ELIMINATION OF Pb (II) FROM WASTEWATER BY USING RIVER JHELUM SAND AS ADSORBENT

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ABSTRACT: Heavy metal contamination has become a major environmental concern in today's world. This study focuses for the removal of Pb(II) ions from wastewater using Jhelum sand as a natural adsorbent. The sand was characterized through Fourier-Transform Infrared Spectroscopy for the identification of functional groups and adsorption sites before and after the adsorption process. Batch experiments were conducted to investigate the adsorption behavior of Pb(II), optimizing key parameters such as shaking speed (120 rpm), adsorbent dose (2.5 g/100 ml), pH (5), and contact time (20 minutes) for a 30 ppm Pb(II) solution. Langmuir and Freundlich isotherm models were applied on adsorption data, showing a good fit that indicates the efficiency and feasibility of the adsorption process. The negative Gibbs free energy and positive enthalpy values further confirm that the process is spontaneous and endothermic. Overall, Jhelum sand proves to be an effective, eco-friendly, and low-cost material for Pb(II) ions removal from wastewater and industrial effluents.

Keywords: Adsorption, Lead, sand, Jhelum river, Wastewater.

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INTRODUCTION

Water is one of nature's most valuable gifts to humanity, essential for maintaining health and sustaining life. Every living organism depends on it for survival. Since the Industrial revolution, industrial activities have become a major contributor to water pollution. Many industries, including textile, leather, sugar, paper and pulp, pharmaceuticals, and thermal power plants, release harmful pollutants into the environment. In most cases, these industries lack adequate treatment systems to clean wastewater before it is discharged into rivers, lakes, or other natural water bodies. When toxic substances enter aquatic systems whether from natural processes or human actions they may dissolve, remain suspended, or settle at the bottom of these water bodies. Over time, this contamination degrades water quality and poses serious risks to public health, potentially leading to widespread diseases among humans, animals, and plants. [1]

Heavy metals often contaminate industrial and municipal wastewater, posing serious health risks to humans and ecosystems. They enter the environment through activities such as mining, metal refining, electroplating, and industrial waste disposal. While trace amounts of some metals are essential for life, high concentrations of mercury, cadmium, arsenic, and lead can be extremely toxic. Among these, lead is particularly harmful it affects the brain, lungs, and nervous system, especially in children who absorb it more easily. Long-term exposure can lead to memory loss, reduced intelligence, and increased blood pressure, making lead pollution a major environmental and public health concern. Lead exposure can cause a wide range of health effects, depending on how long and how intensely a person is exposed. After entering the bloodstream, lead gradually moves into soft tissues such as the brain and can also accumulate in bones by replacing calcium due to their similar ionic size. Research shows that prolonged or occupational exposure to lead weakens the immune system and has been linked to serious conditions, including brain cancer [2-3]

Various methods have been developed for removing heavy metals from industrial wastewater and groundwater, including oxidation, precipitation, reverse osmosis, electrolysis, solvent extraction, and membrane filtration. However, most of these techniques are costly, require high energy, and technical expertise [4-5]. Among them, adsorption stands out as a simple, effective, and eco-friendly approach due to its low cost and high efficiency. It involves the attachment of ions or molecules from a liquid onto the surface of a solid material called an *adsorbent*, while the substance being removed is known as the *adsorbate*. Depending on the nature of the interaction, adsorption can occur through physical attraction (physisorption), chemical bonding (chemisorption), or ion exchange. Sand consists of fine, loose grains formed from the breakdown of rocks through mechanical, chemical, or biological weathering. Sand is commonly found in riverbeds, beaches, and streams, originating from rocks like granite, garnet, and zircon [6]. It can be classified into mineral, biogenic, and precipitated types [7]. In this study, river Jhelum sand was used as an adsorbent for removing lead ions from wastewater.

METHODOLOGY

A. **River Jhelum Sand:** A total of 1000 grams of sand samples were collected from an open pit site located near the village Mahi Khurd, downstream of Sarai Alamgir City. The collected sand was reduced to the desired test size following the procedure outlined in ASTM C 702 [8]. Samples were then oven-dried at 110 ^{o}C ticonstant weight was achieved, then further reduced to the required test size. Gradation was determined using a mechanical sieve shaker. For this study, the sand fraction that passed through ASTM sieve No. 30 and was retained on sieve No. 50 was selected.

Fig 1. Source: Google Earth: location of village Mahi Khurd, downstream of Sarai Alamgir City.

B. **Reagents and Standards:** Chemicals were of analytical grade and were procured from Sigma-Aldrich. No further purification was carried out. Stock solution of 1000 ppm Pb (II) was prepared using $Pb(NO_3)_2$. Deionized water was used for preparing and diluting the solutions. All glassware used during the experiments was of Quick-fit grade (England).

C. **Characterization of Adsorbent:** The chemical surface characteristics of the sand (adsorbent) were analyzed by Fourier-Transform Infrared Spectroscopy (FTIR) with a Perkin Elmer Spectrum RXI instrument.

D. **Analyte Analysis:** The concentration of Pb(II) in the samples was determined by using an atomic absorption spectrophotometer (Perkin Elmer Analyst 800). pH measurements were performed with a Hanna pH 211 meter equipped with a glass electrode. The shaking speed during experiments was controlled using a mechanical shaker (SHO-2D WiseMix, Daihan Scientific).

E. **Batch Sorption Studies:** For the investigation of the influence of various experimental parameters such as shaking speed, adsorbent dose, pH, contact time, and initial concentration of Pb(II) ions, a series of adsorption experiments were conducted. In each experiment, only one parameter was varied while keeping all others constant. After the adsorption process under specific conditions, the solutions were then filtered, and the obtained filtrates were analyzed for remaining concentration of Pb(II).

EXPERIMENTAL RESULTS AND DISCUSSION

A. FTIR Studies: The FTIR spectrum Fig. 2. of the sand sample displays a broad absorption band around 3424 cm^{-1}, attributed to O–H stretching vibrations from surface hydroxyl groups or adsorbed moisture. A smaller peak near 2923 cm^{-1} suggests the presence of slight organic residues due to C–H stretching. The strong absorption at 1082 cm^{-1}, along with peaks around 1639 cm^{-1}, 798 cm^{-1}, and 696 cm^{-1}, corresponds to Si–O–Si stretching and bending vibrations, confirming the dominance of quartz (silica) in the sample. Overall, the spectrum indicates that the sand is mainly composed of silica with traces of water and minor organic matter.

Fig.3. The FTIR spectrum of the sand after lead adsorption shows several noticeable changes compared to the untreated sand. The broad O–H stretching band near 3424 cm^{-1} appears slightly shifted and less intense, suggesting that surface hydroxyl groups were involved in Pb(II) binding. Minor peak shifts around 2920–2850 cm^{-1} and 1639 cm^{-1} indicate possible interactions of lead ions with adsorbed water or organic residues. The Si–O–Si stretching band near 1083 cm^{-1} shows reduced intensity and a slight shift, implying coordination between Pb(II) ions and silanol groups on the sand surface. New or more pronounced bands near 1442 cm^{-1} and 875 cm^{-1} may correspond to Pb–O or metal–oxygen bonding. Overall, these spectral variations confirm that lead ions were successfully adsorbed onto the sand through chemical interactions with silanol and hydroxyl functional groups.

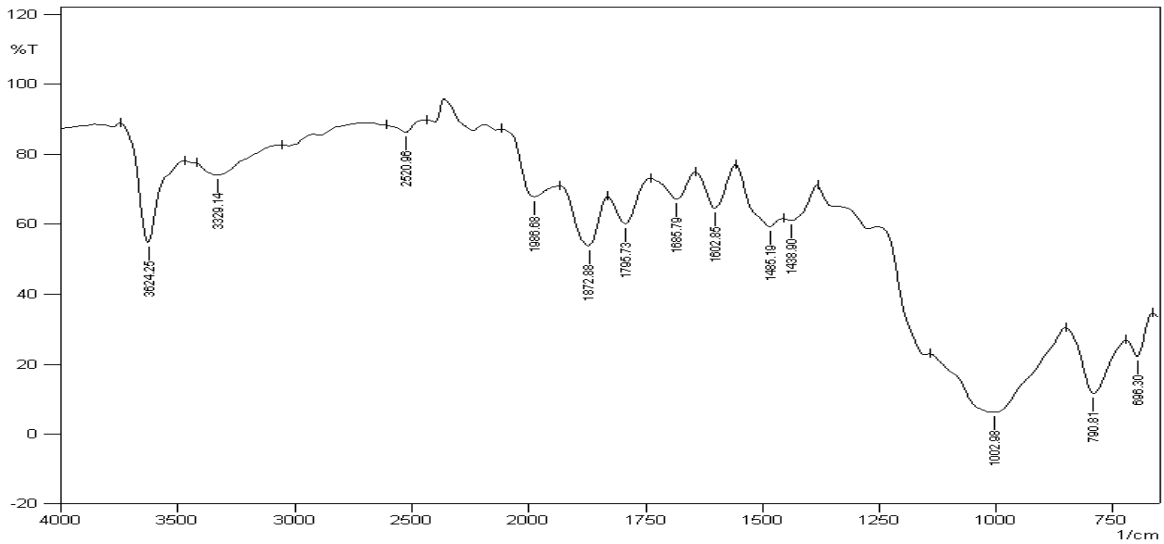

Fig.2: FTIR Spectra of raw sand of river Jhelum .

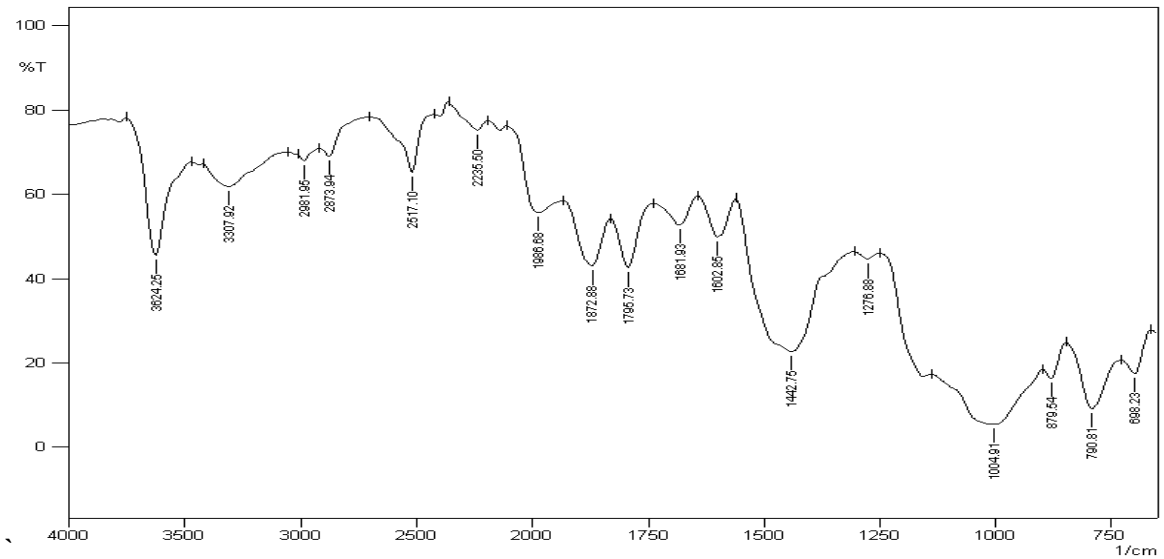

Fig.3: FTIR spectra of Pb(II) loaded sand of Jhelum rive

B. OPTIMIZATION OF ADSORPTION PARAMETERS:

Shaking Speed: To identify the most effective shaking speed, experiments were conducted at various speeds ranging from 40 to 200 rpm. Each experiment was performed using a 30 ppm lead ion solution, an adsorbent dose of 1 g per 100 ml, and a contact time of 60 minutes at room temperature and pH 7. As illustrated in Fig.4. adsorption efficiency increased with shaking speed, reaching a maximum of 69.8% at 120 rpm. Therefore, 120 rpm was chosen as the optimal shaking speed for all subsequent experiments. These results can be explained by considering that at low shaking speeds, the slow movement of Pb(II)ions and adsorbent particles limits their interaction, reducing adsorption. As speed increases, collisions between themenhance contact, leading to higher adsorption, with the best result at 120 rpm. Beyond this speed, excessive particle collisions cause some weakly bound ions to detach, lowering adsorption. Similar trends have been observed by other researchers on different adsorbent processes [9-10].

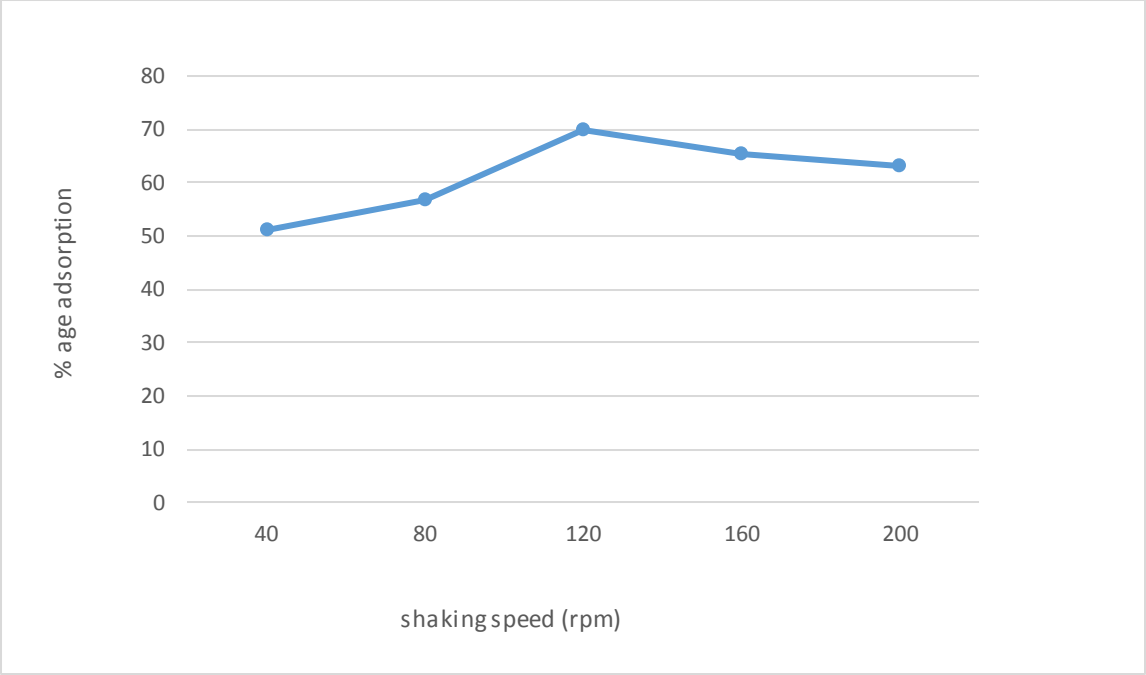

Fig.4: percentage adsorption vs shaking speed

Adsorbent Dose: The influence of adsorbent dosage on lead removal was investigated by changing the adsorbent amount from 0.5 to 6 g per 100 ml under identical experimental conditions: 60 minut contact time, 30 ppm lead solution, 120 rpm shaking speed, pH 7, and room temperature. As shown in Fig.5. the adsorption efficiency improved with increasing adsorbent dose up to 2.5 g/100 ml, beyond which further increments showed negligible enhancement. Hence, 2.5 g/100 ml was determined to be the optimal adsorbent dose for effective removal. This can be explained by considering the fact that by increasing the amount of adsorbent dose more and more active adsorption sites become available to the metal ions to adhere [11].

Contact Time: To examine the effect of contact time on adsorption, a series of experiments were perform at intervals ranging from 20 to 120 minutes while maintaining constant conditions (30 ppm lead solution, 120 rpm shaking speed, 2.5 g/100 ml adsorbent, pH 7, and room temperature). As depicted in Fig.6. adsorption is maximum i.e. 71.65% at 20 minutes. A decline in adsorption after this point was attributed to the possible disruption of weakly bound ions due to prolonged agitation [12-13].

pH: Adsorption phenomenon is significantly affected by the pH of the solution.The pH was varied from 2 to 9 using suitable buffer solutions, while other parameters 30 ppm metal ion concentration, 2.5 g/100 ml adsorbent dose, 120 rpm shaking speed, and 20 minutes contact time remained constant. As presented in Fig.7. the maximum percentage adsorption is 79.54% occurred at pH 5.

It was observed that initially, by increasing the value of pH percentage adsorption increases steadily but after reaching the optimal pH percentage adsorption value decreases by increasing the pH value. This trend may be attributed due to that beyond pH 9, the formation of lead hydroxide precipitates led to a reduction in adsorption efficiency [14].

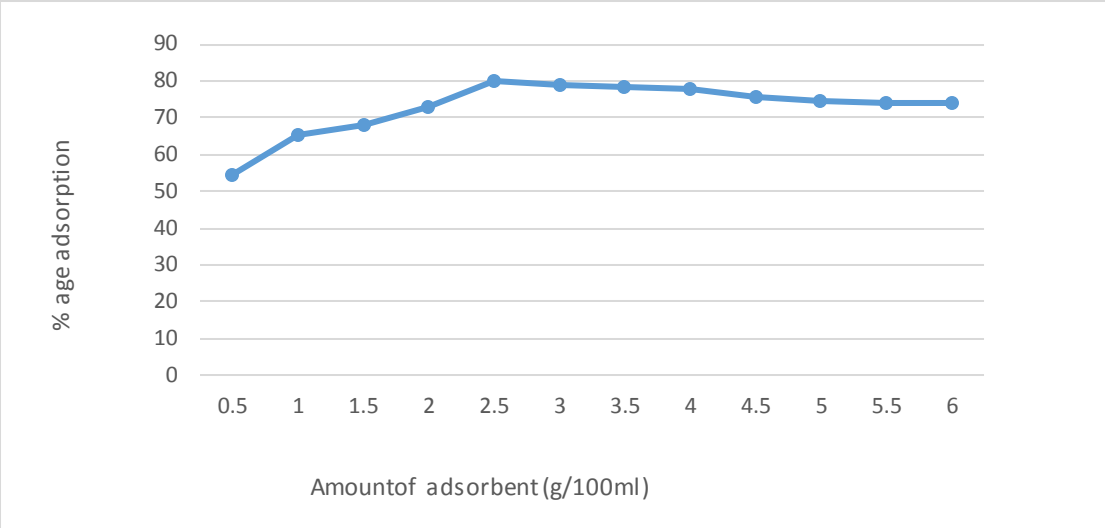

Fig.5. percentage adsorption vs adsorbent dose

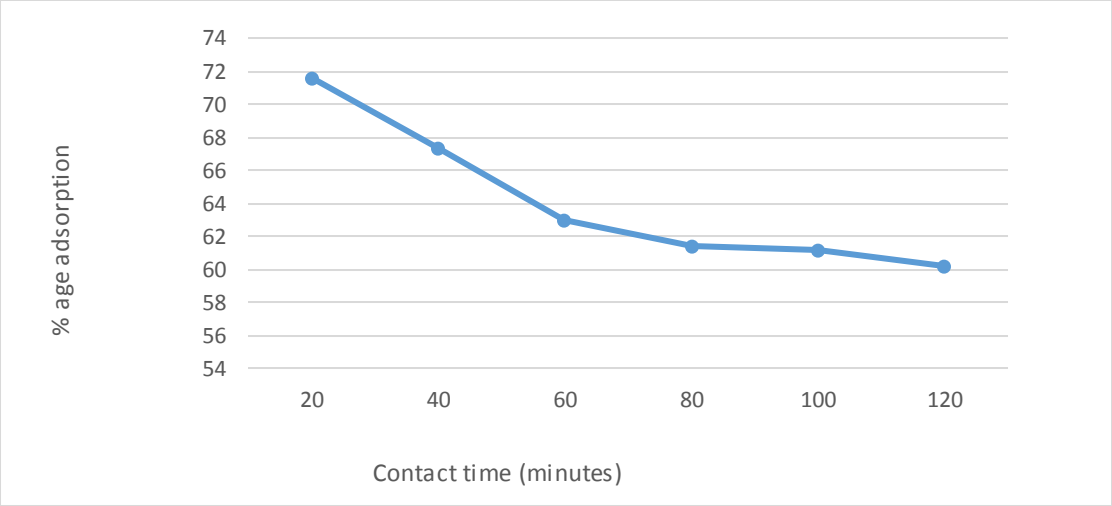

Fig.6: percentage adsorption vs contact time

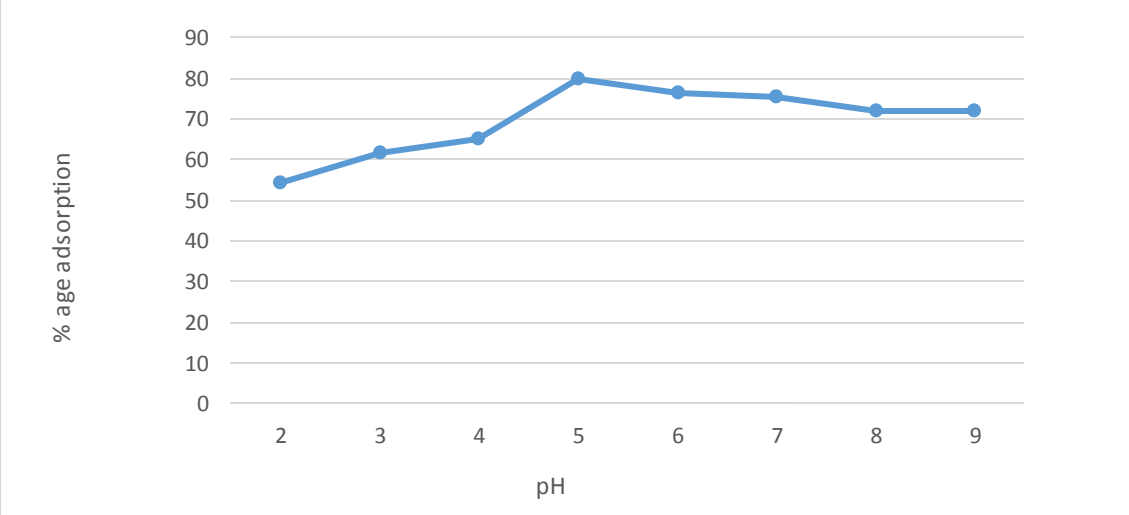

Fig.7: percentage adsorption vs pH

Temperature: Temperature was another critical factor influencing adsorption performance. Experiments were performed at 293 K to 323 K under optimal conditions of 20 minutes contact time and 120 rpm shaking speed. According to Fig.8. adsorption efficiency increased with temperature, achieving a peak value of 72.3% at 323 K. This indicates the adsorption of lead ions on the adsorbent surface is favored at higher temperatures.

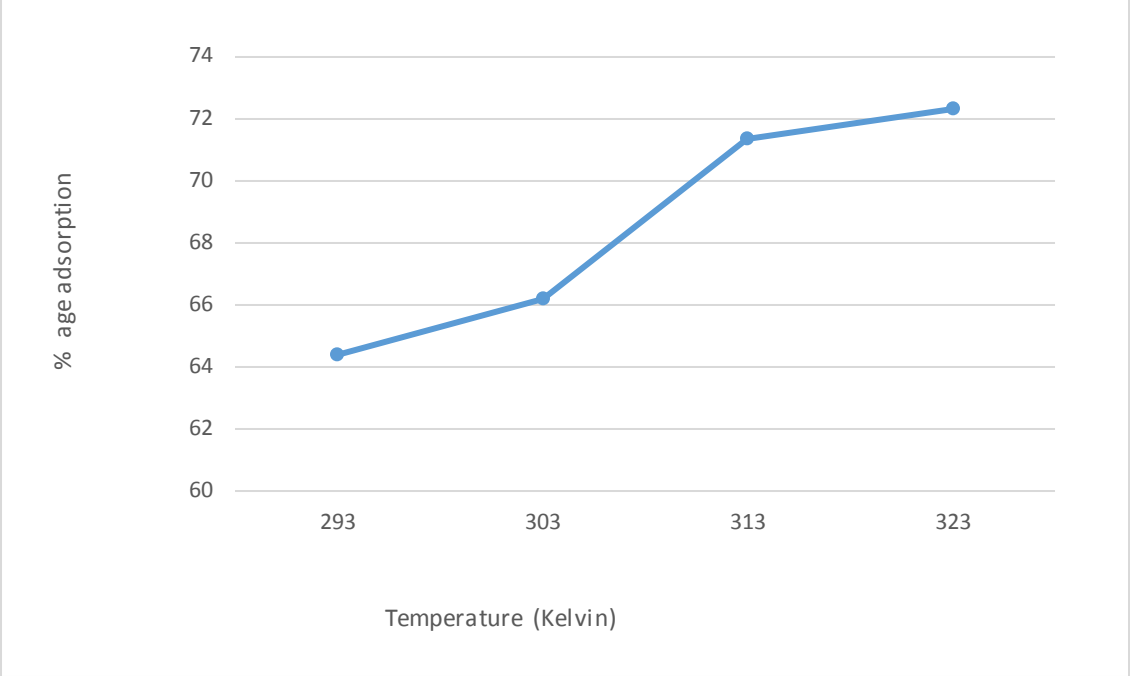

Fig.8: percentage adsorption vs temperature

Adsorption Isotherm and Thermodynamic parameters: Solutions of Pb(II) with from 5 to 50 ppm were analyzed to determine the adsorption capacity of River Jhelum sand under the optimal conditions established in earlier experiments. Two primary adsorption isotherm Langmuir (Eq.1) and Freundlich (Eq.2) were applied using their respective linear forms, and the related constants were obtained using slope and intercept of the plot.

Langmuir isotherm:

$$Ceq / Cads = 1 /Qb + Ceq / Q \quad (1)$$

Freundlich isotherm:

$$\log Cads = 1/n \log Ceq + \log K \quad (2)$$

Here, *q* (mg/g) represents the amount of Pb(II) adsorbed per gram of adsorbent, while *Ce* (mg/L) denotes the equilibrium concentration. *Q* (mg/g) and *b* are the Langmuir constants, whereas *K* (mg/g) and *n* describe the Freundlich constant, indicating the intensity and adsorption capacity.

Thermodynamic parameters were determined using Equatuation (3)

$$\ln Q = \Delta S/R - \Delta H/RT \quad (3)$$

where *R* is the universal gas constant and *T* is the temperature in Kelvin. The values of ΔH (enthalpy change) and ΔS (entropy change) were derived from the slope and intercept of the plot of ln Q versus 1/T. Subsequently, Gibbs free energy (ΔG) was calculated using Equation (4):

$$\Delta G = \Delta H - T\Delta S \quad (4)$$

These thermodynamic evaluations provided insight into the spontaneity and nature of the Pb(II) adsorption process on River Jhelum sand.

Langmuir Isotherm: The adsorption data for lead removal using river Jhelum sand were analyzed using the Langmuir isotherm model. As shown in Fig.9. the plot of C_{eq} versus C_{eq}/C_{ads} produced a straight line, confirming the applicability of the this model. Constants of this model, Q and b, were calculated from the slope and intercept of the plot, and their corresponding values are presented in Table 1. Additionally, the dimensionless separation factor (RL) was calculated using the Langmuir constant (b). For Pb(II), RL values ranged between 0.168 and 0.669, indicating this process of adsorptionwas favorable, as values of RL between 0 and 1 suggest a favorable adsorption.

Fruendlich Isotherm: Freundlich equation, was applied to analyze the Pb(II) adsorption. In this model, log C_{ads} was plotted against log C_{eq}, as shown in Fig.10.. The constants *K* and *n* were determined from the intercept and slope of the plot, and their values are given in Table 1.

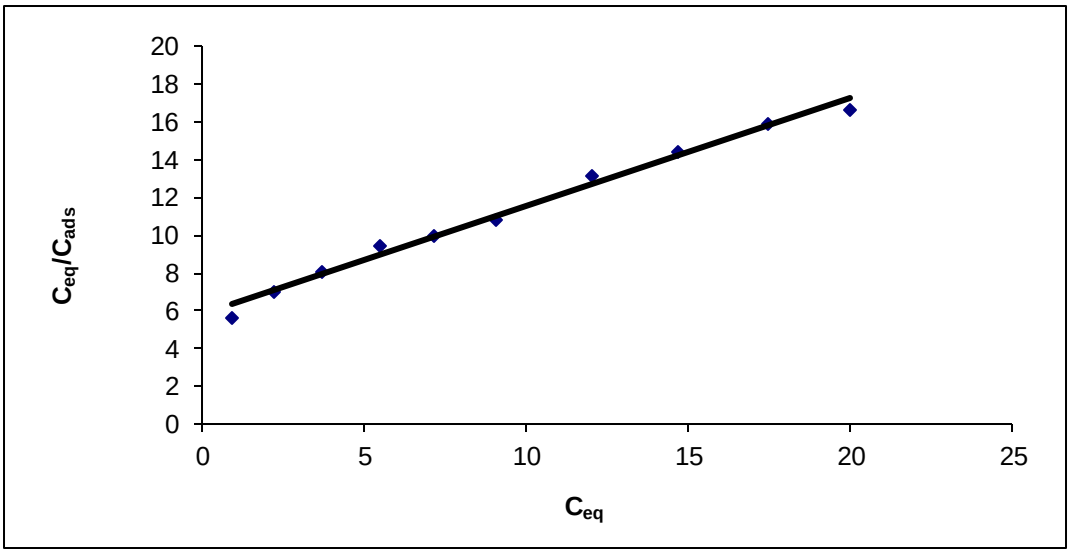

Fig.9: Langmuir adsorption isotherm of Pb(II) on sand

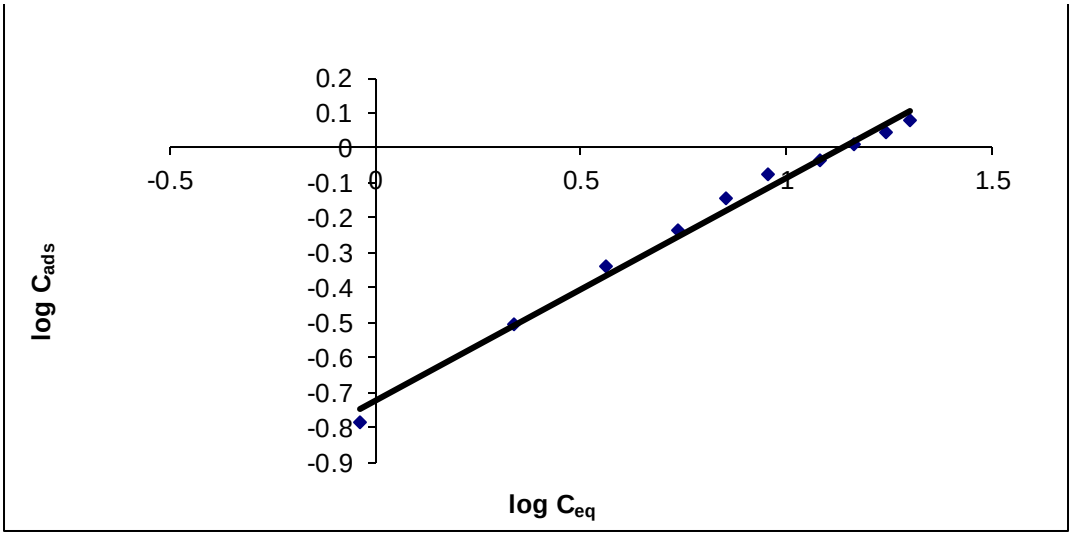

Fig.10: Fruendlich adsorption isotherm of Pb(II) on sand

Table 1. Langmuir and Fruendlich Constants of adsorption for Pb(II) on sand

Metal ion	Langmuir isotherm			Fruendlich isotherm		
	Q(mgg^{-1})	b(Lmg^{-1})	R^2	K(mgg^{-1})	1/n	R^2
Pb(II)	1.747	0.0986	0.995	0.188	0.639	0.964

Table 2: Thermodynamic constants for the adsorption of Pb(II) on sand at various temperatures

Metal ions	Temp (K)	ΔG ($kJmol^{-1}$)	ΔH ($kJmol^{-1}$)	ΔS ($kJmol^{-1}$ K^{-1})	R ($kJmol^{-1}$ K^{-1})
Pb (II)	293	-2.55			
	303	-2.79	2.48	0.034	8.3×10^{-3}
	313	-3.03			
	323	-3.27			

Thermodynamics of Adsorption: For the thermodynamic analysis, the adsorption of lead onto sand was examined at temperatures ranging from 293 K to 323 K under optimal experimental conditions. Enthalpy change ΔH and entropy change (ΔS) were calculated from the intercept and slopeof the plot of log Q versus 1/T (Fig.11). Results summarized in Table 2. The positive value of ΔH confirms that the adsorption process is endothermic, whereas the negative ΔG signifies that the adsorption occurs spontaneously [15].

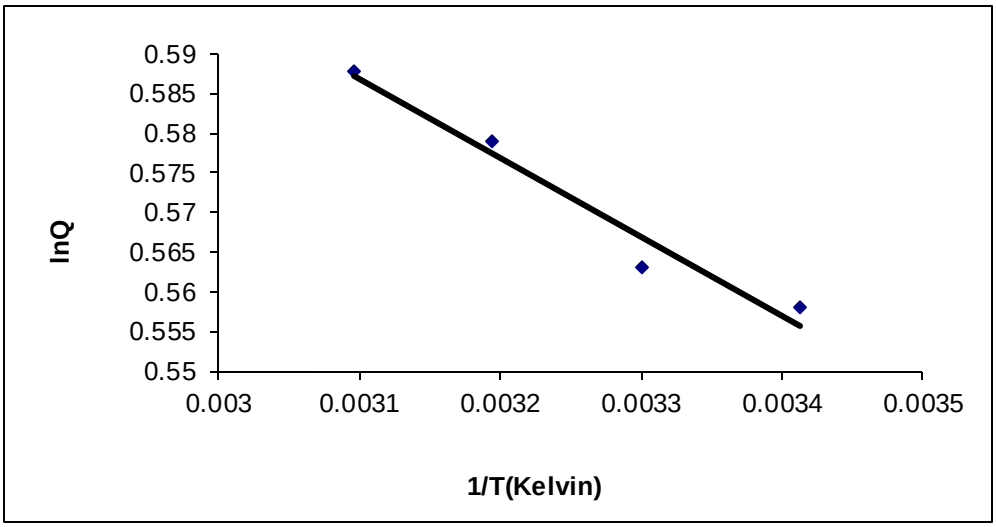

Fig.11: Plot of Langmuir isotherm constant (lnQ) of Pb(II) vs Temp(1/T)

Conclusion: In this study, it was concluded that Jhelum sand serves as an effective and economical adsorbent for the removal of Pb(II) ions. The optimum conditions for this adsorption process are shaking speed 120rpm, adsorption dose 2.5g/100ml, pH 5 and contact time 20minutes.Various adsorption models were applied to describe the adsorption behavior. The negative Gibbs free energy values and positive enthalpy changes confirm that the process is spontaneous and endothermic. Therefore, Jhelum sand presents a safe, low-cost, and efficient alternative to expensive and potentially harmful synthetic adsorbents for treating wastewater and industrial effluents.

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