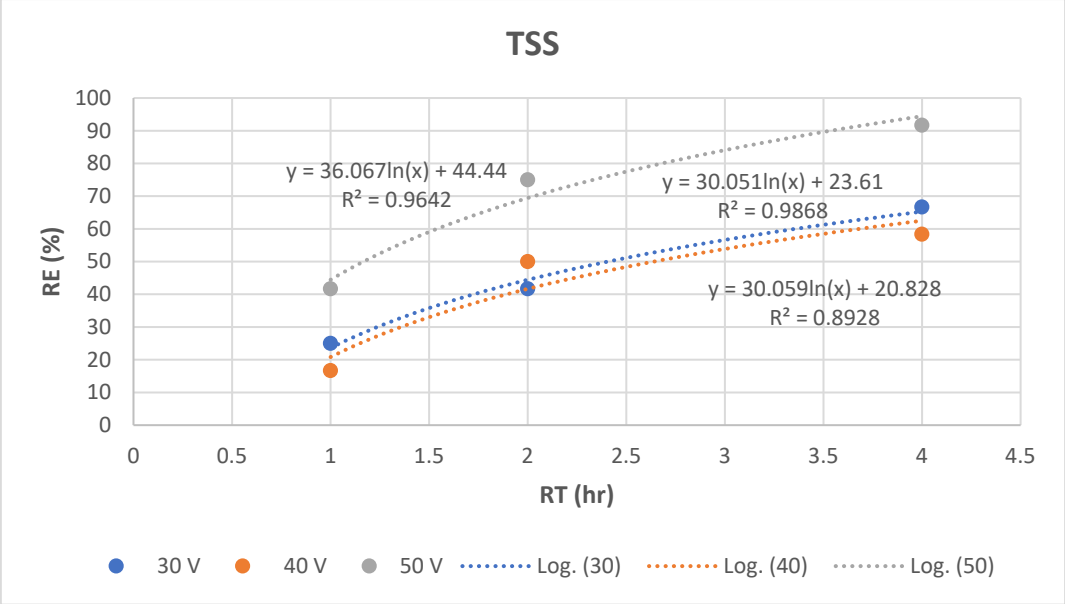


Figure 4.1: Relationship Between TSS Removal Efficiency and Retention Time

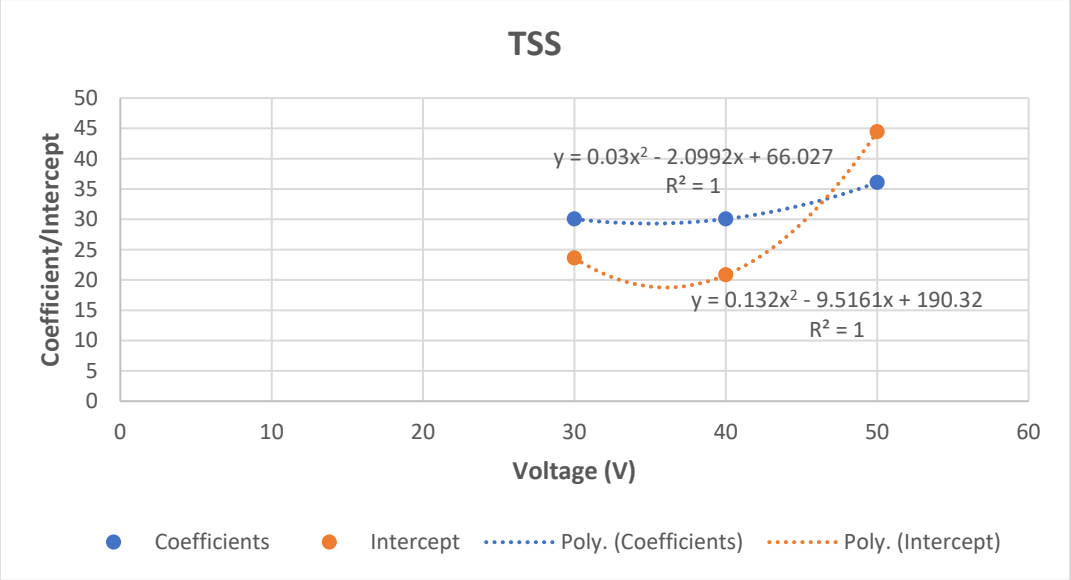


Figure 4.2: Relationship Between TSS Removal Equation Constants

In Figure 4.3, the effects of relatively higher voltage and retention time on color also show us a similar trend in Removal Efficiency (RE). With the increase in retention time (hr) and voltage (V), the removal efficiency keeps increasing. We also get three different logarithmic equations for three different voltages (30V, 40V, and 50V) and for three retention times (1 hr, 2 hr, 4 hr)

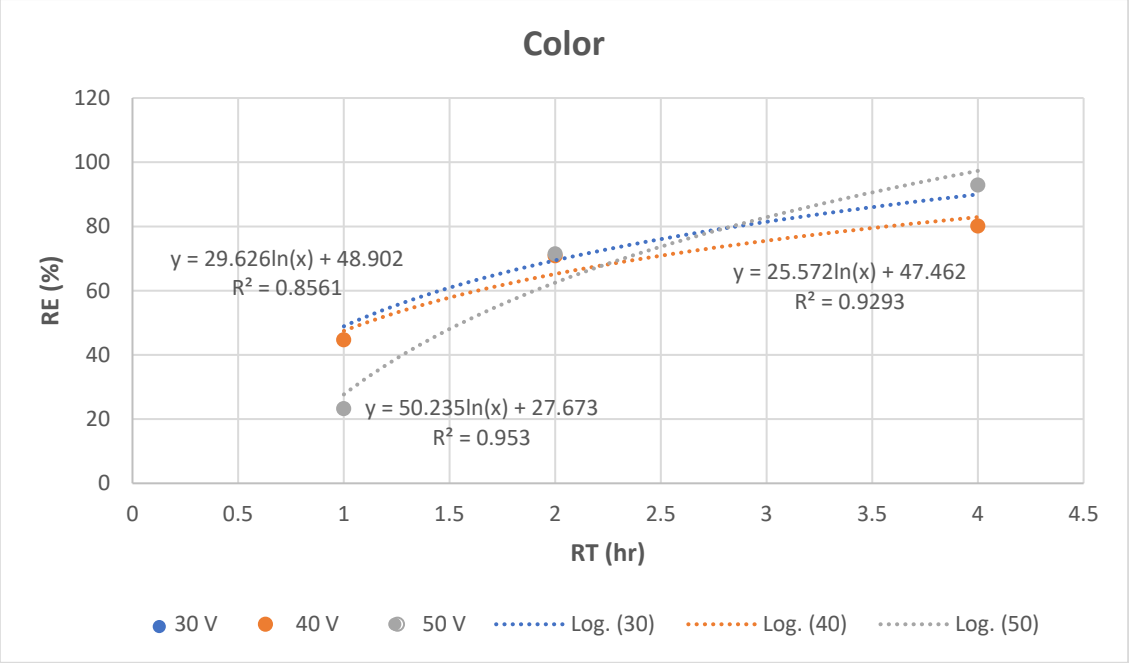


Figure 4.3: Relationship Between Color Removal Efficiency and Retention Time

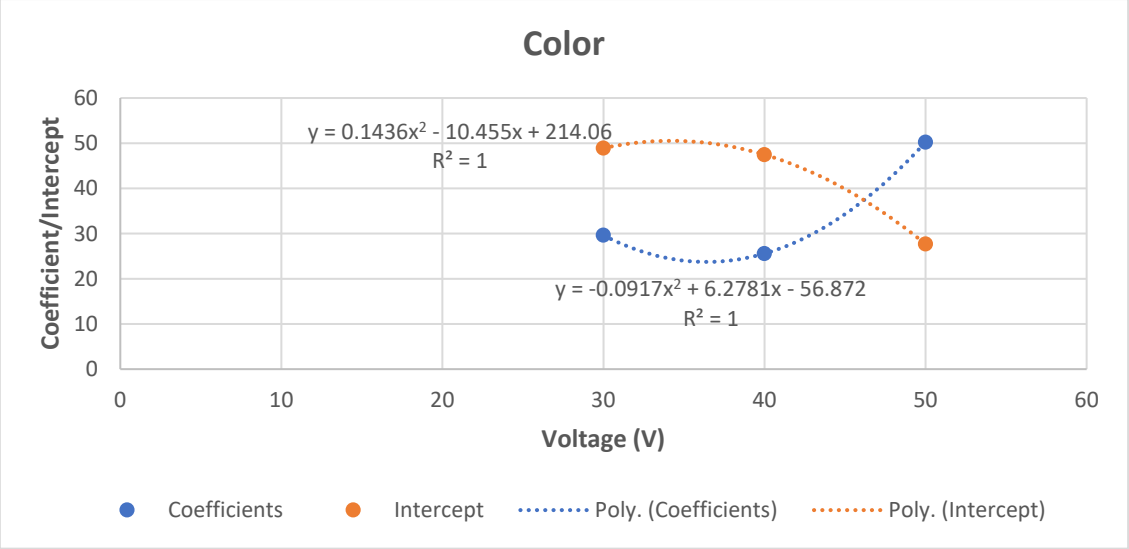


Figure 4.4: Relationship Between Color Removal Equation Constants

In Figure 4.5, the chemical oxygen demand (COD) also follows a similar trend of pattern in removal efficiency (RE). However, it is noticed that for determining the removal efficiency of COD, although for 40V, the removal efficiency is initially more than that of 30V in 1 hour retention time, the removal efficiency is higher for 2 hours and 4 hours retention time for 30V than that of 40V. Removal efficiency for 50V, however, remained higher than 40V and 50V.

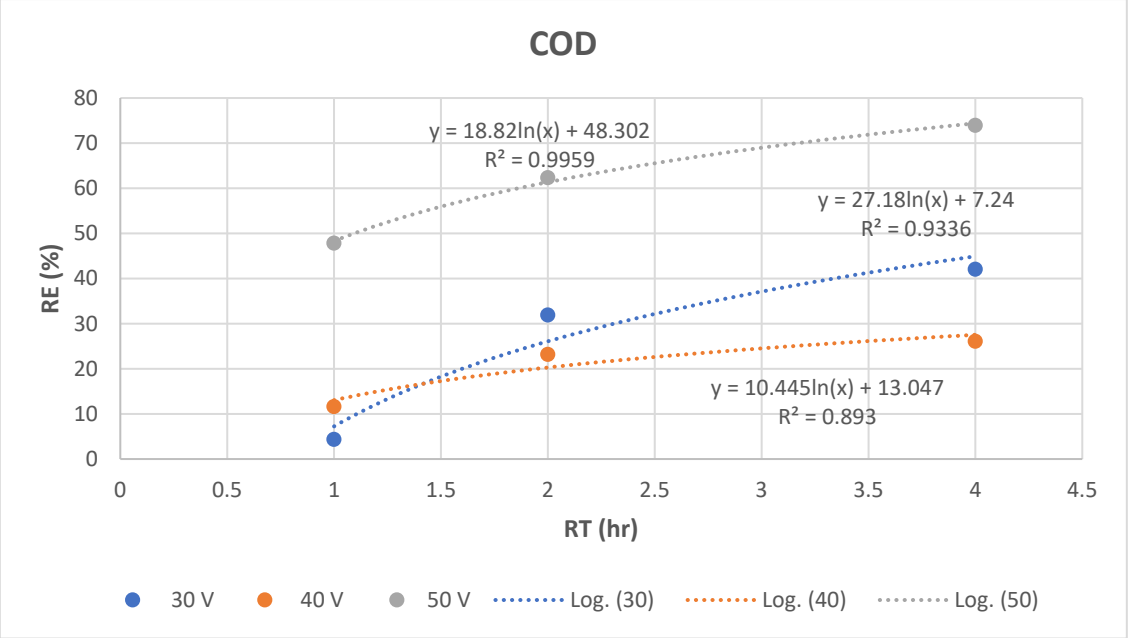


Figure 4.5: Relationship Between COD Removal Efficiency and Retention Time

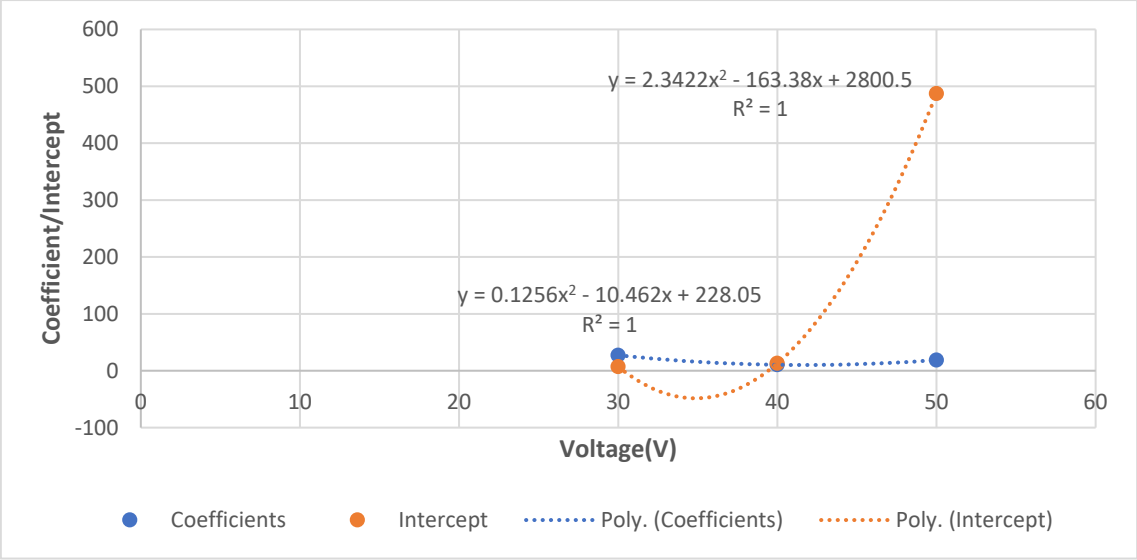


Figure 4.6: Relationship Between COD Removal Equation Constants

In Figure 4.7, the effects of relatively higher voltage and retention time on turbidity also show us a similar trend in removal efficiency (RE). With the increase in retention time (hr) and voltage (V), the removal efficiency (RE) keeps increasing. We also get three different logarithmic equations for three different voltages (30 V, 40 V, and 50 V) and for three retention times (1hr, 2 hr, 4 hr)

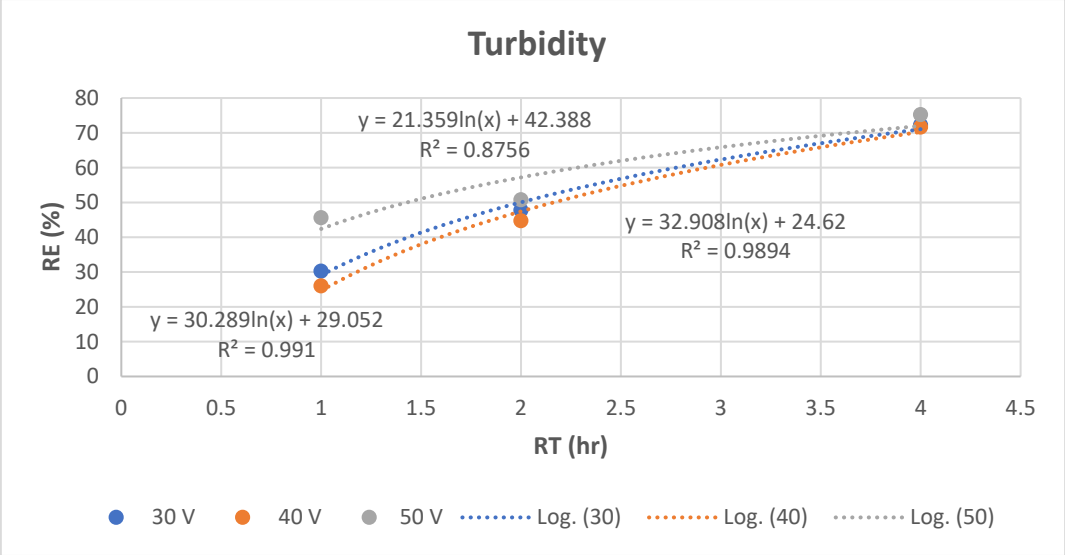


Figure 4.7: Relationship Between Turbidity Removal Efficiency and Retention Time

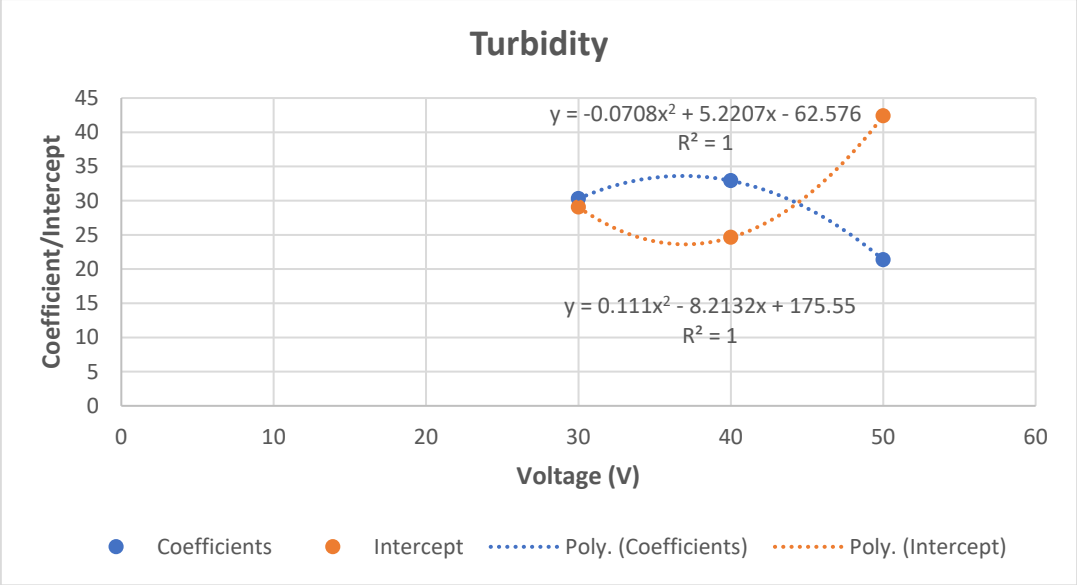


Figure 4.8: Relationship Between Turbidity Removal Equation Constants

.

4.4 Removal Efficiency

Data from the aforementioned trials were displayed against retention time for all three current densities. Pollutant removal efficiencies are shown to follow a pattern with respect to retention time in all circumstances; as retention time increases, removal efficiency increases in a logarithmic pattern. The following equation can be used to duplicate this pattern:

$$RE = a \times \ln (RT) \tag{4.1}$$

where 'RE' stands for removal efficiency, 'RT' stands for retention time, and 'a' and 'b' stand for constants. There will be three such equations for a certain pollutant for three separate times, one for each current density (i.e. voltage). The following equations can be written:

$$RE_1 = a_1 \times \ln (RT) + b_1 \tag{4.2}$$

$$RE_2 = a_2 \times \ln (RT) + b_2 \tag{4.3}$$

$$RE_3 = a_3 \times \ln (RT) + b_3 \tag{4.3}$$

It is found that both the sets of 'a' (a_1, a_2, a_3) and 'b' (b_1, b_2, b_3) can be co-related with the voltage. The relationships follow one of the following patterns:

$$A, b = c \times (V)^2 \pm d \times (V) \pm e \tag{4.5}$$

where 'V' is the current density in voltage and the constants to be obtained are 'c', 'd', and 'e'. Eventually, a generalized single equation for the removal efficiency of a specific pollutant is proposed by replacing the equations for 'a' and 'b' in Eq. 4.1. Similarly, five such equations are generated in total, one for each of TSS, COD, Color, and Turbidity. Finally, the results of the derived equations are compared to actual experimental measurements.

4.5 Relationship Between Turbidity & TSS

The relationship between turbidity and total suspended solids (TSS) gives us better goodness of fit correlation value from our experiment. The unit of turbidity is NTU, and it is placed on the y-axis of the graph, and the unit of TSS is mg/L which is plotted on the x-axis. The result is not very good as we expect from the graph here since the R square value is less than 80%.

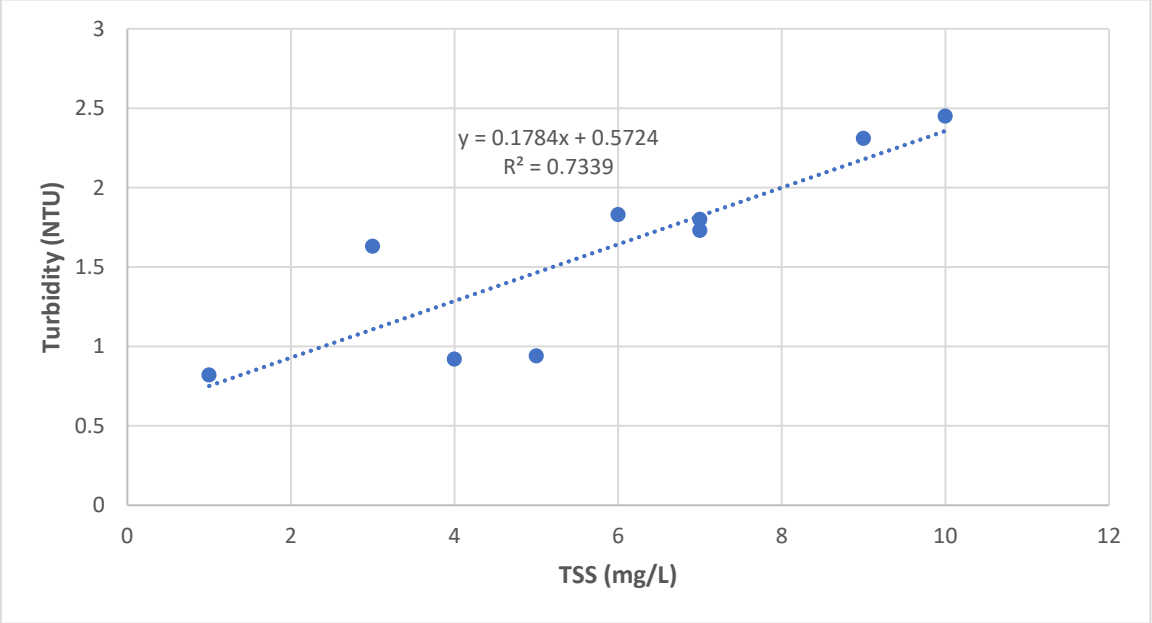


Figure 4.9: Correlation Between Turbidity and TSS

4.6 Relationship Between TDS and EC

The relationship between total dissolved solids (TDS) and Electrical conductivity (EC) gives us better goodness of fit correlation value from our experiment. The unit of EC is uS/cm, and it is placed on the y axis of the graph, and the unit of TDS is mg/L which is plotted on the x-axis.

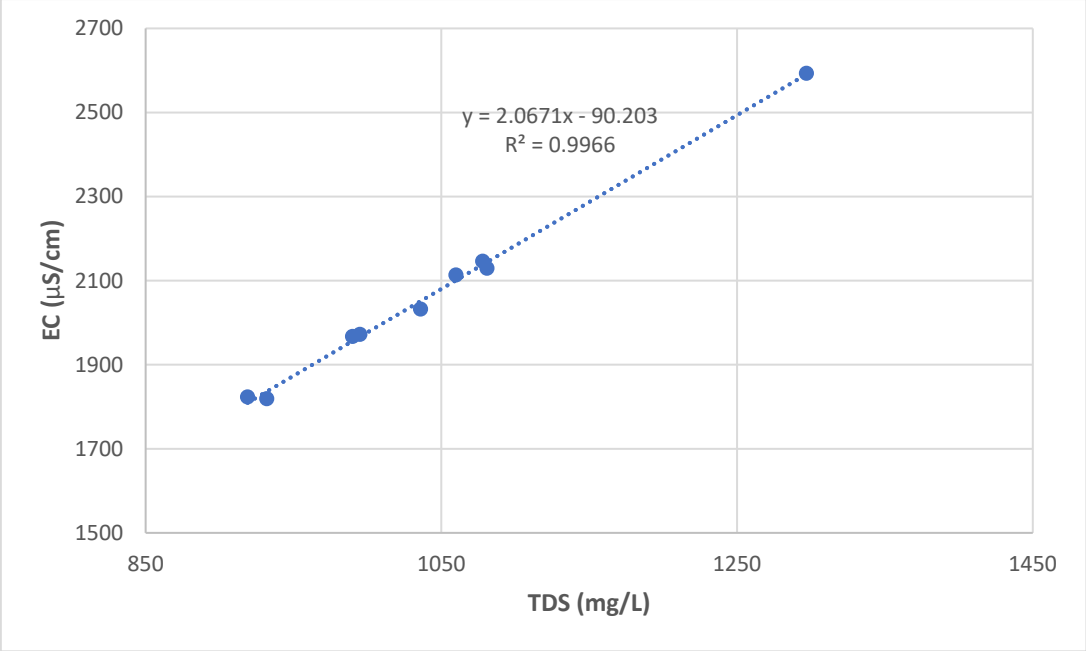


Figure 4.10: Correlation Between EC and TDS

4.7 Scum Height for Three Retention Times

With the progression of our experiment, the scum is found in the upper layer of our beakers after the electrocoagulation treatment. With the progression of time, more scum is clogged at the top layer of the water. This indicates that with the increase in retention time, more scum will be formed. Moreover, it can also be seen that with the rise of voltage, the scum layer increases more and more.

In Figure 4.11, the scum heights were 0.5 cm, 0.8 cm, and 1.8 cm for 1 hour, 2 hours, and 4 hours. Figure 4.12 shows the scum height for 40V, and the scum heights were 0.9 cm, 1.3 cm, and 1.5 cm for 1 hour, 2hour and 4 hours, respectively. And lastly, for 50V, the scum heights were 0.8 cm, 1 cm, and 2 cm for 1 hour, 2 hours, and 4 hours, respectively, as shown in Figure 4.13.

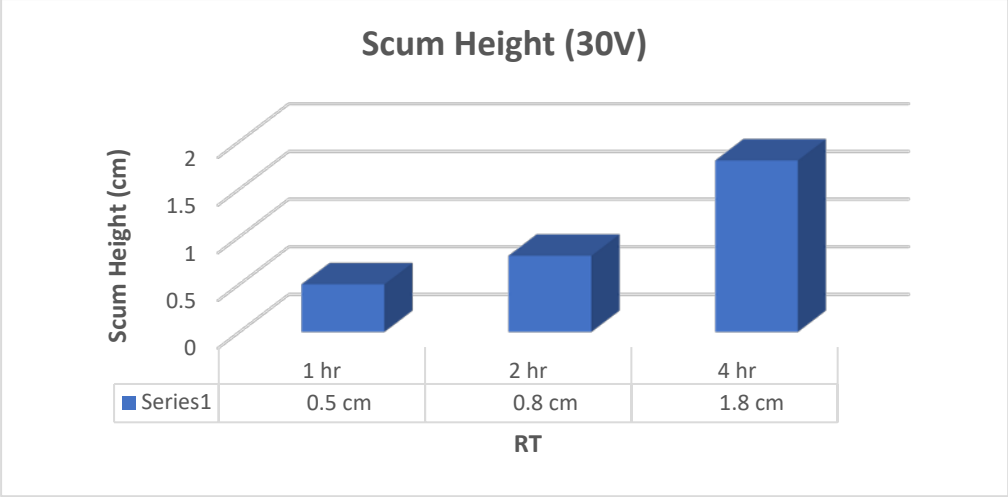


Figure 4.11: Scum Height for 30 V

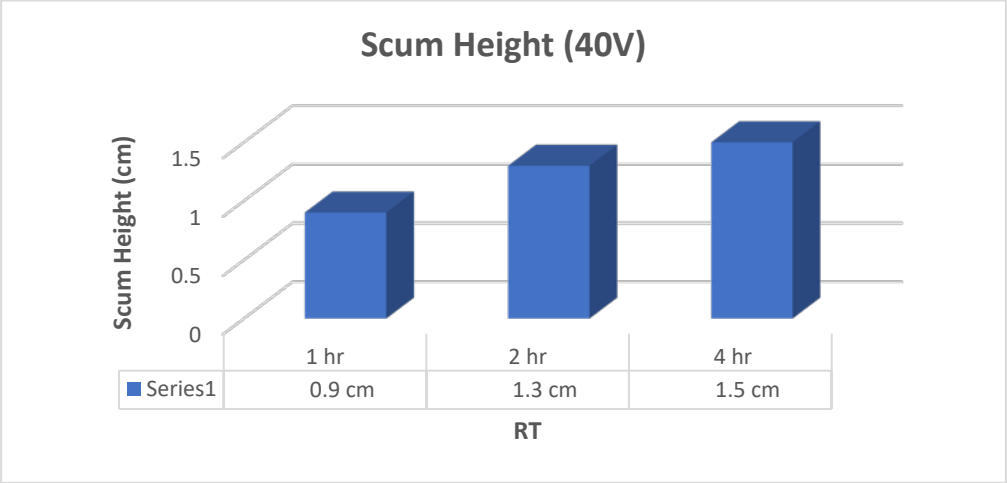


Figure 4.12: Scum Height for 40V

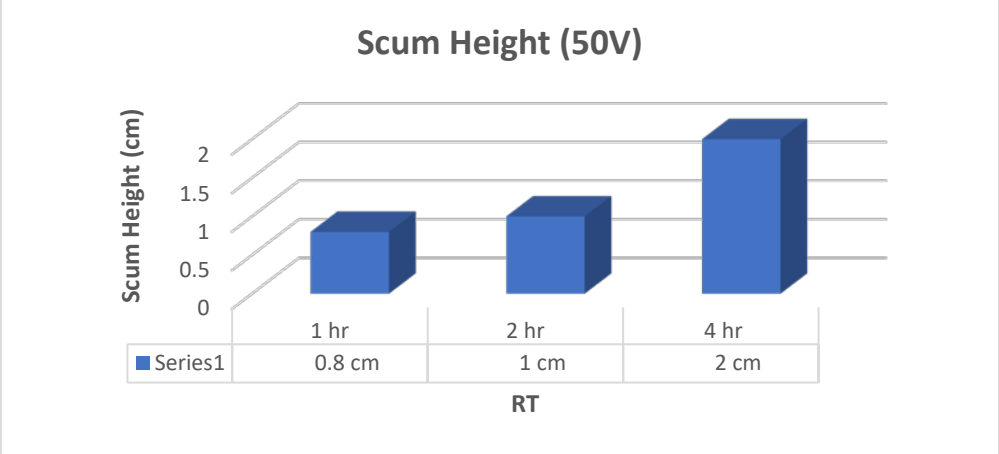


Figure 4.13: Scum Height for 50V

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 General

This chapter summarizes the results and discussions of our study and suggests recommendations, as well as proposes future works related to the research.

5.2 Conclusions

The results of this study have been obtained through multiple experiments. Based on these results, the following conclusions can be drawn:

- The raw wastewater is alkaline, cloudy, saline and electro-conductive.
- After the electrolysis, the values of pH, DO, TDS, salinity and EC was increased. On the other hand, the values of COD, TSS, color and turbidity was decreased and we have got an equation of the removal efficiency for each of these for parameters.
- The pH level also increases along with more retention time. For 30V, pH increases from 1^{st} to 2^{nd} hour and remains almost constant for the 2^{nd} and 4^{th} hours of retention time. For 40V and 50V, the pH increases every hour of retention time.
- Turbidity increases along with increase in retention time. For 30V, 40V and 50V, the increase in turbidity with respect to retention time is almost constant.
- Increase in TDS is proportional to the increase in conductivity.
- Higher value of retention time and voltage causes higher value of removal efficiency.
- Linear relationship was found between TSS &turbidity and EC & TDS.
- For any given voltage (30V, 40V, 50V), higher retention time results in more scum height. For 30V electricity, the final scum height is 1.8 cm, while for 40V and 50V, it is 1.5 cm and 2 cm respectively.

5.3 Recommendations and Future Scope of Research

The study has shown that it is necessary to find a means of reducing the TDS. This is highly recommended because the results of the study will be of little use if the end product still contains intolerable levels of TDS.

It is also recommended to use a stable power source for the electrolysis process and other parameter tests. This is to ensure that the experiment can keep running smoothly even if the electrical power to the laboratory is cut off due to load shedding or any other reason. The water samples used for the experiments should also be kept in such a place where other people cannot tamper with them and cause unnecessary and unwanted changes in the composition.

This study can be used to create portable water treating devices and observe the correlation between different electric parameters other than voltage and retention time with removal efficiency. Moreover, the economic aspect of the water treatment, user-friendly approach, availability, etc., can also be researched in this study in the future. We can also observe how the electrolysis process can treat seawater in different scenarios.

5.4 Limitations

Removal of TDS from the dye house effluent has been a key drawback for this study. This is a significant problem since high amounts of TDS will make the water unusable for consumption or use. The shortage of time is also a drawback since two-parameter tests (BOD and *E.coli*) could not be carried out due to the deadline of the project.

Due to the COVID-19 outbreak, time limitation and limitation of resource was observed. Due to time shortage, seawater was not tested with electrolysis. Also, the BOD test could not be completed due to a lack of time and lab equipment shortage.

References

Shawn Burke, C., Salas, E., Smith-Jentsch, K., & Rosen, M. A. (2018). Measuring Macrocognition in Teams: Some Insights for Navigating the Complexities. In *Macrocognition Metrics and Scenarios* (pp. 29–44). CRC Press.

Chowdhury, I. M., Rahman, I., Sakib, S. S., Hossain, K. I., & Shahid, S. (2018). Is Water Available in the Public Places Safe To Drink in Is Water Available in the Public Places Safe To Drink in Bangladesh ? *8th Int. Conf. on Geotechnique, Construction Materials and Environment, January 2019*.

Kalbusch, A., Henning, E., Brikalski, M. P., Luca, F. V. de, & Konrath, A. C. (2020). Impact of coronavirus (COVID-19) spread-prevention actions on urban water consumption. *Resources, Conservation and Recycling*, *163*(August), 105098.

Jibril, J. D. azimi, Sipan, I. Bin, Sapri, M., Shika, S. A., Isa, M., & Abdullah, S. (2012). 3R s Critical Success Factor in Solid Waste Management System for Higher Educational Institutions. *Procedia - Social and Behavioral Sciences*, *65*(ICIBSoS), 626–631.

Ginja, S., Gallagher, S., & Keenan, M. (2021). Water, sanitation and hygiene (WASH) behaviour change research: why an analysis of contingencies of reinforcement is needed. *International Journal of Environmental Health Research*, *31*(6), 715–728.

Alam, P., & Ahmade, K. (2013). Impact of Solid Waste on Health and the Environment. *International Journal of Sustainable Development and …*, *2*(1), 165–168.

El-fadel, M., Findikakis, A. N., & Leckie, J. O. (1997). *26- El-Fadel1997.Pdf*. *December 1995*, 1–25.

Kirunda, M. P. (2009). A Case of Kira Town Council, Uganda: Public participation in solid waste management: challenges and prospects. *Master Thesis Public Participation in Solid Waste Management : Challenges and Prospects .*, *December*, p.96.

Vanitha, M., & Murugesan, A. (2014). Hydrochemical investigation on ground water quality in and around solid waste dumping site, Chennai city. *International Journal of ChemTech Research*, *6*(9), 4352–4358.

Mishra, S., Tiwary, D., Ohri, A., & Agnihotri, A. K. (2019). Impact of Municipal Solid Waste Landfill leachate on groundwater quality in Varanasi, India. *Groundwater for Sustainable Development*, *9*, 100230.

Powell, J. T., Townsend, T. G., & Zimmerman, J. B. (2016). Estimates of solid waste disposal rates and reduction targets for landfill gas emissions. *Nature Climate Change*, *6*(2), 162–165.

Pereira De Sousa, D. D., Pinto, C. F., Tonhela, M. A., Granato, A. C., De Jesus Motheo, A., De Faria Lima, A., Ferreira, D. C., Fernandes, D. M., De Toledo Fornazari, A. L., & Malpass, G. R. P. (2019). Treatment of real dairy wastewater by electrolysis and photo-assisted electrolysis in presence of chlorides. *Water Science and Technology*, *80*(5), 961–969

Mohamad Zailani, L. W., Mohd Amdan, N. S., & Zin, N. S. M. (2018). Removal Efficiency of Electrocoagulation Treatment Using Aluminium Electrode for Stabilized Leachate. *IOP Conference Series: Earth and Environmental Science*, *140*(1).

Chen, G. (2004). Electrochemical technologies in wastewater treatment. *Separation and Purification Technology*, *38*(1), 11–41

Elabbas, S., Ouazzani, N., Mandi, L., Berrekhis, F., Perdicakis, M., Pontvianne, S., Pons, M. N., Lapicque, F., & Leclerc, J. P. (2016). Treatment of highly concentrated tannery wastewater using electrocoagulation: Influence of the quality of aluminium used for the electrode. *Journal of Hazardous Materials*, *319*, 69–77.

Moussa, D. T., El-Naas, M. H., Nasser, M., & Al-Marri, M. J. (2017). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. *Journal of Environmental Management*, *186*, 24–41.

Módenes, A. N., Espinoza-Quiñones, F. R., Manenti, D. R., Borba, F. H., Palácio, S. M., & Colombo, A. (2012). Performance evaluation of a photo-Fenton process applied to pollutant removal from textile effluents in a batch system. *Journal of Environmental Management*, *104*, 1–8

Benhadji, A., Taleb Ahmed, M., & Maachi, R. (2011). Electrocoagulation and effect of cathode materials on the removal of pollutants from tannery wastewater of Rouïba. *Desalination*, *277*(1–3), 128–134

Trigueros, D. E. G., Módenes, A. N., Ravagnani, M. A. S. S., & Espinoza-Quiñones, F. R. (2012). Reuse water network synthesis by modified PSO approach. *Chemical Engineering Journal*, *183*, 198–211.

Curteanu, S., Piuleac, C. G., Godini, K., & Azaryan, G. (2011). Modeling of electrolysis process in wastewater treatment using different types of neural networks. *Chemical Engineering Journal*, *172*(1), 267–276.

Brillas, E., & Martínez-Huitle, C. A. (2015). Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods. An updated review. *Applied Catalysis B: Environmental*, *166–167*, 603–643.

Tang, C., Chen, J., Shindo, S., Sakura, Y., Zhang, W., & Shen, Y. (2004). Assessment of groundwater contamination by nitrates associated with wastewater irrigation: A case study in Shijiazhuang region, China. *Hydrological Processes*, *18*(12), 2303–2312.

Gößling, S., Stypka, S., Bahr, M., Oberschachtsiek, B., & Heinzel, A. (2018). Proton Exchange Membrane Water Electrolysis Modeling for System Simulation and Degradation Analysis. *Chemie-Ingenieur-Technik*, *90*(10), 1437–1442.

Erabee, I. K., Ahsan, A., Jose, B., Arunkumar, T., Sathyamurthy, R., Idrus, S., & Daud, N. N. N. (2017). Effects of electric potential, NaCl, pH and distance between electrodes on efficiency of electrolysis in landfill leachate treatment. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, *52*(8), 735–741.

Ben Mansour, L., & Chalbi, S. (2006). Removal of oil from oil/water emulsions using electroflotation process. *Journal of Applied Electrochemistry*, *36*(5), 577–581.

Kumar, V., & Kangri Vishwavidyalaya, G. (2017). *A review on the feasibility of electrolytic treatment of wastewater: Prospective and constraints Phytoremediation of Industrial Effluents using Aquatic macrophytes View project Bio-remediation of contaminants along with bio-energy production View project*. *May*.

Kabuk, H. A., Ilhan, F., Avsar, Y., Kurt, U., Apaydin, O., & Gonullu, M. T. (2014). Investigation of leachate treatment with electrocoagulation and optimization by response surface methodology. *Clean - Soil, Air, Water*, *42*(5), 571–577.

Ashworth, William (2015). "Martinus van Marum - Scientist of the Day". Linda Hall Library.

Helmenstine, Todd (2018). "Today in Science History - January 12 - Johan August Arfwedson and Lithium". Science Notes and Projects

Imteaz, M. A., Ahsan, A., Kaur, P., & Shanableh, A. (2020). Mathematical Modelling for Predicting Pollutant Removal Efficiencies of an Electrolysis System. *Water, Air, and Soil Pollution*, *231*(8).

G.B. Raju, Khangaonkar (1984); Trans. Indian Inst., Metals., 37: 59–66.

X. Chen, G. Chen, P. L. Yue (2000); Sep. Purif. Technol., 19: 65–69

Appendix A

DATA COLLECTION FROM ELECTROLYSIS

Data Collection After Electrolysis

Table A1: Data for 30 V

	Wastewater	RT (1hr)	RT (2hr)	RT (4hr)
pH	8.56	8.82	8.83	8.85
TDS (mg/L)	837	995	1060	1081
EC (µS/cm)	1672	1972	2113	2129
Salinity (‰)	0.83	1	1.07	1.09
DO (mg/L)	7.23	7.25	7.28	7.42
Turbidity (NTU)	3.11	2.31	1.73	0.92
TSS (mg/L)	12	9	7	4
Color (PT-Co)	168	94	35	25
COD (mg/L)	69	66	47	40
Scum height (cm)	0	0.5	0.8	1.8

Table A2: Data for 40 V

	Wastewater	RT (1hr)	RT (2hr)	RT (4hr)
pH	8.56	8.72	9	9.06
TDS (mg/L)	837	919	990	1078
EC (µS/cm)	1672	1823	1967	2146
Salinity (‰)	0.83	0.92	1	1.09
DO (mg/L)	7.23	7.5	7.63	7.67
Turbidity (NTU)	3.11	2.45	1.83	0.94
TSS (mg/L)	12	10	6	5
Color (PT-Co)	168	93	49	20
COD (mg/L)	69	61	53	51
Sludge Height (cm)	0	0.9	1.3	1.5

Table A3: Data for 50 V

	Wastewater	RT (1hr)	RT (hr)	RT (4hr)
pH	8.56	9.82	10	10.07
TDS (mg/L)	837	932	1036	1297
EC (µS/cm)	1672	1819	2032	2593
Salinity (‰)	0.83	0.92	1.03	1.33
DO (mg/L)	7.23	7.69	7.73	7.85
Turbidity (NTU)	3.11	1.8	1.63	0.82
TSS (mg/L)	12	7	3	1
Color (PT-Co)	168	129	48	12
COD (mg/L)	69	36	26	18
Sludge Height (cm)	0	0.8	1	2

Removal Efficiency for Different Voltages and Retention Times:

Table A4: RE for 30 V

	RT (1 hr)	RT (2 hr)	RT (4 hr)
Turbidity	25.72	44.37	70.41
TSS	25	41.07	66.67
Color	44.05	79.17	85.12
COD	4.35	31.88	42.03

Table A5: RE for 40 V

	RT (1 hr)	RT (2 hr)	RT (4 hr)
Turbidity	21.22	41.16	69.77
TSS	16.67	50	58.33
Color	44.64	70.83	88.09
COD	11.59	23.19	26.09

Table A6: RE for 50 V

	RT (1 hr)	RT (2 hr)	RT (4 hr)
Turbidity	42.12	47.59	73.69
TSS	41.67	75	91.67
Color	23.21	71.43	92.86
COD	47.83	62.32	73.92

TSS and Turbidity Data:

Table A7: TSS and Turbidity Data

TSS (mg/L)	Turbidity (NTU)
9	2.31
7	1.73
4	0.92
10	2.45
6	1.83
5	0.94
7	1.8
3	1.63
1	0.82

TDS and EC Data:

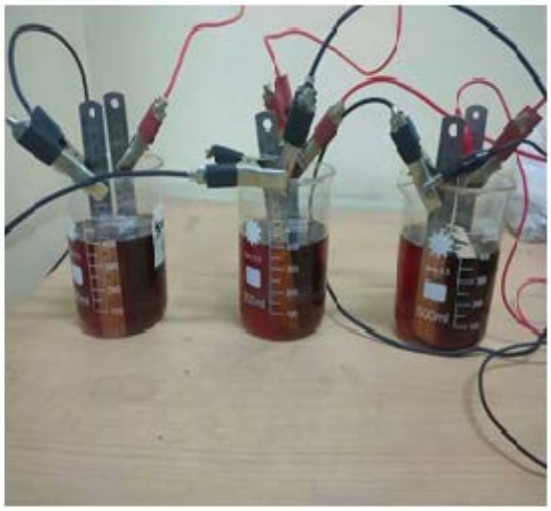
Table A8: TDS and EC Data

TDS (mg/L)	EC (µS/cm)
995	1972
1060	2113
1081	2129
919	1823
990	1967
1078	2146
932	1819
1036	2032
1297	2593

Appendix B

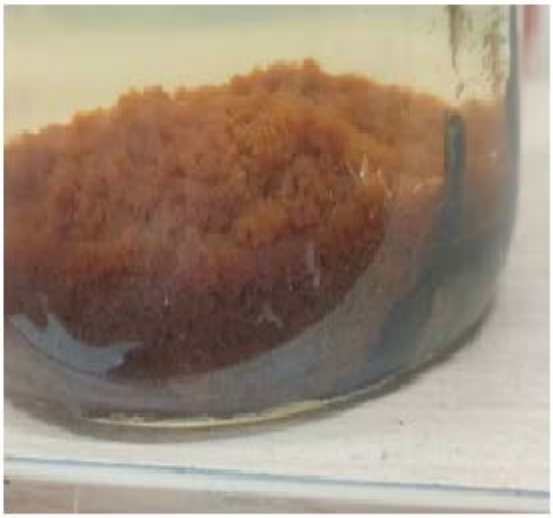
EXPERIMENTAL SETUP

(a)

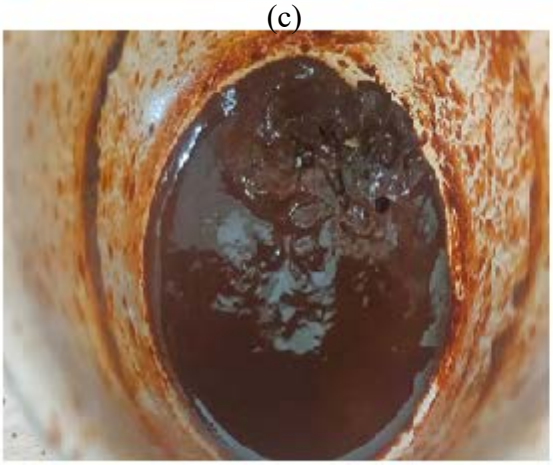


(b)

(c)



(d)



(e)

(f)

Figure B1: (a) Wastewater Sample (b) Setup from Side View (c) Setup from Top View (d) Scum from Side View (e) Scum from Top View and (f) Scum with Water from Top View

(a)

(b)

(c)

(d)

(e)

(f)

Figure B2: (a) Samples with Scum (b) Treating Wastewater by Electrolysis (c) Cathode After Electrolysis (d)Experimenting Electrolysis (e) Testing Samples on Spectrophotometer and (f) Sample Preparation for Testing