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Banana Peel: A Green Solution for Metal Removal from Contaminated Waters

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Abstract

BACKGROUND: Certain crop-based waste materials have been recognized as cost-effective and highly efficient adsorbents for removal and recovery of different kind of heavy metals from aqueous solutions. The ability is strongly attributed to the carboxyl functional group of some pectin substances such as galacturonic acid often found in fruit peels. The present manuscript was aimed at assessing the potential applicability of banana peel for metal removal from contaminated waters.

METHODS AND RESULTS: As revealed by laboratory investigations, banana peel contains pectin (10-21%), lignin (6-12%), cellulose (7.6-9.6%), and hemicelluloses (6.4-9.4%). The pectin extraction is reported to have glucose, galactose, arabinose, rhamnose, xylose, and galactouronic acid. Several studies conducted under different conditions proved that banana peel is capable of adsorbing 5.71, 2.55, 28.00, 6.88, 7.97, and 5.80 mg/g of Cd²⁺, Co²⁺, Cu²⁺, Ni²⁺, Pb²⁺, and Zn²⁺, respectively, from aqueous solutions. Adsorption capacity is, however, dependent upon several factors including solution pH, dose of adsorbent and metal concentration, contact time and

shaking speed.

CONCLUSION(S): Since the annual world production of banana exceeds 100 million tons, about 40 million tons of banana peel (40% of total weight of the fresh fruit) remains vastly unused. Exploring a sound technology with banana peel would therefore, not only address the much needed sustainable tool for cleaning contaminated waters, but of course bring an additional value to the banana industry worldwide.

Key Words: Adsorbent, Aqueous solutions, Banana peel, Metal removal, Pectin substances

Introduction

Metal contamination is considered to be one of the most ubiquitous and complex environmental issues today. Accumulation of heavy metals in soils and water is of particularly important because it can impact upon human health through possible contamination of food (Sadon *et al.*, 2012). With the increasing demand for water for agricultural, domestic, industrial, and recreational purposes, remediation and reuse of contaminated waters receive prime attention globally (Opeolu and Fatoki, 2012). Different technologies, such as adsorption, chemical precipitation, coagulation/flocculation, evaporation, complexation, membrane

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filtration, biological operations, electrochemical operations, ion exchange/solvent extraction, etc., have been employed in removing metals from contaminated water and wastewater. Due to the inherent merits such as easy handling, minimal sludge production, and regeneration capability, etc., associated with adsorption, it has been widely used as an efficient and effective technique for heavy metal removal (Chiban *et al.*, 2012; Pagnanelli *et al.*, 2003). However, the success of this technique is heavily dependent upon the nature of the adsorbent material used for the process. Recently, activated carbon is extensively used as the adsorbent, though the cost involved with the initial establishment and the regeneration system is relatively high (Aktas and Cecen, 2007). Therefore, the search for economically affordable alternatives remains one of the key priorities among researchers.

In this context, agricultural waste materials have been recognized as possible alternative adsorbents mainly due to the fact that they are easily available, cost-effective and highly efficient in adsorbing different kind of heavy metal ions (Montanher *et al.*, 2005; Nasernejad *et al.*, 2005). In fact, certain widely available plant materials remain unused resources, thus the use of them could indeed be an environmentally friendly approach too (Ashraf *et al.*, 2011). Various plant-based adsorbent agents have been tested under different conditions, such as seaweed (Basha *et al.*, 2008; Hashim and Chu, 2004), marine algal biomass (Sheng *et al.*, 2004), seafood processing waste sludge (Lee and Davis, 2001), sugar beet pulp (Reddad *et al.*, 2002b), banana peel (Ashraf *et al.*, 2011; Castro *et al.*, 2011; Hossain *et al.*, 2012), papaya wood (Saeed *et al.*, 2005), grape stalk wastes (Villaescusa *et al.*, 2004), neem bark (King *et al.*, 2007), neem biomass (Arshad *et al.*, 2008), tea-waste (Malkoc and Nuhoglu, 2007; Kamsonlian *et al.*, 2011a), sawdust (Garg *et al.*, 2004; Memon *et al.*, 2005), tamarind bark (Prasad and Abdulsalam, 2009), tamarind hull (Verma *et al.*, 2006), potato peel waste (Ahalya *et al.*, 2005), maize corn cob, jatropha oil cake, sugarcane bagasse (Garg *et al.*, 2007), rice husk (Kumar and Bandyopadhyay, 2006), rice straw (Gao *et al.*, 2008), wheat straw (Robinson *et al.*, 2002), wheat shells (Bulut *et al.*, 2007), wheat bran (Sulak *et al.*, 2006), maize leaf (Babarinde *et al.*, 2006), wood and bark (Mohan *et al.*, 2007), teak leaf powder (King *et al.*, 2006), rubber leaf powder (Hanafiah *et al.*, 2006), pine bark (Al-Asheh *et al.*, 2000), saltbush (Sawalha *et al.*, 2005), and olive pomace (Pagnanelli *et*

al., 2003), orange peel (Kamsonlian *et al.*, 2011b), etc. By contrast, many crop residues are reported to be excellent adsorbents (Table 1) with good adsorption capacity better than activated carbons and commercial ion exchangers. However, the use of them in their original forms is not yet fully exploited (Anirudhan and Shibi, 2007). Moreover, many of the studies have been conducted with particular type of wastes with specific aqueous-phase applications. The present paper reviews literature dedicated to use of banana peel in removal of heavy metals from waters.

Table 1. Crop-based waste materials as metal adsorbents in aqueous mediums

Material	Metal	Maximum Uptake (mg/g)	Reference
Banana peel	Copper(II)	28.00	Hossain et al. (2012)
	Cadmium(II)	5.71	Anwar et al.(2010)
	Lead(II)	7.97	Annadurai et al. (2002)
	Zinc(II)	5.80	
	Nickel(II)	6.88	
	Cobalt(II)	2.55	
Banana stem	Lead(II)	91.74	Noeline et al. (2005)
Barley straw	Copper(II)	4.64	Pehlivan et al.(2009)
	Lead(II)	23.20	
Carrot residues	Chromium(III)	45.09	Nasernejad et al. (2005)
	Copper(II)	32.74	
	Zinc(II)	29.61	
Cassava tuber bark	Cadmium(II)	26.30	Horsfall Jr. et al. (2006)
	Copper(II)	90.90	
	Zinc(II)	83.30	
Corn cob	Cadmium(II)	55.20	Leyva-Ramos et al. (2005)
Grape stalks waste	Nickel(II)	10.62	Miralles et al. (2008)
Groundnut shells	Copper(II)	7.60	Shukla and Pai (2005a)
	Nickel(II)	7.49	
	Zinc(II)	9.57	
Jute fibres	Copper(II)	8.40	Shukla and Pai (2005b)
	Nickel(II)	5.26	
	Zinc(II)	5.95	
Orange peel	Nickel(II)	75.14	Li et al. (2008)
Olive stone waste	Nickel(II)	2.13	Fiol et al. (2006)
Rice bran	Nickel(II)	44.85	Zafar et al. (2007)
Rice husk	Nickel(II)	5.52	Krishnani et al. (2008)
Sawdust	Copper(II)	8.07	Shukla and Pai (2005a)
	Nickel(II)	9.87	
	Zinc(II)	17.09	
Tobacco dust	Nickel(II)	4.48	Qi and Aldrich (2008)
Wheat bran	Copper(II)	51.5	O' zer et al. (2004)
	Cadmium(II)	101	O'zer and Pirincci (2006)
Wheat straw	Chromium(III)	20.0	Chojnacka (2006)

Banana peel as a metal adsorbent

Banana is one of the most popular fruit crops grown in more than 130 countries, particular in tropical and sub-tropical regions of the world. The crop is grown by small-and large-scale producers alike and the annual world banana production exceeds 100 million tons (UNCTAD, 2012). Though the vast majority (over 90%) of the production is auto-consumed, a portion worth about \$ 8 billion is still traded internationally, which shows an almost steady annual growth rate (UNCTAD, 2012).

Banana peel, which represents about 40% of total weight of the fresh fruit (Anhwange *et al.*, 2008) is generally considered to be a waste material. As of the production records mentioned above, it is apparent that the banana industry produces more than 40 million tons of banana peel annually (peel represents about 40% of the total weight of fresh banana). Exploring alternative uses of banana peel would thus bring an additional value to the industry.

Fruit peels generally contain organic compounds such as cellulose, hemicellulose, pectin substances, chlorophyll pigments, and some other low molecular weight compounds (Xiaomin *et al.*, 2007). The pectin substances, a complex heteropolysaccharides containing galacturonic acid, arabinose, galactose, and rhamnose, are found in fruit peels (Reddad *et al.*, 2002a). Galacturonic acid with the carboxyl functions could make pectin substances a strong metal adsorbent in aqueous solutions (Saeed *et al.*, 2005). As reported by Mohapatra *et al.* (2010), banana peel is found to be a good source of pectin (10-21%), lignin (6-12%), cellulose (7.6-9.6%), hemicelluloses (6.4-9.4%), and galactouroninc acid. Furthermore the pectin extracted from banana peel also contains glucose, galactose, arabinose, rhamnose, and xylose (Emaga *et al.*, 2008).

Under this background, banana peel is recognized to be an economically viable and environmentally sound adsorbent for removal of heavy metals from contaminated waters. According to Hossain *et al.* (2012), 1g of banana peel can adsorb 28 mg of Cu^{2+} in a favourable condition, and thus provides with a potential alternative of Cu^{2+} removal from water. Moreover, it could adsorb 5.71 and 2.18 mg/g of Cd^{2+} and Pb^{2+} , respectively (Anwar *et al.*, 2010). Annadurai *et al.* (2002) studied the adsorption capacity of divalent heavy metal ions (Cu^{2+} , Zn^{2+} , Co^{2+} , Ni^{2+} and Pb^{2+}) onto acid (HNO_3) and alkali (NaOH) treated

banana peels. According to them, the adsorption capacity was in the order of $\text{Pb}^{2+} > \text{Ni}^{2+} > \text{Zn}^{2+} > \text{Cu}^{2+} > \text{Co}^{2+}$. The maximum metal adsorptions were recorded as 7.97 (Pb^{2+}), 6.88 (Ni^{2+}), 5.80 (Zn^{2+}), 4.75 (Cu^{2+}), and 2.55 mg/g (Co^{2+}). Memon *et al.* (2008b) assessed the practical applicability of banana peel to remove arsenic from contaminated water samples collected from 8 different areas of Sindh, Pakistan. They collected 100 mL of water samples, filtered and mixed with the banana peel before being shaken for 30 min. The contents of arsenic in the solution were measured before and after adsorption and results revealed that 98-100% of arsenic can be removed successfully using the banana peel. However, successful metal removal can be achieved only if due attention is paid on the followings.

Solution pH

The pH of the medium is considered to be a key factor governing the process of metal adsorption from an aqueous solution (Shafaghat *et al.*, 2012). The solution pH is capable of influencing the dissociation state of the adsorbents, ionic state of functional groups and species of metals (Hossain *et al.*, 2012). As reported by Fiol *et al.* (2006), the effect of pH on solution chemistry of the target metal includes hydrolysis, complexation by organic and/or inorganic ligands and redox potentials. At elevated pH values, adsorption is reduced due to high precipitation, ion exchange and aqueous metal hydroxide formation (Shafaghat *et al.*, 2012). Furthermore, under basic condition, the binding sites may not activate as in acidic medium (Memon *et al.*, 2008a). Analogous to these reports, Demirbas *et al.* (2009) reported that at high pH, copper began to precipitate as $\text{Cu}(\text{OH})_2^+$, resulting in lower adsorption. Hossain *et al.* (2012) also observed gradual reduction in Cu^{2+} adsorption onto banana peel when solution pH increased. According to them, Cu^{2+} adsorption capacity was declined when pH decreased below 2.0. However, it was reported to increase with the increase in pH from 2.0 to 6.0 (Hossain *et al.*, 2012). As observed by Wang and Qin (2005), under slightly acidic conditions, Cu^{2+} is the dominant free species involved in adsorption. In fact, at slightly acidic conditions, linked H^+ is released from the active sites allowing metals ions to be absorbed. However, when pH was further lowered, H_3O^+ ions begin to compete with

Cu^{2+} for binding onto adsorbent sites resulting in poor adsorption capacity (Demirbas *et al.*, 2009). Similar observations were made by Kaewsarn *et al.* (2008) who studied the Cd^{2+} biosorption onto banana peel. According to them, though the biosorption at very highly acidic condition (pH 1.0) was negligible, removal of Cd^{2+} increased with increasing pH from 1.0 to 5.0. In this regard, Shafaghat *et al.* (2012) reported that under highly acidic conditions, formation of links between metal ions and the active site is restricted by the excessive protonation of the active sites which ultimately results in lower adsorption. However, contrary to this Memon *et al.* (2008b) reported that adsorption of arsenic species is independent of pH, which of course raises the practical applicability of banana peel to remove arsenic from contaminated waters.

Contact time

Hossain *et al.* (2012), based on the results of their study, reported that Cu^{2+} adsorption onto banana peel was relatively quicker than those reported for some other bio-adsorbents. They observed a rapid adsorption during the first 30 min, followed by a constant rate of Cu^{2+} removal for further 30 min before reached the equilibrium. In the case of arsenic, Memon *et al.* (2008b) reported that the equilibrium was established within 30 min, and 75% and 95% sorption was recorded for As(III) and As(V), respectively. According to them, no significant increase in the percent sorption onto banana peel was observed after 30 min. When particles of banana peel were introduced to the solution, metal ions could find flurry of vacant active binding sites resulting in rapid initial adsorption. This was further confirmed by Shafaghat *et al.* (2012), who studied the adsorption of Pb^{2+} , Cu^{2+} , and Cr^{3+} by five plant materials. According to them, the maximum removal of three metals was attained after a shaking period of 90 min. Once the majority of binding sites were occupied, formation of repulsive forces between the metal ions on the solid surface and the liquid phase makes it difficult for further binding to the remaining vacant surface sites (Achak *et al.*, 2009; Srivastava *et al.*, 2006). Thus, the adsorption of metal ions gradually decreases as time progressed. In fact, in order to bind, the metal ions have to pass through the deeper surface of the pores, which of course encounter

substantial resistance leading to decreased adsorption during the later phase of adsorption (Srivastava *et al.*, 2006). As stated by Shafaghat *et al.* (2012), the transportation rate of ions from the exterior to the interior sites of the adsorbent particles actually determines the adsorption rate of later phase.

Doses and particle size

It is well understood that the amount of metal removal is vastly dependent upon the metal concentration in the solution. As reported by Chojnacka (2006), who studied the effect of initial concentration of Cr^{3+} on adsorption by wheat straw, the adsorption rate was increased with the increase in the initial metal ion concentration. However, if the amount of biomass remains constant in the system, the metal removal efficiency may be reduced regardless the increased metal concentration (Zhou *et al.*, 2007). Furthermore, Hossain *et al.* (2012) who studied the Cu^{2+} adsorption by banana peel reported that the adsorbent dose is also decisive for metal removal. They observed the highest Cu^{2+} removal (88%) when the initial Cu^{2+} concentration of 10 mg/L with the adsorbent dose of 5 g/L. Similar investigation was conducted by Anwar *et al.* (2010) to study the effect of adsorbent dosage on the adsorption of Cd^{2+} and Pb^{2+} . They used different dosages of banana peel ranging 10-90 g/L, and the maximum removal was observed at the doses of 30 and 40 g/L, respectively, for Cd^{2+} (89.2%) and Pb^{2+} (85.3%). At the high doses of adsorbent, removal of metal may be affected by the partial aggregation among the available active binding sites (Anwar *et al.*, 2010), whereas at low doses, lack of active binding sites may result in lower rate of metal removal (Karthikeyan *et al.*, 2007).

Kaewsarn *et al.* (2008) used dried biosorbent derived from banana peel to study the removal of Cd^{2+} from aqueous solution and reported that particle size of banana peel had no effect on the removal of metal ions, which is analogous to Volesky (2003) who studied the effect of particle size on uranium and cadmium biosorption by *Sargassum* biomass. They used three sizes of biomass (0.5-0.7 mm, 1.0-1.4 mm and native whole seaweed for uranium; 0.5-0.7 mm, 0.84-1.00 mm and 1.0-1.4 mm for cadmium). According to them, no significant difference in sorption rate for the metals among the tested particle

sizes was observed. Cossich *et al.* (2002), based on their finding with biosorption of chromium onto *Sargassum* biomass also reported that the rate of biosorption was independent from the particle size of the biomass. Kaewsarn *et al.* (2008) further stated that the higher biosorption level achieved by smaller particle size of the biosorbents may not be connected to the fact that smaller particle sizes give large surface areas. However, adsorption is considered to be a surface phenomenon; thus sorbents with higher surface area should exhibit a rapid adsorption than that of sorbents with lower surface area. Furthermore, as stated by Daifullah *et al.* (2004), the smaller particles do have higher specific surface area and low mass transfer resistance than the larger biosorbents. In fact, Daifullah *et al.* (2004) observed higher adsorption rate and uptake from the smaller and fine particles of the activated carbon adsorbent prepared from biomass than the larger particles of the same adsorbent. Demirbas *et al.* (2004) also have reported that the equilibrium might be achieved quickly if smaller particles were used. According to Park *et al.* (2010), smaller particles are better suited for a batch type removal setup due to the higher surface area of the biosorbent, however, not for column processes due to its low mechanical strength and clogging of the column. A wide range of particle sizes including 5 x 5 mm, 3 x 3 mm, 2 x 2 mm, 1 x1 mm, fine powder (<150 μm), semi-fine powder (150-300 μm), middle size powder (300-420 μm), semi-coarse size powder (420-600 μm), and coarse powder (600-900 μm) was used to study the effect of particle size of banana peel on the adsorption of Cu^{2+} (Liu *et al.*, 2012). Based on the findings, they claimed that Cu^{2+} removal efficiency of powder particles is much higher than that of in larger sized particles. However, they observed no significant differences among different sized powder particles. As reported by Kaewsarn *et al.* (2008), ground particles irrespectively their sizes, make similar thickness of adsorbents, thus the effect of particle size was hard to observe. Contradicted reports on the effect of particle size might be due to the different experimental conditions under which above investigations have been conducted.

Other factors

Hossain *et al.* (2012) studied the effect of shaking speed (30-200 rpm) on the adsorption of Cu^{2+} by

banana peel. Both at low and high speeds, the rate of Cu^{2+} adsorption decreased and the maximum adsorption (88%) was recorded at near 120 rpm. At low speed, particles could not spread adequately for providing active binding sites for adsorption of metal, while at high speed, vigorously spreading the particles did not allow sufficient time to bind with metal ions (Anwar *et al.*, 2010).

Banana peel has to be dried before being used as adsorbent. The effect of drying temperature on the metal removal efficiency was tested with various drying temperatures (30, 60, 90, 105, 120, and 150°C) (Liu *et al.*, 2012). Based on the results, they reported that banana peel dried at higher temperature is more effective in removing Cu^{2+} than those dried at lower temperatures. As a possible explanation, they claimed that higher temperature could change the interaction area between the ligands on the cell wall and the metal ions through expanding the surface area of the adsorbents. However, taking the energy consumption for drying also into account, they suggested 120°C as the most reasonable temperature for drying banana peels.

Conclusion

Based on the scale of production, banana peel could certainly be recognized as a promising crop-based material available for exploring alternative uses. The proven metal removal capacity of banana peel provides with a favorable platform to researchers to work on and to come out with a sound technology applicable in removal and recovery of metals from water and wastewaters. Such a green technology would not only address the much needed sustainable tool for cleaning contaminated waters, but of course bring an additional value to banana peel enhancing the fruit industry worldwide.

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