

Use of *Phaseolus vulgaris* as an ecofriendly bioadsorbent for the elimination of Pb and Cd from wastewater

Muhammad Alyas Habib¹, Labia Khan¹, Hafiz Talha Akhtar^{1*}, Muhammad Irfan Ilyas¹, Muhammad Ayaz Ashraf², Farhan Asghar², Abdur Rehman Mushtaq Ahmad², Faiqa Perveen², Muhammad Nadir³, Muhammad Salman³

University of Management and Technology Lahore

Faculty of Sciences, Department of Chemistry, The University of Lahore

Islamia university of Bahawalpur

International Islamic university Islamabad

Department of Chemistry, Faculty of Engineering and Applied Sciences, Riphah International University
Faisalabad, Faisalabad

University of Punjab Lahore

University of education Lahore

Abstract

Air, water, and food are essential for human survival, but increasing population and industrialization over the past two centuries have led to rising environmental pollution in many regions. This pollution has also affected the quality of air, water, and food. Consequently, there is an urgent need to purify polluted water, particularly due to the presence of heavy metals as common water pollutants. In this study, we focused on the removal of cadmium (Cd) and lead (Pb) from wastewater using a process called biosorption. We employed the leaves of the *Phaseolus vulgaris* plant as a biosorbent. At a biomass concentration of 0.9 grams, we achieved a significant reduction of 90.56% for cadmium and 58.46% for lead. This purification process occurred within a time frame of 40-50 minutes, with a pH range of 6-7, and at a temperature of 60°C. Our equilibrium modeling revealed that the adsorption process followed the Langmuir model, with high R² values of 0.9911 mg/g for cadmium and 0.9843 mg/g for lead. The maximum adsorption capacity (q_{max}) was determined to be 41.49 mg/g for cadmium and 25 mg/g for lead. Overall, our experimental results and modeling data demonstrated that the selected adsorbent effectively removes lead and cadmium metals from wastewater.

Introduction

Pollution, caused by various harmful substances resulting from industrialization and population growth, is a severe global issue, leading to environmental contamination and significant health impacts, with 2.5 million annual deaths attributed to water pollution [1]. Water pollution results from the contamination of water bodies by both organic and inorganic substances, primarily due to the discharge of untreated industrial waste [2]. Increasing water pollution with high concentrations of heavy metals in rivers like the Indus poses a critical threat to life in Pakistan and other countries [3]. Fertilizers,

pesticides, and insecticides in agriculture contaminate food, leading to various human diseases, while water pollution primarily stems from two sources [4]. Point source pollution is the release of harmful substances into the natural environment from identifiable sources, such as pipes or drains, as defined by the EPA [5]. Land pollution, caused by synthetic chemicals like hydrocarbons, pesticides, and heavy metals, harms the natural soil environment [6]. Air pollution results from the introduction of harmful materials into the atmosphere, including toxic solid particles and gases such as carbon monoxide, sulfur dioxide, carbon dioxide, and hydrogen sulfide,

damaging living organisms and the environment [7]. Heavy metals, found in the Earth's crust, Nutrients enter the body via consumption of food and water, and air, with essential ones like zinc, selenium, and copper supporting metabolism but becoming harmful at higher concentrations due to bioaccumulation [8]. Heavy metal accumulation in soil harms agriculture, alters plant metabolism, reduces growth and biomass, while toxic metals like lead, chromium, mercury, and cadmium threaten both soil fertility and human health through disorders and environmental damage due to their non-biodegradable nature [9]. Non-degradable heavy metals accumulate in the human body over time, leading to severe diseases such as cancer, sourced from the environment via air, skin, water, food, and inhalation [10]. Heavy metal accumulation in the human body can block veins and enzyme active sites, leading to a slowdown in physiological functions [11]. Accumulation of heavy metals in the human brain leads to various diseases and mutations in proteins, causing neurological disorders, memory loss, muscle issues, sensory dysfunction, vomiting, and liver/kidney damage; notable heavy metals include cadmium, chromium, lead, mercury, arsenic [12]. Essential metals like Co, Mn, Fe, and Zn are vital in low quantities for animals and plants, certainly, here's a revised sentence: Meanwhile, metals like lead (Pb), cadmium (Cd), beryllium (Be), arsenic (As), and mercury (Hg), which are considered non-essential, found in excess, can lead to severe diseases like cancer [13]. Cadmium, discovered in 1817 by Karl Samuel, Leberecht Hermann, and Friedrich Stormier, has atomic number 48, atomic mass 112.4, silvery-grey color, malleable and soft properties, eight isotopes, two oxidation states (I and II), primarily exists in the (II) state, occurs naturally in low crustal concentrations, and is increasing due to human activities [14]. Excess cadmium accumulation from sources like metal alloy synthesis, pigments, dust, electroplating, sewage, mining, and batteries leads to serious acute and chronic ecotoxicological diseases [15]. According to the World Health Organization (WHO), the recommended concentration range for cadmium in paints is between 0.04 to 0.06 milligrams per liter (mg/L), can lead to chronic health issues and, at 0.06 mg/L, causes nausea and vomiting in humans [16]. A 0.05 mg/L cadmium concentration is considered harmless but can harm cardiovascular health, affect gene

transcription, lead to male infertility in rats, induce hypertension and oxidative stress, and harm plant membranes [17]. Lead (Pb), with atomic number 82, atomic mass 207.2 amu, and melting/boiling points of 327.5°C and 1749°C, respectively, is a dense, soft, malleable heavy metal that exhibits a silvery/blue color, turning grey upon exposure to air; it forms covalent bonds, primarily in a 2+ oxidation state [18]. Lead is a highly toxic metal that can adversely affect all living organisms, leading to a range of severe health issues, including anemia, kidney failure, neurotoxicity, reproductive problems, carcinogenicity, and more [19]. Heavy metal removal from wastewater is a critical global concern due to its toxicity impacting aquatic life and human health, necessitating various methods to purify water from pollutants [20]. A precipitation method using coagulants like lime, alum, iron salt and organic polymers removes heavy metals at low pH, forming insoluble precipitates, but generates toxic compounds and sludge [21]. *Phaseolus vulgaris*, commonly known as beans or French beans, is a worldwide herbaceous plant with various bean types, edible leaves for bedbug trapping, evergreen foliage for vegetable consumption, straw as fodder, weight loss aid, but with toxic compounds like phytohaemagglutinin and lectin, boasting vigorous climbing habits, lovely pale violet flowers, and ornamental garden use [22].

Material and method

Chemicals

Cadmium nitrate, Lead nitrate, Hydrochloric acid, Sodium hydroxide

Gathering of biological materials

Fresh *Phaseolus vulgaris* leaves were gathered at the University of Punjab in Lahore. They were initially cleaned with distilled water to eliminate surface dust. Subsequently, the leaves were air-dried and then placed in an electric oven at a temperature range of 80-90°C for a period of three days. Following the drying process, the leaves were pulverized using an electric grinder. The resulting powder was filtered through an 80ASTM mesh to achieve a finer particle size.

Preparation of solutions

A solution containing 1000 parts per million (ppm) of cadmium was prepared by dissolving 6.42 grams of cadmium nitrate in 500 milliliters of distilled water.

Preparing a solution that works

Cadmium solutions were made by diluting the initial stock solution as needed.

Preparation of 0.1 M solution of NaOH

I prepared a 0.1M NaOH solution by carefully mixing 0.4 grams of NaOH with 100 milliliters of distilled water in a measuring flask.

Preparation of 0.1 M solution of HCl

To create a 0.1 M HCl solution, mix 1 mL of concentrated HCl with 100 mL of distilled water in a measuring flask. This will yield a 0.1 M HCl solution.

Creating a stock solution of lead nitrate

A 1000 parts per million (ppm) stock solutions of lead nitrate was prepared by dissolving 4.03 grams of lead nitrate in 1000 milliliters of distilled water.

Working of Pb (II) solution preparation

Lead working solutions were created by appropriately diluting a stock lead solution.

Various variables that influence the effectiveness of an adsorbent for capturing Cd (II) ions

Impact of the quantity of adsorbent used

Nine flasks were prepared by drying and labeling them from 1 to 9. Each flask was filled with 50 mL of a working solution containing 50 parts per million (ppm) of cadmium. Then, various amounts of adsorbent ranging from 0.1 to 0.9 grams were accurately measured and added to each flask, all containing 0.1 grams of reference adsorbent. The flasks were placed on an orbital shaker at a speed of 120 rotations per minute for duration of 30 minutes. After this time, the remaining metal ion concentrations were determined using flame atomic adsorption spectroscopy by filtering out the adsorbent

residues. Finally, a graph was created to illustrate the relationship between the removal percentage and the adsorbent dose at q_{max} values.

Impact of the duration of contact

Nine flasks were prepared, dried, and labeled with numbers 1 through 9. Subsequently, 50 mL of a 50 ppm cadmium working solution was added to each flask. A varying amount of adsorbent (ranging from 0.1 to 0.9 g) was weighed and introduced into each flask, ensuring a consistent 0.5 g of adsorbent was used. These flasks were then placed on an orbital shaker operating at 120 rpm for durations of 5, 10, 15, 20, 25, 30, 35, 40, and 45 minutes, respectively. The remaining concentration of metal ions was determined using flame atomic adsorption spectroscopy. Subsequently, a graph was generated, correlating the contact time with the adsorbent dose's maximum adsorption capacity (q_{max}), to gauge the efficiency of the adsorbent.

Impact of pH

Various cadmium solutions were created by adjusting their pH levels within the range of 1 to 9, utilizing 0.1 M HCl and 0.1 M NaOH solutions for pH adjustments. Subsequently, 50 mL of 50 ppm cadmium working solutions were placed in separate flasks, each corresponding to a specific pH level (ranging from 1 to 9). In each flask, an amount of adsorbent ranging from 0.1 g to 0.9 g was added, with 0.1 g being the reference amount. These flasks were then subjected to agitation at 120 rpm for duration of 30 minutes using an orbital shaker. After this time period, the adsorbent residues were filtered out. The remaining concentration of metal ions was determined using flame atomic absorption spectroscopy. A graph was subsequently constructed, illustrating the relationship between pH and the maximum adsorbent dose (q_{max}) value.

The impact of concentration

I took eighteen conical flasks, cleaned and labeled them from 1 to 9. Then, I prepared metal solutions with varying concentrations of 20, 40, 60, 80, 100, 120, 140, 160, and 180 parts per million (ppm). Next, I added these different strength solutions into 50 mL conical flasks and mixed them at 120 revolutions per

minute (rpm) while introducing 0.5 grams of adsorbent into the first nine flasks for duration of 30 minutes. After this time, I filtered out the remnants of the adsorbent, and I determined the remaining concentrations of metal ions using flame atomic adsorption spectroscopy. With the calculated equation, I obtained values for q_{max} and the concentrations of cadmium and lead at equilibrium. To identify the ideal metal concentration, I created a graph showing the relationship between C_e and q_e .

Various factors that impact the effectiveness of an adsorbent for removing lead

The impact of the amount of adsorbent used

Nine conical flasks were first prepared, dried, and labeled with numbers 1 to 9. Next, 50 mL of a working solution containing 50 parts per million (ppm) of lead was added to each flask. Then, varying amounts of adsorbent, ranging from 0.1 to 0.9 grams, were accurately weighed and added to each flask, with a consistent reference amount of 1 gram of adsorbent being used. The flasks were then placed on an orbital shaker and agitated at a speed of 120 revolutions per minute for duration of 30 minutes. After this time period, the adsorbent residues were separated from the solution by filtration. The remaining concentration of metal ions, specifically lead, was determined using flame atomic absorption spectroscopy. Using a calculated equation, we determined the q_{max} value, which represents the maximum adsorption capacity of the adsorbent, as well as the maximum concentration of lead that could be removed. Finally, a graph was constructed to illustrate the relationship between the removal percentage of lead and the q_{max} value as a function of the adsorbent dose.

Influence of Duration of Interaction

Nine flasks were prepared and labeled from 1 to 9. Each flask was filled with 50 mL of a working solution containing 50 ppm of lead. Weighing between 0.1 and 0.9 grams of an adsorbent, we added precisely 0.5 grams of this material to each flask. These flasks were then placed on an orbital shaker set to 120 rpm for varying durations of 5, 10, 15, 20, 25, 30, 35, 40, and 45 minutes. Subsequently, the remaining concentration of metal ions was

determined using flame atomic absorption spectroscopy. Using a specific equation, we calculated the q_{max} value and the maximum concentration of lead adsorbed. To assess the efficiency of the adsorbent, we plotted a graph correlating contact time with the q_{max} value of the adsorbent dose.

Impact of pH

Various lead solutions were created with pH levels spanning from 1 to 9 by manipulating the pH using 0.1 M hydrochloric acid (HCl) and sodium hydroxide (NaOH) solutions. In each flask, 50 mL of a 50 ppm lead working solution was combined with varying amounts of adsorbent (ranging from 0.1 g to 0.9 g), with 0.1 g as the reference amount. These mixtures were agitated at 120 rpm on an orbital shaker for 30 minutes. Afterward, the adsorbent residues were filtered out; the concentration of remaining lead ions was determined utilizing flame atomic absorption spectroscopy. Using an equation, we calculated the maximum adsorption capacity (q_{max}) and the highest achievable concentration of lead. Finally, we plotted a graph to visualize the relationship between pH and the q_{max} value for the adsorbent dose.

The impact of varying metal concentrations on adsorption behavior, as described by the Langmuir and Freundlich isotherm models

First, 18 conical flasks were prepared and numbered from 1 to 9 after being thoroughly cleaned and dried. Solutions containing different concentrations of lead and cadmium metal (ranging from 20 to 180 ppm) were then prepared. These solutions were added to nine of the labeled flasks. In the first set of nine flasks, 0.5 grams of an adsorbent were introduced, and the contents were stirred at a rate of 120 rpm for 30 minutes. The remaining nine flasks were used to measure the initial metal ion concentrations without the adsorbent. After this duration, the adsorbent residues were filtered out, and the concentration of metal ions left in the solutions was determined using flame atomic absorption spectroscopy. Using a specific equation, the q_{max} -value and the maximum concentration of lead and cadmium were calculated. Equilibrium concentrations were then determined from this experimental procedure. A graph was constructed to analyze the relationship between C_e

and q_e to identify the optimal concentration for lead and cadmium adsorption. Additionally, graphs were plotted to evaluate Langmuir and Freundlich models, with one graph depicting $1/C_e$ against $1/q$ for Langmuir modeling and another graph showing $\log C_e$ against $\log q$ for Freundlich modeling.

Results and Discussion

Measure the absorbance of cadmium at different concentrations

Figure 1 displays the calibration line for cadmium, where a linear relationship between concentration and absorption was established. The correlation coefficient (R^2) value, which signifies the reliability of the data in Figure 1, was calculated to be 0.9896. Table 1 presents the absorbance values for cadmium at different solution concentrations (measured in ppm). Notably, the absorbance reached its peak value of 1.389 at a concentration of 50 ppm.

Concentration (ppm)	Absorbance
10	0.168
20	0.314
30	0.476
40	0.599
50	0.759
60	0.923
70	1.008
80	1.098
90	1.254
100	1.389

Table.1 Measure the absorbance of cadmium at different concentration levels

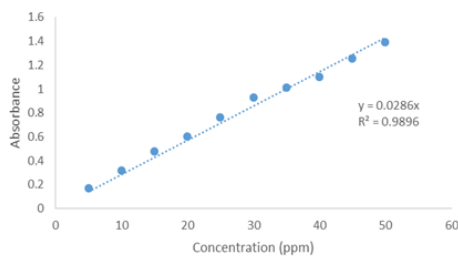


Figure.1 Create a reference curve for measuring the absorbance of cadmium

Measure the absorbance of lead at different concentrations

Figure 2 displays the calibration curve for lead metal, depicting the relationship between metal concentration and absorbance. Figure 2 exhibits a linear calibration curve with a high R -squared (R^2) value of 0.9888, indicating the reliability of the data in Figure 2. Table 2 provides absorbance values for lead at different concentrations, revealing varying absorbance levels for lead metal solutions. Notably, at a concentration of 45 ppm, lead displayed its highest absorbance reading of 0.412.

Concentration(ppm)	Absorbance
10	0.059
20	0.103
30	0.173
40	0.19
50	0.235
60	0.265
70	0.306
80	0.344
90	0.412

Table.2 Measure the amount of light absorbed by lead at different concentrations

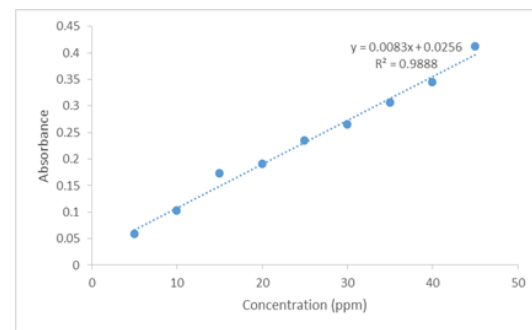


Figure 2: Line of calibration for lead absorbance

Adsorbent dosage

Determine the amount of adsorbent needed to remove cadmium

A study was conducted to investigate how changing the quantity of *P. vulgaris* used as an adsorbent affects the removal of cadmium from a liquid solution containing a consistent initial concentration of 50 mg/L. This investigation was conducted at room temperature with agitation at 150 rpm. Figure 3 illustrates that as the dosage of *P. vulgaris* adsorbent increased, the adsorption of cadmium also increased. However, beyond a certain point, further increases in the adsorbent dosage did not significantly affect the adsorption capacity. Table 3 shows that the highest removal percentages achieved were 95.31% with 0.9

g of adsorbent, 94.97% with 0.8 g, and 94.69% with 0.7 g.

Vol mL	Vol L	Mass g	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.1	50	0.551	19.27	61.47	15.37
50	0.05	0.2	50	0.432	15.10	69.79	8.72
50	0.05	0.3	50	0.341	11.92	76.15	6.35
50	0.05	0.4	50	0.213	7.45	85.10	5.32
50	0.05	0.5	50	0.199	6.96	86.08	4.30
50	0.05	0.6	50	0.132	4.62	90.77	3.78
50	0.05	0.7	50	0.076	2.66	94.69	3.38
50	0.05	0.8	50	0.072	2.52	94.97	2.97
50	0.05	0.9	50	0.067	2.34	95.31	2.65

Table 3: Empirical data regarding the amount of adsorbent required for the removal of cadmium (II) ions

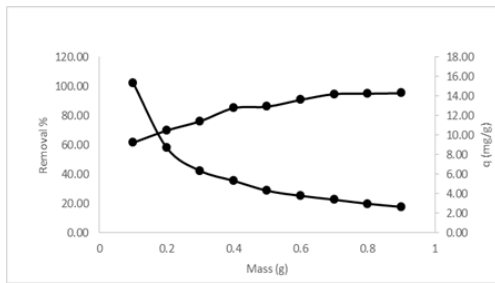


Figure 3: The impact of the amount of cadmium administered

The amount of adsorbent needed for lead removal

The impact of varying dosages of Phaseolus vulgaris as an adsorbent on the removal of lead from a constant the initial concentration in the aqueous solution is 50 milligrams per liter (mg/L) was investigated. This study was conducted at room temperature with constant agitation at 150 rpm. When a limited amount of adsorbent was used, the removal efficiency remained consistent. Figure.4 illustrates the findings. Likewise, the lead removal percentages were determined to be 86.41% for 0.9 g of the biosorbent, 85.45% for 0.8 g, and 78.22% for 0.7 g.

Vol mL	Vol L	Mass g	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.1	50	0.261	28.36	43.28	10.82
50	0.05	0.2	50	0.233	24.99	50.02	6.25
50	0.05	0.3	50	0.185	19.20	61.59	5.13
50	0.05	0.4	50	0.16	16.19	67.61	4.23
50	0.05	0.5	50	0.149	14.87	70.27	3.51
50	0.05	0.6	50	0.142	14.02	71.95	3.00
50	0.05	0.7	50	0.116	10.89	78.22	2.79
50	0.05	0.8	50	0.086	7.28	85.45	2.67
50	0.05	0.9	50	0.082	6.80	86.41	2.40

Table 4: Empirical data regarding the quantity of adsorbent used in the removal of lead (II) ions

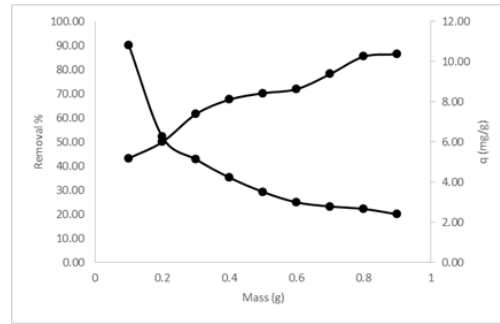


Figure 4: The impact of varying the amount of adsorbent on the removal of lead

In Figure 4, as the concentration of the biosorbent increased, there was a gradual improvement in the removal efficiency of lead metal. This improvement occurred because more binding sites became available on the surface of the biosorbent. However, the q (coefficient) values decreased as the biosorbent surface has reached its saturation point for binding sites.

Impact of the duration of interaction

Impact of the duration of contact on lead

The study investigated the adsorption behavior of Pb-metal on Phaseolus vulgaris at a constant adsorbent dosage (0.1 g/50 mL) and varying contact times ranging from 5 to 45 minutes, with agitation at 150 rpm. As depicted in Figure 5, the rate of Pb-metal removal increased over time until it reached a plateau after 45 minutes, indicating that no further metal was being adsorbed on the surface. This marked the point of dynamic equilibrium, where the amount of metal species adsorbed by Phaseolus vulgaris equaled the amount desorbed from the adsorbent. The contact time required for lead to reach equilibrium with Phaseolus vulgaris, starting with an initial concentration of 50 ppm, was found to be 25-45 minutes, 20-45 minutes, and 20-45 minutes, respectively. The removal percentages of lead metal were measured at 57.98% at 30 minutes, 58.70% at 40 minutes, and 58.46% at 45 minutes for P. vulgaris.

Vol mL	Vol L	Mass g	Time s	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	5	50	0.274	29.93	40.14	5.02
50	0.05	0.2	10	50	0.248	26.80	46.41	5.80
50	0.05	0.2	15	50	0.231	24.75	50.51	6.31
50	0.05	0.2	20	50	0.214	22.70	54.60	6.83
50	0.05	0.2	25	50	0.207	21.86	56.29	7.04
50	0.05	0.2	30	50	0.2	21.01	57.98	7.25
50	0.05	0.2	35	50	0.198	20.77	58.46	7.31

50	0.05	0.2	40	50	0.197	20.65	58.70	7.34
50	0.05	0.2	45	50	0.198	20.77	58.46	7.31

Table 5: Empirical data regarding the duration of contact time involving lead (II) ions

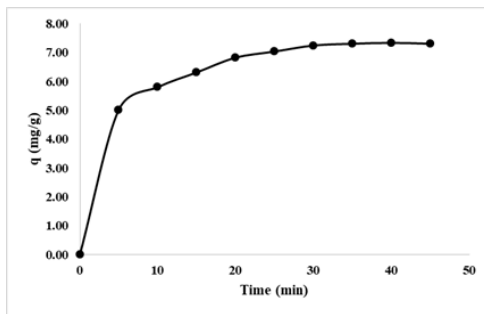


Figure 5: Impact of time on the absorption of lead

Impact of the duration of contact on cadmium

The adsorption of cadmium using a fixed mass of adsorbent (0.2 g) demonstrated outstanding cadmium removal efficiency over time. Equilibrium was reached after 45 minutes of contact time. When using *P. vulgaris* as the adsorbent with an initial solution concentration of 50 ppm, the removal efficiency reached 90.35% within the time range of 35 to 40 minutes, as indicated in Table 6. Furthermore, Figure 4.6 illustrates that as the adsorbent dosage increased gradually, the removal efficiency also increased, with a linear relationship observed at the equilibrium stage.

Vol mL	Vol L	Mass g	Time s	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	5	50	0.158	5.52	88.95	11.12
50	0.05	0.2	10	50	0.151	5.28	89.44	11.18
50	0.05	0.2	15	50	0.149	5.21	89.58	11.20
50	0.05	0.2	20	50	0.149	5.21	89.58	11.20
50	0.05	0.2	25	50	0.149	5.21	89.58	11.20
50	0.05	0.2	30	50	0.148	5.17	89.65	11.21
50	0.05	0.2	35	50	0.145	5.07	89.86	11.23
50	0.05	0.2	40	50	0.138	4.83	90.35	11.29
50	0.05	0.2	45	50	0.135	4.72	90.56	11.32

Table 6: Empirical data regarding the duration of contact for cadmium (II)

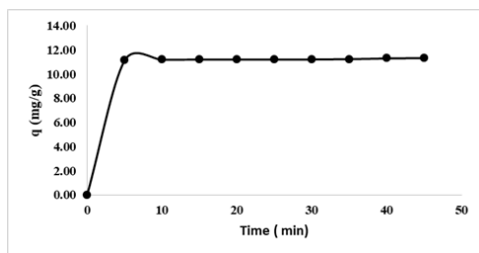


Figure 6: Effect of time for cadmium absorbance

Effect of pH

Influence of pH on Cadmium (Cd)

The distribution of metal ions in the solution and the adsorbent were both factors in the adsorption of cadmium. It was important to assess the ionic state of the functional group of the adsorbents at various pH levels. For *Phaseolus vulgaris*, the adsorption value of cadmium at pH 1 was insignificant. Figure.7 demonstrates that employing *Phaseolus vulgaris*, the effectiveness of cadmium metal ion removal from an aqueous solution increased with higher pH levels, although the adsorbent demonstrated maximum removal in the pH range of 5–6. Table.7. shows the findings.

Vol mL	Vol L	Mass g	pH	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	1	50	0.172	6.01	87.97	11.00
50	0.05	0.2	2	50	0.113	3.95	92.10	11.51
50	0.05	0.2	3	50	0.083	2.90	94.20	11.77
50	0.05	0.2	4	50	0.077	2.69	94.62	11.83
50	0.05	0.2	5	50	0.067	2.34	95.31	11.91
50	0.05	0.2	6	50	0.061	2.13	95.73	11.97
50	0.05	0.2	7	50	0.065	2.27	95.45	11.93
50	0.05	0.2	8	50	0.098	3.43	93.15	11.64
50	0.05	0.2	9	50	0.119	4.16	91.68	11.46
50	0.05	0.2	10	50	0.142	4.97	90.07	11.26

Table 7: pH values that have been tested in relation to cadmium

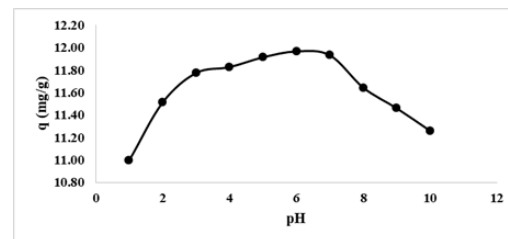


Figure 7: Effect of pH on cadmium absorbance

Influence of pH on lead

The effect of pH is crucial for metal particle adsorption onto the surface. Because of the impact of hydrogen atoms, which is a powerful adsorbate in and of themselves for the removal of metals? The impact of pH on the Pb-metal removal process using artificially modified *Phaseolus vulgaris*. Figure 8 demonstrates that the clearance rate increased as the pH in the acidic medium climbed whereas it continuously decreased as the pH in the basic media increased. *Phaseolus vulgaris* showed a maximum adsorption of lead of 81.83% at pH 6. The effectiveness of elimination was measured in both

acidic and basic media. The reason is that when switching from acidic to basic media, hydroxyl ions connect to the metals, resulting in a reduction in metal concentration during removal.

Vol mL	Vol L	Mass g	pH	Co mg/L	Abs	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	1	50	0.389	43.78	12.43	1.5542169
50	0.05	0.2	2	50	0.324	35.95	28.10	3.5120482
50	0.05	0.2	3	50	0.277	30.29	39.42	4.9277108
50	0.05	0.2	4	50	0.198	20.77	58.46	7.3072289
50	0.05	0.2	5	50	0.128	12.34	75.33	9.4156627
50	0.05	0.2	6	50	0.101	9.08	81.83	10.228916
50	0.05	0.2	7	50	0.132	12.82	74.36	9.2951807
50	0.05	0.2	8	50	0.216	22.94	54.12	6.7650602
50	0.05	0.2	9	50	0.279	30.53	38.94	4.8674699
50	0.05	0.2	10	50	0.356	39.81	20.39	2.5481928

Table 8: Experimental values impact of pH on lead (II)

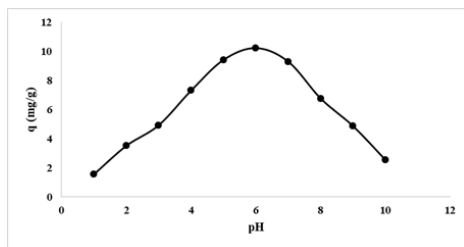


Figure 8: Impact of pH on lead adsorbance

Effect of temperature

Effect of temperature on lead adsorbance

Temperature and the total reaction's enthalpy change are important considerations in the thermodynamic study of adsorption. The study investigated the impact of temperature on adsorption using Phaseolus vulgaris as the adsorbent. The initial concentration was set at 50 mg/L, with a consistent dosage of 0.1 g per 50 mL solution, and a continuous adsorption time of 25 minutes. Table 9 the rapid rise in lead adsorption by Phaseolus vulgaris with temperature increases (10–60 °C) reveals that the reaction was endothermic. At 60 °C, the maximum removal of lead was discovered to be 63.04%. Figure illustrated visually how temperature increases increased lead metal's removal effectiveness up to a concentration limit. Further rises in temperature resulted in a decline in removal rate.

Vol mL	Vol L	Mass g	Temp. °C	Co mg/L	Abs	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	10	50	0.314	34.75	30.51	3.81
50	0.05	0.2	20	50	0.271	29.57	40.87	5.11
50	0.05	0.2	30	50	0.228	24.39	51.23	6.40
50	0.05	0.2	40	50	0.204	21.49	57.01	7.13
50	0.05	0.2	50	50	0.187	19.45	61.11	7.64
50	0.05	0.2	60	50	0.179	18.48	63.04	7.88

Table 9: Experimental values impact of temperature on lead (II)

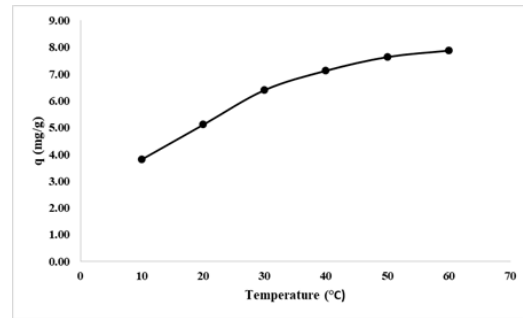


Figure 9: Impact of temperature on lead adsorbance

Impact of temperature on lead adsorbance

Due to the energy needed to bind cadmium with Phaseolus vulgaris, the clearance % increased as temperature increased. If the temperature rose even higher, figure 10 illustrates how the adsorption ratio fell as the temperature rose. At a temperature of 60°C, the maximum removal percentage was discovered to be 89.22%.

Vol mL	Vol L	Mass g	Temp. °C	Co mg/L	Abs	Ce mg/L	Removal %	q _{max} mg/g
50	0.05	0.2	10	50	0.156	6.09	87.81	10.98
50	0.05	0.2	20	50	0.154	6.02	87.97	11.00
50	0.05	0.2	30	50	0.15	5.86	88.28	11.04
50	0.05	0.2	40	50	0.149	5.82	88.36	11.04
50	0.05	0.2	50	50	0.147	5.74	88.52	11.06
50	0.05	0.2	60	50	0.138	5.39	89.22	11.15

Table 10: Experimental values effect of temperature on cadmium (II)

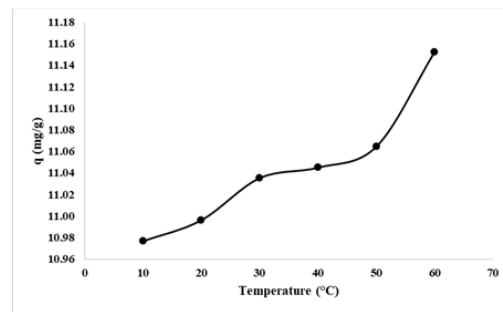


Figure 10: Effect of temperature on cadmium adsorbance

Equilibrium modeling

The data collected during the experiment served as the basis for modeling equilibrium isotherms. Two

models, namely the Langmuir and Freundlich models, were employed for this modeling process. The Langmuir model was used to determine the maximum adsorption capacity, which signifies the formation of a monolayer adsorption process occurring on a homogeneous surface. Table 12 provides Langmuir isotherm data for lead adsorption using *Phaseolus vulgaris* as a biosorbent. Figure 4.12 illustrates the linear Langmuir isotherm for lead, and the calculated parameter values are presented in Table 11. Figure 12 displays the linear plots, with an R2 value of 0.9843 for the adsorbent, indicating a close fit to the Langmuir model. Similarly, Figure 11 depicts the Langmuir isotherm for cadmium metal, with an R2 value of 0.9911 for *Phaseolus vulgaris* as the adsorbent. Table 13 highlights the significant values of qmax, which were 25.00 and 41.49 for lead and cadmium, metal, respectively, representing the maximum adsorption capacity.

33.34	0.02	0.03	66.68
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Table 12: Langmuir values for cadmium (II)

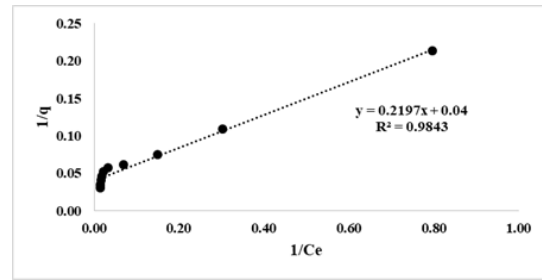


Figure 12: Langmuir model for lead

Metals	Slope	Intercept	R ²	mg/g	b (dm ³ /g)
Pb (II)	0.2197	0.04	0.9843	25.00	0.18
Cd (II)	0.8665	0.0241	0.9911	41.49	0.03

Table 13

Freundlich model

This model characterizes the extent of adsorption onto the outer surface of the adsorbent. It illustrates the diverse nature of surface adsorption, depicting the availability of various binding sites with different energy levels and indicating the occurrence of multilayer adsorption. In Table 14, the results for lead adsorption at different adsorbent concentrations are presented. Figure 14 displays the corresponding graph for lead adsorption on the biosorbent, showing an R2 value of 0.9403. Similarly, Figure 13 presents a linear graph for cadmium metal adsorption, with an R2 value of 0.9729 for the biosorbent. Table 16 provides calculated parameter values for the isotherm, indicating that the data does not conform to the Freundlich model. Specifically, the calculated values for "n" for lead and cadmium metal adsorption on the adsorbent are 1.78 and 2.14, respectively. These values, falling within the range of 1-2, provide strong evidence of effective adsorption.

Q	1/Ce	1/q	% R
mg/g		A	
4.69	0.80	0.21	93.73
9.17	0.30	0.11	91.75
13.33	0.15	0.08	88.88
16.40	0.07	0.06	82.02
17.67	0.03	0.06	70.67
19.42	0.02	0.05	64.72
22.04	0.02	0.05	62.96
24.99	0.02	0.04	62.47
28.75	0.02	0.03	63.90
32.94	0.01	0.03	65.88

Table 11: Langmuir values for lead (II)

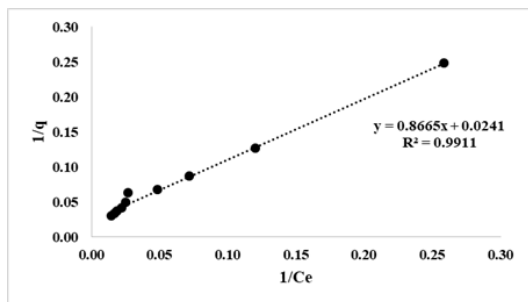


Figure 11: Langmuir model for cadmium

Q	1/Ce	1/q	% R
mg/g		A	
4.03	0.26	0.25	80.66
7.92	0.12	0.13	79.20
11.52	0.07	0.09	76.82
14.85	0.05	0.07	74.27
15.88	0.03	0.06	63.52
20.09	0.03	0.05	66.96
24.00	0.02	0.04	68.58
26.83	0.02	0.04	67.07
30.46	0.02	0.03	67.69

Vol	Vol	Mass	Conc.	Abs	Ce	q _{max}	LogCe	Logq
mL	L	G			mg/L	mg/g		A
50	0.05	0.2	20	0.036	1.25	4.69	0.10	0.67
50	0.05	0.2	40	0.053	3.30	9.17	0.52	0.96
50	0.05	0.2	60	0.081	6.67	13.33	0.82	1.12
50	0.05	0.2	80	0.145	14.39	16.40	1.16	1.21
50	0.05	0.2	100	0.269	29.33	17.67	1.47	1.25
50	0.05	0.2	120	0.377	42.34	19.42	1.63	1.29
50	0.05	0.2	140	0.456	51.86	22.04	1.71	1.34
50	0.05	0.2	160	0.524	60.05	24.99	1.78	1.40
50	0.05	0.2	180	0.565	64.99	28.75	1.81	1.46
50	0.05	0.2	200	0.592	68.24	32.94	1.83	1.52

Table 14: Freundlich values for lead (II)

mL	L	g	Conc.	Abs	mg/L	mg/g	LogCe	Logq
50	0.05	0.2	20	0.099	3.87	4.03	0.59	0.61
50	0.05	0.2	40	0.213	8.32	7.92	0.92	0.90
50	0.05	0.2	60	0.356	13.91	11.52	1.14	1.06
50	0.05	0.2	80	0.527	20.59	14.85	1.31	1.17
50	0.05	0.2	100	0.934	36.48	15.88	1.56	1.20
50	0.05	0.2	120	1.015	39.65	20.09	1.60	1.30
50	0.05	0.2	140	1.126	43.98	24.00	1.64	1.38
50	0.05	0.2	160	1.349	52.70	26.83	1.72	1.43
50	0.05	0.2	180	1.489	58.16	30.46	1.76	1.48
50	0.05	0.2	200	1.706	66.64	33.34	1.82	1.52

Table 15: Freundlich values for Cd (II)

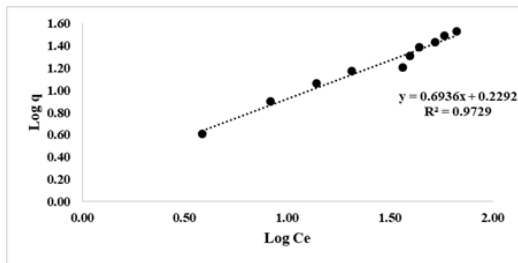


Figure 13: Freundlich model for cadmium

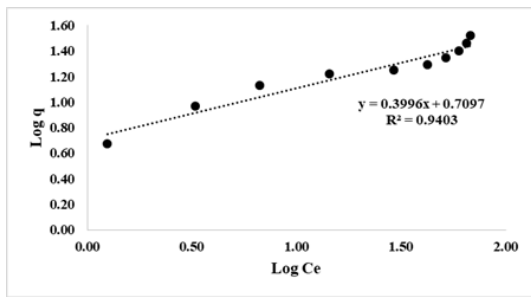


Figure 14: Freundlich model for lead

Metals	slope	intercept	R ²	n	Kf
Pb (II)	0.56	1.44	0.9729	1.78	27.78
Cd (II)	0.47	1.18	0.9403	2.14	13.95

Table 16: Freundlich parameters

Adsorption kinetics

Pseudo first order reaction

The rate equation mentioned here was employed to predict the underlying mechanism in the adsorption process. Figures 15 and 16 present the outcomes for lead and cadmium metal adsorption, respectively. In Figure 16, a linear relationship was observed between time and the natural logarithm of the difference between initial and final adsorbate concentrations (ln(qe-qt)). The coefficient of determination (R2) for lead was calculated to be 0.959, indicating a strong correlation. In contrast, Figure 15 illustrates a linear trend for cadmium metal with an R2 value of 0.66,

suggesting a moderate correlation. However, when we examine Table 19, which presents the calculated parameters for the pseudo-first-order model, it becomes evident that these values do not align with the experimental data. The highest observed adsorption capacity was 8.425 for lead and 3.4827 for cadmium on the given adsorbent.

V ol	Vo l	Ma ss	Ti me	Abs	Ce	Remo val	qt	qe	ln(qe-qt)	
m L	L	g		mg/L	mg/L	%	mg/g		a	
50	0.05	0.2	5	50	0.158	6.17	87.66	10.96	11.18	-1.5007237
50	0.05	0.2	10	50	0.151	5.90	88.20	11.03	11.18	-1.8668535
50	0.05	0.2	15	50	0.149	5.82	88.36	11.04	11.18	-2.001902
50	0.05	0.2	20	50	0.149	5.82	88.36	11.04	11.18	-2.001902
50	0.05	0.2	25	50	0.149	5.82	88.36	11.04	11.18	-2.001902
50	0.05	0.2	30	50	0.148	5.78	88.44	11.05	11.18	-2.0769447
50	0.05	0.2	35	50	0.145	5.66	88.67	11.08	11.18	-2.3432443
50	0.05	0.2	40	50	0.138	5.39	89.22	11.15	11.18	-3.5879035
50	0.05	0.2	45	50	0.135	5.27	89.45	11.18		

Table 17: Pseudo first order values for cadmium (II)

V ol	Vo l	Ma ss	Ti me	Co	Abs	Ce	Remo val	qt	qe	ln(qe-qt)
m L	L	G		mg/L	mg/L	mg/L	%	mg/g		a
50	0.05	0.2	5	50	0.274	29.93	40.14	5.02	7.34	0.8423978
50	0.05	0.2	10	50	0.248	26.80	46.41	5.80	7.34	0.4309998
50	0.05	0.2	15	50	0.231	24.75	50.51	6.31	7.34	0.0263955
50	0.05	0.2	20	50	0.214	22.70	54.60	6.83	7.34	-0.6641734
50	0.05	0.2	25	50	0.207	21.86	56.29	7.04	7.34	-1.1912033
50	0.05	0.2	30	50	0.211	21.01	57.98	7.25	7.34	-2.3750262
50	0.05	0.2	35	50	0.198	20.77	58.46	7.31	7.34	-3.4182087
50	0.05	0.2	40	50	0.197	20.65	58.70	7.34		
50	0.05	0.2	45	50	0.198	20.77	58.46	7.31		

Table 18: Pseudo first order values for lead (II)

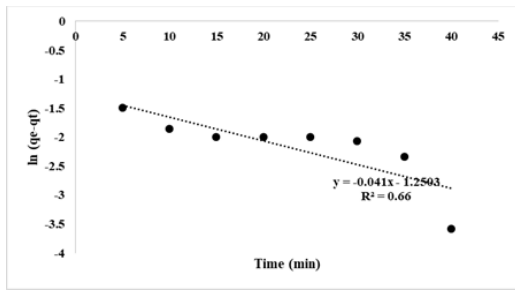


Figure 15: Pseudo 1st order for cadmium

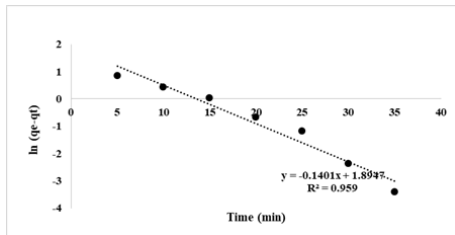


Figure 16: Pseudo 1st order for lead

Met als	Slope	Intercept	R ²	K1	Calculated _q
Pb (II)	-0.157	2.1313	0.9917	0.1565	8.4258
Cd (II)	0.116	1.2478	0.9597	0.1159	3.4827

Table 19: Pseudo first order parameters

Pseudo second order reaction

Lead and cadmium metal's pseudo 2nd order kinetic model's derived parameters are displayed in Tables 20 and 21, respectively. Cadmium is represented by a linear line in Figure 17 with an R2 value of 0.9999. Similar to figure 17, figure 18 displays the lead's linear graph, where R2 = 0.9992. This shows that the model was successfully used to predict the rate of reaction. Lead and cadmium had qe values of 18.64 and 17.39, respectively. This demonstrates that a false second order reaction was used to influence the reaction mechanism.

V ol	Vo l	Ma ss	Tim e	Co	Abs	Ce	Remo val	qt	Qe	t/qt
m L	L	G		mg/L		mg/L	%	mg/g		
50	0.05	0.1	5	50	0.274	29.93	40.14	10.04	14.67	0.4981993
50	0.05	0.1	10	50	0.248	26.80	46.41	11.60	14.67	0.8618899
50	0.05	0.1	15	50	0.224	24.51	50.51	12.14	14.18	

50	0.05	0.1	20	50	0.214	22.70	54.60	13.65	14.67	1.4651368
50	0.05	0.1	25	50	0.207	21.86	56.29	14.07	14.67	1.7765411
50	0.05	0.1	30	50	0.201	21.01	57.98	14.49	14.67	2.0698254
50	0.05	0.1	35	50	0.198	20.77	58.46	14.61	14.67	2.3948887
50	0.05	0.1	40	50	0.197	20.65	58.70	14.67	14.67	2.72578
50	0.05	0.1	45	50	0.198	20.77	58.46	14.61	14.67	3.0791426

Table 20: Lead (II) pseudosecond order values

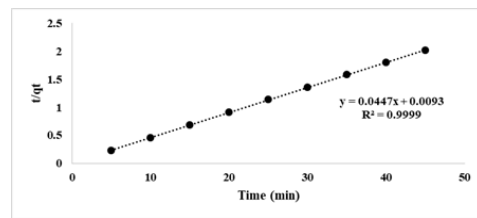


Figure 17: Cadmium pseudo-second order

Vo l	Vol	Ma ss	Tim e	Co	Ab s	Ce	Remov al	qt	Q	t/qt
m L	L	G		mg/L		mg/L	%	mg/g	e	
50	0.05	0.1	5	50	0.158	6.17	87.66	21.91	22.36	0.228164
50	0.05	0.1	10	50	0.151	5.90	88.20	22.05	22.36	0.4534987
50	0.05	0.1	15	50	0.149	5.82	88.36	22.09	22.36	0.6790451
50	0.05	0.1	20	50	0.149	5.82	88.36	22.09	22.36	0.9053935
50	0.05	0.1	25	50	0.149	5.82	88.36	22.09	22.36	1.1317418
50	0.05	0.1	30	50	0.148	5.78	88.44	22.11	22.36	1.3568905
50	0.05	0.1	35	50	0.145	5.66	88.67	22.17	22.36	1.5788546
50	0.05	0.1	40	50	0.138	5.39	89.22	22.30	22.36	1.793345
50	0.05	0.1	45	50	0.135	5.27	89.45	22.36	22.36	2.0122271

Table 21: Cadmium (II) pseudosecond order values

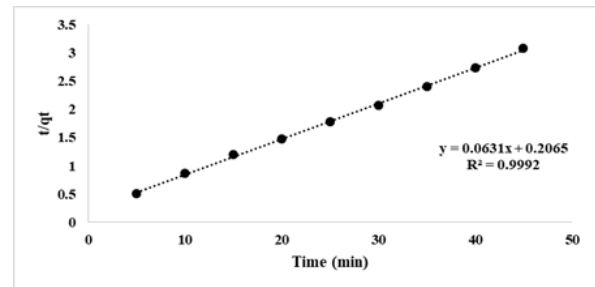


Figure 18: Pseudo 2nd order for lead

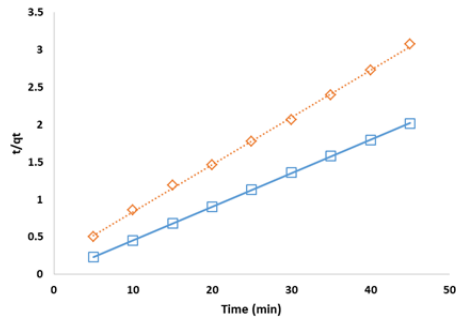


Figure 19: Pseudo 2nd order for lead & cadmium

Metals	Slope	Intercept	R ²	K ²	Calculated qe	Experimental qe
Pb (II)	0.0527	0.0339	0.9987	0.008	18.957	18.64
Cd (II)	0.0055	0.007	0.9995	0.002	18.181	17.39

Table 22: Pseudo second order parameters

Lead adsorption thermodynamic adsorption study

The feasibility and practicality of the adsorption technique were assessed using the thermodynamic study. To calculate enthalpy, free energy, and entropy, these parameters were employed. Lead's thermodynamics plot, shown in Figure 20, exhibits a linear graph and an R² value of 0.949. After some time, the reaction turns spontaneous for Pb-metal G values that were initially favorable before turning negative. The Pb-metal's thermodynamics results are displayed in Table 22.

Vol mL	Vol L	Mass g	Temp. °C	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q mg/g	kd	ΔG j/mol	ΔG kJ/mol
50	0.05	0.2	283.16	50	0.136	5.31	89.38	11.17	8.41	-5013.56	-5.01
50	0.05	0.2	293.16	50	0.134	5.23	89.53	11.19	8.55	-5230.99	-5.23
50	0.05	0.2	303.16	50	0.13	5.08	89.84	11.23	8.85	-5494.59	-5.49
50	0.05	0.2	313.16	50	0.129	5.04	89.92	11.24	8.92	-5698.20	-5.70
50	0.05	0.2	323.16	50	0.127	4.96	90.08	11.26	9.08	-5926.80	-5.93
50	0.05	0.2	333.16	50	0.118	4.61	90.78	11.35	9.85	-6335.33	-6.34

Table 23: Lead (II) adsorption thermodynamics values

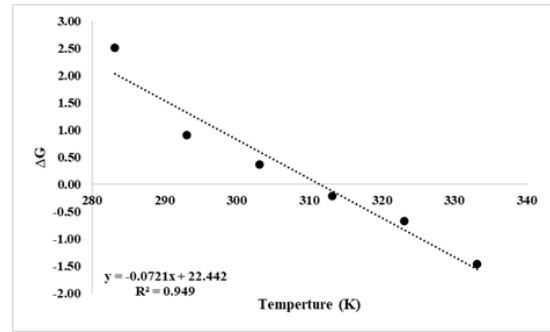


Figure 20: Thermodynamic for lead

For cadmium adsorption, conduct a thermodynamic adsorption research

Table 24 contains the results of the Cd-metal linear graph (Figure 21), where the R² value was 0.9868. The computed thermodynamic parameters for lead and cadmium are displayed in Table 25. At all temperatures, the spontaneous reactions are represented by the negative value of G. All of the components' H values were positive, demonstrating the reaction's spontaneity. For lead and cadmium metal, the computed values for H were 12.394 and 10.951, respectively.

Vol mL	Vol L	Mass g	Temp. °C	Co mg/L	Abs mg/L	Ce mg/L	Removal %	q mg/g	kd	ΔG j/mol	ΔG kJ/mol
50	0.05	0.2	283.16	50	0.136	5.31	89.38	11.17	8.41	-5013.56	-5.01
50	0.05	0.2	293.16	50	0.134	5.23	89.53	11.19	8.55	-5230.99	-5.23
50	0.05	0.2	303.16	50	0.13	5.08	89.84	11.23	8.85	-5494.59	-5.49
50	0.05	0.2	313.16	50	0.129	5.04	89.92	11.24	8.92	-5698.20	-5.70
50	0.05	0.2	323.16	50	0.127	4.96	90.08	11.26	9.08	-5926.80	-5.93
50	0.05	0.2	333.16	50	0.118	4.61	90.78	11.35	9.85	-6335.33	-6.34

Table 24: Values of the adsorption thermodynamics for cadmium (II)

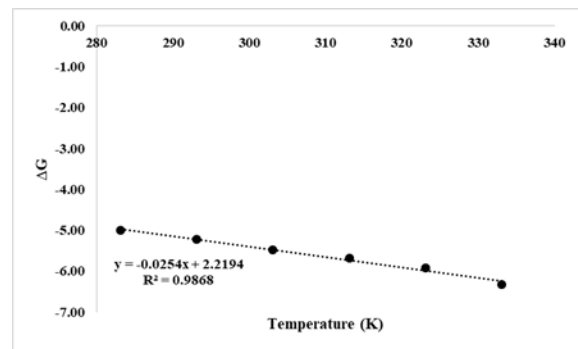


Figure 21: Thermodynamic for cadmium

Metals	Intercept	R ²	ΔH ⁰ (kJ/mol)	ΔS ⁰ (kJ/mol)
Pb (II)		0.9868	12.394	-0.05
Cd (II)	10.951	0.949	10.951	0.048

Table 25: Thermodynamics Parameters

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