

Efficient Removal Lead (II) from the Environment by Adsorption Using Low-Cost Adsorbent Materials

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Abstract: Pollutants, particularly harmful heavy metals, are released into the environment, posing serious health risks to humans and other living species. The human body does not require lead, which is a toxic chemical. As a result, in order to eradicate or remove lead from the environment, a range of technologies must be used. The goal of this research was to use low-cost, high-efficiency adsorbent materials to adsorb lead (II) ions from aqueous solutions. Adsorption capacity, elimination percent, and batch adsorption settings are all discussed in this work. The adsorption capacity and percentage removal of lead from aqueous solutions by adsorption are affected by the initial concentration, pH, adsorbent dose, contact time, and temperature. The goal of this research was to use low-cost, high-efficiency adsorbent materials to adsorb lead (II) ions from aqueous solutions. The impacts of several parameters on the adsorption process such as pH, contact time, initial concentration of lead (II) ions, and temperature were examined. Therefore, lead (II) ions can be removed from the water body effectively using low-cost adsorbent materials.

Keywords: Adsorption, Adsorption Mechanism, Adsorption Kinetics, Adsorption Isotherm, Lead, Low Cost Adsorbent

1. Introduction

Heavy metals are very harmful to the human body even in low concentrations as there is no effective excretion mechanism [1]. Toxic metals and their ions endanger not only human health but also the health of other living things. Mercury, chromium, cadmium, arsenic, nickel, and lead are only a few of the most hazardous industrial water pollutants [2]. The toxicity, duration, and accumulation of these chemicals in living creatures pose a number of health and environmental hazards [3]. In industrial waste, lead is one of the most frequent and dangerous heavy metals. Lead acid batteries, pulp and paper, petrochemicals, refineries, printing, pigments, photographic materials, explosive manufacturing, ceramics, glass, paint, oil, metal, phosphate fertilizer, electronics, wood production, combustion forest fires, mining activity, automobile emissions, fossil fuel, and sewage wastewater all release into the environment [4, 5]. The Environmental Protection Agency (EPA) and the World Health Organization (WHO) have set maximum contamination levels for lead in drinking water at 15 and 50 g/L, respectively [6]. Lead is found in all aspects of our

environment, including the air, soil, water, and even our homes.

1.1. Uses of Lead

Lead is still used in some solders, car batteries, pigments, ammunition, cable sheathing, lifting weights, diving weight belts, lead crystal glass, and radiation protection. It is widely used to store corrosive liquids. With a close-packed metallic lattice, there is only one known crystallographic change. The ductility, ease of welding, low melting point, high density, and ability to absorb gamma and X-rays are all qualities that contribute to the vast range of applications for elemental lead. Molten lead is an excellent solvent and collector for elemental silver and gold. Lead's structural applications are limited due to its poor tensile and fatigue strengths, as well as its inclination to flow even when lightly loaded. Lead oxidizes fast after being freshly cut, leaving a dull gray coating that protects the metal from further corrosion. This coating was once thought to be lead suboxide, Pb_2O , but it is now known to be a mix of lead and lead monoxide.

1.2. Health Effects of Lead

Lead, unlike organic pollutants, is non-biodegradable, tends to accumulate in living beings, and has serious health implications [7]. Nearly every organ and function in your body is susceptible to lead poisoning. Low levels of lead in children's blood can cause behavioral and learning problems, as well as lower IQ and hyperactivity, slower growth, hearing disorders, and anemia. Lead, along with calcium, is liberated from the mother's bones and can pass through her, exposing the fetus or breastfeeding newborn to lead poisoning. This can have serious repercussions for the developing fetus and infant, including as the baby being born prematurely or too small, hurting the baby's brain, kidneys, and nervous system, raising the likelihood of learning or behavioral problems, and putting the mother in danger. Lead poisoning can also affect adults. Adults who have been exposed to lead may experience cardiovascular effects, high blood pressure, hypertension, poor renal function, reproductive concerns, and mental and circulatory system challenges.

2. Removal of Lead by Adsorption

The Environmental Protection Agency (EPA) has defined heavy metals as priority pollutants that must be eliminated or reduced from any water body that may or may not come into contact with the environment [8]. Precipitation, ion exchange, reverse osmosis, membrane separation, adsorption, and other standard heavy metal removal processes have all been effectively tested. Because of its selectivity, cheap cost, ease of use, great efficiency (even at low concentrations), and capacity to reuse the materials involved, adsorption is one of the most promising and commonly utilized technologies [9].

2.1. Adsorption

The process of a material collecting on the surface of another substance, resulting in a higher concentration of molecular species, is known as adsorption. Depending on the substance being deposited and adsorbed, adsorption can be divided into two types (Physisorption and chemisorption). Physical adsorption, or physisorption, is an exothermic process in which gas collects on a solid surface due to weak Van der Waals interactions. When a substance is adsorbed and held together by chemical bonds, it is known as chemisorption or chemical adsorption. Chemisorption has a high selectivity and happens only when the adsorbent and the adsorbate form a chemical connection.

2.2. Adsorption Isotherms and Kinetics

The equilibrium adsorption capacity and the percent removal of Pb^{2+} ions (R %) were calculated using Equations (1) and (2).

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (1)$$

$$\% R = \frac{(C_0 - C_e)100}{C_0} \quad (2)$$

Where q_t (mg/g) is the adsorption capacity of adsorbent for Pb^{2+} at time t (min), C_0 and C_e (mg/L) are the liquid phase concentrations of Pb^{2+} before and after adsorption, respectively. V (L) and m (g) are the volume of the adsorption solution and the mass of the dry adsorbent used, respectively. An adsorption isotherm is a curve relating the equilibrium concentration of a solute on the surface of an adsorbent, q_e to the concentration of the solute in the liquid, C_e which is in contact. The adsorption isotherm is also an equation relating the amount of solute adsorbed onto the solid and the equilibrium concentration of the solute in solution at a given temperature. The two well-known models, Langmuir and Freundlich were used to describe the isothermal characteristics of the adsorbent. The Langmuir isotherm considers adsorption as a chemical phenomenon, assuming that adsorption occurs uniformly on the active sites of the surface and only a monolayer is formed. Freundlich isotherm is a mathematical expression for the adsorption equilibrium between a fluid (liquid or gas) and a solid material. The Freundlich equation is an empirical expression representing the isothermal variation of adsorption of a liquid or gas onto the surface of a solid material. Freundlich on the other hand, assumes a heterogeneous surface and an exponential distribution of active sites and their energies.

Langmuir linear model:

$$\frac{C_e}{q_e} = \frac{1}{K_L q_m} + \frac{C_e}{q_m} \quad (3)$$

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (4)$$

$$R_L = \frac{1}{1 + K_L C_0} \quad (5)$$

Where C_e and q_e have the same meaning as previously noted, q_m (mg/g) is the maximum monolayer adsorption capacity of the adsorbent, K_L (L/mg) is the Langmuir constant describing adsorption affinity for the adsorbent. The value of R_L indicates the type of the isotherm to be either; unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) and irreversible ($R_L = 0$).

Freundlich linear model:

$$q_e = K_F C_e^{\frac{1}{n}} \quad (6)$$

The equation can be linearized and temperature dependent constants K_F and $1/n$ are obtained by linear regression:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e \quad (7)$$

K_F (mg/g) (L/mg) $1/n$ is the Freundlich constant related to the multilayer adsorption capacity and n is the heterogeneity factor, which represents the extent to which the adsorption depends on the equilibrium concentration.

Adsorption kinetics is a curve (or line) that describes the rate of retention or release of a solute from an aqueous environment to solid-phase interface at a given adsorbents dose, flow rate and pH. The data obtained from the kinetic

tests are fitted to the pseudo-first-order and pseudo-second-order models [10] respectively. The kinetic model that fits to Pseudo-first-order reaction plot by giving r^2 value close to 1, it indicates that the reaction is more inclined towards Physisorption. Similarly if the reaction fits well to Pseudo-second-order model it indicates an inclination towards chemisorption. Pseudo-first-order Equation (8) assumes that the adsorption rate is based on the adsorption capacity. The pseudo-second-order model, Equation (9).

Pseudo first order expression

$$\ln(q_e - q_t) = \ln q_e - K_1 t \quad (8)$$

Where q_t and q_e (mg/g) are the amount of Pb^{2+} adsorbed per mass of adsorbent (g) at time t (min) and at equilibrium, respectively, and k_1 (1/min) the rate constants of the pseudo-first-order.

Pseudo second order expression

$$q_t = \frac{q_e^2 K_2 t}{1 + q_e K_2 t} \quad (9)$$

Where q_e (mg/g) and q_t (mg/g) are the adsorbate amount adsorbed at equilibrium and at any time t (min), respectively and K_2 (g/mg min) is the PSO equation constant rate.

$$\frac{t}{q_t} = \frac{1}{h} + \frac{t}{q_e} \quad (10)$$

3. Mechanisms of Adsorption

Molecules naturally diffuse away from a substance's bulk. Through a laminar layer that surrounds the solid particle, the turbulent phase reaches its surface. The bulk of another phase flows through its extreme surface due to concentration. Adsorption happens because the surface particles of the adsorbent are not in the same environment as the bulk particles. Although all of the forces operating between the particles inside the adsorbent are mutually balanced, the particles have unbalanced or residual attractive forces on the surface because they are not surrounded on all sides by atoms or molecules of their kind. Adsorbate particles cling to their surfaces due to these adsorbent forces.

Table 1. Different adsorbent materials for the removal of lead (II) from aqueous solutions.

Adsorbents	%R	q_m (mg/g)	Adsorption Conditions			Ref.
			pH	T (°C)	Dosage	
Hazelnut husk (HH)	-	13		18	200	12 g/L [11]
Chinese walnut shell	94.1	82.0	5.5	-	60	4 g/L [12]
Juniperus procera	98.0	30.3	4.6	25	50	8.0 g/L [13]
Acidified CNTs	-	17.4	5.0	-	10	- [14]
Coconut shell	75	26.5	4.5		50mg/50mL	- [15]
Waste beer yeast	96.4	2.3	1-5		25	2 g/L [16]
Precursor hazelnut husks	97.2	13	6.7	-	30	0.3/25 mL [11]
Peanut hulls	69.8	-	5.0	25	200	1 g/L [17]
Apricot stone	98.1	21.4	6.0	20	50	1.0 g/L [18]
Rice straw	94	42.5	5.5	-	60	4 g/L [19]
Leaves of Date Trees	94	58	5.8	-	10	1 g/L [20]
Coconut	60.0	4.4	4.0	60	100	6 g/L [21]
Albizia lebbeck	62	4.4	5.0	20	40	0.2 g/L [22]
PPy/oMWCNT composite	-	26.3	6.0	25	10	1.0 g/L [23]
Onion skins	93.0	200.0	6.0	30	25-200	0.15 g/L [24]
Tea waste	73.0	96.0	5.0	30	5	0.5 g/L [25]
Natural goethite	100	-	4.5	30	5	100 g/L [26]
Dust of bamboo	66.7	2.2	7.2		600	28 g/L [27]
Banana pseudostem	85	9.5	6.0	-	10	1 g/L [28]
Neem tree leaves	-	41.4	5.0	25	20	1 g/L [29]
Acid treated wheat bran	82.8	79.4	6.0	25	100	0.1 g/L [30]
Polygonum orientale Linn	-	98.4	5.0	25	50	0.6 g/L [31]

Where, %R = removal percentage, q_m (mg/g) = adsorption capacity, T (°C) = temperature, and C_o = initial concentration of the adsorbate.

4. Conclusion

The results of the adsorption investigation show that low-cost adsorbent materials are effective at removing lead. The pseudo-second-order kinetics model was used for most of the adsorbent materials, and it was discovered that the pseudo-second-order rate constant (K_2) was inversely proportional to the initial concentration of Pb (II), implying that surface saturation was dependent on the initial ion concentration, which is chemisorption. The Langmuir equation was used to compute the maximum adsorption

(q_m). The concentration and pH of the solution, as well as the adsorbent dosage, influenced the adsorption capacity at equilibrium, q_e .

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