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Heavy Metals Removal from Polluted Water by Cement Kiln Dust

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ABSTRACT

Two laboratory experiments were conducted in the Desert Studies Center laboratories during the spring season of 2024 to evaluate the efficiency of Cement Kiln Dust (CKD) in removing lead and cadmium from polluted water. The first experiment represents the thermally isotropic adsorption of heavy metals on the cement kiln dust (CKD) surface. The experiment included three diameters of CKD particles, i.e., 0.3, 1.18, and 2 mm, treated with four concentrations of cadmium and lead, namely 20, 40, 80, and 160 $mg.L^{-1}$ for each element (cadmium and lead). The amount of the adsorbed metals on the surface of CKD was calculated according to the Langmuir equation. In contrast, the second experiment represents the effect of contact time between the heavy metals and CKD particles for the same aforementioned diameters and concentrations. The results of the isothermal adsorption experiment showed that the adsorbed amount increased with increasing the added concentrations of heavy metals. The adsorbed quantity of cadmium is superior to that of lead. Also, the adsorption capacity of cadmium was higher compared to the lead adsorption capacity. In this context, the adsorption capacity reached 2880.00 and 2735.58 $mg.kg^{-1}$ for cadmium and lead, respectively. Regarding the second experiment, the results showed that the amount of cadmium and lead adsorbed on the CKD particle's surface increased with time, where the highest amount of cadmium and lead adsorption was 39.94 and 34.93%, respectively, for shaking of 4 h. It is recommended to apply the experiment in real-world projects.

INTRODUCTION

Water pollution is considered one of the major global problems because it poses adverse economic impacts to life, exposes health to danger, and hinders the development of industrial and agricultural activity. Under an insufficient water supply, economic activities may be hampered or even halted (Yang et al. 2024). Excessive heavy metal concentrations in polluted water can indisputably pose a threat to ecological and human health risks by deteriorating freshwater resources such as rivers and streams (Hanif et al. 2025). Consequently, this restricts their use for agricultural, domestic, and industrial purposes (Kumar et al. 2022). Saeed et al. (2024) proposed using some techniques to mitigate the hazards of pollutants in the future. Universally, the agriculture sector consumes over 70% of global freshwater withdrawals. Therefore, wastewater reuse is a reliable and practical way to cope with freshwater scarcity and to provide a sustainable water source for the agricultural sector. However, the high cost of treating polluted water has caused many countries to discharge the polluted water without treatment into freshwater sources such as rivers, lakes, and streams, resulting in adverse effects on human, animal, and plant life. A rapid increase in urbanization and the industrial revolution has recently been attributed to an increase in the production of different kinds of contaminants, such as air pollutants, solid waste, and production of wastewater. Cement industry factories are the largest contributors to the production of these pollutants (Majeed et al. 2021). The cement factories discharge approximately 11 million tons/year of solid waste (Millati et al. 2019). Cement Kiln Dust (CKD) represents the largest by-product of cement factory solid waste and is classified as a non-hazardous by-product (Seo et al. 2019). Previous studies indicated that the cement kiln dust consists of quartz, sodium chloride, and small amounts of gypsum, in addition to containing quantities of coagulants such as CaO, MgO, Al_2O_3, and Fe_2O_3, which make it a good adsorbent material (Rimal et al. 2019). Due to its low cost compared to lime and other coagulants and adsorbents, it could reduce the cost of waste treatment with the same performance (Kiran et al. 2019). Also, due to its availability and eco-friendliness, CKD has recently been used in polluted water treatment. Due to unmanaged anthropogenic activities, toxic heavy metals, such as lead (Pb) and cadmium (Cd), are continuously accumulating in agricultural soils. Plants mainly absorb heavy metals from the contaminated soil solution by roots, resulting in their accumulation in plant parts and transmission through the food chain to humans, posing potential health risks for consumers (Garg et al. 2014). It has become essential to remove heavy metals from water, especially wastewater (Al-Fahdawy et al. 2024a). Furthermore, the efficiency of using Injana clay formation for cadmium sorption was investigated by Ouda et al. (2024). It was concluded that the cadmium concentration was removed within the first 10 minutes of the experiments. The adsorption efficiency was found to

Table 1: The specification of Cement Kiln Dust.

Z	Symbol	Element	Norm Int.	Concentration	Abs. Error
11	Na_2O	Sodium	68.3702	2.082	0.027
12	MgO	Magnesium	167.9553	1.314	0.009
13	Al_2O_0	Aluminum	762.0226	2.028	0.005
14	SiO_2	Silicon	5572.71	7.406	0.008
15	P_2O_5	Phosphorus	47.7422	0.0313	0.0011
16	SO_3	Sulfur	12699.73	4.824	0.004
17	CL	Chlorine	2742.246	0.2004	0.0003
19	K_2O	Potassium	276.6975	0.8989	0.0043
20	CaO	Calcium	15123.35	52.12	0.04
22	TiO_2	Titanium	42.4222	0.2168	0.0034
23	V_2O_5	Vanadium	4.0752	0.014	0.0017
24	Cr_2O_3	Chromium	7.4002	0.00368	0.00024
25	MnO	Manganese	159.4424	0.1436	0.001
26	Fe_2O_3	Iron	5108.417	3.35	0.004
27	CoO	Cobalt	0.00000	0.00039	0.0000
28	NiO	Nickel	19.3438	0.00473	0.00017
29	CuO	Copper	20.6685	0.00412	0.00013
30	ZnO	Zinc	47.0666	0.00711	0.0001
31	Ga	Gallium	2.1121	0.0002	0.00007
32	Ge	Germanium	0.00000	0.00005	0.0
33	As_2O_3	Arsenic	21.0834	0.00152	0.00016
34	Se	Selenium	3.3357	0.00016	0.00003
35	Br	Bromine	63.4311	0.00287	0.00004
37	Rb_2O	Rubidium	180.7971	0.005031	0.00004
38	SrO	Strontium	5320.73	0.1524	0.0002
39	Y	Yttrium	19.6576	0.00046	0.00003
40	ZrO_2	Zirconium	12.3474	0.00601	0.00038
41	Nb_2O_5	Niobium	0.00000	0.00014	0.0
42	Mo	Molybdenum	3.2408	0.00084	0.00007
47	Ag	Silver	0.00000	0.0002	0.0
48	Cd	Cadmium	0.7683	0.0002	0.0
50	SnO_2	Tin	5.65900	0.00091	0.00009
51	Sb_2O_5	Antimony	3.7924	0.00072	0.0001
52	Te	Tellurium	4.71830	0.0003	0.0
53	I	Iodine	2.5906	0.0002	0.00007
55	Cs	Cesium	0.00000	0.0004	0.0
56	Ba	Barium	31.2651	0.02821	0.00098

increase as the temperature increased. The urgent need to understand human exposure to heavy metals in contaminated soils and to prevent the great threat resulting from human and environmental exposure to these metals is due to the considerable threats caused by heavy metal pollution to marine and terrestrial environments (Ekere et al. 2020, Al-Fahdawy et al. 2024b). The extensive contamination of soils with Cd and Pb, especially in agricultural soils, illustrates the need to highlight the risks caused by heavy metal accumulation (Zhao et al. 2022). The agricultural areas surrounding the Kubaisa cement factory were reported to be affected by the dust produced from the cement factory, which has an impact on the agricultural area by heavy metals (lead and cobalt) (Gharbi et al. 2024). Therefore, the current study was conducted to evaluate the efficiency of Cement Kiln Dust (CKD) in removing lead and cadmium from polluted water.

MATERIALS AND METHODS

A laboratory experiment was conducted at Anbar University, Desert Studies Center, during the spring season of 2024. In this study, two heavy metals were selected, namely Cd (II) and Pb (II). The selected heavy metals were prepared from their salts ($PbCl_2$ and $CdCl_2$) with a concentration of 1000 mg.L^{-1} by dissolving 2.51 and 2.099 g in one litre of distilled water for lead and cadmium, respectively. The quantity of each heavy metal was calculated by dividing the atomic weight of each element by the required concentration, divided by the total atomic weight. On this basis, the above concentration was prepared. Due to its availability, cement kiln dust (CKD) was used in this study as an adsorbent. The CKD by-product was brought from the Kabaisa Cement Factory, located west of Ramadi city. The analysis was conducted in the Center of Desert Studies Lab – University of Anbar. The specification of the used by-product is listed in Table 1. Thermal isotropic adsorption experiment of heavy metals on the adsorbent material.

One gram of cement kiln dust (CKD) was weighed with different diameters, namely 0.3, 1.18, and 2 mm, using sieves. Four concentrations, i.e., 20, 40, 80, and 160 mg.L^{-1} of each considered heavy metal (cadmium and lead), were added to each diameter. The mixture of CKD and heavy metal solution was placed in a flask and shaken for 2 h. The mixture was filtered using Whatman 42 filter paper. The output extract was collected using plastic containers to estimate the concentrations of heavy metals (cadmium and lead) in the resulting extract using an atomic absorption device. The amount of these adsorbed metals on the treatment material (CKD) was calculated and subjected to the Langmuir equation to describe the adsorption. The Langmuir equation, derived by Langmuir (1918), was used to describe the adsorption of heavy metals lead and cadmium. The linear equation is:

$$C/X = \frac{1}{kXm} + \frac{1}{Xm}C \quad \text{... (1)}$$

Where: C is the concentration of heavy metals in the equilibrium solution (mg.L^{-1}), X is the amount of heavy metals adsorbed on the material surfaces (mg.kg^{-1}), Xm is the maximum adsorption, and K is the bonding energy.

Effect of the Contact Time of the Treatment Material Used on the Concentration of Heavy Metals

One gram of cement kiln dust was taken (which is the by-product of the Kabaisa Cement Factory), with different diameters of 0.3, 1.18, and 2 mm, and mixed with different concentrations of 20, 40, 80, and 160 mg.L^{-1} of heavy metals (lead and cadmium). The mixture was placed in tightly closed plastic containers. The containers were subjected to different shaking times, namely 0.5, 2, and 4 h for each element separately. After the shaking process was completed, the mixture was filtered using filter paper. The collected extract was kept in plastic containers and transferred to the laboratory to determine the heavy metal concentration using atomic absorption.

RESULTS AND DISCUSSION

Determining the thermally isotropic adsorption curves for heavy metals (cadmium and lead) on the used surface particles of CKD, when different concentrations of heavy metals were applied to the water, provided a comprehensive understanding of the nature of the reaction and the adsorbed amount (Fig. 1). It is noted that the adsorbed amount of cadmium and lead on the used surface particles of CKD increased with increasing the applied concentration of heavy metals in water (20, 40, 80, and 160 mg.L^{-1}).

Also, it can be seen from Fig. 1 that the adsorbed cadmium is superior to that of lead, since the amount adsorbed depends mainly on the nature of the adsorbed material. Moreover, the adsorption of cadmium and lead is similar to a C-type isotherm curve, which indicates the mechanism of partition adsorption, where the adsorbed material is distributed between the separation surface of the solid and liquid phase without any connection occurring between the adsorbed material and the adsorption surface (Sposito 2008). The adsorption capacity of cadmium was higher compared to the adsorption capacity of lead, as the adsorption capacity of cadmium reached 2880.00 mg.kg^{-1}, while the adsorption capacity of lead reached 2735.58 mg.kg^{-1}. Regarding the thermally isotropic adsorption, the values of Langmuir equation parameters shown in Fig. 2 and listed in Table 3 show that the highest adsorption observed for lead reached 3333.333 mg.kg⁻¹ with a binding capacity of 0.0245 L.mg⁻¹, which is superior to that of cadmium, which had an adsorption of 2000 mg.kg⁻¹ and a binding capacity of 0.0105 L.mg⁻¹. The bond strength of lead on the surface of the adsorbent may be due to lower hydration energy, which makes it less strongly bound to water molecules and potentially more available for adsorption onto the CKD surface (Alghamdi et al. 2019). However, the coefficient of determination (R^2) for the simple linear regression for cadmium is higher than the coefficient of determination for lead, with values reaching 0.9968 and 0.9738, respectively. The superiority of the coefficient of determination for cadmium over lead may be due to the smaller ionic radius of cadmium, which gives it the ability to fit easily into smaller pores or spaces on the adsorbent surface compared to lead.

Effect of the Contact Time of CKD Particles on the Concentration of Cadmium (20 mg.L⁻¹)

Fig. 3 shows the effect of contact time on cadmium adsorption for different shaking times. The results show that different cadmium concentrations affect the cement kiln dust adsorption efficiency, which indicates that CKD

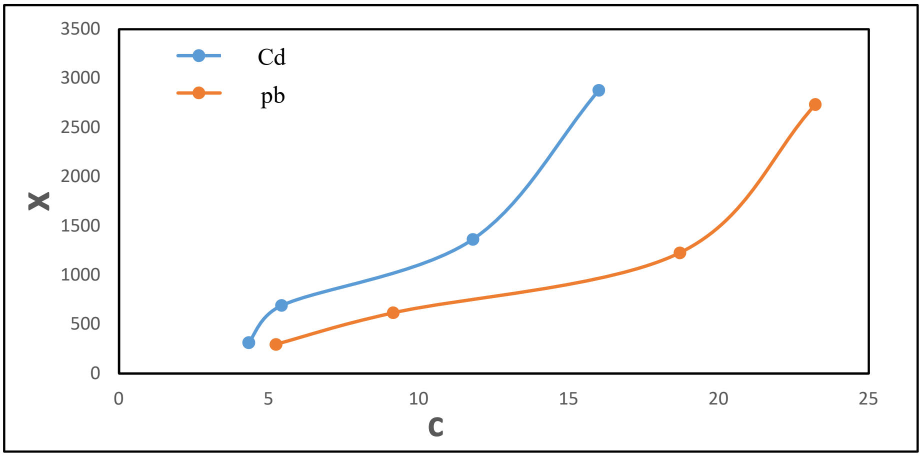

Fig. 1: The relationship between the concentration of the equilibrium solution and the adsorbed amount.

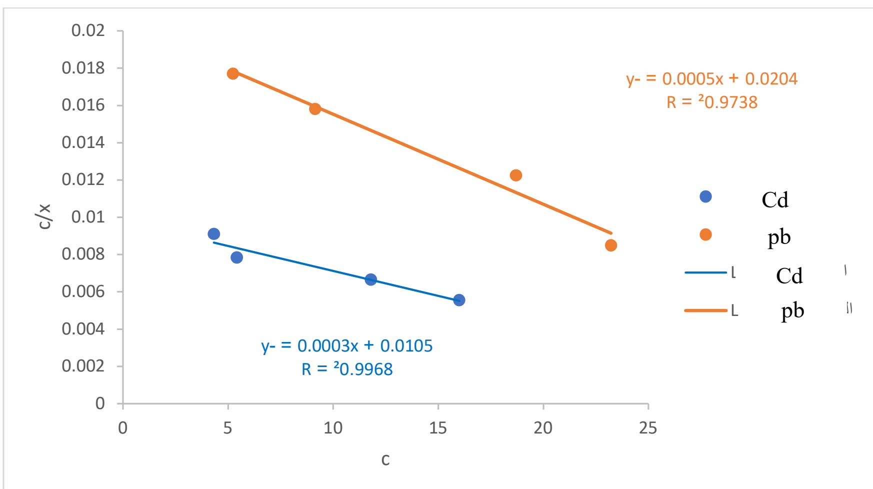

Fig. 2: Thermal isotropic adsorption according to the Langmuir equation for the adsorption of some heavy metals on the adsorbent material.

Table 2: Parameters of thermal isotropic adsorption of selected heavy metals on the adsorbent materials

Adsorbent material	Heavy metals	Maximum adsorption [mg.kg⁻¹]	Binding energy [L.mg⁻¹]
CKD	Cd	2000.000	0.0245
	Pb	3333.333	0.0105

may have an effect in regulating the cadmium concentration in the medium (Naushad et al. 2019). The CKD adsorption efficiency depends on several factors, such as pH, the chemical composition of CKD, and time (Elbaz et al. 2019). With increasing the CKD particle diameter from 0.3 to 2.0 mm, the adsorption shows increasing efficiency but only up to a certain point. After that, the adsorption starts to reach a saturation state. In this regard, the highest amount of cadmium adsorption reached 566.31 $\mu g.g^{-1}$ with a removal rate of 28.32% at a concentration of 20 $mg.L^{-1}$ of cadmium, 4 h of shaking time, and 2 mm diameter of CKD particles. The cadmium adsorption decreased to 409 $\mu g.g^{-1}$ with a removal rate of 20.45% at 4 h of shaking time and 0.3 mm diameter of CKD particles. Decreasing the adsorption when the diameter of the CKD particles decreased to 0.3 mm may be attributed to the aggregation of these particles, which limited pore accessibility, decreased effective surface area, kinetic limitations, and potential competitive adsorption. The combination of these factors could explain the decrease in cadmium adsorption to 409 $\mu g.g^{-1}$. Similarly, the adsorbed amount of cadmium decreased to 350.11 $\mu g.g^{-1}$ with a removal rate of 17.51% when the shaking time decreased to 0.5 h, and the diameter of CKD particles was 0.3 mm. The decrease in the adsorption rate compared to the aforementioned treatment may be due to the decrease in both CKD particle diameter and shaking time.

Concerning 1.18 mm and 4 h of shaking time, the cadmium adsorption slightly differs compared to 2 mm of CKD particles and 4 h of shaking time, where the adsorption reached 498.66 $\mu g.g^{-1}$ with a removal rate of 24.94% at 20 $\mu g.g^{-1}$ of cadmium concentration, 4 h of shaking time, and 1.18 mm diameter of CKD particles. Decreasing shaking time under the same CKD particle diameter (1.18 mm) led to a decrease in cadmium adsorption to 402.51 $\mu g.g^{-1}$ with a removal rate of 20.13%.

Effect of the Contact Time of CKD Particles on the Concentration of Cadmium (40 $mg.L^{-1}$)

Fig. 4 shows that increasing the concentration of cadmium from 20 $mg.L^{-1}$ to 40 $mg.L^{-1}$ in the solution led to an increase in the amount of adsorbed cadmium, where the

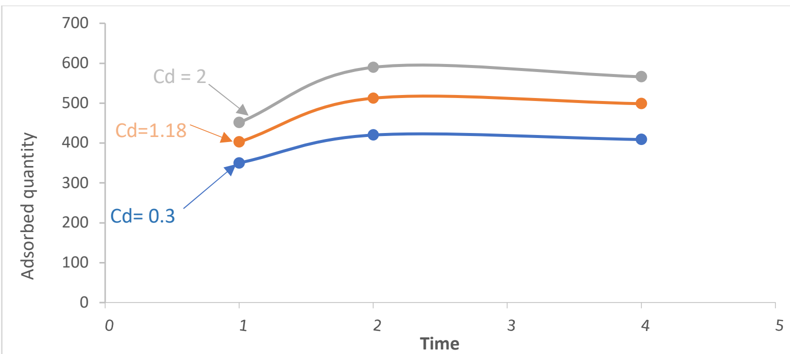

Fig. 3: Contact time for cadmium at a concentration of 20 and different diameters of CKD (0.3,1.18, and 2 mm).

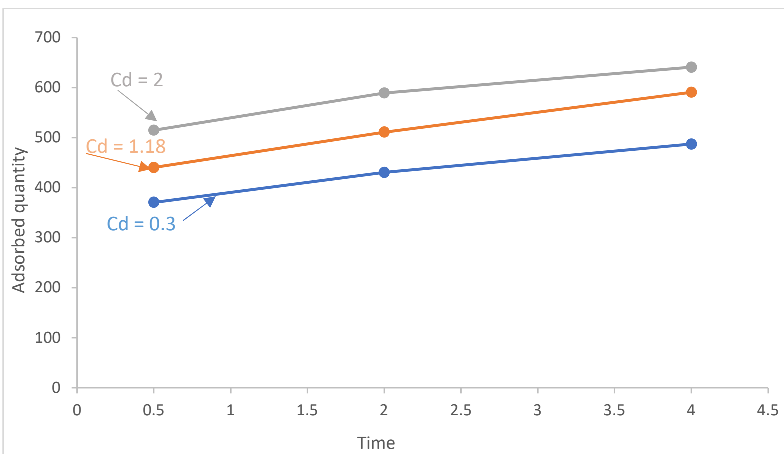

Fig. 4: Contact time for cadmium at a concentration of 40 and different diameters of CKD (0.3,1.18, and 2 mm).

line of adsorption became steeper and took a near-linear state. The steep behavior of cadmium adsorption (increases in the amount of adsorbed cadmium) can be attributed to the increased driving force for adsorption, availability of cadmium ions in the solution, and enhanced mass transfer (Basu et al. 2019). The combination of these three factors generates a linear relationship between contact time and the adsorbed cadmium.

The adsorbed cadmium increased with increasing shaking time. In this context, the highest amount of cadmium adsorption reached 640.65 $\mu g.g^{-1}$ with a removal rate of 32.04% at 40 $\mu g.g^{-1}$ of cadmium concentration, 4 h of shaking time, and 2 mm diameter of CKD particles. Decreasing the diameter of cement kiln dust particles led to a decrease in cadmium adsorption to 486.98 $\mu g.g^{-1}$ with a removal rate of 24.35% at 4 h of shaking time and 0.3 mm diameter of CKD particles.

The reduction of cadmium adsorption might be attributed to the fact that during the shaking process, large molecules may maintain their structure more than small molecules that aggregate to form larger molecules (more than 2 mm), thus reducing the adsorption efficiency. The same pattern of decline was observed at 0.5 h of shaking time and 0.3 mm diameter of CKD particles, where the adsorbed cadmium reached 370.51 $\mu g.g^{-1}$ with a removal rate of 18.53%. The decrease in cadmium adsorption was a result of the combination of reduced shaking time and the small diameter of the CKD particles.

Increasing both the shaking time and the diameter of cement particles (4 h and 1.18 mm) led again to an increase in the adsorption efficiency, where the adsorbed cadmium reached 590.76 $\mu g.g^{-1}$ with a removal rate of 29.54%, while the adsorbed cadmium decreased to 370.51 $\mu g.g^{-1}$ with a removal rate of 18.53 % at ½ h shaking time and 1.18 mm diameter of CKD particles.

Effect of the Contact Time of CKD Particles on the Concentration of Cadmium (80 $mg.L^{-1}$)

Fig. 5 showed that increasing the cadmium concentration to 80 mg led to the affinity of the adsorption curves, indicating saturation of all sites on the surface of the adsorbent. The same trend was observed at 80 $\mu g.g^{-1}$ concentration of cadmium, where the bigger particles were superior to the smaller particles (0.3 mm) in adsorption efficiency. In this sense, the adsorbed cadmium increased with increasing shaking time (Fig. 5). The highest amount of cadmium adsorption was 662.32 $\mu g.g^{-1}$, with a removal rate of 34.02%, observed at a concentration of 80 $\mu g.g^{-1}$, a shaking time of 4 h, and a 2 mm diameter of CKD particles. Also, the decrease in the diameter of cement kiln dust particles to 0.3 mm, with constant shaking time (4 h), led to a decrease in the efficiency of cadmium adsorption, where the adsorbed cadmium reached 560.64 $\mu g.g^{-1}$ with a removal rate of 28.04%. As previously mentioned, decreasing the shaking time and cement kiln dust diameter led to a decrease in the adsorbed cadmium, where the adsorbed cadmium reached 410.60 $\mu g.g^{-1}$ with a removal rate of 20.53% at 0.5 h of shaking time and a 0.3 mm diameter of CKD particles.

When the amount of adsorbed cadmium on the adsorbent reached equilibrium, the amount of adsorbed cadmium reached 560.64 $\mu g.g^{-1}$ with a removal rate of 28.04%, at 80 $\mu g.g^{-1}$ of cadmium concentration, 4 h of shaking time, and

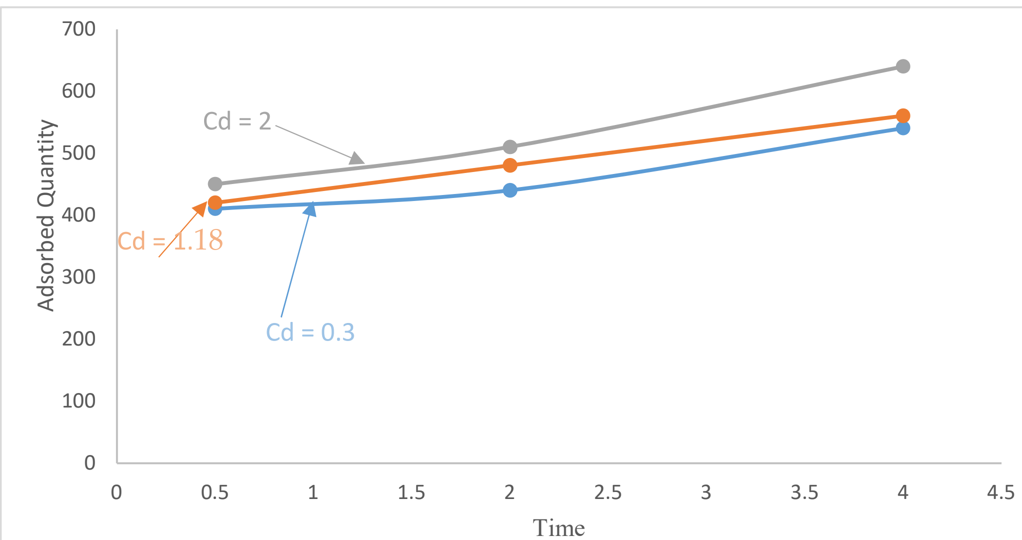

Fig. 5: Contact time for cadmium at a concentration of 80 and different diameters of CKD (0.3,1.18, and 2 mm).

1.18 mm diameter of CKD particles. The adsorbed cadmium decreased to 420.08 μg.g⁻¹ when the shaking time decreased to half an h, with a removal rate of 21.01% under the same CKD particle diameter (1.18 mm).

Effect of the Contact Time of CKD Particles on the Concentration of Cadmium (160 mg.L^{-1})

The observed results showed an interaction between the treatments due to increasing the cadmium concentration to 160 μg.g^{-1}, which increased the adsorption speed at the beginning of the reaction time (first h) until most of the active sites on the surfaces of the adsorbent material were saturated (Fig. 6). After that, the reaction speed decreased. The continued closeness between the diameters of 0.3 and 1.18 mm may be due to them containing approximately the same number of active sites on the surfaces, due to the accumulation of cement particles with a diameter of 0.3 mm into diameters approaching 1.18 mm. Increasing cadmium to 160 μg.g^{-1} led to an increase in the amount of cadmium adsorbed (Fig. 6). In this context, the highest amount of cadmium adsorption reached 798.62 μg.g^{-1} with a removal rate of 39.94% at 160 μg.g^{-1} of cadmium concentration, 4 h of shaking time, and 2 mm diameter of CKD particles. The amount of adsorbed cadmium decreased to 609.72 μg.g^{-1} with a removal rate of 30.49% at 4 h of shaking time and 0.3 mm diameter of CKD particles. The same pattern of decline was observed at 0.5 h of shaking time and 0.3 mm diameter of CKD particles, where the adsorbed cadmium reached 501.10 μg.g^{-1} with a removal rate of 25.06%.

When the amount of adsorbed cadmium on the adsorbent reached equilibrium, the amount of adsorbed cadmium reached 630.12 μg.g^{-1} with a removal rate of 31.51%, at 160 μg.g^{-1} of cadmium concentration, 4 h of shaking time and 1.18 mm diameter of CKD particles, while the adsorbed cadmium

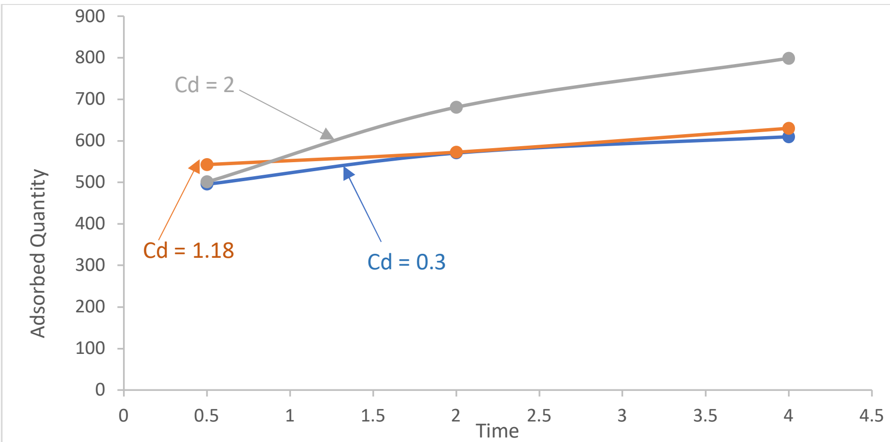

Fig. 6: Contact time for cadmium at a concentration of 160 and different diameters of CKD (0.3,1.18, and 2 mm).

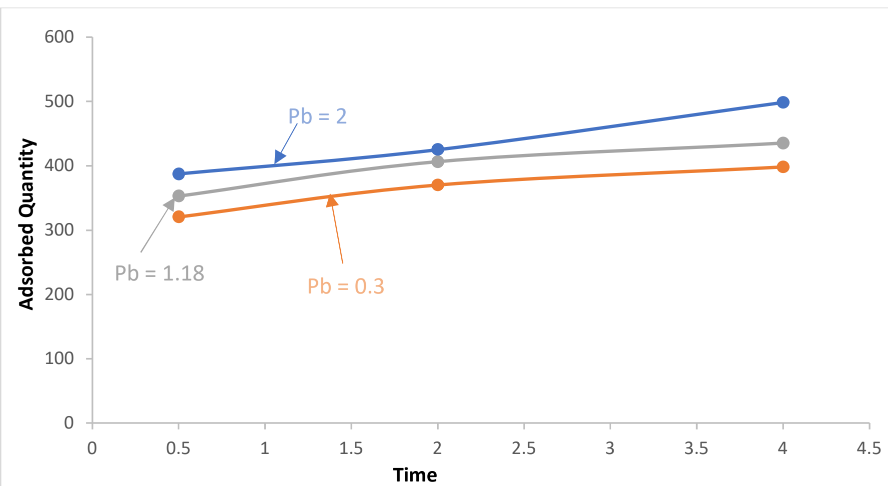

Fig. 7: Contact time for lead at a concentration of 20 and different diameters of CKD (0.3,1.18, and 2 mm).

decreased to 542.75 μg.g^{-1} with a removal rate of 27.14% at ½ h shaking time and 1.18 mm diameter of CKD particles.

Effect of the Contact Time of CKD Particles on the Concentration of Lead (20 mg.L^{-1})

Unlike cadmium, lead adsorption at a concentration of 20 mg.L^{-1} was lower (Fig. 7). Despite that, the results showed that the amount of adsorbed lead had almost a positive relationship with time (Fig. 7), where the highest amount of lead adsorption reached 498.68 μg.g^{-1} with a removal rate of 24.94% of the added amount at 20 μg.g^{-1} of lead, 4 h of shaking time, and 2 mm diameter of CKD particles. The adsorbed lead decreased to 387.30 μg.g^{-1} as a result of a decrease in the diameter of the CKD particles to 0.3 mm, with a removal rate of 19.36% at 4 h of shaking time. Increasing the diameter of the CKD particles to 1.18 mm, along with increasing the shaking time to 4 h, led to an increase in the amount of adsorbed lead up to 435.22 μg.g^{-1}, with the removal rate reaching 21.76%. The lowest amount of adsorbed lead was at a shaking time of 0.5 h, reaching 352.98 μg.g^{-1} with a removal rate of 17.64%.

As shown in Fig. 7, the amount of adsorbed lead on the adsorbent material increases with time. The highest amount of lead adsorption at a shaking time of 4 h and a diameter of 0.3 mm reached 398.24 μg.g^{-1}, with a removal rate of 19.91%, while the lowest removal rate was at a shaking time of 0.5 h, reaching 320.60 μg.g^{-1}, with a removal rate of 16.03%.

Effect of the Contact Time of CKD Particles on the Concentration of Lead (40 mg.L^{-1})

By increasing the concentration of lead to 40 mg.L^{-1}, the adsorption of lead on the surface of the adsorbent material increased (Fig. 8). However, this adsorption was still lower compared to the adsorption of cadmium under the same conditions. The superiority of cadmium over lead in the adsorption process on the CKD surface may be due to differences in their chemical properties, such as ionic radius, charge density, and lead ion binding affinity on the CKD surface. In this sense, the highest amount of lead adsorption at a shaking time of 4 h and a diameter of 2 mm was 540.61 μg.g^{-1}, with a removal rate of 27.03% of the added amount. The smallest amount of adsorbed lead was at a shaking time of 0.5 h, reaching 389.76 μg.g^{-1}, with a removal rate of 19.48%. Concerning the amount of lead adsorption at a shaking time of 4 h and a diameter of 1.18 mm, it was 498.65 μg.g^{-1}, with a removal rate of 24.93% of the added amount. The smallest amount of adsorbed lead was at a shaking time of 0.5 h, reaching 375.46 μg.g^{-1}, with a removal rate of 18.77% of the added amount.

Also, Fig. 8 shows that the adsorbed lead on the adsorbent material increased with time, where the highest amount of lead adsorption at a shaking time of 4 h and a diameter of 0.3 mm reached 400.31 μg.g^{-1}, with a removal rate up to 20.01%, while the lowest removal rate was at a shaking time of 1/2 h, reaching 351.45 μg.g^{-1}, with a removal rate of 17.57%.

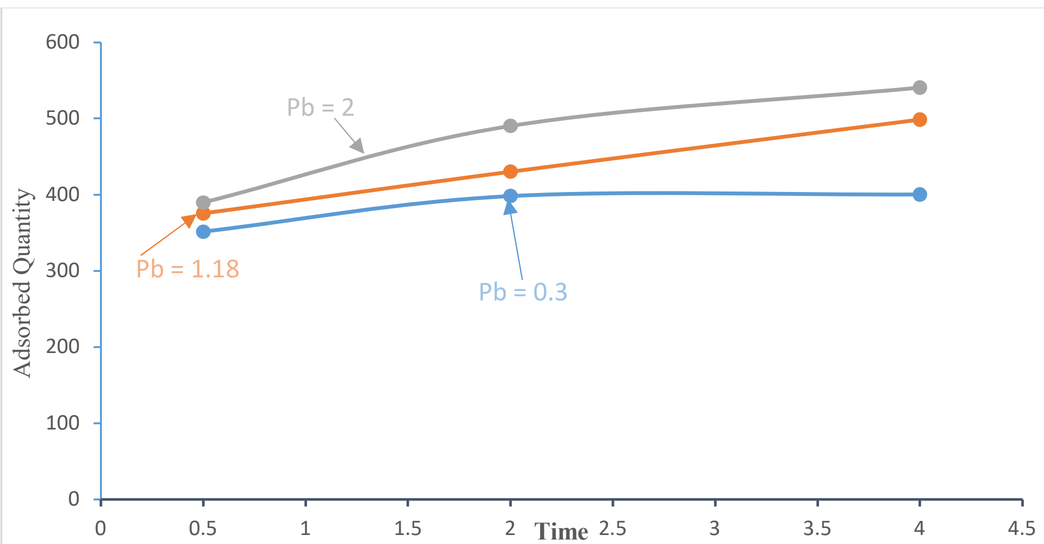

Fig. 8: Contact time for lead at a concentration of 40 and different diameters of CKD (0.3,1.18, and 2 mm).

Effect of the Contact Time of CKD Particles on the Concentration of Lead (80 mg.L^{-1})

Fig. 9 shows the high affinity in the adsorption process between diameters 1.18 and 2 mm. This is probably because larger diameters have a larger surface area for reaction, resulting in higher adsorption efficiency. Conversely, smaller diameters, such as 0.3 mm, may be subject to aggregation, which reduces the overall adsorption efficiency compared to larger diameters. Supporting this theory is the superiority of the diameter of 2 mm over other diameters (0.3 and 1.18 mm). It is noted from the Fig.9 that the amount of adsorbed lead on the adsorbent increases with increasing contact time, where the highest amount of adsorbed lead was observed at a contact time of 4 h and a diameter of 2 mm, reaching 624.40 µg.g^{-1}, with a removal rate up to 31.20, while the lowest amount of lead adsorption was 433.54 µg.g^{-1}at a contact time of 1/2 h, with a removal rate of 21.67%. The amount of adsorbed lead increased when the size of cement kiln dust particles and the shaking time increased. At a shaking time of 4 h and the diameter of 1.18 mm was 572.31 µg.g^{-1}, with a removal rate of 28.61% of the added amount. The smallest amount of adsorbed lead was 487.05 µg.g^{-1} at a shaking time of 1/2 h, with a removal rate of 24.35%.

Furthermore, Fig. 9 shows that the adsorbed lead on the adsorbent surface increased with time, where the amount of adsorbed lead increased from 401 µg.g^{-1} after two h to 486.34 µg.g^{-1} after four h of shaking time and at 0.3 mm of CKD particles, with a removal rate of up to 24.31%, while the lowest removal rate was at a shaking time of 0.5 h, reaching 401.2 µg.g^{-1}, with a removal rate of 20.06%.

Effect of the Contact Time of CKD Particles on the Concentration of Lead (160 mg.L^{-1})

Fig. 10 shows that the adsorption at diameters 0.3 and 1.18 mm was slightly different during the first 1.5 h from the start of the reaction. Later, the match between the 0.3 and 1.18 mm adsorption lines becomes perfect, highlighting the similarity of the adsorption on the adsorbent (0.3 and 1.18 mm). This is consistent with earlier observations indicating that small particles (0.3 mm) tend to aggregate, forming larger particles. Consequently, their behavior mimics that of larger particles.

Concerning the particles with a diameter of 2 mm, the adsorption continued to increase even after 4 h. The continuation of adsorption at a diameter of 2 mm and when adsorption lines emerge at diameters 0.3 and 1.18 mm supports the conclusion that larger diameters of cement kiln dust are more efficient in the adsorption process than smaller particles.

Regarding the adsorption efficiency, Fig. 10 shows that the adsorbed lead on the adsorbent material increases with time, where the highest amount of lead adsorption at a shaking time of 4 h and a diameter of 2 mm was 698.76 µg.g^{-1}, with a removal rate of up to 34.93%. The smallest adsorbed lead was observed at a shaking time of 0.5 h, which amounted to 488.64 µg.g^{-1}, with a removal rate of 24.43%. The adsorption increased again with increasing shaking time and diameter of cement particles, where at a shaking time of 4 h and a diameter of 1.18 mm, it reached 576.60 µg.g^{-1}, with a removal rate of 28.83%. The smallest amount of adsorbed lead was at a shaking time of 0.5 h, reaching 487.00 µg.g^{-1}, with a removal rate of 24.35%.

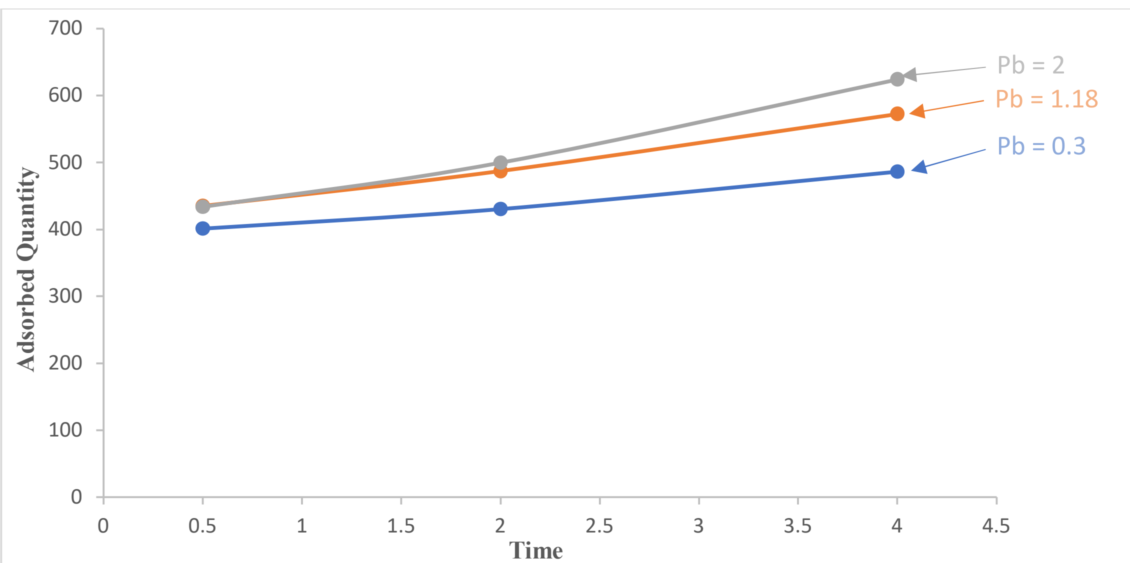

Fig. 9: Contact time for lead at a concentration of 80 and different diameters of CKD (0.3,1.18, and 2 mm).

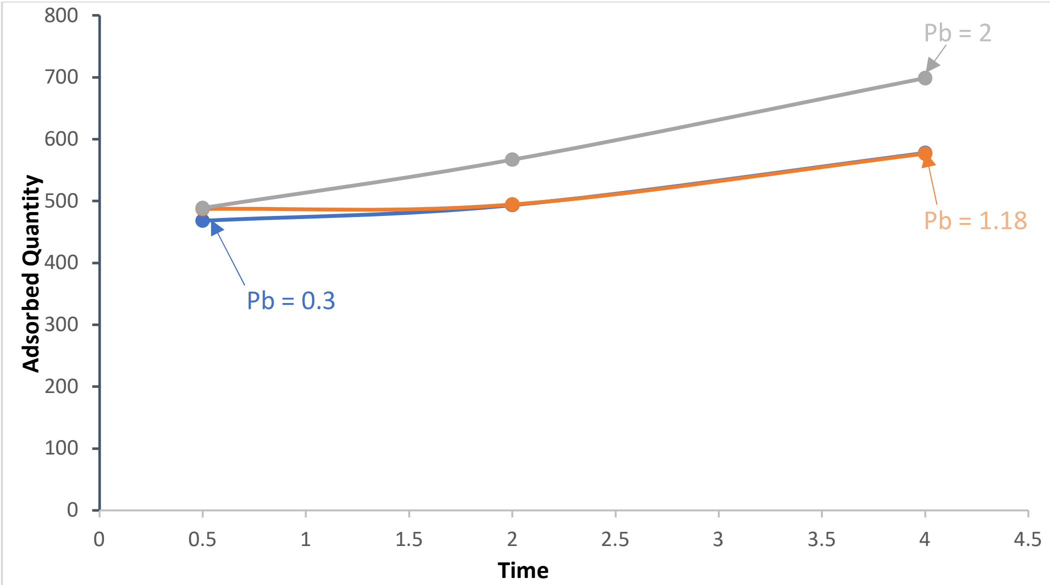

Fig. 10: Contact time for lead at a concentration of 160 and different diameters of CKD (0.3,1.18, and 2 mm).

It is noted from Fig. 10 that the amount of adsorbed lead on the adsorbent increases with time. The highest amount of lead adsorption at a shaking time of 4 h and a diameter of 0.3 mm reached 577.62 $\mu g.g^{-1}$, with a removal rate of 28.88%, while the lowest removal rate was observed at a shaking time of 1/2 h, reaching 468.00 $\mu g.g^{-1}$, with a removal rate reached 23.40%.

CONCLUSIONS

The current study found that the concentration of cadmium and lead ions had different adsorption efficiencies. The findings show that the adsorbent (CKD) absorbs the cadmium ions more efficiently than lead. Also, the study findings show that the bigger particles had bigger surfaces to absorb the polluted ions. In terms of concentration, the study shows that the adsorption efficiency increased with increasing concentration due to the ion availability in the polluted aqueous solution. Moreover, the study shows that small particles require a longer time to complete the adsorption process. Perhaps the reason for this is that small particles are more likely to collect than large particles. This technology can be used to remove heavy elements from sewage, and treatment systems can be created to get rid of these elements. There are future ideas for this work.

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