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Removal of Arsenic and Lead from Aqueous Solutions by Palm Kernel Cake and Shea Nut Cake Adsorbents

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ABSTRACT

The capacity of Palm Kernel Cake and Shea Nut Cake in adsorbing arsenic and lead in mine processed wastewater was studied. Simulated arsenic and lead wastewater samples were prepared and the adsorption capacities of the cakes were studied at varying concentrations of arsenic and lead, and also, at varying masses of the adsorbents. Results of the study show that adsorption capacities of the materials depended on the mass of the adsorbent material, as well as on the concentration of the metals in solution. With a fixed mass of adsorbents, maximum adsorption capacities of 55.2% and 71.4% were attained with Palm Kernel Cake and Shea Nut Cake, respectively, in varying concentrations of As solution. The capacities increased with increase in concentration of As in the wastewater. However, the capacity of adsorption decreased with increasing concentrations of Pb in the wastewater, with maximum values of 88.8 and 98%, respectively for Palm Kernel Cake and Shea Nut Cake. With varying mass of adsorbents in 100 mg/l solution of A s, maximum adsorption capacities were 62.7% and 74%, respectively for Palm Kernel Cake and Shea Nut Cake. Adsorption capacity increased with mass of Shea Nut Cake whereas it decreased with that of Palm Kernel Cake. Again, adsorption capacity increased with mass of Palm Kernel Cake and Shea Nut Cake in 100 mg/l solution of Pb. Thus, Palm Nut Cake and Shea Nut Cake offer a simple, safe and inexpensive way of effectively cleaning-up arsenic and lead contaminated wastewater.

Keywords: *Arsenic, Lead, Adsorption Capacity, Palm Kernel Cake, Shea Nut Cake*

1. INTRODUCTION

One of the most reported environmental problems associated with mining operations in Ghana is the contamination and pollution of surface water bodies with heavy metals such as arsenic, lead, mercury, and other chemical substances (Agyapong et al., 2012; Armah et al., 2010; Asante et al., 2007; Akabza et al., 2005). Some of these contaminants have been found in drinking water sources in several mining communities in the country. The health implications of heavy metal contamination of drinking water sources is particularly important because of their toxic effects and ability to accumulate through the food chain.

Various techniques have been used to treat heavy metal contaminated mine wastewater. These methods include chemical and physical stabilization, biological remediation and adsorption methods (Kurniawan et al., 2006). After comparing the various techniques, adsorption was chosen for this study because of its simplicity, safety and cost-effectiveness in treating wastewater (Balkose and Baltacioglu, 1992). Another advantage of this technique is that it allows for the use of agricultural waste materials as adsorbents to treat the heavy metal contaminated wastewater. Among the agricultural materials that have been used as adsorbents include maize leaves (Adesola et al., 2006); plants seeds (Edogbanya et al., 2013; Oboh and Alluyor, 2008; Kumari et al., 2006); pomegranate peels (El-Ashtoukhy et al., 2007) and orange and banana peels (Annadurai et al., 2002). The mode of sorption by these agricultural waste products has been attributed to intrinsic adsorption and Columbic interaction between the biosorbent and the toxic metal ions (Igwe et al., 2006). In this study, palm nut cake and shea nut cake are used as adsorbents to treat arsenic and lead contaminated wastewater. With relatively high crude protein content of these two materials (Hassan and Yeong, 1999; Boateng et al., 2008), they present huge potential for use as adsorbents for heavy metal contaminated water environments. Another advantage is that the utilization of these materials represents a conversion of agricultural waste into useful by-products and thus, encourages reuse of materials leading to waste minimization.

2. MATERIALS AND METHODS

2.1. Materials

Palm kernel cake (PKC) was obtained from Asante Bekwai palm kernel oil extraction industrial area in the Ashanti Region of Ghana while the shea nut cake (SNC) was obtained from Buipe in the Northern Region of Ghana. The adsorbents were kept in small transparent polythene bags and stored in a desiccant until use. The materials were dried for 3 days and blended separately in a blender to produce uniform samples. Each sample was sieved through 2 mm pore spaces. The sieved samples were air-dried at room temperature (25ºC) for 7 days followed by drying in an electric oven at 50°C for 3 hours.

Synthetic arsenic and lead "wastewater" at concentrations of 10, 20, 30, 40, 50 and 100 mg/l were prepared by serial dilutions of stock solutions of 1000 ppm (1000 mg/l) in approximately 0.5 nitric acid. For example, to prepare 10 mg/l arsenic wastewater or solution, 5 ml of the stock solution was pipetted into a volumetric flask and distilled water was added to the 500 ml mark, and properly shaken.

2.2. Experimental

Adsorption at varying metal concentrations

Fifty (50) ml of the different arsenic solutions (at concentrations 10, 20, 30, 40 and 50 mg/l) were measured into 5 separate beakers each containing 2 grams of PKC or SNC. All beakers were manually swirled for a minute and their contents transferred into corresponding labeled bottles. The bottles were packed in HS501 digital shaker and swirled for two hours. The samples were allowed to settle for one hour, after which they were filtered using a vacuum filter and the filtrates transferred into corresponding labeled test tubes. The samples were then processed for Atomic Absorption Spectrophotometer (AAS) measurements. The whole procedure was repeated for PKC and SNC in varying concentrations of Pb solution.

Adsorption at varying masses of adsorbents

To determine the adsorption capacity of arsenic by palm kernel cake and shea nut cake at fixed concentrations, 50 ml each of 100 mg/l arsenic solutions were measured into 5 separately labeled beakers containing 2, 4, 6, 8 and 10 grams of the cake. The beakers were manually swirled for a minute and their contents transferred into corresponding labeled bottles. The bottles were packed in HS501 digital shaker and swirled for two hours. The samples were allowed to settle for one hour. Subsequently, the samples were filtered using a vacuum filter and the filtrates transferred into corresponding labeled test tubes. The samples were processed for Atomic Absorption Spectrophotometer (AAS) measurements. The whole procedure was repeated for PKC and SNC in varying concentrations of Pb solution
The initial pH of the working solutions was 2.67 and all experiments were carried out at a temperature of 25

3. RESULTS AND DISCUSSION

Sorption capacity in varying concentrations of arsenic and lead wastewater

Adsorption capacity of both palm kernel cake (PKC) and shea nut cake (SNC) increased as the concentration of arsenic in the solution increased. With 2 g of PKC or SNC, mean adsorption of arsenic was 19.7-55.2% and 30.0-71.4%, respectively (Fig. 1). With a fixed mass of 2 g of PKC adsorbent, percentage adsorption of between 30.0 and 88.8 were attained in various concentrations of simulated lead wastewater (Fig. 2). The rate decreased as lead concentration in the solution increased. For the SNC adsorbent, mean percentage adsorption for lead ranged from 93 to 98, and adsorption generally decreased slightly with lead concentration (Fig. 2).

The adsorption capacity of the materials investigated in this study is attributed to the electrostatic forces of attraction between the positively charged ions of the metal species (arsenic and lead) and the positively and negatively charged protein ends of the PKC and SNC adsorbents. The general increase in adsorption with an increase in the concentration of arsenic could be attributed to the increasing presence of metal ions in solution, and possibly the experimental conditions (pH=2.67 and temperature=25ºC) under which the experiments were performed. This conclusion on adsorption capacity has also been made by Afidenyo (2011) and Hunter *et al*. (1993).

However, increasing the concentration of lead led to general reductions in the adsorption capacity by fixed masses of PKC and SNC. This behaviour of the materials could probably be attributed to the fact that so many lead ions may have dissociated into solution leading to a state of super-saturation, which reduced the mobility of ions, and hence hindered the sorption of lead ions onto the cakes. Another possible cause for this observation could be a weaker force of electrostatic attraction between lead and the adsorbents. Also, clogging at binding sites could have contributed to the observed trends in these experiments.

Differences in adsorption capacity of PKC and SNC in varying concentrations of both metals were statistically insignificant ($p = 0.08$). This implies that the adsorption capacity of both adsorbents were roughly the same. That is, in both cases, almost the same amounts of dissociated ions were available and that both PKC and SNC could be used to achieve similar results in remediating a contaminated medium of arsenic and lead pollutants.

Results from the experiments also show that shea nut cake performed better than palm kernel cake in adsorbing arsenic and lead ions from wastewater (Fig. 1 & Fig. 2). For both adsorbents, capacity of adsorption increased with increasing concentration of arsenic ions in solution. The capacity of adsorption depended on the amount of protein in the adsorbents. Sharma *et al.* (2007), explain that depending on the pH, amino acids possess both negative and positive charged ends, and thus, are capable of generating the appropriate binding sites for attracting anionic or cationic metal ions. Therefore, given the fact that shea nut cake contains 40% crude protein mainly of saponine, theobromine, and tannins (Hassan and Yeong, 1999), it provided more binding sites for the metal ions to be adsorbed. The crude protein content of PKC is 14-21% (Boateng et al., 2008), and mainly comprises of argine, sevine, valine and leucine (Hair-Bejo and Alimon, 1995), and provided fewer binding sites for adsorption, and this could have accounted for the lesser capacity of adsorption observed at all concentrations of arsenic and lead ions in the wastewater. Again, the acidic medium (pH=2.67) under which the experiments were performed enhanced the adsorption process since proteins are known to work better in acidic media than in basic or neutral media. This means that adsorption would be higher for the adsorbent with higher protein content compared with one with lower protein content; hence, the observed higher capacity in SNC compared with PKC.

Another reason which could have accounted for the lower capacity of PKC was the presence of some oily substance on the surface of the filtrate seen after the mixing and vacuum filtration. This oily substance could have possibly hindered the drying of the PKC when both adsorbents were subjected to the same conditions of drying in the Sun and the electric oven.

Adsorption* capacity *in varying masses of adsorbents

The capacity of the PKC and SNC adsorbents also depended on the mass of the adsorbents in fixed concentration (100 mg/l) of arsenic or lead solution. The sorption capacity increased from 52.3 to 74% when SNC mass was varied from 2 to 10 g. However, the capacity decreased from 62.7% to 49.5% as the mass of PKC was varied from 2 to 10 g in 100 mg/l simulated arsenic solution (Fig. 3).

For lead, the capacity of both adsorbents increased with increasing adsorbent mass in 100 mg/l of lead "wastewater" (Fig. 4). With 10 g of PKC, sorption rate of 95.1% was attained whereas 77.6% was attained with 2 g. Similarly, sorption capacity increased from 83.2 to 99.1% when SNC mass was varied from 2 to 10 g.

Differences in adsorption capacities of the PKC and SNC as their masses were varied could, again, be related to the availability of binding sites (surface area). The larger the mass, the more are the binding sites available and the better the adsorption capacity of the adsorbent; hence, the high adsorption capacity being observed in the 10 g of both adsorbents. This observation is supported by Journal of American Chemical Society (2009). No significant statistical difference in mean percentage adsorption of lead was observed for PKC and SNC at varied masses (p = 0.08). This implies that, the adsorption capacities of PKC and SNC with respect to lead were not too different, and that these adsorbents provided almost the same amount of active binding sites for adsorption. Thus, in the application of PKC and SNC to clean up lead pollution, similar results can be expected from both sorbents.

However, in the case of mean percentage adsorption of arsenic by PKC and SNC at varied masses, significant statistical differences were observed for the adsorbents (p = 0.01). The implication of this is that, the adsorption capacity of PKC was very different from that of SNC, probably due to the differences in the amount of dissociated ions in solution.

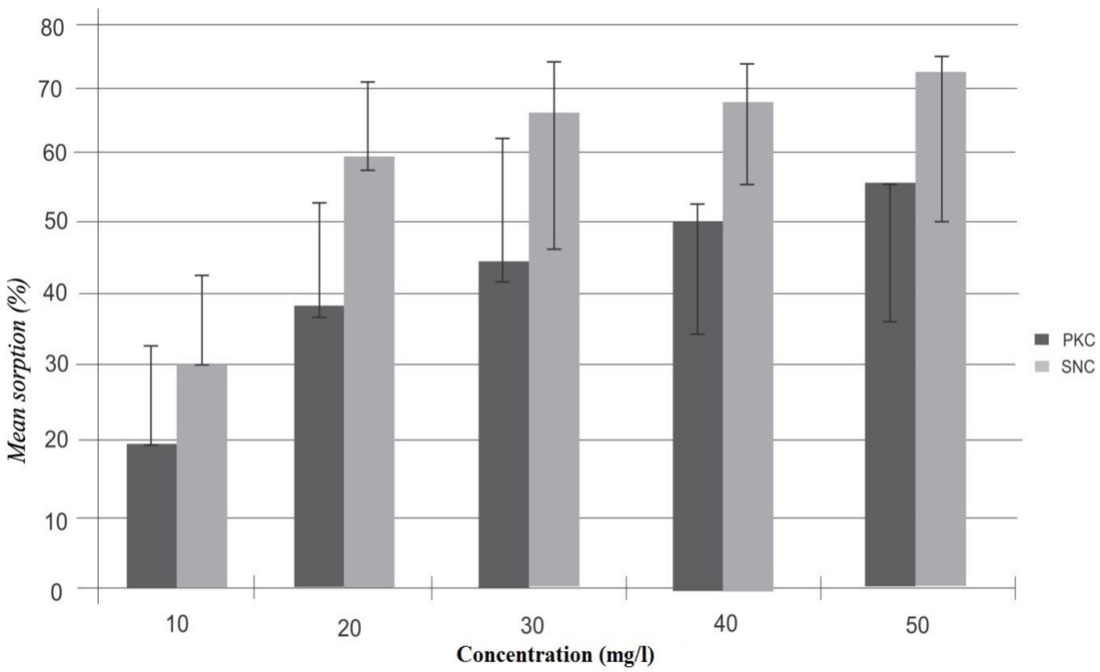

Fig. 1. Sorption of arsenic by fixed mass of PKC and SNC in varying concentrations of arsenic solution

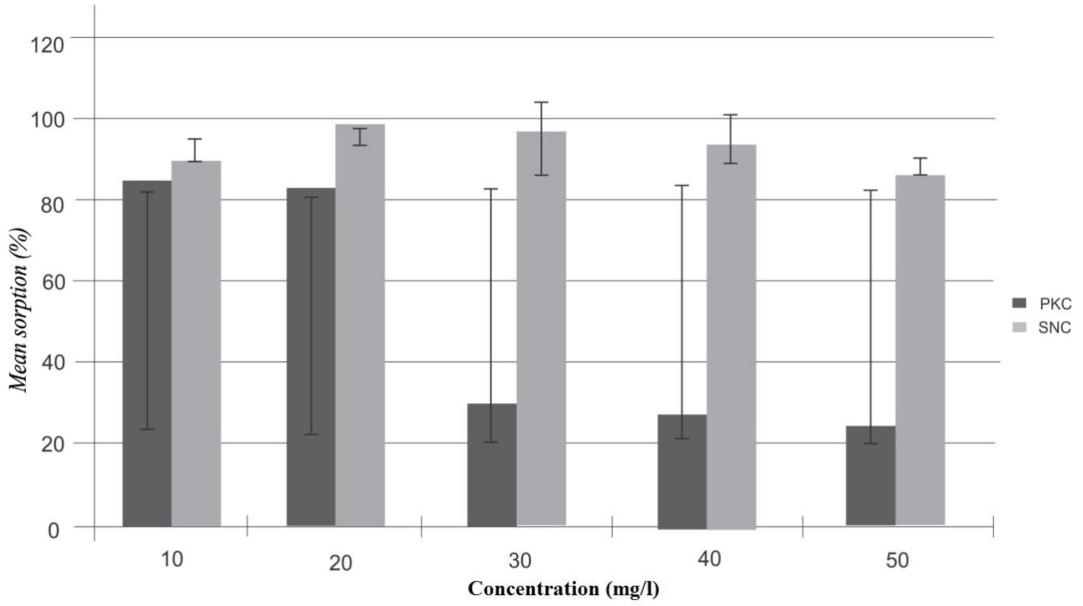

Fig 2. Sorption of lead by fixed mass of PKC and SNC in varying concentrations of lead solution

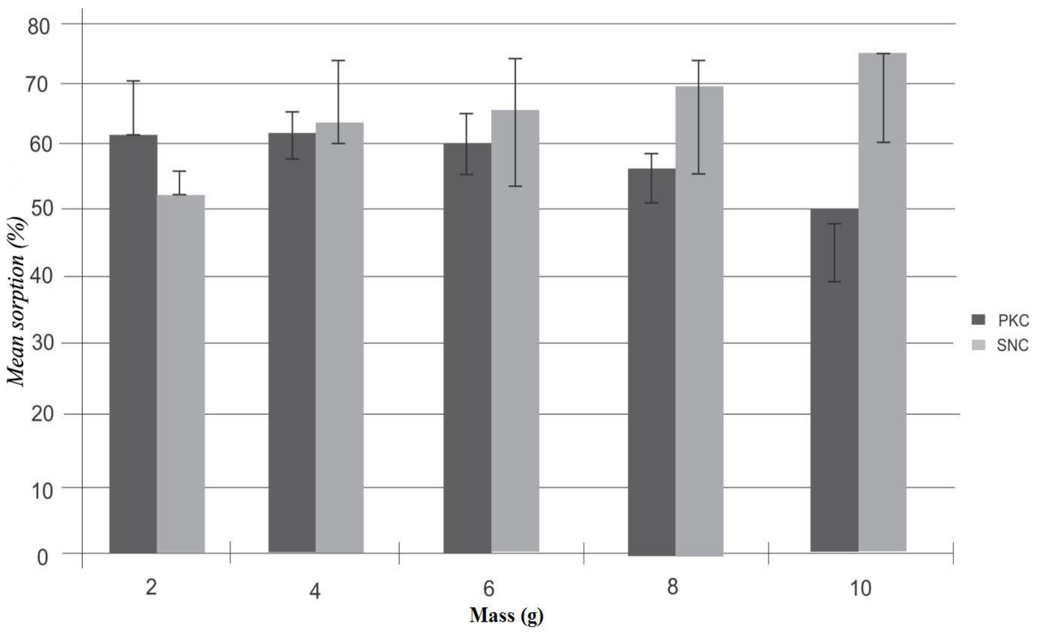

Fig 3. Sorption of arsenic by varying masses of PKC and SNC in 100 mg/l arsenic solution

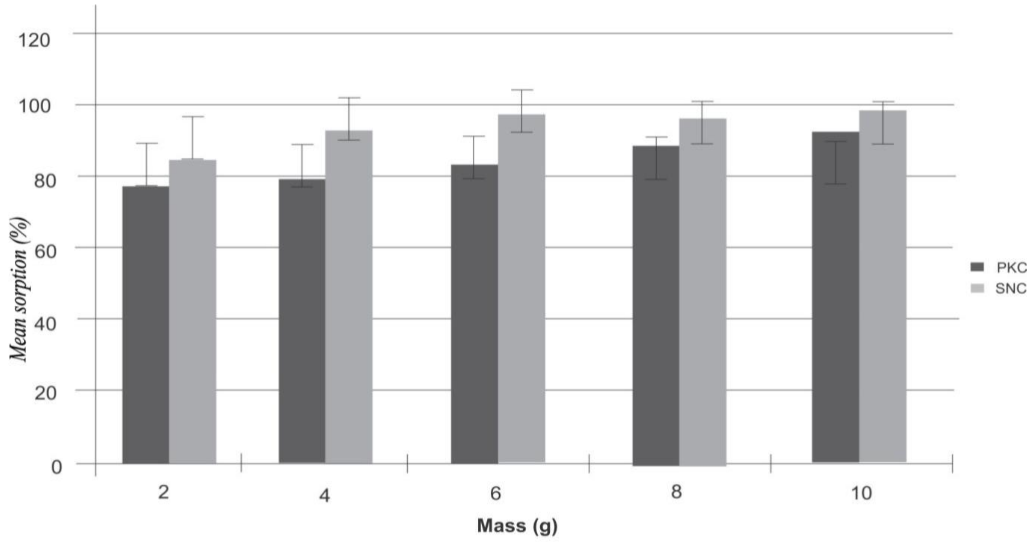

Fig 4. Sorption of lead by varying masses of PKC and SNC in 100 mg/l lead solution

4. CONCLUSION

The results of the experiments indicate that palm kernel cake and shea nut cake were effective adsorbents in removing arsenic and lead ions from the wastewater. The adsorption capacity depended on the mass of the adsorbent material as well as the concentration of the metal (As or Pb) in solution. With a fixed mass of the materials in varying concentrations of As in wastewater, maximum adsorption capacity of 55.2% and 71.4% were attained with palm kernel cake and shea nut cake, respectively. Adsorption capacities increased with increase in concentration of As in the wastewater, whereas the capacities decreased with increase in concentration of Pb in the wastewater, with maximum capacities of 88.8% and 98%, respectively for palm kernel cake and shea nut cake. With varying mass of palm kernel cake and shea nut cake in 100 mg/l solution of As, maximum adsorption capacities were 62.7% and 74% for palm kernel cake and shea nut cake, respectively. Adsorption capacity increased with mass of shea nut cake but decreased with that of shea nut cake. Also, adsorption capacity increased with mass of adsorbents in 100 mg/l solution of Pb with maximum capacities of 95.1% and 99.1%, respectively for palm kernel cake and shea nut cake. Thus, palm kernel cake and shea nut cake offer a simple, safe and inexpensive way of effectively cleaning-up arsenic and lead contaminated wastewater.

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