

Original Research

# 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<sup>-1</sup> 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 lead adsorption capacity. In this context, the adsorption capacity of reached 2880.00 and 2735.58 mg kg<sup>-1</sup> for cadmium and lead respectively. Regarding, 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 were 39.94 and 34.93 % respectively, for shaking of 4 hours. 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 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, restrict their use for agricultural, domestic, and industrial purposes (Kumar et al., 2022). (Saeed et al., 2024) proposed using some techniques to mitigate the hazard of the 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 fresh water 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 contributor 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  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ , 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-friendly, 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 transmitted 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., 2024 a). 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 be increased 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 and Al-Fahdawy et al., 2024 b). 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 Kubaisa cement factory was reported to be effected 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). referred to Therefore, the current study was conducted to evaluate the efficiency of Cement kiln dust (CKD) in removing lead and cadmium from polluted water.

## 2. 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 ( $\text{PbCl}_2$  and  $\text{CdCl}_2$ ) with a concentration of  $1000 \text{ mg. L}^{-1}$  by dissolving 2.51 and 2.099 g in one liter of distilled water for lead and cadmium respectively. The quantity of each heavy metal was calculated by dividing the atomic weight of each element multiplied 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 Center of Desert Studies Lab's – 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.

**Table 1:** The specification of Cement Kiln Dust.

Z	Symbol	Element	Norm Int.	Concentration	Abs. Error
11	$\text{Na}_2\text{O}$	Sodium	68.3702	2.082	0.027
12	$\text{MgO}$	Magnesium	167.9553	1.314	0.009
13	$\text{Al}_2\text{O}_0$	Aluminum	762.0226	2.028	0.005
14	$\text{SiO}_2$	Silicon	5572.71	7.406	0.008
15	$\text{P}_2\text{O}_5$	Phosphorus	47.7422	0.0313	0.0011
16	$\text{SO}_3$	Sulfur	12699.73	4.824	0.004
17	CL	Chlorine	2742.246	0.2004	0.0003
19	$\text{K}_2\text{O}$	Potassium	276.6975	0.8989	0.0043
20	$\text{CaO}$	Calcium	15123.35	52.12	0.04
22	$\text{TiO}_2$	Titanium	42.4222	0.2168	0.0034
23	$\text{V}_2\text{O}_5$	Vanadium	4.0752	0.014	0.0017
24	$\text{Cr}_2\text{O}_3$	Chromium	7.4002	0.00368	0.00024
25	$\text{MnO}$	Manganese	159.4424	0.1436	0.001
26	$\text{Fe}_2\text{O}_3$	Iron	5108.417	3.35	0.004
27	$\text{CoO}$	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 <sub>2</sub> O <sub>3</sub>	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 <sub>2</sub> O	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 <sub>2</sub>	Zirconium	12.3474	0.00601	0.00038
41	Nb <sub>2</sub> O <sub>5</sub>	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 <sub>2</sub>	Tin	5.65900	0.00091	0.00009
51	Sb <sub>2</sub> O <sub>5</sub>	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

One gram of cement kiln dust (CKD) was weighed with different diameters, namely 0.3, 1.18, and 2 mm by using sieves. Four concentrations i.e., 20, 40, 80, and 160 mg. l<sup>-1</sup> of each considered heavy metals (cadmium and lead) were added to each diameter. The mixture of CKD and heavy metals solution was placed in flask and shaken for 2 hours. The mixture was filtered using the 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 materials (CKD) was calculated and subjected to the Langmuir equation to describe the adsorption. Langmuir equation was derived by Langmuir (1918), this equation was used to describe the adsorption of heavy metals lead and cadmium. The linear equation is:

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

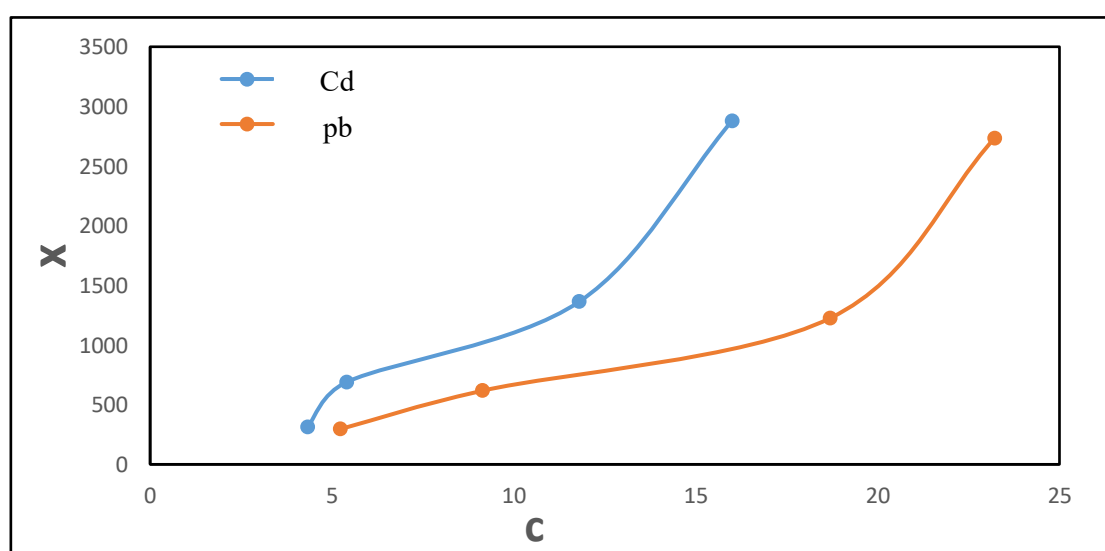
Where:  $C$  is the concentration of heavy metals in the equilibrium solution ( $\text{mg L}^{-1}$ );  $X$  is the amount of heavy metals adsorbed on the material surfaces ( $\text{mg kg}^{-1}$ );  $X_m$  is the maximum adsorption;  $K$  is the bonding energy.

Effect of contact time of the treatment material used in 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  $\text{mg L}^{-1}$  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 hours for each element separately. After the shaking process was completed, the mixture was filtrated by using filter Paper, the collected extract was kept in plastic containers and transferred to the laboratory to determine the heavy metals concentration by using atomic absorption.

### 3. RESULTS OR RESULTS AND DISCUSSIONS

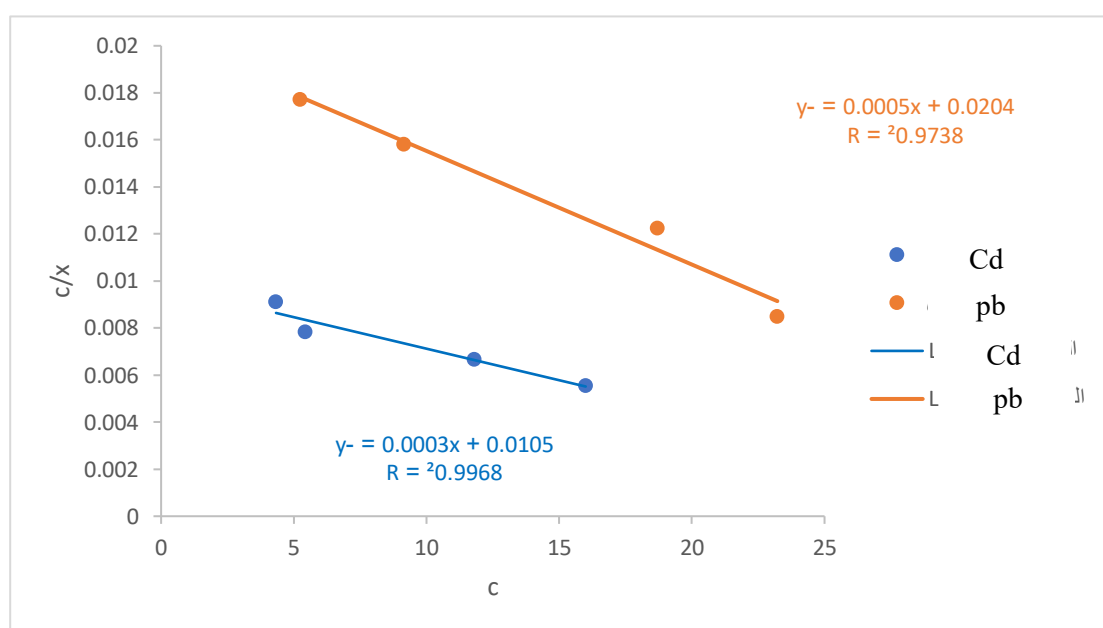
Thermal isotropic adsorption of cadmium and lead on CKD Determining the thermally isotropic adsorption curves for heavy metals (cadmium and lead) on the used surface particles of CKD when different concentrations of heavy metals were applied to the water, provided a comprehensive understanding of the nature of the reaction and the adsorbed amount (Figure 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 to water (20, 40, 80, and 160  $\text{mg L}^{-1}$ )



**Figure 1: the relationship between the concentration of the equilibrium solution and the adsorbed amount**

Also, it can be seen from Figure 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, where this curve 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  $2880.00 \text{ mg kg}^{-1}$ , while the adsorption capacity of lead reached  $2735.58 \text{ mg kg}^{-1}$ . Regarding the thermally isotropic adsorption, the values of Langmuir equation parameters shown in Figure 2 and listed in Table 3, show that the highest adsorption was observed for lead reached  $3333.333 \text{ mg kg}^{-1}$  with a binding capacity of  $0.0245 \text{ L mg}^{-1}$ , where it superior to that of the cadmium, which had an adsorption of  $2000 \text{ mg kg}^{-1}$  and a binding capacity of  $0.0105 \text{ L. mg}^{-1}$ . 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, where its values reached 0.9968 and 0.9738, respectively. The superiority of the coefficient of determination for cadmium over lead may be due to its small ionic radius of cadmium, where a smaller radius of cadmium gave it the ability to fit easily into smaller pores or spaces on the adsorbent surface compared to lead.



**Figure 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 ( $\text{mg kg}^{-1}$ )	Binding energy ( $\text{L mg}^{-1}$ )
CKD	Cd	2000.000	0.0245
	Pb	3333.333	0.0105

Effect of the contact time of CKD particles on the concentration of cadmium ( $20 \text{ mg. l}^{-1}$ ) Figure 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 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 particles 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  $566.31 \text{ } \mu\text{g.g}^{-1}$  with a removal rate of 28.32% at a concentration of  $20 \text{ mg. l}^{-1}$  of cadmium, 4 hours of shaking time, and 2 mm diameter of CKD particles. The cadmium adsorption decreased to  $409 \text{ } \mu\text{g.g}^{-1}$  with a removal rate of 20.45%, at 4 hours 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  $409 \text{ } \mu\text{g.g}^{-1}$ . Similarly, the adsorbed amount of cadmium decreased to  $350.11 \text{ } \mu\text{g.g}^{-1}$  with a removal rate of 17.51%, when the shaking time decreased to  $\frac{1}{2}$  hours and the 0.3 mm diameter of CKD particles. The decrease in the adsorption rate compared to the aforementioned treatment may be due to the decrease in both CKD diameter particles and the decrease in the shaking time.

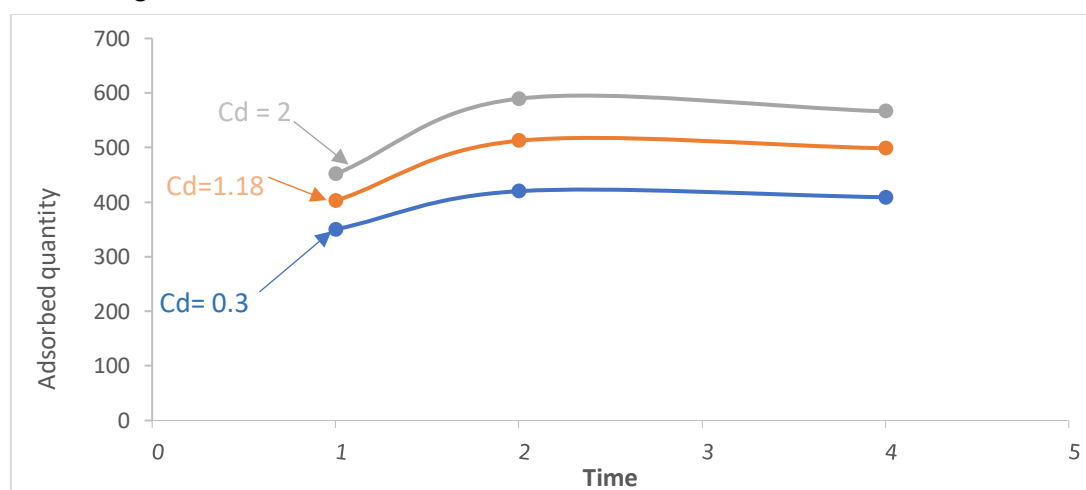
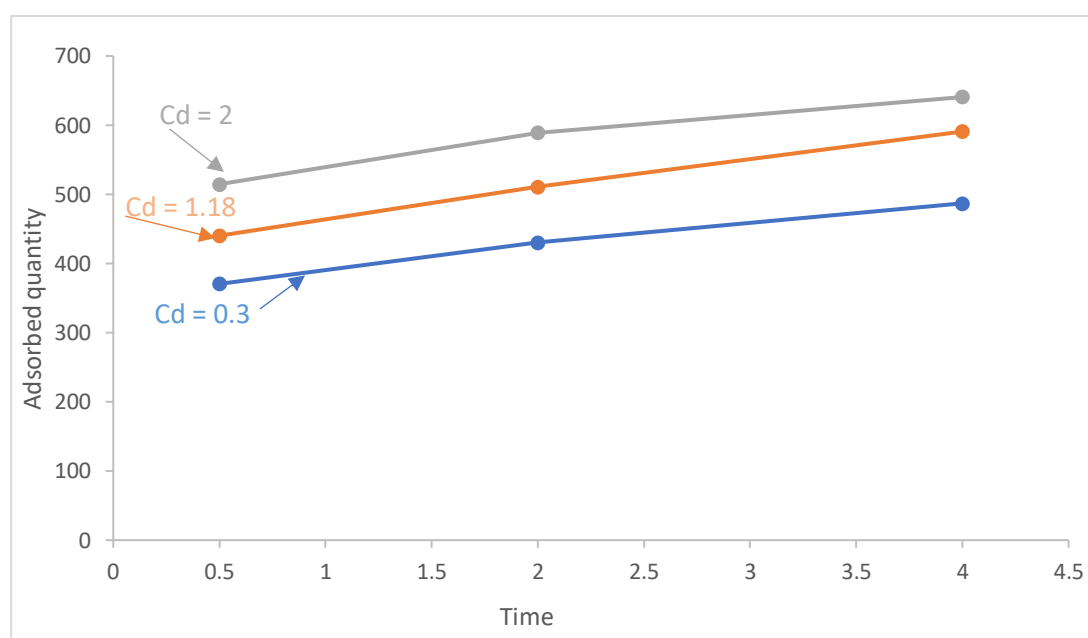


Figure 3: Contact time for cadmium at a concentration of 20 and different diameters of CKD (0.3, 1.18 and 2 mm)

Concerning 1.18 mm and 4 hours of shaking time, the cadmium adsorption slightly differs compared to 2 mm of CKD patterns and 4 hours of shaking time, where the adsorption reached  $498.66 \text{ } \mu\text{g.g}^{-1}$  with a removal rate of 24.94%, at  $20 \text{ } \mu\text{g.g}^{-1}$  of cadmium concentration, 4 hours 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 the cadmium adsorption to  $402.51 \text{ } \mu\text{g.g}^{-1}$  with a removal rate of 20.13%. Effect of the contact time of CKD particles on the concentration of cadmium ( $40 \text{ mg. l}^{-1}$ ) Figure 4 shows that increasing the concentration of cadmium from  $20 \text{ mg.l}^{-1}$  to  $40 \text{ mg.l}^{-1}$  in the solution led to an increase in the amount of adsorbed cadmium, where the 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  $640.65 \mu\text{g.g}^{-1}$  with a removal rate of 32.04%, at  $40 \mu\text{g.g}^{-1}$  of cadmium concentration, at 4 hours 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  $486.98 \mu\text{g.g}^{-1}$  with a removal rate of 24.35%, at 4 hours of shaking time and 0.3 mm diameter of CKD particles. The reduction of cadmium adsorption might have 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 reduce the adsorption efficiency. The same pattern of decline was observed at  $\frac{1}{2}$  hours of shaking time and 0.3 mm diameter of CKD particles, where the adsorbed cadmium reached  $370.51 \mu\text{g.g}^{-1}$  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 particles of CKD.



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

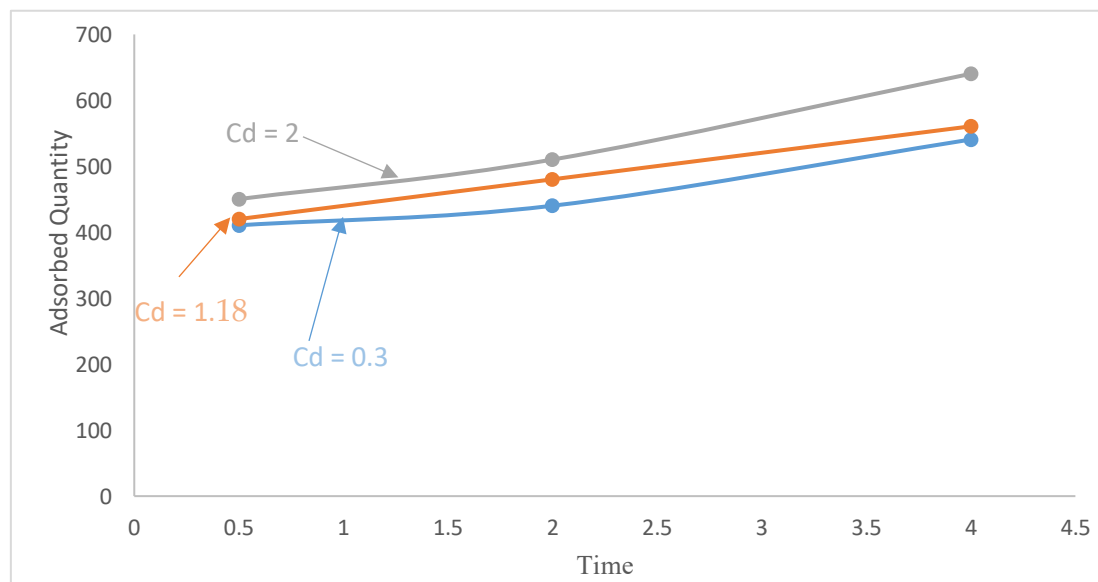
Increasing both the shaking time and the diameter of cement particles (4 hours and 1.18 mm) led again to increase the adsorption efficiency, where the adsorbed cadmium reached  $590.76 \mu\text{g.g}^{-1}$  with a removal rate of 29.54%, while the adsorbed cadmium decreased to  $370.51 \mu\text{g.g}^{-1}$  with a removal rate of 18.53 % at  $\frac{1}{2}$  hour 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)**

Figure 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  $80 \mu\text{g.g}^{-1}$  concen-



tration of cadmium, where the bigger particles were superior to smaller particles (0.3 mm) in adsorption efficiency. In this sense, the adsorbed cadmium increased with increasing shaking time Figure 5. Where the highest amount of cadmium adsorption was  $662.32 \mu\text{g.g}^{-1}$ , with a removal rate of 34.02%, observed at a concentration of  $80 \mu\text{g.g}^{-1}$ , a shaking time of 4 hours, and a diameter of 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 hours) led to a decrease in the efficiency of cadmium adsorption, where the adsorbed cadmium reached  $560.64 \mu\text{g.g}^{-1}$  with a removal rate of 28.04%. As previously mentioned, decreasing the shaking time and cement kiln dust led to a decrease in the adsorbed cadmium, where the adsorbed cadmium reached  $410.60 \mu\text{g.g}^{-1}$  with a removal rate of 20.53% at  $\frac{1}{2}$  hour of shaking time and a diameter of 0.3 mm diameter of CKD particles.



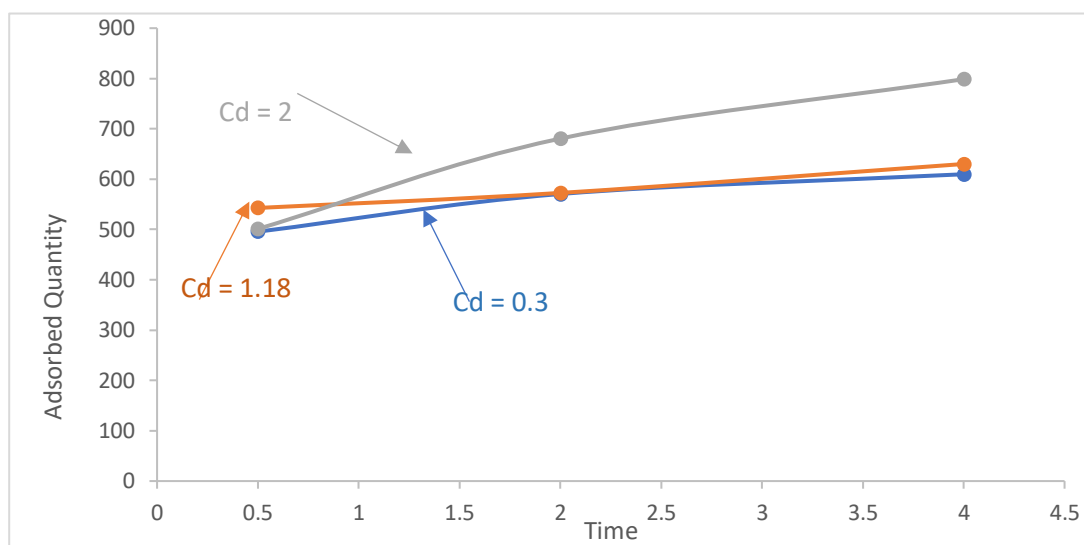
**Figure 5: Contact time for cadmium at a concentration of 80 and different diameters of CKD (0.3, 1.18 and 2 mm)**

When the amount of adsorbed cadmium on the adsorbent reached equilibrium, the amount of adsorbed cadmium reached  $560.64 \mu\text{g.g}^{-1}$  with a removal rate of 28.04%, at  $80 \mu\text{g.g}^{-1}$  of cadmium concentration, 4 hours of shaking time and 1.18 mm diameter of CKD particles. The adsorbed cadmium decreased to  $420.08 \mu\text{g.g}^{-1}$  when the shaking time decreased to half an hour 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 ( $160 \text{ mg.l}^{-1}$ )**

The observed results showed an interaction between the treatments, due to increasing the cadmium concentration to  $160 \mu\text{g.g}^{-1}$ , which increased the adsorption speed at the beginning of the reaction time (first hour) until most of the active sites on the surfaces of the adsorbent material were saturated (Figure 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 led to an increase in the amount of cadmium adsorbed (Figure 6). In this context, the highest amount of cadmium adsorption reached  $798.62 \mu\text{g.g}^{-1}$  with a removal rate of 39.94%, at  $160 \mu\text{g.g}^{-1}$  of cadmium concentration, at 4 hours of shaking time and 2 mm diameter of CKD particles. While the amount of adsorbed cadmium decreased to  $609.72 \mu\text{g.g}^{-1}$  with a removal rate of 30.49%, at 4 hours of shaking time and 0.3 mm diameter of CKD particles. The same pattern of decline was observed at  $\frac{1}{2}$  hours of shaking time and 0.3 mm diameter of CKD particles, where the adsorbed cadmium reached  $501.10 \mu\text{g.g}^{-1}$  with a removal rate of 25.06%.



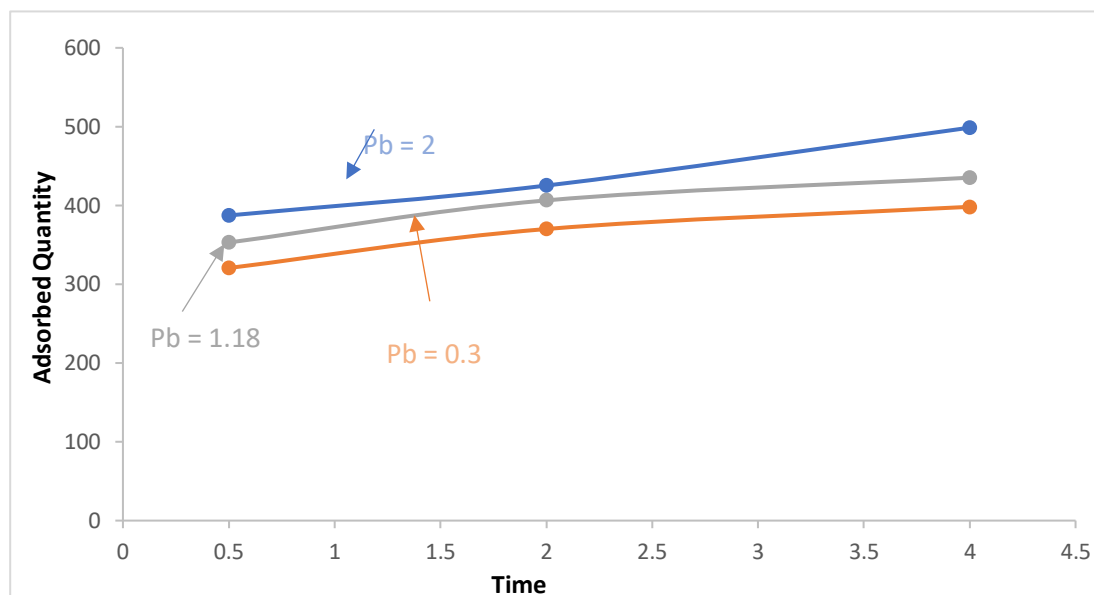
**Figure 6: Contact time for cadmium at a concentration of 160 and different diameters of CKD (0.3,1.18 and 2 mm)**

When the amount of adsorbed cadmium on the adsorbent reached equilibrium, the amount of adsorbed cadmium reached  $630.12 \mu\text{g.g}^{-1}$  with a removal rate of 31.51 %, at  $160 \mu\text{g.g}^{-1}$  of cadmium concentration, 4 hours of shaking time and 1.18 mm diameter of CKD particles. while the adsorbed cadmium decreased to  $542.75 \mu\text{g.g}^{-1}$  with a removal rate of 27.14 % at  $\frac{1}{2}$  hour shaking time and 1.18 mm diameter of CKD particles.

#### **Effect of the contact time of CKD particles on the concentration of lead ( $20 \text{ mg l}^{-1}$ )**

Unlike cadmium, lead adsorption at a concentration of  $20 \text{ mg.l}^{-1}$  was lower Figure 7. Despite that, the results showed that the amount of adsorbed cadmium had almost a positive relationship with time Figure 7, where the highest amount of lead adsorption reached  $498.68 \mu\text{g.g}^{-1}$  with a removal rate of 24.94 % of the added amount at  $20 \mu\text{g.g}^{-1}$  of lead, 4 hours of shaking time and 2 mm diameter of CKD particles. while the adsorbed lead decreased to  $387.30 \mu\text{g.g}^{-1}$  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 hours of shaking time. Increasing the diameter of the CKD particles to 1.18 mm along with increasing the shaking time to 4 hours led to an increase in the amount of adsorbed lead up to  $435.22 \mu\text{g.g}^{-1}$ , with the removal

rate reached 21.76%. The lowest amount of adsorbed lead was at a shaking time of ½ hour, reached 352.98  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 17.64%.

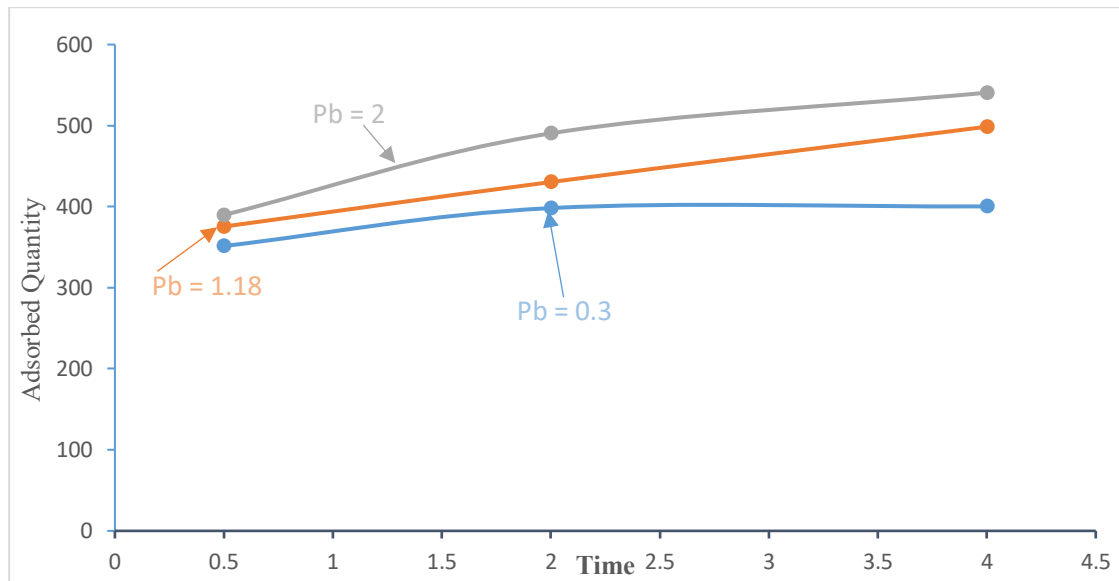


**Figure 7: Contact time for lead at a concentration of 20 and different diameters of CKD (0.3,1.18 and 2 mm)**

As shown in Figure 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 hours and a diameter of 0.3 mm reached 398.24  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 19.91%, while the lowest removal rate was at a shaking time of 1/2 hour, reaching 320.60  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 16.03%.

#### **Effect of the contact time of CKD particles on the concentration of lead (40 $\text{mg}\cdot\text{l}^{-1}$ )**

By increasing the concentration of lead to 40  $\text{mg}\cdot\text{l}^{-1}$ , the adsorption of lead on the surface of the adsorbent material increased Figure 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 ions binding affinity on the CKD surface. In this sense, the highest amount of lead adsorption at a shaking time of 4 hours and a diameter of 2 mm was 540.61  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 27.03% of the added amount. While the smallest amount of adsorbed lead was at a shaking time of 1/2 hour, reached 389.76  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 19.48%. Concerning the amount of lead adsorption at a shaking time of 4 hours and a diameter of 1.18 mm, it was 498.65  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 24.93% of the added amount. While the smallest amount of adsorbed lead was at a shaking time of 1/2 hour, reached 375.46  $\mu\text{g}\cdot\text{g}^{-1}$ , with a removal rate of 18.77% of the added amount.

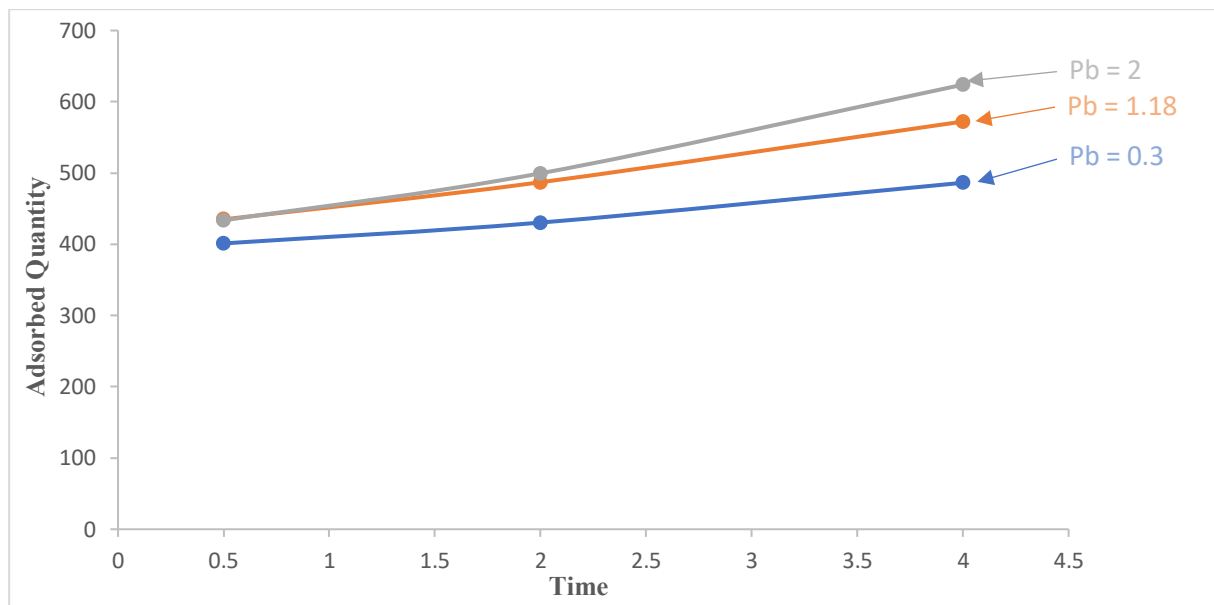


**Figure 8: Contact time for lead at a concentration of 40 and different diameters of CKD (0.3,1.18 and 2 mm)**

Also, Figure 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 hours and a diameter of 0.3 mm reached 400.31  $\mu\text{g.g}^{-1}$ , with a removal rate up to 20.01%, while the lowest removal rate was at a shaking time of 1/2 hour, reaching 351.45  $\mu\text{g.g}^{-1}$ , with a removal rate of 17.57%.

#### **Effect of the contact time of CKD particles on the concentration of lead (80 mg. L<sup>-1</sup>)**

Figure 9 shows the high affinity in the adsorption process between diameters 1.18 and 2 mm. This is probably due to the fact that 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 figure 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 hours and a diameter of 2 mm, reaching 624.40  $\mu\text{g.g}^{-1}$ , with a removal rate up to 31.20, while the lowest amount of lead adsorption was 433.54  $\mu\text{g.g}^{-1}$  at a contact time of 1/2 hour, 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. Where at a shaking time of 4 hours and a diameter of 1.18 mm was 572.31  $\mu\text{g.g}^{-1}$ , with a removal rate of 28.61% of the added amount. The smallest amount of adsorbed lead was 487.05  $\mu\text{g.g}^{-1}$  at a shaking time of 1/2 hour, with a removal rate of 24.35%.



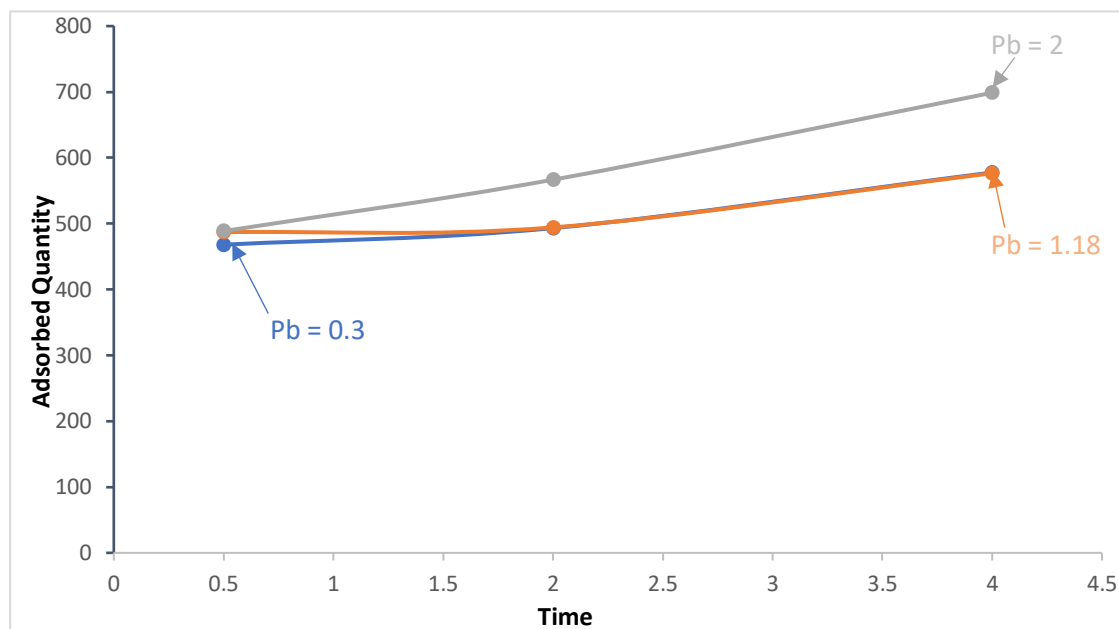
**Figure 9: Contact time for lead at a concentration of 80 and different diameters of CKD (0.3,1.18 and 2 mm)**

Furthermore, Figure 9 shows that the adsorbed lead on the adsorbent surface increased with time, Where the amount of adsorbed lead increased from 401 after two hours to 486.34 after four hours of shaking time and at 0.3 mm of CKD particle with a removal rate up to 24.31%, while the lowest removal rate was at a shaking time of 1/2 hour, reaching 401.2 µg.g<sup>-1</sup>, with a removal rate of 20.06%.

#### **Effect of the contact time of CKD particles on the concentration of lead (160 mg. l<sup>-1</sup>)**

Figure 10 shows that the adsorption at diameters 0.3 and 1.18 mm was slightly different at the first 1.5 hours from the start of the reaction. Later, the match between the 0.3 and 1.18 mm adsorption lines becomes perfect and this highlights 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 ascending even after 4 hours. The continuation of adsorption at a diameter of 4 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, figure 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 hours and a diameter of 2 mm was 698.76 µg.g<sup>-1</sup>, with a removal rate of up to 34.93%. The smallest adsorbed lead was observed at a shaking time of 1/2 hour, which amounted to 488.64 µg.g<sup>-1</sup>, 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 hours and a diameter of 1.18 mm reached 576.60 µg.g<sup>-1</sup>, with a removal rate

of 28.83%. While the smallest amount of adsorbed lead was at a shaking time of 1/2 hour, reached 487.00  $\mu\text{g.g}^{-1}$ , with a removal rate of 24.35%.



**Figure 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 Figure 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 hours and a diameter of 0.3 mm reached 577.62  $\mu\text{g.g}^{-1}$ , with a removal rate of 28.88%, while the lowest removal rate was observed at a shaking time of 1/2 hour, reaching 468.00  $\mu\text{g.g}^{-1}$ , with a removal rate reached 23.40%.

## 5. CONCLUSIONS

The current study found that the concentration of cadmium and lead ions had different adsorption efficiency. 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 big surfaces to absorb the polluted ions. In terms of concentration, the study shows that the adsorption efficiency increased with increasing the concentration. Due to 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-sized 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.

**Author Contributions:** For research articles with multiple authors, include a brief paragraph outlining each author's contributions using the following format: “Conceptualization, H.S.M.A; methodology, H.S.M.A, M.I.K.A. formal analysis,

H.S.M.A, O.I.A, M.I.K.A; investigation, H.S.M.A, M.I.K.A data curation, H.S.M.A, A.H.A writing—original draft preparation, H.S.M.A, O.I.A; writing—review and editing, M.I.K.A, A.H.A; visualization, H.S.M.A, M.I.K.A; supervision, H.S.M.A, O.I.A, M.I.K.A, A.H.A.; project administration, H.S.M.A. All authors have read and agreed to the published version of the manuscript.” Authorship should be restricted to individuals who have made significant contributions to the research.

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