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Removal of lead ions in drinking water by coffee grounds as vegetable biomass

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Abstract

In an attempt to reuse food waste for useful purposes, we investigated the possibility of using coffee grounds to remove lead ions from drinking water. We studied the lead ion adsorption characteristics of coffee beans and grounds by measuring their fat and protein content, adsorption isotherms for lead ions, and adsorption rates for lead ions. The number of lead ions adsorbed by coffee grounds did not depend on the kind of coffee beans or the temperature at which adsorption tests were performed. The rate of lead ion adsorption by coffee grounds was directly proportional to the amount of coffee grounds added to the solution. When coffee grounds were degreased or boiled, the number of lead ions decreased. When proteins contained in coffee grounds were denatured, the lead ion adsorption was considerably reduced. The lead ion adsorption capacity of coffee grounds decreased with increased concentration of perchloric acid used for treating them and disappeared with 10% perchloric acid. The experiments demonstrated that proteins contained in coffee beans depend upon the adsorption of lead ion. The present study gave an affirmative answer to the possibility of using coffee grounds, an abundant food waste, for removing lead ions from drinking water.

Keywords: Lead ion; Adsorption; Coffee grounds; Vegetable biomass

1. Introduction

Lead-containing paint was commonly used in the United States until the 1950s, and it was sold until around 1978. Then concerns were raised about the lead pollution of indoor air in old houses and buildings caused by lead-containing dust from old paint coming off the walls. In 1992, the United States Environmental Protection Agency (USEPA) revised the Residential Lead-Based Paint Hazard Reduction Act, and in 1998, it recommended that acceptable lead levels be set for most of the houses and the facilities for children built and painted before 1978. In 2001, it also published Identification of Dangerous Levels of Lead [1] and Identifying Lead Hazards in Residential Properties [2].

On the other hand, drinking water in many countries contains lead. For example, in Bangladesh, a high level of lead is detected in drinking water [3]. In Japan, lead piping has been widely used, because lead is inexpensive and easy to fabricate. This has caused lead to dissolve into tap water, which has raised concern in society. Lead accumulates in human bodies and causes abnormal calcium metabolism [4] and immune disorders [5]. Fetuses and babies are particularly vulnerable to lead-induced intelligence impairment [6]. In light of this, replacement of lead piping with polyethylene piping has been undertaken, but the Japan Water Research Center reported in 1999 that 8,520,000 households still use lead pipes and the total length of lead piping amounts to more than 27,000 km [7]. The WHO guideline for drinking water stipulates that the lead concentration in drinking water be less than 0.01 mg/L. In Japan, the maximum lead concentration allowed in drinking water was changed from 0.1 to 0.05 mg/L in 1992, and it was further changed in 2003 to 0.01 mg/L, which is the same as the WHO standard. It

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is predicted that retained water of a lot of the households that still use lead pipes will not be able to meet the new standard. Therefore, it is urgent to find ways to remove lead from drinking water passing through lead piping.

Adsorption of lead ions by activated charcoal [8–10] and silica [11] and removal of heavy metal ions by coffee hide [12] have been studied and reported. But the use of waste food products for lead removal and the mechanisms of lead adsorption by such materials have not been investigated.

On the other hand, coffee has become an established beverage in many parts of the world including Europe, America, and Japan, and large amounts of coffee grounds are discharged from food industries. Although part of them is reused as compost and animal feed, most of the coffee grounds are burned as waste, which results in production of carbon dioxide, the green house gas. Approximately 400,000 tons of coffee grounds are generated in Japan and 6,000,000 tons in the world. Developing technology to reuse coffee grounds for useful purposes would help convert this large amount of waste into a new resource.

In the present study, we investigated the feasibility of reusing coffee grounds to remove hazardous lead ions from drinking water. In particular, we studied how the adsorption capacity of coffee beans and grounds for removing lead ion is correlated to such components as proteins, fat, and caffeine.

2. Materials and methods

2.1. Materials

The adsorbate used for the experiment was a 100 mg/L standard solution of lead chloride (Wako Pure Chemical Industries, Ltd.). The adsorbents were coffee grounds from five kinds of coffee beans, activated clay (Wako Pure Chemical Industries, Ltd.), activated alumina (Tomita Pharmaceutical Co., Ltd.), and activated carbon made from steam-activated coconut shell (Takeda Chemical Industries, Ltd.). Their manufacturers and origins are as follows: Used coffee grounds are *Coffea robusta* (Thailand), *C. arabica* (20% Bourbon, 80% Tipica) (Guatemala), *C. arabica* (Tipica) (Jamaica), *C. arabica* (Kent) (Tanzania), and *C. arabica* (Tipica) (Hawaii). Raw coffee beans (RCB-A (>1.7 mm), RCB-B (0.5–1.7 mm), and RCB-C (<0.5 mm)) are prepared from *C. arabica* (Tipica) (Jamaica). Degreased coffee grounds are prepared from *C. robusta* (Thailand) coffee grounds by degreasing through a 6-h reflux using a Soxhlet extractor with diethyl ether as the solvent. Denatured coffee grounds are prepared from *C. robusta* (Thailand) coffee grounds by boiling with 10% perchloric acid for 10 min to denature protein. Boiled coffee grounds are prepared from *C. robusta* (Thailand) coffee grounds by boiling for 5 min.

2.2. Fat and protein contents

The fat content was determined as follows: fat was extracted from coffee grounds using a Soxhlet's extractor with diethyl ether as the solvent [13]. A 5.0-g sample of coffee grounds was weighed out, placed in cylindrical filter paper, and subjected to reflux for 6 h for fat extraction. After the coffee grounds were removed from the extractor, the diethyl ether in the flask of the extractor was evaporated. Then the flask with a residue in it was dried at 373 K for 1 h, cooled in a desiccator, and weighed. The fat content of the coffee grounds was calculated by the equation

$$F = (W - W_0) \times 100/M, \tag{1}$$

where F is the fat content (%), W is the weight of the flask (g), W_0 is the weight of the flask plus a dried residue, and M is the weight of the sample coffee grounds (g).

The total nitrogen content was determined by the semimicro Kjeldahl method as follows [14]. A 200-g sample of coffee grounds was weighed out and placed in the Kjeldahl decomposition flask, to which approximately 0.5 g of reagents (K_2SO_4 and $CuSO_4 \cdot 5H_2O$ in a 10:1 ratio) to accelerate decomposition, 3.0 ml of concentrated sulfuric acid, and 1.0 ml of 30% (w/v) hydrogen peroxide were added. The contents of the flask was heated and carbonized. Then 20 ml of distilled water and 25 ml of 30% (w/v) sodium hydroxide solution were added, and the solution was distilled. Distillation continued until approximately 100 ml of distillate was deposited in a flask containing 15 ml of 4% (w/v) boric acid solution. Finally, the distillate was titrated with 0.025 mol/L sulfuric acid with bromocresol green–methyl red as the indicator. The same steps were followed by a blank test. The total nitrogen and protein contents were calculated by the equations [15]

$$N = 0.7003 \times (a - b) \times 100/M, \tag{2}$$

$$P = N \times 6.25, \tag{3}$$

where N is the total nitrogen content (%), a and b are the amounts of sulfuric acid (ml) used for titrating the sample and blank distillates, respectively, M is the weight of the sample coffee grounds (mg), and P is the protein content (%).

2.3. Measuring lead ion concentration

The concentration of lead ions was measured with an HAS-1000 portable scanning lead ion tester made by the HACH Company in the United States.

2.4. Adsorption isotherms of lead ions

The adsorption isotherms of lead ions were obtained as follows. Lead chloride solutions of predetermined concentrations were prepared. To 100 ml of each solution, 10 mg of one of the adsorbents chosen for the experiment was added.