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Electrocoagulation Treatment of Synthetic Wastewater Containing Methyl Orange and Rhodamine B Dye using Stainless Steel Electrode: A Comparative Study

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DECLARATION

I declare that this thesis entitled "Electrocoagulation Treatment of Synthetic Wastewater Containing Methyl Orange Dye and Rhodamine Blue Dye Using Stainless Steel Electrode: A Comparative Study" is the results of my own research except as cited in the references.

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Electrocoagulation Treatment of Synthetic Wastewater Containing Methyl Orange Dye and Rhodamine Blue Dye Using Stainless Steel Electrode: A Comparative Study

ABSTRACT

The electrocoagulation treatment is a promising technique to treat or remove pollutants from water or wastewater. It is a method of water treatment that combines coagulation and electrochemistry principles. In this research, synthetic wastewater containing Methyl orange and Rhodamine b dye were subjected to treatment using the electrocoagulation technique utilizing stainless steel electrodes. The experiments were carried out using electrochemical cells equipped with monopolar stainless-steel electrodes connected in parallel. The study examined the comparative of electrocoagulation treatment efficiency of synthetic wastewater containing Methyl orange and Rhodamine B dye using stainless steel electrodes. The result revealed correlation between the types of dyes and initial dye concentration due to synthetic wastewater's treatment efficiency. The highest treatment efficiency percentage was observed at initial concentration 500ppm for Rhodamine B dye, while the treatment efficiency percentage for Methyl orange is lower. The statistical data based on experimental results were analyzed using statistical analysis from General Full Factorial Design (GFFD). The quadratic model is deemed appropriate owing to its substantial coefficient of determination ($r^2 = 0.910$) and statistically significant p-value (≤ 0.003) for Methyl orange, and ($r^2 = 0.842$) and statistically significant p-value (≤ 0.000) for Rhodamine B dye, suggesting the model's significance. The experimental results indicate that the utilization of electrocoagulation as a treatment method for synthetic wastewater containing Methyl orange and Rhodamine B dye has demonstrated superior efficacy compared to the adsorption technique.

Rawatan Elektokoagulasi Air Sisa Sintetik yang Mengandungi Pewarna Methyl Orange dan Pewarna Rhodamine Blue Menggunakan Elektrod Keluli Tahan Karat: Satu Kajian Perbandingan

ABSTRAK

Rawatan elektokoagulasi merupakan kaedah yang menjanjikan untuk merawat atau mengeluarkan pencemar dari air atau air sisa. Ia adalah kaedah rawatan air yang menggabungkan prinsip koagulasi dan elektrokimia. Dalam penyelidikan ini, air sisa sintetik yang mengandungi pewarna Methyl orange dan Rhodamine B telah dirawat menggunakan teknik elektokoagulasi dengan menggunakan elektrod keluli tahan karat. Eksperimen dijalankan menggunakan sel elektrokimia yang dilengkapi dengan elektrod monopolar keluli tahan karat yang disambungkan secara selari. Kajian ini mengkaji kecekapan rawatan elektokoagulasi bagi air sisa sintetik yang mengandungi Methyl orange dan Rhodamine B menggunakan elektrod keluli tahan karat. Keputusan menunjukkan korelasi antara jenis pewarna dan kepekatan pewarna awal dengan kecekapan rawatan air sisa sintetik. Peratusan kecekapan rawatan tertinggi diperhatikan pada kepekatan awal 500ppm untuk pewarna Rhodamine B, sementara peratusan kecekapan rawatan untuk Methyl orange lebih rendah. Data statistik berdasarkan keputusan eksperimen dianalisis menggunakan analisis statistik dari Reka Bentuk Faktorial Penuh Am (GFFD). Model kuadrat dianggap sesuai disebabkan koefisien penentu yang substansial ($r^2 = 0.910$) dan nilai p yang secara statistik signifikan (≤ 0.003) untuk Methyl Orange, dan ($r^2 = 0.842$) dan nilai p yang secara statistik signifikan (≤ 0.000) untuk Rhodamine B, menunjukkan kepentingan model tersebut. Keputusan eksperimen menunjukkan bahawa penggunaan elektokoagulasi sebagai kaedah rawatan untuk air sisa sintetik yang mengandungi Methyl Orange dan Rhodamine B telah menunjukkan keberkesanan yang lebih superior berbanding dengan teknik penyerapan.

Kata Kunci: Methyl orange, Rhodamine B, air sisa

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LIST OF ABBREVIATIONS

MO	Methyl Orange
RhB	Rhodamine Blue
EC	Electrocoagulation
Al	Aluminum
Fe	Stainless Steel
MF/UF	Microfiltration/ultrafiltration
BOD	Biological oxygen demand
DC	Direct Current
ANOVA	Analysis of Variance
GFFD	General Full Factorial Design
At	Atomic
Wt	Weight
SEM/EDX	Scanning Electron Microscope/ Energy Dispersive X-ray Spectroscopy
UV-Vis	Ultraviolet – visible spectroscopy

LIST OF SYMBOLS

%	Percentage
° c	Degree Celsius
v	Voltage
ml	Milliliter
L	Liter
g	Gram
A	Ammeter
ppm	Parts-per-million
C_i	The initial degradation of dyes
C_f	The degradation after each treatment
nm	Nanometer
r^2	R-squared
mA/cm^2	Current Density

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water pollution is one of the biggest environmental problems in the world. The textile sector is one of the major contributors to water pollution since it discharges wastewater containing dye effluent into water sources. The release of untreated dye effluent into water bodies can cause major environmental problems, including aesthetic pollution, oxygen depletion, and aquatic life poisoning. Rhodamine B (RhB) and Methyl orange (MO) are dyes that are extensively used in the textile industry and are linked to cancer. Therefore, removing RhB and MO coloration from wastewater is essential to prevent water pollution and maintain public health. Adsorption is a popular technique for removing pollutants from wastewater, particularly dye. The adaptability of absorption is one of the advantages. Removing both manufactured and natural colors from wastewater may be accomplished via adsorption. Due to its adaptability, it is a useful approach for handling a variety of dye-containing effluents from sectors including textile and dye manufacture.

Adsorption is a typical technique, although it has drawbacks, including its saturation and regeneration. Adsorption techniques have limited capacity, which means adsorbent materials have a finite capacity for dye adsorption (Husien et al., 2022). Once they reach saturation, they can no longer effectively remove the dyes, requiring replacement or regeneration (Da Silva Santos et al., 2022). This can add to operational costs and generate waste if not managed properly. While some adsorbent materials can be regenerated and reused, the process can be energy-intensive and expensive. It may only sometimes be fully effective, leading to decreased adsorption capacity over time.

The electrocoagulation (EC) technique has been chosen for this experiment because of its specialty, which can overcome the drawbacks of adsorption. EC offers distinct advantages over the adsorption technique regarding the continuous generation of coagulants. As mentioned previously, the finite capacity of adsorbents requires frequent replacement or regeneration, adding to operational costs and generating waste. EC eliminates this issue by continuously generating fresh coagulants through electrolysis, potentially reducing waste, and lowering long-term costs. EC continuously generates fresh coagulants to remove pollutants, eliminating the need for frequent replacement or regeneration of adsorbents. Besides, EC has broader applicability. Non-target molecules and other contaminants can compete with the dyes for adsorption sites, compromising efficiency. Meanwhile, EC can remove a wider range of pollutants besides dyes. It relies not on specific surface interactions but charge neutralization within the bulk solution, potentially offering broader removal of various pollutants without significant competition.

Numerous environmental issues have been resolved because of more than 20 years of study into developing EC systems and the widespread use of EC to treat wastewater (Othmani et al., 2022). EC is a preferred treatment method for degrading synthetic wastewater containing the MO and RhB dye due to its high removal efficiency, versatility in treating different dye compositions, rapid treatment rates, self-sustaining process, reduced sludge generation, oxidation potential, and environmental compatibility. The findings of this research will aid in developing a system that is both accessible and effective for treating wastewater containing dye colorant. Pollutant treatment effectiveness is influenced by operational factors such as the type of dyes and the initial dye concentration. Therefore, to compare the treatment efficiency of RhB dye and MO in synthetic wastewater utilizing parameters such as the types of pollutants and the initial concentration, the general full factorial statistical design will be the main emphasis of this project.

1.2 Problem Statement

The textile sector poses significant environmental challenges due to the presence of various harmful chemicals in its effluent, such as dyes, pigments, surfactants, acids, alkalis, and finishing agents. These substances can persist and negatively impact aquatic ecosystems and human health when released untreated. Wastewater treatment methods are crucial to mitigate these issues, with adsorption being a commonly used technique despite drawbacks like saturation, regeneration issues, and spent adsorbent disposal. This study proposes electrocoagulation (EC) as an alternative to address these drawbacks, offering advantages such as continuous coagulant generation, broader applicability, and reduced waste in treating textile wastewater containing RhB dye and MO.

As mentioned previously, one of the weaknesses of absorption is in terms of saturation and regeneration. Like activated carbon or other materials, adsorbents can become saturated with dyes over time (Husien et al., 2022b). Regeneration processes are often required to restore their adsorption capacity, which can be cumbersome and may involve additional costs (Da Silva Santos et al., 2022b). As mentioned earlier, EC continuously generates fresh coagulant through electrolysis. This eliminates the saturation issue since there is a constant supply of coagulants, potentially reducing the need for frequent replacement or regeneration of adsorbents.

Based on the research conducted in this project, many researchers have investigated the use of the EC technique for wastewater containing MO and RhB dye, but these studies were conducted separately. However, no study currently compares the treatment efficiency between

MO and RhB Dye using the EC technique in a single experiment. The study only involved comparing two different dyes, employing various methods. (Chen et al., 2019). Therefore, in this experiment, the EC technique is implemented using stainless steel electrodes with different dyes: Methyl orange and Rhodamine B dye. This experiment aims to determine whether the treatment efficiency performance depends on the dye types and its initial concentration. The research gap identified in the literature review highlights the lack of a comparative analysis of treatment efficiency between MO and RhB. Consequently, this experiment is conducted to investigate whether using different dyes through the EC technique will significantly change treatment efficiency. Therefore, a general full factorial statistical design is employed to determine the significance of these treatment efficiency differences.

1.3 Objective

1. To compare the electrocoagulation (EC) treatment efficiency of synthetic wastewater containing Methyl orange (MO) and Rhodamine B (RhB) dye using stainless steel electrodes.
2. To correlate the types of dyes and initial dye concentration due to synthetic wastewater's treatment efficiency.

1.4 Scope of Study

This study aims to investigate whether using different dyes through the EC technique will significantly change the treatment efficiency of the MO and RhB dyes using the EC technique. Synthetic wastewater with known amounts of the MO and RhB dye will be used in the project.

The type of dyes and the initial concentration will be evaluated as parameters in this research. The study aims to determine how these parameters affect how well the EC procedure removes dye. The physical and chemical characteristics of the wastewater before and after treatment will be compared to understand how the dye is removed from the wastewater in the EC process.

The study will show if it is possible to use the EC method to clean up colored pollutant wastewater and if it could be used in the textile business. The research on the scalability of the EC technique will be limited to theoretical analysis, even if it will be carried out indirectly in this work.

1.5 Significant of Study

Due to their durability and toxicity, the widely used textile dyes RhB and MO are dangerous to the environment. The research intends to propose an efficient and long-lasting solution for removing this dangerous dye from synthetic wastewater by examining the EC technique for its degradation. EC-based RhB and MO degradation may help minimize the negative environmental effects of wastewater discharges from the textile sector.

The EC technique has shown potential for removing various contaminants, including dyes. This technique's breakdown of MO and RhB in synthetic wastewater may be studied to determine how well it treats the substance. The results provide light on the ideal operating parameters for achieving effective dye degradation, such as the types of pollutants and the initial concentration. Designing and enhancing EC procedures for treating industrial wastewater may benefit from this expertise.

CHAPTER 2

LITERATURE REVIEW

2.1 Wastewater of Textile Industry

In the textile industry, wastewater is a challenging and intricate environmental issue. It is produced throughout many stages of the textile production process, including chemical printing, dyeing, finishing, and washing processes. According to Azanaw et al. (2022), there is a significant pollution issue worldwide due to the growth of textile mills and the wastewater they produce. Its intense hue, toxicity, and high oxygen needs for chemical and biological processes stand out. In addition to offering a considerable challenge to the current conventional water treatment systems, the fast rise in hazardous dye wastewater produced by different sectors continues to be a critical public health problem and a huge environmental concern (Azanaw et al., 2022).

One of the biggest issues with water contamination is the coloring and oxygen depletion. Diverse colors in textile wastewater provide the water source. It is discharged into vibrant colors. The hue prevents light from penetrating, affecting photosynthesis and aquatic plants' growth. When organic pollutants, such as those in textile effluent, are present, the biological oxygen demand (BOD) in receiving water sources rises. Oxygen is depleted during the breakdown of these nutrients by bacteria and other microbes, which is harmful to aquatic life.

Ecosystem disturbance comes next to the pollution problem caused by dye wastewater from the textile industry. If wastewter from the textile sector is released into the water environment, aquatic habitats might suffer severe damage. The toxicity of wastewater and lack of oxygen may result in the decline or extinction of a few species, which would disturb the ecological balance. Effective wastewater treatment and management is necessary for the textile industry to minimize its environmental impact and maintain sustainable practices.

2.2 Adsorption Technique of Wastewater Treatment

In conventional treatment methods, physical processes are typically utilized to eliminate dye pollutants from wastewater. One of the physical treatment processes is adsorption. Due to their ineffective decolorization efficacy and high sludge production, these techniques are only sometimes used (Halepoto et al., 2022). Water-soluble molecules or microscopic particles (the adsorbate) are pulled to and attached to the surface of a larger item (the adsorbent) during the physical process of adsorption. Adsorption is a reasonably simple and user-friendly procedure. It needs little equipment and is easily incorporated into already-in-place wastewater treatment systems. Due to its simplicity, it may be used in manufacturing environments without requiring major changes.

The application of the adsorption technique in industrial settings faces several challenges and considerations, contributing to its limited widespread adoption. The main reason is the relative saturation and regeneration in the adsorption process, which hinders the wide application of the technology in industry. Adsorbents are materials that attract and retain molecules of other substances on their surface. In water treatment, adsorbents are often used to remove contaminants. However, these adsorbents have a finite capacity, meaning they can only adsorb a certain amount of contaminants before becoming saturated. Once an adsorbent is saturated, it must be replaced or regenerated to restore its adsorption capacity (Da Silva Santos et al., 2022b). Regeneration involves removing the adsorbed contaminants from the adsorbent, making it usable again. The regeneration process can be complex and often requires additional resources and energy.

On the other hand, competition and selectivity are also one of the reasons contributing to its limited widespread adoption. In adsorption, removing contaminants, such as dyes, relies on specific surface interactions between the adsorbent material and the molecules to be removed. This interaction involves binding molecules to the active sites on the surface of the adsorbent. Besides, non-target molecules or other contaminants in the wastewater may compete with the target dyes for the available adsorption sites (Rápó & Tonk, 2021). This competition can compromise the efficiency of the adsorption process, leading to reduced removal of the target contaminants. The selectivity of adsorption is determined by the affinity of the adsorbent for different molecules. If the adsorbent is not highly selective, it may adsorb various substances, making it less specific for the targeted dyes. The selectivity of adsorption is determined by the affinity of the adsorbent for different molecules. If the adsorbent is not highly selective, it may adsorb various substances, making it less specific for the targeted dyes. Therefore, the electrocoagulation (EC) technique is a good approach to overcome these limitations in adsorption technique.

2.3 Electrocoagulation (EC)

EC is a type of electrochemical procedure that uses metal ions produced by dissolving sacrificial electrodes to destabilize and remove pollutants from water or wastewater. It is a method of water treatment that combines coagulation and electrochemistry principles. Using EC, many organic and inorganic contaminants may be reduced easily and quickly. (Riyanto & Puspitasari, 2018). In EC, a pair of electrodes submerged in the water or wastewater to be processed receive a direct current (DC). Iron is often used as a material for electrodes. Metal ions are discharged into the water because the current flows through the electrodes. These metal ions function as coagulants, causing the colloids, suspended particles, and dissolved contaminants in the water to become unstable. The type of dyes and initial concentration are the typical operational parameters that affect the treatment efficiency of pollutants in wastewater.

EC has gained popularity and is widely applied in various industries for wastewater treatment due to several advantages and effective mechanisms. EC offers distinct advantages over the adsorption technique in terms of continuous generation of coagulant, broader applicability, and reduced waste. EC is an electrochemical process that uses an electric current to destabilize and aggregate suspended or dissolved particles in water. This process generates fresh coagulant in situ through the electrolysis of metal electrodes, usually aluminum or iron (Mahmoud et al., 2013). These coagulants play a role in removing contaminants by promoting the formation of flocs, which can be easily separated from water. As mentioned earlier, EC continuously generates fresh coagulant through electrolysis. This eliminates the saturation issue since there is a constant supply of coagulants, potentially reducing the need for frequent replacement or regeneration of adsorbents.

Furthermore, EC can treat a wider range of pollutants besides dyes, thanks to its charge-based mechanism, potentially simplifying treatment for complex wastewater streams. Unlike adsorption, EC does not rely on specific surface interactions between the contaminants and the treatment medium. Instead, it operates through charge neutralization within the bulk solution (Yasri et al., 2020). This means that the removal mechanism is not limited to specific adsorption sites on the surface of a material. Because EC acts within the bulk solution, it can address a broader range of pollutants without significant competition. The process is not as dependent on the specific characteristics of the removed molecules, making it more versatile in handling various contaminants in the wastewater.

2.3.1 Type of Dyes

The industrial production of textiles is a long and complex process where natural or artificial fibers are converted into yarn and fabrics. The increasing rise of hazardous dye wastewater generated by various industries is a serious public health issue and a huge environmental concern. Directly discharging untreated dye-containing wastewater into natural water bodies hurts aquatic ecosystem photosynthetic activity. Dyeing is a technique for enhancing material appearance by putting various colors and shades onto a fabric. Dyeing can be done at any stage of manufacturing textile-fiber, yarn, fabric, or a finished textile product. Dyes are chemicals that absorb and reflect light at specific wavelengths to provide color perception to the human eye (Azanaw et al., 2022).

Methyl orange (MO) and Rhodamine B (RhB) are synthetic dyes commonly used in the textile industry for coloring fabrics (Huang et al., 2008). While they serve aesthetic purposes in textile production, their discharge into wastewater can pose environmental hazards and harm aquatic life. MO is an azo dye belonging to synthetic dyes characterized by azo functional groups (–N=N–) (Pham et al., 2023). MO may exhibit toxicity to aquatic organisms when released into water bodies. This can negatively impact the health of aquatic life, such as fish and other organisms residing in the affected ecosystems (Verdeguer et al., 2020). Some azo dyes, including MO, can persist in the environment, resisting degradation over time. This persistence can prolong their environmental impact (Kubínová & Kyncl, 2021). MO imparts a distinct orange color to fabrics when used in the textile industry for dyeing. The discharge of wastewater containing this dye contributes to the coloration of water bodies, affecting their visual aesthetics.

RhB is a member of the rhodamine dye class, known for its vibrant pink-to-red color and fluorescence. Like many synthetic dyes, RhB can be toxic to aquatic life. Its discharge into water bodies may harm the organisms residing in these ecosystems (Baldev et al., 2013). There is a potential for bioaccumulation of RhB in the tissues of aquatic organisms. This accumulation can occur as the dye moves up the food chain, potentially impacting higher trophic levels. Like MO, using RhB in textile dyeing contributes to the visual impact on water bodies. Discharged wastewater can alter the color and appearance of rivers, lakes, and other aquatic environments.

Based on the research conducted in this project, many researchers have investigated the significance of treatment efficiency on wastewater containing MO and RhB separately by using the EC technique. However, no study currently compares the treatment efficiency between MO and RhB dye using the EC technique in a single experiment. Therefore, MO and RhB dyes were selected in this study to make a comparative study on the differences in the treatment efficiency of the two dyes. The type of dyes became a measure in this experiment to determine whether the performance of treatment efficiency depends on the type of dyes. Therefore, this experiment is conducted to investigate whether using different dyes through the EC technique will significantly change treatment efficiency.

2.3.2 Initial Concentration

A part of from type of dyes, the initial concentration of pollutants is another important key parameter. It plays a crucial role in assessing the effectiveness of treatment processes and evaluating the capabilities of different technologies. Therefore, initial concentration became an important parameter in this experiment to compare treatment efficiency between MO and RhB dye.

Initial concentration is a baseline measurement of the concentration of pollutants in the synthetic wastewater before treatment. This measurement is essential for understanding the extent of contamination and determining the effectiveness of the treatment process. The initial concentration of pollutants is crucial in determining the efficiency of synthetic wastewater treatment. According to Irki (2018), after 12 minutes of EC treatment, decolorization efficiencies of 71.11% and 60% for the initial concentrations of 25 and 55 mg/L increase gradually to 86.89% and 73.81% for 15 minutes. Therefore, through the data, it can be proven that initial concentration plays an important role in determining the efficiency of synthetic wastewater treatment.

In addition, the absorption of dye molecules onto metallic hydroxide flocs is a crucial mechanism in the electrocoagulation process for dye elimination. Metallic hydroxide flocs have a limited capacity for adsorption, meaning they can only adsorb a specific quantity of dye molecules. When the dye concentration increases, the formation of flocs becomes insufficient to adsorb all dye molecules, resulting in a decrease in dye removal effectiveness (Almaz Negash et al., 2023). Utilizing initial concentration data allows for the adjustment of parameters, such as dye types, to optimize treatment efficiency and cost-effectiveness. This information is essential for safeguarding the environment and ensuring the proper disposal of treated wastewater. The concentration of dyes in the effluent is known to vary (Iwaponline.com).

By understanding the impact of initial concentration of dye, researchers can develop and implement effective strategies for optimizing treatment processes, designing efficient systems, and maximizing the removal of pollutants. This knowledge is essential for protecting the environment and ensuring the safe disposal of treated wastewater.

2.3.3 Statistical Analysis

Statistical analysis plays a crucial role in assessing and interpreting the effectiveness of treatment methods for synthetic wastewater. It provides a robust framework for evaluating the reliability and significance of treatment results, enabling researchers to draw accurate conclusions and make informed decisions. This study's statistical analysis is performed to quantify the removal efficiency of different pollutants, including organic matter, nutrients, and specific dye molecules like MO and RhB. This is done by comparing initial and final concentrations and calculating various metrics like removal percentage, degradation rate, and color removal. For example, in adsorption studies, factors are the variables that can affect the adsorption process. These may include parameters like the initial concentration of adsorbate, temperature, pH, adsorbent dosage, and contact time. In adsorption techniques, which involve the adhesion of molecules or particles to a surface, a full factorial design analysis helps identify the significant factors and their interactions that influence the adsorption process (Montgomery, n.d.). This statistical analysis is also carried out to investigate whether the treatment efficiency of MO and RhB dye will change significantly.

In a study by Bassyouni et al. (2023), statistical analysis was employed to assess the treatment of real wastewater from the pulp and paper industry using electrocoagulation techniques. The investigation explored the influence of operational factors, including initial pH, current density, number of plates, and electrolyte concentration, on both percentage removal and power consumption. The findings indicated a positive correlation between color removal percentage and electrolysis duration, current density, sodium chloride concentration, and the number of electrodes. Statistical analysis, specifically central composite design from response surface methodology (RSM), was applied to interpret the experimental results, with a quadratic model deemed suitable due to a high coefficient of determination ($r^2 = 0.99$) and a statistically significant p-value (≤ 0.0002), suggesting the model's reliability. The study concluded that electrocoagulation, as a treatment method for paper mill effluents, exhibited superior efficacy compared to the adsorption technique. Overall, the statistical analysis provided valuable information indicating the influence of the studied treatment parameters on treatment efficiency.

2.4 Summary

The literature reviews provide an overview of textile wastewater and its treatment. Textile wastewater has many negative impacts on the environment. The selection of the EC method is based on its efficiency in removing contaminants from wastewater. This research found that the adsorption technique is commonly used to remove dye contaminants from wastewater. However, this method has many limitations. The EC technique was chosen to overcome these weaknesses. This experiment implements the EC technique using stainless steel electrodes with different dyes, MO and RhB dye, separately. This experiment consists of two parameters: type of dyes and initial concentration. These parameters are used to study whether the performance of treatment efficiency depends on the type of dyes and its initial concentration and to identify the effectiveness of the EC technique in removing impurities in wastewater.

CHAPTER 3

MATERIAL AND METHOD

3.1 Research Flow

Three stages were involves in the research flow chart. Stage 1 involves the preparation of the materials, Stage 2 is the electrocoagulation treatment process, and Stage 3 involves the analysis, evaluation, and comparison of the obtained experimental data, as shown in Figure 3.1.

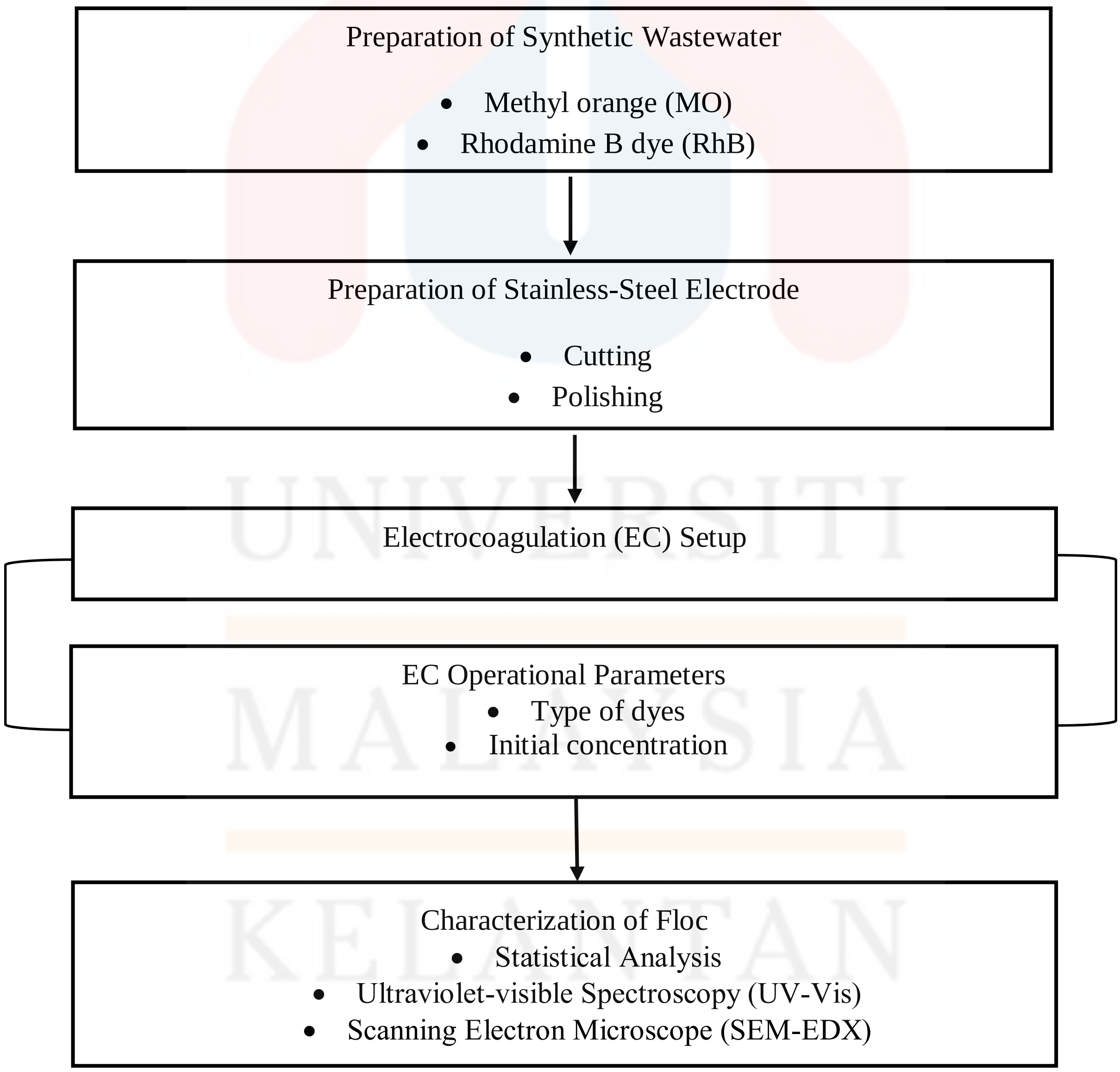

Figure 3.1: Research flow for Electrolysis research project

3.2 Synthetic Wastewater

The 0.5g of Methyl orange (MO) powder is used to make the concentration of 1000 ppm for the stock for 500 ml synthetic wastewater. The powder is poured into the 1L beaker with 500 ml of deionized water. It was mixed using the digital magnetic stirrer with a heat of 50°c and speeds of 800, 500, and 1000 for 15 minutes. The steps are being repeated for the Rhodamine B (RhB) dye synthetic wastewater.

3.2.1 Electrocoagulation (EC) Setup

Synthetic wastewater containing MO and RhB dye is utilized. When experimenting, we will be going back to the findings of Bajpai et al. (2021). The EC reactor tank will be a 1L cylindrical glass beaker manufactured from borosilicate glass. The diameter of the electrode rods being researched is 10mm, and the studied materials are Stainless Steel (Fe) rods. The quality of electrodes is more than 98%. To minimize electrical resistance, the space between the anode and cathode electrodes is kept at a constant 3cm. The regulated DC power supply will generate the electrical potential, which has a voltage range of 0-30 V and a current range of 0-40 A. The following parameters will be varied during the experiments:

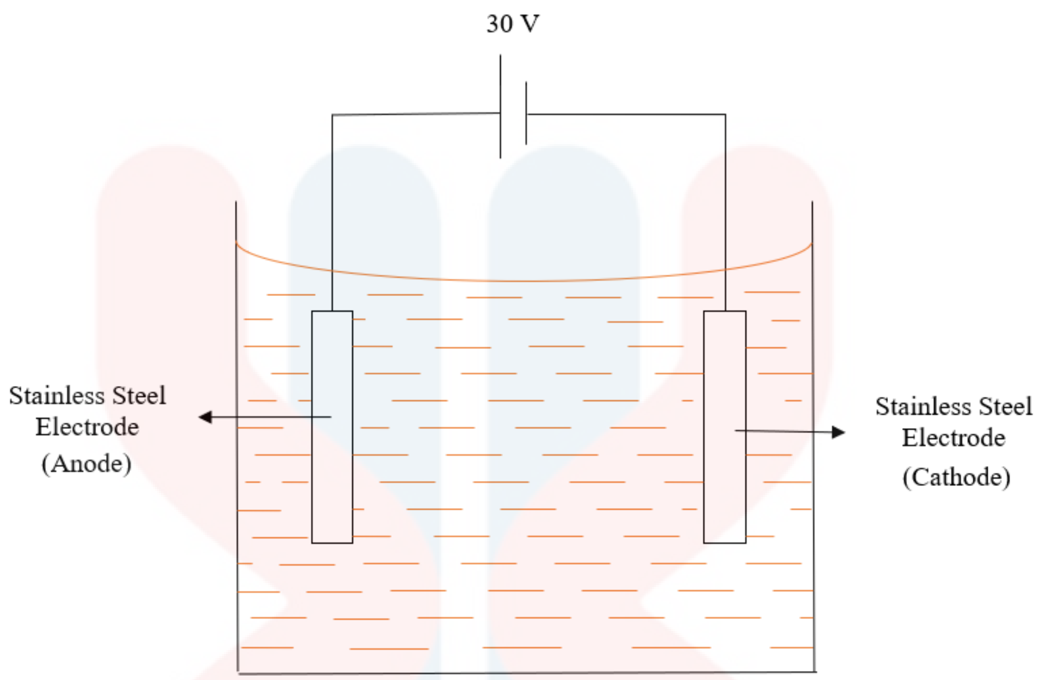

Figure 3.2: The electrocoagulation (EC) setup for MO dye wastewater

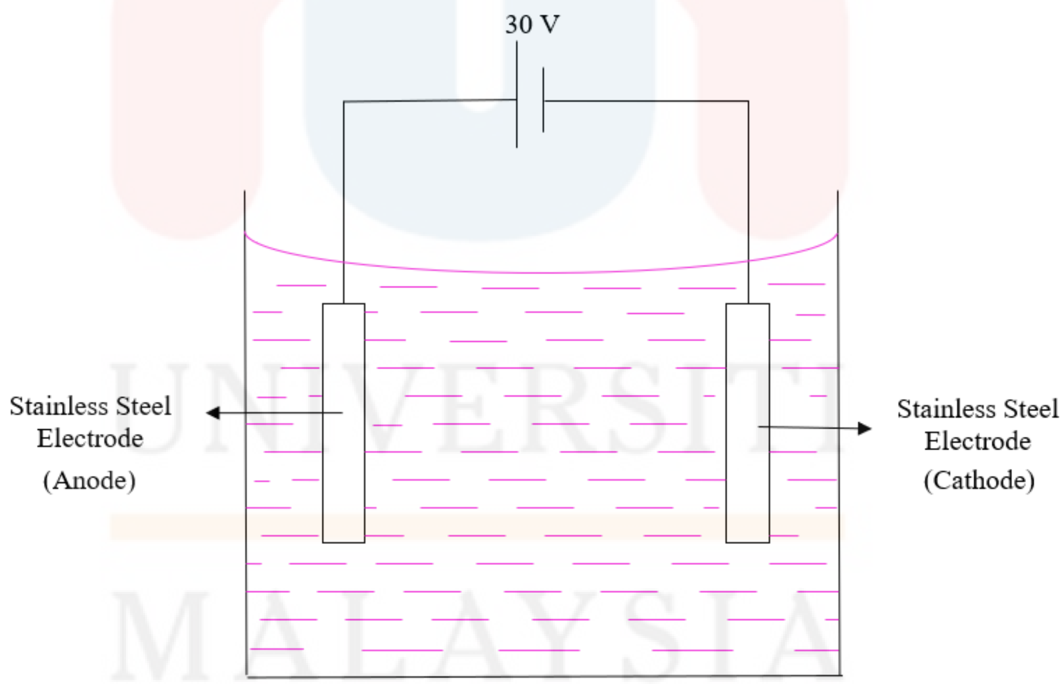

Figure 3.3: The electrocoagulation (EC) setup for RhB dye wastewater

In general, the effectiveness of EC treatment for contaminants in wastewater depends on operational factors such as the type of dyes and the initial concentration.

3.2.2 Type of dyes

In this study, MO and RhB dye were chosen to be made of synthetic wastewater. It is intended to compare the differences in the treatment efficiency of the two dyes. The type of dyes became a measure in this experiment to determine whether the performance of treatment efficiency depends on the type of dyes.

3.2.3 Initial Concentration

The initial concentration can be defined as treatment objectives, such as making regulatory compliance or minimizing pollutant concentrations. The treatment goals determine the initial concentration selection and the overall design of the electrocoagulation procedure. Research must be conducted to identify the best beginning concentration for the given water matrix and pollutants. The research can provide useful information on the system's performance in real-world settings.

Table 3.1: Value of Concentration standard Solution

Stock solution (1000 ppm)	Concentration Standard Solution (ppm)	Volume Standard Solution (L)	Volume from 1000 ppm (mL)
1000	100	0.05	5
1000	500	0.05	25
1000	10	0.05	0.5
1000	20	0.05	1
1000	30	0.05	1.5
1000	40	0.05	2
1000	50	0.05	2.5
1000	60	0.05	3

After treating wastewater containing the MO and RhB dye color, the statistics analysis is run before the UV-vis spectroscopy to get more accurate results later. The UV-vis spectroscopy will assess the degree to which the dye has degraded precisely.

Equation V: Treatment Efficiency of Dye

$$\text{Treatment efficiency (\%)} = \frac{c_i - c_f}{c_i}$$

C_i is the initial degradation of MO dye-color wastewater, and C_f is the degradation after each treatment, evaluated by UV-vis. After EC, floc was collected by filtration and then put in the oven for drying at 60°C.

3.2.4 Statistical Analysis

In this study, Minitab16 was used to analyze the comparative treatment efficiency of the EC technique between MO and RhB dye. It consists of an experimental design matrix, model adequacy checking, analysis of variance (ANOVA), and main effects and interaction plots. This statistical analysis is performed to quantify the removal efficiency of different pollutants, including organic matter, nutrients, and specific dye molecules like MO and RhB dye. This is done by comparing initial and final concentrations and calculating various metrics like removal percentage, degradation rate, and color removal. This statistical analysis is also carried out to investigate whether the treatment efficiency of MO and RhB dye will change significantly.

CHAPTER 4

RESULT AND DISCUSSION

4.1 General Full Factorial Design (GFFD)

The General Full Factorial Design (GFFD) is a crucial statistical experimental design strategy used to systematically analyze variables' main effects and interactions at different levels. When applied to electrocoagulation (EC) wastewater treatment, it allows for a comprehensive assessment of the influence of various parameters on pollutant elimination. In this experimental framework, different types of dye and their initial concentrations are systematically varied to understand their effects and correlations. A general multilevel factorial design with two independent variables (factors A and B) is employed to statistically evaluate the impact of operating factors on types of dye and initial concentration. Factor A represents types of dye (coded as '1' and '2'), while Factor B represents the initial concentration of dye (coded as '1' and '2'). The objective is to compare the EC treatment efficiency for synthetic wastewater containing Methyl orange (MO) and Rhodamine Blue (RhB) dyes using stainless steel electrodes. This analysis aims to establish correlations between types of dyes and initial dye concentration concerning wastewater treatment efficiency, utilizing the statistical software package MINITAB 16. Various statistical analyses, including analysis of variance (ANOVA), normal probability plot, residual versus fit plot, main effects plot, and interaction plot, were conducted as part of the experimental design.

4.1.1 Experimental Design Matrix

Table 4.1 shows the experimental design matrix and the responses obtained from 12 random experimental runs conducted in two rounds of applications. As mentioned earlier, coding was employed to represent the quantity or range of each examined element on a standardized scale, with '1' representing factor A and '2' representing factor B. Subsequently, a set of statistical analyses was carried out for each response, including ANOVA, normal probability plot, residual versus fits plot, main effects plot, and interaction plot. The results of these analyses are presented in Figures 4.1, 4.2, and 4.3.

Table 4.1: Experimental design matrix for electrocoagulation wastewater treatment design (including values for all responses)

	Factor		Response
Run Order	**Types of Dye**	**Initial Concentration of Dye (ppm)**	**Treatment Efficiency (%)**
1	Methyl Orange	2	89.66
2	Rhodamine Blue	2	98.68
3	Methyl Orange	2	89.43
4	Methyl Orange	2	89.70
5	Methyl Orange	1	47.15
6	Methyl Orange	1	45.54
7	Methyl Orange	1	45.00
8	Rhodamine Blue	1	93.56
9	Rhodamine Blue	2	98.72
10	Rhodamine Blue	2	98.72
11	Rhodamine Blue	1	93.20
12	Rhodamine Blue	1	93.21

*For factor 'A' (types of dyes), '1' and '2' represent treatment efficiency, respectively.

*For factor 'B' (initial concentration of dye), '1' and '2' represent treatment efficiency, respectively.

4.1.2 Model Adequacy Checking

Assessing adequacy is a crucial step in statistical modelling and experimental design, involving determining whether a chosen model accurately captures the underlying patterns in observed data (Jun Zhang et al., 2014). In this context, the observed response values were obtained from the experiment, as presented in Table 4.1, while the expected response values were derived from an equation developed through regression analysis. The evaluation of assumptions includes checking for (i) the normality of residuals, (ii) the constancy of residual variance, and (iii) the independence of residuals. A comprehensive assessment of model adequacy entails identifying significant data points or outliers, considering the assumption of residual independence, and conducting overall model diagnostics. Various statistical residual plots, such as the normal probability plot of residuals, the histogram of frequency versus residuals, the plot of residuals versus fitted or predicted values, and the plot of residuals in chronological or observational order, can be utilized to validate the three assumptions.

The residual plots for electrocoagulation wastewater treatment efficiency are depicted in Figure 4.1. Upon analyzing the normal probability plots, it was observed that most residual points deviate slightly from the straight line. However, the data for treatment efficiency exhibited a normal distribution, meeting the first criterion for assessing model adequacy. Additionally, the histogram plot indicated an asymmetrical distribution of the histogram bars.

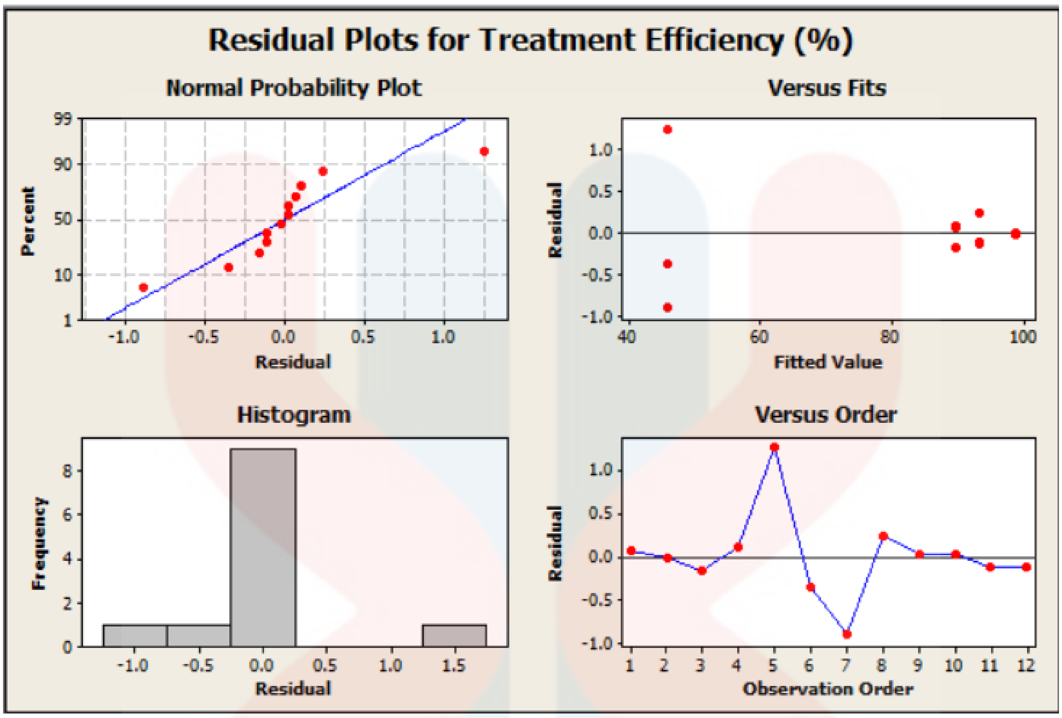

Figure 4.1: Residual plots for treatment efficiency; (i) Normal probability plot, (ii) Histogram of frequency versus residual, (iii) Residual versus fit, (iv) Residual versus observation order of data

Furthermore, according to residual versus fitted value graphs, treatment efficiency allocation was randomized to preserve a constant residual variance. Moreover, the residual points' symmetrical reflection suggests they are in equilibrium. The residual compared to the observation order shows that all the residual points are there, regardless of the observation order. As per the third assumption, this also implies that the residuals were independent.

4.1.3 Analysis of Variance (ANOVA)

The analysis of variance (ANOVA) method is frequently employed in statistical experimental design to evaluate the significant influence of operational parameters on the properties or responses of a particular manufactured product or application. In this context, ANOVA determines the notable effects of dye types and initial dye concentration on treatment efficiency. This assessment involves calculating the probability value, commonly known as the 'p-value.' The experimental design and data analysis were conducted using MINITAB 16 Statistical Software. The p-value is crucial in confirming the statistical hypothesis for a given model. When examining a statistical hypothesis for a specific model, the p-value, or probability value, signifies the likelihood that the statistical summary will be as extreme as or more extreme than the observed results, assuming the null hypothesis is true. This summary could represent, for instance, the absolute mean difference between two groups in the sample. The p-value needs to be less than 0.05. A smaller p-value offers more compelling evidence to reject the null hypothesis. Consequently, it was demonstrated that the quadratic model holds statistical significance.

Table 4.2 shows the ANOVA results for the effectiveness of electrocoagulation in wastewater treatment.

Table 4.2: ANOVA for treatment efficiency

Source	P-value
Types of Dye	0.000
Initial Concentration of Dye	0.000
Types of Dye * Initial Concentration of Dye	0.000

According to the table, the initial dye concentrations set at 100 ppm and 500 ppm, yielded a p-value of 0.000, falling below the significance threshold of 0.05. Treatment efficacy is demonstrated to vary based on the initial concentrations—specifically, 100 ppm and 500 ppm. Altering the starting concentration significantly impacts treatment efficiency when using a single dye type. The study found that the types of dye and the initial dye concentration, treated as linear factors for treatment effectiveness, have a p-value of 0.000 each, indicating statistical significance below 0.05. This compelling evidence contradicts the null hypothesis, supporting the alternative hypothesis. A lower p-value suggests a stronger association between variables. The statistical significance implies that the null hypothesis is improbable, indicating that the types of dye and initial dye concentration influence treatment efficiency. Therefore, the null hypothesis is rejected in favor of the alternative hypothesis. Further investigations are required to understand the reasons behind these significant findings.

4.1.4 Main Effect and Interaction Plots for Treatment Efficiency

Main effects plots illustrate how factors with varying levels influence changes in a specific response. As previously discussed, in this comprehensive factorial design, the primary factors under consideration were the types of dye and the initial dye concentration. Concurrently, interaction plots depict the joint impact of both main factors, each with distinct levels, on the specific response, namely treatment efficiency.

Figure 4.2 and Figure 4.3 shows the main effect and interaction plots illustrating the impact of individual components or parameters and their combined influence on treatment efficiency.

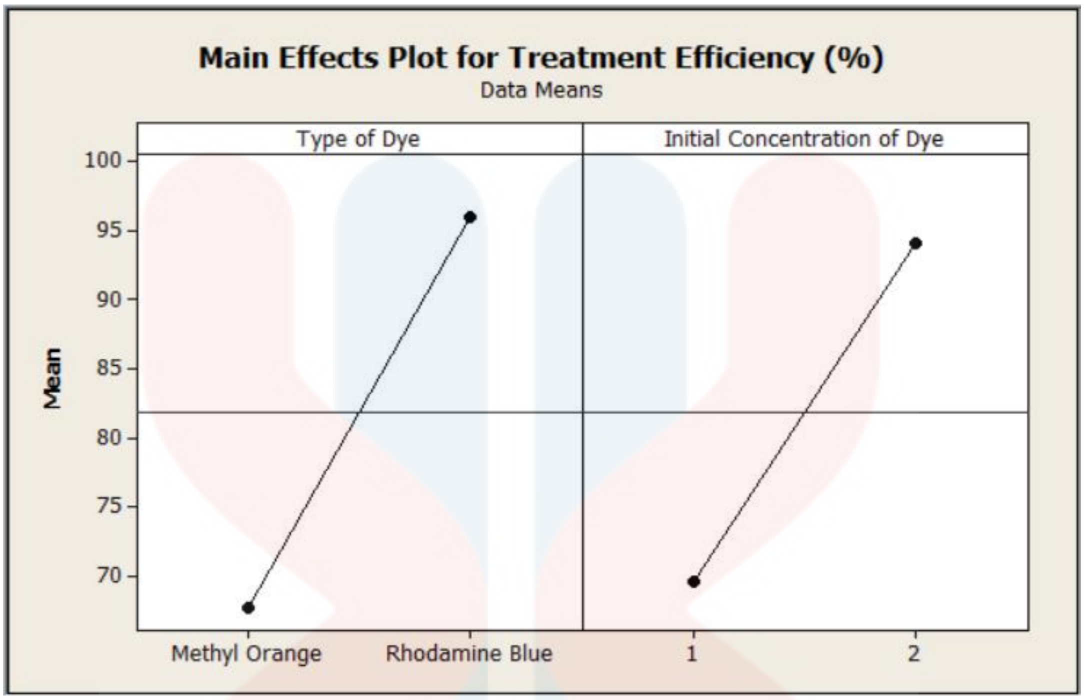

Figure 4.2: Main effect plot for treatment efficiency.

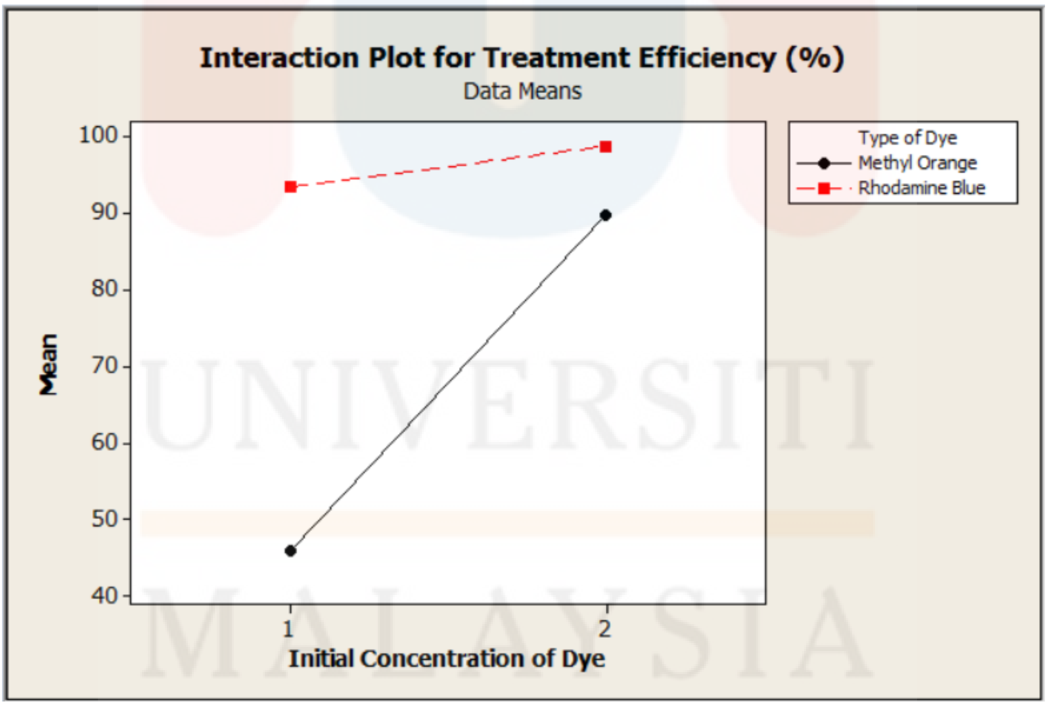

Figure 4.3: Interaction plot for treatment efficiency.

The first plot focuses on the influence of different types of dye, while the second plot examines the effect of initial concentration. This graph effectively captures the combined impact of both components. Transitioning from MO dye to RhB dye results in an overall improvement in treatment effectiveness for RhB dye, surpassing that of MO dye. Notably, the treatment efficiency for RhB dye remains consistently higher regardless of the initial concentration.

In contrast, the interaction plots in Figure 4.4 concurrently incorporate both components. At an initial concentration of 100ppm, treatment efficiency for MO is relatively low, while RhB dye exhibits higher efficiency than MO dye. Furthermore, the treatment efficiency for MO dye is higher at an initial concentration of 500ppm than at an initial concentration of 100ppm. However, according to RhB dye's treatment efficiency, when the initial concentration is 500ppm, RhB dye's efficiency surpasses that of MO. The non-parallel lines in the graph indicate varying gradients, suggesting interdependence between the two elements (Li et al., 2022). This underscores the significance of the combined impact of both factors on treatment efficiency.

4.1.5 Contour Plot

Contour plot is a graphical representation of the regression model, showing prediction of responses (treatment efficiency) according to desired factors (types of dye and initial concentration). The contour plots for types of dye and initial concentration are shown in Figure 4.3. It could be observed that all the contour plots consisted of contour or curve lines. This further support the presence of interaction between the types of dye (factor A) and initial concentration (factor B).

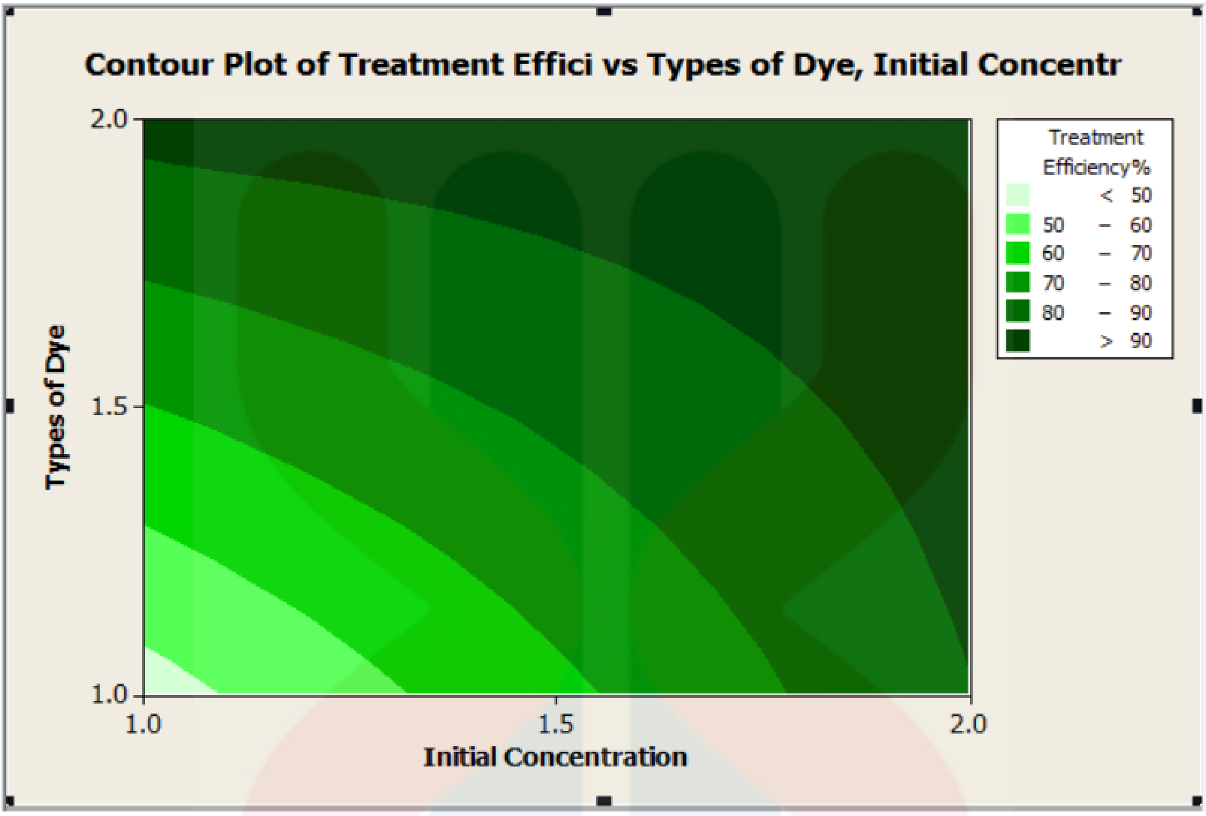

Figure 4.4: Contour plot for treatment efficiency

Figure 4.4 show the colored lines represent different levels of treatment efficiency. The color legend on the right side of the plot indicates the percentage of treatment efficiency for each contour color. For example, light green corresponds to 60-70% efficiency, green to 70-80% efficiency, and dark green to 80-90% efficiency. The contour plot exhibited a series of contour lines, which were either straight or curved. This provides more evidence for the existence of the type of dyes (with 1.0 is MO and 2.0 is RhB) and the initial concentration of dye (with 1.0 is 100 ppm and 2.0 is 500 ppm). From the contour plots, it was predicted that treatment efficiency generally increases with increasing initial dye concentration for dye types. This suggests that the treatment process is more effective at higher concentrations.

This study's targeted treatment efficiency is set at a maximum of 90%. Figure 4.4 indicates that the darkest colored area, representing a treatment efficiency of 90%, corresponds to RhB dye at an initial concentration of 500 ppm. Consequently, the optimal treatment efficiency is achieved when utilizing an initial concentration of 500 ppm for RhB dye. Figure 4.4 show that the treatment efficiency for MO is lower compared to RhB, ranging between 50% and 60%. This suggests that the treatment is more effective for RhB dye than MO, irrespective of the initial concentration.

Therefore, a comprehensive full factorial design allows for identifying influential parameters, such as the initial concentration, in UV-Vis spectra or analyte response. This facilitates targeted optimization efforts towards key factors. Through systematic exploration of various factor combinations, optimal settings can be pinpointed to achieve heightened sensitivity, selectivity, or repeatability in UV-Vis measurements. The results of the design yield mathematical models that accurately predict reactions based on specific factor settings, enhancing precision and reliability.

4.2 Treatment Efficiency

4.2.1 UV-vis Analysis of Treated Dye Synthetic Wastewater

UV-Vis spectroscopy is crucial for quantitatively assessing concentrations of absorbing species while treating synthetic wastewater containing Methyl orange dye (MO) and Rhodamine B dye (RhB). The Beer-Lambert Law proves to be a valuable method for estimating the initial concentration of a substance in a solution, as it establishes a relationship between absorbance and concentration. A thorough understanding of UV-Vis analysis greatly aids in predicting and controlling outcomes, ensuring reliable and precise measurements. This proficiency allows for the customization of UV-Vis protocols tailored to specific samples or conditions, leading to savings in time and resources. UV-Vis procedures ensure precise results, even with slight variations in experimental factors. Figure 4.5 and Figure 4.6 depict the concentration of the synthetic wastewater.

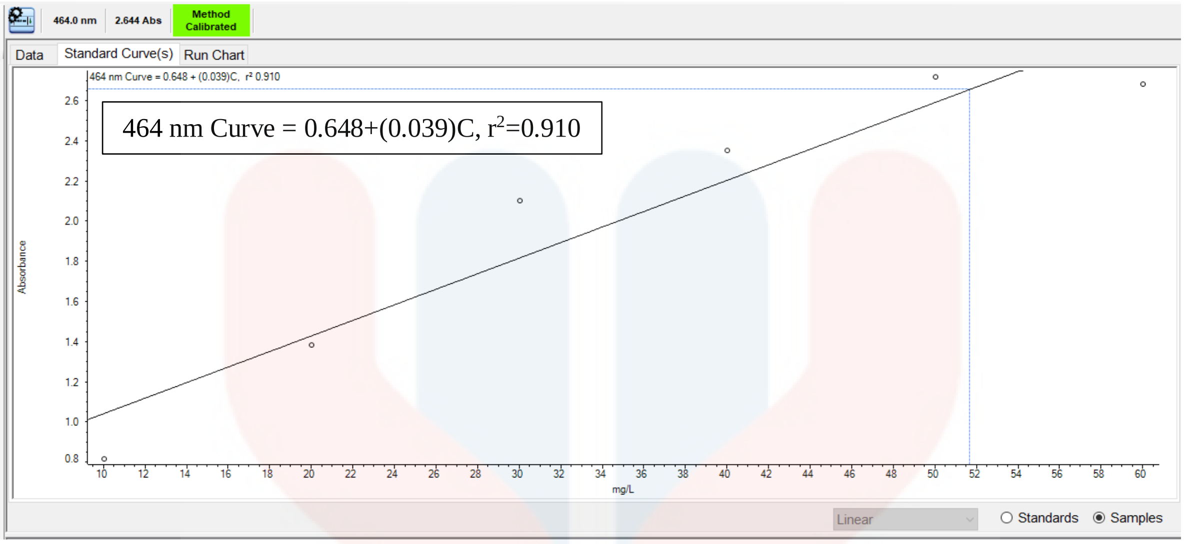

Figure 4.5: The concentration treatment of the synthetic wastewater containing Methyl orange dye (MO)

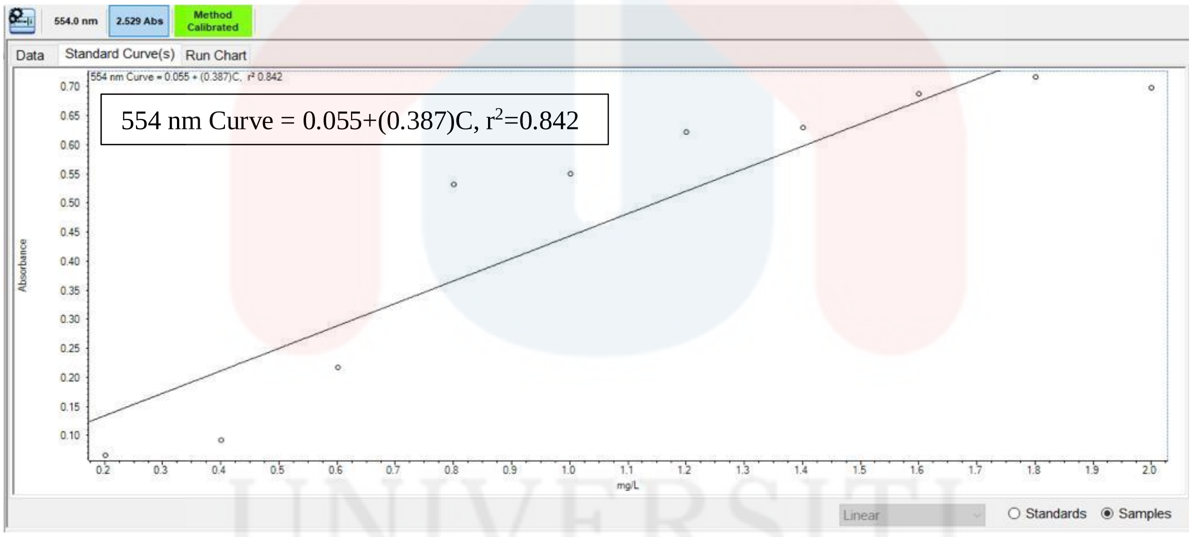

Figure 4.6: The concentration treatment of the synthetic wastewater containing Rhodamine B dye (RhB)

Figures 4.5 and 4.6 depict a direct correlation between dye concentration and absorbance, suggesting the efficiency of the electrocoagulation (EC) process in eliminating dye from wastewater. Analyzing absorbance at 464 nm (Figure 4.5) and 554 nm (Figure 4.6) allows a best-fit line to determine dye concentration in wastewater samples. The equation for the 464 nm curve is 0.648 + (0.039) C, with an r^2 value of 0.910. In comparison, the equation for the 554 nm curve is 0.055 + (0.387) C, with an r2 value of 0.842 (Chong et al., 2024), providing evidence of the EC technique's effectiveness in removing MO and RhB dyes from synthetic wastewater. The linear relationship between dye concentration and absorbance suggests an efficient and predictable removal process. However, it is important to note that real wastewater results may vary due to its complexity and diversity compared to synthetic wastewater.

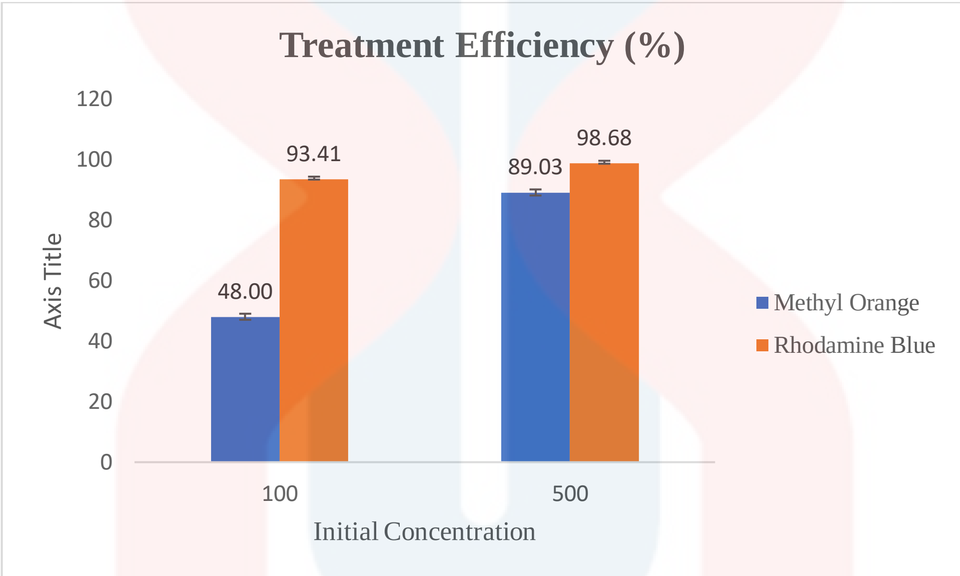

Figure 4.7: The treatment efficiency of MO and RhB dyes (%)

Figure 4.7 shows the EC technique's effectiveness in treating MO and RhB dyes in wastewater. At the highest current density (2 mA/cm²), the removal efficiency for both dyes surpasses 90%, suggesting the potential of EC as an efficient method for treating wastewater containing these specific color dyes. The treatment efficacy for both dyes improves with increasing current density, as higher current density generates more coagulant ions, effectively eliminating a larger quantity of dye molecules from the wastewater (Khan et al., 2023). However, it is important to note that excessively high current density may lead to increased energy consumption and electrode degradation. The data also indicates that the treatment effectiveness for RhB is slightly superior to that of MO across all current densities, possibly due to differences in the chemical characteristics of the two dyes—RhB being cationic and MO being anionic. EC is particularly effective in eliminating cationic dyes compared to anionic dyes. Additionally, it's essential to emphasize that this study was conducted using a synthetic wastewater solution, and the results may not directly apply to real wastewater, which can be more complex and include a diverse range of additional pollutants.

In addition, the efficiency of the EC treatment process was assessed by treating dye solutions with varying initial concentrations of 100 ppm and 500 ppm. As depicted in Figure 4.7, the results indicate that the treatment efficiency for MO and RhB improves with increasing initial concentrations. Specifically, for MO, the treatment efficiency reaches approximately 50% at an initial concentration of 100 ppm and rises to around 80% at 500 ppm. Conversely, RhB exhibits a treatment efficiency of about 80% at an initial concentration of 100ppm and more than 90% at 500ppm (Irki, 2018b). These findings suggest that the treatment efficiency of RhB surpasses that of MO, whether at an initial concentration of 100ppm or 500ppm.

In summary, the data suggests that EC holds significant promise as an effective method for treating wastewater containing dyes such as MO and RhB. The detailed analysis of UV-Vis results obtained from the MO and RhB dye wastewater treatment is further substantiated by the complementary EDX results, enhancing the precision and reliability of the characterization of the treatment efficiency.

4.2.2 EDX Analysis of Floc Generated during Treatment

Figure 4.8 show the schematic of floc generated on MO and RhB dye after wastewater treatment by EC technique.

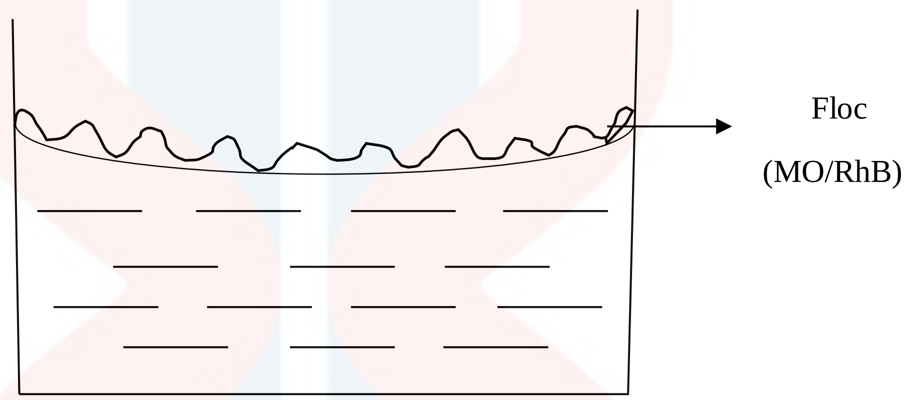

Figure 4.8: The floc after wastewater treatment MO / RhB dyes

During the electrocoagulation (EC) treatment process, floc formation is observed. A floc is a mixture of solidified small particles in a liquid or solution. It typically takes the form of enormous amounts or a cloud-like structure. The presence of flocs is crucial for removing suspended particles and contaminants. This mechanism leads to the development of larger flocs, facilitating easier settling or more efficient filtration. As illustrated in Figure 4.8, the image depicts the floc generated post-wastewater treatment of MO and RhB dyes.

Figures 4.9 and 4.10 show the floc generated of MO and RhB dye after wastewater treatment by EC technique at initial concentration 100ppm and 500ppm.

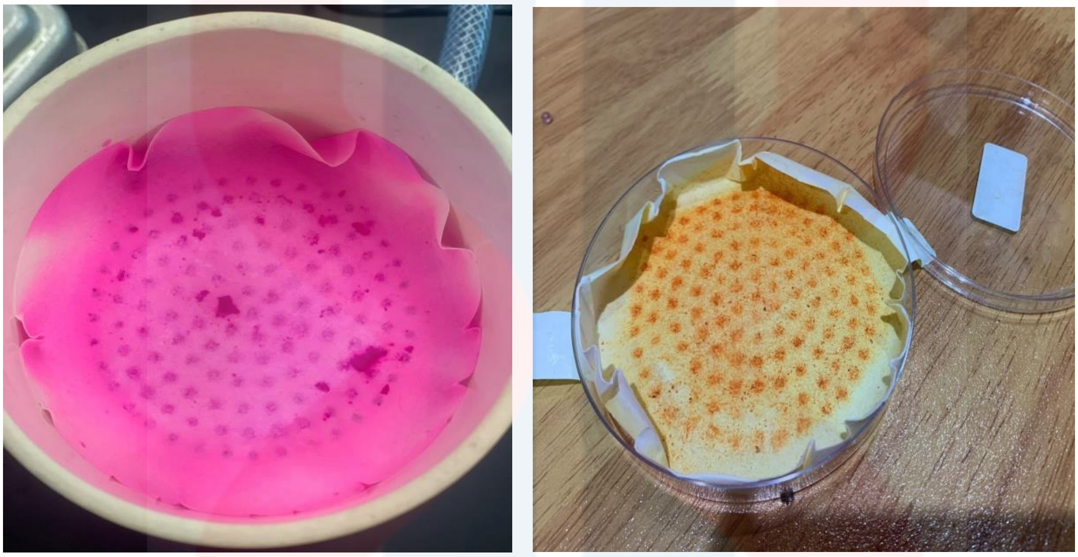

Figure 4.9: The floc generated after wastewater treatment of MO and RhB dyes at 100 ppm.

Figure 4.10: The floc generated after wastewater treatment of MO and RhB dyes at 500 ppm.

Figure 4.9 and Figure 4.10, shows the production of flocs during the wastewater treatment process, as the stainless-steel reaction efficiently attracts negatively charged contaminants such as phosphate and organic materials. Additionally, a higher current density accelerates the floc production rate; however, this may lead to the formation of smaller and less stable flocs with inferior settling characteristics (Zhang et al., 2023). Upon examination of Figures 4.9 and 4.10, the visual assessment of the generated floc appears consistent in color and powder shade between initial concentration 100 ppm and 500 ppm. Nevertheless, it is essential to acknowledge that the composition may vary due to the differences in experimental parameters. As indicated in the De Lange et al. (2023), alterations in testing parameters can impact treatment efficiency and result in different floc compositions. To substantiate this claim, an EDX analysis has been conducted.

The chosen samples for this analysis comprised wastewater treated with MO dye (initial concentrations of 100 ppm and 500 ppm) and RhB dye (initial concentrations of 100 ppm and 500 ppm). This selection was made to investigate the treatment efficiency morphology across different dye types and initial concentrations. The elemental composition identified by EDX analysis of the wastewater floc directly correlate the potential functional groups and organic compounds revealed by the UV-vis analysis, providing a more comprehensive understanding of the treated wastewater's composition and treatment efficiency. Figures 4.11 show the morphology of treatment efficiency using EDX.

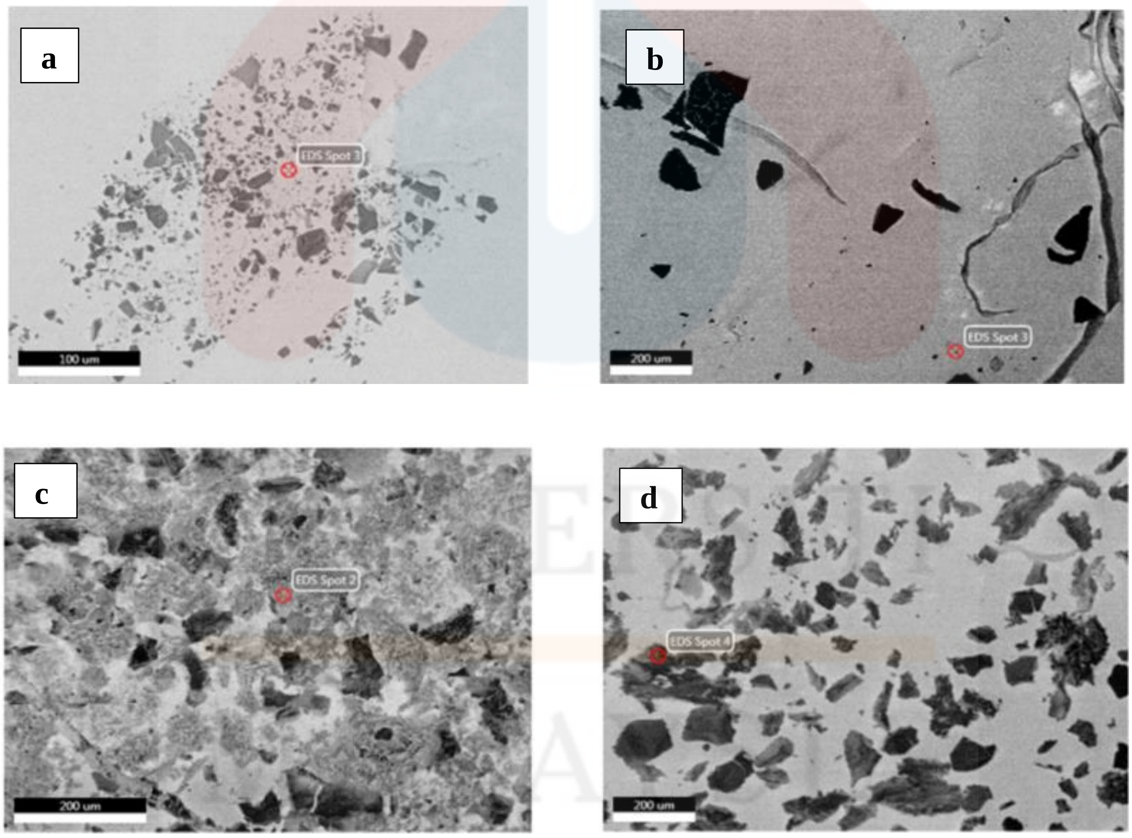

Figure 4.11: EDX images of wastewater treatment with (a) MO at 100ppm initial concentration, (b) RhB at 100ppm initial concentration, (c) MO at 500ppm initial concentration, and (d) RhB at 500ppm initial concentration

Tables 4.3, 4.4, 4.5, and 4.6 lists the quantitative composition for atomic (At) and weight (Wt) percentage of the elements in the floc generated by EC.

Table 4.3: Quantitative composition of the elements presents in the floc generated by EC for MO at 100 ppm.

Element	Fek	OK	CK	NK	NaK	SK
Weight%	46.16	37.51	0.03	0.02	16.27	0.00
Atomic%	21.29	60.38	0.07	0.04	18.23	0.00

Table 4.4: Quantitative composition of the elements presents in the floc generated by EC for RhB at 100 ppm.

Element	Fek	OK	CK	NK	ClK	SK
Weight%	16.91	54.59	0.14	0.08	0.00	0.10
Atomic%	6.10	68.78	0.24	0.11	0.00	0.06

Table 4.5: Quantitative composition of the elements presents in the floc generated by EC for MO at 500 ppm.

Element	Fek	OK	CK	NK	SK
Weight%	35.21	18.44	0.08	0.05	36.98
Atomic%	20.15	36.84	0.021	0.11	36.87

Table 4.6: Quantitative composition of the elements presents in the floc generated by EC for RhB at 500 ppm.

Element	Fek	OK	CK	NK	ClK	SK
Weight%	55.25	28.63	0.01	0.01	0.19	3.15
Atomic%	31.62	57.19	0.02	0.01	0.17	3.14

The EDX analysis of the surface of the flocs formed after the EC treatment shows the quantitative composition of the elements present in the floc (Table 4.3, 4.4, 4.5, and 4.6) with the levels of major elements of iron and oxygen. Table 4.3 shows the levels of the major composition of the elements present in the floc generated by EC for MO at 100 ppm were iron at 46.16wt%, oxygen at 54.59wt%, and atrium at 16.27wt%, as well as nitrogen, carbon, and sulfur, were detected as minor elements with 0.03wt%, 0.02wt% and 0.00wt% respectively. While for RhB dye (Table 4.4), the levels of the major composition of the elements present in the floc generated by EC at 100ppm were iron at 16.91wt% and oxygen at 54.59wt%, as well as carbon, nitrogen, chlorine, and sulfur, were detected as minor elements with 0.14wt%, 0.08wt%, 0.00wt% and 0.10wt% respectively.

Table 4.5 show the quantitative composition of the elements in the floc generated by EC for MO at 500 ppm. Iron, oxygen, and sulfur were the major elements in the floc generated by EC treatment. The weight percentage of each element was 35.21wt%, 18.44wt%, and 36.98wt%, respectively. Carbon with 0.08wt% and nitrogen with 0.05wt% were detected as minor elements. Meanwhile, for RhB dye at 500ppm (Table 4.6) shows the levels of the major composition of the elements were iron at 55.25wt%, oxygen at 28.63wt%, as well as carbon and nitrogen at 0.01wt%, chlorine at 0.19wt% and sulfur at 3.15wt%, were detected as minor elements.

The tables above show the EDX results with several peaks corresponding to different elements. Approximately results are obtained by Irki (2018c). The strongest peaks are labeled as Fe, the main components of stainless steel. So, Fe has the highest peak. This suggests that the EDX analysis was performed on the stainless-steel electrode after electrocoagulation. The oxygen element in the floc could be from the oxide layer on the stainless-steel electrode surface or adsorbed organic compounds from the wastewater. The carbon element could be from organic contaminants in the wastewater or the decomposition of MO and RhB during electrocoagulation. For sulfur, this could be from sulfate ions in the wastewater, which can be reduced to sulfide during electrocoagulation.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

At the end of this research work, the electrocoagulation (EC) process has been found effectively to treat contaminants from wastewater. The study aimed to examined the comparative of EC treatment efficiency on synthetic wastewater containing Methyl orange (MO) and Rhodamine B (RhB) dye using stainless steel electrode. The study revealed that several factors, including type of dyes and initial dye concentrations significantly affected the percentage of treatment efficiency. Specifically, it was determined that the highest percentage of treatment efficiency was achieved at 500ppm for RhB dye compared to MO. The utilization of General Full Factorial Design (GFFD) for experimental design has been found to be an effective approach to improve the type of dyes and the initial concentration to enhance the effectiveness of wastewater treatment. Several conclusions were made based on the result presented and discussed in Chapter 4:

(a) Electrocoagulation (EC) treatment utilizing stainless steel electrodes demonstrates higher efficacy in treating synthetic wastewater containing Rhodamine Blue (RhB) dye compared to Methyl Orange (MO).

(b) There is a correlation between the type of dyes and the initial concentration of the dye. The effectiveness of wastewater treatment increases as the starting concentration of a certain color decreases.

5.2 Recommendation

Based on the results, future research can focus on scaling up the electrocoagulation process for treating synthetic wastewater containing Methyl orange and Rhodamine B dye using stainless steel, conducting a comparative study. Further exploration of using aluminum electrodes for sustainable wastewater treatment is also recommended. This is prompted by the fact that the stainless steel electrode employed in this research has a current of 2+ (Fe2+), while the aluminium electrode has a current of 3+ (Al3+). Therefore, further investigation into the electrocoagulation treatment of synthetic wastewater containing Methyl orange and Rhodamine B dye using aluminium electrodes with higher current density should be undertaken to determine if the treatment efficiency obtained is superior to that achieved using stainless steel electrodes, as already explored in this research. Another recommendation in this research is to employ higher dye concentrations and longer treatment times. This recommendation is intended to assess whether the treatment efficiency improves with increased dye concentration, extended treatment duration, and higher voltage levels.

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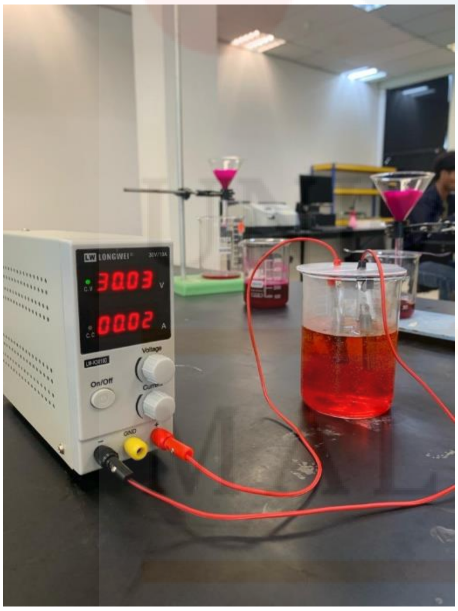
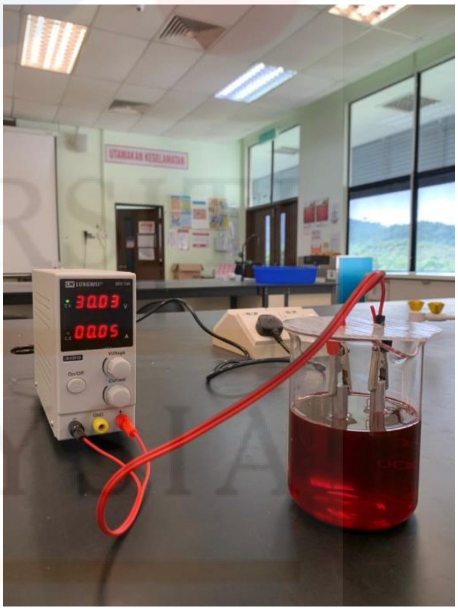
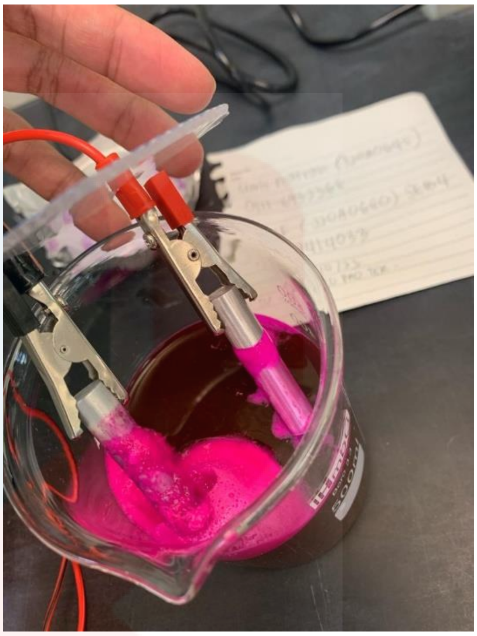
APPENDIX A

Apparatus and preparation of electrode for electrocoagulation process

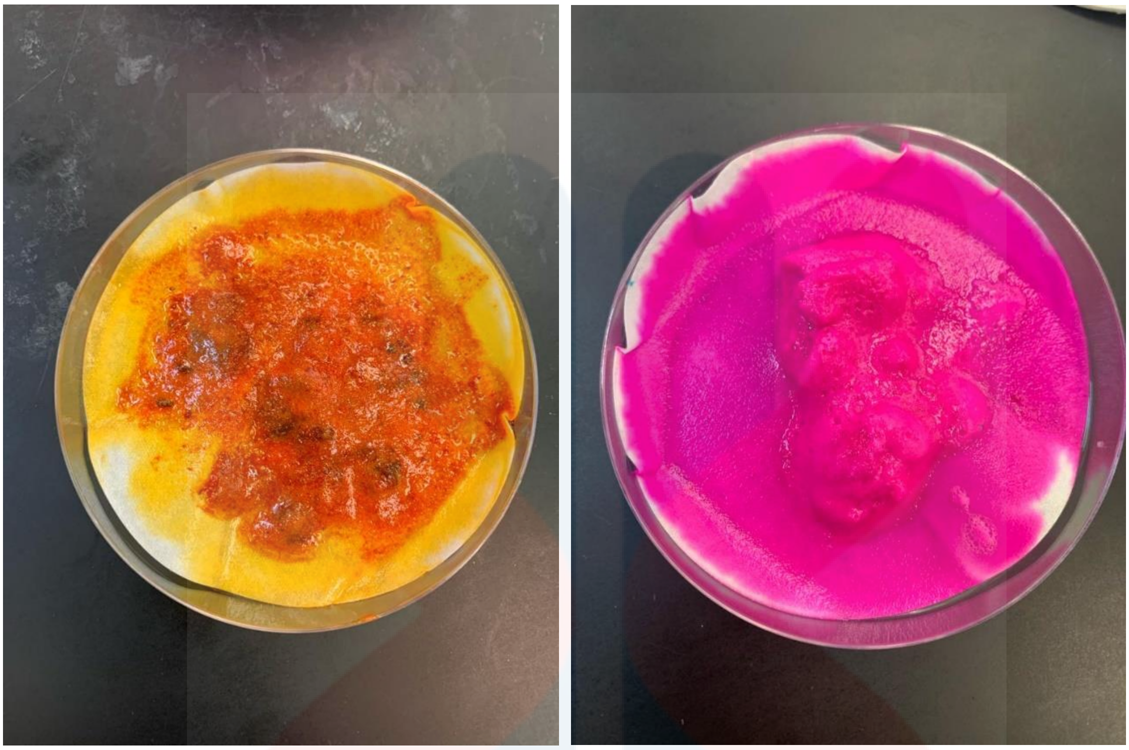




Electrocoagulation process of synthetic wastewater treatment containing Methyl orange and Rhodamine B dye using Stainless steel electrode



Floc filteration after the electrocoagulation process



Floc generated by electrocoagulation process.