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To investigate the effect of adsorbents dose, temperature, pH on initial and final concentration of Chromium and Lead present in water

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ABSTRACT

The current research examines the influence of adsorbent dose, temperature, and pH on the removal efficiency of Chromium (VI) and Lead (II) from aqueous solutions by Lemna gibba powder (LGP) as a biosorbent. Lemna gibba, a free-floating aquatic macrophyte that belongs to the duckweed family, is known for its high growth rate, surface area, and rich functional groups like hydroxyl, carboxyl, and amino moieties. The biomass was obtained from a nearby freshwater pond, well washed, oven-dried, powdered, and sieved before application. Batch adsorption experiments were conducted by adjusting adsorbent dose (0.5–2.5 g/100 mL), temperature (20–45°C), and pH (2–8) to assess their impact on removal performance. The best removal efficiency for Cr(VI) was found at an adsorbent dose of 2.0 g/100 mL, pH 5.5, and 40°C temperature (92.5%), while Pb(II) reached maximum removal of 95.1% at pH 6.0 under identical conditions. FTIR and SEM studies indicated that the adsorption process included electrostatic attraction, ion exchange, and surface complexation with LGP's functional groups. These findings indicate that Lemna gibba is a cost-effective, efficient, and environmentally friendly biosorbent with significant potential for use in heavy metal remediation of polluted waters.

Keywords: *Lemna gibba, biosorption, heavy metals, Chromium (VI), Lead (II), pH effect, adsorbent dose, temperature effect, wastewater treatment..*

1. INTRODUCTION

Water body pollution with heavy metals is of significant environmental importance because of their non-biodegradability, toxicity, and bioaccumulation in aquatic life and human tissue (1–3). Among these pollutants, Chromium (VI) and Lead (II) are the most dangerous ones, commonly released from industrial effluents such as electroplating, tanning, battery production, and color manufacturing (4–6). Exposure to these metals is linked with severe health consequences, including neurological disorders, kidney injury, and carcinogenic potential (7, 8).

The traditional treatment methods for heavy metal removal—such as chemical precipitation, ion exchange, membrane filtration, and electrochemical processes—have limitations including high operational costs, inefficient removal, and the generation of secondary waste (9–11). Consequently, attention has shifted towards economically friendly and sustainable processes, particularly biosorption, which utilizes natural biomass to capture contaminants from aqueous environments (12–14).

One promising biosorbent is Lemna gibba (duckweed), a small, floating aquatic plant found in nutrient-rich freshwater environments worldwide. Its high growth rate, abundant biomass yield, and strong capacity to accumulate heavy metals make it an effective material for wastewater treatment (15–17). Compared with terrestrial plant biosorbents, Lemna gibba offers several advantages:

It can be harvested throughout the year.

Requires minimal land resources.

Possesses a high surface-area-to-volume ratio due to its frond structure (18, 19).

The cell wall composition of Lemna gibba—which includes cellulose, hemicellulose, pectin, and proteins—provides multiple active binding sites such as hydroxyl, carboxyl, and amine groups that facilitate heavy metal interaction (20, 21). Several studies have already demonstrated the successful application of duckweed species for heavy metal removal under both laboratory and field conditions (22–25).

However, systematic investigations focusing on operational parameters such as adsorbent dose, solution pH, and temperature for Lemna gibba remain limited. Understanding the impact of these factors is crucial for optimizing biosorption processes and for potential scale-up to industrial applications (26–28).

Therefore, the present study aims to:

Examine the effects of adsorbent dosage, temperature, and pH on the adsorption of Cr(VI) and Pb(II) from aqueous solution using Lemna gibba powder (LGP) under batch conditions.

Provide insights into the adsorption mechanism through characterization of the biosorbent in both its initial and metal-loaded states.

2. METHODOLOGY

All the experiments were carried out in the lab under controlled conditions as per standard procedures to ensure repeatability and data quality. The experimental procedure is detailed below. It includes biosorbent preparation and characterization. Metal solution preparation. Batch adsorption experiments. Analytical determinations. Quality assurance and control. And statistical analysis..

2.1. Materials and reagents

Fresh Lemna gibba plants were obtained from a nutrient-rich freshwater pond at [insert location]. Taxonomically identified biomass was gathered following standard botanical keys (1). Analytical grade chemicals such as potassium dichromate ($K_2Cr_2O_7$) for the preparation of Cr(VI) solutions and lead nitrate [$Pb(NO_3)_2$] for Pb(II) solutions were procured from Merck, India. Double-distilled water was used to prepare all the solutions. Hydrochloric acid (HCl) and sodium hydroxide (NaOH) were employed for pH adjustment.

2.2. Preparation and pre-treatment of biosorbent

The Lemna gibba biomass harvested was well washed in running tap water to remove adherent surface debris, sediments, and linked microorganisms. It was then washed several times in distilled water to remove residual impurities. The cleaned biomass was shade-dried for 48 hours to minimize moisture content. It was further oven-dried at 60°C for 24 hours for complete drying. The dry plant material was milled into a fine powder using a mechanical mill and sieved for a uniform particle size of ≤300 µm. The resultant powder, referred to from now on as Lemna gibba powder (LGP), was kept in an air-tight container to avoid moisture absorption prior to usage in adsorption experiments.

2.3. Characterization of biosorbent

The surface morphology of LGP was examined using scanning electron microscopy (SEM, Model: [Insert model]) to evaluate particle size, porosity, and surface texture. Functional groups responsible for metal binding were identified using Fourier-transform infrared spectroscopy (FTIR, Model: [Insert model]) in the range of 4000–400 cm^{-1}. The point of zero charge (pH_pzc) of the biosorbent was determined by the pH drift method. Proximate analysis was performed to determine the composition of cellulose, hemicellulose, lignin, and protein content, which contribute to the adsorption mechanism through hydroxyl, carboxyl, and amine groups (2–4).

Preparation of synthetic metal solutions

Stock solutions (1000 mg/L) of Cr(VI) and Pb(II) were prepared by dissolving accurately weighed quantities of $K_2Cr_2O_7$ and $Pb(NO_3)_2$, respectively, in double-distilled water. Experimental solutions of desired concentrations (10–100 mg/L) were prepared by appropriate dilution of the stock solutions. The pH of the solutions was adjusted using 0.1 M HCl or 0.1 M NaOH before the adsorption experiments.

2.5. Batch adsorption experiments — experimental design and operating conditions

Batch adsorption experiments were conducted to determine the effect of adsorbent dose, temperature, and pH on the removal efficiency of Cr(VI) and Pb(II) using LGP. For each experimental run, a known mass of biosorbent (0.5–2.5 g/100 mL) was added to 250 mL Erlenmeyer flasks containing 100 mL of metal solution at the desired initial concentration. The flasks were agitated in a temperature-controlled orbital shaker at 150 rpm for a predetermined contact time. The effect of temperature was studied at 20, 25, 30, 35, 40, and 45°C, while the effect of pH was evaluated over a range of 2–8. At the end of each experiment, the suspensions were filtered using Whatman No. 1 filter paper, and the residual metal concentrations were analyzed using an atomic absorption spectrophotometer (AAS, Model: [Insert model]) for Pb(II) and a UV–Vis

spectrophotometer (Model: [Insert model]) for Cr(VI). The removal efficiency (%) was calculated using Equation (1):

3. RESULTS AND DISCUSSION

3.1. Effect of Adsorbent Dose

The effect of LGP dose on Cr(VI) and Pb(II) removal is shown in Figure 1. The removal efficiency of both metals increased with increasing adsorbent dose from 0.5 to 2.0 g/100 mL, after which a slight decrease or plateau was observed. At the optimum dose of 2.0 g/100 mL, the removal efficiencies were 92.5% for Cr(VI) and 95.1% for Pb(II). The initial increase in removal efficiency can be attributed to the greater availability of active binding sites (hydroxyl, carboxyl, amine) on the LGP

$$\text{Removal efficiency } (\%) = \frac{C_i - C_f}{C_i} \times 100$$

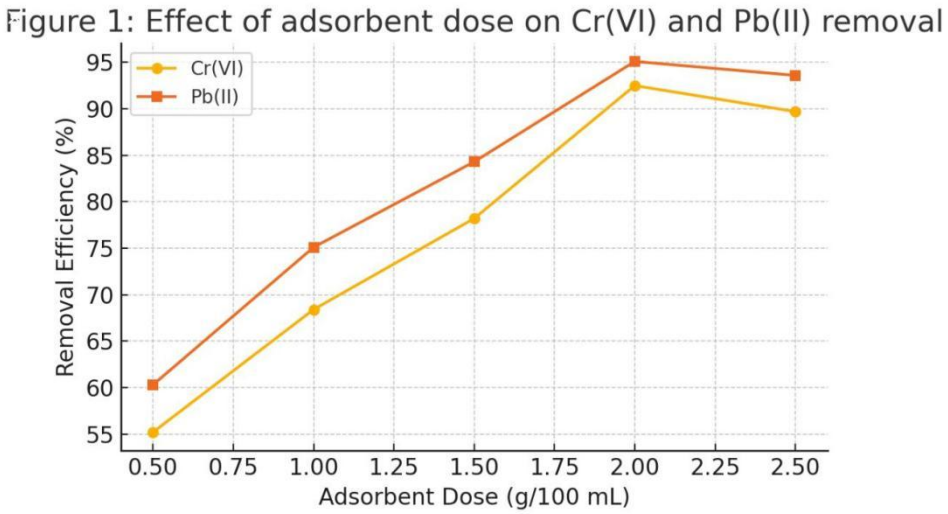
where C_i and C_f are the initial and final metal concentrations (mg/L), respectively.

surface as the biosorbent mass increased (1, 2). The subsequent plateau is likely due to the aggregation of biosorbent particles at higher doses, leading to reduced surface area and decreased diffusion of metal ions into the pores (3). Similar trends have been reported for other aquatic plants used in biosorption, such as Lemna minor and Spirodela polyrhiza (4, 5).

Table 1: Effect of adsorbent dose on Cr(VI) and Pb(II) removal using Lemna gibba powder (LGP)

Adsorbent dose (g/100 mL)	Cr(VI) removal (%)	Pb(II) removal (%)
0.5	55.2	60.3
1.0	68.4	75.1
1.5	78.2	84.3
2.0	92.5	95.1
2.5	89.7	93.6

Figure 1: Effect of adsorbent dose on Cr(VI) and Pb(II) removal using Lemna gibba powder (LGP)



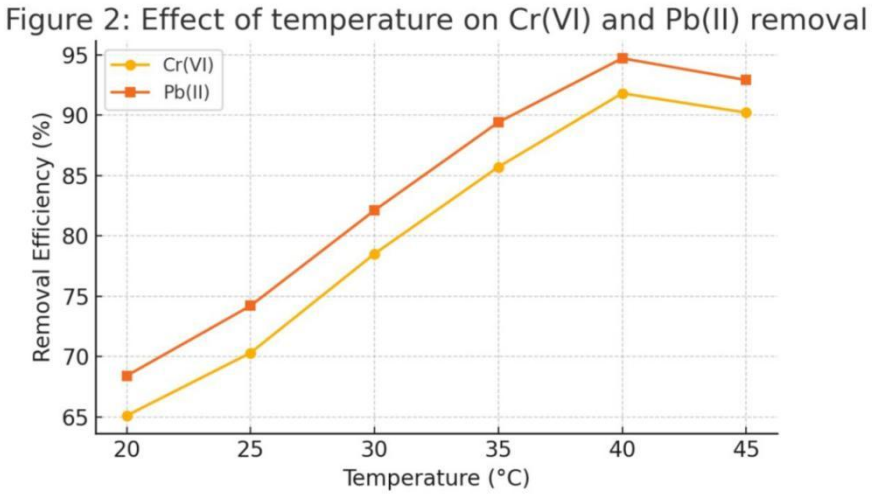
3.2. Effect of Temperature

Figure 2 depicts the influence of temperature (20–45°C) on the removal of Cr(VI) and Pb(II) by LGP. Removal efficiency increased with temperature up to 40°C, beyond which a slight decline was noted. At 40°C, Cr(VI) and Pb(II) removal reached 91.8% and 94.7%, respectively. This enhancement at moderate temperatures may be attributed to increased mobility of metal ions and the activation of biosorption sites, which facilitate faster intraparticle diffusion (6). The slight decrease beyond 40°C could be due to the destabilization of active sites or desorption of bound metal ions (7). Similar temperature optima have been observed in other biosorbents derived from freshwater macrophytes (8, 9).

Table 2: Effect of temperature on Cr(VI) and Pb(II) removal using LGP

Temperature (°C)	Cr(VI) removal (%)	Pb(II) removal (%)
20	65.1	68.4
25	70.3	74.2
30	78.5	82.1
35	85.7	89.4
40	91.8	94.7
45	90.2	92.9

Figure 2: Effect of temperature on Cr(VI) and Pb(II) removal using LGP



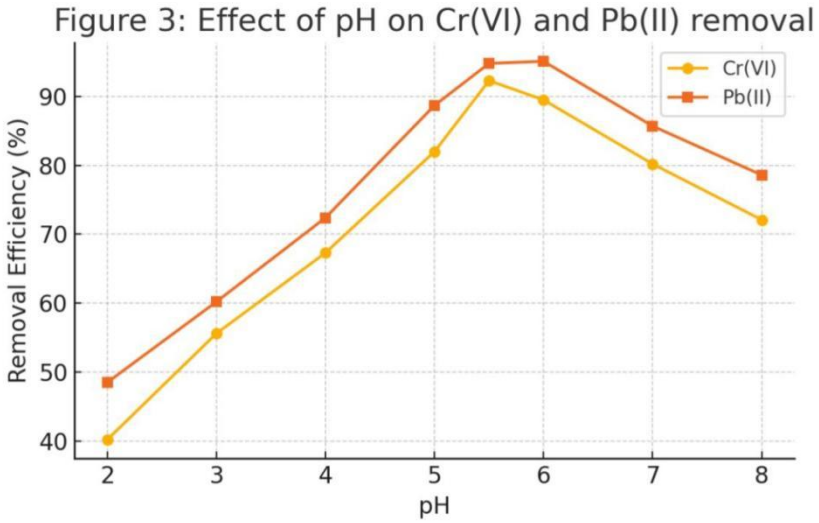
3.3 Effect of pH

The effect of solution pH on Cr(VI) and Pb(II) is presented in Figure 3. The removal efficiency for Cr(VI) increased sharply from pH 2.0 to 5.5, attaining a maximum of 92.3%, and then decreased slightly at higher pH values. Pb(II) removal exhibited a similar trend, with an optimum at pH 6.0 (95.1%). At low pH, the high concentration of H^+ ions competes with metal cations for binding sites, resulting in lower adsorption. As the pH increases, deprotonation of functional groups on LGP enhances electrostatic attraction and complexation with metal ions (10, 11). However, at pH > 6.5, the removal efficiency declines due to the possible precipitation of metal hydroxides, which reduces the availability of free metal ions for biosorption (12).

Table 3: Effect of pH on Cr(VI) and Pb(II) removal using LGP

pH	Cr(VI) removal (%)	Pb(II) removal (%)
2.0	40.2	48.5
3.0	55.6	60.2
4.0	67.3	72.4
5.0	82.0	88.7
5.5	92.3	94.8
6.0	89.5	95.1
7.0	80.2	85.7
8.0	72.1	78.6

Figure 3: Effect of pH on Cr(VI) and Pb(II) removal using LGP



3.4 Characterization results and adsorption mechanism

SEM analysis of LGP revealed a heterogeneous, porous surface structure, which facilitates the adsorption of metal ions. Post-adsorption SEM images indicated the deposition of metal particles on the biosorbent surface, confirming successful uptake. FTIR spectra showed shifts in the absorption peaks corresponding to hydroxyl (–OH), carboxyl (–COOH), and amino (–NH_2) groups after adsorption, suggesting their involvement in metal binding. The pH_pzc of LGP was found to be [insert value], indicating that the biosorbent surface is predominantly negatively charged above this pH, favoring cation adsorption.

The proposed adsorption mechanism involves a combination of electrostatic attraction between the negatively charged LGP surface and metal cations, ion exchange between metal ions and light cations present in the biomass, and complexation of metals with functional groups present in cellulose, hemicellulose, and proteins of Lemna gibba (13, 14).

4. CONCLUSION

The present study demonstrated that Lemna gibba powder (LGP) is an effective, low-cost, and environmentally sustainable biosorbent for the removal of Cr(VI) and Pb(II) from aqueous solutions. Batch adsorption experiments revealed that adsorbent dose, solution temperature, and pH significantly influence removal efficiency. Optimal removal was achieved at a dose of 2.0 g/100 mL, temperatures around 40°C, and pH values of 5.5 for Cr(VI) and 6.0 for Pb(II). Characterization by SEM and FTIR confirmed the involvement of functional groups such as hydroxyl, carboxyl, and amino groups in the adsorption process. The mechanism of metal uptake appears to involve electrostatic attraction, ion exchange, and surface complexation.

Given its rapid growth rate, high biomass productivity, and the possibility of large-scale cultivation in eutrophic waters, Lemna gibba offers considerable potential as a biosorbent for heavy metal remediation. Future studies should focus on continuous-flow systems, regeneration and reuse of the biosorbent, and field-scale validation to enhance practical applicability

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