



**OPTIMIZATION AND DESIGN OF LAUNDRY GREYWATER TREATMENT PROCESS  
WITH MULTIPLE ELECTRODES ELECTROCOAGULATION.**

by

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## ABSTRACT

It is becoming increasingly important to relook at the impact that greywater has on the environment and the opportunities that it can provide for water re-use. This is particularly true for South Africa which has an average sewer blockage rate that far supersedes international averages. Population growth, and the resulting increase in the rate of inflow or infiltration often results in wastewater treatment plants being stretched beyond their design capacity. To cope with current and future wastewater treatment demands, developments of alternative efficient and ecologically safe wastewater treatment methods are an absolute imperative. Treatment of greywater with electrocoagulation-flocculation (ECF) techniques is one of the promising technologies. However, ECF applications seem to be heuristically approached, perhaps due to the complexity and multitude of ECF process control variables and a lack of understanding of their interactions. These variables such as, electrode types; effluent types; voltage; current density; ECF, reactor volume; mixing speeds; and many others, may not only have a single effect on output but multiple inter-variable effects that need multi-parameter factor analysis. Design of Experiment (DoE) and Response Surface Methodology (RSM) are statistical techniques that can be employed to investigate the interaction of factors on the treatment efficiency of the ECF.

In this research, the ECF efficacy was investigated by varying electrode types (iron and aluminum, alternatively as anodes) in 800 mL and 2000 mL reactors to treat laundry greywater (LGW) under varying operating conditions of initial pH (3.5 to 8.5), voltage (10 to 15 V) and mixing speed (0 to 500 rpm) that were carefully planned with DoE.

The optimum operating conditions were found to be at initial pH of 4.5 to 5.75; applied voltage of 10V to 13.5 V; at mixing speeds between 125 and 350 rpm. Aluminium electrodes favoured effluents with more chlorides in LGW than the iron electrodes, therefore the addition of chlorides may improve iron ECF. In this study, the results revealed that the volume of the effluent can be increased to values 2000 mL while achieving favorable treatment efficiency. This suggests that the ECF method can be scaled-up for the treatment of LGW with high TSS, pH, turbidity, and color removal efficiency.

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## **DEDICATION**

To my mother, Tembisa Mula, you are the reason I am who I am today because of your unwavering support and care.

## RESEARCH OUTPUTS

Articles submitted to accredited journals.

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## **GLOSSARY**

### **Greywater**

Greywater (GW) is defined as wastewater that comes from the hand wash basin, shower and bathtubs, laundering (laundry greywater in this study) and kitchen sink. (Pedro-Monzonís, et al., 2014).

### **Response Surface Methodology**

Response Surface Methodology (RSM) is a branch of applied statistics that deal with three dimensional mathematical modeling in optimization parameters under investigation using applied statistical methods (Montgomery, 2013).

### **Coagulation**

The agglomeration of colloidal or suspended matter brought about by the addition of some chemical to the liquid, by contact, or by other means.

### **Floc**

The agglomeration of smaller particles in gelatinous mass that can be more easily removed from the liquid than the individual small particles.

### **Flocculation**

The coming together of coalescing and minute particles in a liquid

## ACRONYMS AND ABBREVIATIONS

COD – Chemical Oxygen Demand

DoE - Design of Experiment

GW - Greywater

GWEC - Greywater Electrocoagulation

GWT - Greywater Treatment

ISC - Informal Settlement Communities

RSM - Response Surface Methodology

TDS –Total Dissolved Solids

TSS - Total Suspended Solids

WCG - Western Cape

Government

Al - Aluminium

SS - Stainless Steel

EC - Electrocoagulation

BOD - Biological Oxygen Demand

BOD<sub>5</sub> - Biological Oxygen Demand

ORP - Oxidation-reduction potential

V<sub>eff</sub> - Effective Voltage

FOG - Fats, oils and grease

## LIST OF SYMBOLS

$\rho$  – Resistivity ( $\Omega$ )

$L$  - Length (m)

$A$  - Cross-sectional area (m<sup>2</sup>)

$I$  – Current (A)

$V$  – Voltage (V)

# 1. INTRODUCTION

## 1.1 Research Background

Water plays an indispensable role in sustainable development and has a direct impact on all aspects of human activity. It is used in households as well as in industrial and commercial processes. Its applications include use as a solvent, cleaning and washing agent, and for irrigation. Population growth and economic activities have led to increased water utilisation, adding more stress to the already scarce water resources in low-income communities in South Africa. Available water supply systems such as municipal portable water supply, roof tops water harvesting, and boreholes do not provide sufficient and efficient water resources; and are generally not well-maintained (Pedro-Monzonís, 2015). Lifestyles and the consequential generation of chemical and biological waste contribute to an elevated level of pollution in domestic wastewater, leading to compromised water quality for communities (Pedro-Monzonís, 2015).

It is estimated that 50-75 percent of used water is discharged as grey water (GW). This makes GW treatment for reuse a potentially good strategy for the mitigation of water shortage (Pedro-Monzonís, 2015). Greywater harvesting and treatment for re-use can provide a potential water resource for bathrooms, showers; toilet flushing, car washing, irrigation and laundering in domestic utilities and process water for chemical plants (Pedro-Monzonís, 2015). Reuse of GW as a method of water conservation, and recycling would also save on pumping and piping costs. It would also relieve the hydraulic overflows in the sewer piping network that are a common occurrence in many low-income communities in South Africa as shown in Figure 1.1.



**Figure 1. 1 : Sewer Overflow (Picture Taken in Enkanini Informal Settlement, in Stellenbosch)**

Grey water re-use is encouraged by water services authorities in South Africa as one of the water-saving strategies (Dana, 2021). However, GW smells within days of storage, and contain pathogenic micro-organisms which are not safe for human contact. Grey water treatment is therefore necessary to guarantee public health safety, aesthetic appeal of water and the sustainability of re-use. However, conventional wastewater treatment of domestic effluents is centralised and not currently available as decentralised units. Methods that have been widely applied for treatment including physical systems such as filtration; screening and ultra-filtration membranes; chemical systems such as coagulation/flocculation with ion exchange resins; biological systems such as constructed wetlands (Li *et al.*, 2003); rotating biological reactor; membrane bioreactors and sequencing batch reactors are not efficient and easy to apply in domestic environment (Lesjean & Gnirss, 2006).

There are several reasons why the method used in the study is better for treating greywater than the methods listed above (filtration, screening, ultra-filtration membranes, coagulation/flocculation with ion exchange resins, constructed wetlands, rotating biological reactor, membrane bioreactors, and sequencing batch reactors).

### **Complexity and Technical Requirements**

Since simplicity is frequently preferred in-home contexts, many of the previously listed approaches are less appropriate because they need complex technological setups and operational requirements. Certain processes, such as membrane bioreactors, sequencing batch reactors, and ultra-filtration membranes, are too complex and expensive for home usage without specialised tools.

### **Costs Considerations**

For individual families, the cost of establishing and maintaining advanced treatment techniques like membrane bioreactors or ion exchange resins could be expensive.

### **Space constraints**

Constructed wetlands and other biological systems frequently require large space, making them unsuitable for urban or densely populated locations with limited space.

### **Maintenance challenges**

Rotating biological reactors and membrane bioreactors may require constant maintenance and monitoring, which can be difficult for homeowners who lack the necessary skills or time.

### **Energy consumption**

Certain technologies, such as membrane bioreactors and ultrafiltration membranes, can be energy-intensive, potentially increasing the overall environmental effect and expense of greywater treatment.

## **Chemical usage and residue**

Coagulation/flocculation techniques frequently entail the use of chemicals, which may be incompatible with the goal of sustainable and ecologically friendly greywater treatment. Furthermore, residues from these substances may pose challenges in disposal.

## **Adaptability to variable greywater characteristics**

Greywater properties can fluctuate, and some systems may fail to handle fluctuations in flow rates or impurities often present in-home greywater.

Recent advances in wastewater treatment technologies indicate that electrocoagulation methods should be directed towards a decentralised wastewater treatment system providing communities with packaged units that meets individual needs.

In recent years, several studies have focused on the treatment of industrial effluents using electrocoagulation-flotation (ECF). The effluents in these studies include electroplating wastewater (Adhoun *et al.*, 2004); paper mill bleaching wastewater (Sivakumar, 2011) chemical mechanical polishing wastewater (Li *et al.*, 2003), textile wastewater (Kobya, 2003) and wastewater olive oil (Inan *et al.*, 2004). ECF offers several advantages including ease of operation, robustness to varying reaction conditions and types of effluent, lower retention time, rapid sedimentation of electro-generated flocculants together with pollutants, lower sludge production, and lower space and capital costs (Bektas *et al.*, 2004). However, little attention has been given to greywater treatment, more particularly laundry greywater (LGW) due to its biological nature. Laundry greywater has proved to be resistant to biological treatment. Biological treatment methods have many other operational challenges such long hydraulic residence times, bioreactor poisoning, long inoculations periods, smell to the nearby communities; sludge generation and disposal problems (Jiang, 2002).

## **1.2 Problem Statement**

Wastewater from all laundry sources accounts for about 10% of municipal sewer discharges. The COVID-19 pandemic has given rise to many informal settlement communities (ISC) in South Africa. Some ISC are provided with laundering services in their communal ablution facilities; however, wastewater management is a challenge. Laundering wastewater can be recovered, treated and reused for water conservation and minimising the negative



environmental impact. Laundry effluents typically contain more than 1000 ppm suspended solids, 5000 ppm COD, 1100 ppm fats, oil, and grease (FOG), and 1300 ppm BOD, as well as metals and organic solvents such as toluene, benzene, and perchlorethylene.

Traditional methods, such as coagulation, floatation, adsorption, and chemical oxidation are insufficient for laundry waste-water treatment due to the following reasons:

**Complex composition:** Laundry wastewater comprises a wide range of contaminants, including detergents, surfactants, oils, dyes, and other organic and inorganic chemicals. Traditional approaches may struggle to address the complex and varied nature of these pollutants.

**High chemical oxygen demand (COD):** Laundry wastewater often has a high COD, suggesting the presence of organic chemicals that might exert a large oxygen demand during degradation. Conventional treatment procedures might not successfully break down or eliminate these organic compounds, resulting in inadequate purification.

**Foaming agent:** The presence of foaming agents in laundry wastewater can interfere with conventional treatment methods like flotation, as these compounds may stabilise foam and make it harder to separate and remove contaminants from the water.

**Scale up challenges:** When scaling up for larger volumes of wastewater, such as those produced by industrial laundry facilities, traditional methods may face challenges. The scalability of these methods can be limited, making them less suitable for dealing with large amounts of wastewater generated in industrial processes.

### **1.3 Aims and Objectives**

The aim of this study was to determine the effectiveness of ECF in treatment of laundry greywater by developing an optimized system of greywater electrocoagulation treatment that can be used in decentralised domestic greywater treatments.

The objectives were to:

- Evaluate the effect of operating parameters and their interactions through a factorial trial, specifically by interrogate the following EC operating parameters within ranges:
  - Greywater Volume (800 mL to 2000 mL)
  - Applied voltage (10 V – 15 V)
  - Initial pH (3.5 to 8.5)
  - Electrode types (Aluminium (Al) and Stainless Steel (SS))
  - Mixing (0 – 1000rpm)
- To identify the critical conditions for optimum performance of EC.
- Run experiments on optimised parameters to test reproducibility.

### **1.4 Investigative Research Questions**

The following questions were asked and addressed in this study:

- What are the process adjustments on an electro-coagulator to efficiently produce clean treated GW?
- What are the combination process parameters that interact to efficiently produce clean treated GW?
- Are the concentrations of pollutants produced below minimum values of re-use values given in the guideline for wastewater re-use standards by DWAF?

### **1.5 Delineation**

This study focused only on laundry greywater because of the synthetic chemical nature of detergents used in the laundering applications and because of its difference from GW coming from other domestic utilities and GW from bathroom and kitchens are therefore delineated.

### **1.6 Overview**

#### **Chapter 1**

Introduces and provides background information on the optimization and design of the laundry greywater treatment process using multiple electrodes electrocoagulation. This chapter presents the research statement, project objectives, and project rationale.

#### **Chapter 2**

This chapter presents the comprehensive literature in which the electrocoagulation process is discussed and compared to other industrial effluent treatment technologies. The rest of Chapter 2 focuses on greywater treatment re-use, characterization of greywater, raw water reuse, the fate and resilience of biological wastewater treatment technologies, electrocoagulation technology, and laundry electrocoagulation flocculation optimum. It also focuses on domestic wastewater and industrial effluent quality standards of different countries and municipalities.

### **Chapter 3**

This chapter describes procedures; equipment's and chemical reagents that were used in this study. The procedures for operating the electrocoagulation process reactor and doing the analysis of different parameters are described.

### **Chapter 4**

Discusses the outcomes of the effects of voltage and mixing speed on TSS, Turbidity, colour and TDS removal efficiency. The effect of Initial pH and mixing on Hazen Colour and Chlorides removal, the removal efficiencies. The effectiveness of Aluminium electrodes in in greywater treatment (GWT) with electrocoagulation flocculation (ECF) using 800 mL and 2000 mL reactor. The effectiveness of Iron electrodes in GW- ECF using 800 mL and 2000 mL reactor and energy and electrode consumption is also analysed. The raw data from the experiments are presented in appendix A and as graphs showing all sets of experiments.

### **Chapter 5**

Discusses conclusions and recommendations.

## 2 LITERATURE REVIEW

### 2.1 Greywater Treatment

Grey water is wastewater that comes from baths, showers, hand basins, washing machines, dishwashers, and kitchen sinks but excludes toilet streams, also known as black water. It has been reported to constitute between 50 and 80% of the total household wastewater (Eriksson *et al.*, 2002). Typical pollutants in GW include grease oil and fat, toothpaste residues, soaps and detergent surfactants, and other organic substances. Grey water quality and quantity depend on household lifestyle, income, and the choice of cleansing chemicals used during washing up, laundry washing, and showering (Li *et al.*, 2009; Boyjoo *et al.*, 2013; Ahmadi & Ghanbari, 2016). Grey water harvesting and treatment for re-use is one of the most effective ways of addressing water shortages and managing water resources in developing countries (Leong *et al.*, 2017). Table 2.1 above shows findings from different countries.

**Table 2.1: Findings of different countries**

Parameter	Low-income countries					High-income countries				
	India (Parjane & Sane, 2011)	Pakistan (Pathan <i>et al.</i> , 2011)	Niger; (Wu <i>et al.</i> , 2015)	Yemen (Al-Mughalles <i>et al.</i> , 2012)	Averages	USA (Jokerst <i>et al.</i> , 2011)	UK (Birks & Hills, 2007)	Spain (March <i>et al.</i> , 2004)	Germany (Merz <i>et al.</i> , 2007)	Averages
pH	7.3-8.1	6.2	6.9	6	<b>6.37</b>	6.4	6.6–7.6	7.6	7.6	<b>7.2</b>
Turbidity (NTU)	–	–	85	619	<b>352</b>	31.1	26.5–164	20	29	<b>26.7</b>
EC (µS/m)	–	–	–	–		23	32.7	–	64.5	<b>40.067</b>
TSS (mg/L)	100–283	155	–	511	<b>333</b>	17	37–153	32	–	<b>24.5</b>
TDS (mg/L)	573	102	–	–	<b>338</b>	171	–	–	–	<b>171</b>
BOD <sub>5</sub> (mg/L)	100–188	56	106	518	<b>227</b>	86	39–155	–	59	<b>72.5</b>
COD (mg/L)	250–375	146	–	2000	<b>1073</b>	–	96–587	151–177	109	<b>109</b>
Cl (mg/L)	53	–	–	–	<b>53</b>	–	–	–	–	
Oil & Grease (mg/L)	7	–	–	–	<b>7</b>	–	–	–	–	
Nitrate (mg/L)	0.67	–	–	98	<b>49.3</b>	–	3.9	–	–	<b>3.9</b>
T. Nitrate (mg/L)	–	–	–	–		13.5	4.6–10.4	10–11	15.2	<b>14.35</b>
T. Phosp (mg/L)	0.012	–	–	–	<b>0.01</b>	4	0.4–0.9	–	1.6	<b>2.8</b>
FC (CFU) x10 <sup>5</sup>	–	–	–	1.9	<b>1.9</b>				1.4	<b>1.4</b>
E.coli (CFU) x10 <sup>5</sup>	–	–	–	–		5.4	10			<b>7.7</b>
Ca (mg/L)	0.13	–	–	–	<b>0.13</b>	–	–	–		
Mg (mg/L)	0.11	–	–	–	<b>0.11</b>	–	–	–		
Na (mg/L)	32–50	–	–	–		–	–	–		

## **2.2 Characterisation of greywater**

### **2.2.1 Physical Constituents**

Physical constituents in GW give rise to its characteristics, such as temperature, turbidity, electrical conductivity, and suspended solids. The temperature range of GW usually is between 18 and 35 °C. The high temperatures come from warm water used for personal hygiene and cooking (Ciabatti *et al.*, 2009; Prathapar *et al.*, 2005). These high temperatures favour unwanted microbiological growth and may also lead to the precipitation of certain carbonates, such as CaCO<sub>3</sub> and other inorganic salts, which become less soluble at high temperatures (Jakobi & Lohr, 1987). As reported by Edwin *et al.* (2014) and Oteng-peprah (2014), the concentration of total suspended solids in GW can range from 190 to 537 mg/L. Greywater from the kitchen and laundry accounts for the relatively high Total Suspended Solids (TSS) values, and this may be due to washing clothes, shoes, vegetables, fruits, tubers, and many others that may contain sand, clay and other materials that may increase TSS (Jakobi & Lohr, 1987).

The ranges of conductivities recorded in Ciabatti *et al.* (2009) and Prathapar *et al.* (2005) for GW are between 14 and 3000 µS/cm due to high dissolved solids materials. The turbidity range recorded for GW ranges from 19 to 444 NTU and is mainly influenced by water use activities. Grey water is expected to become more turbid due to the presence of suspended material (Ciabatti *et al.*, 2009; Prathapar *et al.*, 2005)

### **2.2.2 Chemical Contaminants**

It is essential to understand the sources of contaminants to identify the various chemical constituents in GW. Significant chemical components in GW come from chemicals used to clean, cook, and bathe. The pH in GW largely depends on the pH and alkalinity of the water supply and is usually within 5–9. GW will generally exhibit high pH because of the alkaline materials used in detergents (Jakobi & Lohr, 1987). Surfactants are the major chemical components found in GW generated by cleaning or washing activities (Jakobi & Lohr, 1987). In most cleaning products, these surfactants serve as the primary active agent. Because of the alkaline materials used in detergents, GW, with most of its sources from the laundry, will generally exhibit high pH (Jakobi & Lohr, 1987). Most cleaning and laundry products are anionic (Jakobi & Lohr, 1987) but can be cationic or anionic. Cationic surfactants are generally based on salt and constitute an ammonium source in GW. Other components found in GW

also include nitrates and phosphates derived from ammonium, cationic surfactants, and laundry disinfectants (Eriksson *et al.*, 2002).

Other components, such as sodium chlorides, can also be found in appreciable levels from cooking and preservatives used in the kitchen. Sodium-based soaps also add substantial amounts of sodium to GW. Other additives, such as constructors, control water hardness in detergents and serve as the primary source of contaminant phosphate in GW. Kitchen and laundry activities are associated with nutrients such as N and P. Grey water sources with high concentrations of nutrients mainly consist of a high fraction of kitchen and laundry sources (Boyjoo *et al.*, 2013). Kitchen waste is the primary nitrogen source in GW, ranging from 4 to 74 mg/L while washing detergents are the primary source of phosphates found in grey water, ranging from 4 to 14 mg/L (Boyjoo *et al.*, 2013).

The conventional parameters of wastewater, such as five-day biochemical demand for oxygen (BOD<sub>5</sub>) and chemical oxygen demand (COD), always show a COD dominance over BOD<sub>5</sub>. The BOD<sub>5</sub>/COD ratios determine the biodegradability of GW. The ratio determines how easily bacteria in the GW can decompose the organic matter. Mostly, in terms of BOD<sub>5</sub>/COD ratios, all types of GW show good biodegradability (Li *et al.*, 2009). The average GW BOD<sub>5</sub>/COD ratios ranged from 0.31 to 0.71, indicating that nearly half of the organic matter in GW is biodegradable (Halalsheh *et al.*, 2008), however, ratios as high as 4:1 recorded in other studies (Boyjoo *et al.*, 2013). COD's dominance in BOD<sub>5</sub> has been mainly due to xenobiotic organic compounds (XOCs), which increase COD. XOCs are synthetic organic compounds in household chemicals and pharmaceuticals such as bleaches, surfactants, softeners, and beauty products. XOCs may also be formed by partial chemical or biological modification of GW treatment chemicals (Fatta-Kassinos *et al.*, 2011). XOCs are recalcitrant to conventional treatment protocols and can quickly accumulate and pose risks to the natural environment in plants and animals (Fatta-Kassinos *et al.*, 2011).

Eriksson *et al.* (2002) identified 900 potential XOCs in GW based solely on Denmark's various cosmetics and detergent ingredients. Le-Minh *et al.* (2010) identified antibiotics in GW that could lead to the proliferation of resistant bacteria strains. Revitt (2011) also identified in significant concentrations the presence of benzene and 4-nitrophenol in GW. Other hazardous substances have been identified in GW, including brominated flame retardants, polycyclic aromatic hydrocarbons, monocyclic aromatics, triclosans, and phthalates (Palmquist & Hanaeus, 2005).

### 2.2.3 Surfactants Pollution

Anionic surfactants are currently the most widely utilized, with anionic surfactants found in most of the detergent and cleaning-product compositions. The most often utilized synthetic anionic surfactants are linear chain alkyl benzenesulfonate kinds. They've been widely used for almost 30 years, with global usage estimated at 2.8 million tons in 1998. These surfactants make their way into sewage treatment plants, where they are partially destroyed aerobically and adsorbed to sewage sludge applied to landfills. They are discharged into rivers through treated effluent streams from wastewater treatment plants and onto the ground, where they're one of the most significant variables harming the natural ecology (McEvoy & Giger, 1985). As a result, it's critical to determine the concentration of anionic surfactants accurately and have quick and simple methods to track their biodegradation over time.

Spectrophotometric methods utilising methylene blue are commonly used to determine anionic surfactants, and this standard approach is also used to assess surface agents in tap- water samples. This procedure, on the other hand, is not only time-consuming and tedious but also necessitates a large amount of chloroform and sample. The approach works by forming an ionic pair between the anionic surfactants and methylene blue.

Koga *et al.*, 1999 presented simplified techniques for lowering reagent quantities (Chitikela *et al.*, 1995) by employing a specific type of adsorbent (Moskvin *et al.*, 1996) or by reducing the volume of sample and reagents used. However, this method entails time-consuming operations that do not eliminate the filtration stage. This technique becomes even more complicated when monitoring the biodegradation of anionic surfactants. Until the biodegradation is complete, it is essential to make successive determinations at low surfactant concentrations.

Further simplification of the spectrophotometric methylene blue approach is suggested, which may be used to determine anionic surfactants in relatively clean aqueous samples. This technique is used to track the primary biodegradation of LAS. Several authors have investigated the primary biodegradation of LAS. Yakabe *et al.* (1992) showed that the surfactant concentration declined according to a zero-order kinetic in healthy water in the presence of acclimated bacteria at an initial concentration of 2.44 mg/l (Quiroga & Sales, 1991) provided a model based on a second-order polynomial equation for seawater with a starting concentration of 4 mg/l. This model fits the experimental data reasonably and supports the microorganisms' adaption period and residual surfactant concentration. Moreno *et al.* (1990) and Berna *et al.* (1989) examined the biodegradation of surfactants in wastewaters and found that the residual surfactant content declined according to a first-order kinetic.

## 2.2.4 Micro-Biological Characteristics

Greywater contains microorganisms like bacteria, protozoa, and helminths introduced by contact with the body. Inappropriate food handling in the kitchen and direct handling of contaminated food have been identified as sources of enteric pathogenic bacteria such as Salmonella and Campylobacter in GW (Maimon *et al.*, 2014; Ottoson & Stenström, 2003). Also shared in GW is faecal contamination, which is primarily associated with poor personal hygiene. Pathogenic E. coli and enteric viruses have been detected in GW with most of the domestic wastewater samples from laundry sources, of which 18% of the samples included enteric viruses, 7% enterovirus, and 11% E. coli (Ottoson & Stenström, 2003). Coliform bacteria and E. coli are the most common indicators used to evaluate faecal contamination. E. coli studies by Eriksson *et al.* (2002) and Ottoson Stenström (2003) revealed an extensive collection of GW-related excreta pathogens. Pseudomonas (Benami *et al.*, 2015); Legionella Staphylococcus aureus (Benami *et al.*, 2015; Kim *et al.*, 2009; Maimon *et al.*, 2014; Shoults & Ashbolt, 2017) have also been identified in GW studies.

## 2.3 Raw wastewater re-use

Greywater can be reused without prior treatment, bearing in mind the unnecessary increases in volumes of wastewater that go to the wastewater plants and its dilution effect of 65% (Vuppaladadiyam & Ming, 2018) to 70% (Radingoana *et al.*, 2020) of backwater to the total wastewater that goes to the Wastewater Treatment Plants. While it has a long history in developed nations, greywater reuse is held back by social stigma and the need for knowledge (Radingoana *et al.*, 2020). South Africa has a domestic wastewater reuse standard (DWAf), which allows for the reuse of greywater. Typical values of pollution tolerances are shown in Table 2.2 below.

**Table 2.2: South African Domestic water reuse standards**

Parameters	South African domestic use Standards
Aluminium	0 -1.5 mg/l
Chlorides	200 – 600 mg/l
Colour	30-200 PtCo units
Dissolved organic carbon	0 – 5 mg/l
Calcium	0 – 32 mg/l
Iron	0.3– 1 mg/l
Nitrates	0 – 6 mg/l
Odour	1 ton
pH	6 – 9
EC	0 – 70 mS/m
Total dissolved solids	0 – 450 mg/l
Turbidity	5 – 10 NTU
Phosphate	5-10 mg/l
Sulphate	0-200 mg/l



The pH for the South African Domestic reuse standard is comparable with USEPA (USA); however, it is shallow in nitrogen compounds compared to the World Health Organisation. Table 2.3 compares the South African greywater reuse guidelines with other national and international standards.

**Table 2.3: Water quality standards for reuse in different countries**

Standard		pH	SS mg/L	BOD mg/L	N mg/L	REFERENCE
WHO	Restricted irrigation				50	WHO (2006)
	Unrestricted irrigation	6.5-				
	Drinking quality	8.5				
USEPA (USA)	Unrestricted use	6–9	<30	<10		(Russell, 2004)
	Restricted use	6–9		<30		
CPCB-India	On land for irrigation	5.5–9	200	100		(Central Pollution
(for quality of treated wastewater)	Into inland surface water	5.5–9	100	30		Control Board, 2008)
	Into Public sewers	5.5–9	600	350		

Greywater can be used as it is or treated to reduce nutrients and disease-causing microbes to varied degrees. The best way to use greywater is to consider both the source and the level of treatment. Agriculture, landscape, public parks, and golf course irrigation are all examples of non-potable (not for drinking) uses for recycled water. Once treated, other non-potable uses include cooling water for power plants and oil refineries, industrial process water for paper mills and carpet dyers, toilet flushing, dust control, building activities, concrete mixing, and artificial lakes, to name a few (Program, 2015). Although most water recycling systems are designed to address non-potable water demands, several uses recovered water for potable uses indirectly. These efforts include recharging groundwater aquifers and supplementing surface water reservoirs with recycled water. Reclaimed water can be dispersed or injected into groundwater aquifers as part of groundwater recharge operations to supplement groundwater supplies and prevent saltwater intrusion in coastal locations.

Using greywater for landscape irrigation and toilet flushing at decentralized sites reduces the amount of potable water delivered to these locations, the quantity of fertilizer required, and the amount of wastewater created, transported, and treated at wastewater treatment plants. Water reuse saves water, energy, and money (Program, 2015). Electrocoagulation (EC) is the

simplest, most cost-effective, and most highly effective method for water and wastewater treatment (Eriksson *et al.*, 2002).

## **2.4 The Fate and Resiliencies of Biological Wastewater Treatment Technologies**

Although there is much research for new and better wastewater treatment technologies, the after-World War II centralized conventional gravity wastewater channeling with open loop to the environment sanitation systems seem still to denominate the wastewater treatment technology arena but not without challenges (Kooattatep *et al.*, 2019). The biggest challenges of the new wastewater treatment technologies are the lack of funding and their popularization by researchers to the government institutions and communities because water and sanitation methods and types have psycho-social elements attached to the re-use of treated (Kooattatep *et al.*, 2019). However, due to high levels of water scarcity during drought seasons, household irrigation activities with untreated greywater have become one of the water-saving strategies. Discharging contaminated water into the ecosystems in this way may have significant environmental and public health impacts, such as waterborne diseases still common in developing countries (Eriksson *et al.*, 2002; Pedro-Monzonis *et al.*, 2014). Conventional wastewater treatment plants use microbiological methods, amongst others, to remove total suspended solids (TSS), turbidity, chemical oxygen demand (COD), biological oxygen demands (BOD), nutrients such as phosphorus and nitrates, and pathogens to meet regulatory standards. However, conventional wastewater plants do not meet the effluent discharge standards, creating a need to develop new wastewater treatment technologies (Chong *et al.*, 2015; Ushijima *et al.*, 2013).

There have been numerous studies on the treatment of greywater with various technologies, including a flow anaerobic sludge blanket (UASB) reactor (Oteng-Peprah & de Vries, 2018), sequence batch reactor (Kim *et al.*, 2009), membrane bioreactor (Lesjean & Gnriss, 2006) and vertical flow designed wetlands (Li *et al.*, 2018), however, without a wide scale application. For many years, these techniques have been used as the primary method for treating combined wastewater without consideration of separating the wastewater streams and harnessing the benefits of their different characteristics.

Recent literature identifies various gaps and challenges in wastewater treatment research. One key barrier is the scalability and cost-effectiveness of developing technologies, which frequently prevent their widespread adoption beyond small-scale demonstrations (Abuabdou *et al.*, 2021). In addition, standardised protocols and performance indicators are required to assess the efficacy and reliability of novel treatment techniques (Rosenfeldt *et al.*, 2020). Furthermore, integrating decentralised treatment systems into existing infrastructure and

regulatory frameworks creates logistical and regulatory challenges (Khadre et al., 2022).

## **2.5 Wastewater Treatment Technologies a Need for a Paradigm Shift**

Diversifying wastewater technologies and decentralizing wastewater treatment units based on wastewater provide pilot research opportunities for diversifying wastewater and its treatment technologies. Electrocoagulation and flocculation (ECF) technology are promising technologies that can be made as a packaged unit because it is a simple, cost-effective, and highly effective water and wastewater treatment (Eriksson et al., 2015).

In recent years, several studies have focused on the treatment of industrial effluents using electrocoagulation-flotation (ECF). The effluents in these studies include electroplating wastewater (Adhoun et al., 2004); paper mill bleaching wastewater (Sivakumar, 2011) chemical mechanical polishing wastewater (Li et al., 2003), textile wastewater (Kobya, 2003) and wastewater olive oil (Inan et al., 2004). ECF offers several advantages, including ease of operation, robustness to varying reaction conditions and types of effluent, lower retention time, rapid sedimentation of electro-generated flocculants together with pollutants, lower sludge production, and lower space and capital costs (Bektas et al., 2004). However, little attention has been given to greywater treatment, perhaps due to its biological nature, which is more amenable to treatment by biological methods than chemical or physical methods. However, these biological methods have many other operational changes, such as long hydraulic residence times, bioreactor poisoning, long inoculation periods, smell to the nearby communities, sludge generation, and disposal problems (Jiang, 2002).

## 2.6 Greywater Treatment, Re-Use and Ecological Benefit

Conventional wastewater treatment methods are mainly used to remove total suspended solids (TSS), chemical oxygen demand (COD), and nutrients to sufficient levels that meet regulatory standards for non-potable GW reuse, such as for irrigation and toilet flushing (Chong *et al.*, 2015; Ushijima *et al.*, 2013). Greywater (GW) recycling could reduce the amount of water consumed and discharged into the sewer systems, saving money on water bills. All but toilet flushing water or Blackwater may be recycled outside, diverting from environmental disasters (Chong *et al.*, 2015; Ushijima *et al.*, 2013). The following are some of the many ecological advantages of greywater recycling:

- (a) Lowering the freshwater use: There are many cases where GW can be used after treatment instead of fresh water, such as in irrigation process water, saving money and improving the adequate water supply, reducing wastewater that does to municipal wastewater treatment systems resulting in improved treatment efficiency and decreased treatment costs (Chong *et al.*, 2015; Ushijima *et al.*, 2013).
- (b) Less strain on septic tank or treatment plant: Septic systems' usable life and capacity are considerably extended when greywater is separated from the blackwater at the source (Li *et al.*, 2009; Boyjoo *et al.*, 2013; Ahmadi & Ghanbari, 2016).
- (c) Less energy and chemical use: The amount of freshwater and wastewater that needs to be pumped and treated can be minimized by using recycled water, resulting in less

energy usage for pumping and chemicals usage needed for the treatment of potable water, thereby making every kilolitre go a long way (Thole, 2015). The benefit of lessening stress on the system is immediately seen by people who provide water or energy utilities.

(d) Highly effective purification: Greywater is cleaned to an astonishing degree in the soil's higher, biologically active zone. The quality of natural surface and ground waters is therefore protected (Li *et al.*, 2009; Boyjoo *et al.*, 2013; Ahmadi & Ghanbari, 2016).

(e) Groundwater recharge: GW used in excess can be used to recharge the groundwater table (Li *et al.*, 2009; Boyjoo *et al.*, 2013; Ahmadi & Ghanbari, 2016).

Plant growth: Untreated GW can be used for landscapes to thrive in areas without enough water to sustain significant plant growth (Leong *et al.*, 2017).

## **2.7 Electrocoagulation Technology**

Electrocoagulation is an electrochemical treatment system that involves electro-oxidation and electro-flotation of pollutants with minimum addition of chemicals such as electrolytes. It is a promising advanced wastewater treatment technology. Since Faraday's invention, electrochemical technology has advanced in many fields, such as the battery industry electroplating. It is a hopeful technique for destroying organic pollutants in the vast wastewater treatment collection without adding additional chemicals. In addition, the highest property of the electrochemical process is that it prevents the assembly of unwanted by-products (Bektas *et al.*, 2004). So far, although these technologies have shown a potential for removing most pollutants in many effluent streams, they have not been applied systematically and sufficiently to derive a conclusive understanding of their technology, Therefore, this is a preliminary study for the screening and optimizing factors that affect greywater treatment (GWT) with EC that future studies can use. This research determines the best operating conditions of the (ECF) process in treating GW by manipulating ECF operating parameters such as electrode types, effluent volume, pH, mixing, and current density. The electrochemical method was proposed in 1889 with a well-established plant for sewage treatment. In this process, wastewater is electrolyzed with seawater (Elmitwalli *et al.*, 2007). The prime interest of the primary stage development of the ECF process is to generate chlorine to remove odors and disinfect sewage wastewater (Elmitwalli *et al.*, 2007).

### **2.7.1 The advantages of the Electrocoagulation Process (Elmitwalli *et al.*, 2007)**

- Involves simple equipment and is easy to work with.
- Requires low investment, maintenance, energy, and treatment costs.
- Treated wastewater furnishes pleasant, odorless, clear, and colorless water.

- Low sludge-producing process, sludge is less water bound but large, mainly composed of metallic matter (Elmitwalli *et al.*, 2007).
- Does not need additional chemicals required in the EC process.
- Produced effluent contributes to a lesser water recovery cost because it contains a lesser amount of total dissolved solids (TDS) as related to chemical treatments.
- Gas-generated bubbles at the time of electrolysis can proceed the pollutants to the top of the solution, where they can be separated without any difficulties.
- Provides more excellent and efficient pH range and pH neutralization result (Elmitwalli *et al.*, 2007).
- It can use DC-current and therefore be suitably used with all forms of electrical renewable energy.

### **2.7.2 The disadvantages of the Electrocoagulation Process (Elmitwalli *et al.*, 2007):**

- It complicated ECF process mechanisms and parameters that are not easily quantifiable.
- The sacrificial anodes are dissolved into solution due to oxidation and must be replaced regularly.
- The conductivity of the wastewater suspension must be high.
- Viscous hydroxide may be likely to solubilize in some cases.
- The efficiency of the electrocoagulation unit decreases due to an impervious oxide film shaped on the cathode or passivation.
- Electrocoagulation has the challenge of short-circuiting.

### **2.7.3 Mechanism of Electrocoagulation**

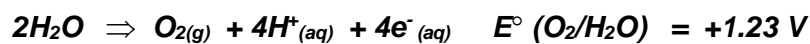
During (ECF), oxidation reactions take place on the sacrificial anode, and reduction reactions occur on the cathode (Figure 2.2). Oxidation and reduction occur at the electrode, co-occur, and responses are immediately at the electrodes/electrolyte interface, which are the chemical processes. At the same time, electrolytic gases, typically hydrogen, are generated at the cathode. The anode is the electrode in which procedures of oxidation happen. The anode electrode, also known as the sacrificial electrode, corrodes to release active coagulant cations to the solution, usually made of aluminium or iron. Aluminium and iron electrodes are commonly used in EC processes to produce aluminium and iron hydroxide flocs (Eriksson *et al.*, 2015); the anode electrode, therefore, provides metal cations dosage in-situ rather than external dosage in conventional chemical coagulation.

The present flow is preserved in the electrocoagulation cell by the flow of electrons arising from the electrical source's driving force. The electrolyte solution enables the current to flow through the movement of its loaded ionic species. High conductivity benefits the method by

decreasing the solution's electrical resistance and consumption. There are significant responses to the electrocoagulation process:

- The electrode.
- Electrolyte responses.
- Coagulant formation.
- Pollutant adsorption.
- Removal by sedimentation or floatation of colloids.

When current is introduced to the EC process, the anode starts to dissolve and form cations of the electrode material ( $Mz^+$ ), e.g.,  $Fe^{2+}$  and  $Fe^{3+}$  are produced for iron electrodes and  $Al^{3+}$  from aluminum electrodes, including electro-decomposition of water, producing electrolysis oxygen gas at the anode that is responsible for electrodeposition (Raju, 2008).



Simultaneously, all anions are reduced at the cathode. The cations near the surfaces react with water in the bulk of the effluent medium, forming a hydration layer around the cation and other forms of aquametalhydroxo complexes. Hydrolysis reactions are followed by chemisorption reactions, forming many forms of hydroxides of cations in the aqueous medium and precipitates that settle as sludge (Larue *et al.*, 2003).

Metal hydroxide species provide effective destabilization of suspended solids. The removal mechanism could be adsorption, charge neutralization, and sweep coagulation. A simplified schematic diagram is shown below.

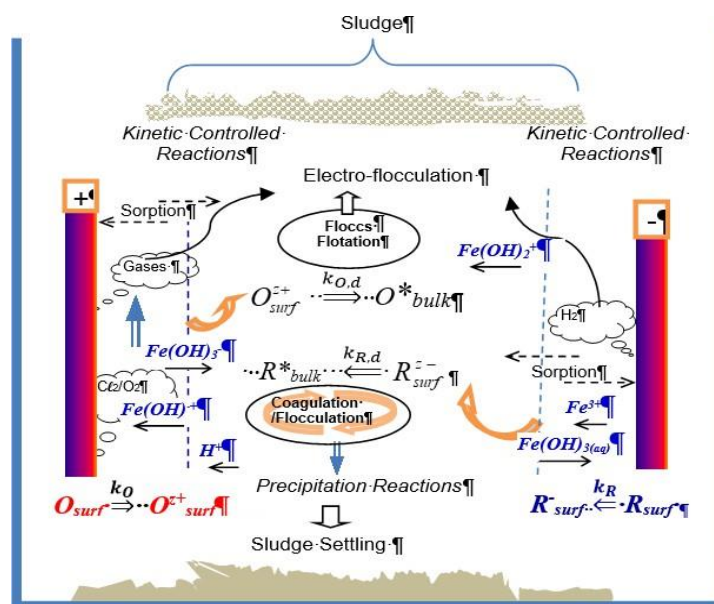


Figure 2. 1: Mechanism of EC removal of micro pollutants (Thole, 2015)

### 2.7.4 Reactions at the electrode

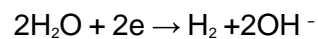
A simple electrocoagulation reactor consists of one anode and one cathode. The anode material undergoes oxidation when a potential is applied from an external power source, while the cathode is subject to reduction or deposition of elemental metals (Eriksson *et al.*, 2002). This coagulant affects the procedures of coagulation and efficacy. The primary responses occur at the Iron Electrode metal electrodes (Larue *et al.*, 2003)

Iron Electrode

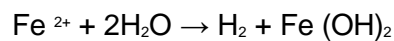
Anode:



Cathode:



Overall:

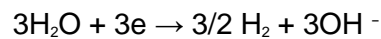


OR

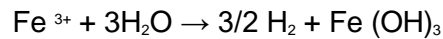
Anode:



Cathode:

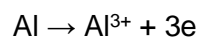


Overall:

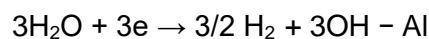


Aluminium Electrode

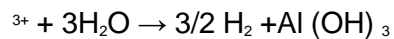
Anode:



Cathode:



Overall:



### 2.8 Factors that Affect Electrocoagulation

It is known that several parameters affect the effectiveness of electrocoagulation and its capacity to remove pollutants from wastewater; the most significant parameters in this chapter are addressed.



### 2.8.1 Current Density and Supporting Electrolyte

One of the most critical operation parameters in EC has an integral effect on process efficiency (Lesjean & Gnirss, 2006). Sodium chloride is usually employed to increase the conductivity of the water or wastewater to be treated (Zodi *et al.*, 2009). Therefore, characterization of the laundry greywater is very much needed. Current density, the present per electrode region, determines the quantity of metal ions released from the electrodes. Overall, the dissociation of metal ions is directly proportional to the current density applied (Zodi *et al.*, 2009). When too big a current is used, there is a high likelihood that electrical energy will be wasted in water heating and even a reduction in present effectiveness expressed as the proportion of the current consumed to the complete present consumption of a particular item.

The current density also determines the size of the gas bubbles produced from the anode or the cathode, affecting the process's effectiveness. There is a critical value for current density that shows no significant improvement if the quality of treated water is surpassed (Maimon *et al.*, 2014). Other parameters such as pH, temperature, and water flow rate (Chen, 2004) (Khandegar & Saroha, 2013) also affect the selection of an optimal value for current density. Several scientists have researched the impact of current density on EC's operation/efficiency under various operating conditions (Moskvin *et al.*, 1996) and (Bayar *et al.*, 2011). One of the significant factors influencing the electrocoagulation method is current density. The extraction effectiveness of TSS and COD is discovered to be quickly increased up to the present 20 mA / cm<sup>2</sup> density to increase the formation of flocks of metal hydroxide (M(OH)<sub>3</sub>) in the reactor and hence the improvement in extraction efficiencies but at greater present density (25–30 mA/cm<sup>2</sup>) for removal of TSS, and COD.

### 2.8.2 Electrolysis Time

Electrocoagulation time is another critical parameter influencing the process of electrocoagulation. An increase in electrolysis time leads to an increase in coagulant concentrations that has been reported to reduce the floc density and their settling velocity (Zodi *et al.*, 2009). Because metal hydroxide formation and levels play a significant part in removing pollutants (COD, turbidity, and phosphorus), increased electrolysis time contributes to a rise in levels of coagulants that have been reported to decrease floc density and then decrease their settling velocity (Zodi *et al.*, 2009) and (Mahajan *et al.*, 2013). In the EC efficiency phase, electrolysis time is of essential significance.

It was discovered that removing TSS, COD, and faecal coliform improves with an increase in electrolysis times of up to 15 min, followed by almost steady extraction effectiveness

(Thirugnanasambandham, 2013). Nearly all poisonous substances are subsequently removed as flocs in 15–30 minutes, after which there is no change in removing TS, COD, and faecal coliform with further increased electrolysis time (Thirugnanasambandham, 2013). The effectiveness of COD removal relies directly on the concentration of electrochemically produced hypochlorite ions in the bulk solution. When electrolysis is longer, more hypochlorite ions will be produced under fixed current density. Although some workers realized the importance of the natural settlement process, little information is available in the literature on the effect of the preliminary settlement time on the capacity to remove pollutants (Bazrafshan *et al.*, 2008). That removal effectiveness improved with the settling moment. According to the hypothesis of fast coagulation suggested by (Smoczynski *et al.*, 2009), there is a sharp boost in removal effectiveness with time at the early settling point.

### **2.8.3 Effect of pH**

The pH of the reaction solution changes during the EC process, and the final pH of the effluent usually goes up towards the end of the EC. The pH affects the overall treatment performance. It is generally found that the aluminum current efficiencies are higher at either acidic or alkaline conditions than at neutral (Zodi *et al.*, 2009).

### **2.8.4 Effect of electrode type**

In most studies reported in the literature, aluminum (Al), mild steel, and stainless steel (SS) electrodes have been used as electrode materials. The size of the cation produced is suggested to be 10-30  $\mu\text{m}$  for  $\text{Fe}^{3+}$  compared to 0.05 - 1  $\mu\text{m}$  for  $\text{Al}^{3+}$  to the higher efficiency of iron electrodes (Lesjean & Gnirss, 2006). It is critical to select the appropriate electrode material as it determines the responses and the type of metal coagulants that would be produced. The selection criteria include the metal electrode's price, accessibility, reliability, and efficacy. As stated above, owing to their demonstrated reliability and accessibility, Al and Fe electrodes are most used. It is usually demonstrated in most research that Al electrodes improve the effectiveness of pollutant removal better than Fe electrodes (Khandegar & Saroha, 2013). A wide variety of electrode components were also tested besides Al and Fe (Khandegar & Saroha, 2013) compared to zinc, copper, aluminum, and iron electrode efficiency to remove Pb (II) from aqueous solutions. The authors concluded that zinc electrodes were superior by achieving maximum removal of Pb (II) (97.5%) with minimum sludge generation and lowest energy consumption (0.325 kWh/m<sup>3</sup>) and operating costs (0.664\$/m<sup>3</sup>) within 30 minutes of operation (Khandegar & Saroha, 2013).

Kamaraj and Vasudevan (2015) explored the impact of anode material on the effectiveness of removal of radioactive materials such as strontium and cesium. The authors conducted a series of experiments using anodes of aluminum, iron, zinc, and magnesium while maintaining the cathode of galvanized iron unchanged. Magnesium anode has proven to be the most efficient anodic material, with 97% strontium removal and 96.8% cesium removal (Vasudevan & Lakshmi, 2009). Genesan obtained a 97.2% removal of manganese from drinking water using a magnesium anode EC cell and a stainless steel cathode. The optimum requirements for operation were 00.05 A / dm<sup>2</sup> and seven pH.

Govindan *et al.* (2015). Studied the electro-denitrification of removal of nitrate ions from aqueous solutions by aluminum, iron, and inert graphite electrodes, of which aluminum and iron electrodes are used as anodes, were found to be the best. However, nitrate ions are absorbed in the ammonia production process during electro-reduction, resulting in ammonia production.

On the other hand, the ammonia production process was very close to removing nitrate ions when a non-dissolving graphite electrode was used.

### **2.8.5 Electrode Assembly Configurations**

In monopolar-parallel configuration (MP-P), all anodes are connected to the external supply of DC, and the same applies to cathode electrodes (Kobya, 2003), (Thole, 2015). In this configuration, if compared to the series-connected electrodes, the current is divided between the electrodes, resulting in a lower potential difference. On the other hand, a monopolar-series (MP-S) connection is achieved when the two outermost electrodes are connected to the external circuit, forming the anode and cathode. In contrast, each pair of the inner electrodes is connected without the external electrodes being interconnected. In this situation, a more significant potential difference is added to the cell voltage (Kobya, 2003) and (Thole, 2015). The internal electrodes are known as the "sacrificial electrodes" that can be produced from comparable or distinct metals, and their function is to decrease the cathode's anode consumption and passivation (Vasudevan & Lakshmi, 2009). The third alternative is the configuration of the bipolar series (BP-S), in which the outermost electrodes are attached straight to the outer power supply, with the internal electrodes not linked by any means (Thole, 2015). Once the current moves through the primary electrodes, it polarizes the adjacent side of the internal electrodes and carries a charge contrary to the neighbouring electrode charging. In such a configuration, while the inner sacrificial electrodes are bipolar, the two outermost electrodes are known to be (Khandegar & Saroha, 2013).

## 2.8.6 Economic Evaluation of Electrodes using Electrode Assembly Configurations

The selection of the suitable electrode connection mode is determined by the price of the electrode's material and its efficacy or effectiveness in removing pollutants and researched the economic impact of various electrode relations (MP-P, MPS, BP-P) on EC's color, turbidity removal and complete wastewater treatment price of 19 textile treatment plants. His findings showed comparable extraction efficiencies for all three relations. However, the most cost-effective is the MP-P configuration (Koby, 2003), which demonstrated the same outcomes where MP-P mode provided the most excellent efficiencies in the removal and the minor working costs for EC therapy of sewage can be produced. (Golder *et al.*, 2007) researched the impact of monopolar and bipolar relations on present effectiveness, Cr<sup>3+</sup> removal, and working costs in an experiment to extract Cr<sup>3+</sup> from aqueous solutions using ECF with mild steel electrodes. (Golder *et al.*, 2007), Findings showed that monopolar connections gave greater present effectiveness with reduced working costs compared to bipolar connections. However, bipolar connection resulted in an almost complete removal of Cr<sup>3+</sup> compared to 81.5% with monopolar connection. The removal of fluoride from drinking water was better when bipolar electrodes were used, but the total operating cost of monopolar electrodes was much less, as reported (Ghosh, 2017)

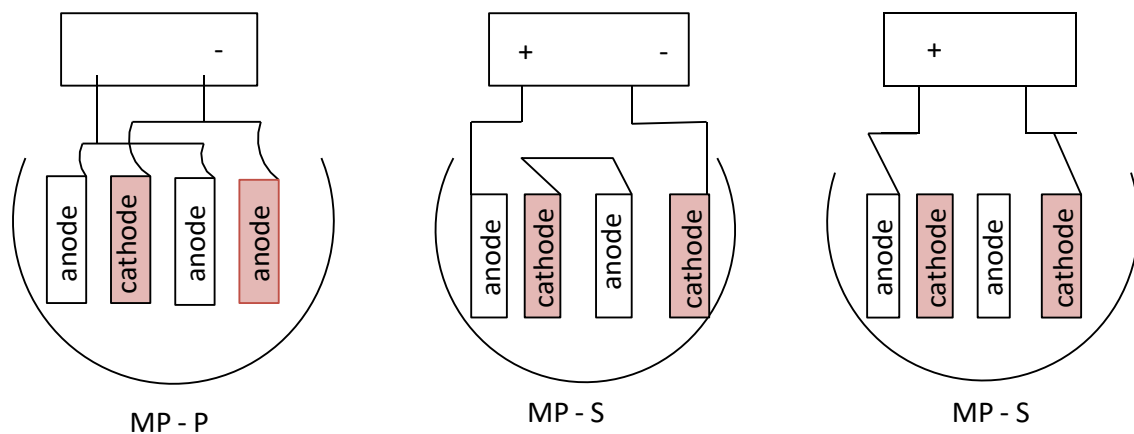


Figure 2. 2: Electrode assembly configuration

## 2.8.7 The Effect if Anion Concentrations on ECF

Various anions have various impacts on metal ions ' destabilization characteristics. Sulfate ions are also known to inhibit electrode corrosion/metal dissolution and thus reduce colloid destabilization and reduce present effectiveness by enhancing the capacity between electrodes; conversely, by breaking down the passive layer, chloride and nitrate ions stop

sulfate ion inhibition. The solution's conductivity is a significant variable affecting the ECF's effectiveness and power consumption; the more significant the conductivity, the more the ECF's power consumption is reduced owing to the enhanced pollutant removal effectiveness. Therefore, adding anions in salts, such as NaCl, enhances the solution's conductivity. Chlorine ions have also been discovered to contribute efficiently to water disinfection (Chen, 2004).

## **2.9 Design of Experiments (DoE)**

Most wastewater treatment system optimization studies have concentrated on the traditional one-factor-to-a-time strategy (Bezerra & Santelli, 2008). However, this strategy needs to consider the cross effects of the variables considered, which is time-consuming and results in lousy optimization outcomes (Box & Hunter, 2005). The design of the experiment can be used as a preliminary planning of the experiment as the DoE statistical software can develop a table, such as shown in Table 4.2, with the order of how the experimental runs must be performed (Montgomery, 2013). Optimization technique with the following application stages: to carry out screening studies and to define the experimental ranges according to the objective of the study and the experience of the researcher and to select independent variables that have significant effects on the system,

We are conducting experiments using the chosen experimental design method and the generated experimental matrix, fitting the polynomial function to the experimental data obtained by mathematical-statistical treatment, evaluating the fitness of the model to the data, Investigating the necessity and possibility of displacement through the direction of the optimal region and achievement of the optimum values of each independently studied variable (Bezerra & Santelli, 2008).

### **2.9.1 Screening Design Methodology**

Many factors are screened to see which factors drive the system's performance. Most of the time, the number of experiments depends on the literature review and the experimenter's knowledge of the system. Also, it depends on the workforce and equipment resources at the disposal of the experimenter (Box & Hunter, 2005) and (Montgomery, 2013). Once the number of experiments has been decided on and is manageable, the entire range of factors can be explored in a complete factorial design. However, as the number of factors increases, the number of combinations increases geometrically. For this reason, studies employing experimental design should use techniques like the Fractional Factorial Method, which produces high confidence in sensitivity results using tiny fractions, that is, a small subset of

the overall number of combinations, in some cases as small as 1 in a million (Box & Hunter, 2005) and (Montgomery, 2013).

Usually, two values of the X's (called X's levels) are used in the screening experiment for every factor, denoted by "high" and "low," and coded + 1 and -1. Using only two levels implies that the results are monotonic on the response variable but not necessarily linear. A minimum of three factors would be required to detect curvature. Interaction is present when the effect of an element on the response variable depends on the level of another factor (Box & Hunter, 2005) (Montgomery, 2013).

### **2.9.2 Response Surface Methodology (RSM)**

Response Surface Methodology is a statistical technique for experimental designs, model developments, evaluating interaction effects of several independent variables (factors) on dependent variables (responses), and searching for optimum conditions for desirable responses. Interactions of possible factors can be evaluated with a limited number of RSM-designed experiments compared to DoE (Box & Hunter, 2005).

Three types of experimental designs are commonly used for response surfaces methodology: the central composite design (CCD), the three-level fractional factorial design, and the D- or 1- "optimal" designs (reference here). For the (CCD), the planning points are the augmentation of the two-level fractional factorial with points on the faces of the hypercube (or further out if a rotatable design is desired). In the middle of the design space for the three-level fractional factorial design, the design points are a subset of all the possible 3P points within the design space. For the "optimal" design, the design points are selected by a statistical criterion like minimizing the uncertainty on the estimated effects, the determinant of  $X'X$ , where X is the design matrix, which is called D-optimal designs (Box & Hunter, 2005) and (Montgomery, 2013). The design of the experiment methodology also helps as an experimentation planning for sequencing and prioritizing the experimental numbers, orders, and interaction of variables and how the experiments will be done, such as shown in Appendix A

### **2.10 Laundry greywater ECF Optimization**

The electrocoagulation floatation process has many parameters that would only be possible to optimize their success if one factor at a time method is used. There are statistical methods such as Design of Experiment (DoE) and Response Surface Methodologies (RSM) that come

with statistical packages such as Design Expert and Minitab or SPSS that make multi-parameter optimization possible (Montgomery, 2013). These methods do parameter characterization and screening, such as interrogations, interaction of factors, and elimination of factors that do not contribute to the multi-parameter (Montgomery, 2013).

Predominately, p-value (or the probability of incorrectly rejecting the null hypothesis based on a t-test p-value=0.05 while it was correct) of less than 0.05, which analysis the null hypothesis that there are no differences between the means (typically  $\leq 0.05$ ), which statistically enormously significant (Keith & Bower, 2001). However, this threshold is limiting, indicating strong evidence against the null hypothesis, as there is less than a 5% probability that the null is correct (and the results are random) and ignoring near misses that may have a significant impact on the study and as results, there may be contrasting views in the analysis of p-values given in the ANOVA tables are sometimes as they sometimes affected by the p-value criteria (Keith & Bower, 2001)

## **2.11 Summary**

The literature reveals that the developing countries or low-income communities in which our country, South Africa, categorically belong, and the informal settlements and townships are characterized by heavy water pollution in terms of concentrations. Further articles used to characterize greywater gave enough data on the physical, chemical, and biological nature of greywater. They revealed that greywater characteristics from baths, kitchens, and laundry differ. This characterization was required to decide whether adding electrolytes is the standard practice. However, the literature reveals that electrical conductivities for greywater are elevated; therefore, there is no need to add electrolytes.

There are limited articles on optimizing the greywater treatment with electrocoagulation; only one article has been found so far. It is standard practice in EC that most research studies are heuristically approached without considering a systematic, progressive approach for continuations.

### 3 MATERIALS AND METHODS

The purpose of this research was to investigate and evaluate the impact of ECF process variables such as mixing, electrode types; initial pH, voltage supply and volume have on TSS, turbidity, pH, Chlorides (Cl<sup>-</sup>), and free chlorine (fCl<sub>2</sub>) and Hazen true colour removal. DoE Minitab software was used to design the order in which the experiments were going to be ran and analysed. Five factors set lower and higher values such as (i) mixing (0 to 500 r/min), (ii) Voltage (10 to 15 V), (iii) Initial pH (3.5 to 8.5), (iv) effluent volume (800 to 2000 mL) and (v) electrode types (aluminium and stainless steel) were investigated.

Generally, Hazen true colour, chlorides, and free chlorines analysis require sample preparation for pH adjustment and turbidity removal. The samples were centrifuged at 4500 rpm or filtered with 0.45 µm membrane sheets to remove or lower turbidity and neutralise to pH 7.6 to avoid interferences for some analyses.

#### 3.1 Materials, Equipment and Instruments

Greywater samples were collected from a household in Milnerton, Cape Town. The main GW type used in this research was laundry greywater (LGW). The choice of this effluent was made because it is not easily treatable with conventional wastewater treatment methods. LGW samples were pre- treated by adjusting the pH between pH 3.5 and 8.5 as desired by the DoE optimization procedure with hydrochloric acid. All samples were stored in the refrigerator at 4 °C and processed within a week.

The analysis of free chlorine was conducted using chemical reagents such as N, N-diethyl-p-phenylene diamine (DPD) reagents, while chlorides analysis involved the use of mercuric thiocyanate and iron solutions. The determination of chemical oxygen demand (COD) was performed using reagent solutions in n-tube vials, and all analyses were carried out on the HACH DR3900 UV-spectrophotometer, adhering to the standard operating procedures outlined in the HACH 2007 guidelines. These reagents were procured from Agua Africa. HI98703-02 Hanna Portable Turbidity Meter was bought from Hanna Instruments and was for turbidity analysis. For pH adjustments, analytical grade chemicals used such as caustic soda; and hydrochloric acid was bought by Science World (SA). pH can be affected by chemical compounds in the water, pH is an important indicator of water quality. A multi- parameter pH-EC meter bought from Lasec South Africa was used to measure pH, EC, TDS, and salts.

#### 3.2 Electrocoagulation Process Experimental set-up

The Electrocoagulation and Flocculation (ECF) experiments were conducted in 800 mL and 2000 mL beakers alternatingly, with aluminium (Al) or iron (Fe) plates with dimensions of 200



mm × 80 mm or a surface area of 0.016 m<sup>2</sup>, making a surface area to volume ratio of 20 m<sup>2</sup>/m<sup>3</sup> for 800 mL and 8 m<sup>2</sup>/m<sup>3</sup> for 2000 mL, alternatingly constituting an electrochemical reactor. The figure 3.1 shows the electrocoagulation experimental set-up.



**Figure 3. 1: Electrocoagulation experimental set-up**

The two electrodes were assembled 15 mm apart and were connected in a monopolar mode, yielding a total effective electrode surface area of 160 cm<sup>2</sup> electrodes. The electrodes were separated with spacers made out from plastic tubing inserted into a plastic rod. Plastics materials of construction were used to avoid contacts between electrodes. The upper section of the electrodes was painted to avoid unnecessary pitting and side reactions of electrodes at the air water interphase. The anode always came out clean after electrolysis, but cathode came out black. The blackened surface indicates passivation which is not desirable because it causes higher mass transfer rates. Therefore, it was necessary to clean it with a wire brush in between runs. Each electrode had its own connecting cable, as shown below in Figure 3.2.



**Figure 3. 2: Electrode assembly**

The electrodes assembly was inserted into the electrolytic cell with LGW. The electrodes assembly was connected to a digital DC power (DF 1731SB, 30V-5A) supply operated (15 V, 10 A) operated between (10 V and 15 V), bought from RS-Components SA.



**Figure 3. 3: DC power**

In each run, 2000 mL or 800 mL of the wastewater solutions were placed into the ECF reactor and the solution was mixed. The ECF reactor was commissioned and operated for 1 hours. At the end of the run, the electrodes were taken out of the ECF reactor, washed thoroughly with water to remove any solid residues on the surfaces, dried, and reweighed. At the end of the ECF process, certain samples necessitated preparation steps, including true color analysis through centrifugation using the Ortoalresa Digtor 21 centrifuge at 3500 rpm.

### **3.3 Analysis of Chemical Parameters**

Total suspended solids (TSS) are particles that are larger than 2 microns found in the water. Anything smaller than 2 microns is considered a dissolved solid. Most suspended solids are made up of inorganic materials, although bacteria and algae can also contribute to the total dissolved solids (TSS) concentration, they were not analysed. The TSS was measured with HACH DR3900 UV – spectrophotometer, method 8006. The turbidity was measured with Hanna, HI98703-02 turbidimeter in Nephelometric Turbidity Units (NTU). This is a measure of the light intensity scattered at 90 degrees as a beam of light passes through a water sample

Based on the theory of complementary colour, the colour of wastewater is measured by integral spectrophotometry in colour scales of potassium hex chloroplatinate and cobalt chloride complex with units of Pt-Co (HACH 2007). HACH method 8025 was used in HACH DR3900 UV – spectrophotometer to measure Hazen's true colour (HACH 2007).

Free chlorine ( $f\text{-Cl}_2$ ) is mostly determined calorimetrically by developing colour for detection in spectrophotometers (DR3900, was used). In this research N, N, -diethyl-p-phenylene diimine, (DPD) reagents, sourced from Agua Africa were used. DPD forms a bright pink colour with a wavelength,  $\lambda_{\text{max}}$  of 530 nm, in the presence of  $f\text{Cl}_2$  (Thole, 2015). The analysis was done with HACH DR3900 UV – spectrophotometer, HACH method 10069. HACH method 8113, was used for chlorides analysis with iron and mercuric thiocyanate solution that was bought from Agua Africa. A volume of 0.8 mL of mercuric thiocyanate solution and 0.4 mL of ferric solution were pipetted into both blank sample cells and sample cells with a total volume of 3 mL, swirled to mix and the analysis was done per procedure.

### **3.3.1 Determination of COD Procedure**

While preparing the samples, the HACH DRB200 reactor was powered up and preheated to 150 °C. The samples of treated samples were prepared by removing the caps from COD vials for the 20 to 1500 mg/ $\text{LO}_2$  range to add 2.0 mL of treated samples to each vial. The vials were held at a 45-degree angle while a 2.00 mL of sample was added with a clean pipet tip connect to 1000 mL micro pipet. The 1000 mL volume of sample was dispensed twice into the vial to make 2.0 mL of sample. One vial was used to prepare a blank by adding 2.0 mL of deionised water. The vials were tightly sealed, wiped clean with a clean paper towel, gently inverted many times. The vials were placed in the DRB200 reactor, which had been preheated to 150 °C and the vials were heated for 2 hours after which, the reactor's power was turned off. The vials were left in the reactor for about 20 minutes to cool down to below 100 °C or less, after which, they were transferred the sample rack for further cooling to room temperature. Program 435 in the DR3900 Hach spectrophotometer was chosen to determine COD for all samples. The blank sample was wiped cleaned on the outside. The blank sample was inserted into the DR3900 Hach spectrophotometer, already in Program 435, the Zeroing button was pressed. Then display showed 0.0 mg/L  $\text{O}_2$ , COD. The prepared samples were wiped cleaned and inserted into the cell holder. The READ button was pressed, and the results were displayed in mg/L COD.

### **3.3.2 Determination of Chlorides Procedure Mercuric Thiocyanate HACH Method 8113 using DR3900 Spectrophotometer**

Program 70 was selected for chlorides analysis. The blank was made by adding 10 mL of deionized water in a 10 mL square sample cell. The sample was prepared by filling up second sample cell with 10 mL of sample. A micro pipet was used to add 0.8 mL of Mercuric Thiocyanate Solution into each sample cell, and it was swirled to mix it. Then after 0.4 mL of Ferric Ion Solution was pipetted into each same sample cells. Swirled to mix until the sample turned orange if chloride was present. A 2-minute reaction timer was set. After the timer expired, the blank was placed in the cell holder and then zeroed to 0.0 mg/L Cl<sup>-</sup>. After cleaning the outside of the prepared sample cell, it was inserted into the cell holder. then pressed READ, the results were displayed in mg/L Cl<sup>-</sup>.

### **3.3.3 Determination of free Chlorines Procedure**

USEPA DPD Method 8021 DPD for Free Chlorine Reagent Powder Pillows. Chlorine F&T PP was chosen. The blank was prepared by filling the sample cell with 10 mL of the square bottle sample cell. The DPD for Free Chlorine Reagent Powder Pillows was added into square bottle sample cell with the prepared sample, after which it was wiped clean. The blank sample was inserted into the cell holder, the Zero button was pressed and 0.00 mg/L Cl<sub>2</sub> was displayed. In the similar way, all samples were prepared in a 10 mL square bottle sample cell. The contents of one powder pillow were added to square bottle sample cell with a sample to be analysed. The sample was mixed and swirled for 20 seconds. If chlorine was present, a pink colour developed. The prepared sample cell was inserted into the cell holder, 60 seconds after the reagent was added. READ, button was pressed to obtain the results in mg/L Cl<sub>2</sub>.

### **3.3.4 Determination of total TSS Procedure -Photometric Method1 Method 8006**

HACH for Suspended Solids was chosen. The sample was poured into the 10 mL squared bottle sample cell. The blank was prepared by adding 10 mL of deionized water was added to a second 10 mL squared bottle sample cell. The blank sample cell was wiped cleaned on the outside and placed it in the spectrophotometer's cell holder then the spectrophotometer Zeroed by pressing the sample was prepared by swirling it to remove any gas bubbles and to suspend any residue uniformly. The outside sample cell was cleaned and placed in the cell holder; the results were displayed in mg/l TSS.

### **3.3.5 Determination of total Turbidity Procedure**

Turbidity was measured using a turbidity meter. Turbidity meters use a light and photo detector to measure light scatter and provide turbidity readings in units such as nephelometric turbidity units (NTU) or formazan turbidity units (FTU).

### **3.3.6 Determination of nitrate Procedure (Method 8039)**

Program 355 N was chosen for Nitrate High Range analysis. The sample was prepared by adding 10 mL of sample into a squared bottle sample cell. The contents of one NitraVer 5 Nitrate Reagent Powder Pillow were added to the squared bottle sample cell and swirled and shaken for 5 minutes before being left to react. When nitrate was present, the colour changed to amber. The blank was prepared by filling a second squared bottle sample cell with 10 mL of the sample. The blank sample in the squared bottle sample cell was cleaned, and the blank was placed in the spectrophotometer and zeroed to show 0.0mg/L  $\text{NO}_3^-$ -N. The prepared sample the squared bottle sample cell was wiped cleaned on the outside and put in the spectrophotometer. READ button was pressed to read results in mg/L  $\text{NO}_3^-$ -N.

### **3.3.7 Determination of phosphate Procedure (Method 8048)**

490 P React program was chosen for phosphate analysis. The samples were prepared by adding 10mL of sample to a squared bottle sample cell. The contents of one PhosVer 3 Phosphate Reagent Powder Pillow were added to the sample in the squared bottle sample cell and swirled for 5 minutes before being left to react. When phosphorus was present, the colour changed to blue. The blank was prepared by filling a second squared bottle sample cell with 10 mL of sample. The blank sample squared bottle sample cell was wipe cleaned on the outside before putting it in the sample holder inside the spectrophotometer and zeroed to show 0.0mg/L  $\text{PO}_4^{3-}$ . All other samples analysed in the spectrophotometer in the same way but by pressing READ to show results in mg/L.  $\text{PO}_4^{3-}$ .

### **3.3.8 Surfactant's analysis**

The purpose of surfactant analysis is to identify and quantify surfactants in detergents, as well as to identify and quantify surfactants in cleaners and other consumer products, and to check the composition of anionic, cationic, and non-ionic surfactants.

#### Reagents

- Stock linear alkylate sulfonate solution: Dissolve 10 g LAS in deionized water and dilute to one liter to get a concentration of 1.00 mg/1.00mL LAS on a 100 percent active basis. To prevent biodegradation, the solution was put in the refrigerator.
- Standard solution LAS: To get a concentration n of 1.00 ml = 50.00 LAS, dilute 50.00 ml of stock LAS solution to one liter with distilled water.
- Methylene blue reagent: In 500 mL distilled water, dissolved 400 mg Azure A and

5 mL 1.0 N sulfuric acid, then make up to 1000 mL with distilled water.

- Commercial surfactant solution standard: Using distilled water, dilute 50.00 ml of stock commercial surfactant solution to one liter.
- Methyl-red solution: in a little amount of distilled water, dissolve 0.10 g methyl orange powder. To make the concentration 0.1 percent by weight, dilute this volume to 100 ml.
- Buffer solution: mixed 250 mL 0.5 M citric acid and 250 mL 0.2 M disodium hydrogen orthophosphate together.
- Chloroform, anhydrous.

### 3.4 Identification of samples ions charge

Surfactants are found as cationic and anionic. The first step is to determine their ionic state. This is a qualitative method, only indicated by color.

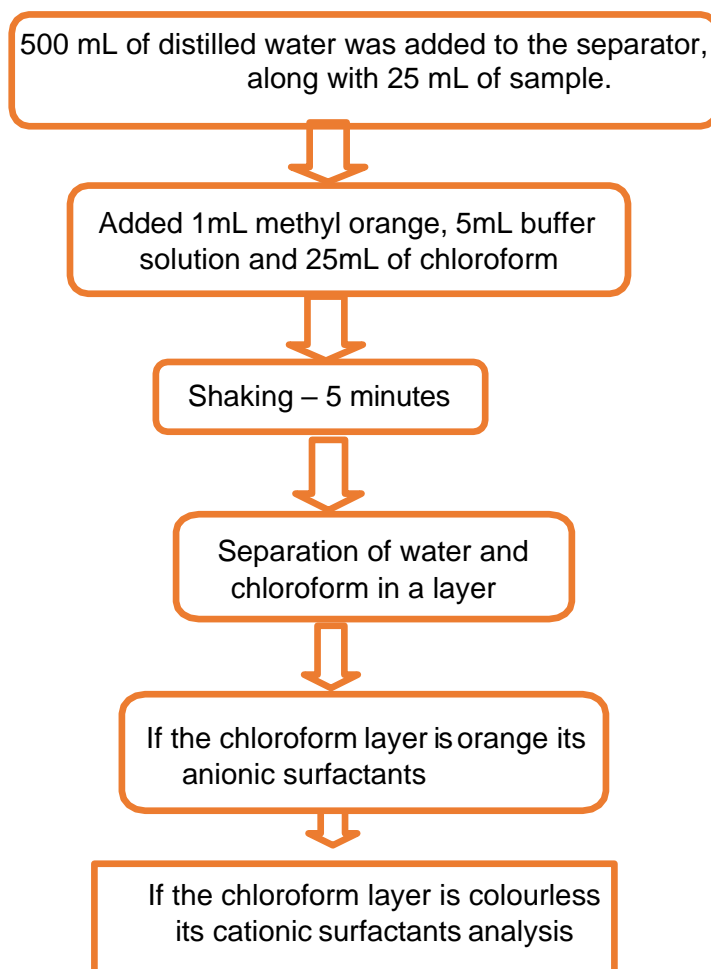


Figure 3. 4: Steps to determine ionic state.

A separator funnel was filled halfway with distilled water and pipetted an 50mL of the water sample in. To the separator funnel, 1 mL methyl orange reagent, 5 mL buffer solution, and 25 mL chloroform were added. The separator funnel was closed and vigorously shaken it for 30 seconds. After shaking, the samples were left undisturbed for 5 minutes. Chloroform was separated from the water and drop to the bottom of the container. When anionic surfactants were present in the water sample the chloroform layer was orange in colour and the sample was examined as a result.



**Figure 3. 5: Experimental Setup**

When the sample did not have an anionic surfactant the chloroform layer was colorless, and it was discarded. After that, a new sample was made and tested for cationic surfactants.

### **3.5 Anionic Surfactant Analysis**

The new sample was taken when the chloroform layer was blue in colour:

In the stem of a filtering funnel, a small plug of glass wool was wedged inside. The chloroform layer was filtered through the glass wool to remove the water and the treated chloroform was collected in the cell by placing the filtering funnel above a clean, dry test cell with a 1 cm (or longer) light path. In a spectrophotometer, the absorbance of the chloroform solution was compared to a blank chloroform sample at a wavelength of 623 nm. The equivalent LAS was calculated using a previously established calibration curve of absorbance vs. LAS concentration (in mg/l) for ionic surfactants. The calibration curve's content (in mg/l).

### **3.6 Cationic surfactants analysis**

The new sample was taken when the original sample was colourless methyl blue reagent, buffer solution and chloroform were added:

The separator funnel was filled halfway with distilled water and an amount of 25ml of water was pipetted into the sample in. To the separator funnel, 1 mL methyl orange reagent was added, 5 mL buffer solution, and 50 mL chloroform. The separator funnel was closed and vigorously shook for 30 seconds. The sample was allowed to rest for 20 minutes undisturbed after shaking. The chloroform was separated from the water and sank to the bottom of the container. In the stem of a filtering funnel a small plug of glass wool was wedged inside, and the chloroform layer was filtered through the glass wool to remove the water by placing the filtering funnel over a clean, dry test cell (10 cm light path). The chloroform that has been processed was collected in the cell. In a spectrophotometer, the absorbance (or equivalent) of the chloroform solution was compared to a blank chloroform sample at a wavelength of 415 nm. The equivalent commercial surfactant content (in mg 1) was calculated for cationic surfactants using a previously created calibration curve of absorbance vs. commercial surfactant concentration (in mg/L) for cationic surfactants.

After checking the sample ionic charges, it was found that the layer was colorless so the cationic surfactants analysis was performed so that we can get the calibration curve.



## 4. RESULTS AND DISCUSSION

The following section presents the results of the experimental investigation, organized according to the research objectives outlined in Chapter 1. The data was collected through a carefully plan process using DoE experimental randomised plan. Double experiments were done and are presented in Tables A.1 and A.2 in the appendices. Laundry greywater (LGW) was recovered at elevated pH, therefore pre-treatment with HCl for pH adjustment to pH 3.5 and 8.5 was required and performed. The pH pre-treated LGW was subjected to treatment with Electrocoagulation-flocculation (ECF) system under the variations of five factors such as mixing (0 to 500r/min), Voltage (10 to 15 V), Initial pH (3.5 to 8.5), effluent volume (800 to 2000 mL) and electrode types (Aluminium and iron) to interrogate their inter-parameter effects (inter-dependences) in contributing to the best responses.

There were many pollutants that were studied, such as chemical oxygen demands (COD), various nutrients or anions and metals but the most representative pollutants responsive control parameters (factors) to the optimization exercise considered were total suspended solids (TSS); Turbidity; Hazen Colour and total dissolved solids (TDS), free chlorine and chlorides.

The Design of Experiment (DoE) and ANOVA was used to create various plots such normality, probability and surface plots to analyse the data. However, the resolution of the surface plot is not as good as it was desired.

### 4.1 Optimisation and Confirmation

The Optimisation tool of the employed software (Design-Expert) and Minitab were used to examine the best condition for all the responses via EC process. The goal of this tool is to obtain as many responses as possible while keeping all operating parameters within their limits. The optimum operating conditions were found to be initial pH of 4.5 to 5.75, applied voltage of 10V to 13 V, electrode type (iron) and mixing speed of 125 to 350 rpm. These results suggested that the ECF method can be used to scale-up this EC-reactor treatment to higher volumes than 2000 mL. However, differences with the literature review may exist in the precise ranges of ideal operating settings, as variations in experimental setup, wastewater composition, and reactor design can result in different conclusions. For example, while the current study recommends an ideal voltage range of 10V to 13V, other studies may have discovered somewhat different voltage ranges based on electrode configuration or specific pollutants in the wastewater.

Differences in the composition and properties of the wastewater being treated could be one possible explanation for discrepancies in optimal operating conditions. Different types and amounts of pollutants in wastewater might affect the electrocoagulation process, resulting in differences in the optimal operating parameters needed for efficient treatment. Furthermore, differences in reactor design and setup can affect electrocoagulation performance. Electrode spacing, surface area, and the presence of baffles or flow control mechanisms all have an impact on mass transfer, current distribution, and overall treatment efficiency. Based on the results of laboratory studies of LWW, four experiments were done using the optimum values. The test results for the optimum values are shown in the Table 4.1.

**Table 4. 1: Optimum values experiment results**

Runs	Before ECF Treatment										
	TSS (mg/l)	TDS (ppm)	Turbidity	Colour	Chlorides	Conductivity	Salt	Sulphate (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	COD (Mg/L)
1	16	673	17.8	203	8.8	1465	449	60	3,65	0,2	395
2	514	415	749	930	15	583	272	19	6,19	0,3	2404
3	31	786	17	226	10.5	1449	527	48	3,76	0,3	469
4	149	467	86.2	920	13.03	1214	310	41	3,09	0,3	520
Runs	After ECF Treatment										
	TSS	TDS	Turbidity	Colour	Chlorides	Conductivity	Salt	Sulphate (mg/L)	Phosphate (mg/L)	Nitrate (mg/L)	COD (Mg/L)
1	5	117	5.51	143	5.5	937	312	45	2,46	0,1	371
2	334	200	173	156	7.8	300	120	19	4,81	0	2065
3	5	103	5.67	101	5	1100	200	46	2,49	0,3	382
4	8	230	13.9	202	6.6	657	112	32	2,95	0	409

## 4.2 ANOVA Analysis

Model summary statistics were used to evaluate the experimental data to obtain regression models and to decide on the adequacy of different models (linear, interactive, quadratic and cubic) to substantially represent the EC method. The results are shown in the Tables below. It was found from the tables that linear and interactive (2FI) models show a lower determination coefficient (R<sup>2</sup>), adjusted-R<sup>2</sup>, predicted-R<sup>2</sup> and have high p-values compared to the quadratic model. The cube model has been found to be an alias. The quadratic model is therefore chosen to describe the effects of the operating variables on the grey wastewater treatment EC process. In addition, variance analysis (ANOVA) is often used to evaluate the adequacy of the quadratic model.

#### 4.2.1 Model statistics predicted.

Table 4.2 shows significant statistical parameters for the pH prediction model. These metrics provide a full evaluation of the model's performance and reliability in estimating pH values.

**Table 4. 2: pH predicted**

<b>Std. Dev.</b>	1,32	<b>R<sup>2</sup></b>	0,3242
<b>Mean</b>	8,97	<b>Adjusted R<sup>2</sup></b>	0,3017
<b>C.V. %</b>	14,77	<b>Predicted R<sup>2</sup></b>	0,2311
		<b>Adeq Precision</b>	5,3648

The pH predictions have a standard deviation of 1.32. This measure quantifies the degree of variability or dispersion in expected pH values. A higher standard deviation indicates more variability in the model's predictions. The mean expected pH value is 8.97. This serves as a reference point for the model's predictions. The coefficient of variance is 14.77 percent. It is expressed as a percentage and represents the relative variability of the projected pH values in relation to their mean. A higher C.V. signifies a greater degree of relative variability. The coefficient of determination is 0.3242. This score shows the proportion of the variance in anticipated pH values that the model can account for. The model accounts for approximately 32.42% of pH variability ( $R^2=0.3242$ ). The Predicted  $R^2$  of 0,2311 is in reasonable agreement with the Adjusted  $R^2$  of 0,3017; i.e., the difference is less than 0.2. Adeq Precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of this model is 5,365 indicates an adequate signal. This model can be used to navigate the design space.

#### 4.2.2 The model's fit statistics responses

**Table 4. 3: pH out response**

Source	Sum of Squares	df	Mean Square	F-value	p-value	
<b>Model</b>	25,24	1	25,24	14,39	0,0007	significant
C-Initial pH	25,24	1	25,24	14,39	0,0007	
<b>Residual</b>	52,62	30	1,75			
Lack of Fit	49,44	29	1,70	0,5370	0,8171	not significant
Pure Error	3,18	1	3,18			
<b>Cor Total</b>	77,86	31				

The model F-value of 14,39 implies the model is significant. There is only a 0,07% chance that an F-value this large could occur due to noise. P-values less than 0,0500 indicate model terms are significant. In this case C is a significant model term. Values greater than 0.1000 indicate

the model terms are not significant. The Lack of Fit F-value of 0,54 implies the Lack of Fit is not significant relative to the pure error. There is an 81,71% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good for the model to fit.

### **4.3 Effect of Electrode Types and Volume of the Reactor on COD**

The data was processed in experimental blocks of by electrode types and them ECF reactor volume. These where the only two blocks that could be grouped without troubles of other interactions. The blocking technique helped in analysis that data that is obviously affected by all parameter such as COD. COD is a combination of many other pollutants; therefore, it is affected by so many interferences that analysing it through the interaction of factors would not be sensible..

Table 4.4 shows that the COD was measured to be 225 mg/L O<sub>2</sub> on average with a standard deviation  $\pm 79$  mg/L O<sub>2</sub> after treatment for Aluminium ECF but better with iron ECF with COD down to 206 mg/L O<sub>2</sub> but higher standard deviation of  $\pm 102$  mg/L O<sub>2</sub>. High standard deviation is an indication of variation. As shown in Table 4.4 below, the variations were analysed by further grouping the parameters and blocking the volume of the ECF reactor, Lower COD values are observed in in 2000 mL reactor for iron ECF with 153,  $\pm 35$  mg/L O<sub>2</sub> which is closer to the environmental disposal limit of 100 mg/L. There are possible outliers of COD values of 214 mg/L O<sub>2</sub> for Iron ECF. While the average is higher for the aluminium electrodes (277  $\pm 86$  mg/L O<sub>2</sub>) at the same volume, but lower values for aluminium electrodes for a small ECF reactor with an average of 230,  $\pm 80$  mg/L O<sub>2</sub>. Therefore, there seem to be correlation between the reactor volumes and electrode types for COD removals.

**Table 4. 4: Iron and aluminium subdivide by volume of the reactors**

VOLUMES (mL)	pH	Mixing (rpm)	COD Iron ECF.	COD Alum. ECF
2000	3,5	0	114	187
2000	3,5	0	214	220
2000	3,5	500	156	368
2000	3,5	500	144	156
2000	8,5	0	115	311
2000	8,5	0	170	344
2000	8,5	500	184	248
2000	8,5	500	128	384
Average COD at Constant Volume			<b>153.</b>	<b>277.3</b>
Standard Deviation of COD			<b>35.2</b>	<b>86.4</b>
800	3,5	0	196	163
800	3,5	0	134	303
800	3,5	500	325	245
800	3,5	500	258	344
800	8,5	0	179	130
800	8,5	0	128	156
800	8,5	500	189	202
800	8,5	500	464	303
Average COD at Constant Volume			<b>234.</b>	<b>230.8</b>
Standard Deviation of COD			<b>113.</b>	<b>79.8</b>

The Initial pH seem to have an effect only for Alum electrodes. Staring at a low pH does not end with lower COD values for ECF process with Aluminium electrodes.

#### 4.4 Effect of Mixing Speed and Voltage on Total Suspended Solids

Figures 4.1 (a) and (b) and others to come were generated with a DoE software. Figures 4.1 (a) and (b) are interaction and probability plots respectively of the experimental data. Most of the time, the interest in using the statistics is to interrogate the quality of the data and for making decision about it. But in this study, it is used to interrogate the relationships between the parameters that control a process.

Figure 4.1 (a) shows TSS output for mixing speed of 0-500 rpm and voltage of 10-15V interactions plot. The graph in Figure 4.1 (b) shows that there is a very weak interaction between these two factors for the response of TSS because these lines are almost parallel lightly cross. This shows a weak interaction between voltage and mixing for removal of TSS. Perhaps this can be because mixing at high-speed causes breaking of the already formed flocs. However, the TSS as a single parameter shows a significant result with a p- value less than 0.005 for normality plots in Figure 4.1 (b) under the influence of these two parameters, perhaps the interaction cannot be ignored.

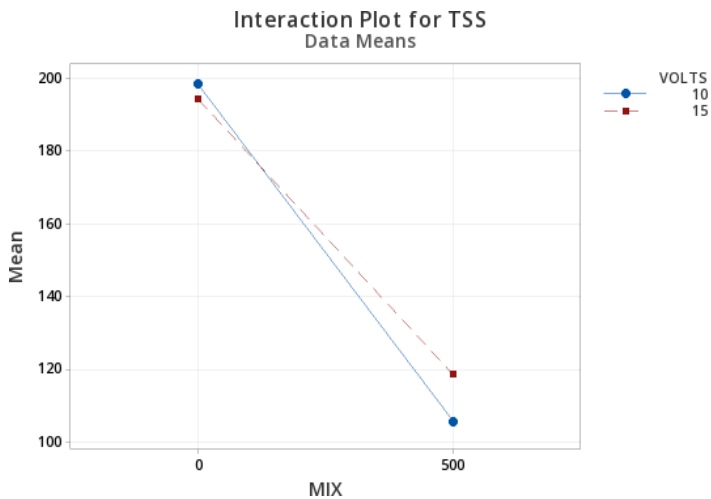
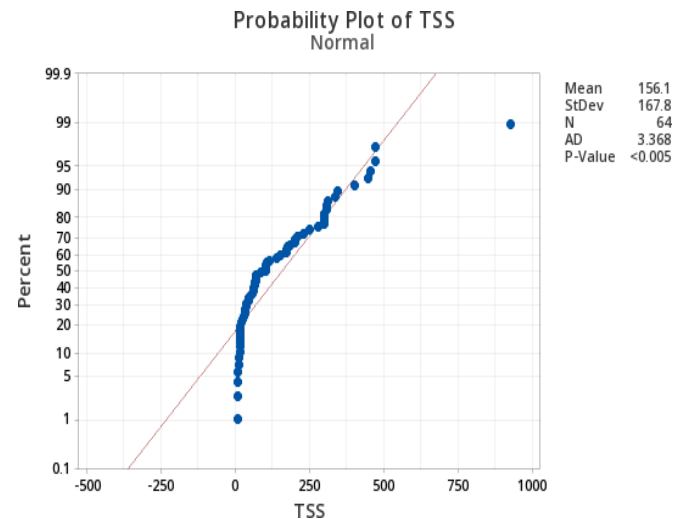


Figure 4. 1: (a) TSS vs Mixing interaction plots



(b) TSS vs Mixing probability plots

To achieve good electrocoagulation, rapid mixing is needed to bring the particles together to facilitate particle collisions and adherence for coagulation and flocculation and for homogeneity in the reactor mixture.

#### 4.5 Effect of Voltage, Volume and Mixing on Total Suspended Solid Removal

The mixing speed that was used for this experiment was 0-500 rpm and volume of 800-2000 mL. However, agitation outside of the optimum range can reduce EC efficiency by breaking down the flocs that trap contaminants and probably restabilising the colloids. It can be observed from the surface plots in Figure 4.2 (a) that the optimum values for TSS removal could be achieved when the mixing speed is 150 rpm, a volume of about a 1000 mL at 10 V (see Figure 4.2 (b)). The beauty of the Surface plot is that it analyse multiple parameters for single response and predict the optimum. Therefore, 150 rpm, a volume of about 1000 mL and a voltage of 10 V are optimum values.

Cloudiness, or haziness of a fluid which gives mostly greyish to whitish colour like Greywater defines the turbidity of the fluids. It is created by large amounts of individual particles that are usually visible to the naked eye is a very important physical wastewater parameter.

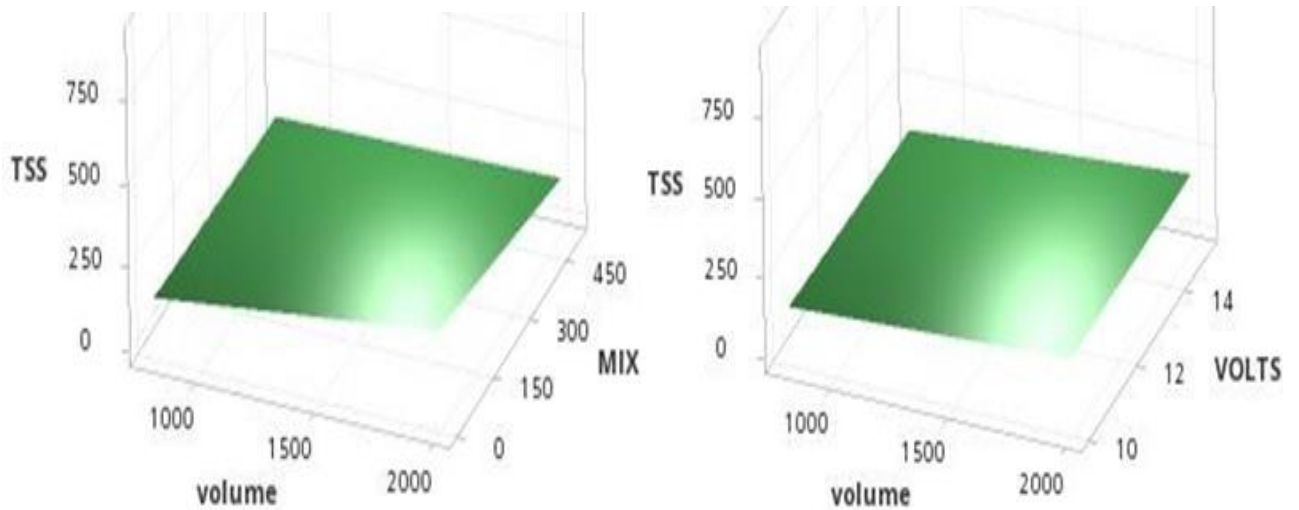


Figure 4. 2 : (a)TSS vs Mixing and vol. Surface. (b) TSS vs Volts and Vol. Surface Plot

#### 4.6 Effect of Volume and Mixing Speed on Turbidity Removal

The graph in Figure 4.3 (a) shows the effect of changing the volume of the liquid and varying the mixing speed. The interaction effect creates a change in turbidity towards higher volumes. Higher or large reactors are required for scale ups. Turbidity removals require low mixing speed for large volumes. The probability plots in Figure 4.3 (b) for turbidity shows that p-value less than 0.05 which shows that data is significantly good, although there is a huge variant.

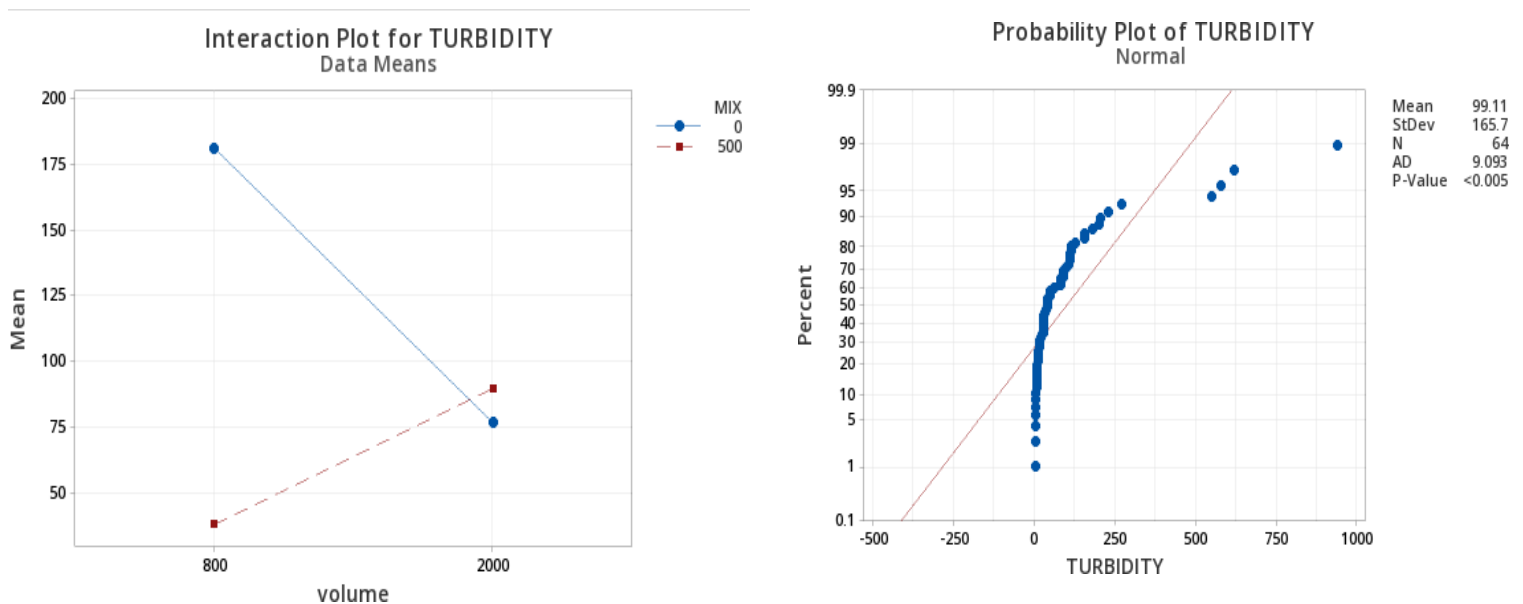


Figure 4. 3: (a) Interaction plot for turbidity

(b) Normality plot for Turbidity.



Voltage and mixing speed are important factors that are known to influence the electrocoagulation process. Using surface plots for different operating conditions of mixing speed of (0-500 rpm) and voltage (10-15 V), mixing speed and voltage factors were optimized for turbidity removal to values ranging from 100 to 125 NTUs. Figure 4.4 below shows that good turbidity removal required only 13V at approximately 100 rpm.

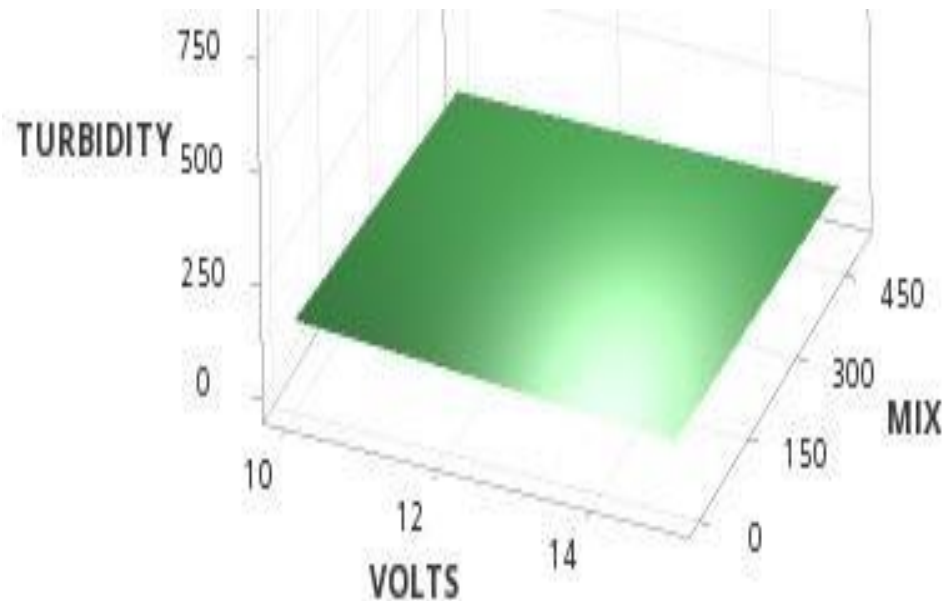
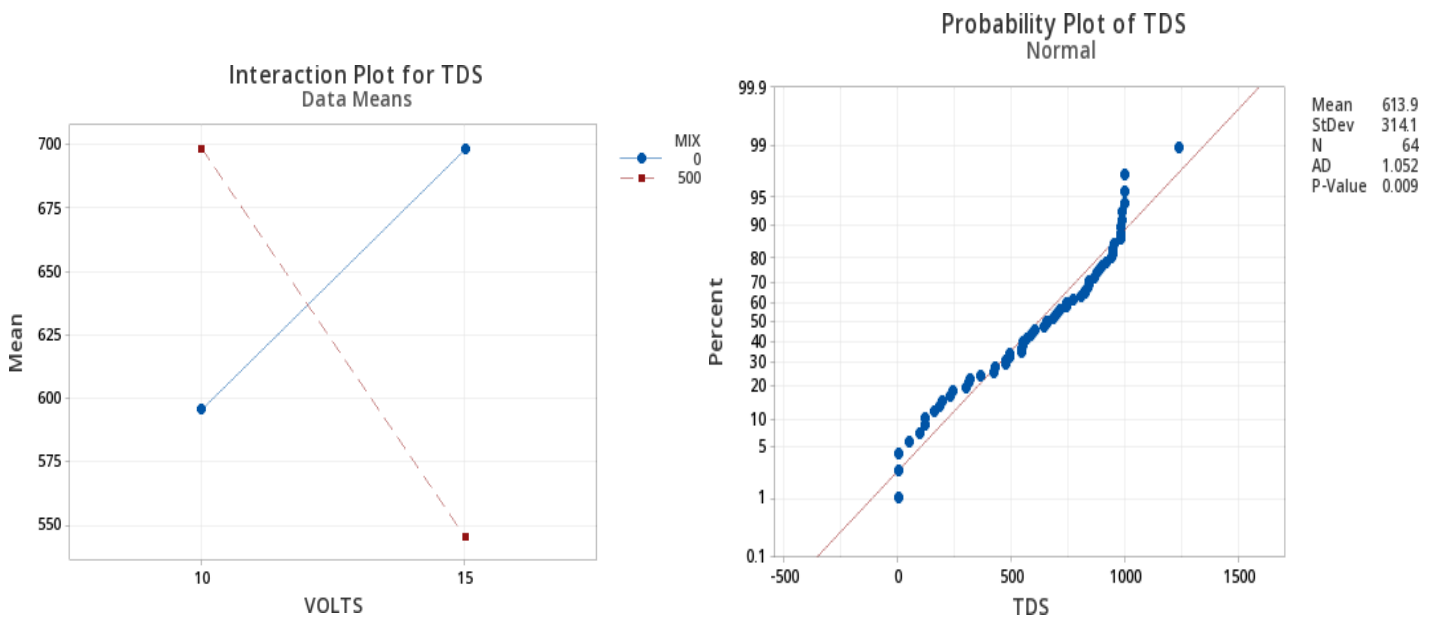


Figure 4. 4: surface plot of turbidity vs mixing and voltage.

#### 4.7 Effect of Volume and Mixing Speed on Total Dissolved Solids Removal

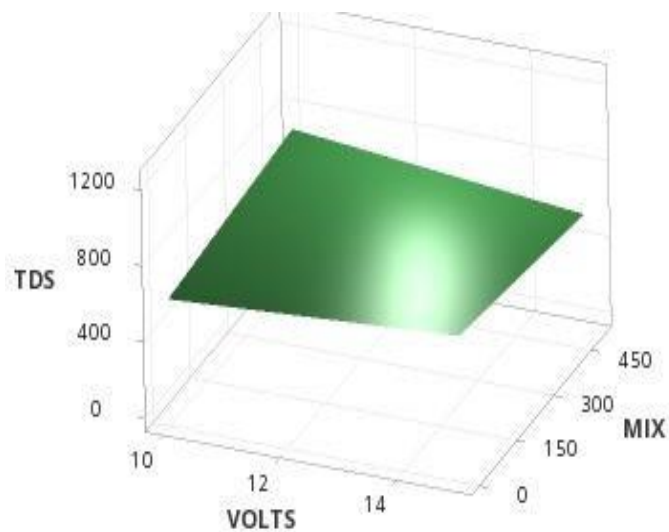
Turbidity and total suspended solids are an indication of the pollutant particles are floating and cannot be settled. If they could be removed the only particles that remain in the solution are total dissolved solids (TDS). The Total Dissolved Solids (TDS) is an electrochemical measure of the effluent that strongly influences the overpotential of the Electrochemical Cell (EC) and the current density.

As shown in Figure 4.5, (a) and (b) display an interaction plot indicating a positive slope when there was no mixing and a negative slope at higher mixing speeds but toward a higher voltage.



**Figure 4. 5 :(a) Interaction plot for TDS (b) Normal probability Plot for TDS**

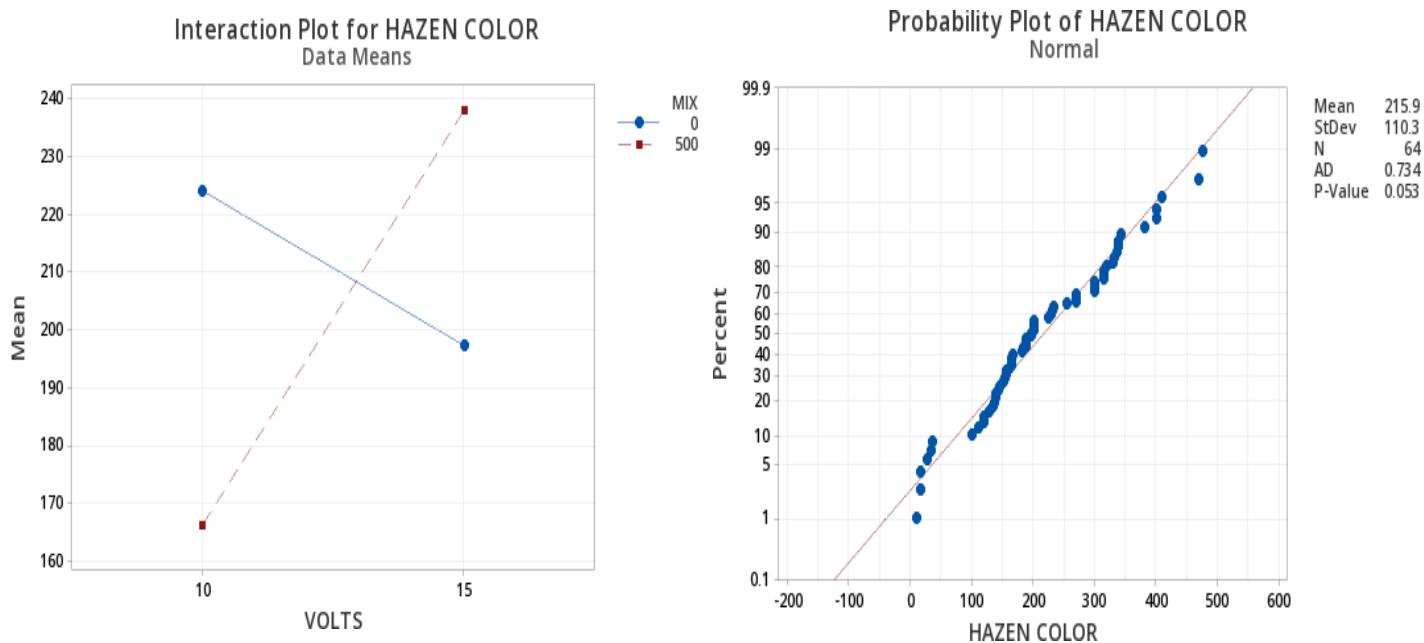
As shown in Figure 4.6, the optimal TDS removal occurred at a concentration of 500 mg/L, with a mixing speed of approximately 100 rpm and a minimum voltage of 10V.



**Figure 4. 6: Surface plot for TDS vs mixing and voltage.**

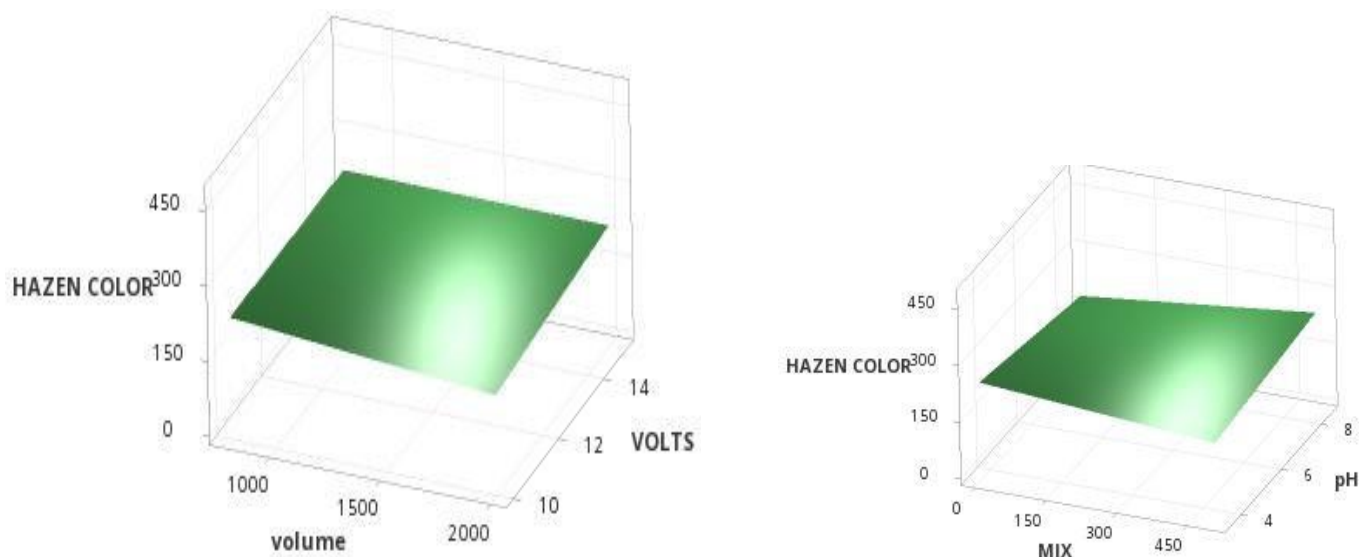
#### 4.8 Effect of Voltage and Mixing on Hazen Colour Removal

The hazen colour data proves that there was no need to increase the voltage and at a voltage of 10 there is lower mean for colour removal, which means small hazen colour values at a minimum voltage, the hazen colour removal was lightly significantly with p-value slightly of 0.053 as displayed in Figure 4.7 (b).



**Figure 4. 7: (a) Hazen colour interaction plot (b) Hazen colour Probability Plot**

Voltage is one of the important factors that influence the electrocoagulation process. Increasing voltage did not have an impact on the removal efficiencies of hazen colour, perhaps this is due to the high electrical conductivities of the laundry greywater and at low voltage the electrical energy is saved. Increasing the volume of the greywater does not have much effect on the removal hazen-colour as well. As shown in the figure below at 10 V and 2000 mL lower hazen colour values were achieved. Optimum values for best Hazen colour (150 Pt-Co) removal were about 2000 mL and 13 V (Figure 4.8 (a)) at mixing of 350 rpm and pH of 5.5.

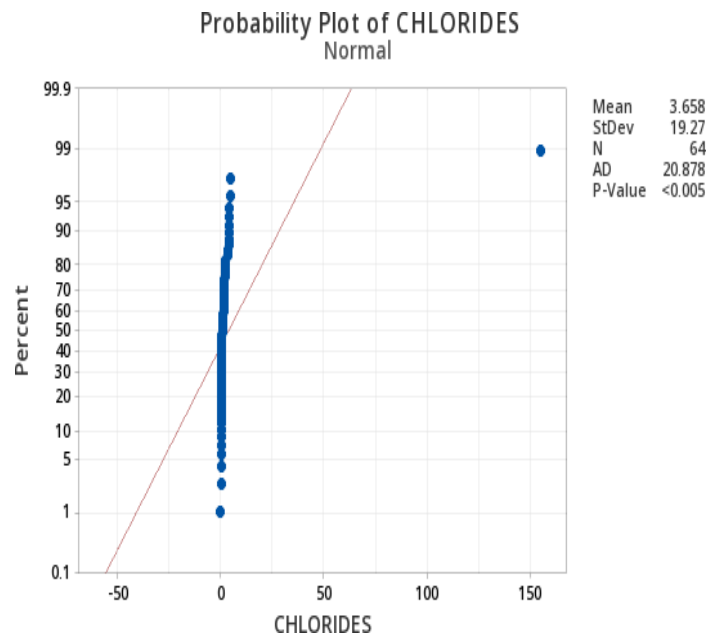
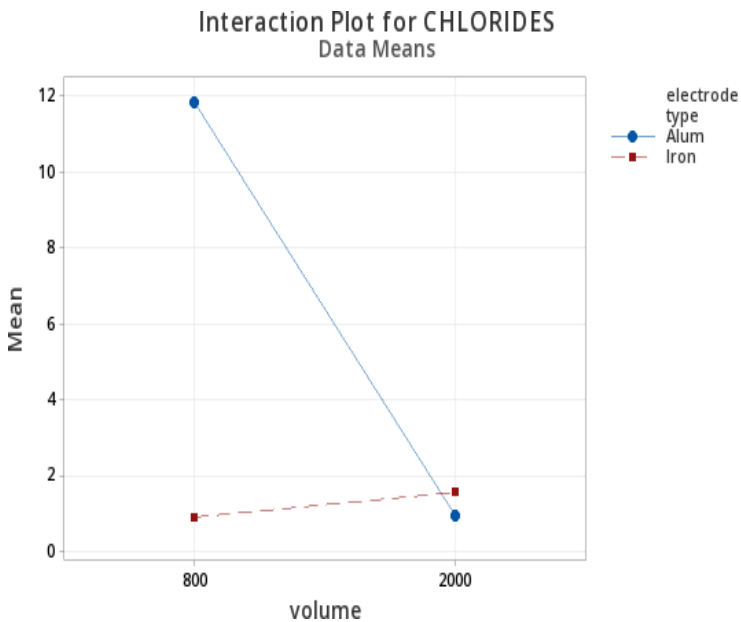


**Figure 4. 8 : (a) Colour vs Volume and Voltage surface plot**

**(b) Colour vs Volume & Voltage Surface Plot**

**4.9 Effect of Volume and electrode types on Chlorides Removal**

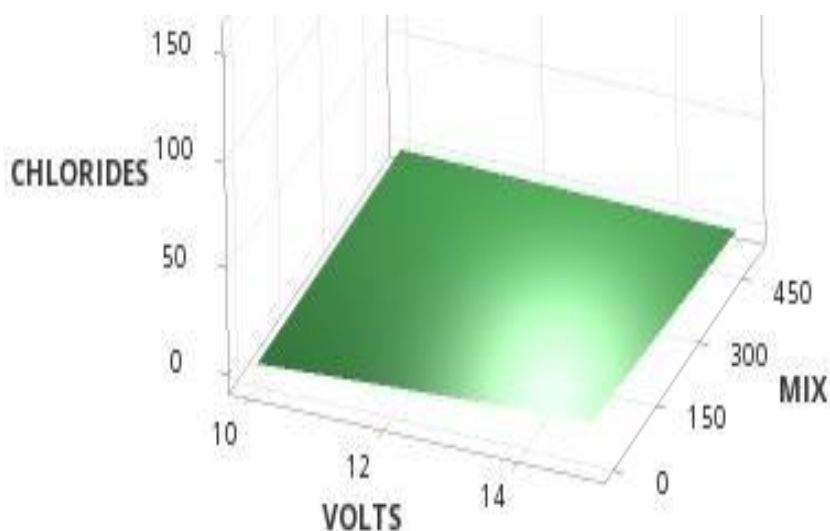
Chlorides are salts of calcium and magnesium commonly found in hard water. Normal salt is sometimes added to the effluent to be treated by ECF improve conductivity for better ECF but in this research it was not added because the LGW had elevated conductivity and there were many control parameters to evaluate during the experiments. However, the chlorides source was the HCl that was used for pH adjustment. Chlorides are electroactive species that are formed when the gas chlorine during ECF is evolved with other aqueous chlorines products of electrolysis such as free chlorines are formed. It can be observed from the Figure 4.9 (a) and (b) that the interaction of volumes of ranging between 800-2000 mL and electrode type of alum. or iron give rise to lower levels chlorides for iron electrodes with low gradient because of increasing the volume of the effluent. While aluminium electrodes remove chlorides effectively, iron also eliminates chlorides as the volume increases. This is not appreciated because chlorides are synergetic in ECF as a disinfectant and improvement of electrical conductivity. Therefore, in this regard iron electrodes take precedence over aluminium.



**Figure 4. 9: (a) Interaction plot for chlorides**

**(b) Normal Probability Plot for Chlorides**

The optimum values of chlorides removal were found to be mixing speed of 0 rpm and voltage of 10V as shown in figure 4.10 and could be lower if it were not for the short range of applied voltage choice for in this study.

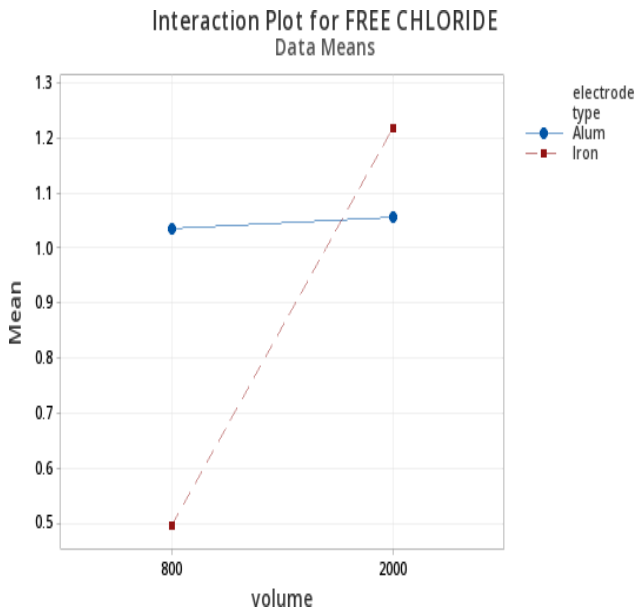


**Figure 4. 10: Surface plots od chlorides vs voltage and mixing**

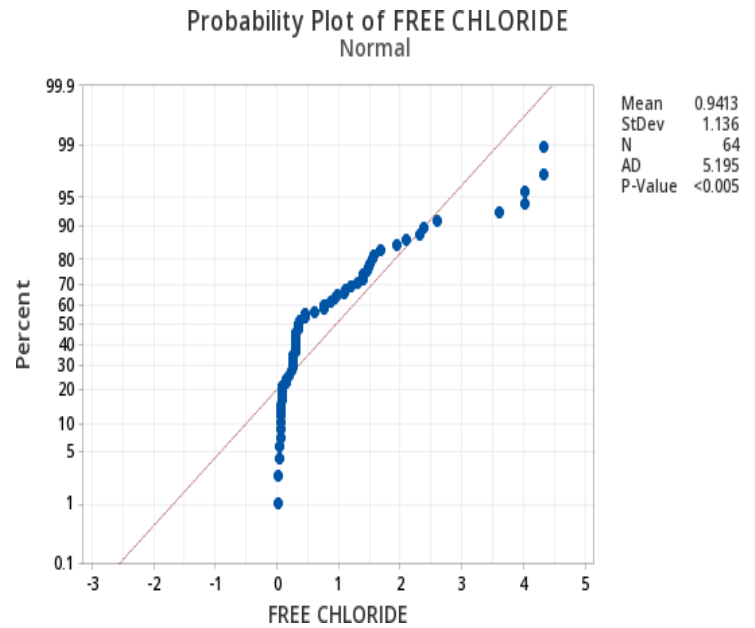
The reasons for these results are that chlorides increase lower ohmic overpotentials by allowing current flow and producing electrolytic chlorine gases, which are responsible for mixing.

#### **4.10 Effect of Volume and electrode types on free Chlorines Removal**

Figures 4.11 (a) and 4.11 (b) show some images different electrodes such as iron and aluminium. Contrarily, to the behaviour iron electrodes in chlorides removal upon increasing volumes, aluminium electrodes kept the free chlorine constant means see Figure 4.11(a), but iron increased the free chlorine yields appreciably. Better yields of the free chlorines at high volumes and strong significance of data with a p-value less than 0.005 are shown in Figure. 4.11 (b). This can be attributed to the fact that the produced chlorine gas has hydraulic long resident time in the effluent with large volume for more conversion to other free chlorines components, as chlorines remains in aqueous mode shown by nearly constant trends in Figure. 4.11 (a) for Aluminium.



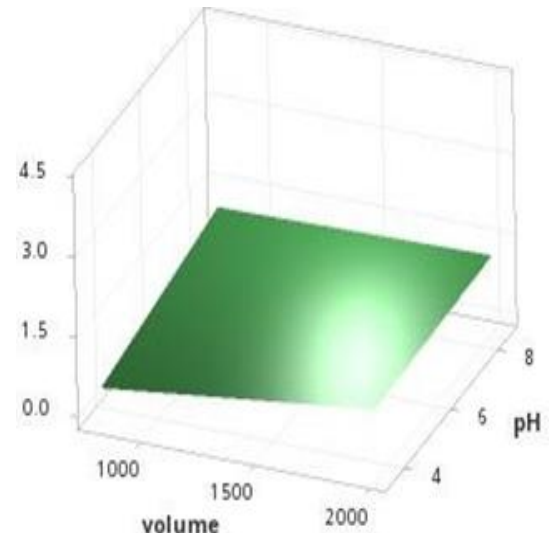
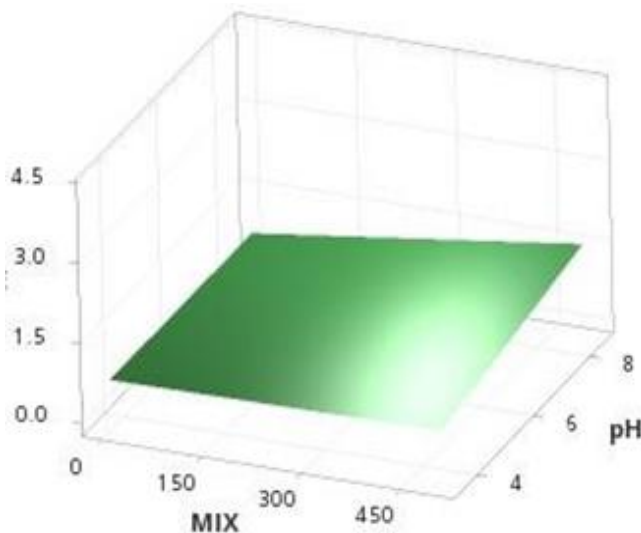
**Figure 4. 11: (a) Interaction plot for free chlorine**



**(b) Normal Probability Plot for Free Chlorine**

#### 4.11 Effect of Initial pH Volume and mixing on Hazen Colour and Chlorides Removal

According to (Parga *et al.*, 2005), pH is a significant factor affecting the efficiency of the ECF processes. During the operation of ECF, the pH of the medium generally changes, and this change is dependent on the type of electrode material used and the initial pH. The ECF method, on the other hand, has some buffering ability, particularly in alkaline medium, which prevents large pH changes and reduces pollutant removal performance as some of them already form flocs which disintegrate. The occurrence of water electrolysis, which results in hydrogen evolution and the release of OH ions, may explain the rise in pH. The formation of insoluble Fe (OH)<sub>3</sub> flocs and the rest of the metal hydroxides may account for pH variations and subsequent relative stability.



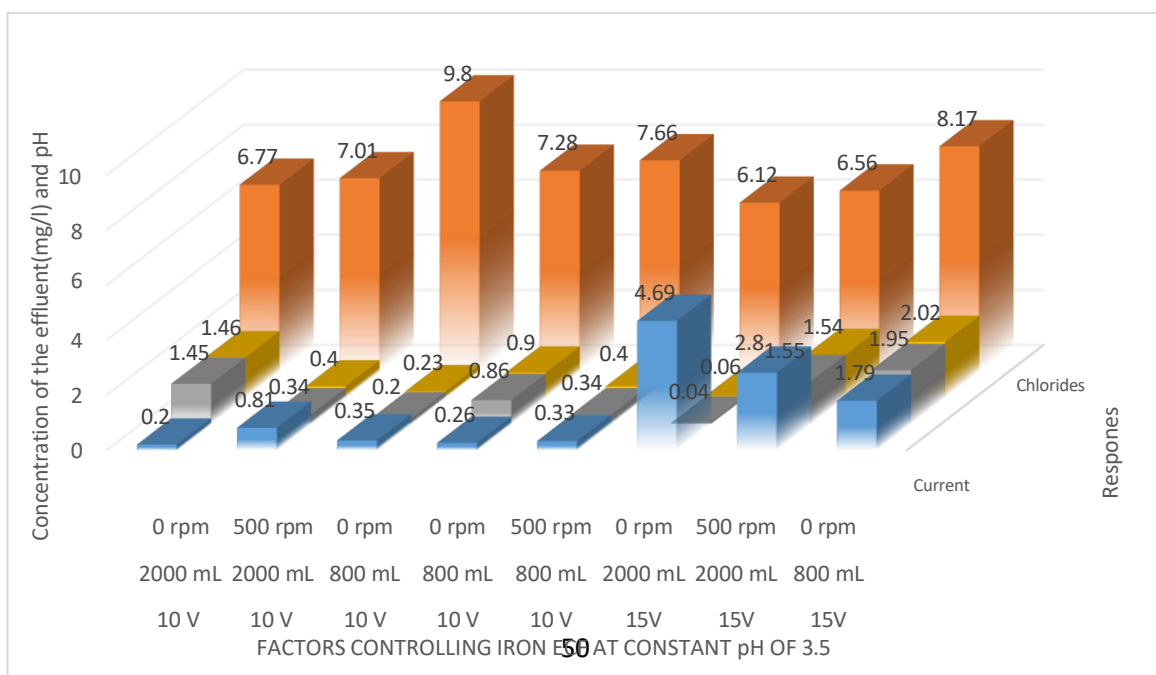
**Figure 4. 12: (a) Free Cl<sub>2</sub> vs mixing and pH surface plot**

**(b) Free Cl<sub>2</sub> vs Volume.**

Higher efficiencies were observed in the pH range of 3.5–8.5 in Figure 4.12 (a) and (b), which is like the ideal pH for the formation of iron hydroxide solids. The pH of laundry greywater was initially set at 3.5 and 8.5 by adding HCl to adjust the pH values at the start. It was observed at low pH of 4.5 and mixing speed of 450 rpm for 1000 liters volumes there was highest colour removal and chlorides and that there was no significant difference in colour and chlorides removal for pH 8.5. Free chlorines production was however higher pH, 8.5. and lower volumes but required mixing.

**4.12 Various Factors Controlling Iron ECF at Constant pH of 3.5.**

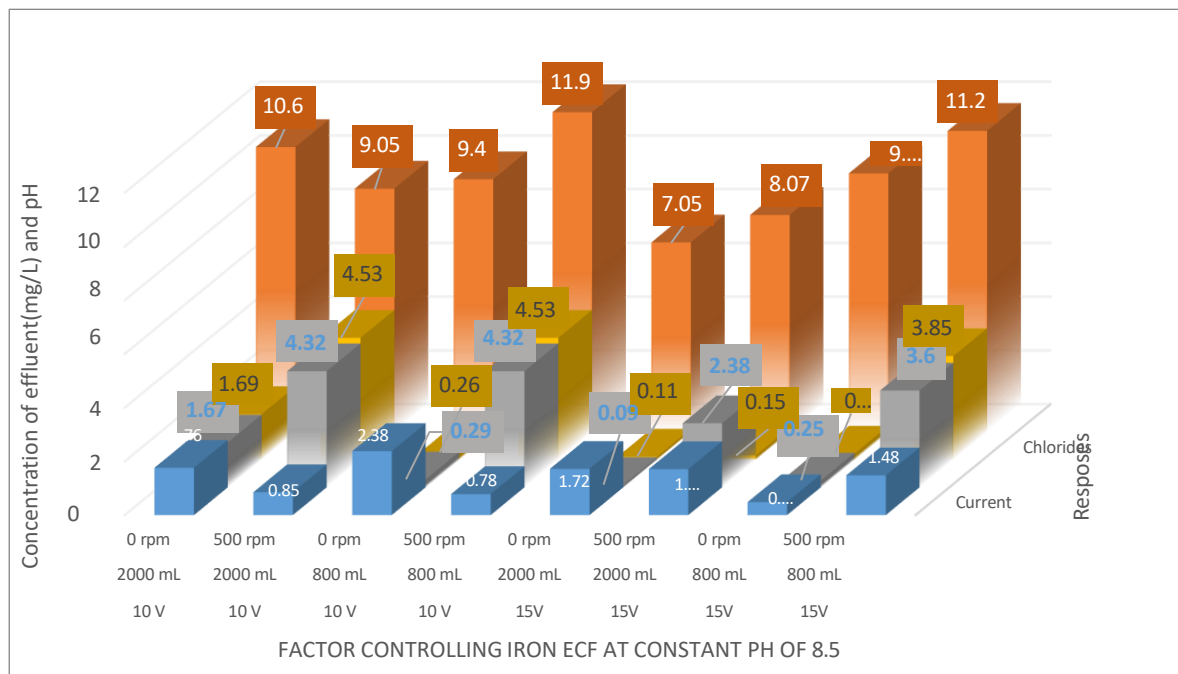
From the previous discussions, there seem to strong influence of pH on iron electrodes to chlorides and free chlorines yields and consequentially the pollutant removal, however parameters effects were analysed in parts and their overall effects are now shown in Figure 4.13 below. The pH of the LGW varied between 3.5 and 8.5 to observe its effect on interaction with other parameters such as applied voltage, effluent volume, electrode types and mixing speed on effectiveness of the electrocoagulation process. The output pH is very important because the free chlorines and total chlorine swings between low and high concentrations depending on pH. Also, iron coagulants produced in-situ ECF are dependent on pH. It can be noted from Figure 4.13 below that no mixing at low effluent volumes set at 800 mL resulted in higher output pH for both low and high voltages with a pH of 9.8 with low chlorides and free chlorine production for voltage but higher values for higher voltage with an average output pH of about 7.42. An appreciably improvement of current output at higher voltage is noted with higher consumption of chlorides and free chlorines perhaps through chlorine gassing.



**Figure 4. 13: Various factors controlling iron ECF at constant pH of 3.5**

#### 4.13 Various Factors Controlling Iron ECF at Constant pH of 8.5

Higher pH setting of 8.5 shown in Figure 4.14 below for larger effluent volume at high mixing rate settings seem to produce more chlorides and free chlorines for both low and higher voltages. However, without higher pollutant removals than when pH was set at 3.5. Perhaps, the disparities are caused by the mixing



**Figure 4. 14: Various factors controlling iron ECF at constant pH of 8.5**

The removal efficiencies percentages were calculated as follows:

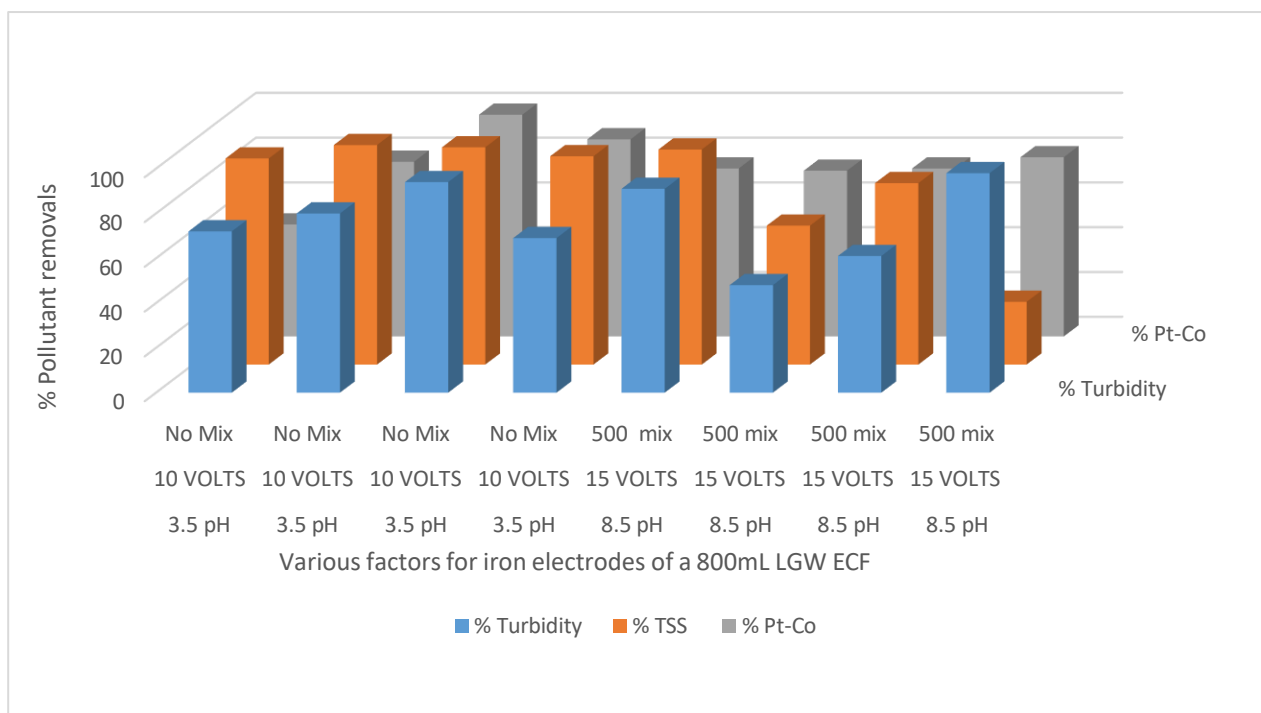
$$\%RE = \frac{initial - final}{initial} \times 100$$

The effects of electrode types (iron and aluminum, alternatively as anodes) in 800 mL and 2000 mL reactors at initial pH of 3.5 and 8.5, voltages of 10V and 15 and mixing speeds of 0 and 500 rpm were investigated to determine the optimum operating conditions for maximum removal efficiency of turbidity, TSS and colour. The results of these operating parameters are presented below.



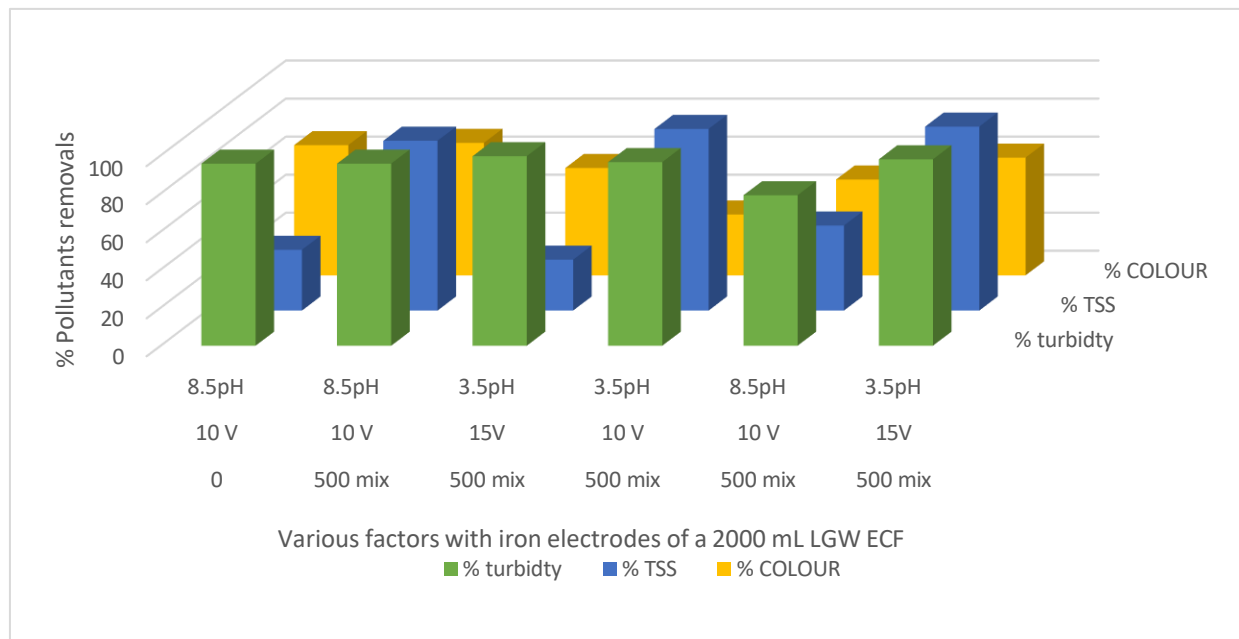
Figures 4.15 and 4.16 below show the effectiveness of iron electrodes in GW-ECF using 800 mL and 2000 mL reactors. Figure 4.15 shows that at a lower mixing speed of 0 rpm the highest removal percentage of turbidity was 94.5%, TSS of 98 % and 98 % of colour of the Greywater. Also, at a higher mixing speed of 500rpm, the percentage removal of turbidity, TSS and colour of the Greywater were 98 %, 96% and 80 % respectively just before trended downwards while changing other parameters which is voltage and pH. The best result of the mixing speed was using 0 rpm mixing than 500 rpm. Increasing stirring speed decreased turbidity, TSS and colour removal efficiency. This could be due to the dissolution of already form flocs due to their instability or increasing stirring speed decreased capability of floc formation with electrode ions. Perhaps electrolysis gases evolution provided enough turbulence to sustain mixing required. Not using mixer also saved electricity.

Figure 4.15 and 4.16 shows that increasing voltage did not have much impact on the removal efficiencies, perhaps this is due to the high pH and the iron electrodes interactions independent of voltage supply and conductivities of the laundry greywater.



**Figure 4. 15: Various factors for iron electrodes of an 800mL LGW ECF**

Figure 4.16 below, shows the effectiveness of iron electrodes in GW-ECF using 2000 mL reactors. Figure 4.16 shows that at a lower mixing speed of 0 rpm the highest removal percentage of turbidity was 95 %, TSS of 32 % and 65 % of colour of the Greywater. Also, at a higher mixing speed of 500rpm, the percentage removal of turbidity, TSS and colour removal of the Greywater were 99.6 %, 97% and 70 % respectively, just before trended downwards while changing other parameters which is voltage and pH.



**Figure 4. 16: Various factors with iron electrodes of a 2000mL LGW ECF**

The results show that changing the volume of the reactor between 2000 mL reactor and 800 mL reactors did not influence removal efficiencies of turbidity, TSS and colour, for the iron electrode but significant influences the process that is caused by the pH. Best performances are shown to be at initial of pH 3.5 at low voltages and no mixing than at pH of 8.5 and voltages 15V. The 2000 mL reactor performed better with 87 percent average consistently for turbidity but fluctuated for TSS. TSS and turbidity seem to be affected strongly by the pH and mixing.

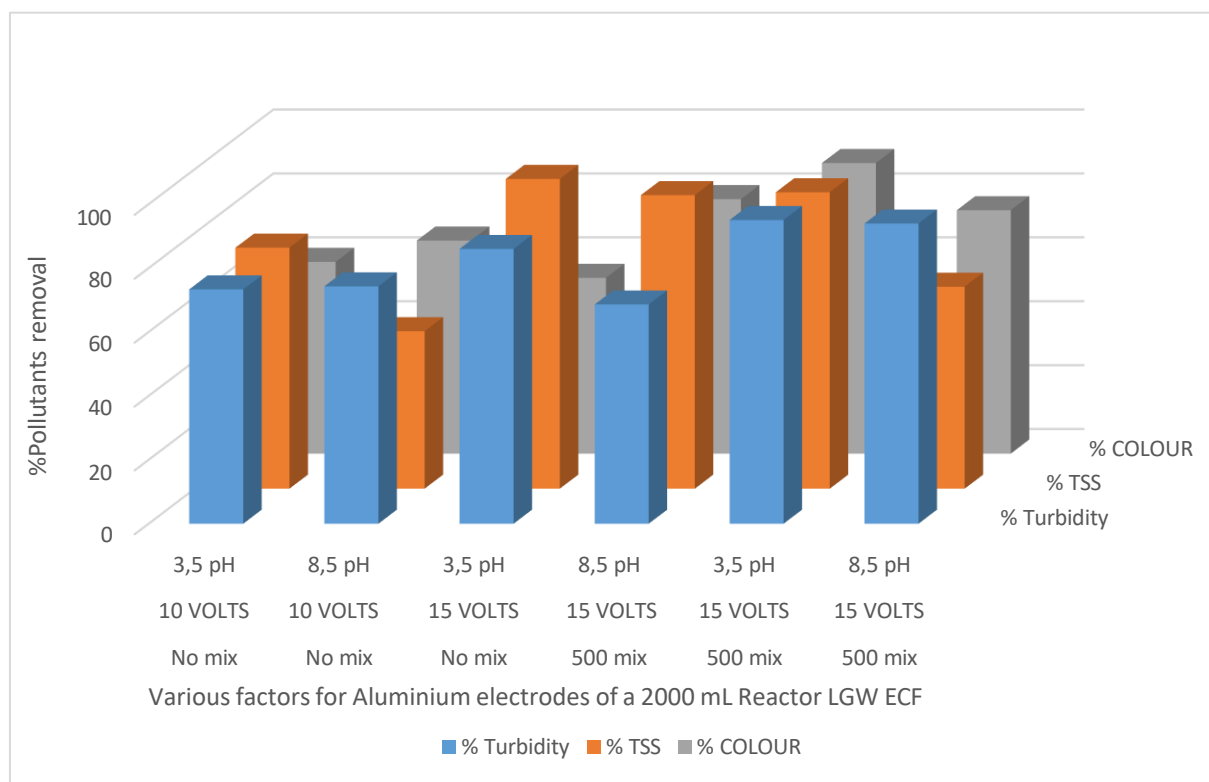
#### **4.14 The Effectiveness of Alum electrodes in GW- ECF using 2000 mL reactor.**

The effects of electrode types (iron and aluminum, alternatively as anodes) in 800 mL and 2000 mL reactors initial pH (3.5 to 8.5), voltage (10 to 15 V) and Mixing speed (0 to 500 rpm) were investigated to determine the optimum operating conditions for maximum removal efficiency of turbidity, TSS and colour. The results of these operating parameters using aluminium are presented below.

Figures 4.17 and 4.18 below show the effectiveness of aluminium electrodes in GW-ECF using 800 mL and 2000 mL reactors. The aluminium electrodes in 2000 mL ECF reactor have a

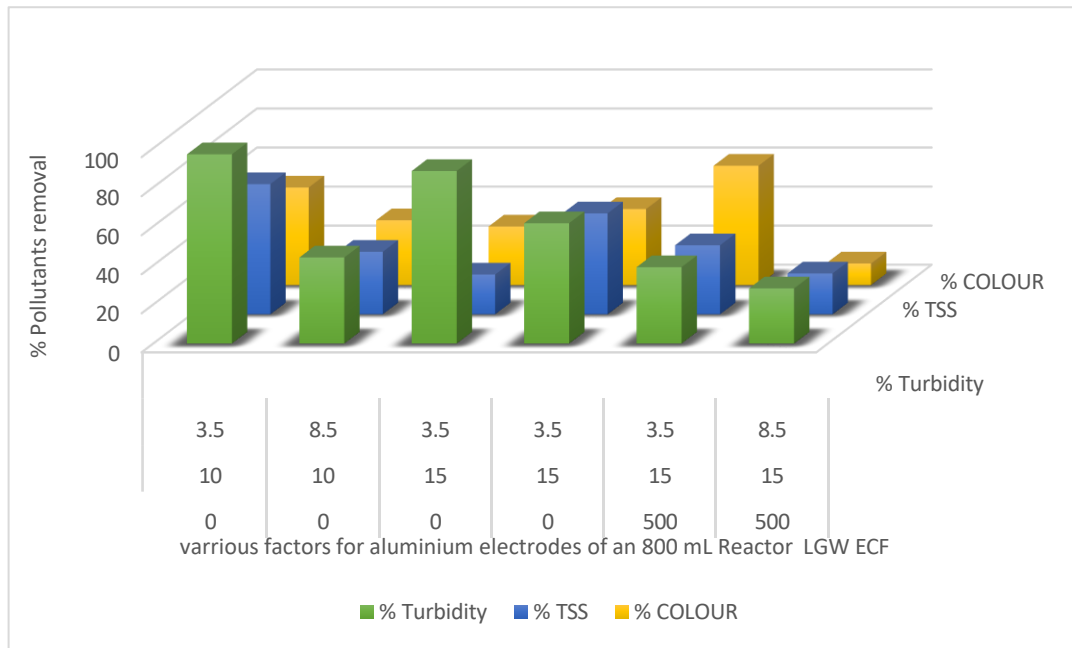
maximum efficiency removal of 95%, 97% and 91% for turbidity, TSS and colour respectively. While aluminium in an 800 mL ECF reactor has a maximum removal of 97%, 67% and 61% turbidity, TSS and colour respectively. The voltage applied to the EC system determines the amounts of coagulants released from the respective electrodes. As a result, more  $Al^{3+}$  ions dissolve into the solution, increasing the rate of  $Al(OH)_3$  formation. It is also well known that electrical potential influences not only the coagulant dosage rate but also the bubble production rate, size, and flocs growth, all of which can affect the EC's treatment efficiency. Higher currents result in a faster supply of metal ions than the coagulation process, resulting in a lower removal efficiency calculated on an equivalent Al or Fe basis.

As it seems in in Figure 4.17, the pH does not have lot of influence on removal efficiency but requires more mixing for turbidity, colour and TSS and high voltage for higher volumes.



**Figure 4. 17: Various factors for aluminium electrodes of a 2000mL LGW ECF**

For smaller reactor, 800 mL reactor, the aluminium electrodes did not perform very well compared to the bigger reactor (2000 mL). This can be due to excessive coagulation in that the reactor got over flooded with flocs. As seen in Figure 4.17 better efficiencies were achieved at low voltages of 10 V. The question that can be asked is, is 10 V is low enough for the best performance of the 800 mL reactor in figure 4.18 below. Even mixing did not make any impact



**Figure 4. 18: Various factors for aluminium electrodes of an 800mL reactor LGW**

#### 4.15 Energy and Electrode Consumptions

Economic studies should be carried out while considering the practical application of EC. The consumption of electrical energy and electrode material are two of the most significant operating costs of the electrocoagulation techniques. The following equations were used to quantify energy and theoretical electrode consumption.

$$C_{energy} \left[ \frac{kWh}{m^3} \right] = \frac{UIt}{V}$$

where U represents the average cell voltage (V), I represents the current (A),  $t$  represents the operating time (h), and V represents the volume of GW put in the EC reactor ( $m^3$ ).

$$C_{electrode} \left[ \frac{kg}{m^3} \right] = \frac{ItM_w}{zFV}$$

where  $M_w$  represents the molecular weight of iron or aluminium (g/mol), z represents the number of electrons involved in the process (2 for Fe and 3 for Al), and F represents the Faraday constant (96485C/mol).

**Table 4. 5: Operating cost**

Electrode type	C <sub>electrode, exp</sub> kg/m <sup>3</sup>	C <sub>electrode, theo</sub> kg/m <sup>3</sup>	Current Efficiency %	C <sub>energy</sub> kWh/m <sup>3</sup>
Iron (800 mL)	2.32	1.7	73	15625.00
Iron (2000 mL)	0.93	0.8	86	6250.00
Aluminium (800 mL)	1.55	0.2	77	15625.00
Aluminium (2000 mL)	0,62	0,4	65	6250.00

The EC process's operating cost for GW treatment was estimated, considering both energy and electrode usage. The power supplier's unit electrical price was R2090.34 in February 2013. For Fe and Al electrode materials, the prices were R74 and R85, respectively.

The following equation below is to calculate current efficiency:

$$\text{Current efficiency}(C_E) (\%) = \frac{C_{\text{electrode, theo}}}{C_{\text{electrode, exp}}} \times 100$$

The decrease of the electrodes after the EC phase was calculated using  $C_{\text{electrode, exp}}$ . The lifetime of the electrodes used is affected by current efficiency. Finally, we report the LGW purification findings for the EC/EF procedure (see Table 4.1, optimal experimental conditions). The values of TSS, pH, TDS, Turbidity, colour and chlorides, as demonstrated in the experimental findings, suggest a considerable removal of contaminants from LWW.

#### 4.16 Comparison of results with previous studies

Several studies have investigated the efficacy of electrocoagulation (EC) for treating laundry wastewater, each focusing on different aspects of the process. In this work, iron was used over aluminium electrodes, with optimal operating conditions including an initial pH range of 4.5 to 5.75, an applied voltage of 10V to 13V, and a mixing speed of 125 to 350 rpm. This study reported outstanding removal percentages of 94.5% for turbidity, 97% for TSS, and 98.7% for colour, demonstrating high efficiency in treating laundry greywater (LGW) in a 2000mL reactor capacity. By comparison, Nugroho *et al.*, (2020) investigated various aluminium electrode configurations and discovered that a setup with two anodes and three cathodes operating at a current strength of 6 A resulted in significant reductions in COD (80.76%), surfactant (27.11%), TDS (17.66%), and turbidity (74.12%).

The second study by Dimoglo *et al.*, (2019) focused on aluminium electrodes and established optimal conditions for attaining 90% pollutant removal, including a current density of 5.26 mA/cm<sup>2</sup>, a pH of 5.5, a processing duration of 5 minutes, and an energy usage of 1.25 kWh/m<sup>3</sup>. Lastly, Oktiawan *et al.*, (2021) investigated surfactant removal using an Al-Al electrode configuration and discovered that applying 30 volts for 30 minutes resulted in a

surfactant effluent concentration of 5.77 mg/L with a removal efficiency of 72.89%. These studies highlight the versatility and efficacy of EC in treating laundry wastewater, emphasising the importance of considering various experimental parameters. Differences in the composition and properties of the wastewater being treated could be one possible explanation for discrepancies in optimal operating conditions. Different types and amounts of pollutants in wastewater might affect the electrocoagulation process, resulting in differences in the optimal operating parameters needed for efficient treatment. Furthermore, differences in reactor design and setup can affect electrocoagulation performance. Electrode spacing, surface area, and the presence of baffles or flow control mechanisms all have an impact on mass transfer, current distribution, and overall treatment efficiency.

## 5. CONCLUSION

The optimisation technique employed Design-Expert software to examine the best experimental conditions for ECF. The responses could tell which control operational variables contributed to its best performance. The purpose of this study was to obtain as many response behaviours as possible while keeping all control operating parameters within their limits. The optimum operating conditions were found to be pH of 4.5 to 5.75, applied voltage of 10V to 13 V, electrode type (iron) and mixing speed of 125 to 350 rpm. These results suggested that the ECF method can be used to scale-up this EC-reactor treatment to higher volumes than 2000 mL. The test results for the optimum responses values demonstrate fitness to the water quality assessment parameters that allow water reuse have satisfactory findings. They are standard parameters used in South African Domestic Water Re-Use Standards (see Table 2.2).

TSS removal depends strongly on voltage supply and mixing. Turbidity removal depends on mixing rate and reactor volume and was optimized to values 100 to 125 NTUs, by manipulating reactor volume to 2000 mL mixing rate at 100 rpm, voltage supply of 13V. The most efficient electrodes type was found to be iron over aluminium electrodes. The optimum operating conditions were found to be initial pH of 4.5 to 5.75, an applied voltage of 10V to 13 V, electrode type (Aluminium) and mixing speed of 125 to 350 rpm. These results suggest that the ECF method can be used to scale up this EC-reactor treatment to higher volumes than 2000 mL or less ratio of electrode surface area to volume of the effluent. The surface area of electrodes to reactor volume and current to the surface of electrodes or current density (1.5 A per 0.016 m<sup>2</sup> or 94 A/m<sup>2</sup>) are strong reactor design parameters, which can lead to a need for reactor design methodologies.

LGW can be treated successfully with ECF at these levels of highest removal percentage of turbidity was 94.5% NTU, 97 % TSS and 98.7 % colour in an electrocoagulation reactor at 2000mL. Some are achieved without mixing which is a saving electricity.

### 5.1 Recommendation

Recommendation is that there is still room left to optimize for reaction time for less reaction time and more volume at the same operating conditions at 1.5 A and 10 V or 15 Wh. This system can be power operated by a small photovoltaic panel for a small household facility to power up ECF reactor for greywater treatment for reuse to reduce potable water consumption and reduce domestic effluent going to the sewers, thereby diverting and reverting sewer pipelines flooding, sewer pipes overflows and sewer bursts and ultimately environmental disasters.

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## APPENDIX A

### RAW DATA

**Table A. 1: Raw data experimental set#1**

Raw Data Block	1Std_order	Run order	Mix	Voltage (V)	pH initial	Electrode Types	Volume (mL)	Current (A)	pH Out	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	Electrical Conductivity	ORP (V)	Chlorides (mg/L)	Free chlorines(mg/L)	Turbidity (NTU)	Ferrous iron (mg/L)	Total iron (mg/L)	Hazen Colour (Pt-Co)	PO <sub>4</sub> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
1	85	0	10	3,5	Iron	800	0,35	9,8	496	61	915	2,09	0,44	0,23	0,2	112	1,05	2,01	299	8,3	0,33	0,2	
2	90	0	10	3,5	Iron	2000	0,2	6,77	114	116	851	12,06	0,56	1,46	1,45	126	1,46	0,35	330	11,9	0,56	1,5	
3	65	0	10	3,5	Alum	800	1,02	7,93	163	343	873	3,76	0,03	0,47	0,45	939	0,65	0,77	468	13,8	0,31	2,5	
4	86	0	10	3,5	Alum	2000	0,81	9,96	187	172	494	3,3	0,75	1,03	1,08	230	1,47	1,54	229	13,2	0,31	3,2	
5	92	0	10	8,5	Iron	800	2,38	9,4	179	24	568	4,13	0,36	0,26	0,29	27,6	2,38	1,06	224	15,7	0,04	2,2	
6	81	0	10	8,5	Iron	2000	1,76	10,6	115	338	586	5,9	0,15	1,69	1,67	35	3,01	1,46	134	1,0	0,04	4,4	
7	71	0	10	8,5	Alum	800	0,4	9,47	130	200	241	4,24	10,2	1,49	1,47	619	2,12	2,54	157	10,3	0,07	5,0	
8	73	0	10	8,5	Alum	2000	0,88	10,6	311	307	862	3,39	1,77	0,36	0,34	5,55	0,52	0,58	35	21,8	0,56	4,4	
9	67	0	10	3,5	Iron	800	0,26	7,28	325	10	693	4,63	6,39	0,9	0,86	29,2	1,47	1,06	157	11,9	0,45	1,2	
10	80	0	15	3,5	Iron	2000	4,69	6,12	214	36	681	9,42	0,33	0,06	0,04	108	0,84	2,36	152	8,3	0,44	1,1	
11	91	0	15	3,5	Alum	800	1,45	7,9	303	13	986	3	0,03	0,15	0,14	12,2	0,26	0,67	196	10,3	0,07	0,9	
12	75	0	15	3,5	Alum	2000	1,64	8,1	220	924	315	3,05	0,6	0,16	0,29	99	1,43	1,03	145	21,8	0,08	4,5	
13	93	0	15	8,5	Iron	800	0,48	9,62	128	69	820	2,77	2,3	0,22	0,25	203	1,97	1,75	153	20,0	0,06	3,3	
14	88	0	15	8,5	Iron	2000	1,72	7,05	170	140	654	0,56	0,45	0,11	0,09	80	1,05	2,64	34,25	12,2	0,9	3,5	
15	74	0	15	8,5	Alum	800	1,13	10,2	156	17	937	3,34	0,33	1,94	0,01	41,2	2,37	0,92	233	21,8	0,56	4,6	
16	77	0	15	8,5	Alum	2000	2,2	11,3	344	103	1232	3,29	2,5	1,18	1,39	47,7	1,43	1,87	138	16,5	0,59	1,5	
17	68	0	15	3,5	Iron	800	1,79	8,17	134	45	541	2,65	3,5	2,02	1,95	156	0,46	1,46	110	14,6	0,58	3,5	

Raw Data Block	Run order	Mix	Voltage (V)	pH initial	Electrode Types	Volume (mL)	Current (A)	pH Out	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	Electrical Conductivity	ORP (V)	Chlorides (mg/L)	Free chlorines(mg/L)	Turbidity (NTU)	Ferrous iron (mg/L)	Total Iron (mg/L)	Hazen Colour (Pt-Co)	PO <sub>4</sub> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
18	69	500	10	3,5	Iron	2000	0,81	7,01	156	10	841	15,93	1,3	0,4	0,34	4,51	0,38	0,36	166	16,4	0,24	0,9
19	72	500	10	3,5	Alum	800	0,83	10,4	245	68	998	2,93	2,5	0,36	0,25	88,4	0,34	0,32	188	11,6	0,58	3,6
20	94	500	10	3,5	Alum	2000	0,58	10,8	368	107	641	0,85	1,56	4,27	2,32	272	1,45	1,04	17	27,7	0,76	1,4
21	87	500	10	8,5	Iron	800	0,78	11,9	189	306	122	2,73	0,3	4,53	4,32	31,2	3,08	2,47	231	14,6	0,58	5,1
22	84	500	10	8,5	Iron	2000	0,85	9,05	384	310	941	2,73	0,3	4,53	4,32	26,5	0,58	0,66	401	16,4	0,34	3,8
23	82	500	10	8,5	Alum	800	1,02	10,3	202	15	941	3,08	1,01	0,18	0,15	8,36	0,36	0,2	136	11,6	0,64	2,4
24	78	500	10	8,5	Alum	2000	1,06	9,5	248	17	985	3,72	0,01	1,21	1,3	7,35	1,61	1,87	182	10,3	0,24	2,9
25	96	500	10	3,5	Iron	800	0,33	7,66	258	15	121	9,76	0,7	0,4	0,34	3,3	0,06	0,14	11	12,1	0,58	3,9
26	95	500	15	3,5	Iron	2000	2,81	6,56	144	10	545	3,36	10,5	1,54	1,55	2,51	2,02	2,34	343	17,1	0,24	1,1
27	83	500	15	3,5	Alum	800	0,48	7,97	344	45	428	591	1,56	1,21	0,09	2,03	2,06	3,05	255	30,2	0,59	0,6
28	70	500	15	3,5	Alum	2000	0,97	6,8	156	455	603	159	0,65	0,06	2,6	2,04	3,06	4,05	196	22,0	0,06	5,6
29	76	500	15	8,5	Iron	800	1,48	11,2	464	446	590	2,99	12,2	3,85	3,6	10,7	4,25	5,62	183	27,7	0,08	2,3
30	66	500	15	8,5	Iron	2000	1,71	8,07	128	85	767	11,04	0,33	0,15	2,38	181	5,03	6,03	188	19,0	0,76	1,2
31	89	500	15	8,5	Alum	800	1	9,75	303	17	976	1598	2,3	1,97	2,09	155	2,36	1,06	189	14,6	0,36	2,3
32	79	500	15	8,5	Alum	2000	1,45	9,64	490	37	895	1224	0,55	0,24	0,3	113	1,1	2,2	200	8,2	0,46	4,1

**Table A. 2 : Raw date experimental set#2**

Raw Data Block 1Std order	Run order	Blocks	Mix	Voltage (V)	pH initial	Electrode Types	Volume (mL)	Current (A)	pH Out	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	Electrical Conductivity	ORP (V)	Chlorides (mg/L)	Free chlorines(mg/L)	Turbidity (NTU)	Ferrous iron (mg/L)	Total Iron (mg/L)	Hazen Colour (Pt-Co)	PO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)	SO <sub>4</sub> (mg/L)
32	79	2	500	15	8,5	Alum	2000	1,45	9,64	490	37	895	1224	0,55	0,24	0,3	113	1,1	2,2	200	8,21	0,46	4.1
33	58	2	0	10	3,5	Iron	800	0,85	9,8	496	61	95	2,09	0,44	0,23	0,3	112	1,05	2,01	299	8,31	0,38	3.2
34	44	2	0	10	3,5	Iron	2000	0,96	7,5	466	300	490	6,66	285	1,29	0,45	16	1,3	2,12	200	9,03	0,36	1.2
35	54	2	0	10	3,5	Alum	800	1,95	8,4	400	470	822	3,55	285	1,78	0,75	15	1,69	2,12	315	9,39	0,46	1.1
36	42	2	0	10	3,5	Alum	2000	1,85	9,94	200	200	841	2,49	250	3,59	0,6	14	0,8	0,55	200	9,93	0,05	1.7
37	62	2	0	10	8,5	Iron	800	0,79	8,56	300	205	708	1,109	174	3,58	0,23	80	1,16	0,3	300	15,4 4	0,04	2.5
38	38	2	0	10	8,5	Iron	2000	1,91	8,66	100	104	998	1,121	250	1,78	0,25	90	1,61	0,62	200	13,5	0,03	2.6
39	46	2	0	10	8,5	Alum	800	0,44	9,75	245	68	710	7,1	360	0,26	0,25	88,4	0,34	0,52	163	13,5	0,04	3.4
40	47	2	0	10	8,5	Alum	2000	2,03	8	400	300	183	8	0,13	1,9	0,02	50	0,33	2,98	100	14,0 2	0,84	2.9
41	51	2	0	15	3,5	Iron	800	3,34	7,83	210	10	651	1,121	174	1,67	0,09	8,19	0,13	2,92	28	15,3	0,5	1.9
42	49	2	0	15	3,5	Iron	2000	1,51	7,66	250	30	888	1,027	285	1,97	0,75	14	1,8	2,77	315	9,39	0,3	2.0
43	37	2	0	15	3,5	Alum	800	1,95	8,4	300	470	832	2,85	285	1,78	1,2	15	1,09	2,12	315	0	0,46	2.1
44	40	2	0	15	3,5	Alum	2000	0,54	5,89	120	300	162	2,35	419	1,55	1,56	200	2,03	2,2	400	1,3	0	2.8
45	35	2	0	15	8,5	Iron	800	1,81	8,72	113	228	549	1,337	350	155	1,5	576	2,01	2,23	476	15	0,01	4.3
46	33	2	0	15	8,5	Iron	2000	1,64	9,25	200	208	995	1,418	250	1,78	1,39	40	1,44	1,8	128	0	0,6	4.4
47	57	2	0	15	8,5	Alum	800	2,2	10,3	344	103	232	3,29	294	0,08	1,1	47,7	1,48	1,86	138	14,5	0	4.8
48	43	2	0	15	8,5	Alum	2000	1,82	7,55	400	400	193	1,82	174	0,07	0,05	40	1,1	0,99	120	9,39	0,05	3.5
49	53	2	500	15	3,5	Iron	800	0,24	5,1	350	150	299	3,83	145	0,05	0,04	60	1	0,36	320	8,31	54	1.2

Raw Data Block 1Std order	Run order	Blocks	Mix	Voltage (V)	pH initial	Electrode Types	Volume (mL)	Current (A)	pH Out	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	Electrical Conductivity	ORP (V)	Chlorides (mg/L)	Free chlorines(mg/L)	Turbidity (NTU)	Ferrous iron (mg/L)	Total Iron (mg/L)	Hazen Colour (Pt-Co)	PO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)	SO <sub>4</sub> (mg/L)
50	39	2	500	15	3,5	Iron	2000	0,85	6,27	425	175	550	9,97	143	0	0,05	80	1,2	0,52	410	9,39	0,09	2.2
51	61	2	500	15	3,5	Alum	800	2,26	9,41	455	64	475	6,29	180	0,27	0,25	9,06	0,1	0,12	164	15,4 7	0,05	0.8
52	45	2	500	15	3,5	Alum	2000	0,92	9,93	246	278	951	3,3	0,88	3,83	4,01	548	0,36	0,4	381	16	0,56	0.3
53	52	2	500	15	8,5	Iron	800	1,09	6,4	334	34	980	1,94	0,77	3,85	0,98	30,4	0,84	0,88	332	13,5	0,54	0.9
54	50	2	500	15	8,5	Iron	2000	0,85	7,69	324	57	363	5,9	0,01	0,87	0,94	113	1,6	1,2	338	14,5	0,09	0.7
55	55	2	500	15	8,5	Alum	800	0,91	9,94	115	174	804	3,19	106	0,27	0,3	112	1,54	0,35	338	13,0 5	0,08	0.5
56	34	2	500	15	8,5	Alum	2000	0,75	11,7	227	15	741	2,66	175	0,06	0,3	30,1	0,35	0,43	270	15,4 2	0,09	1.6
57	56	2	500	15	3,5	Iron	800	0,45	7,15	257	13	313	9,77	150	0,06	0,05	5,98	0,13	2,17	16	13,5	0,05	1.8
58	63	2	500	15	3,5	Iron	2000	1,83	8,88	415	50	422	1,672	143	0,06	0,05	9,9	0,55	0,88	165	14,0 8	0,03	2.4
59	36	2	500	15	3,5	Alum	800	2,76	9,41	455	64	476	6,29	99	3,88	0,05	9,06	0,1	0,12	164	14,9	0,084	3.9
60	64	2	500	15	3,5	Alum	2000	4,16	6,64	945	20	1,12	1,672	88	3,83	0,05	40,2	0,55	0,99	144	13,5	0,03	1.4
61	59	2	500	15	8,5	Iron	800	1,09	6,4	334	34	980	1,94	99	0,28	0,09	30,4	0,84	0,88	337	16,3	0,84	1.6
62	41	2	500	15	8,5	Iron	2000	2,66	9,34	330	184	2,25	3,14	106	0,27	4,01	30,4	0,84	0,44	420	13,5	0,46	2.2
63	60	2	500	15	8,5	Alum	800	1,72	11,7	227	15	741	2,66	130	0,288	0,36	20	0,35	0,43	270	12,3	0,55	3.6
64	48	2	500	15	8,5	Alum	2000	4,61	9,93	800	28	0,913	3,16	180	0,28	0,3	30,1	0,35	0,44	270	15,4 2	0,6	1.5



**Table A. 3: Aluminium electrode experiment block 1**

Std order	Run order	elect-type	Volume (mL)	pH initial	Mix	Voltage (V)	Current (A)	pH output	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	EC	ORP (V)	Chlorides(mg/L)	Free chlorines(mg/L)	Turbidity (NTU)	Ferrous iron(mg/L)	Total Iron(mg/L)	Hazen colour (pt-CO)	PO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)	SO <sub>4</sub> (mg/L)
3	65	Alum	800	3,5	0	10	1,02	7,93	163	343	873	3,76	0,03	0,47	0,45	939	0,65	0,77	468	13,8	0,31	2,5
11	91	Alum	800	3,5	0	15	1,45	7,9	303	13	986	3	0,03	0,15	0,14	12,2	0,26	0,67	196	10,24	0,07	0,9
19	72	Alum	800	3,5	500	10	0,83	10,4	245	68	998	2,93	2,5	0,36	0,25	88,4	0,34	0,32	188	11,64	0,58	3,6
27	83	Alum	800	3,5	500	15	0,48	7,97	344	45	428	591	1,56	1,21	0,09	2,03	2,06	3,05	255	30,2	0,59	0,6
7	71	Alum	800	8,5	0	10	0,4	9,47	130	200	241	4,24	10,2	1,49	1,47	619	2,12	2,54	157	10,24	0,07	5
15	74	Alum	800	8,5	0	15	1,13	10,2	156	17	937	3,34	0,33	1,94	0,01	41,2	2,37	0,92	233	21,83	0,56	4,6
23	82	Alum	800	8,5	500	10	1,02	10,3	202	15	941	3,08	1,01	0,18	0,15	8,36	0,36	0,2	136	11,64	0,64	2,4
31	89	Alum	800	8,5	500	15	1	9,75	303	17	976	1598	2,3	1,97	2,09	155	2,36	1,06	189	14,58	0,36	2,3
4	86	Alum	2000	3,5	0	10	0,81	9,96	187	172	494	3,3	0,75	1,03	1,08	230	1,47	1,54	229	13,06	0,31	3,2
12	75	Alum	2000	3,5	0	15	1,64	8,1	220	924	315	3,05	0,6	0,16	0,29	99	1,43	1,03	145	21,83	0,08	4,5
20	94	Alum	2000	3,5	500	10	0,58	10,8	368	107	641	0,85	1,56	4,27	2,32	272	1,45	1,04	17	27,7	0,76	1,4
28	70	Alum	2000	3,5	500	15	0,97	6,8	156	455	603	159	0,65	0,06	2,6	2,04	3,06	4,05	196	22,03	0,06	5,6
8	73	Alum	2000	8,5	0	10	0,88	10,6	311	307	862	3,39	1,77	0,36	0,34	5,55	0,52	0,58	35	21,83	0,56	4,4
16	77	Alum	2000	8,5	0	15	2,2	11,3	344	103	1232	3,29	2,5	1,18	1,39	47,7	1,43	1,87	138	16,5	0,59	1,5
24	78	Alum	2000	8,5	500	10	1,06	9,5	248	17	985	3,72	0,01	1,21	1,3	7,35	1,61	1,87	182	10,24	0,24	2,9

Table A. 4: Iron electrode experiment block 1

Std order	Run order	elect-type	Volume (mL)	pH initial	Mix	Voltage (V)	Current	pH output	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	EC	ORP(V)	Chlorides (mg/L)	Free chlorines	Turbidity (NTU)	Ferrous iron (mg/L)	Total Iron(mg/L)	Hazen colour (Pt-	PO <sub>4</sub> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
2	90	Iron	2000	3,5	0	10	0,2	6,77	114	116	851	12,06	0,56	1,46	1,45	126	1,46	0,35	330	11,91	0,56	1,5
10	80	Iron	2000	3,5	0	15	4,69	6,12	214	36	681	9,42	0,33	0,06	0,04	108	0,84	2,36	152	8,31	0,44	1,1
18	69	Iron	2000	3,5	500	10	0,81	7,01	156	10	841	15,93	1,3	0,4	0,34	4,51	0,38	0,36	166	16,4	0,24	0,9
26	95	Iron	2000	3,5	500	15	2,81	6,56	144	10	545	3,36	10,5	1,54	1,55	2,51	2,02	2,34	343	17,09	0,24	1,1
6	81	Iron	2000	8,5	0	10	1,76	10,6	115	338	586	5,9	0,15	1,69	1,67	35	3,01	1,46	134	1,024	0,04	4,4
14	88	Iron	2000	8,5	0	15	1,72	7,05	170	140	654	0,56	0,45	0,11	0,09	80	1,05	2,64	34,25	12,09	0,9	3,5
22	84	Iron	2000	8,5	500	10	0,85	9,05	384	310	941	2,73	0,3	4,53	4,32	26,5	0,58	0,66	401	16,4	0,34	3,8
30	66	Iron	2000	8,5	500	15	1,71	8,07	128	85	767	11,04	0,33	0,15	2,38	181	5,03	6,03	188	19,03	0,76	1,2
1	85	Iron	800	3,5	0	10	0,35	9,8	196	61	915	2,09	0,44	0,23	0,2	112	1,05	2,01	299	8,31	0,33	0,2
17	68	Iron	800	3,5	0	15	1,79	8,17	134	45	541	2,65	3,5	2,02	1,95	156	0,46	1,46	110	14,58	0,58	3,5
9	67	Iron	800	3,5	0	10	0,26	7,28	325	10	693	4,63	6,39	0,9	0,86	29,2	1,47	1,06	157	11,91	0,45	1,2
25	96	Iron	800	3,5	500	10	0,33	7,66	258	15	121	9,76	0,7	0,4	0,34	3,3	0,06	0,14	11	12,09	0,58	3,9
5	92	Iron	800	8,5	0	10	2,38	9,4	179	24	568	4,13	0,36	0,26	0,29	27,6	2,38	1,06	224	15,71	0,04	2,2
13	93	Iron	800	8,5	0	15	0,48	9,62	128	69	820	2,77	2,3	0,22	0,25	203	1,97	1,75	153	20,03	0,06	3,3
21	87	Iron	800	8,5	500	10	0,78	11,9	189	306	122	2,73	0,3	4,53	4,32	31,2	3,08	2,47	231	14,58	0,58	5,1
29	76	Iron	800	8,5	500	15	1,48	11,2	464	446	590	2,99	12,2	3,85	3,6	10,7	4,25	5,62	183	27,7	0,08	2,3

**Table A. 5: Aluminium electrode experiment block 2**

Std order	Run order	Mix (rpm)	Voltage(V)	pH Initial	Electrodes Type	Current (A)	pH output	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	EC	ORP (V)	Chlorides (mg/L)	Free chlorines(mg)	Turbidity (NTU)	Ferrous iron(mg/L)	Total Iron(mg/L)	Hazen colour	PO <sub>4</sub> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> (mg/L)
35	54	0	10	3,5	Alum	1,95	8,4	400	470	822	3,55	285	1,78	0,75	15	1,69	2,12	315	9,39	0,46	1,1
36	42	0	10	3,5	Alum	1,85	9,94	200	200	841	2,49	250	3,59	0,6	14	0,8	0,55	200	9,93	0,05	1,7
39	46	0	10	8,5	Alum	0,44	9,75	245	68	710	7,1	360	0,26	0,25	88,4	0,34	0,52	163	13,5	0,04	3,4
40	47	0	10	8,5	Alum	2,03	8	400	300	183	8	0,13	1,9	0,02	50	0,33	2,98	100	14,02	0,84	2,9
43	37	0	15	3,5	Alum	1,95	8,4	300	470	832	2,85	285	1,78	1,2	15	1,09	2,12	315	0	0,46	2,1
44	40	0	15	3,5	Alum	0,54	5,89	120	300	162	2,35	419	1,55	1,56	200	2,03	2,2	400	1,3	0	2,8
47	57	0	15	8,5	Alum	2,2	10,3	344	103	232	3,29	294	0,08	1,1	47,7	1,48	1,86	138	14,5	0	4,8
48	43	0	15	8,5	Alum	1,82	7,55	400	400	193	1,82	174	0,07	0,05	40	1,1	0,99	120	9,39	0,05	3,5
51	61	500	10	3,5	Alum	2,26	9,41	455	64	475	6,29	180	0,27	0,25	9,06	0,1	0,12	164	15,47	0,05	0,8
52	45	500	10	3,5	Alum	0,92	9,93	246	278	951	3,3	0,88	3,83	4,01	548	0,36	0,4	381	16	0,56	0,3
55	55	500	10	8,5	Alum	0,91	9,94	115	174	804	3,19	106	0,27	0,3	112	1,54	0,35	338	13,05	0,08	0,5
56	34	500	10	8,5	Alum	0,75	11,7	227	15	741	2,66	175	0,06	0,3	30,1	0,35	0,43	270	15,42	0,09	1,6
59	36	500	15	3,5	Alum	2,76	9,41	455	64	476	6,29	99	3,88	0,05	9,06	0,1	0,12	164	14,9	0,084	3,9
60	64	500	15	3,5	Alum	4,16	6,64	945	20	1,12	1,672	88	3,83	0,05	40,2	0,55	0,99	144	13,5	0,03	1,4
63	60	500	15	8,5	Alum	1,72	11,7	227	15	741	2,66	130	0,288	0,36	20	0,35	0,43	270	12,3	0,55	3,6
64	48	500	15	8,5	Alum	4,61	9,93	800	28	0,913	3,16	180	0,28	0,3	30,1	0,35	0,44	270	15,42	0,6	1,5

**Table A. 6: Iron electrode experiment block 2**

Std order	Run order	Mix (rpm)	Voltage(V)	pH Initial	Electrodes Type	Current (A)	pH output	COD (mg/L)	TSS (mg/L)	TDS (mg/L)	EC	ORP (V)	Chlorides (mg/L)	Free chlorines(	Turbidity (NTU)	Ferrous iron(mg/L)	Total iron(mg/L)	Hazen colour	PO <sub>4</sub> (mg/L)	SO <sub>4</sub> (mg/L)	NO <sub>3</sub> - (mg/L)
33	58	0	10	3,5	Iron	0,85	9,8	496	61	95	2,09	0,44	0,23	0,3	112	1,05	2,01	299	8,31	0,38	3,2
34	44	0	10	3,5	Iron	0,96	7,5	466	300	490	6,66	285	1,29	0,45	16	1,3	2,12	200	9,03	0,36	1,2
37	62	0	10	8,5	Iron	0,79	8,56	300	145	708	1,1	174	3,58	0,23	80	1,16	0,3	300	15,44	0,04	2,5
38	38	0	10	8,5	Iron	1,91	8,66	100	104	998	1,12	250	1,78	0,25	90	1,61	0,62	200	13,5	0,03	2,6
41	51	0	15	3,5	Iron	3,34	7,83	210	10	651	1,12	174	1,67	0,09	8,19	0,13	2,92	28	15,3	0,5	1,9
42	49	0	15	3,5	Iron	1,51	7,66	250	50	888	1,06	285	1,97	0,75	14	1,8	2,77	315	9,39	0,3	2,0
45	35	0	15	8,5	Iron	1,81	8,72	113	228	549	1,34	350	155	1,5	576	2,01	2,23	476	15	0,01	4,3
46	33	0	15	8,5	Iron	1,64	9,25	200	208	995	1,45	250	1,78	1,39	40	1,44	1,8	128	0	0,6	4,4
49	53	500	10	3,5	Iron	0,24	5,1	350	150	299	3,83	145	0,05	0,04	60	1	0,36	320	8,31	54	1,2
50	39	500	10	3,5	Iron	0,85	6,27	425	175	550	9,97	143	0	0,05	80	1,2	0,52	410	9,39	0,09	2,2
53	52	500	10	8,5	Iron	1,09	6,4	334	34	980	1,94	0,77	3,85	0,98	30,4	0,84	0,88	332	13,5	0,54	0,9
54	50	500	10	8,5	Iron	0,85	7,69	324	57	363	5,9	0,01	0,87	0,94	113	1,6	1,2	338	14,5	0,09	0,7
57	56	500	15	3,5	Iron	0,45	7,15	257	13	313	9,77	150	0,06	0,05	5,98	0,13	2,17	16	13,5	0,05	1,8
58	63	500	15	3,5	Iron	1,83	8,88	415	50	422	1,67	143	0,06	0,05	9,9	0,55	0,88	165	14,08	0,03	2,4
61	59	500	15	8,5	Iron	1,09	6,4	334	34	980	1,94	99	0,28	0,09	30,4	0,84	0,88	337	16,3	0,84	1,6
62	41	500	15	8,5	Iron	2,66	9,34	330	184	2,25	3,14	106	0,27	4,01	30,4	0,84	0,44	420	13,5	0,46	2,2

## APPENDIX B

### SCALE-UP DATA

**Table B. 1: Iron electrode using volume of 800mL block 1**

Std order	Run order	pH initial	Voltage (V)	Mixing (rpm)	% Turbidity	%TSS	% Pt-Co
1	85	3.5	10	0	72	92	50
9	67	3.5	10	0	80	98	78
25	96	3.5	10	0	94	97	99
17	68	3.5	10	0	69	93	88
5	92	8.5	15	500	91	96	75
21	87	8.5	15	500	48	62	74
13	93	8.5	15	500	61	81	75

**Table B. 2: Iron electrode using volume of 2000mL block 1**

Std orcer	Mix (rpm)	Voltage (V)	pH initial	% Turbidity	% TSS	% COLOUR
8	0	10	8.5	95,6641	31,929	68,46847
24	500	10	8.5	95,7018	89,2405	69,66667
28	500	15	3.5	99,6151	26,7311	56,44444
18	500	10	3.5	96,4984	95,4545	31,96721
22	500	10	8.5	79,0845	44,6429	50,37129
26	500	15	3.5	97,9839	96,6667	61,88889

**Table B. 3: Aluminium electrode using volume of 800mL block 2**

Std order	Mixing (rpm)	Voltage (V)	pH initial	initial Tubidity (NTU)	Final tubidity(NTU)	% Turbidity	Initial TSS (mg/L)	final TSS (mg/L)	% TSS	initial Colour	Final Colour	% COLOUR
36	0	10	3.5	451	14	97	600	200	67	400	200	50
39	0	10	8.5	158	88,4	44	100	68	32	244	163	33
43	0	15	3.5	128,8	15	88	590	470	20	450	315	30
44	0	15	3.5	521	200	62	621	300	52	655	400	39
52	500	15	3.5	900	548	39	430	278	35	980	381	61
55	500	15	8.5	156	112	28	220	174	21	380	338	11,

**Table B. 4: Iron electrode using volume of (2000mL) block 2**

<b>Std order</b>	<b>Mix (rpm)</b>	<b>Voltage (V)</b>	<b>pH initial</b>	<b>initial Turbidity (NTU)</b>	<b>Final turbidity (NTU)</b>	<b>% Turbidity</b>	<b>initial TSS (mg/L)</b>	<b>final TSS (mg/L)</b>	<b>% TSS</b>	<b>initial Colour</b>	<b>Final Colour</b>	<b>% COLOUR</b>
34	0	10	3,5	60	16	73	1220	300	75	500	200	60
38	0	10	8,5	350	90	74	205	104	49	600	200	67
42	0	15	3,5	100	14	86	980	30	97	700	315	55
54	500	15	8,5	360	113	69	700	57	92	1660	338	80
58	500	15	3,5	200	9,9	95	690	50	93	1820	165	91
62	500	15	8,5	502	30,4	94	500	184	63	1133	270	76

## APPENDIX C

### ANOVA ANALYSIS

**Table C. 1: TSS predicted**

Std. Dev.	221,01	R <sup>2</sup>	0,3850
Mean	151,91	Adjusted R <sup>2</sup>	-0,2711
C.V. %	145,49	Predicted R <sup>2</sup>	NA
		Adeq Precision	3,1043

**Table C. 2: Turbidity predicted**

Std. Dev.	192,92	R <sup>2</sup>	0,0000
Mean	118,08	Adjusted R <sup>2</sup>	0,0000
C.V. %	163,39	Predicted R <sup>2</sup>	-0,0656
		Adeq Precision	NA

**Table C. 3: Colour predicted**

Std. Dev.	101,90	R <sup>2</sup>	0,0927
Mean	190,01	Adjusted R <sup>2</sup>	-0,0045
C.V. %	53,63	Predicted R <sup>2</sup>	-0,1726
		Adeq Precision	2,1016

**Table C. 4: TSS response**

<b>Source</b>	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F-value</b>	<b>p-value</b>	
<b>Model</b>	4,586E+05	16	28662,59	0,5868	0,8496	not significant
A-Mix	18720,68	1	18720,68	0,3833	0,5452	
B-Voltage	1436,63	1	1436,63	0,0294	0,8661	
C-Initial pH	835,65	1	835,65	0,0171	0,8977	
D-Electrode Types	29058,78	1	29058,78	0,5949	0,4525	
E-Effluent Volume	90512,40	1	90512,40	1,85	0,1935	
AB	5811,17	1	5811,17	0,1190	0,7349	
AC	18641,15	1	18641,15	0,3816	0,5460	
AE	62477,30	1	62477,30	1,28	0,2758	
BC	50188,21	1	50188,21	1,03	0,3268	
BE	25262,65	1	25262,65	0,5172	0,4831	
CE	39816,03	1	39816,03	0,8151	0,3809	
ABC	6356,69	1	6356,69	0,1301	0,7233	
ABE	18897,86	1	18897,86	0,3869	0,5433	
ACE	3360,03	1	3360,03	0,0688	0,7967	
BCE	1,140E+05	1	1,140E+05	2,33	0,1474	
ABCE	10025,29	1	10025,29	0,2052	0,6570	
<b>Residual</b>	7,327E+05	15	48845,55			
Lack of Fit	7,314E+05	14	52241,62	40,17	0,1231	not significant
Pure Error	1300,50	1	1300,50			
<b>Cor Total</b>	1,191E+06	31				



**Table C. 5: Turbidity response**

Source	Sum of Squares	df	Mean Square	F-value	p-value	
<b>Model</b>	0,0000	0				
<b>Residual</b>	1,154E+06	31	37218,60			
Lack of Fit	1,150E+06	30	38345,24	14,21	0,0006	significant
Pure Error	3419,65	1	3419,65			
<b>Cor Total</b>	1,154E+06	31				

**Table C. 6: Hazen colour**

Source	Sum of Squares	df	Mean Square	F-value	p-value	
<b>Model</b>	29702,33	3	9900,78	0,9536	0,4282	not significant
A-Mix	4,88	1	4,88	0,0005	0,9829	
B-Voltage	2322,26	1	2322,26	0,2237	0,6399	
AB	27260,17	1	27260,17	2,63	0,1164	
<b>Residual</b>	2,907E+05	28	10382,85			
Lack of Fit	2,806E+05	27	10393,99	1,03	0,6666	not significant
Pure Error	10082,00	1	10082,00			
<b>Cor Total</b>	3,204E+05	31				