

Efficient Adsorption of Zinc (II) Ions from Aqueous Solution onto A Low-Cost Adsorbent Developed from Vitis Vinifera (Grape Branch Stem Powder)

Balasaheb V. Umbarkar¹, Rakesh Kumar¹, Shashikant R. Kuchekar², Haribhau R. Aher³

¹Department of Chemistry Shri JYT University, Jhunjhunu Rajasthan, India

²PMT'S Art, Commerce and Science College Shevgoan, Dist. Ahilyanagar, MS, India.

³JYT University Rajasthan, Principal ASC College Kolhar, Ahilyanagar

DOI: <https://doi.org/10.51583/IJLTEMAS.2025.1407000039>

Abstract: This study explores the use of Vitis vinifera (grape branch stem powder) as an eco-friendly and cost-effective biosorbent for the removal of Zn (II) ions from aqueous solutions. With the increasing concern over heavy metal pollution, especially zinc contamination from industrial activities, the development of sustainable remediation strategies has become essential. The objective of this work is to evaluate the adsorption capacity of grape branch stem powder for zinc ions and investigate the influence of various operational parameters on the adsorption process. The biosorbent was prepared by washing, drying, grinding, and sieving grape branches to obtain a fine powder, which was stored in airtight containers. Batch adsorption experiments were performed by varying key parameters such as pH, contact time, adsorbent dosage, initial metal ion concentration, and temperature to determine optimal conditions for maximum zinc removal. Zinc ion concentrations before and after adsorption were measured using Atomic Absorption Spectrophotometry (AAS). Characterization of the biosorbent before and after adsorption was carried out using FTIR, SEM, and EDX to understand surface morphology, functional groups, and elemental composition. The study concludes that Vitis vinifera branch stem powder shows significant potential as a natural biosorbent for zinc.

Keywords: Zinc, Vitis vinifera, biosorption, grape branch stem powder, eco-friendly biosorbent.

I. Introduction

Heavy metal contamination poses a significant environmental threat due to its persistence, non-biodegradability, and toxic effects on ecosystems and human health. Among various pollutants, heavy metals such as zinc (Zn), lead (Pb), copper (Cu), manganese (Mn), cadmium (Cd), iron (Fe), and bismuth (Bi) pose significant risks because of their ability to persist in ecosystems and accumulate through the food chain (Alloway, 2013). These metals originate mainly from anthropogenic sources such as mining, electroplating, battery manufacturing, fertilizer production, and other chemical industries, leading to extensive contamination of aquatic and terrestrial environments (Mustafa & Hassan, 2024).

The rapid pace of industrialization and urbanization during the 19th and 20th centuries significantly worsened this issue. Large-scale mining operations, metal processing plants, and chemical industries discharged vast quantities of toxic metals into natural ecosystems (Bhardwaj et al., 2019). The unregulated disposal of industrial effluents, combined with the widespread use of metal-based products and agrochemicals, has contributed to the contamination of soils and water bodies across the globe (Kakkar et al., 2010).

Unlike organic pollutants, which can degrade over time, heavy metals persist in the environment due to their non-biodegradable nature. Once released, they accumulate in soil, water, and living organisms, disrupting natural biochemical cycles and posing long-term risks to ecosystems and human health (Kakkar et al., 2010). These metals undergo bioaccumulation building up in living tissues and biomagnification, where their concentrations increase as they move up the food chain (Radisson et al., 2023). Contaminated soils can remain toxic for centuries, reducing soil fertility, affecting crop growth, and threatening food safety (Alloway, 2013). The mobility and bioavailability of heavy metals in the environment depend on complex interactions with soil pH, redox conditions, and organic matter content, which make their remediation particularly challenging (Olaniran et al., 2013).

Due to their health impacts, regulatory bodies such as the Environmental Protection Agency (EPA) and the World Health Organization (WHO) have established permissible limits for heavy metals in air, water, and soil to prevent long-term damage (Mustafa & Hassan, 2024).

Among these toxic metals, Zn (II) presents a paradoxical challenge. While it is an essential micronutrient involved in enzymatic activities, immune function, and cellular metabolism, its excessive accumulation can lead to toxicity. In humans, high Zn (II) levels can interfere with copper absorption, leading to anemia, immune suppression, gastrointestinal distress, and neurological disorders (Osredkar et al., 2011; Plum et al., 2010). In aquatic systems, elevated Zn concentrations are lethal to fish, causing oxidative stress, gill damage, and disruption of metabolic processes. In soils, excess Zn impairs plant growth and reduces microbial diversity (Alloway, 2013).

Zinc contamination in water bodies has become a significant environmental and public health issue due to its extensive use in

industrial, agricultural, and domestic applications. Key contributors to Zn pollution include metal plating, alloy production, battery manufacturing, and the indiscriminate use of zinc-based fertilizers and pesticides. The problem is further aggravated by the improper disposal of Zn-containing products. Zinc's non-biodegradable nature means it can accumulate in living organisms and magnify up the food chain, ultimately threatening aquatic ecosystems and human health.(Kuchekar et al., 2019)

The environmental persistence and toxic effects of Zn (II), there is an urgent need for effective and sustainable remediation technologies. Among various treatment options, adsorption using natural materials has emerged as a promising alternative due to its high efficiency, low cost, and environmental compatibility. Natural adsorbents have shown strong potential for zinc (II) removal through various mechanisms such as ion exchange, surface complexation, electrostatic interactions, and physical adsorption.

Various categories of natural materials have been widely explored for this purpose. **Agricultural wastes**, including rice husk, banana peels, coconut shells, and sawdust, are rich in functional groups like hydroxyl and carboxyl, which can effectively bind metal ions (Raikar et al., 2015). **Clay minerals**, such as bentonite, montmorillonite, and kaolinite, are valued for their high surface area and cation exchange capacity, enabling efficient adsorption. **Biomass and biochar**, derived from sources like algae, fungi, and plants, offer porous structures and large surface areas that enhance metal retention (Moghaddam et al., 2015). Additionally, **plant-derived materials** such as neem leaves, orange peels, *Moringa oleifera* seeds, and *Vitis vinifera* (grape branch stem powder) have gained significant attention due to their natural bioactive compounds, which contribute to high metal-binding efficiency (Adebayo et al., 2016). These diverse natural adsorbents not only provide a sustainable solution to heavy metal pollution but also utilize waste materials, aligning with circular economy and eco-friendly remediation practices.

The efficiency of Zinc adsorption depends on critical parameters such as solution pH, contact time, biosorbent dosage, initial metal concentration, and temperature. Understanding the influence of these factors is crucial for optimizing the biosorption process. Adsorption mechanisms such as ion exchange involve the replacement of metal ions by functional groups on the adsorbent surface, while surface complexation and electrostatic attraction facilitate stable bonding and effective removal. Porous surface structures also contribute to zinc retention through physical adsorption.

Considering the limitations of conventional treatment methods and the urgent need for environmentally benign approaches, the use of plant-based adsorbents presents a viable and sustainable solution for Zinc removal. This study focuses on the use of *Vitis vinifera* (grape branch stem powder), a naturally abundant and low-cost agricultural byproduct, to explore its efficiency in adsorbing Zn ions from aqueous solutions. The study also investigates how different environmental parameters affect adsorption performance and evaluates the material using advanced characterization techniques, aiming to offer a green and economical approach for water purification and heavy metal remediation.

II. Background of the Proposed Project

Heavy metal pollution has become a serious concern due to its toxicity, persistence, and accumulation in the environment. Among these, zinc (Zn (II))—although essential in trace amounts—can pose significant environmental and health hazards when present in excess. Conventional methods for heavy metal removal are often expensive, energy-intensive, and may generate secondary pollutants. As a result, biosorption has emerged as a cost-effective, eco-friendly, and sustainable alternative.

In this context, natural materials such as agricultural waste and plant residues have shown great promise as biosorbents. *Vitis vinifera*, commonly known as grape, is widely cultivated and its branches are often discarded as waste. Utilizing grape branch powder for the removal of Zn(II) not only promotes waste management but also contributes to sustainable water purification methods.

Objectives:

- To prepare *Vitis vinifera* (grape branch) stem powder and characterize it as a natural bioadsorbent.
- To evaluate the efficiency of the prepared adsorbent for Zn(II) ion removal from aqueous solutions.
- To investigate the effects of various parameters such as contact time, pH, adsorbent dosage, initial metal concentration, and temperature on zinc adsorption.
- To analyze the functional groups and morphological characteristics of the biosorbent using FTIR, SEM, and EDX techniques.

Scope:

This study explores the use of *Vitis vinifera* stem powder as a bioadsorbent for the removal of Zn(II) ions. The scope includes evaluating adsorption performance under different experimental conditions, identifying optimal removal parameters, and characterizing the adsorbent material using modern analytical techniques.

III. Related Review Literature and Studies

Adebayo et al. (2016) used modified orange peels to remove Fe(II) and Cd(II) from water, analyzing factors like pH, contact

time, dosage, and temperature. Their findings support the use of agricultural waste as cost-effective biosorbents. Similarly, our study uses *Vitis vinifera* branch powder for Bi(III) removal, following the same adsorption parameters, showing comparable potential for eco-friendly water treatment. 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.

Bhardwaj et al. (2019) highlighted how industrialization caused heavy metal pollution in the Sirsa River, affecting water quality and aquatic life. They stressed the need for sustainable solutions. Our study aligns with this by offering a natural, low-cost biosorbent (*Vitis vinifera* branch powder) to help reduce such heavy metal contamination from water bodies.

Kakkar and Shaw (2010) discussed toxicological impacts of environmental pollution and stressed the need for monitoring and regulation. Our study contributes to this approach by exploring biosorption using *Vitis vinifera* branch powder as an eco-friendly method to mitigate heavy metal contamination in water.

Kuchekar et al. (2019) evaluated *Syzygium cumini* bark for zinc removal, demonstrating effective biosorption under optimized conditions. Similarly, our study uses *Vitis vinifera* branch powder, supported by FTIR analysis and batch experiments, to establish its potential as a sustainable biosorbent for heavy metal remediation.

Moghaddam et al. (2015) reviewed the eco-friendly biosynthesis of metal nanoparticles using fungi and yeast. Though focused on nanotechnology, the study supports the broader concept of biological materials serving as effective agents in environmental remediation—paralleling our use of *Vitis vinifera* for biosorption of heavy metals.

Mustafa and Hassan (2024) discussed the health risks associated with water contamination from pollutants like heavy metals. Their findings reinforce the significance of our study, which targets the removal of such toxic metals using natural biosorbents to promote safe and clean water.

Olaniran et al. (2013) highlighted how heavy metals in soil reduce microbial degradation of pollutants, stressing the urgency of effective remediation. This supports the relevance of biosorption studies like ours, which aim to remove heavy metals and reduce their ecological impact.

Osredkar and Sustar (2011) emphasized the essential roles and toxicity risks of Cu (II) and Zn (II), showing how their imbalance leads to serious health issues. This underscores the importance of controlling heavy metal levels in water, aligning with our study's goal of removing Cu and Zn using eco-friendly biosorbents.

Plum et al. (2010) explored zinc's dual nature—vital at trace levels but harmful in excess—highlighting its biological importance and toxicity risks. This supports the need for efficient Zn (II) removal from wastewater, as addressed in our study using *Vitis vinifera*-based biosorbents.

Radisson (2023) examined biomagnification and its ecological effects, emphasizing how toxic substances like heavy metals intensify through the food chain. This underscores the relevance of our study, which aims to remove such metals at the source using sustainable biosorption techniques to prevent long-term environmental harm.

Raikar et al. (2015) investigated the use of natural and activated rice husk for Pb(II) removal, finding enhanced adsorption in the activated form. This supports the current study's focus on low-cost biosorbents like *Vitis vinifera* branch powder, reinforcing the importance of agricultural waste valorization for heavy metal remediation.

IV. Methodology

Preparation of *Vitis vinifera* Adsorbent

The preparation of *Vitis vinifera* (grape branch stem powder) as a biosorbent was carried out through a multistep process designed to enhance surface area and adsorption efficiency.

Collection and Pre-treatment: Fresh grape branches were collected from local vineyards. The branches were cut into small sections to facilitate further processing.

Washing and Sun Drying: The pieces were washed thoroughly with distilled water to eliminate surface impurities such as dust, dirt, and organic residues. The cleaned samples were then sun-dried for 4–5 days until complete dehydration was achieved.

Grinding and Sieving: The dried material was ground using a mechanical grinder to obtain fine particles. The ground powder was sieved through a 150-micron mesh to ensure uniform particle size suitable for adsorption experiments.

Purification Step: The sieved powder was subjected to hot distilled water treatment. It was repeatedly boiled and filtered until the wash water appeared clear, indicating the removal of soluble organic and inorganic impurities.

Final Drying and Storage: The purified material was dried in a hot air oven at $70 \pm 5^\circ\text{C}$ for 4 hours to remove any residual moisture. The adsorbent was then cooled, sealed in an airtight container, and stored in a desiccator until further use.

This preparation method ensured the production of a low-cost, eco-friendly biosorbent suitable for heavy metal ion removal from aqueous solutions.

Reagents and Solutions

A 1000 ppm stock standard solution of zinc(II) (Merck, Germany) was used as the primary source for all adsorption experiments. Working solutions of desired concentrations (ranging from 50 µg to 500 µg per 25 mL) were prepared by serial dilution with freshly prepared, double-distilled deionized water. All reagents used were of analytical grade.

Glassware was cleaned thoroughly with 1% nitric acid, followed by multiple rinses with deionized water before each experiment to avoid contamination. Zinc(II) solutions were stored in airtight polyethylene containers and freshly prepared before each adsorption run to ensure consistency.

Batch Adsorption Procedure

Batch experiments were conducted to evaluate the removal efficiency of zinc(II) ions using *Vitis vinifera* (grape branch stem powder) as the biosorbent. A fixed volume (25 mL) of zinc(II) solution was placed in a 100 mL Erlenmeyer flask, and a pre-weighed amount of biosorbent (ranging from 0.5 to 3.0 g) was added.

The flasks were agitated on a rotary shaker at a constant speed (150 rpm) to ensure uniform contact between adsorbent and metal ions. Contact time was varied from 15 to 120 minutes, and samples were withdrawn at predetermined intervals. Each sample was immediately filtered using Whatman No. 41 filter paper, previously conditioned with deionized water.

The residual zinc(II) concentration in the filtrate was determined using Atomic Absorption Spectroscopy (AAS) at 213.9 nm, following external calibration with standard solutions. The percentage removal (%R) was calculated using the equation:

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

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

All experiments were performed in triplicate, and average values were reported with standard deviations where applicable.

Parameters Studied

Effect of Contact Time: 15–120 minutes

Adsorbent Dosage: 0.5–3.0 g

Initial Metal Ion Concentration: 50–500 µg/25 mL

Temperature: 20°C–50°C

pH Range: 4.0–9.0, adjusted using 0.01 N HCl or NaOH

Each parameter was optimized to determine the most effective conditions for zinc(II) removal.

V. Results and Discussion

Effect of Contact Time

The contact time between biosorbent and adsorbate is a fundamental parameter in adsorption studies, as it governs the interaction period available for metal ions to bind to active sites on the biosorbent surface. In the present study, the effect of contact time on the adsorption of Zn (II) ions by *Vitis vinifera* (grape branch stem powder) was examined over a range of 15 to 120 minutes, using a constant Zn (II) ion concentration of 500 µg, an adsorbent dose of 1.0 g, and 50 mL of solution. (Fig.5.1)

The adsorption efficiency exhibited a progressive increase with time, peaking at 84.2% at 45 minutes. Initially, rapid uptake of Zn (II) ions occurred, attributed to the large number of vacant active sites on the biosorbent surface. This phase is typically governed by external surface adsorption, where the ions rapidly adhere to the adsorbent exterior. As time advanced, the rate of adsorption slowed, reflecting a transition into a phase where intra-particle diffusion and equilibrium dynamics became dominant. Beyond 45 minutes, a slight reduction in adsorption efficiency was observed, likely due to the saturation of accessible sites and possible desorption of previously bound ions, leading to an equilibrium state.

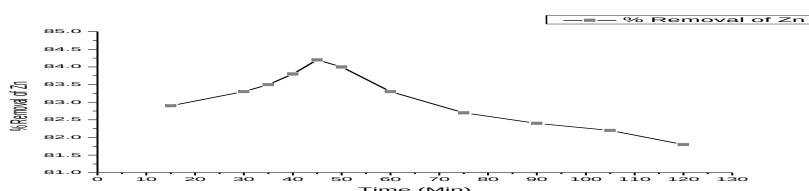


Figure 5.1: Effect of Contact time on adsorption of Zn (II)

Thus, 45 minutes was determined to be the optimal contact time for Zn (II) removal using *Vitis vinifera* (grape branch stem powder). Prolonging the contact time beyond this point did not significantly improve adsorption efficiency and could lead to unnecessary energy usage and time expenditure. These findings underline the kinetic behavior of the biosorption process and assist in optimizing adsorption conditions for future batch-scale treatments.

Effect of Adsorbent Dosage The amount of adsorbent utilized in any adsorption process is a key factor that influences the availability of binding sites and the overall performance of metal ion removal. To assess the influence of adsorbent dosage, experiments were conducted by varying the mass of grape branch stem powder from 0.5 g to 3.0 g while maintaining a fixed Zn (II) ion concentration 500 µg, contact time 45 minutes, and solution volume 50 mL. (Fig.5.2)

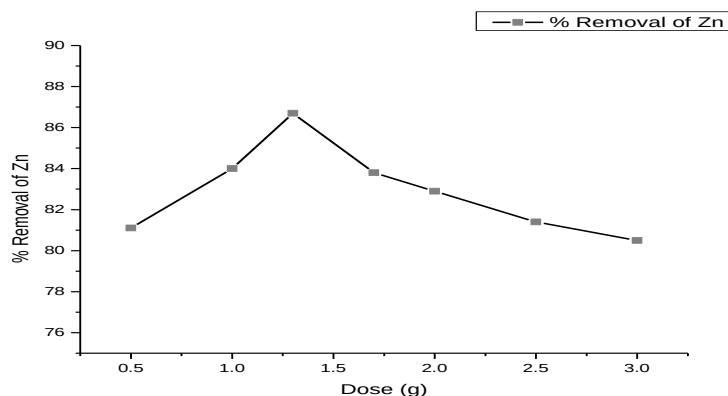


Figure 5.2: Effect of Adsorbent dose on adsorption of Zn (II)

The data revealed a marked increase in Zn (II) removal efficiency with rising adsorbent dosage, with a maximum efficiency of 86.7% recorded at a dosage of 1.3 g. This improvement is explained by the increase in total surface area and active sites available for adsorption. At lower dosages, the biosorbent had insufficient surface area to accommodate all the Zn (II) ions, resulting in suboptimal removal. However, with increasing mass, the availability of active sites improved, allowing for enhanced ion capture.

Interestingly, a minor decline in efficiency was noticed beyond 1.3 g. This is likely due to particle agglomeration, which reduces effective surface area and may restrict access to internal binding sites through pore blockage or intra-particle diffusion resistance. Additionally, at higher biosorbent concentrations, the number of active sites may surpass the available Zn (II) ions in solution, resulting in inefficient utilization of the adsorbent.

Therefore, 1.3 g was established as the optimal dosage for achieving maximum removal efficiency. This balance ensures effective Zn (II) ion removal without unnecessary excess of biosorbent, thereby contributing to the economic feasibility of the treatment system.

Effect of Temperature

Temperature affects the thermodynamic behavior of adsorption, influencing ion mobility, reaction kinetics, and binding affinity between metal ions and the adsorbent surface. In this study, the adsorption of Zn (II) ions was evaluated at varying temperatures 20°C to 50°C, using constant conditions for metal concentration 500 µg, contact time 45 minutes, and biosorbent dose 1.3 g. (Fig.5.3)

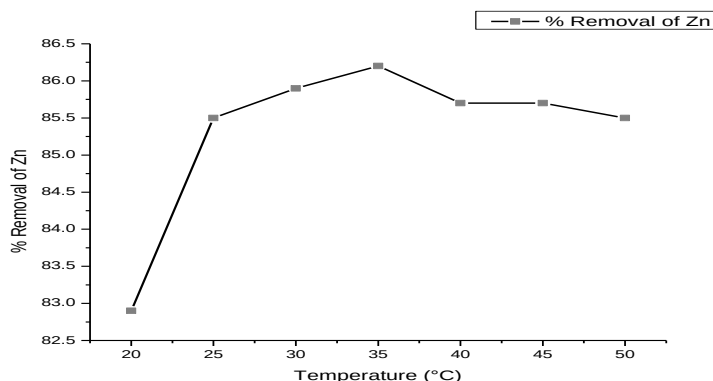


Figure 5.3: Effect of Temperature on adsorption of Zn (II)

An increasing trend in zinc (II) adsorption efficiency was observed with temperature, achieving the highest removal of 86.2% at 35°C. The enhancement in efficiency can be attributed to increased kinetic energy and diffusion rate of Zn (II) ions in solution, which promotes their migration towards the adsorbent surface and enhances interaction with binding sites. Moreover, elevated temperatures may cause structural modifications in the biosorbent, making active sites more accessible.

However, temperatures beyond 35°C resulted in a slight decline in adsorption efficiency. This drop may be attributed to the weakening of metal-sorbent interactions or the onset of desorption, where adsorbed ions begin to detach from the surface due to excess thermal energy. High temperatures might also disrupt the physical structure of the biosorbent, reducing its capacity to retain ions.

From these observations, 35°C was identified as the optimal temperature for Zn (II) biosorption using grape branch stem powder, striking a balance between enhanced ion mobility and retention capacity.

Effect of pH

The pH of the aqueous solution significantly affects the speciation of metal ions and the surface charge of the biosorbent, thereby influencing adsorption performance. The effect of pH on Zn (II) adsorption was examined by adjusting the pH from 4.0 to 9.0 using dilute HCl and NaOH, while keeping all other parameters constant. (Fig.5.4)

The experimental findings indicated that the optimal Zn (II) removal efficiency of 90.2% was achieved at pH 5.8. At lower pH values pH 4.0–5.0, excess H^+ ions competed with Zn (II) ions for binding sites on the adsorbent surface, leading to decreased removal efficiency. Additionally, the positive surface charge of the biosorbent in acidic conditions may repel Zn (II) ions, which are also positively charged, further reducing adsorption.

As the pH approached 5.8, the surface of the grape branch stem powder likely acquired a more negative charge, promoting electrostatic attraction and efficient binding of Zn (II) ions. Beyond this point, especially above pH 7, a gradual decline in adsorption efficiency was observed. This was likely due to the formation of zinc hydroxide precipitates, which decreased the free Zn (II) ion concentration in solution, interfering with the adsorption process.

The pH value of 5.8 was thus established as optimal for Zn (II) removal, as it ensured favorable electrostatic conditions without inducing precipitation or altering the adsorption mechanism.

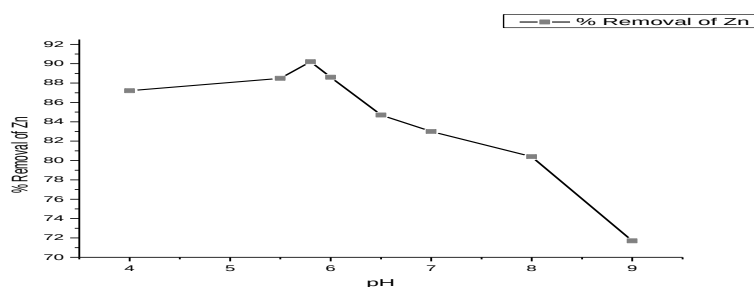


Figure 5.4: Effect of pH on adsorption of Zn (II)

Effect of Initial Metal Ion Concentration

The initial concentration of metal ions in solution determines the driving force for mass transfer and influences adsorption capacity and efficiency. In this study, initial Zn (II) concentrations ranging from 50 μg to 500 μg were tested under optimized conditions: 1.3 g adsorbent, 45 minutes contact time, pH 5.8, and temperature 35°C. (Figure 5.5)

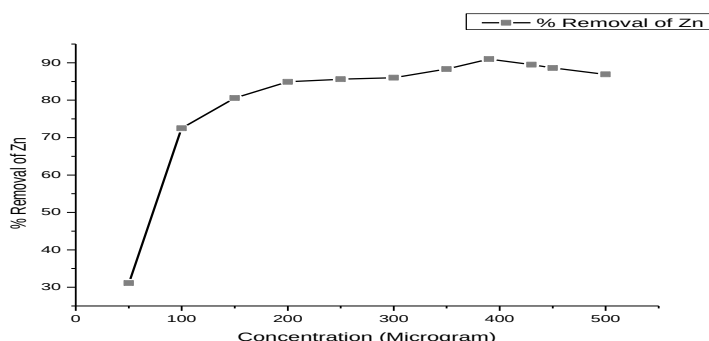


Figure 5.5: Effect of initial metal ion conc. on adsorption of Zn (II)

The results showed that adsorption efficiency improved with increasing Zn (II) concentration up to 390 µg, where the maximum removal of 91.0% was recorded. At lower concentrations, an abundance of vacant adsorption sites ensured efficient uptake of Zn (II) ions. As the concentration increased, more ions competed for the same number of active sites, enhancing adsorption until the biosorbent neared saturation.

Beyond 390 µg, a slight decrease in adsorption efficiency was observed, attributed to the saturation of binding sites and the inability of the adsorbent to accommodate excess ions. This finding underscores the finite capacity of the biosorbent and highlights the importance of optimizing metal ion concentrations to avoid overloading the system.

Therefore, 390 µg was identified as the optimal initial concentration for efficient Zn (II) removal using *Vitis vinifera* (grape stem powder), ensuring maximum uptake while maintaining biosorbent effectiveness.

FTIR Spectra of *Vitis vinifera* stem powder before and after adsorption of Zn (II)

FTIR Spectra of *Vitis vinifera* stem powder before and after biosorption is reported in figure 5.6 and 5.7. The strong peaks observed in *vitis vinifera* stem powder at 1020 cm⁻¹ (-CN stretching vibrations of protein functions), 2364 cm⁻¹ (vibrations of -NH₂), 1422 cm⁻¹ (vibrations for symmetric bonding of -CH₃ acetyl moiety), 1592 cm⁻¹ (amide bond), 1730 cm⁻¹ (C=O chelate stitching), 3016 cm⁻¹ and 2905 cm⁻¹ (C-H stretching) and 3418 cm⁻¹ (bonded -OH group and -NH stretching), 492 cm⁻¹ (for C-X).

The peaks after biosorption with Zn (II) become more prominent, slight shifted and large of 3331 cm⁻¹, 1522 cm⁻¹ wave number respectively. The increase in intensity of major peaks, after Zn (II) biosorption is probably due to chelating effect of Zn (II) with the functional group of biosorbent.

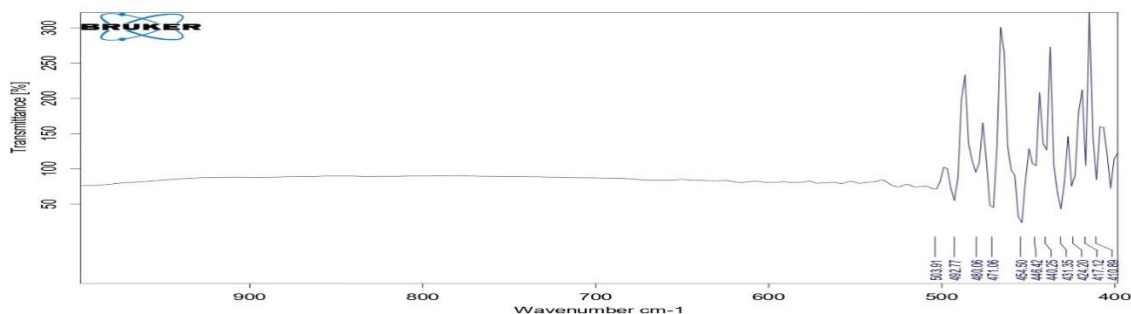


Figure 5.6: FTIR spectra of *Vitis vinifera* without Zn (II) adsorption

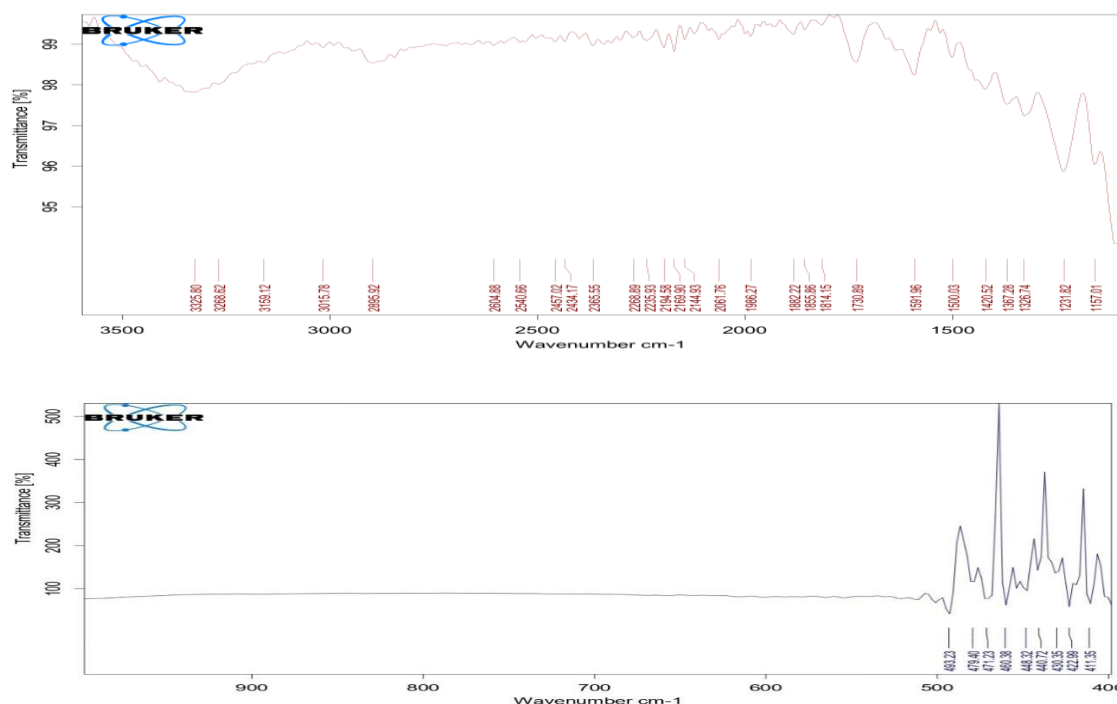


Figure 4.7: FTIR spectra of *Vitis vinifera* with Zn (II) adsorption

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

The morphological analysis of phenol formaldehyde treated vitis vinifera stem powder was performed by SEM is shown in figure 5.8. Small pore and particles are observed on the surface of biosorbent. It clearly indicates biosorption of Zn (II) on adsorbent. EDX spectrum from figure 5.9 also shows peaks at 1.1 Kev and 8.6 Kev which conformed that Zn (II) was adsorbed on adsorbent and which was not in figure 4.8. It supports that the reaction of metal ion and phenolic -OH group on phenol formaldehyde treated vitis vinifera stem powder surface may be partly ion exchange or coplexation

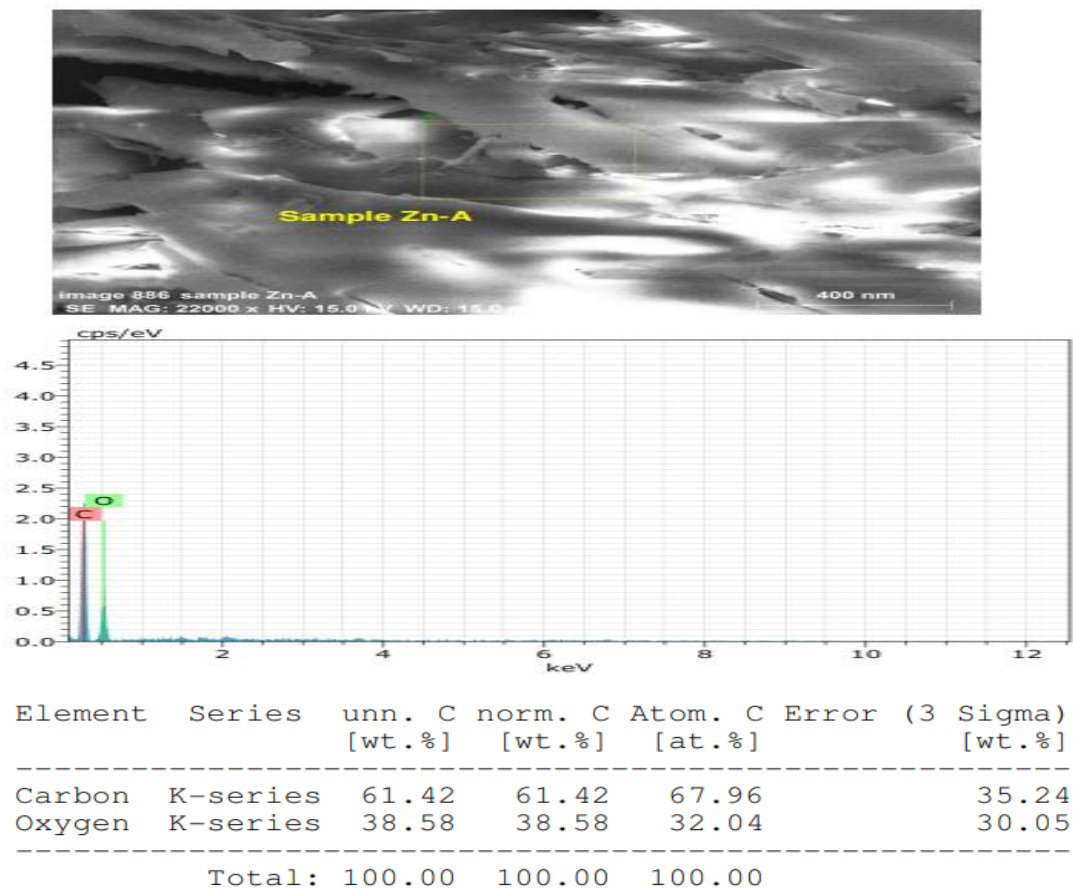
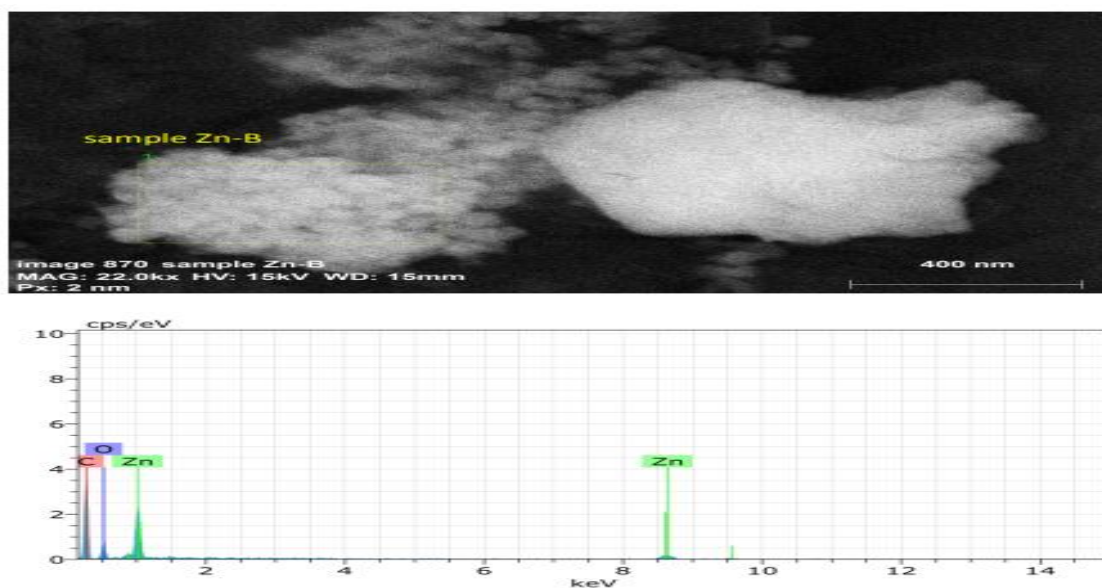


Figure 5.8: SEM micrograph and Energy Dispersive X-ray Analysis of Zn (II) Before Adsorption



Element	Series	unn. C [wt. %]	norm. C [wt. %]	Atom. C [at. %]	Error (3 Sigma) [wt. %]
Carbon	K-series	103.05	59.75	79.78	54.25
Zinc	K-series	45.85	26.58	6.52	8.92
Oxygen	K-series	23.58	13.67	13.70	18.87
Total:		172.48	100.00	100.00	

Figure 5.9: SEM micrograph and Energy Dispersive X-ray Analysis of Zn (II) After Adsorption

V. Conclusion

The findings of this study confirm that *Vitis vinifera* (grape branch stem powder) is an efficient, cost-effective, and eco-friendly biosorbent for removing Zn (II) ions from aqueous solutions. The adsorption process was notably influenced by factors such as contact time, adsorbent dosage, temperature, pH, and initial metal ion concentration. A maximum removal efficiency of 91.0% was achieved under optimal conditions, with equilibrium reached within 45 minutes. Adsorption was highly pH-dependent, peaking at pH 5.8, while efficiency declined at extreme pH levels due to metal precipitation or reduced ion availability.

The process was found to be endothermic, with the best results at 35°C. Efficiency increased with higher initial metal concentrations up to 390 µg/L, after which it plateaued due to binding site saturation. Compared to conventional methods like chemical precipitation or membrane filtration, the use of *Vitis vinifera* offers advantages such as low cost, natural availability, and sustainability, making it suitable for large-scale wastewater treatment.

Future studies should explore its performance in real wastewater, assess reusability and regeneration, and investigate kinetic and thermodynamic parameters to better understand the adsorption mechanism and enhance its practical application.

VI. Acknowledgements

Research Scholar is thankful to Arts, Commerce and Science College Kolhar, and Shevgaon for allowing to work as research scholar for JJTU University Rajasthan and also Authors are thankful to management of Pravara Rural Education Society and Pravara Medical Trust's Arts, Commerce and Science College, Shevgaon for allowing me to work as a research Co-Guide for JJTU University Rajasthan.

References

1. Adebayo, G. B., Mohammed, A. A., & Sokoya, S. O. (2016). Biosorption of Fe (II) and Cd (II) ions from aqueous solution using a low-cost adsorbent from orange peels. *Journal of Applied Sciences and Environmental Management*.
2. Alloway, B. J. (2013). Heavy metals in soils: Trace metals and metalloids in soils and their bioavailability. Springer Science & Business Media.
3. Bhardwaj, S. K., Sharma, R., & Aggarwal, R. K. (2019). Impact appraisal of industrialization on heavy metal contamination of Sirsa River located in the Shivalik foothills of North Western Himalayas. *Current World Environment*.
4. Kakkar, P., & Shaw, A., ENVIS Newsletter, Indian Institute of Toxicology Research.
5. Kuchekar, S. R., Patil, M. P., Aher, H. R., Gaikwad, V. B., & Han, S. H. (2019). Biosorption efficiency of *Syzygium cumini* bark for removal of zinc from industrial effluent. *IJRAR*.
6. Moghaddam, A. B., Namvar, F., Moniri, M., Tahir, P. M., Azizi, S., & Mohamad, R. (2015). Nanoparticles biosynthesized by fungi and yeast: A review of their preparation, properties, and medical applications. *Molecules*.
7. Mustafa, B. M., & Hassan, N. E. (2024). Water contamination and its effects on human health: A review. *Journal of Geography, Environment and Earth Science International*.
8. Olaniran, A. O., Balgobind, A., & Pillay, B. (2013). Bioavailability of heavy metals in soil: Impact on microbial biodegradation of organic compounds and possible improvement strategies. *International Journal of Molecular Sciences*.
9. Osredkar, J., & Sustar, N. (2011). Copper and zinc: Biological role and significance of copper/zinc imbalance. *Journal of Clinical Toxicology*.
10. Plum, L. M., Rink, L., & Haase, H. (2010). The essential toxin: Impact of zinc on human health. *International Journal of Environmental Research and Public Health*.
11. Radisson, N. (2023) A case study of biomagnification and its effects on the environment. *International Research Journal of Research in Environmental Science and Toxicology*.
12. Raikar, R. V., Correa, S., & Ghorpade, P. (2015). Removal of lead (II) from aqueous solution using natural and activated rice husk. *International Research Journal of Engineering and Technology*.