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ORIGINAL ARTICLE

Valorization of two waste streams into activated carbon and studying its adsorption kinetics, equilibrium isotherms and thermodynamics for methylene blue removal

Zeid Abdullah AlOthman [a], Mohamed Abdelaty Habila [a,*], Rahmat Ali [a], Ayman Abdel Ghafar [a], Mohamed Salah El-din Hassouna [b]

[a] Department of Chemistry, College of Science, King Saud University, P.O. Box 2455, Riyadh 11451, Saudi Arabia
[b] Department of Environmental Studies, Institute of Graduate Studies and Research, Alexandria University, 163 El-Horreya Avenue, P.O. Box 832, Alexandria, Egypt

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Abstract Wastes must be managed properly to avoid negative impacts that may result. Open burning of waste causes air pollution which is particularly hazardous. Flies, mosquitoes and rats are major problems in poorly managed surroundings. Uncollected wastes often cause unsanitary conditions and hinder the efforts to keep streets and open spaces in a clean and attractive condition. During final disposal methane is generated, it is much more effective than carbon dioxide as a greenhouse gas, leading to climate change. Therefore, this study describes the possible valorization of two waste streams into activated carbon (AC) with added value due to copyrolysis. High efficiency activated carbon was prepared by the copyrolysis of palm stem waste and lubricating oil waste. The effects of the lubricating oil waste to palm stem ratio and the carbonization temperature on the yield and adsorption capacity of the activated carbon were investigated. The results indicated that the carbon yield depended strongly on both the carbonization temperature and the lubricating oil to palm stem ratio. The efficiency of the adsorption of methylene blue (MB) onto the prepared carbons increased when the lubricating oil to palm stem ratio increased due to synergistic effect. The effects of pH, contact time, and the initial adsorbate concentration on the adsorption of methylene blue were investigated. The maximum adsorption capacity (128.89 mg/g) of MB occurred at pH 8.0.

* Corresponding author. Address: Department of Chemistry, College of Science, Building # 5, P.O. Box 2455, King Saud University, Riyadh 11451, Saudi Arabia. Tel.: +966 595184785.
E-mail address: mhabila@ksu.edu.sa (M.A. Habila).

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The MB adsorption kinetics were analyzed using pseudo-first order, pseudo-second order and intraparticle diffusion kinetic models. The results indicated that the adsorption of MB onto activated carbon is best described using a second order kinetic model. Adsorption data are well fitted with Langmuir and Freundlich isotherms. The thermodynamic parameters; $\Delta G°$, $\Delta H°$ and $\Delta S°$ indicate that the adsorption is spontaneous and endothermic.

1. Introduction

Agricultural wastes are produced from farming activities, including planting and marketing; therefore various residues, by-products and remains are generated. Plant stems and corncobs are the most abundant components of solid agricultural waste (Tchobanoglous and Kreith, 2002). Each year, date palm trees must be pruned to remove old, dead or broken leaves. In the Kingdom of Saudi Arabia, this practice produces each year approximately 100,000 tons of date palm waste (Al-Jurf, 1988). Also used lubricating oil is produced in very large amount in Kingdom of Saudi Arabia due to large number of cars and long distance travel. These large amounts of waste can be converted into activated carbon, which is perhaps the most widely used adsorbent material for removing organic and inorganic pollutants from water and wastewater. The process for producing high-efficiency activated carbon is not completely investigated in developing countries. Furthermore, there are many problems with the regeneration of used activated carbon. Nowadays, there is a great interest in finding inexpensive and effective alternatives to the existing commercial activated carbon (Soylak and Dogan, 1996; Soylak et al., 1999; Lili et al., 2009; Ghaedi et al., 2011, 2012). Exploring effective and low-cost activated carbon may contribute to environmental sustainability and offer benefits for future commercial applications. The costs of activated carbon prepared from biomaterials are very low compared to the cost of commercial activated carbon. Waste materials that have been successfully used to manufacture activated carbon in the recent past include waste apricots (Onal et al., 2007), rubber seed coat (Rengaraj et al., 2002), plum kernels (Tseng, 2007), apricot shell (Karagozoglu et al., 2007), rice straw (Daifullah et al., 2007; Wang et al., 2007), bamboo (Hameed et al., 2007), sunflower seed hull (Thinakaran et al., 2008), agricultural waste (Singh et al., 2008), mixed solid waste (AlOthman et al., 2011b) and rubber wood sawdust (Kumar et al., 2006).

The preparation of activated carbon in laboratory-scale can be categorized into two groups: synchronous carbonization and activation (i.e., a one-stage process), and an asynchronous process in which a separate carbonization process is performed before the activation process (i.e., a two-stage process) (Minkova et al., 1991). If the raw material is heat-treated by one of the above-mentioned processes, the resultant activated carbons should have different burn-off ratios and, thus, different pore characteristics and adsorption capacities because of their distinctly different thermal histories. This process produces activated carbon with a high adsorption capacity (Sabio et al., 1996). Pyrolysis is a good method for waste treatment and at the same time produces high efficiency activated carbon. Many authors have studied the pyrolysis of biomass and plastic waste and have demonstrated that it is a suitable waste processing (Scott and Czernic, 1990; Conesa et al., 1997; Kaminsky et al., 1997; Williams and Williams, 1997; Lee and Shin, 2007). In the recent years, a novel approach to the wastes' recovery via their co-processing has been proposed. The existence of synergistic effects between the blend components during their conversion into solid products is still an open issue. Some authors have observed the absence of synergistic effects (Pinto et al., 2003), whereas evidence of their presence has been reported for co-gasification (Chmielniak and Sciazko, 2003) and co-pyrolysis (Collot et al., 1999).

Methylene blue is a dark-green powder or a crystalline solid cationic dye (Han et al., 2006). This dye is usually selected as a model compound for evaluating the adsorption efficiency of activated carbon (El Qada et al., 2006). In addition, MB is useful as an indicator for evaluating the adsorption capacity of activated carbon in liquid-phase adsorption (Tor and Cengeloglu, 2006). Also MB is usually discharged in high levels in industrial wastewater, specially textiles, paper and cosmetics industries. The complex structure of MB dye makes it very stable and difficult to degrade leading to many environmental problems such as preventing sunlight penetration into water, reducing photosynthetic activity and causing bad appearance of water surfaces (Dursun et al., 2007; Chih et al., 2009). Thus, the goals of this study were to enhance the efficiency of waste activated carbon in MB removal. The copyrolysis of palm stems and lubricating oil waste as well as chemical activation with K_2SO_4 was used to enhance the efficiency of waste activated carbon. The effect of the carbonization temperature and mixing ratio (lubricating oil to palm waste) on the properties of the activated carbon was investigated. The adsorptive properties of the prepared activated carbon were also evaluated using a model compound, MB. The effects of pH, contact time, and the initial adsorbate concentration on the adsorption of methylene blue were investigated. The MB adsorption kinetics were analyzed using pseudo-first order, pseudo-second order and intraparticle diffusion kinetic models.

2. Materials and methods

2.1. Materials

The precursors used in this study included the stems of palm trees collected from the agricultural solid waste in Riyadh, Saudi Arabia. Lubricating oil waste was collected from a petrol station in Riyadh. The palm waste was washed with distilled water to remove sand and dirt and then soaked in a 10% acid solution to remove fiber and traces of inorganic residue. The wastes were then dried in an oven at 110 °C for 24 h and crushed and ground into 0.5–2.0 mm particle size. The proximate and ultimate analyses of the palm wastes and lubricating oil were determined according to ASTM standard techniques, and the results are provided in Table 1.