Application of Kenaf to Biofiltration of Wastewater and Contaminated Water for Removal of Heavy Metals - 11349

Fengxiang X. Han, Yi Su and David L. Monts
Institute for Clean Energy Technology (ICET), Mississippi State University, Mississippi State, MS 39762
* Corresponding Author, Email: han@ICET.msstate.edu

ABSTRACT

Kenaf (*Hibiscus cannabinus* L.) is a warm-season, annual, fiber crop. Two distinct fibers from kenaf stalks (long, jute-like bast fibers from the bark and short and balsawood-like fiber from the stem core) have been extensively used in various applications for remediation. Bast fibers are used to manufacture products such as burlap, carpet padding, and pulp, while the short-fibered core is processed into animal house bedding, packing materials, and oil-adsorbent mats.

With the increase in demand for energy consumption, the US coal-fueled electric power industry annually produces 72 million tons of fly ash and 55 million tons of other coal combustion products (CCP) with a total production of 131 million tons in 2007. These by-products include mainly fly ash, bottom ash, boiler slag, flue gas desulphurization (FGD) gypsum, and FGD material dry/wet scrubbers. Moreover, the total CCP production increased linearly from 1966 through the early 21st century. In 1966, the total CCP production generated by the US coal-fueled electric power industry was about 25 million tons; it reached about 130 million in 2007. At the same time, a vast amount of processing water from power plants has been discharged into ponds or rivers. This waste water requires a cost-effective remediation technology. The current study was to explore the potential of kenaf materials to remove heavy metals from waste water. Both batch and column experiments were designed to remove heavy metals such as Cr(VI), Pb, U, Cd, Ni, Hg, Sr, Ni, and metalloids As and Se. The column study results indicate that kenaf fibers can effectively remove the majority of Cr (VI) (84%), Pb (96%), U (93%) and almost all Hg (98%) from contaminated water.

Current and previous studies suggest that that kenaf biofiltration could be incorporated into the early stages of wastewater processing to remove heavy metals from wastewater ponds and/or other water bodies. Adsorption mechanisms and methodology(s) to enhance filtration efficiency warrant further systematic studies. We are working toward development of a field-deployable biofiltration system that meets the remediation requirements for CCP-related and other relevant wastewater. In addition to cost saving for power plants, benefits will include creating new revenues for farmers and businesses that grow and process kenaf.

INTRODUCTION

With the increase in demand for energy consumption, the US coal-fueled electric power industry annually produces 72 million tons of fly ash and 55 million tons of other coal combustion products (CCP) with a total production of 131 million tons (Bardhan et al., 2009). These by-products mainly include fly ash, bottom ash, boiler slag, flue gas desulphurization (FGD) gypsum, and FGD material dry/wet scrubbers. Moreover, the total CCP production continued to increase linearly from 1966 through the early 21st century. In 1966, total CCP production generated by the US coal-fueled electric power industry was about 25 million tons, and it reached about 130 million (in 2007) (Stewart and Kalyoncu, 1999). At the same time the beneficial use of these by-products has increased as well. However, beneficial use has increased much slower than has total production. In 2007, the total usage of these by-products was overall around 42% of total production. Concrete product industry, structural fills/embarkments, gypsum panel products, and mining applications were the largest categories of re-usage of these products. This indicates that about 57% of CCP has been disposed or stored (Bardhan et al., 2009).

The earthen dike of the Kingston Fossil Plant (TVA) failed in Dec., 2008, leading to the release of about 5 million cubic yards of fly ash onto the surrounding land and into a river. TVA analysis following the accident proclaimed that the release did not cause serious contamination to the area. However, comparing their findings with the local background levels of most heavy metals and trace elements, As, Se and Tl were found at elevated levels. Vast amounts of contaminated water require a cost-effective treatment.

Kenaf (*Hibiscus cannabinus* L.) is a warm-season, annual, fiber crop. Two distinct fibers from kenaf stalks (long, jute-like bast fibers from the bark and short and balsawood-like fiber from the stem core) have been extensively used in various applications for remediation. Bast fibers are used to manufacture products such as burlap, carpet padding, and pulp, while the short-fibered core is processed into animal house bedding, packing materials, and oil-adsorbent mats. The objectives of the current study were to investigate the potential of kenaf for biofiltration of heavy metals and trace elements from wastewater ponds and/or other water bodies.

MATERIALS AND METHODS

Batch experiment design

A series solutions (20 ml) containing 0.1, 0.5, 1, 5, 10, 20, 50, and 100 ppm of As, Pb, Se, Ba, Sr, Cr, Hg, Ni, and Cd will be added to 1 g dry kenaf fibers and kenaf core materials and shaken for 24 hours. A separate series of solutions containing 0.1, 0.5, 1, 5, 10, 20, 50, and 100 ppm of U will be also added to 1 g of kenaf fibers and kenaf core materials. Supernatant solutions were decanted and were around 10-15 ml and will be analyzed for these elements by Inductively Coupled Plasmas-Atomic Emission Spectroscopy (ICP-AES).

Column experiment design

A solution containing 1 ppm of As, Pb, Se, Ba, Sr, Cr, Hg, Ni, and Cd will be pumped into the three consecutive columns (containing 40-50 g dried kenaf fibers). A separate solution containing 1ppm U will be pumped into the new column. The solution was continued to be cycled for 7 hours. The outlet solution was about 800 ml and will be analyzed by ICP-AES for all these elements.

RESULTS AND DISCUSSION

Batch experiments

Batach experiments showed that adsorption of Cr^{6+}, Pb and U by both fibers and stalk materials of kenaf was characterized by Langmuir model (Fig. 1). The maximum adsorption capacity of fibers for these three elements were 65.4, 57.8 and 416 mg/kg, respetively (Table 1). However, the maximum adsorption capacity by stalk materials of kenaf was greater than fiber materials. The maximum adsorption capacity of stalk were 96.2, 1250, and 333 mg/kg for Cr^{6+}, Pb and U, respectively (Table 1). On the other hand, adsorption of Cd, Ni, Sr and Hg by both fibers and stalk materials of kenaf was characterized by Freundlich model (Fig. 1). During the current concentrations, there were no observations of the maximum absorption for these heavy metals.

Column study

Column experiments indicate that after 7 hours of continuing flowing through kenaf fibers, the removing efficiency for initial 1 mg/L of Cr (VI), Pb and U was 84%, 96% and 93%, respectively and the removing efficiency for the initial 5 mg/L Hg was 98%. The removal efficiency for Ni was only 40%. The fiber materials of kenaf did not efficiently remove Se and As.

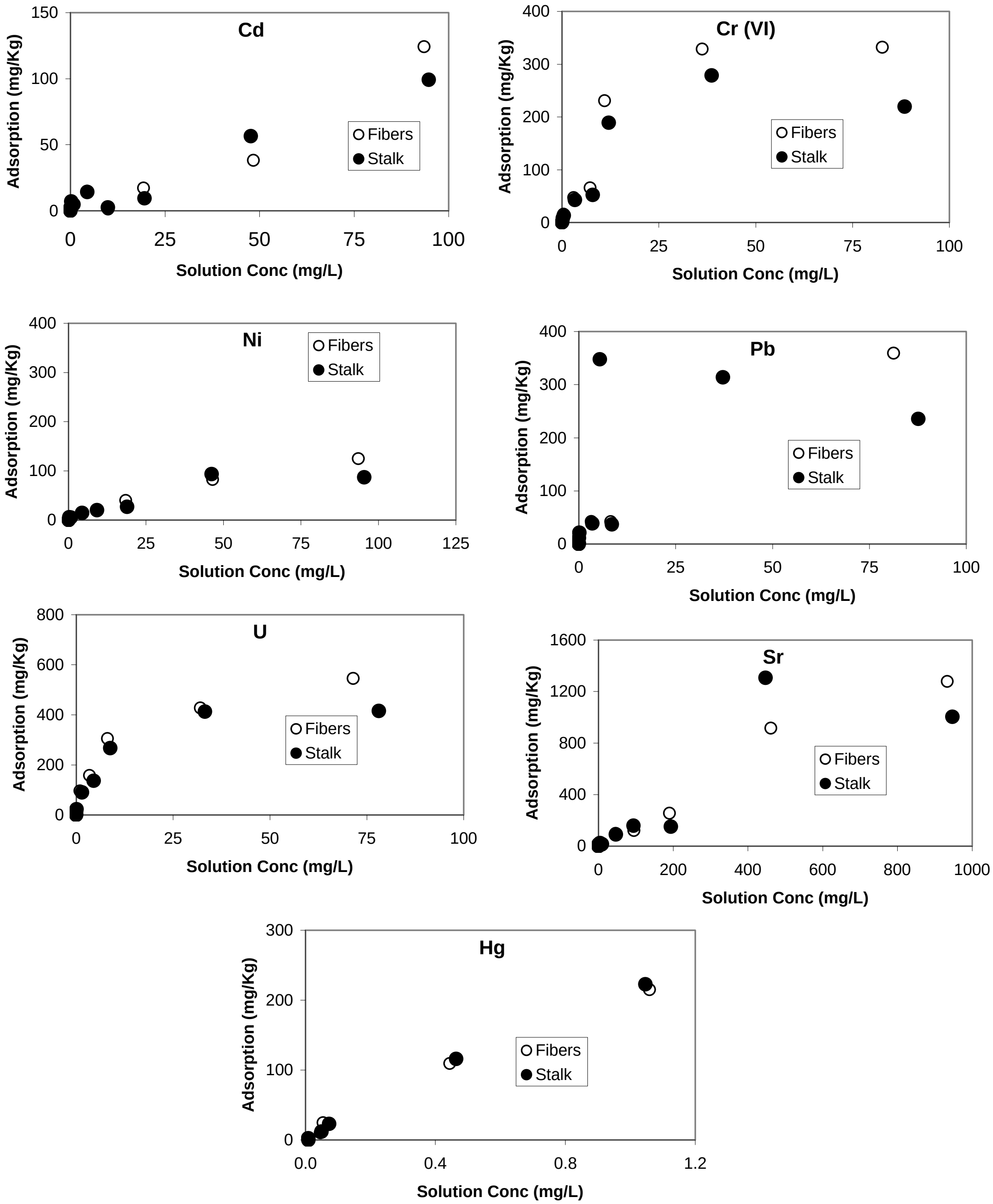

Fig. 1. Isotherm of adsorption of heavy metals by fibers and stark of kenaf in batch experiments.

Table 1. Summary of characteristics of adsorption of heavy metals by kenaf from water

		Langmuir				Freundlich			
		Cr^{6+}	Pb	U		Cd	Ni	Sr	Hg
Fiblers	q_m (mg/kg)	65.36	57.80	416.67	K	10.85	8.38	2.94	210.04
	Ka (L/mg)	1.50	0.54	0.29	n	2.95	1.82	1.14	1.17
	R^2	0.99	0.98	0.94	R^2	0.81	0.95	0.90	0.98
Stalk	q_m (mg/kg)	96.15	1250.00	333.33	K	9.09	4.86	10.50	269.96
	Ka (L/mg)	0.24	0.08	1.15	n	2.74	1.45	1.60	0.99
	R^2	0.96	0.98	0.99	R^2	0.79	0.90	0.84	0.99

Table 2. Adsorption of trace elements by kenaf fiber and stalk materials from water (Column experiment)

Element	Initial Solution Conc. mg/L	Initial Total Volume ml	Final solution Conc mg/L	Adsorption mg/kg
As	1.0	1000	0.87	3.65
Ba	1.0	1000	0.89	3.13
Se	1.0	1000	1.00	0.00
Cd	1.0	1000	0.62	11.12
Cr (VI)	1.0	1000	0.16	24.37
Ni	1.0	1000	0.60	11.45
Pb	1.0	1000	0.04	27.76
U	1.0	1000	0.07	26.74
Sr	10.0	1000	7.12	83.27
Hg	5.0	1000	0.10	141.65

Conclusions

The current preliminary laboratory tests suggest that kenaf fibers and stalk materials could be used for biofiltration of the wastewater such as CCP-related and other wastewater to remove heavy. Adsorption mechanisms and methodology(s) to enhance filtration efficiency warrant further systematic studies. In addition to cost saving for power plants, benefits will include creating new revenues for farmers and businesses that grow and process kenaf.

REFERENCES

S. Bardhan, Y. Chen, and W.R. Dick, "Recycling for sustainability: Plant growth media from coal combustion products, biosolids and compost". International Jounral of Civil and Environmentakl Engineering 1: 177-183 (2009)

B.R. Stewart and R.S. Kalyoncu, "Materials flow in the production and use of coal combustion products". 1999 International Ash Utilization Symposium, Center for Applied Engery Research, Universiyt of Kentucky (1999).