

Removal of Iron (II) from Aqueous Solutions Using Natural Adsorbent

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Abstract:Iron (Fe) contamination in water poses significant environmental and health risks due to its persistence and potential toxicity. This study investigates the use of *Vitisvinifera* (grape branch stem powder) as a low-cost, eco-friendly biosorbent for the removal of Fe(II) ions from aqueous solutions. Batch experiments were conducted to examine the effects of pH, contact time, adsorbent dosage, initial metal concentration, and temperature on the adsorption process. The biosorption occurred through mechanisms such as ion exchange, electrostatic attraction, and surface complexation, facilitated by functional groups like hydroxyl and carboxyl present in the biomass. The results demonstrated effective Fe(II) removal, with optimal conditions observed at lower pH and moderate temperatures. The study highlights the potential of *Vitisvinifera* as a sustainable alternative to conventional treatment methods for iron-contaminated water.

Keywords:Removal of iron, *Vitisvinifera*, biosorption, natural adsorbent, water treatment, adsorption isotherms, eco-friendly remediation.

1. Introduction

Heavy metal contamination poses a significant environmental threat due to its persistence, non-biodegradability, and toxic effects on ecosystems and human health. Unlike organic pollutants, which can degrade over time, while heavy metals such as iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), bismuth (Bi), lead (Pb), and cadmium (Cd) accumulate in the environment and undergo bioaccumulation and bio magnification, thereby increasing in concentration through trophic levels of the food chain (Alloway, 2013; Radisson et al., 2023).

Among these, iron (Fe) plays a dual role in biological systems. It is essential for oxygen transport and enzymatic processes, but its excess concentration in water and soil can have adverse environmental and health effects (Yan et al., 2022). Iron overload can lead to oxidative stress, liver fibrosis, cardiovascular disorders, organ damage, and neurological complications (Suja et al., 2024). In aquatic environments, elevated iron levels reduce dissolved oxygen, discolour water, and impair gill function in fish, while in soil iron toxicity disturbs nutrient availability and reduces plant productivity (Harish et al., 2023).

The problem of iron contamination has intensified due to rapid industrialization and urban expansion over the past two centuries. Major sources include mining, metal coating, steel production, and electroplating, which discharge large volumes of iron-rich effluents into aquatic systems (Bhardwaj et al., 2019). Pipeline corrosion in aging water infrastructure also contributes significantly to Fe contamination in drinking water, releasing dissolved and particulate forms of iron that degrade water quality and pose serious health risks (Hussain et al., 2010). Additionally, agricultural runoff from

excessive use of iron-based fertilizers and pesticides mobilizes iron into surface and groundwater, contributing to eutrophication and microbial imbalance in soils (Sial et al., 2022).

Iron's environmental mobility and bioavailability are influenced by pH, organic matter, and redox potential, making its removal from aqueous systems challenging (Olaniran et al., 2013). Recognizing the hazards, organizations such as the World Health Organization (WHO) and the Environmental Protection Agency (EPA) have established permissible limits for iron concentrations in air, water, and soil to protect public health (Mustafa & Hassan, 2024).

In response to the limitations of conventional iron removal methods such as chemical precipitation, ion exchange, and membrane filtration which are often expensive and generate secondary pollutants, researchers have turned to natural adsorbents as a sustainable solution. These include agricultural byproducts (e.g. rice husk, sawdust, banana peels), clay minerals (e.g., bentonite, kaolinite), biochar, and plant-based materials (Bernard et al., 2013).

Among natural adsorbents, *Vitisvinifera* (grape branch steam powder) has emerged as a promising material for Fe(II) removal due to its porous structure and abundance of functional groups such as hydroxyl and carboxyl, which enhance metal binding (Khokhotva, 2010). Other mechanisms contributing to Fe(II) adsorption include ion exchange, surface complexation, electrostatic attraction, and physical adsorption through Van der Waals forces and pore diffusion. These mechanisms are influenced by parameters such as pH, contact time, adsorbent dosage, and initial metal concentration.

Overall, the application of natural adsorbents offers a cost-effective, eco-friendly, and efficient approach for iron remediation from contaminated water bodies. Future studies should focus on optimizing adsorption conditions, enhancing adsorbent regeneration, and testing performance in real wastewater scenarios to promote their widespread use in environmental clean-up efforts.

2. Literature review

Alloway (2013) provided a comprehensive overview of heavy metals and metalloids in soils, focusing on their sources, mobility, bioavailability, and environmental impacts. The book examines factors influencing metal accumulation in soils and plants, emphasizing risks to ecosystems and human health. It also discusses remediation strategies to mitigate contamination and ensure sustainable soil management.

Bernard et al. (2013) investigated the use of activated carbon derived from coconut shells to remove Cu(II), Fe(II), Zn(II), and Pb(II) ions from electroplating industrial wastewater. Optimal adsorption occurred with an adsorbent dosage of 1 g, stirring rate of 350 rpm, and pH 6. Kinetic analysis indicated that the adsorption process followed a pseudo-second-order reaction model. The findings suggest that coconut shell-based activated carbon is an effective and low-cost alternative for heavy metal remediation in industrial wastewater.

Bhardwaj et.al (2019) reviewed the impact of industrialization on heavy metal contamination in the Sirsa River, located in the Shivalik foothills. The study identifies major pollutants, their sources, and their effects on water quality and aquatic life. The authors emphasize the need for regular monitoring and sustainable management strategies to mitigate heavy metal pollution in the region.

Harish et al. (2023) review iron toxicity in plants, highlighting its occurrence in crops like rice and soybean, especially in regions with high soil pH and organic matter. They discuss mechanisms such as nutrient competition and oxidative stress leading to root damage. The study emphasizes understanding these processes to develop effective management strategies.

Hussain et.al (2010) investigated the corrosion issues affecting metallic water pipelines and their subsequent impact on drinking water quality. The study emphasizes that corrosion is influenced by the physical and chemical characteristics of the surrounding soil and water environments. The authors discuss how corrosion can lead to the leaching of heavy metals such as lead, copper, zinc, and iron into drinking water, posing significant health risks. They highlight the importance of implementing anti-corrosive protection measures and selecting appropriate materials to mitigate these risks and ensure the longevity and safety of water distribution systems.

Khokhotva (2010) investigated the adsorption capacity of pine bark-based sorbent for heavy metal removal from aqueous solutions. The study focused on key parameters such as contact time, pH, and metal ion concentration. Results indicated that the sorbent exhibited high efficiency in removing heavy metals, particularly at optimal pH values, with rapid adsorption kinetics. The adsorption process followed Langmuir and Freundlich isotherm models, suggesting both monolayer and heterogeneous surface adsorption. The research concluded that pine bark is a cost-effective and eco-friendly option for treating metal-contaminated water.

Lasheen et al. (2012) builds on existing research into biosorption as a low-cost method for heavy metal removal from wastewater. Prior studies have shown that agricultural wastes like orange peel contain functional groups capable of binding metals such as Cd(II), Cu(II), and Pb(II). Chemical modification of these biosorbents improves their adsorption capacity by enhancing surface properties and functional group availability. Previous work has focused on single-metal systems, but this study explores simultaneous removal of multiple metals. It fills a gap by combining equilibrium, kinetic, and desorption analyses using modified orange peel. The findings support its potential as an efficient, reusable biosorbent.

Mustafa and Hassan (2024) reviewed the impact of water contamination on human health, discussing key pollutants, their sources, and associated health risks. The study highlights microbial pathogens, heavy metals, and chemical contaminants as major contributors to waterborne diseases. The authors emphasize the need for effective water treatment and policy measures to mitigate risks and ensure safe drinking water.

Olaniran et.al (2013) reviewed the bioavailability of heavy metals in soil and their impact on microbial degradation of organic pollutants. The study discusses how heavy metals hinder microbial activity, reducing biodegradation efficiency. It also explores strategies to improve microbial resilience and enhance bioremediation, emphasizing the need for sustainable soil management practices.

Radisson (2023) explored biomagnifications and its environmental effects through a case study. The study highlights how toxic substances accumulate and intensify through the food chain, leading to adverse ecological and health impacts. The study emphasizes the need for monitoring and regulatory measures to mitigate biomagnification-related risks.

Sial et al. (2022) investigated the impact of agricultural and industrial activities on water pollution in Faisalabad City, Pakistan. They collected 150 drinking water samples from various locations and found that areas influenced by industrial waste had elevated nitrate levels, while regions with better drainage exhibited lower nitrate concentrations. The study underscores the significant role of both

agriculture and industry in water quality degradation and emphasizes the need for effective management strategies to mitigate pollution.

Suja et al. (2024) provided a comprehensive overview of the sources and environmental impacts of heavy metal contamination in water bodies. The authors discuss various treatment methods for removing heavy metals from contaminated water, including chemical precipitation, ion exchange, adsorption, membrane filtration, and electrochemical treatments. They emphasize the effectiveness of adsorption techniques, particularly using low-cost and sustainable adsorbents, in mitigating heavy metal pollution. The review highlights the need for developing efficient and eco-friendly treatment technologies to ensure safe water quality.

3. Research Methodology

This study was conducted to investigate the adsorption potential of *Vitis vinifera* (grape branch stem powder) for the removal of iron (II) Fe (II) ions from aqueous solutions under various physicochemical conditions. The experimental work was performed in a batch mode setup, where multiple adsorption parameters were carefully optimized to evaluate their influence on metal removal efficiency. All experimental procedures were carried out using high-purity analytical-grade chemicals to ensure precision and eliminate any contamination that might interfere with the accuracy of the results.

A commercially available 1000 ppm stock standard solution of iron (II) obtained from Merck was used throughout the study. Working solutions of desired concentrations were prepared by performing serial dilutions of the stock solution using deionized water. Deionised water was used consistently throughout the study to avoid interference from other ionic species or impurities that may be present in tap or distilled water. All reagents and chemicals used were of analytical reagent (AR) grade to maintain high levels of purity. The glassware used, including volumetric flasks, Erlenmeyer flasks, pipettes, and beakers, was thoroughly cleaned with and rinsed with deionised water to remove any residual contaminants before each use.

pH adjustments were made using freshly prepared 0.01 N hydrochloric acid (HCl) and 0.01 N sodium hydroxide (NaOH) solutions. These were carefully added drop wise with continuous monitoring using a digital pH meter to achieve the desired pH levels during experimentation. All experiments were carried out in triplicates to ensure reproducibility and reliability of data.

The general adsorption procedure involved the addition of a specific amount of adsorbent (*Vitis vinifera* branch stem powder) to a 50 mL solution of Fe (II) ions with a known initial concentration. The mixtures were placed in 250 mL Erlenmeyer flasks and agitated at a constant speed on a rotary shaker to ensure proper dispersion and interaction between the adsorbent surface and Fe (II) ions. Contact time, one of the most crucial parameters in adsorption studies, was varied from 5 to 90 minutes to identify the equilibrium time required for maximum removal of Fe (II) ions. The influence of adsorbent dosage was also examined by varying the amount from 0.05 g to 0.4 g. This helped to determine the optimal quantity of adsorbent required to achieve efficient removal while avoiding unnecessary excess.

Temperature plays a vital role in the kinetics and thermodynamics of adsorption. Therefore, experiments were carried out at different temperatures viz-20°C, 25°C, 30°C, 35°C, 40°C, and 45°C to assess its effect on the adsorption process. These experiments were important to understand whether the process is endothermic or exothermic in nature. Likewise, the pH of the solution was varied systematically from 1 to 12 to determine the optimal pH conditions that favour maximum adsorption of Fe (II) ions, as pH significantly affects the surface charge of the adsorbent and the speciation of metal ions.

Another critical variable studied was the initial metal ion concentration, which was varied from 200 µg/L to 2000 µg/L. This was done to assess the adsorbent's capacity under varying Fe (II) ion loads and to analyze its behaviour at both low and high concentrations. The data obtained helped evaluate the saturation point of the biosorbent and its suitability for different pollution levels.

Upon completion of the adsorption process, the mixtures were filtered through Whatman No. 41 filter paper to remove the adsorbent. The residual Fe (II) concentration in the filtrate was analyzed using Atomic Absorption Spectroscopy (AAS), which offers high precision and sensitivity for metal detection. Calibration curves were prepared using standard solutions to ensure accurate quantification. The removal efficiency of Fe (II) was calculated using the formula:

$$R\% = [(C_o - C_e) / C_o] \times 100$$

Where, C_o and C_e represent the initial and final concentrations of Fe (II) ions, respectively.

This comprehensive methodology facilitated the evaluation of the adsorption capacity and effectiveness of *Vitis vinifera* stem powder under various controlled experimental conditions. The results obtained provide valuable insights into the optimization of parameters influencing Fe (II) removal and highlight the potential of this low-cost, eco-friendly biosorbent in wastewater treatment applications.

4. Results and Discussion

4.1 Effect of Contact Time :

The effect of contact time on the adsorption of Fe (II) ions was investigated by varying the duration from 5 to 90 minutes while maintaining a constant adsorbent dosage of 0.1 g and an initial metal ion concentration of 1000 µg. The results revealed a rapid increase in Fe (II) removal during the initial stages, with maximum adsorption (92.1%) achieved at 10 minutes (Fig. 4.1).

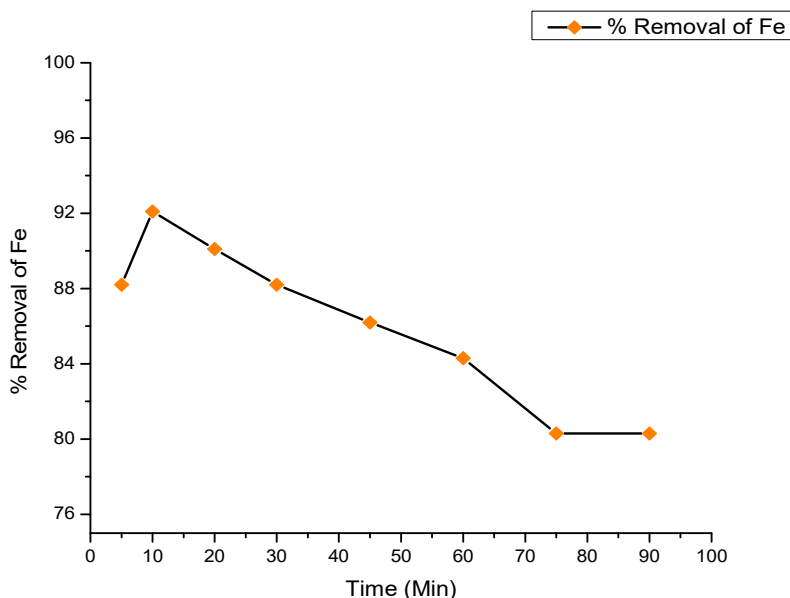


Figure 4.1: Time Effect of Contact time Fe(II)

As the contact time increased beyond 10 minutes, a gradual decline in removal efficiency was observed, which may be due to the saturation of adsorption sites or slight desorption of previously

adsorbed Fe (II) ions. Additionally, steric hindrance caused by already adsorbed ions may inhibit further ion access to the remaining active sites. These findings suggest that equilibrium is rapidly established, and extending the contact time beyond 10 minutes does not enhance removal but may even lead to a slight reduction in adsorption efficiency. Thus, 10 minutes is identified as the optimal contact time for the efficient removal of Fe (II) ions using the prepared biosorbent.

4.2 Effect of Adsorbent Dosage:

To determine the optimal amount of biosorbent for effective Fe (II) removal, the adsorbent dosage was varied from 0.05 g to 0.4 g, while keeping the initial metal ion concentration at 1000 μg and the contact time fixed at 10 minutes. The percentage removal of Fe (II) increased progressively with increasing adsorbent dosage, reaching a peak value of 96.0% at 0.25 g and 0.3 g (Fig. 4.2). This trend can be explained by the greater availability of active binding sites as more adsorbent is added, enhancing the uptake of Fe (II) ions from the solution. However, a slight decline in removal efficiency was noted when the dosage exceeded 0.3 g, which may be due to aggregation of adsorbent particles at higher concentrations. Such aggregation can reduce the effective surface area available for adsorption and lead to overlapping of active sites, thereby limiting metal ion binding. Furthermore, excessive adsorbent might result in unsaturated active sites, decreasing the adsorption capacity per unit mass. Therefore, 0.25 g of biosorbent was found to be the most effective dosage for maximum removal of Fe (II) under the studied conditions.

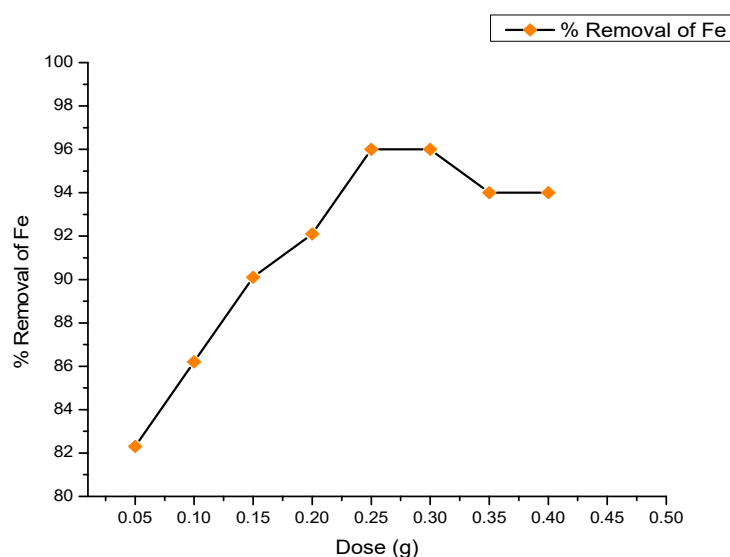


Figure 4.2: Effect of Adsorbent dose Fe(II)

4.3 Effect of Initial Metal Ion Concentration:

The effect of varying initial concentrations of Fe(II) ions on adsorption capacity was evaluated within the range of 200 μg to 2000 μg , using a fixed adsorbent dosage 0.25 g, contact time 10 minutes, and temperature 30°C under natural pH conditions. The adsorption efficiency was found to be 100% at lower concentrations 200–600 μg , (Fig. 4.3) indicating complete metal ion removal due to the abundant availability of active adsorption sites. However, as the concentration increased beyond 600 μg , a gradual reduction in removal efficiency was observed 95.1% at 800 μg and only 68.6% at 2000 μg . This decline is likely due to the saturation of active sites on the adsorbent surface and intensified

competition among Fe (II) ions for limited binding sites. Despite the decrease in efficiency, high removal rates even at higher concentrations suggest the adsorbent's strong affinity for Fe (II) ions.

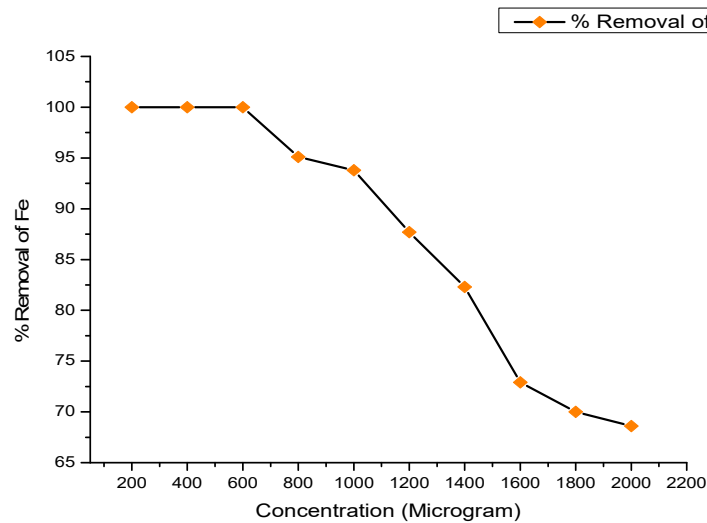


Figure 4.3: Effect of initial metal ion conc. Fe(II)

The study concludes that initial concentrations up to 600 µg ensure complete and efficient removal of Fe (II) ions without requiring pH adjustments, making the process more practical and environmentally sustainable.

4.4 Effect of Temperature:

The influence of temperature on the adsorption performance of the biosorbent was assessed by conducting experiments at temperatures ranging from 20°C to 45°C, while keeping the metal ion concentration 1000 µg, adsorbent dosage 0.25 g, and contact time 10 minutes constant.

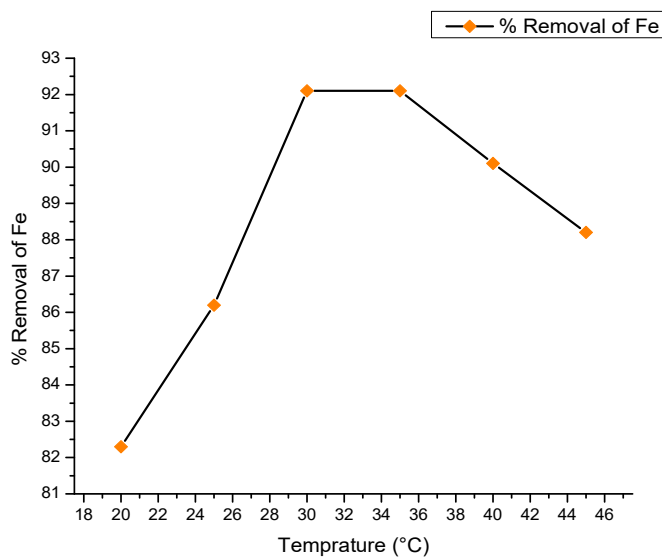


Figure 4.4 : Effect of Temperature Fe(II)

The results demonstrated that Fe (II) removal efficiency increased with temperature, achieving maximum adsorption of 92.1% at 30°C and 35°C.(Fig. 4.4) The initial enhancement in adsorption can be attributed to the increased kinetic energy of Fe (II) ions at elevated temperatures, which improves diffusion rates and enhances interactions between the adsorbate and the adsorbent's active sites. However, beyond 35°C, a decline in removal efficiency was observed, possibly due to desorption of Fe (II) ions or weakening of the adsorbent–adsorbate interactions as a result of thermal agitation. Additionally, structural changes in the biosorbent at higher temperatures may negatively impact the number and accessibility of binding sites. Therefore, it can be concluded that the optimal temperature for Fe (II) adsorption using the grape branch steam powder based adsorbent lies between 30°C and 35°C.

4.5 Effect of pH:

pH is a crucial parameter affecting both the adsorbent surface charge and the speciation of metal ions in solution. The effect of pH on Fe (II) adsorption was examined over a wide range 1–12 under controlled conditions: 1000 µg metal ion concentration, 10 minute contact time, 0.25 g adsorbent dosage, and temperature of 30°C.

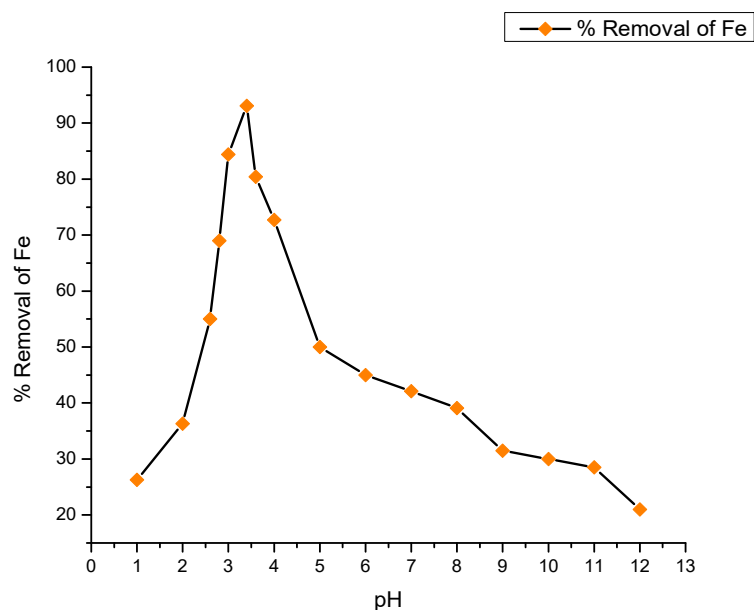


Figure 4.5: Effect of pH Fe(II)

The results showed that Fe (II) removal efficiency increased with rising pH, reaching an optimum value of 93.1% at pH 3.4. At low pH, the high concentration of hydrogen ions competes with Fe (II) ions for binding sites, thereby reducing adsorption. As the pH increases, the number of negatively charged sites on the adsorbent surface increases, enhancing electrostatic attraction toward the positively charged Fe (II) ions. However, at pH values above the optimum, the formation of insoluble iron hydroxide precipitates reduce the availability of free Fe (II) ions in the solution, resulting in a decline in adsorption efficiency. These results suggest that pH 3.4 offers the most favourable (Fig. 4.5) conditions for effective Fe (II) adsorption, balancing between maximum ion availability and strong adsorbent-adsorbate interaction.

4.6 Fourier Transform Infrared (FTIR) Spectral Analysis

Fourier Transform Infrared Spectroscopy is often used to identify the surface area of adsorbents and determine those groups in binding of metal ions (Lasheen et al.). Fourier Transform Spectra obtained from vitis vinifera before and after absorption of Fe (II) metal ion reported in figure 4.6 and 4.7 respectively. The strong band observed in 1324 cm⁻¹ 1332cm⁻¹ indicating –CN starching vibration of protein fractions. The peak at 1422 cm⁻¹ showing symmetric banding of CH₃ of acetyl moiety.

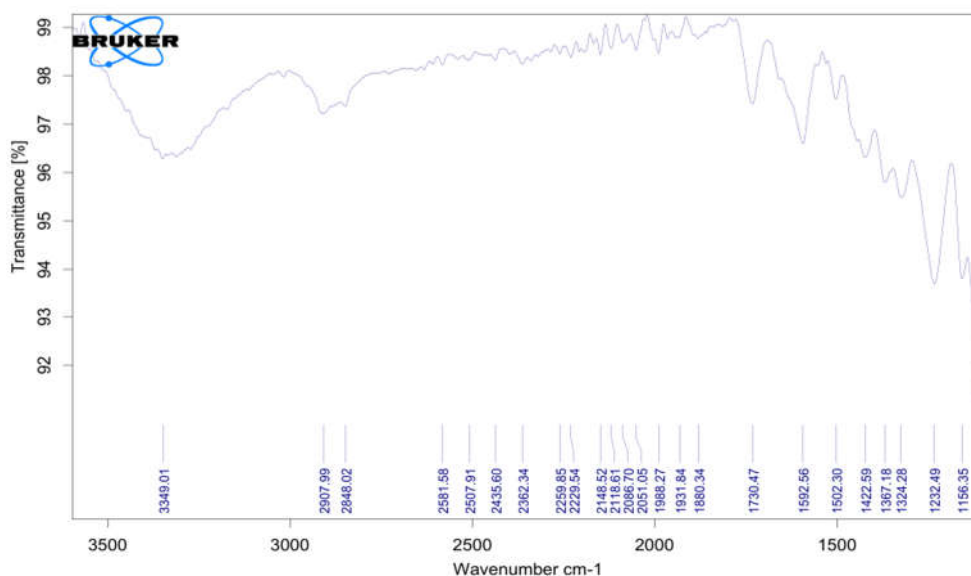


Figure 4.6: FTIR spectra of Vitisvinifera without Fe (II) adsorption

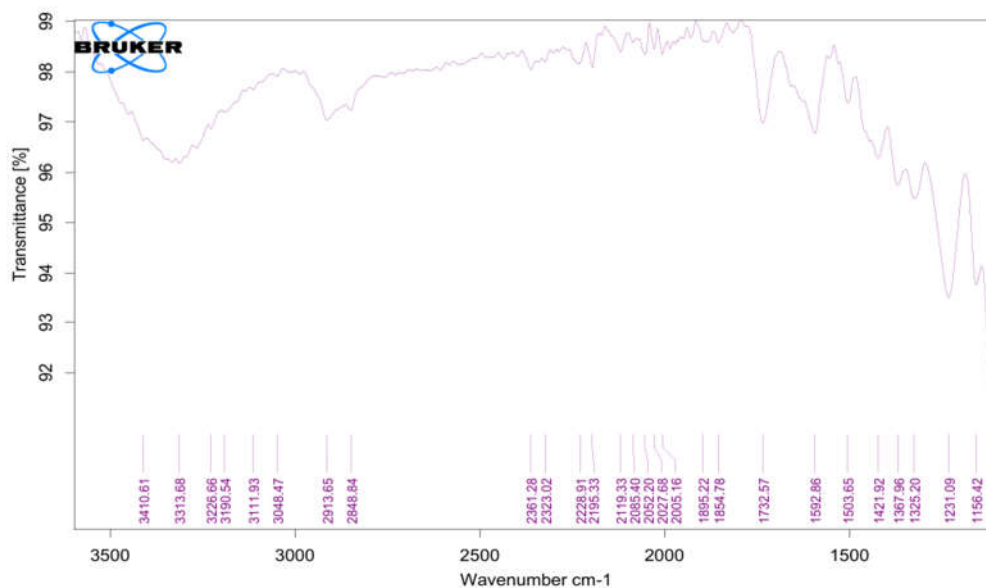
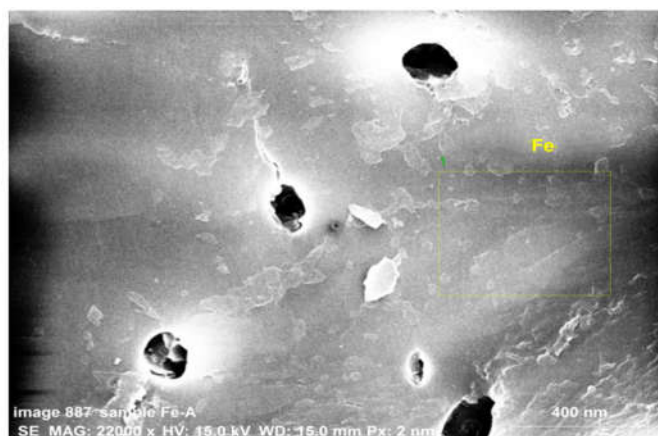


Figure 4.7: FTIR spectra of Vitisvinifera with Fe (II) adsorption

The band at 1592 cm⁻¹ due to C=O stretching vibrations, the absorption band at the region between 2907 cm⁻¹, 3349 cm⁻¹, showed the presence of CH Stretching vibration pack at 2259cm⁻¹ to 1880cm⁻¹ and 1050cm⁻¹ to 800cm⁻¹ indicates C-X bond. The –NH group at variable wave number 1332cm⁻¹, 2259cm⁻¹, attributing vibrations of NH₂.

The spectra obtained due to interaction of functional groups on the vitis vinifera with Fe (II), the FTIR peak might shift to lower to higher wave numbers after absorption of Fe (II) (Fig.4.7). The peak obtained in vitis vinifera at 2848 cm^{-1} shifted to 2907 cm^{-1} in Fe(II) loaded adsorbent. The peaks around 1324 cm^{-1} , 1592 cm^{-1} , 1156 cm^{-1} suggest that carbonyl and amine groups may participate in adsorption. The peaks at 1332 cm^{-1} , 3349 cm^{-1} were attributed to metal chelate of amine, carboxyl and hydroxyl group respectively.

4.7 SEM micrograph and Energy Dispersive X-ray Analysis of Fe (II)



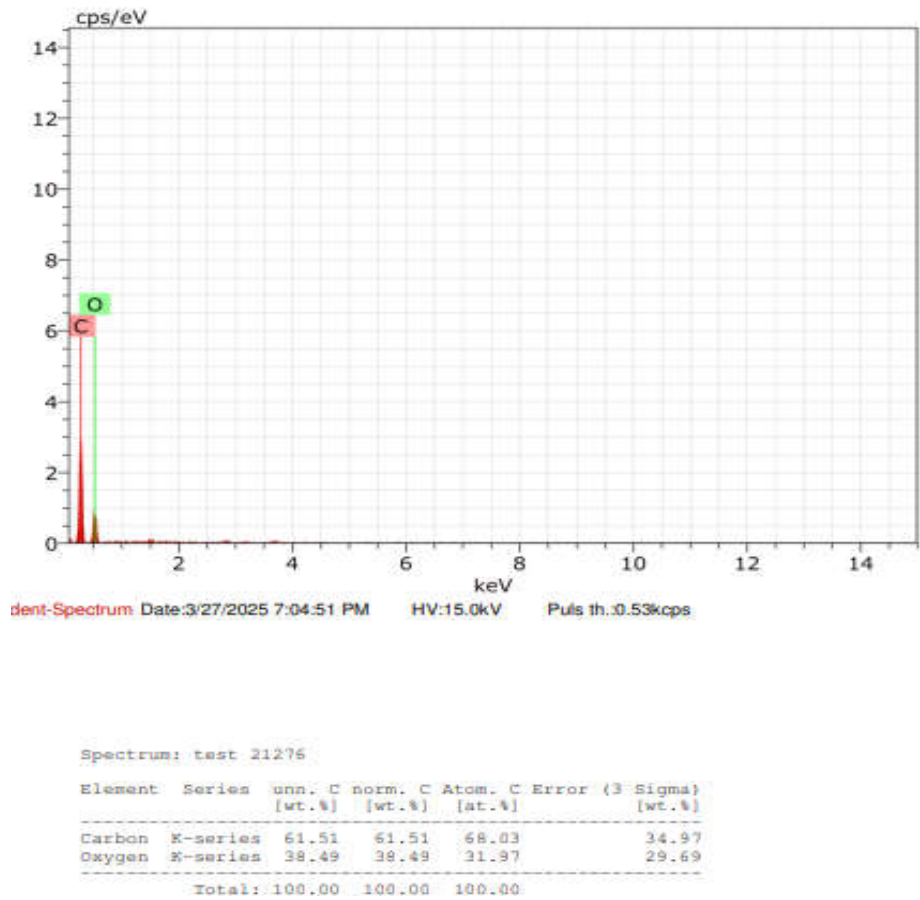
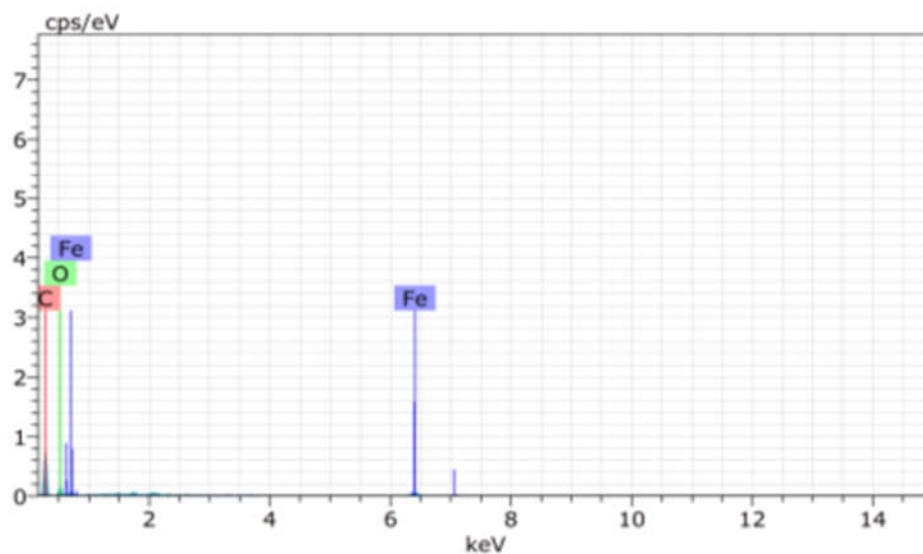
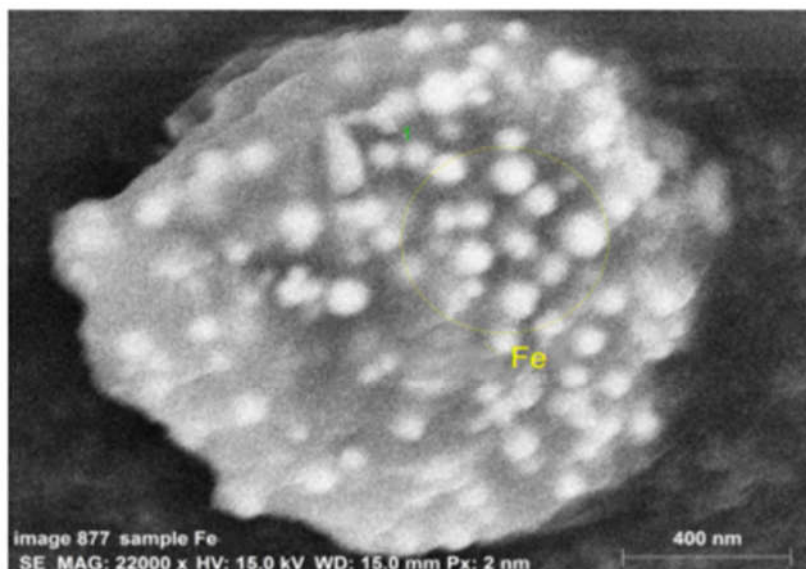


Figure 4.8: SEM micrograph and Energy Dispersive X-ray Analysis of Fe(II) Before Adsorption



Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (3 Sigma) [wt.%]
Carbon	K-series	37.78	62.08	75.82	18.43
Oxygen	K-series	13.23	21.73	19.93	9.36
Iron	K-series	9.85	16.19	4.25	1.54
Total:		60.86	100.00	100.00	

Figure 4.9: SEM micrograph and Energy Dispersive X-ray Analysis of Fe(II) After Adsorption

The morphological analysis of phenol formaldehyde treated with vitisvinifera branch steam powder was performed by as shown in fig. 4.8. Many small pores and particles are observed on the surface of adsorbent. In fig 4.9 pores are not observed. It clearly indicates that biosorption of Fe (II) on vitis vinifera adsorbent EDX spectrum from Fig 4.9 also showed peak of 0.5 Kev and 6.4 KeV which conform that iron (II) was adsorbed on adsorbent. Which was absent in fig 4.8. It support that the

reactions of metal ion and phenolic –OH group on treats adsorbent powder, surface may be partly ion exchange or complexation.

6. Conclusion

This study demonstrated that *Vitis vinifera* (grape branch stem powder) is an effective biosorbent for the removal of Fe(II) ions from aqueous solutions. The adsorption efficiency was strongly influenced by parameters such as contact time, dosage, temperature, pH, and initial metal ion concentration. Maximum Fe(II) removal of 92.1% was achieved at 10 minutes, beyond which efficiency declined due to site saturation and potential desorption. An adsorbent dose of 0.25 g was found to be optimal, yielding 96% removal, with higher doses showing a slight decrease due to particle aggregation.

Optimal adsorption occurred at 30°C, and pH 3.4 showed the highest removal (93.1%). Efficiency remained 100% for Fe(II) concentrations up to 600 µg, after which it declined as adsorption sites became saturated. Overall, the results confirm that *Vitis vinifera* is a low-cost, eco-friendly, and efficient material for iron removal, with strong potential for wastewater treatment applications. Further studies on reusability and regeneration could enhance its practical utility.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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