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Experimental Investigation of Heavy Metal Ion Removal Using Agricultural Waste Derived Biochar Adsorbents

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Abstract: ***Heavy metal contamination in water resources has become a serious environmental concern due to increasing discharge from industrial and domestic activities. The present investigation evaluates the adsorption performance of agricultural waste derived biochar prepared from coconut husk, rice husk and sugarcane bagasse for removal of Cu^{2+}, Fe^{2+} and Co^{2+} ions from aqueous solutions using batch adsorption experiments conducted at room temperature (27°C) with an equilibrium contact duration of 30 minutes. Colorimetric analysis supported by calibration curve validation demonstrated linear absorbance–concentration behaviour for the investigated metal ion solutions. Comparative adsorption analysis indicated that coconut husk biochar achieved approximately 67% removal efficiency for Cu^{2+} ions, while rice husk biochar showed improved adsorption performance for Co^{2+} ions with removal efficiency of about 43%, compared with approximately 50% removal obtained using commercial activated carbon under identical experimental conditions. Adsorption equilibrium behaviour evaluated using Freundlich isotherm modelling for cobalt ion dataset produced regression coefficient $R^2 = 0.9362$, indicating favourable heterogeneous multilayer adsorption behaviour. The results confirm that agricultural waste derived biochar materials can serve as economical alternatives to commercial activated carbon for removal of transition metal ions from aqueous systems.***

Keywords: biochar adsorption, agricultural residues, heavy metals, cobalt removal, Freundlich isotherm, low-cost adsorbents

1. Introduction

Rapid industrial growth has resulted in increased discharge of heavy metal ions into water bodies, creating serious environmental and health concerns. Transition metals such as copper, iron and cobalt frequently originate from electroplating industries, mining activities, fertilizer manufacturing and pigment production processes and can accumulate in aquatic systems if untreated [1].

Among several treatment techniques available for removal of dissolved heavy metal ions, adsorption has emerged as an effective and economical method due to its simplicity of operation and lower sludge generation compared with precipitation and membrane separation techniques [2].

Commercial activated carbon is widely used as an adsorbent; however, its relatively higher production cost encourages the development of alternative adsorption materials derived from locally available biomass resources. Agricultural residues such as coconut husk, rice husk and sugarcane bagasse can be converted into porous biochar adsorbents through controlled thermal processing and contain surface functional groups capable of interacting with metal ions through ion exchange and electrostatic attraction mechanisms [3–5].

The present study evaluates the adsorption performance of biochar prepared from selected agricultural residues for removal of Cu^{2+}, Fe^{2+} and Co^{2+} ions and compares their effectiveness with commercial activated carbon under identical experimental conditions.

2. Literature Review

Biochar derived from agricultural biomass has gained considerable attention as a low-cost adsorbent for removal of heavy metal ions from aqueous solutions due to its porous structure and abundance of oxygen-containing functional groups [4,5].

Rice husk biochar is particularly attractive because of its silica-rich composition, which improves adsorption affinity toward divalent metal ions such as cobalt and iron [6]. Similarly, coconut husk derived biochar develops improved pore structure after carbonization and exhibits favourable adsorption characteristics toward copper ions [7].

Several investigations have reported that adsorption behaviour of lignocellulosic biochars generally follows heterogeneous surface interaction patterns that can be represented effectively using Freundlich adsorption isotherm models rather than ideal Langmuir monolayer assumptions [8].

Comparative adsorption studies using different agricultural residues further confirm that locally available biomass materials can serve as sustainable alternatives to commercial activated carbon for wastewater purification applications [9].

3. Objectives

The objectives of the present investigation are:
- To prepare biochar adsorbents from coconut husk, rice husk and sugarcane bagasse
- To evaluate adsorption performance for Cu^{2+}, Fe^{2+} and Co^{2+} ions

- To compare removal efficiency with commercial activated carbon
- To establish calibration relationship between absorbance and concentration using UV–Visible spectrophotometry
- To analyze adsorption equilibrium behaviour using Freundlich isotherm modelling based on representative cobalt ion dataset

4. Materials and Methods

4.1 Preparation of Biochar Adsorbents

Agricultural biomass materials including coconut husk, rice husk and sugarcane bagasse were washed thoroughly to remove surface impurities and dried prior to carbonization. The dried biomass samples were converted into biochar through controlled heating conditions and ground into fine particles suitable for adsorption experiments. Fig. 1 shows conversion of agricultural biomass into biochar adsorbents.

Figure 1: Conversion of agricultural biomass into biochar adsorbents

Figure 2: Experimental workflow adopted in the present study

4.2 Preparation of Metal Ion Solutions

Aqueous solutions of copper chloride, iron chloride and cobalt chloride were prepared using analytical grade salts. Solutions of different concentrations were prepared for calibration curve development and adsorption studies.

4.3 Batch Adsorption Experiments

Batch adsorption experiments were carried out at room temperature (27°C) using an equilibrium contact duration of 30 minutes. Equal quantities of adsorbent materials were added to metal ion solutions and mixed uniformly to ensure adequate interaction between adsorbent and adsorbate species. After adsorption, the samples were filtered prior to spectrophotometric analysis. Fig. 2 presents the experimental workflow adopted in the present study.

4.4 Spectrophotometric Calibration and Analysis

Residual metal ion concentration after adsorption was determined using UV–Visible spectrophotometric measurement. A calibration curve relating absorbance and concentration was established prior to adsorption evaluation using least-squares regression analysis. Fig. 3 shows the calibration relationship between concentration and absorbance for cobalt ion solution.

Similar calibration procedures were followed for copper and iron ion solutions. Regression analysis and adsorption isotherm fitting were supported using adsorption modelling utilities available through POSCO-supported workflow environments [15].

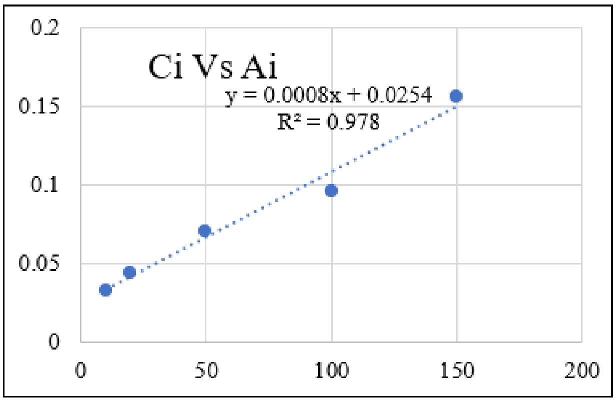

Figure 3: Calibration relationship between concentration and absorbance for cobalt ion solution.

5. Results and Discussion

5.1 Comparative Removal Efficiency

Comparative adsorption performance of different adsorbents for Cu^{2+}, Fe^{2+} and Co^{2+} ions is presented in Fig. 4. The results indicate that adsorption efficiency varies depending on the surface characteristics and composition of biomass precursor materials.

Rice husk biochar exhibited improved removal efficiency for cobalt ions, which may be attributed to its silica-rich surface composition enhancing adsorption interaction between adsorbent and metal ions [6]. Coconut husk biochar demonstrated comparatively higher removal efficiency for copper ions due to development of porous carbon structure during thermal carbonization process [7].

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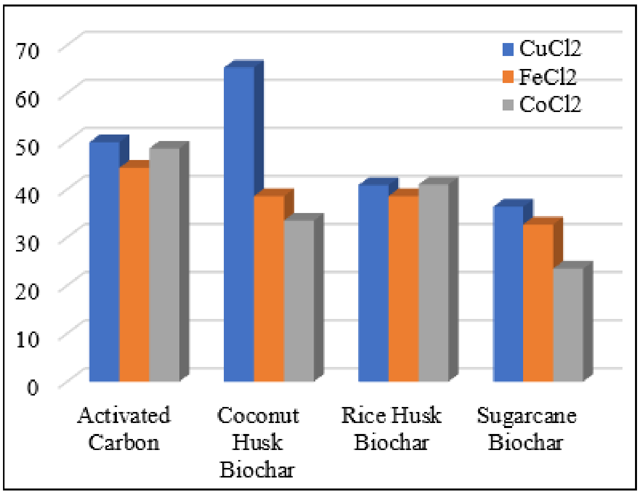

Figure 4: Comparative adsorption performance of different adsorbents for Cu^{2+}, Fe^{2+} and Co^{2+} ions

Commercial activated carbon showed relatively consistent adsorption behaviour across all investigated metal ions, while sugarcane bagasse derived biochar exhibited moderate adsorption capacity under similar experimental conditions.

These observations confirm that adsorption selectivity of biomass-derived adsorbents depends strongly on pore structure and surface functional group distribution [9].

5.2 Freundlich Isotherm Analysis

Adsorption equilibrium behaviour for cobalt ions was evaluated using Freundlich adsorption isotherm model:

$$\log q_e = \log K_f \pm \frac{1}{n} \log C_e$$

Fig. 5 presents the Freundlich adsorption isotherm plot obtained for cobalt ion adsorption. Linear regression obtained from experimental data produced the relation: y = 0.7379x + 0.4761 with correlation coefficient: $R^2 = 0.9362$

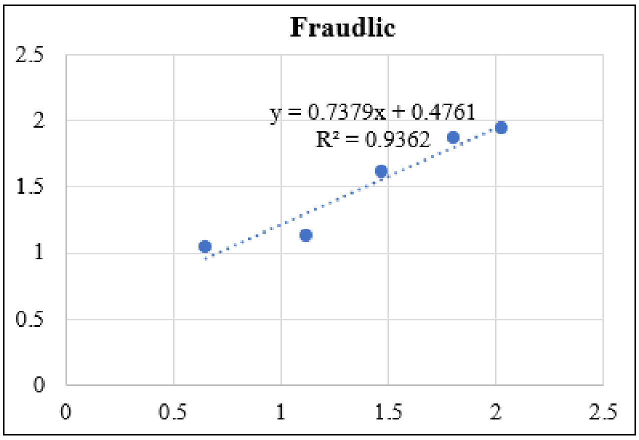

Figure 5: The Freundlich adsorption isotherm plot obtained for cobalt ion adsorption

The slope value less than unity indicates favourable adsorption conditions over heterogeneous surface structure. The high correlation coefficient confirms suitability of Freundlich model for representing adsorption behaviour of cobalt ions on biomass-derived adsorbents. Similar heterogeneous adsorption behaviour of biochar materials has been reported in earlier studies [8].

Langmuir model fitting for the same dataset resulted in lower correlation coefficient ($R^2 = 0.5639$), indicating deviation from ideal monolayer adsorption assumptions typically associated with uniform adsorption surfaces [10].

6. Conclusion

The present investigation confirms that agricultural waste derived biochar materials can effectively remove transition metal ions from aqueous solutions under ambient conditions. Coconut husk biochar achieved approximately **67% removal efficiency for Cu^{2+} ions**, while rice husk biochar showed improved adsorption performance for Co^{2+} ions with efficiency of about **43%**. Freundlich isotherm modelling produced correlation coefficient **$R^2 = 0.9362$**, indicating favourable heterogeneous adsorption behaviour, while lower Langmuir correlation (**$R^2 = 0.5639$**) confirmed deviation from monolayer adsorption assumptions. The results demonstrate that biomass-derived adsorbents provide a viable low-cost alternative to commercial activated carbon for decentralized wastewater treatment applications.

References

[1] Fu F., Wang Q., Removal of heavy metal ions from wastewater, Journal of Environmental Management
[2] Crini G., Non-conventional low-cost adsorbents for wastewater treatment, Bioresource Technology
[3] Lehmann J., Joseph S., Biochar for Environmental Management, Earthscan
[4] Mohan D. et al., Removal of contaminants using biochar, Bioresource Technology
[5] Ahmad M. et al., Biochar as sorbent for contaminant management, Chemosphere
[6] Tan X. et al., Application of biochar for pollutant removal, Bioresource Technology
[7] Demirbas A., Agricultural based activated carbons for heavy metal removal, Energy Sources
[8] Foo K.Y., Hameed B.H., Adsorption isotherm modeling insights, Chemical Engineering Journal
[9] Malik R., Ramteke D.S., Wate S.R., Adsorption using agricultural residues, Waste Management
[10] Ho Y.S., McKay G., Sorption of heavy metals on adsorbents, Process Biochemistry
[11] Inyang M. et al., Biochar from biomass for remediation applications, Critical Reviews in Environmental Science
[12] Gupta V.K., Ali I., Environmental Water Treatment Technologies, Elsevier
[13] Vijayaraghavan K., Yun Y.S., Biosorption of heavy metals review, Biotechnology Advances
[14] Babel S., Kurniawan T.A., Low-cost adsorbents for heavy metal removal, Journal of Hazardous Materials
[15] POSCO Technical Resources Portal, adsorption modelling workflow utilities and environmental process documentation (software access reference)