The Effect of Electric Voltage Variation and Flow Rate on Decreasing Remazol Red Rb 133 Dye Levels in a Continuous Electrocoagulation Process

Meutia Nurfahasdi[1*], *Seby* Sabrina[1], *Amir* Husin[1], *Kartini Noor* Hafni[1], *Novrida Harpah* Hasibuan[1], *Abdugani* Rakhmatov[2], *Matluba* Turayeva[3], *Shirin* Yuldosheva[4]

[1]Department of Environmental Engineering, Faculty of Engineering, Universitas Sumatera Utara, Sumatera Utara 20155, Indonesia
[2]Department of Power Supply and Renewable Energy Sources, National Research University TIIAME, Tashkent 100000, Uzbekistan
[3]Karshi State University, 180119 Karshi, Uzbekistan
[4]Department of Automation and Control of Technological Processes, Karshi Institute of Irrigation and Agrotechnologies, 180119 Karshi, Uzbekistan

Abstract. The usage of synthetic dyes, such as Remazol Red RB 133, benefits the product by boosting its added value, but it also has a negative influence on the aquatic environment when waste water is disposed of directly. As a result, electrocoagulation technology is utilized to lower the levels of Remazol Red RB 133 dye, ensuring that it does not affect the environment. This study seeks to examine the influence of variations in electric voltage (10, 12, 14 volts) and flow rate (80, 100, and 120 mL/minute) on decreasing concentrations of the colorant RB-133 Remazol in the Continuous Electrocoagulation Process. A UV-Vis spectrophotometer will be used to see the dye concentration after the electrocoagulation process and will be analyzed using the adsorption kinetics model and the Langmuir and Freundlich adsorption isotherm models.

1. Introduction

Liquid waste contains chemicals that are difficult to remove and can affect environmental quality, especially decreasing water quality [1]. The textile industry is among the world's greatest generators of refuse. In the textile industry, the dyeing and stamping process uses several dyes, one of which is reactive dyes such as Remazol Red RB 133 which is commonly used for textile dyes. This type of reactive dye has high efficiency in forming covalent bonds with fabric fibers [2]. However, not all dyes can stick to fabric fibers. About 15% of dyes are estimated to be wasted along with waste water [3].

Most azo dyes are difficult to degrade biologically because of their complex structure and stability. In addition, the carcinogenic and mutagenic properties of azo dyes have the potential to endanger health [4]. If this substance enters the body for a short time, it will cause nausea, and if it occurs in the long term, it can cause cancer. Apart from that, dyes can inhibit the entry of light into the water and disrupt the photosynthesis process and threaten the survival of the ecosystem in the environment [5]. Therefore, effective processing of textile dye waste is needed to reduce the resulting negative impacts.

There are several techniques for treating textile wastewater to reduce dyes, such as: adsorption, ultrafiltration, ozonation and coagulation processes. Some of these technologies are less effective because they have limitations in their application [6]. For this reason, new breakthroughs are needed for processing dye waste that is cheap, efficient and easy, and can be done continuously, such as using electrocoagulation technology [7]. Several previous studies have used the electrocoagulation method to reduce the dye content of liquid waste. In research [8] it was successful in reducing the levels of the dye remazol red rb 133 with variations in electrical voltage of 6 volts, 9 volts and 12 volts, it was found that the efficiency of the dye waste removal process was 91.38% at a voltage of 12 volts, concentration NaCl electrolyte 7 g/L cm, at pH 4 conditions, and contact time for 60 minutes. Then, Hendaoui et al. (2021) [9] produced an efficiency of the removal process from indigo dye waste of 94.083% at a flow rate of 2 L/minute, an electric voltage of 27 volts,

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and at a pH of 7.2, with a flow rate variation of 1.5 L /minute; 2 L/min; 2.5 L/min; and 3 L/minute and an electric voltage of 5 volts; 20 volts; 25 volts; 35 volts; 50 volts; and 65 volts. Apart from that, Abdulhadi et al. (2019) [10] also used the electrocoagulation method and succeeded in reducing reactive red 120 dye by 98.5% per unit of time of 100 mL/minute, current density of 6 mA/cm2, and distance between electrodes of 5 mm. Finally, Setianingrum et al. (2017) [11] succeeded in reducing the levels of Remazol red rb 133 dye by 80% through the electrocoagulation method using iron electrodes at a 2 cm separation between electrodes and a 10 volt electrical potential, with variations in electrical voltage of 10 volts and 12 volts.

2. Research Methods

The research was carried out between August and November 2023. The research was carried out at the Environmental Engineering Water Laboratory at the University of North Sumatra to conduct the operating procedure of the wastewater electrocoagulation technique and carry out tests on the parameters assessed, namely dye levels.

The equipment used in this research is an electrocoagulation reactor measuring 15 cm × 10 cm × 17 cm, DC power supply, iron (Fe) electrode measuring 15 cm × 4 cm × 1 mm, electrode support, cables and crocodile clamps, peristaltic pump, filter paper, hose, 20 L bucket, analytical balance, dropper pipette, 100 mL beaker glass, 1000 mL beaker glass, glass funnel, UV-VIS spectrophotometer, spatula, 10 mL sample bottle, stir bar, and pH meter. Meanwhile, this research used Remazol red rb 133, distilled water, and NaCl.

This research carried out the electrocoagulation process using a continuous reactor with a series of equipment consisting of an influent tank, peristaltic pump, electrocoagulation reactor and effluent storage tank. The synthetic liquid waste sample is then flowed to the reactor using a peristaltic pump at a certain flow rate. A pair of iron (Fe) electrode plates was placed vertically in the electrocoagulation reactor with a distance between electrodes of 2 cm. Then, the electrode is connected to a power supply and the voltage is adjusted according to predetermined variations. Based on trials with variations in research variables, dye levels were checked in samples that had undergone the electrocoagulation procedure to ensure removal efficiency by applying the UV-Vis spectrophotometry method.

Fig. 1. Continuous Electrocoagulation Process Equipment Series

Table 1. Experimental design

Electrical Voltage (A)	Flow Rate (B)		
	B1	B2	B3
A1	A1-B1-U1	A1-B2-U1	A1-B3-U1
	A1-B1-U2	A1-B2-U2	A1-B3-U2
A2	A2-B1-U1	A2-B2-U1	A2-B3-U1
	A2-B1-U2	A2-B2-U2	A2-B3-U2
A3	A3-B1-U1	A3-B2-U1	A3-B3-U1
	A3-B1-U2	A3-B2-U2	A3-B3-U2

Notice: A1 (10 volt); A2 (12 volt); A3 (14 volt); B1 (80 mL/min); B2 (100 mL/min); B3 (120 mL/min); U1 (1st experiment); U2 (2nd experiment).

In this study, data was analyzed quantitatively and analytically to evaluate the results of testing the quality of synthetic wastewater effluent based on dye parameters. Statistical analysis of the two-way Anova test was applied to the research

data. In addition, this research also includes modeling activities using pseudo first also the second order adsorption kinetic frameworks, in addition to the Freundlich along with Langmuir adsorption isotherm models.

3. Results and Discussion

3.1 Analysis of Remazol Red Rb 133 Reduction

The Influence of Electric Voltage on the Reduction of Remazol Red Rb 133

Electrical voltage is one of the factors that influences effectiveness in reducing dye levels. Electrical voltage can increase floc formation as a contaminant binder, because electrical voltage applied to the anode can produce the release of metal ions, while at the cathode it results in the release of hydrogen gas bubbles. In this research, variations in electrical voltage were carried out at 10 volts, 12 volts and 14 volts. The analysis information uses dye reduction data in the 60th minute after balance is reached as a reference for comparing the effect of electrical voltage variations on dye reduction which can be seen in the graph below.
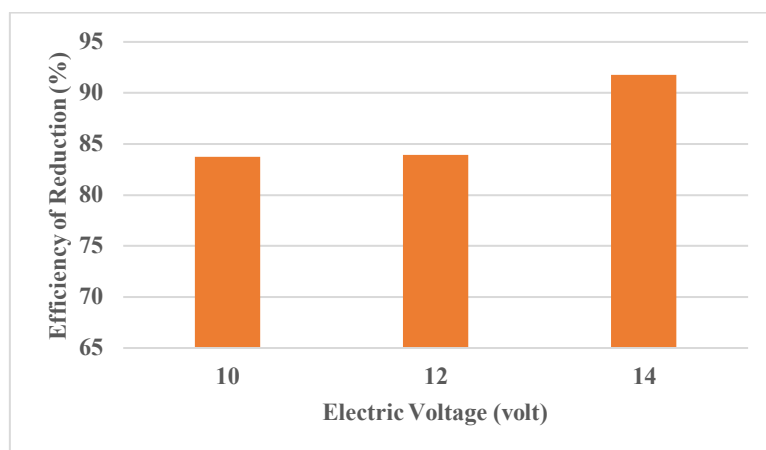

Fig. 2. Profile of the Relationship between Voltage Variation and the Efficiency of Color Removal

Figure 2 shows that the color removal efficiency obtained at 10 volts is 83.75%. The removal efficiency increases to 83.90% when the voltage is raised to 12 volts. Subsequently, the electric voltage is further increased to 14 volts, resulting in an improvement in the color removal efficiency to 91.75%. Based on the available data, it can be inferred that higher electric voltage leads to better color removal efficiency, with the highest removal efficiency observed at 14 volts, reaching 91.75%. This is because as the electric voltage increases, there is a greater potential for the breakdown of the Fe electrode to release Fe2+, thereby producing larger $Fe(OH)_2$ flocs. These larger flocs can bind more pollutants with the assistance of NaCl electrolyte, leading to a more efficient process [12]. However, at 10 volts, the less optimal efficiency of the electrocoagulation process is attributed to the insufficient or sufficiently strong supply of electric voltage to support the process. The electric voltage in electrocoagulation has a substantial impact on current density, which increases with increased voltage. The coagulant dose, flocculation, speed, as well as size of bubbles produced by the electrode process all depend on the current density. The amount of coagulant dissolved by the anode also plays a crucial role in removing color from the solution. The more coagulant produced, the larger the flocs and the higher the pollution removal efficiency. Additionally, the color of the solution will change over time [13].

The Influence of Flow Rate on the Reduction of Remazol Red Rb 13

The flow rate is one of the factors influencing the effectiveness of reducing the concentration of color substances. In this study, variations in flow rates of 80 mL/minute, 100 mL/minute, and 120 mL/minute were implemented. Analytical information was derived from the data of color substance reduction at the 60th minute after reaching equilibrium, serving as a reference to compare the influence of voltage and flow rate variations on color substance reduction, as depicted in Figure 3.

Figure 3 shows that the efficiency of color substance reduction obtained at a flow rate of 80 mL/minute is 91.75%. The efficiency decreases to 91.45% when the flow rate is increased to 100 mL/minute. Subsequently, the flow rate is further increased to 120 mL/minute, resulting in a decrease in color substance reduction efficiency to 84.35%. According to the available data, as the discharge rate increases, the efficacy decreases in reducing the color ingredient concentration, with the highest reduction efficiency attained at a flow rate of 80 mL/minute, or 91.75%. This occurs because at higher flow rates, the contact time between the impurities and the coagulant becomes shorter, making the impurity absorption process by the coagulant less effective. Additionally, at higher flow rates, the quantity of impurities entering the reactor in the same time period is greater than the amount of coagulant produced by the electrode. As a result, some impurities in the

wastewater cannot form flocs due to insufficient coagulant availability. This ultimately leads to lower efficiency compared to slower flow rates [14].
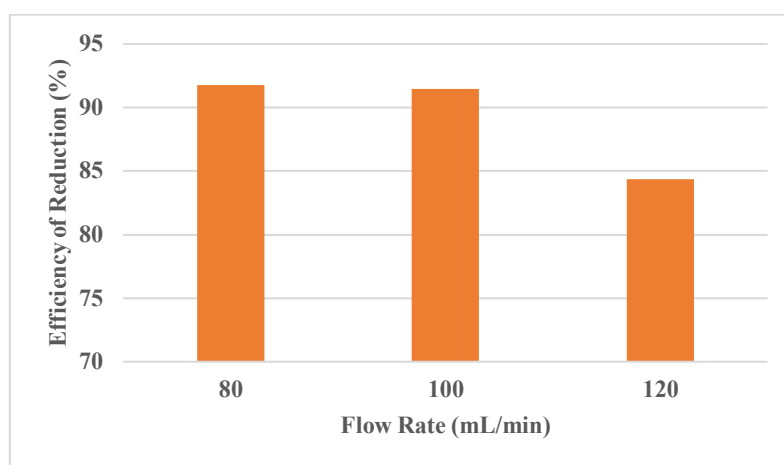

Fig. 3. Profile of the Relationship between Flow Rate Variations and the Efficiency of Color Substance Reduction

The Influence of Residence Time on the Reduction of Remazol Red Rb 133

Residence time is one of the factors influencing the effectiveness of reducing the concentration of Remazol Red Rb 133 color substances. Residence time refers to the duration during which a substance or wastewater remains in the treatment system or reactor for the electrocoagulation process to occur. The residence times applied in this continuous electrocoagulation are 20 minutes, 16 minutes, and 13.3 minutes. Analytical information is derived from the data of color substance reduction at the 60th minute after reaching equilibrium, serving as a reference to compare the influence of voltage residence time variations on color substance reduction, as depicted in the graph below.
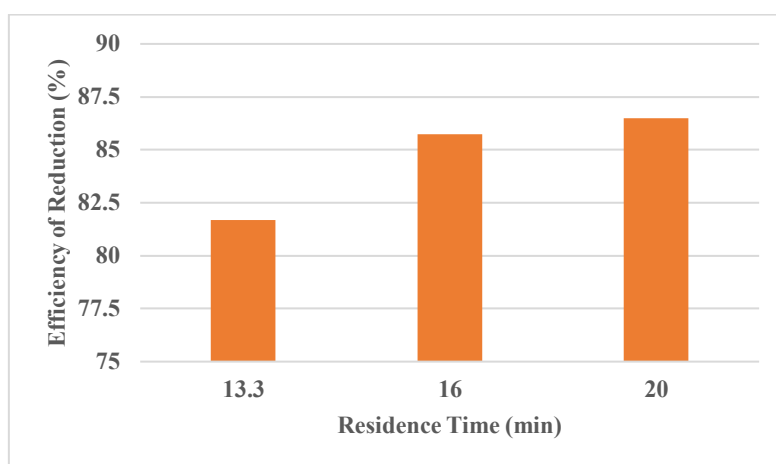

Fig. 4. Profile of the Relationship between Residence Time Variations and the Reduction of Remazol Red Rb 133

Figure 4 shows that the efficiency of color substance reduction obtained at a residence time of 13.3 minutes is 81.69%. The reduction efficiency increases to 85.72% as the residence time extends to 16 minutes. Subsequently, when the residence time is further increased to 20 minutes, the efficiency of color substance reduction experiences a further enhancement, reaching 86.5%. From the available data, it can be observed that with an increasing residence time, the efficiency in reducing the color substance content also rises. The highest reduction efficiency is achieved with a residence time of 20 minutes, at 96.5%. This is attributed to the increased dissolution of the anode, resulting in more cationic hydroxide ions. Consequently, the colorants in the wastewater form larger aggregates (flocs), leading to a greater amount of sludge formation and, consequently, an increase in the content of colorants that can be separated [15].

3.2 Statistical Analysis

The two-way ANOVA test with SPSS revealed that the electric voltage variable had a sig = 0.000 level of significance, or sig < 0.05. As a result, (H0) is rejected, showing that differences in electrical voltage (10, 12, and 14 volts) have a varied effect on the effectiveness of color subtance reduction. Additionally, the significance value for the flow rate

variable is sig = 0.000, or sig < 0.05, leading to the rejection of H0. This implies that variations in flow rate (80, 100, and 120 mL/minute) have a different effect on the efficiency of color substance reduction. Finally, the significance value for the interaction between Electric Voltage and Flow Rate is sig = 0.000, or sig < 0.05, leading to the rejection of H0. This indicates that there is an interaction between variations in electric voltage and flow rate concerning the efficiency of color substance reduction.

Table 2. Results of Two-Way ANOVA Test

Tests of Between-Subjects Effects

Dependent Variable: Efficiency of Reduction

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	291,565[a]	8	36,446	25,060	,000
Intercept	4255,031	1	4255,031	2925,705	,000
Jarak_Elektroda	190,471	2	95,236	65,483	,000
Laju_alir	79,127	2	39,564	27,204	,000
Jarak_Elektroda * Laju_alir	21,965	4	5,491	3,776	,045
Error	13,089	9	1,454		
Total	4559,686	18			
Corrected Total	304,654	17			
a. R Squared = ,957 (Adjusted R Squared = ,919)					

3.3 Adsorption Kinetics Model

Adsorption kinetics are employed to depict how rapidly an adsorbent absorbs its adsorbate [16]. In this study, adsorption kinetics are utilized to illustrate the changes in the concentration of color substances absorbed on the surface of iron plates over time. The adsorption utilized kinetics models are pseudo-second-order and pseudo-first-order kinetics. Figures representing pseudo-first-order and pseudo-second-order adsorption kinetics models are shown in Figures 5 and 6.
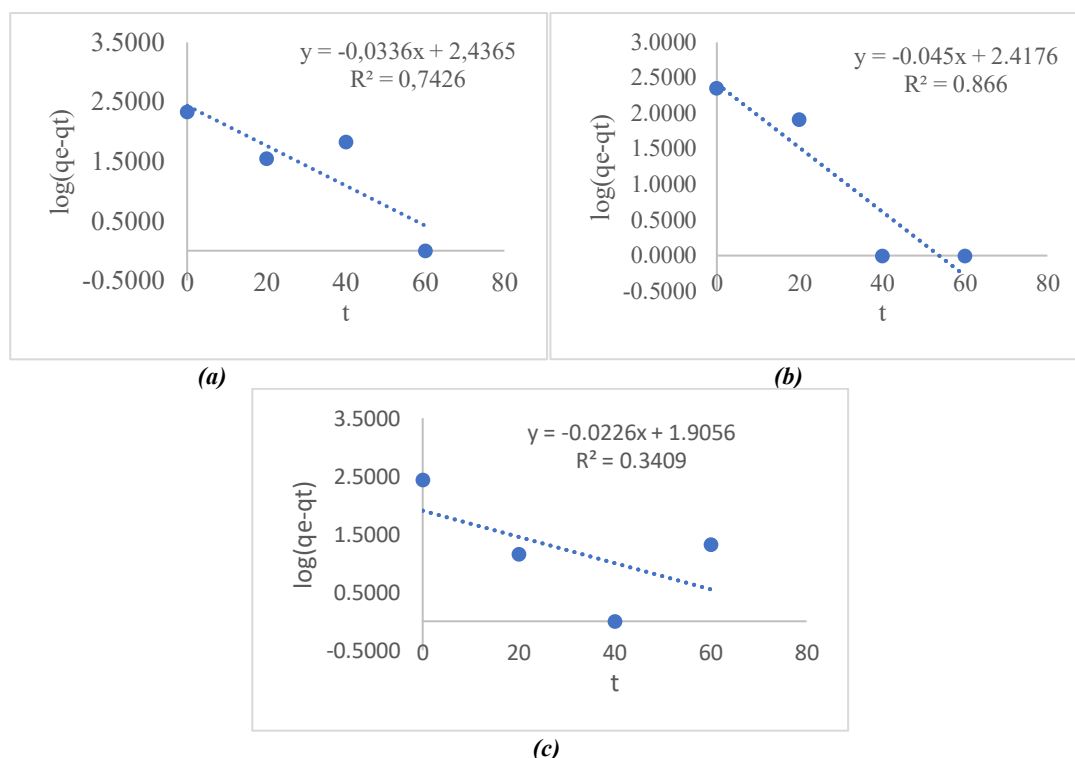
(a)

(b)

(c)

Fig. 5. Adsorption Kinetics Graphs at Flow Rate-Electric Voltage 80 mL/minute-10 volts, 100 mL/minute-12 volts, 120 mL/minute-14 volts (a), (b), (c) Pseudo-First-Order

The coefficient of determination (R^2) can be used to determine the optimal kinetic model. A coefficient of determination value near to one indicates an adequate or suitable model for modeling the Remazol Red Rb 133 adsorption process on iron plates [17]. Table 3 shows that its pseudo-first-order construct (0,7426; 0,866; 0,3409) has lower coefficient of determination values compared to the pseudo-second-order construct (0,912; 0,9555; 0,9969). As a result, we can

conclude that the pseudo-second-order kinetic construct is the best fit for adsorption. The pseudo-second-order construct depicts a reaction pace equation influenced by chemical adsorption, with valence bonds produced by electron exchange between the adsorbent and adsorbate. The kinetic construct that is pseudo-second-order predicts a relatively slow adsorption process [18].
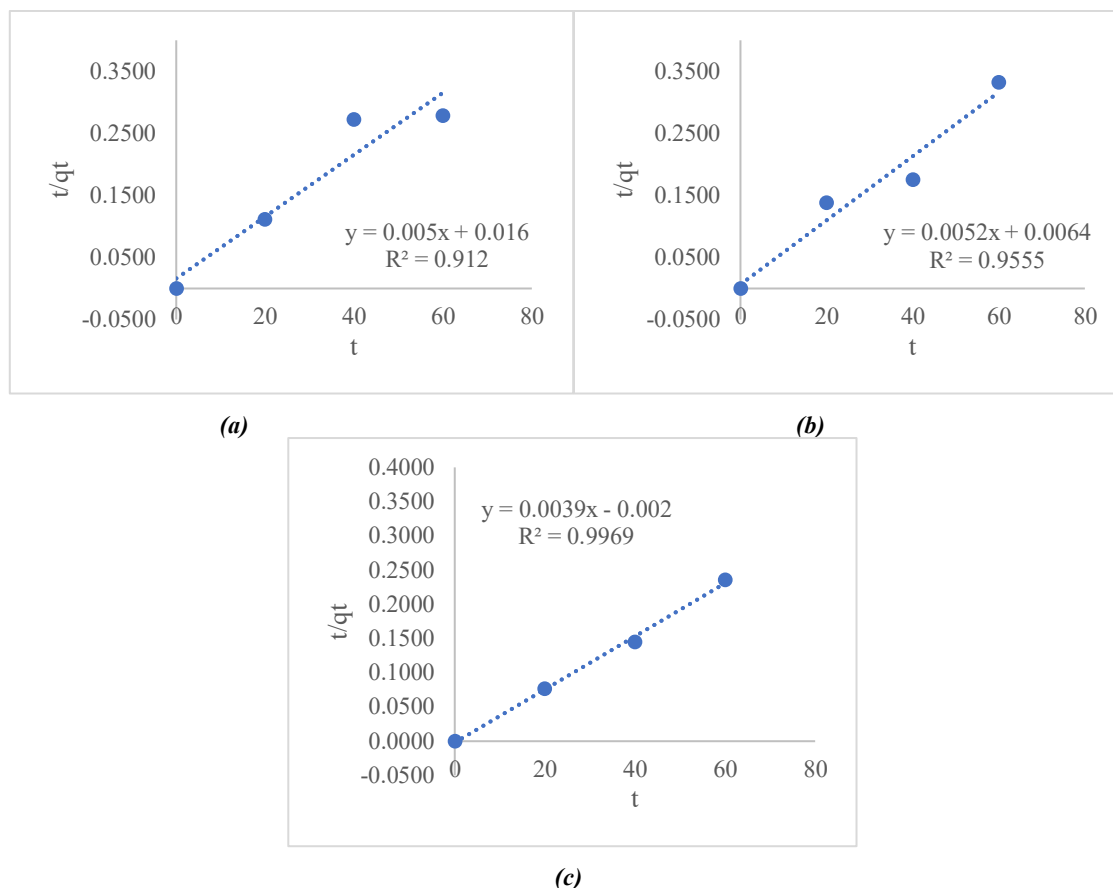

(a)   *(b)*

(c)

Fig. 6. Adsorption Kinetics Graphs at Flow Rate-Electric Voltage 80 mL/minute-10 volts, 100 mL/minute-12 volts, 120 mL/minute-14 volts (a), (b), (c) Pseudo-Second-Order

Table 3. Equations and Coefficient of Determination Values for Adsorption Kinetics

Electric Voltage (volt)	Flow Rate (mL/min)	Kinetics Model					
		Pseudo First Order			Pseudo Second Order		
		R^2	qe	k1	R^2	qe	k2
10	80	0,7426	273,21	0,08	0,912	200,00	0,4167
12	100	0,866	261,58	0,10	0,9555	192,31	0,4507
14	120	0,3409	80,46	0,05	0,9969	256,41	0,2535

The adsorption rate constant (k) is a value that shows whether the adsorption process is quick or slow; a larger value suggests a faster adsorption process (Sihombing, 2019). The obtained values for k2 in the most suited adsorption kinetics model, the pseudo-second-order model, are 0,4167 g/mg.minute, 0,4507 g/mg.minute, and 0,2535 g/mg.minute. The best adsorption rate is achieved with the highest reduction efficiency, which is with an electric voltage of 12 volts and a flow rate of 100 mL/minute.

3.4 Adsorption Isotherm Model

The adsorption isotherm is used in this study to understand how the iron electrode (Fe) absorbs Remazol Red Rb 133 and to find equilibrium equations used to measure the quantity of the contaminant that the adsorbent absorbs. Both Langmuir and Freundlich isotherms are employed in this study as models for the adsorption equations. The Langmuir isotherm occurs in a monolayer, while the Freundlich isotherm occurs in a multilayer [19]. The results of the adsorption isotherm calculations using both models are graphically depicted in Figures 7 and 8.
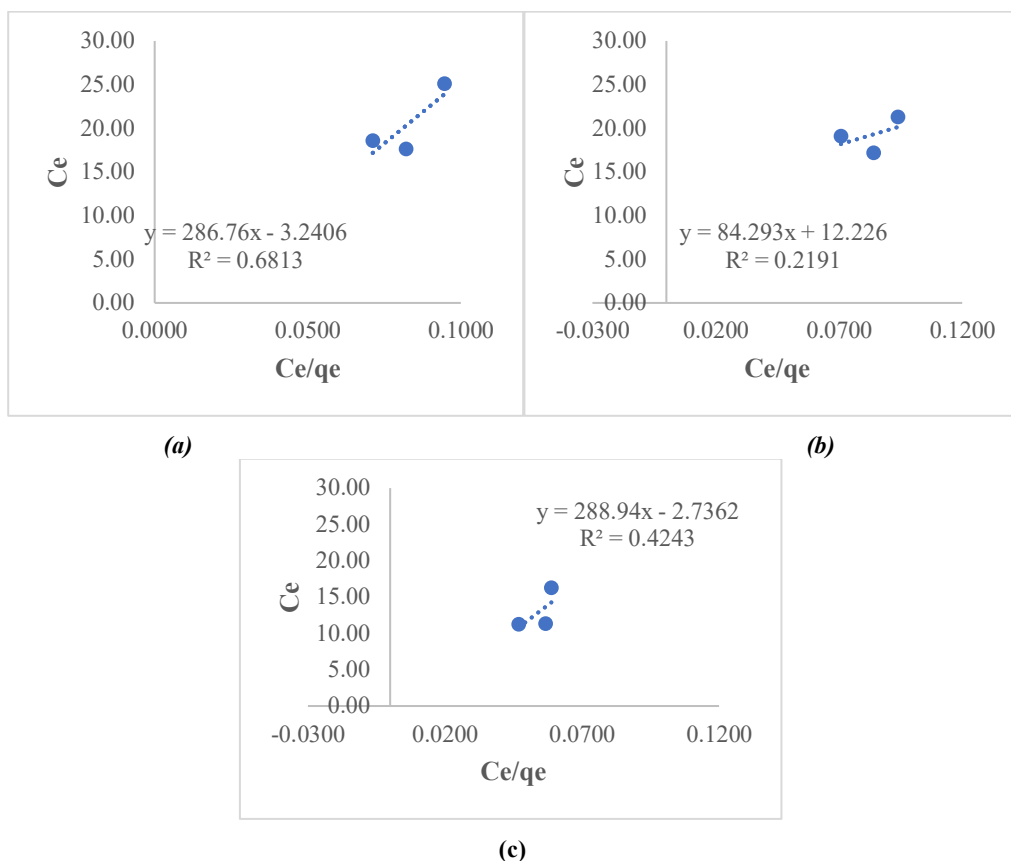
(a)

(b)

(c)

Fig. 7. Langmuir Adsorption Isotherm Graphs: (a) Electric Voltage 10 volts; (b) Electric Voltage 12 volts; (c) Electric Voltage 14 volts
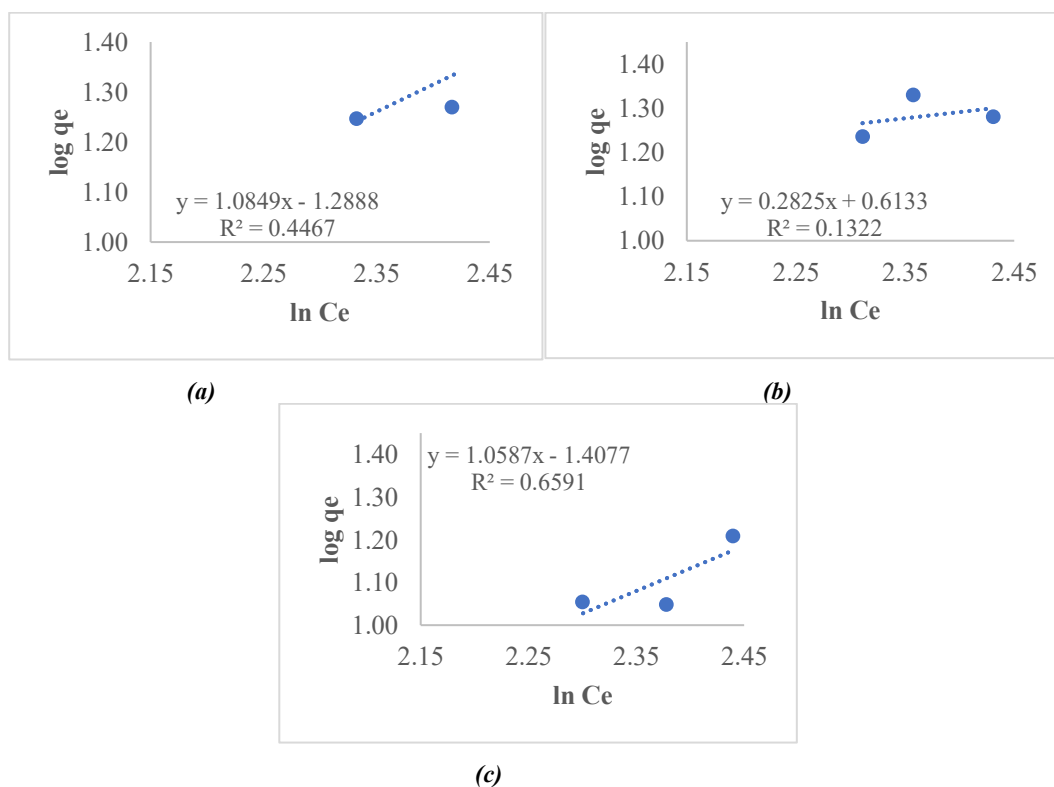

(a)

(b)

(c)

Fig. 8. Freundlich Adsorption Isotherm Graphs: (a) Electric Voltage 10 volts; (b) Electric Voltage 12 volts; (c) Electric Voltage 14 volts

Table 4. Isotherm Constants and R^2 for Langmuir and Freundlich Isotherm Models

Electric Voltage (volt)	Kinetics Model					
	Langmuir			Freundlich		
	R^2	Qm	b	R^2	Kf	n
10	0,6813	0,00349	0,62	0,4467	19,44	0,92
12	0,2191	0,01186	0,79	0,1322	4,10	3,54
14	0,4243	0,00346	0,62	0,6591	25,57	0,94

The suitable isotherm should have an R^2 value close to one [20]. As demonstrated Table 4 displays the coefficient for the Langmuir adsorption isotherm model of determination worth (0,6813; 0,2191; 0,4243) are closer to 1 than the Freundlich isothermal adsorption model (0,4467; 0,1322; 0,6591). Therefore, the optimal adsorption kinetics model is the isotherm of Langmuir adsorption. The Langmuir isotherm describes how adsorption occurs uniformly across the entire surface of the adsorbent, with constant adsorption energy and no interaction between adsorbates [21]. Additionally, from Table 4, the adsorption capacity of the iron electrode plate (Fe) for Remazol Red Rb 133 (maximum adsorption capacity) is 0,00349 mg/g at an electric voltage of 10 volts, 0,01186 mg/g at 12 volts, and 0,00346 mg/g at 14 volts.

4. Summary

According to the research findings, electric voltage, flow rate, and residence time all have an impact on the reduction of Remazol Red Rb 133 in synthetic wastewater. The greatest percentage of Remazol Red Rb 133 elimination was observed in studies with an electric voltage of 14 volts and a flow rate of 80 mL/minute, reaching 91.75%. Furthermore, a significant difference is shown by the two-way ANOVA test in the effect of electric voltage and flow rate variations on the elimination of Remazol Red Rb 133. Furthermore, there is an interplay of these two variables in determining the reduction process of Remazol Red Rb 133. Finally, the suitable kinetic adsorption model and adsorption isotherm for the adsorption process are:

a. The appropriate kinetic adsorption model for the Remazol Red Rb 133 absorption process by iron plates follows the pseudo-second-order construct.
b. The suitable adsorption isotherm model for the Remazol Red Rb 133 absorption process by iron plates follows the Langmuir adsorption isotherm model.

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