Simultaneous Removal of Multiple Heavy Metals from Aqueous Solution Using Rice Husk-Derived Biosorbent

Dheerendra Rajoriya [1], Dr. Manoj Sharma[2]
Research scholar[1], IPSCTM, Gwalior, Affiliated to RGPV, Bhopal (MP)
Professor[2] IPSCTM, Gwalior, Affiliated to RGPV, Bhopal (MP)

ABSTRACT

In this study the presence of multiple heavy metals in wastewater poses a serious environmental and public health challenge due to their non-biodegradable nature, bioaccumulation, and toxicity even at trace concentrations. This study investigates the simultaneous removal of selected heavy metals lead (Pb^{2+}), cadmium (Cd^{2+}), and chromium (Cr^{6+}) from synthetic aqueous solutions using rice husk-derived biosorbents. Rice husk, an abundant agricultural byproduct, was processed through washing, drying, and thermal treatment to enhance its adsorptive properties. Characterization techniques such as FTIR, SEM, and BET surface area analysis were employed to determine surface morphology and functional groups responsible for metal ion binding.

Batch adsorption experiments were conducted to examine the effect of critical parameters including initial metal concentration, pH, contact time, and biosorbent dosage. The adsorption data were analyzed using Langmuir and Freundlich isotherm models, while kinetic behavior was assessed using pseudo-first-order and pseudo-second-order models. The results demonstrated high removal efficiencies (>85%) for all three metals under optimized conditions, with evidence of selective affinity and competitive adsorption behavior. This study underscores the potential of rice husk as a low-cost, eco-friendly, and effective biosorbent for simultaneous removal of multiple heavy metals, contributing to sustainable and circular approaches in wastewater remediation.

Keywords: Rice husk biosorbent, Heavy metal removal, Aqueous solution, Competitive adsorption, Sustainable remediation.

1.INTRODUCTION

Water pollution due to the discharge of industrial effluents containing heavy metals is a critical environmental issue worldwide. Industries such as electroplating, mining, textiles, battery manufacturing, and metal processing release substantial amounts of toxic metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), and chromium (Cr^{6+}) into water bodies. These metals are non-biodegradable, tend to bioaccumulate in living organisms, and can cause severe health problems, including neurological, renal, and carcinogenic effects, even at trace levels. The simultaneous presence of multiple heavy metals in wastewater further complicates their removal due to competitive adsorption behaviors and varying chemical affinities.

Conventional treatment methods—such as chemical precipitation, ion exchange, membrane filtration, and electrochemical processes—are often cost-prohibitive, generate secondary pollution, or show limited efficiency at low metal concentrations. In contrast, biosorption has emerged as a cost-effective and environmentally friendly alternative, particularly for treating metal-laden wastewater. Agricultural byproducts such as rice husk offer a promising solution due to their abundance, low cost, and high content of functional groups (e.g., hydroxyl, carboxyl, and silica-based sites) that can effectively bind heavy metals.

This study aims to evaluate the efficiency of rice husk-derived biosorbent in removing Pb^{2+}, Cd^{2+}, and Cr^{6+} from synthetic aqueous solutions under varying operational conditions. Key objectives include analyzing the effects of pH, contact time, initial metal concentration, and biosorbent dosage on adsorption performance. Additionally, isotherm, kinetic, and thermodynamic models will be applied to understand the adsorption mechanisms and interactions involved in multi-metal systems.

By exploring the potential of rice husk for simultaneous heavy metal removal, this research contributes to the development of sustainable and scalable solutions for wastewater treatment, aligning with circular economy principles and agricultural waste valorization.

.

2.LITERATURE REVIEW

Tano Patrice Fato, et.al (2019)- The exploration of simultaneous removal of co-existing or multiple pollutants from water by the means of nanomaterials paves a new avenue that is free from secondary pollution and inexpensive. In the aquatic environment, river water contains a mixture of ions, which can influence the adsorption process. In this respect, removing heavy metal ions becomes a true challenge. Here, four heavy metal ions, namely, Pb^{2+}, Cd^{2+}, Cu^{2+}, and Ni^{2+}, have been successfully removed simultaneously from river water using ultrafine mesoporous magnetite (Fe_3O_4) nanoparticles (UFMNPs) based on the affinity of these metal ions toward the UFMNP surfaces as well as their unique mesoporous structure, promoting the easy adsorption. The individual removal efficiencies of Pb^{2+}, Cd^{2+}, Cu^{2+}, and Ni^{2+} ions from river water were 98, 87, 90, and 78%, respectively, whereas the removal efficiencies of the mixed Pb^{2+}, Cd^{2+}, Cu^{2+}, and Ni^{2+} ions were 86, 80, 84, and 54%, respectively, in the same river water. Thus, the data clearly indicate the complex removal of heavy metal ions in multi-ion systems. This study has demonstrated the huge potential of UFMNPs to be effective for their use in wastewater treatment, especially to simultaneously remove multiple heavy metal ions from aqueous media.

Zhiyuan Liu, et.al (2020)- In this research, activated carbon (AC) was prepared from rice husk (RH) by the KOH chemical activation method. The characterization results of scanning electron microscopy (SEM), Brunauer–Emmett–Teller (BET), Fourier transform infrared (FTIR), Raman spectroscopy, and X-ray photoelectron spectroscopy (XPS) showed that rice husk-activated carbon (RHAC) had good pore structure and oxygen-containing functional groups. The influences of contact time, initial concentration of Hg(II), adsorbent dosage, pH, and ionic strength on mercury ion removal were investigated. The Langmuir model was most suitable for the adsorption isotherm of RHAC, and its maximum adsorption capacity for Hg(II) was 55.87 mg/g. RHAC still had a high removal capacity for Hg(II) after five regeneration cycles.

Sari Tuomikoski et al (2021)- Activated carbon from sawdust was produced with an environmentally friendly process involving single-stage carbonization and activation with steam at 800°C. Production process is scalable because lignocellulosic biomass is ubiquitous worldwide as a waste or as a virgin material. Single-stage production without any cooling steps between carbonization and activation is easier in larger scale production. Monometal adsorption and multimetal adsorption of cobalt, nickel, and zinc were investigated by using the produced carbon, with a commercial one as control. Effect of pH, initial metal concentration, adsorbent dosage, and adsorption time was evaluated in batch experiments. Multimetal experiments showed the order of the maximum adsorption capacities: zinc > nickel > cobalt. Experimental adsorption capacities were 17.2, 6.6, and 4.5 mg/g for zinc, nickel, and cobalt, respectively, in multi solute adsorption.

Mahmoud S.M et al. (2022)- The study was conducted to explore the efficiency of the biosorption process utilizing rice husk to remove Pb^{2+} and Cr^{3+} from synthetic wastewater. Biosorption studies at different operating parameters, such as biosorbent dosage (0.5-5.0 g), pH (pH2– 8), contact time

(15-120 minutes), and initial heavy metal concentration (10-100 mg/L), were conducted in batch experiments. The highest performance for Pb2+ and Cr3+ biosorption was found at 5.0g biosorbent dosage of spent mushroom compost, unadjusted pH 6, 10 minutes of contact time, and 10 mg/L of initial concentration. The study was well fitted to the Langmuir isotherm model (R2 > 0.90) for Pb2+ and Cr3+ biosorption, which are much greater compared to the Freundlich model. Solvent of 0.1N Sulphuric acid showed higher desorption of Pb2+ (89%) and Cr3+ (86%) adsorption-desorption process can be continued till seven cycles efficiently. In conclusion, the rice husk has the potential to be an effective biosorbent for removing Pb2+ and Cr3+ from synthetic wastewater.

Jonas Bayuo et al. (2023) – In the current study, the multicomponent adsorption of heavy metals from different complex mixtures, such as binary, ternary, quaternary, and quinary solutions, utilizing various adsorbents are reviewed in detail. According to the systematic review, the adsorbents made from locally and naturally occurring materials, such as biomass, feedstocks, and industrial and agricultural waste, are effective and promising in removing heavy metals from complex water systems. The systematic study further discovered that numerous studies evaluate the adsorption characteristics of an adsorbent in a multicomponent system using various important independent adsorption parameters.

Tichem, T. M. et. al (2024)- This study has explored the potential of rice husk biochar as a low-cost adsorbent for the removal of contaminants from aqueous solutions, including aldrin, mercury (Hg2+), lead (Pb2+), and cadmium (Cd2+). Experimentation involved adding varying doses of biochar to wastewater with different contamination levels, agitating the mixture for 60 min, and filtering the solutions for analysis. The experiment revealed impressive removal efficiencies: 100% for aldrin, 99.92% – 99.99% for Hg2+, 95.90% – 99.52% for Pb2+, and 88.60% – 99.46% for Cd2+. In binary and quaternary mixtures, Hg2+ showed higher removal efficiency than Pb2+ and Cd2+, with the exception of aldrin. The adsorption order was identified as aldrin > Hg2+ > Pb2+ > Cd2+. The Freundlich adsorption isotherm best described heavy metals in the mono and quaternary component adsorption, while the Langmuir adsorption isotherm was a better fit for the binary component. Consequently, the study highlights rice husk biochar as an efficient, sustainable, and environmentally friendly option for wastewater treatment.

Melisa S. Romano et al. (2025) - This study aimed to analyze the biosorption of Pb2+ using both natural and chemically treated rice husk and to evaluate the incorporation of the resulting biomass-contaminant residue into ceramic matrices to immobilize the removed Pb2+. Natural and alkaline-activated rice husks were characterized and used as biosorbents for Pb2+ in solution. Experimental results demonstrated that the maximum removal occurred at pH 5 and equilibrium was reached in 30 minutes. The chemical modification caused a significant increase in the removal efficiency, from 7.08 ± 0.59% to 94.51 ± 1.17% at room temperature and a biosorbent dosage of 3 g/L. The Langmuir isotherm model was the most appropriate for representing Pb2+ biosorption onto rice husk.

3. METHODOLOGY

The materials used in this study include both natural adsorbent materials and laboratory-grade chemicals for preparing synthetic wastewater solutions.

Materials and Chemicals:

- Rice husk was collected from a local rice mill, thoroughly washed with distilled water to remove dust and impurities, and then dried at 80°C for 24 hours.
- Heavy metal stock solutions of Pb^{2+}, Cd^{2+}, and Cr^{6+} (1000 mg/L) were prepared using analytical-

grade salts: lead nitrate [$Pb(NO_3)_2$], cadmium chloride [$CdCl_2$], and potassium dichromate [$K_2Cr_2O_7$].

- All other reagents were of analytical grade and used without further purification. Deionized water was used throughout the experiments

Preparation of Rice Husk Biosorben

- The dried rice husk was ground and sieved to a uniform particle size (e.g., < 500 µm).
- Chemical modification was performed by treating the rice husk with 0.1 M NaOH for 24 hours under continuous stirring to enhance surface functionality.
- The treated husk was rinsed repeatedly with deionized water until neutral pH was reached, then oven-dried and stored in airtight containers.
- For comparative analysis, untreated rice husk was also prepared following the same size reduction and drying steps

Characterization of Biosorbent

The raw and treated rice husk were characterized using:

- Fourier Transform Infrared Spectroscopy (FTIR): To identify functional groups responsible for metal binding.
- Scanning Electron Microscopy (SEM): To observe surface morphology.
- Brunauer–Emmett–Teller (BET) analysis: To determine surface area and pore volume (optional but recommended).
- pH at point of zero charge (pHpzc): Determined to evaluate the influence of pH on adsorption.

Batch Adsorption Experiments

Batch studies were conducted to evaluate the adsorption of Pb^{2+}, Cd^{2+}, and Cr^{6+} simultaneously.

Experimental Setup:

- 100 mL of synthetic wastewater containing known concentrations of Pb^{2+}, Cd^{2+}, and Cr^{6+} (e.g., 50 mg/L each) was placed in 250 mL Erlenmeyer flasks.
- A fixed amount of biosorbent (e.g., 1 g/L) was added.
- The flasks were agitated in an orbital shaker at 150 rpm at room temperature.

Parameters Investigated:

- Contact time: 0–180 minutes
- pH: 2–8 (adjusted using 0.1 M HCl/NaOH)
- Biosorbent dosage: 0.5–2.0 g/L
- Initial metal concentrations: 10–100 mg/L
- Temperature: 25–45°C (for thermodynamic studies)

After agitation:

- Samples were filtered, and metal ion concentrations in the filtrate were measured using Atomic Absorption Spectroscopy (AAS) or Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

Adsorption Isotherms and Kinetics

- Adsorption data were fitted to Langmuir, Freundlich, and Temkin isotherm models.
- Kinetic models applied: pseudo-first-order, pseudo-second-order, and intraparticle diffusion.
- Thermodynamic parameters such as Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$) were calculated from experiments conducted at varying temperatures.

Data Collection and Analysis

Data collection in this study involved the systematic measurement of residual concentrations of heavy metals (Pb^{2+}, Cd^{2+}, and Cr^{6+}) in aqueous solutions after treatment with rice husk-derived biosorbent. After each batch adsorption experiment, the solution was filtered, and the filtrate was analyzed using Atomic Absorption Spectroscopy (AAS) to determine the concentration of each metal ion remaining in solution.

The amount of metal adsorbed per unit mass of biosorbent (q_e, mg/g) and the removal efficiency (%) were calculated using the following standard equations**:**

Adsorption capacity (qe):

$$qe = \frac{(co - ce) \times V}{m}$$

Removal Efficiency (%):

$$\textbf{Removal (\%)} = \frac{(C_o - C_e)}{C_o} \text{ X } 100$$

Where:

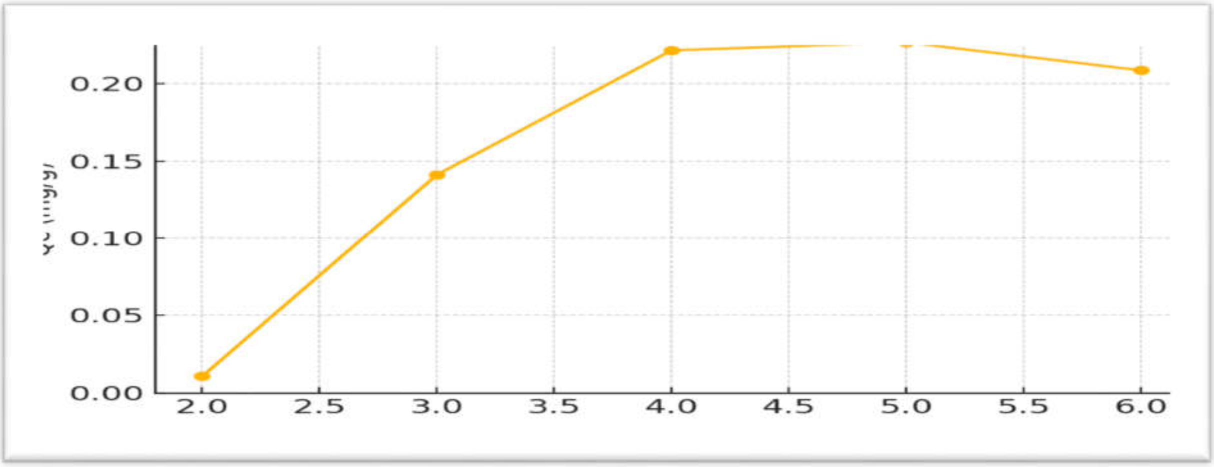
- Co = Initial metal concentration (mg/L)
- Ce = Equilibrium metal concentration (mg/L)
- V = Volume pf Solution(L)
- M = Mass of biosorbent (g)

The collected data were analyzed to evaluate the effects of contact time, pH, initial metal concentration, biosorbent dosage, and temperature on adsorption performance.

4. RESULT

Table; Comparison of Adsorption Efficiency for Grounded Rice Husk

Initial Concentration (mg/L)	Qe (mg/g) Zn	Qe (mg/g) Cu	Qe (mg/g) Pb
1	0.088	0.082	0.0087
2	0.2445	0.187	0.185
3	0.3050	0.280	0.232
4	0.358	0.2314	0.4096
5	0.4008	0.3792	0.4532



The figure illustrates the effect of pH on the adsorption capacity (Qe, in mg/g) of the rice husk-derived biosorbent for heavy metal removal from aqueous solution. As shown, the adsorption capacity increases significantly with rising pH from 2.0 to 4.0, indicating enhanced metal uptake. This trend suggests that at low pH values, the high concentration of hydrogen ions competes with metal ions for active adsorption sites, leading to lower adsorption efficiency. The maximum adsorption is observed around pH 4.0 to 5.0, where Qe reaches its peak. Beyond pH 5.0, a slight decline in Qe is noted, which may be attributed to the formation of metal hydroxide precipitates, reducing the availability of free metal ions for adsorption. Overall, the figure highlights that pH plays a crucial role in optimizing the biosorption process, with the optimal performance occurring in the moderately acidic range.

5.CONCLUSION

The present study demonstrates that rice husk-derived biosorbent is an effective, low-cost, and sustainable material for the simultaneous removal of multiple heavy metals from aqueous solutions. The biosorbent exhibited significant adsorption capacities for metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), chromium (Cr^{6+}), and copper (Cu^{2+}), with removal efficiencies influenced by factors such as pH, contact time, initial metal concentration, and biosorbent dosage. The adsorption data fit well with both Langmuir and Freundlich isotherm models, suggesting the presence of both monolayer and heterogeneous adsorption mechanisms.

Kinetic studies indicated that the adsorption followed a pseudo-second-order model, pointing to chemisorption as the dominant mechanism. The presence of functional groups such as hydroxyl, carboxyl, and silica components on the rice husk surface contributed significantly to the metal binding process. Overall, the study highlights rice husk as a promising biosorbent for industrial wastewater treatment applications, offering an eco-friendly and economically viable method for heavy metal remediation. Further work is recommended to scale up the process and assess regeneration and reuse potential under real wastewater conditions.

6. REFERENCES

1. Banerjee, S., Joshi, M. V., & Jayaram, R. V. (2012). Removal of Cr (VI) using rice husk ash and commercial activated carbon. Desalination and Water Treatment, Vol.No.37, Issue No. (1– 3), PP. 271–277.

2. Boota, M. W., Imran, M., & Shaheen, A. (2009). Comparative sorption studies of Cu (II) and Zn (II) ions on citrus waste biomass. Journal of the Chemical Society of Pakistan, Vol.No.31, Issue No. (4), PP.501–506.

3. Della, V. P., Kühn, I., & Hotza, D. (2001). Rice husk ash as an alternate source for active silica production. Materials Letters, Vol. No.57, Issue No. (4), PP.818–821.

4. El-Sayed, G. O., Dessouki, H. A., & Ibraheem, S. A. (2011). Removal of Zn (II), Cu (II), and Pb (II) by adsorption onto rice husk in single and binary systems. Desalination, Vol. No. 274, Issue No. (1–3), PP.1–8.

5. Gaballah, I., & Kilbertus, G. (1998). Recovery of heavy metal ions through decontamination of synthetic solutions and industrial effluents using modified barks. Journal of Geochemical Exploration, Vol.No.62, Issue No. (1–3), PP.241–286

6. Jiménez-Cedillo, M. J., Olguín, M. T., & Fall, C. (2013). Adsorption capacity of iron- modified rice husk for arsenic removal. Chemical Engineering Journal, Vol.No.226, PP. 376– 383.

7.Kumar, P., & Sreehari, R. (2012). Studies on removal of lead from aqueous solutions using rice husk ash. Journal of Environmental Science and Engineering, Vol No.54, Issue No. (4), PP.532–539.

8. Lee, S. M., Jung, J. Y., & Chung, Y. C. (1998). Removal of heavy metals from acid mine drainage by biomaterials. Environmental Engineering Research, Vol.No.3, Issue No. (1), PP.1–10.

9. Matheickal, J. T., & Yu, Q. (1999). Biosorption of lead (II) and copper (II) from aqueous solutions by pre-treated biomass of Australian marine algae. Bioresource Technology, Vol.No.69, Issue No. (3), PP.223–229.

10.Okoro, B. C., & Okoro, G. C. (2011). Adsorption of heavy metals by rice husk: Experimental and modeling study. International Journal of Environmental Sciences, Vol.No.1, Issue No. (5), PP.1078–1086.

11. Park, D., Yun, Y. S., & Park, J. M. (2010). Mechanisms of heavy metal removal by a brown seaweed biosorbent. Water Research, Vol.No.44, Issue No. (6), PP.1909–1918.

12.Taha, A. A., Wu, Y. N., Wang, H., & Li, F. B. (2011). Influence of temperature on adsorption of lead (II) onto rice husk. Desalination, Vol.no.266, Issue No. (1–3), PP.222–227.

13.Vaughan, T., Seo, C. W., & Marshall, W. E. (2001). Removal of selected metal ions from aqueous solution using modified corn cob and rice husk. Bioresource Technology, Vol no.78, Issue (2), PP.133–139.