

Removal of Remazol Red Dye: The Influence of Acid Type, FeCl₃ Coagulant, and Chia Seed (*Salvia hispanica* L.) Flocculant Dosages

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Abstract

Waste from the batik industry has become increasingly abundant as the textile sector has grown. One significant pollutant in aquatic environments is the synthetic dye Remazol Red. This study investigates the removal of Remazol Red as a solution to mitigate environmental pollution. The method employed is coagulation-flocculation, using the synthetic coagulant FeCl₃ modified with a natural flocculant, specifically chia seeds (*Salvia hispanica* L.). The research parameters included the type of acid (HCl, H₂SO₄, and HNO₃), coagulant dosage, and flocculant dosage. The coagulation process was conducted at 700 rpm for 4 minutes, followed by flocculation at 50 rpm for 30 minutes. The results indicated that HCl yielded the highest removal percentage (98.98%). Furthermore, the optimum coagulant concentration resulted in 97.11% removal, while the optimum flocculant dose was 300 mg/L with a removal percentage of 98.57%. FTIR spectrophotometry characterization revealed that the sulfonate group (SO₂) of Remazol Red and the Fe-Cl group in FeCl₃ interacted with the carbonyl group (C=O) of the chia seeds.

Keywords: Synthetic coagulants, Natural flocculants, Coagulation-flocculation, Azo dyes

1 Introduction

The textile industry, particularly the batik sector, extensively utilizes synthetic dyes. The Indonesian batik industry continues to flourish, bolstered by its recognition as a UNESCO Intangible Cultural Heritage in 2009 [1]. Dyeing processes in this industry generally employ three categories of dyes: cationic, anionic, and nonionic [2]. Remazol Red is an anionic dye characterized by the presence of an azo group [3], [4]. Furthermore, anionic dyes typically contain sulfonate (–SO₃[–]) and carboxylate (–COOH) functional groups [5, 6]. During the dyeing process, only approximately 5% of the dye is effectively absorbed by the fabric, while the remainder is discharged as liquid effluent [7].

Azo dyes, such as Remazol Red, are organic contaminants that are difficult to degrade naturally and are carcinogenic, posing risks to aquatic ecosystems and organisms when discharged into water bodies [8, 9]. Remazol Red (C₂₀H₂₂N₂NaO₁₁S₃) is a synthetic monoazo dye with a molecular weight of 562.58 g/mol, characterized by the presence of an azo bond (N=N) that forms its chromophore structure, enabling the dye to dissolve in water and bind

strongly to textile fibers [10, 11, 12]. The structure of Remazol Red is shown in Fig. 1.

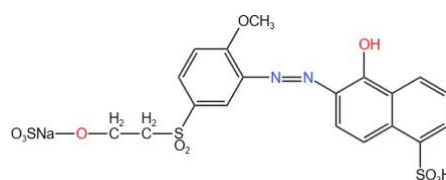


Figure 1. Structure of Remazol Red

Although synthetic dyes offer advantages such as stable coloration, a wide range of colors, ease of application, and low energy consumption, their persistence in wastewater requires effective treatment methods [13, 14]. Several dye removal processes have been developed, including coagulation-flocculation, electrocoagulation, and adsorption, among which coagulation-flocculation is considered one of the most effective methods for removing dyes from wastewater [15, 16].

Coagulation-flocculation is a process of agglomerating suspended and colloidal materials so that they can be removed through sedimentation and filtration [17, 18]. Coagulation-

flocculation is a scalable and cost-effective option. This method not only improves water quality but also makes subsequent processing procedures easier [19]. The coagulation-flocculation approach exhibits considerable potential for usage in large-scale dye wastewater treatment, with additional benefits such as a straightforward procedure and the lack of hazardous byproducts [20].

This study used the coagulation-flocculation method. The coagulant used was FeCl_3 (ferric chloride) as a synthetic coagulant and chia seed flocculant (*Salvia hispanica* L.) as a natural flocculant. FeCl_3 coagulant has a wide pH range, the ability to bind organic matter quickly, and the ability to form flocs [21]. FeCl_3 has strong precipitation and coagulation capabilities, enabling better sludge drying and shorter water treatment times [22]. In addition, chia seed flocculant is effective as a natural flocculant due to its polysaccharide content that can bind dyes and coagulates. This natural flocculant can agglomerate flocs into larger flocs [23, 24]. Flocculants can neutralize and bind colloidal

particles through functional groups such as hydroxyl and carboxyl groups, thereby accelerating the precipitation of pollutants [25].

A modification of synthetic coagulants and natural flocculants can achieve high effectiveness in removing Remazol Red. Factors that influence the effectiveness of the coagulation-flocculation process include the type of acid, coagulant dose, flocculant dose, pH, temperature, wastewater composition, and mixing conditions [14, 26]. This study focuses on the type of acid, coagulant dose, and flocculant because they are important. Absorbance measurements were made using a UV-Vis spectrophotometer with a maximum wavelength (λ_{max}) of 520 nm [27]

2 Method

Fig. 2 illustrates the coagulation-flocculation process for removing Remazol Red dye. The coagulation process was carried out at 700 rpm for 4 minutes, and the flocculation process at 50 rpm for 30 minutes. Sedimentation was carried out for 30 minutes, followed by filtration

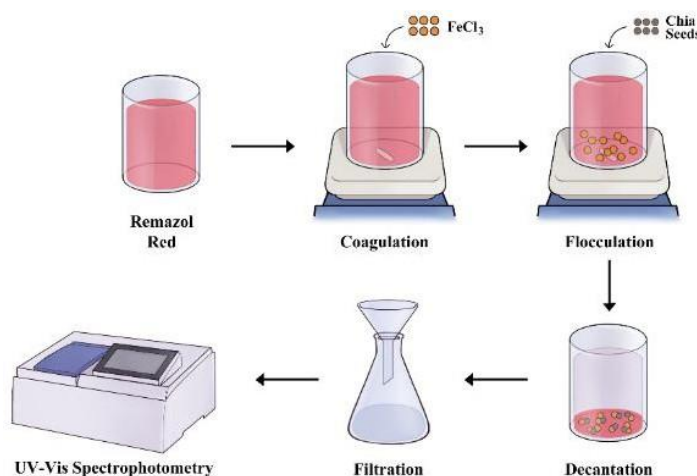


Figure 2. Illustration of the coagulation-flocculation process

2.1 Preparation of FeCl_3 coagulant

FeCl_3 powder is weighed according to the desired dosage variation.

2.2 Preparation of chia seed flocculant (*Salvia hispanica* L.)

Weigh 20 grams of chia seeds and soak them in 400 ml of distilled water at 50°C . They are then blended and centrifuged. The supernatant is collected and filtered through two gauze pads. The gel-like filtrate is collected.

2.3 The effect of the type of acid on the removal of Remazol Red dye

Remazol Red solution of 50 mg/L was conditioned at pH 1, 2, 3, 4, and 5 with 0.5 M HCl, 0.5 M H_2SO_4 , and 0.5 M HNO_3 , respectively. This test solution was added with 550 mg/L FeCl_3 coagulant and stirred at 700 rpm for 4 minutes. Then, 300 mg/L chia seed flocculant was added and stirred again at 50 rpm for 30 minutes. After treatment, absorbance was measured with a UV-Vis spectrophotometer λ_{max} 520 nm.



2.4 The effect of FeCl_3 coagulant dosage on Remazol Red removal

Coagulant doses of FeCl_3 with variations of 450, 500, 550, 600, and 650 mg/L were added to a 50 mg/L red remazol solution. This test solution was coagulated at 700 rpm for 4 minutes. Furthermore, flocculation was carried out at 50 rpm for 30 minutes. After treatment, absorbance testing was carried out with a UV-Vis spectrophotometer at λ_{max} 520 nm.

2.5 Effect of Chia seed flocculant dose on Remazol Red dye removal

A coagulant dose of 550 mg/L of FeCl_3 was added to a 50 mg/L Remazol Red solution. The coagulation process involved stirring for 4 minutes at 700 rpm. Dosages of chia seed flocculant at 100, 200, 300, 400, and 500 mg/L were tested in the flocculation process at 50 rpm for 30 minutes. The treatment results were measured for absorbance using a UV-Vis spectrophotometer at λ_{max} 520 nm.

2.6 Fourier Transform Infrared (FTIR) Characterization

This characterization is used to analyze the

functional groups of remazol red, FeCl_3 , and chia seeds, and to determine the optimum floc yield.

2.7 Calculation of the percentage of Remazol red dye removal

Eq. 1 was used to determine the percentage reduction in a dye solution. Where C_0 is the remazol red solution's beginning concentration (mg/L) and C is the test solution's final concentration following treatment (mg/L).

$$\text{removal efficiency (\%)} = \frac{C_0 - C}{C_0} \times 100\% \quad (\text{Equation 1})$$

3 Result and Discussion

3.1 Effect of acid type on Remazol Red dye removal

The acids used were HCl, H_2SO_4 , and HNO_3 at a concentration of 0.5 M. These acids are strong acids. In the coagulation-flocculation process, the type of acid used to adjust the pH affects the dye removal efficiency. Although the pH is the same, the differences in anions produced by HCl, H_2SO_4 , and HNO_3 affect coagulant speciation, the ionic state of the solution, and the characteristics of the floc formed [28]

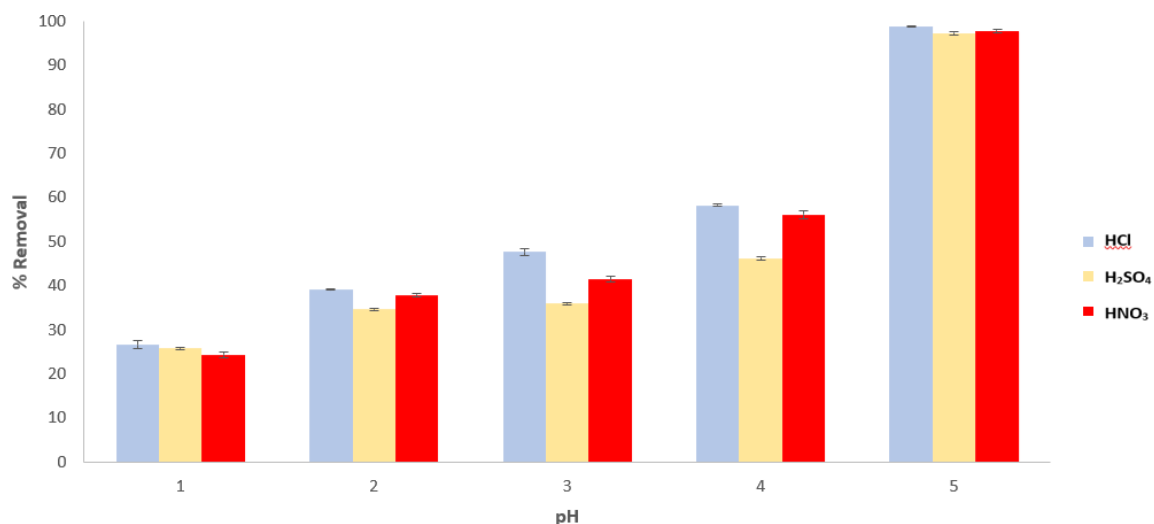
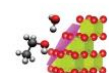


Figure 3. Effect of acid type on the removal of Remazol Red dye

Fig 3. HCl showed the highest removal efficiency of Remazol Red dye among the acids tested and the optimum pH was pH 5. As shown in Table 1, at the optimum pH of 5, the acids HCl, H_2SO_4 , and HNO_3 each have removal percentages of 98.98%, 97.36%, and 97.95%, respectively. At each pH, the removal percentage of HNO_3 was relatively higher than that of H_2SO_4 .

However, both do not differ much in the percentage of Remazol Red dye removed.

FeCl_3 coagulant works optimally in the pH range of 4-8 [29, 30]. In the acid conditioning charge-neutralization process, FeCl_3 is hydrolyzed to the positively charged species $\text{Fe}(\text{OH})_2^+$ [4], [31]. Conditioning the pH with HCl often produces large flocs and a high percentage



of dye removal. This is because HCl is more stable, and Cl^- is not reactive to Fe^{3+} [32, 33]. The use of H_2SO_4 to adjust pH can affect the coagulation-flocculation process by either facilitating or hindering floc formation. The presence of sulfate ions and high acidity can change the speciation and stability of Fe^{3+} in solution. As a result, the interaction of Fe^{3+} with contaminants becomes less stable. Conditioning the pH with strong sulfate-based acids alters iron reactivity and interferes with floc formation [34]. In addition, HNO_3 also acts as an acidifier. HNO_3 produces lower coagulation-flocculation efficiency than HCl. The presence of NO_3^- anions inhibits the optimal interaction between Fe(III) and dyes [35].

Table 1. Effect of acid type on the removal of red remazol dye

pH	%Removal		
	HCl	H_2SO_4	HNO_3
1	26.64	25.82	24.39
2	39.13	34.67	38.00
3	47.67	35.97	41.48
4	58.27	46.24	56.15
5	98.98	97.36	97.95

In the coagulation-flocculation process with

FeCl_3 coagulant, HCl effectively lowers the solution pH to 5, the optimum pH, without disturbing the stability of the Fe^{3+} species in the solution. The HCl acid type can produce more effective flocs than the H_2SO_4 and HNO_3 acid types. Therefore, pH conditioning using HCl can support the coagulation-flocculation process more optimally as indicated by the increased efficiency of Remazol Red dye removal.

3.2 Effect of FeCl_3 coagulant dosage on Remazol Red dye removal

In this study, FeCl_3 coagulant dosage was added to the Remazol Red solution to determine its effect on Remazol Red dye removal. FeCl_3 is a coagulant belonging to the metal salt group. The Fe^{3+} ion formed by the oxidation of FeCl_3 in water makes it suitable as a coagulant. This ionization results in the formation of a water-insoluble metal hydroxide solid. This occurs because the Fe^{3+} cation reacts with alkalinity, leading to hydrolysis in the formation of a precipitate.

Fig. 4 shows the FeCl_3 coagulant dosage that achieved the highest Remazol Red dye removal at 550 mg/L.

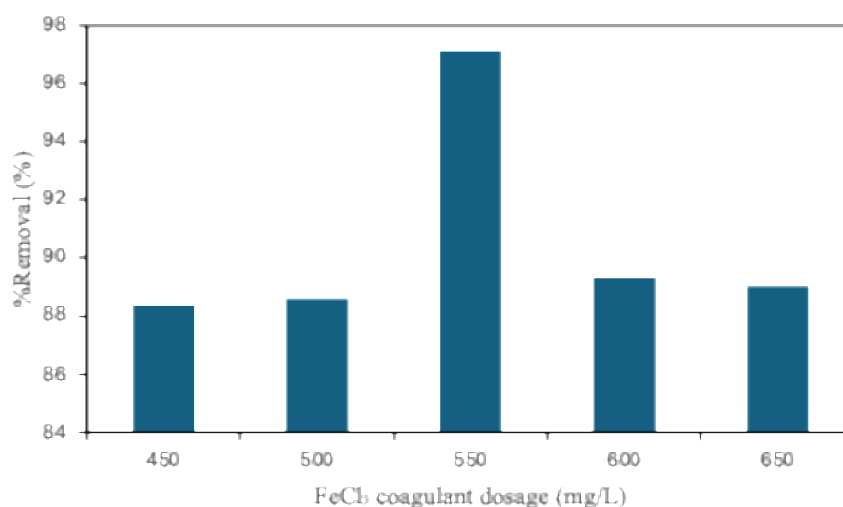
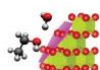


Figure 4. Effect of FeCl_3 coagulant dose on the removal of Remazol Red dye

The percentage of Remazol Red dye removed was 88.39%, 88.60%, 97.11%, 89.35%, and 89.03% for each FeCl_3 coagulant dose of 450, 500, 550, 600, and 650 mg/L, respectively. **Table 2.** shows that the FeCl_3 coagulant dose of 550 mg/L, with coagulation at 700 rpm and flocculation at 50 rpm, achieved a removal percentage of almost 100%.

The results of this study showed an increase in

the FeCl_3 coagulant dose from 450 mg/L to 550 mg/L. At the optimal FeCl_3 coagulant dose of 550 mg/L, the percentage of Remazol Red dye removal decreased. As the dose increases, the coagulant's positive charge becomes increasingly dominant. Electrostatic repulsion between particles decreases dye removal efficiency [36]. For the optimum FeCl_3 coagulant dose, removal values below this value require further FeCl_3



coagulant doses. If the FeCl_3 coagulant dose is lower than the optimum dose, the removal results in less effective Remazol Red dye.

Table 2. Effect of FeCl_3 coagulant dose on the removal of Remazol Red dye

FeCl_3 flocculant dosage (mg/L)	%Removal of Remazol Red Dye			
	1	2	3	Average
450	88.38	88.26	88.52	88.39
500	88.49	88.71	88.59	88.60
550	97.11	96.93	97.30	97.11
600	89.52	89.10	89.42	89.35
650	88.97	88.84	89.29	89.03

The optimum coagulant dose indicates a condition in which the destabilization of colloidal particles occurs effectively. This is characterized

by the formation of stable flocs, resulting in maximum dye removal efficiency. Adding coagulant above the optimum dose does not provide a significant increase in efficiency and can cause particle restabilization due to charge reversal [37].

3.3 Effect of Chia seed flocculant dose on Remazol Red dye removal

The chia seed flocculant dose affected the removal of Remazol Red dye. The chia seed flocculant was added to the flocculation process at 50 rpm for 30 minutes. **Fig. 5** shows that a chia seed flocculant dose of 300 mg/L resulted in the highest removal of Remazol Red dye.

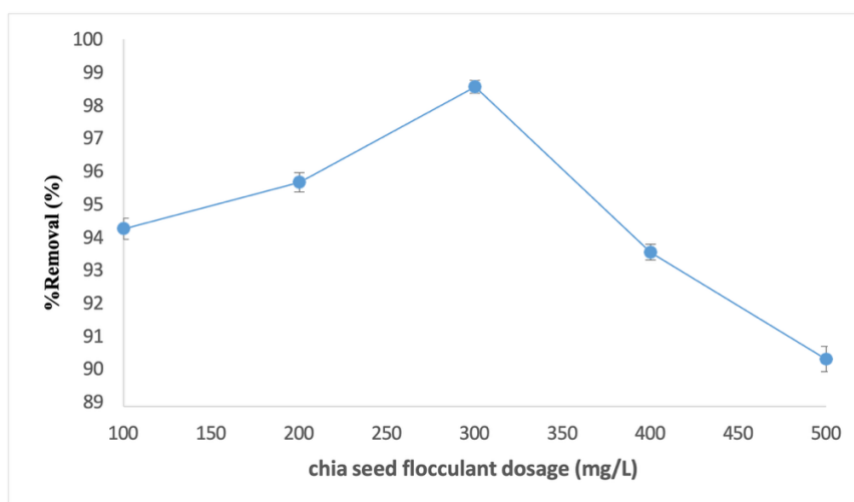


Figure 5. Effect of seed flocculant dosage on Remazol Red dye removal

The percentage of Remazol Red dye removed at chia seed flocculant dosages of 0, 0.5, 1, 2, and 3 was 94.32%, 95.71%, 98.57%, 93.62%, and 90.42%, respectively. Remazol Red dye removal increased with flocculant dosages of 100-300 mg/L. The optimum point was at a chia seed flocculant dosage of 300 mg/L, as shown in **Table 3**. Meanwhile, the percentage of Remazol Red removed decreased at flocculant dosages of 300-600 mg/L.

The flocculation process is aided by electrostatic attraction between oppositely charged particles [38]. A higher flocculant dose can increase interactions with the FeCl_3 coagulant and the Remazol Red dye, resulting in more flocs. However, an excess of flocculant inhibits flocculation due to electrostatic repulsion. With strong charge neutralization, flocculant performance improves because the FeCl_3 coagulant and Remazol Red dye can be well

stabilized.

Table 3. Effect of chia seed flocculant dose on Remazol Red dye removal

Chia seed flocculant dosage (mg/L)	%Removal of Remazol Red Dye			
	1	2	3	Average
100	94.67	94.21	94.07	94.32
200	95.99	95.71	95.42	95.71
300	98.42	98.79	98.51	98.57
400	93.58	93.40	93.87	93.62
500	90.52	90.00	90.73	90.42

The results above indicate that adding the FeCl_3 coagulant destabilizes the suspension, leading to attractive interactions. The optimum coagulant dose increases the attractive forces between the chia seed flocculant particles. Therefore, the chia seed flocculant does not destabilize at either too high or too low doses. The more coagulant added, the greater the

destabilization of the suspension and the aggregation events. Consequently, the attractive forces between the chia seed particles increase with increasing coagulant concentration, resulting in the formation of larger flocs [39, 40].

3.4 Fourier Transform Infrared (FTIR) Characterization

FTIR characterization was performed to confirm the removal process of Remazol Red dye. This characterization was performed by comparing Remazol Red, FeCl_3 coagulant, and chia seed flocculant. FTIR wavenumbers ranged

from 4000 cm^{-1} to 400 cm^{-1} .

Fig. 6 shows the spectra produced by remazol red, FeCl_3 , and chia seeds. The spectrum of Remazol Red shows the $\text{N}=\text{N}$ azo group and the $\text{S}=\text{O}$ deformation of sulfonic acid and sulfite. The spectrum of FeCl_3 shows absorption at 826 cm^{-1} , assigned to the $\text{Fe}-\text{O}$ group, and at 526 cm^{-1} , assigned to the $\text{Fe}-\text{Cl}$ group. Additionally, an $\text{O}-\text{H}$ group is present at 3187 cm^{-1} . The spectrum of chia seeds shows the $\text{O}-\text{H}$ functional group at 3315 cm^{-1} and the $\text{C}=\text{O}$ functional group at 1652 cm^{-1} .

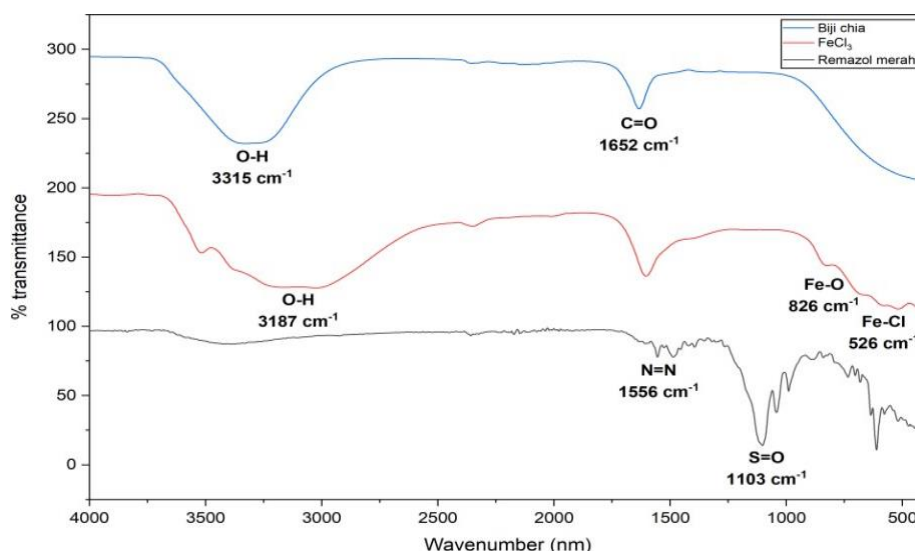


Figure 6. FTIR spectra of Remazol Red, FeCl_3 , and chia seeds

4 Conclusion

Based on this study, the combination of the synthetic coagulant FeCl_3 and the natural flocculant chia seed mucilage was highly effective for the removal of Remazol Red dye. The optimum conditions, consisting of 550 mg/L FeCl_3 and 300 mg/L chia seed flocculant, achieved a removal efficiency of 98.57%, with HCl providing the most effective pH adjustment. FTIR characterization confirmed the presence of functional groups involved in the coagulation-flocculation process. These findings indicate that the combined use of FeCl_3 and chia seed mucilage has promising potential as an environmentally friendly alternative for dye removal in wastewater treatment. Future studies should evaluate the performance of this coagulant-flocculant system using real batik wastewater and investigate its scalability, economic feasibility, and long-term application under industrial operating conditions.

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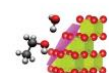
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