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Assessing Lead Removal from Contaminated Water Using Solid Biomaterials: Charcoal, Coffee, Tea, Fishbone, and Caffeine

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ABSTRACT

Previous research has documented that solid biomaterials such as charcoal or waste coffee and tea have been used to remove heavy metals from contaminated aqueous solutions through adsorption. However, these studies used very low heavy metal concentrations between 10 to 100 ppm. Recently published research work reported that extracts of edible plants and fruits were able to effectively remove lead from contaminated aqueous solution. This paper evaluates the ability of charcoal, un-brewed coffee and tea, fishbone, and caffeine to remove lead from contaminated aqueous solutions. The order of lead removal from 1300 ppm of lead solution is Charcoal (100%) > Tea (97%) > Coffee Ground (88%) > Instant Coffee (83.5%) > Coffee Bean (82%) > Fishbone (76%) > Caffeine (1.3%). These results clearly demonstrate that not all solid biomaterials can adsorb lead and that caffeine, a component of coffee and tea does not participate in the removal of lead from contaminated solutions. Furthermore, the results suggest that two possible processes may be involved in the reactions presented here: adsorption of lead by the solid substrates and precipitation of lead by the solubilized biochemical components of the substrates.

Keywords: Heavy Metals; Chemisorptions; Coffee; Lead; Fishbone; Phytoremediation

1. Introduction

The world is becoming a global village, thus heavy metal contamination in one region will inherently have global consequences [1-5]. Contamination of soil, water, and air by heavy metals, particularly lead, poses a detrimental threat to our environment, humans, animals, plants, and marine life. Lead uptake, transport, and accumulation by plants and animals as well as the potential for its propagation into the food chain exacerbate its toxic health effects. Lead pollution is a consequence of many human activities such as lead paint production [6], mining [7], agricultural fertilizers, insecticides and pesticides [8]. Studies have shown that there is a strong correlation between chronic lead exposure to children and impaired cognitive skills [9], intellectual impairment [10], reduced IQ [11], and mental retardation [12]. Similarly, chronic lead exposure to adults has been linked to damage to the neurological, reproductive, central nervous and renal systems respectively [13-15]. Thus, removal of lead from water and soil will have positive and beneficial implications on the ecosystem, global economy, agriculture, and health. Currently, many technologies such as phytoremediation (extraction, stabilization, and volatilization) have emerged for the removal of lead from soil [16-22]. Until recently, only expensive and unsafe technologies such as electro-deposition [23] and chemical precipitation [24] were available for heavy metal removal from contaminated water. Emerging research has provided safe and cheap technologies for the remediation of heavy metal contaminated water. Such technologies include precipitation and biosorption using safe liquid substrates [25-27], adsorption using solid chemical and biological adsorbents such as Louisiana red clay and soil [25]. Modified clay [28,29], soil [30], seed powder [31], waste coffee and tea [32-34], maize tassels [35], modified coconut fiber [36], and saw dust [37] have been used as adsorbents to remove heavy metals from contaminated water. However, most of these reported adsorption experiments with solid substrates were carried out at conditions that are not natural such as very low pH, low heavy metal concentra-

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tions, and modified substrates. Therefore, the study reported here utilized natural solid substrates such as tea, coffee, fishbone, and spinach with out modification and at neutral pH. The unnatural substrates (activated carbon and caffeine) used in this study were for comparison purposes.

2. Materials & Methods

The lead nitrate, charcoal, and caffeine were purchased from Aldrich Chemicals and were used without further purification. Community Red Rose instant coffee, coffee ground, and coffee bean were bought from a local Wal-Mart store. The coffee bean was ground in the store using store provided grinding machine.

2.1. Preparation of Lead Nitrate Solution 1300 ppm

Using an analytical balance, 1.3 g of lead Nitrate from Fisher Scientific (L6200) was dissolved in enough deionized water (added incrementally) to give 1000 ml of solution. Then a stirring bar was dropped into the volumetric flask and the mixture was stirred until all the lead was completely dissolved. The flask was wrapped with aluminum foil to avoid much exposure to light while the solution continued to stir at room temperature until it was used.

2.2. Preparation of Charcoal and Caffeine Solid Substrates

Three 50 ml centrifuge tubes were charged with 4.0 g of charcoal and labeled CC-S. Similarly, three other tubes were each filled with 4.0 g of caffeine and labeled CAF-S.

2.3. Preparation of Coffee and Tea Solid Substrates

Separate triplicate 4.0 g samples of Lipton Tea and Community Dark Roast instant coffee, coffee ground, and coffee bean were respectively weighed out and placed in their respective 50 ml centrifuge tubes labeled TEA-S, IC-S, CG-S, and CB-S.

2.4. Preparation of Stock Fish Bone Substrate

Six-2ft dried stockfish from Norway were bought from a local market, deboned after soaking in water at room temperature for 3 hr. The bones were washed with deionized water and dried in an oven at 50˚C for 24 hr. The dried bones were pulverized using a blender. Three 50-ml centrifuge tubes were charged with 4.0 g of the fishbone respectively. The tubes were labeled FB-S.

3. Reaction of the Substrates with Lead

Into each of the respective triplicate centrifuge tubes containing the substrates was added 50 ml of 1300 ppm of lead nitrate solution prepared above. The tubes and their contents were vortexed, secured tightly on a heavy duty Eberbach 6000 shaker, and agitated for 48 hr at room temperature.

4. Sample Preparation and Analysis

4.1. Sample Preparation

After 48 hr, the shaker was stopped and the centrifuge tubes and their contents were centrifuged at 3000 rpm for ten minutes. The resulting supernatant in each tube was transferred into another labeled clean centrifuge tube. All the labeled centrifuge tubes with their liquid contents were sent to PACE Analytical Services, Inc for lead analysis using EPA method 6010. Note that PACE Analytical Services, Inc is a commercial environmental laboratory that is accredited in accordance to the National Environmental Laboratory Accreditation Conference (NELAC).

4.2. Sample Analysis for Lead after Reaction

After the reaction period, the lead concentration (in ppm) in the liquid from each reaction tube was analyzed using EPA Method 6010 (Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)).

5. Results

Data on **Table 1** show residual lead in ppm in each reaction tube after contaminated water was treated with each solid substrate for 48 hr and the percent of lead removed relative to the control: CTR (1280, 0%); CC-S (0, 100%), IC-S (212, 83%), CB-S (226, 82%), CG-S (151, 88%), Tea-S (44, 97%), FB-S (298, 77%) CAF-S (1263, 1%). **Figures 1** and **2** show the amount of lead remaining in the reaction mixture after charcoal, coffee, tea, fish bone and caffeine solids were agitated with lead solution and the percent of lead removed, respectively.

In another but related experiment, each of a triplicate 5 g sample of ground salmon fish bone was mixed with 50 ml of 1000 ppm lead solution for 48 hr at room temperature on a shaker. The results in **Figure 3** below suggest that salmon fishbone removed over 90% of the lead from contaminated water.

6. Discussions

The results on **Table 1** and **Figures 1** and **2** showed that the solid substrates except caffeine removed over 70% of the lead from contaminated water.

Table 1: Residual & removed lead in contaminated water after treatment with solid charcoal, coffee, tea, fishbone, and caffeine.

Sample	[Pb] in PPM	Std. Dev.	Std. Err.	% Lead Removed
Control (Ctr.)	1280	1632	9.42	0
Charcoal (CC-S)	0	0	0	100
Instant Coffee (IC-S)	211	24	14	83.5
Coffee Bean (CB-S)	225	10	6	82.4
Coffee Ground (CG-S)	151	7	4	88
Tea (Tea-S)	44	2.6	1.5	97
Fish Bone (FB-S)	298	13.5	8	77
Caffeine (CAF-S)	1263	41	24	1

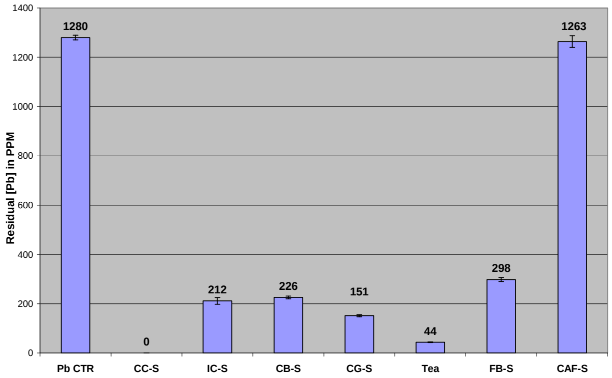

Figure 1. Residual lead concentration after contaminated water was treated with solid charcoal, coffee, tea, fish bone, and caffeine.

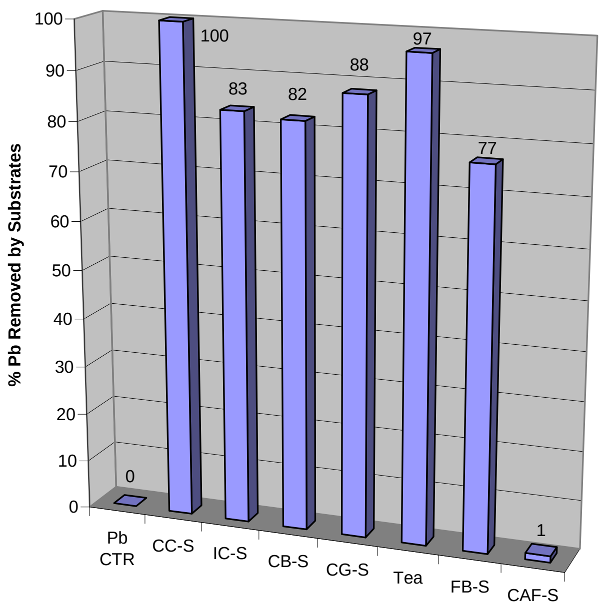

Figure 2. Percent Lead removed after contaminated water was treated with solid charcoal, coffee, tea, fish bone, and caffeine.

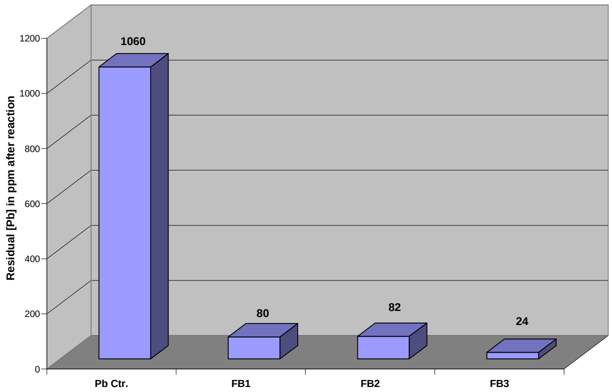

Figure 3. Residual Lead concentration after contaminated water was treated with salmon fish bone compared to 1000 ppm lead control.

Table 1 and **Figures 1** and **2** clearly suggest that with the exception of caffeine, all the solid substrates (charcoal, tea, coffee ground, instant coffee, coffee bean and fishbone) have great ability to remove lead from contaminated water.

7. Conclusion

Solid charcoal, tea, coffee ground, instant coffee, coffee bean and fishbone were all able to remove from 70% - 100% of lead from contaminated water. When the results of lead removal by solid coffee and tea are compared to those of aqueous extracts, it appears that a different mechanism is occurring for lead removal by the solid substrates and by the liquid extracts. Thus the results suggest that in the reaction of lead solution with solid substrates, adsorption is the predominant mechanism for lead removal while with liquid extracts, precipitation predominates. Caffeine did not remove lead from contaminated water in any appreciable amount (1% lead removed). This suggests that caffeine is neither lead adsorbing nor lead precipitating agent.

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