International Journal of Science, Environment and Technology, Vol. 2, No 5, 2013, 805 – 812

ISSN 2278-3687 (O)

KENAF FIBRES (*Hibiscus Cannabinus*) AS A POTENTIAL LOW-COST ADSORBENT FOR WASTEWATER TREATMENT

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Abstract: Kenaf (*Hibuscus cannabinus*) is a widely cultivated crop, particularly in the tropics. Kenaf fibre is a natural cellulosic fibre derived from the plant and is an important raw material for a variety of products. The potential of this low-cost agricultural material as adsorbent for application in wastewater treatment was investigated. A series of batch adsorption tests were undertaken involving three types of adsorbates, namely malachite green (dye), Pb(II) and Cr(III) (cationic heavy metals) and Cr(VI) (anionic heavy metal). The effect of contact time (kinetics) and initial concentration (equilibrium) were investigated. In the case of Cr(VI), the effect of surfactant modification of the fibre was also investigated. Results indicated that kenaf fibre is an effective adsorbent for malachite green, Pb(II) and Cr(III). Percent removal above 90 % was achieved for initial concentrations up to 50 mg/L. The rate of adsorption was rapid with above 90 % removal within 5 minutes contact time. Comparatively, Cr(VI) adsorption was very low (< 25 %). However, surface modification of the fibre using a cationic surfactant (i.e HDTMA-Br), was able to enhance significantly it's ability to adsorb Cr(VI). Percent removal of Cr(VI) above 90 % was attained for initial concentrations up to 50 mg/L. Overall, while the natural fibre is an effective adsorbent for cationic pollutants, it can be equally effective for anionic pollutant following surface modification.

Keywords: Kenaf fibre; adsorbent; adsorption; kinetics; equilibrium.

INTRODUCTION

Increasing levels of inorganic and organic pollutants (e.g heavy metals and dyes) in the environment pose a serious threat to the environment and public health. To alleviate this problem, industrial effluents and contaminated water resources are treated prior to discharge or usage. A number of treatment methods have been reported, including physico-chemical and biological processes [1].

Adsorption is a widely used physico-chemical process and have been proven to be effective in removing pollutants from aqueous solutions and effluents. Among the drawbacks, however, the conventional adsorbents used are relatively expensive (e.g activated carbon), while some are only effective for a specific category of pollutants (e.g zeolite). Consequently,

*Received August 14, 2013 * Published October 2, 2013 * www.ijset.net*

there is a growing interest on the development of low-cost adsorbents which include biological materials (natural & agricultural) and industrial by-product wastes [2, 3, 4]. A number of agricultural fibres have been investigated, including oil palm fibre [5, 6, 7], coconut fibre [8] and jute fibre [9].

The present study aims to evaluate the potential of kenaf fibres as adsorbent for inorganic and organic pollutants. Kenaf (*Hibiscus cannabinus*) is widely cultivated in many tropical countries, including Malaysia, for its fibre. It is a fast growing annual plant with slender straight stems. The fibres in kenaf are found in the bast (bark) and core (wood). The bast constitutes 40% of the plant. Kenaf fibres are used in a number of products or applications. Unlike many other agricultural fibres, little is known on the potential of kenaf fibre as adsorbent [10, 11].

MATERIALS AND METHODS

Materials

The adsorbents investigated were natural kenaf fibre (KF) and surfactant-modified kenaf fibre (SMKF). KF was obtained from a local kenaf plantation. The material was cut into smaller pieces (< 1 cm), washed and dried. A portion of the fibre was treated with 0.1 M hexadecyltrimethylammonium bromide (HDTMA-Br), a cationic surfactant, to produce SMKF [8, 12].

The adsorbates investigated were Pb(II) and Cr(III), representing cationic heavy metal, Cr(VI), representing anionic heavy metal, and malachite green (MG), representing cationic dye. KF was tested using MG, Pb(II), Cr(III), and Cr(VI) while SMKF was tested using Cr(III) and Cr(VI).

Kinetic studies

0.2 or 0.5 g adsorbent was placed in each of six Erlenmeyer flasks containing 20 mL of 10 mg/L of metal or dye solution. The flask represents 5, 10, 20, 30, 40, 50, 60 and 90 min contact time, respectively. The flasks were shaken on an orbital shaker and when the respective contact time was attained, the mixture was filtered and the residual metal or dye concentration determined. All the above experiments were carried out in duplicate.

Equilibrium studies

0.2 g KF was placed in each of six Erlenmeyer flasks containing 20 mL of 20, 40, 60, 80 and 100 mg/L Pb(II) or MG . The flasks were shaken for 30 min, filtered and the residual metal or dye concentration determined. In the case of Cr(III) and Cr(VI), the initial concentrations ranged 2 – 10 mg/L and 10 – 50 mg/L depending whether KF or SMKF (0.5 g) was used as the adsorbent.

Determination of metal and dye concentrations

The residual Pb(II), Cr(III) and Cr(VI) concentrations were determined using atomic absorption spectrophotometer, while residual MG concentration was determined using UV-Vis spectrophotometer based on absorbance at λ_{max} = 617 nm.

RESULTS AND DISCUSSION

Adsorption kinetics

The removal (adsorption) of MG, Pb(II), Cr(III) and Cr(VI) was rapid in the first 5 min and attained equilibrium after 30 min (Fig. 1). The majority of metal and dye removal occurred within 5 min and further increase in contact time resulted in only a small increase in percent removal. This trend is in reasonable agreement with those reported in other heavy metal and dye adsorption studies. The higher rate in the beginning can be due to large available surface area / adsorption sites of the adsorbents while the subsequent slower rate can be due to intraparticle diffusion.

Further analysis of the kinetic data using using pseudo-1st order, pseudo-2nd order and intraparticle diffusion kinetic models, showed that the adsorption of MG, Pb(II) and Cr(III) by KF , and Cr(VI) by SMKF can well represented by pseudo-2nd order kinetics (R^2 ~ 1.000), suggesting that the adsorption is due to chemisorption.

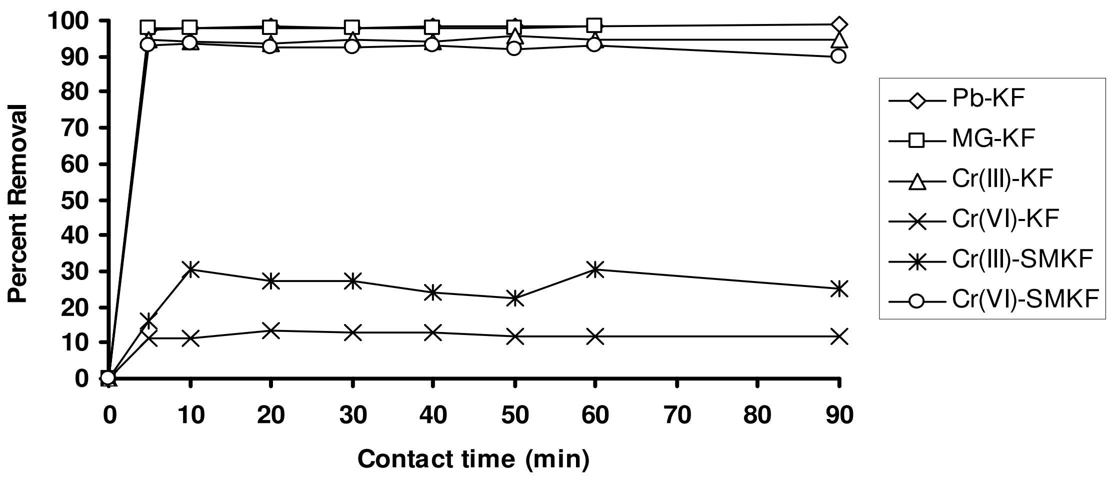

Fig. 1. Effect of contact time on the removal of Pb(II), Cr(III), Cr(VI) and MG by KF and SMKF

Adsorption equilibrium

KF showed high affinity for both Pb(II) and MG. Percent removal exceeded 90 % for the initial concentrations range 20 – 100 mg/L (Fig. 2). The fibre also showed high removal efficiency for Cr(III) for initial concentrations range 10 - 50 mg/L but ineffective (i.e < 25 %) for Cr(VI) even at initial concentrations 2–10 mg/L (Fig. 3). Comparatively, SMKF has high affinity for Cr(VI) with percent removal exceeding 90 % for the initial concentrations range 10–50 mg/L. It's ability to adsorb Cr(III), however, is low with percent removal < 25 % for the initial concentration range 2–10 mg/L (Fig. 4). The efficiency of both adsorbents showed a decreasing trend with increase in initial concentration of adsorbate.

The adsorption isotherms for MG, Pb(II), Cr(III) and Cr(VI) adsorptions are shown in Fig. 5 and Fig. 6. The equilibrium data can be well represented by both Freundlich and Langmuir isotherms ($R^2 > 0.90$). Based on the Langmuir model, the calculated maximum adsorption capacity, Q_{max}, of KF for MG, Pb(II), Cr(III) and Cr(VI) is 14.3, 10.0, 2.0 and 0.06 mg/g, respectively. Comparatively, the Q_{max} of SMKF for Cr(III) and Cr(VI) is 0.05 and 10.0 mg/g, respectively. The adsorption capacities of KS for Pb(II), MG and Cr(III) are within the range reported in the literatures for other adsorbates.

It is apparent that the efficiency of KF as an adsorbent is dependent on the type of adsorbate. Being a lignocellulosic material [13], the surfaces of the fibre are expected to be largely negative charged. Consequently, the fibre can interact with positive charged adsorbates such as Pb(II) and MG. The affinity of the fibre, however, is lower for Cr(III) although this adsorbate is also cationic in solution. In contrast to Cr(III), Cr(VI) is anionic in solution. Due to repulsive forces, there is minimum interaction between the fibre and Cr(VI). Treatment of the fibre with a cationic surfactant, namely HDTMA, enhanced it's capacity to adsorb Cr(VI) approximately 160X. Interaction of the cationic surfactant with the fibre is expected to produce positive charged sites on the surfaces of the fibre [12], thus enabling SMKF to adsorb anions effectively. The surface modification, however, resulted in the fibre losing its ability to adsorb cations such as Cr(III). The enhanced ability of the fibre in the removal of Cr(VI) from solution upon surface modification using HDTMA is comparable to those exhibited by other cationic surfactant treated adsorbents [8, 12, 14, 15].

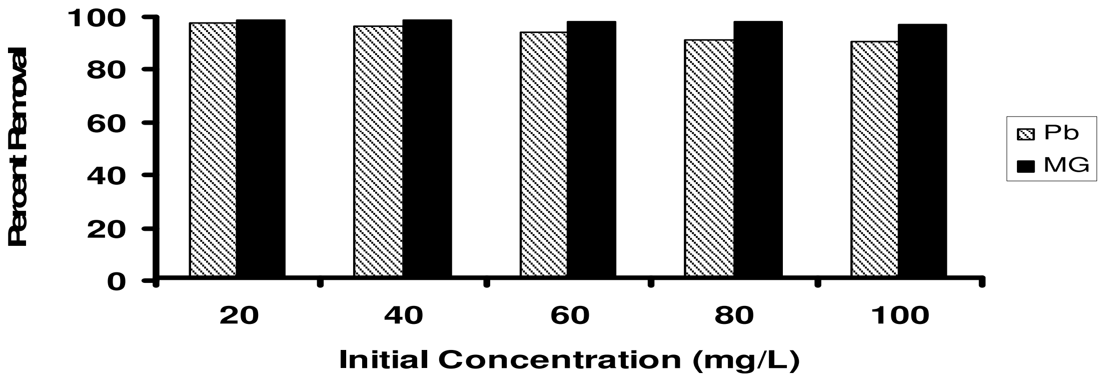

Fig 2: Effect of initial concentrations on the efficiency of Pb and MG removal from aqueous solutions. (Conditions: adsorbent dose = 0.2 g; contact time = 30 min)

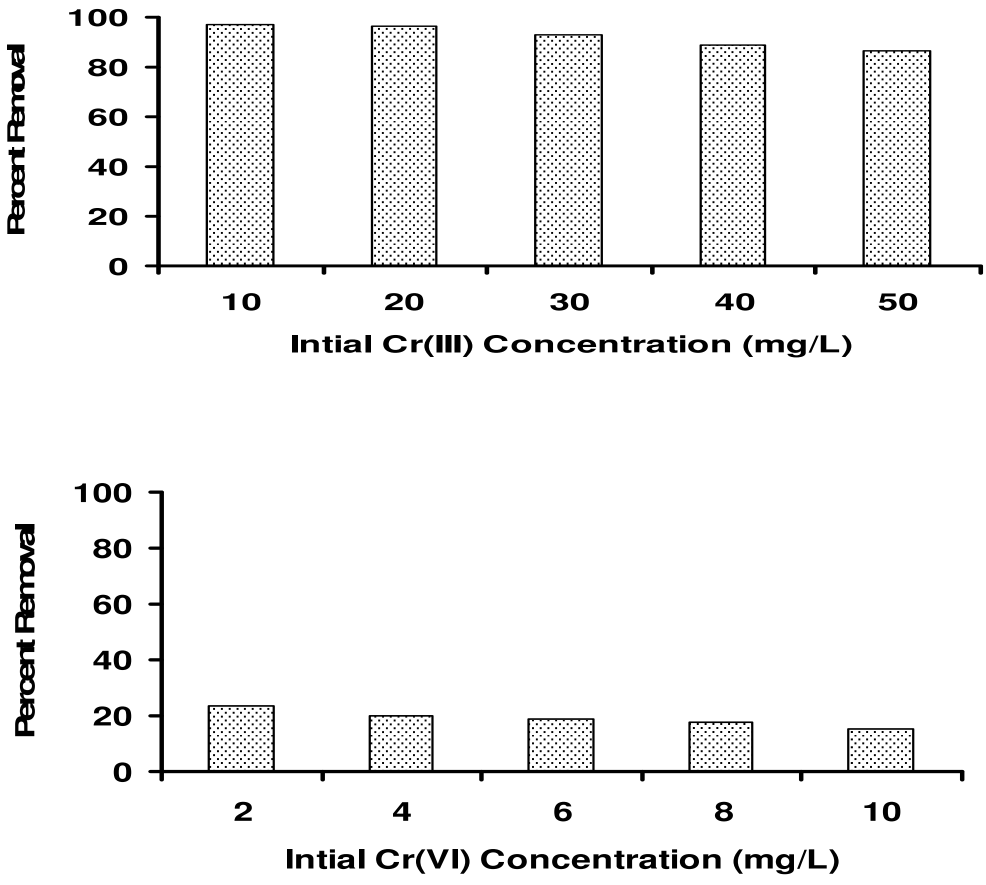

Fig. 3: Removal efficiency of Cr(III) and Cr(VI) by kenaf fibre (KF) at different initial concentration in solution. (Condition: adsorbent dose = 0.5 g; contact time = 30 min)

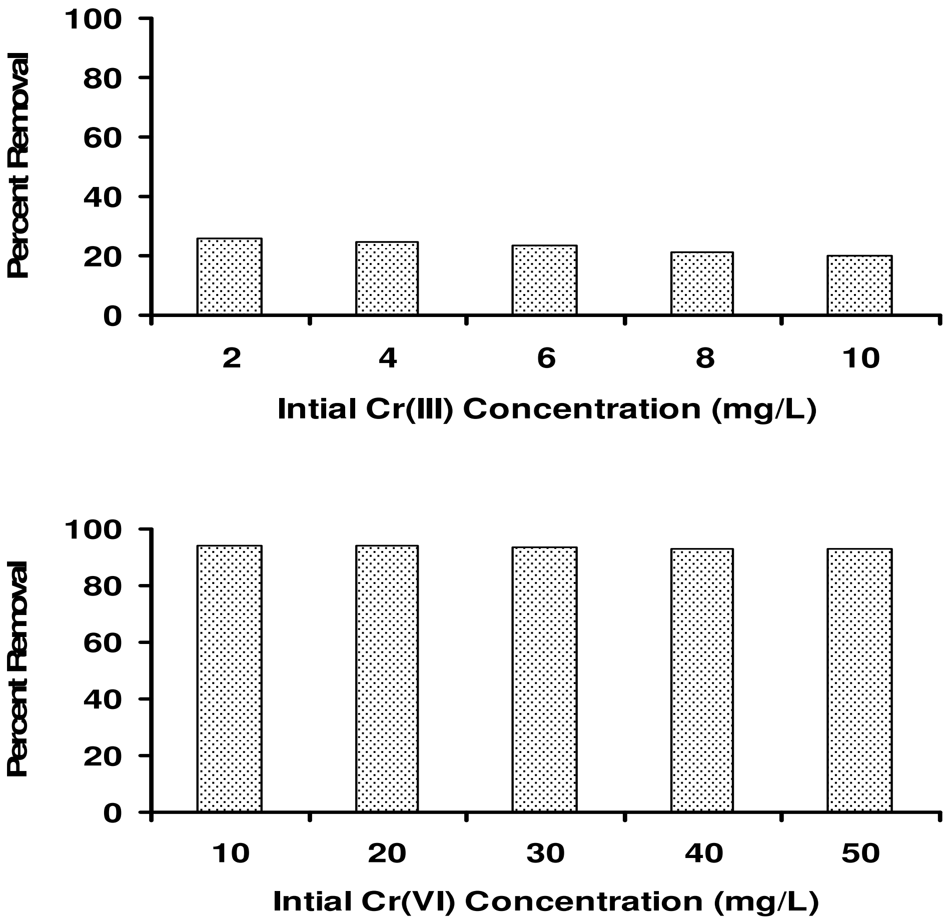

Fig. 4: Removal efficiency of Cr(III) and Cr(VI) by surfactant-modified kenaf fibre (SMKF) at different initial concentration in solution. (Condition: adsorbent dose = 0.5 g; contact time = 30 min)

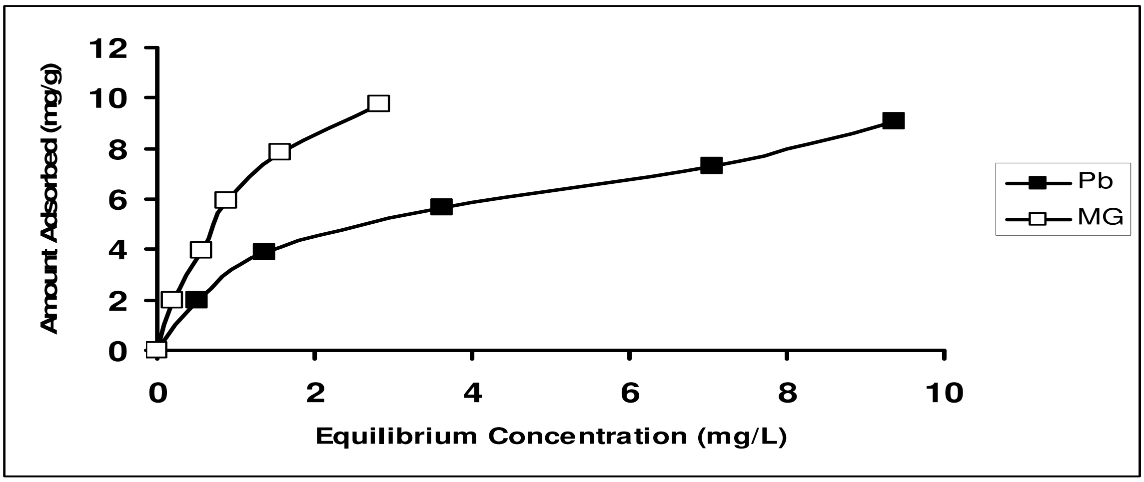

Fig. 5: Adsorption isotherms of Pb(II) and MG on KF

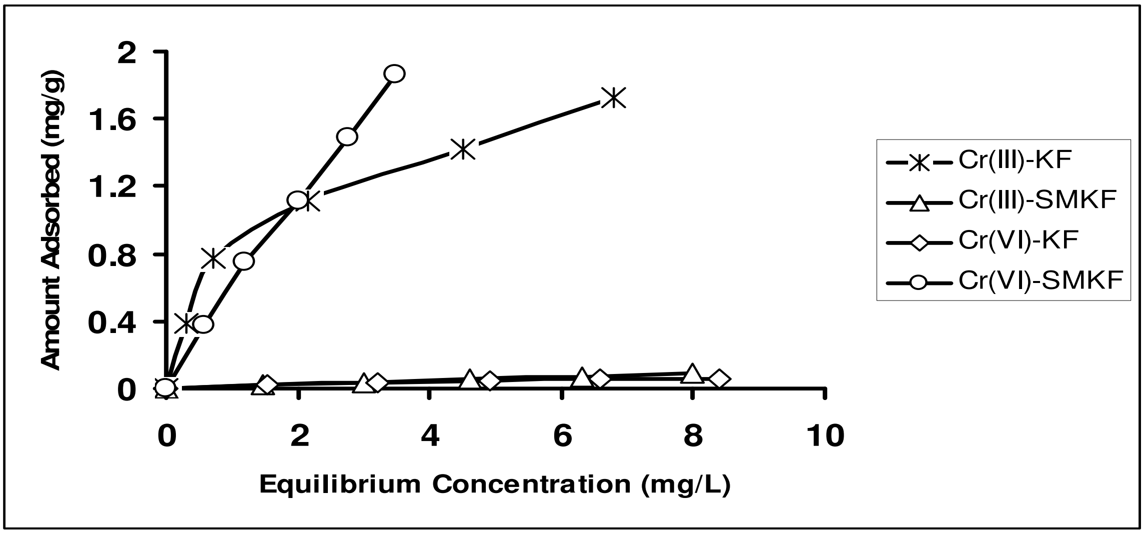

Fig. 6: Adsorption isotherms of Cr(III) and Cr(VI) on KFand SMKF

CONCLUSION

The present study shows that kenaf fibre can potentially be employed as low-cost alternative to commercial adsorbents in water and wastewater treatment for the removal of cationic pollutants, including heavy metals and cationic dyes. This natural fibre is also an effective adsorbent for anions, including Cr(VI), following surface modification using a cationic surfactant.

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