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ORIGINAL ARTICLE

Coconut coir dust as a low cost adsorbent for the removal of cationic dye from aqueous solution

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Abstract Adsorption of methylene blue from aqueous solution onto coconut coir dust (CCD) a low cost agricultural waste material in a batch process was investigated. Adsorption was studied as a function of amount of adsorbent, pH and concentration with time. It was found that percentage adsorption varied linearly with the amount of adsorbent and concentration with time but varies non-linearly with pH. Adsorption equilibrium data were represented by isotherm, kinetics and thermodynamics models. Three isotherm models namely Langmuir, Freundlich and Temkin were tested and adsorption was found to fit well into these models with $R^2 \geqslant 0.90$. The kinetic data were well described by the pseudo-second order kinetic model. The adsorption process was endothermic with a mean change in enthalpy (ΔH) ($+17.87\ \text{KJ mol}^{-1}$) and spontaneous with a mean free energy change (ΔG) ($-9.69\ \text{KJ mol}^{-1}$). FTIR analyses of the adsorbent suggest that adsorption of the dye was through a chemical interaction of the functional groups on the surface of the adsorbent.

1. Introduction

Removal of dye from effluents of chemical industries such as plastics, dyestuffs, textile, pulp and paper has remained a problem of increasing concern to the environmentalists. It is estimated that 2% of dyes produced annually are discharged as effluents from manufacturing operations whilst 10% are discharged from textile and associated industries (Easton, 1995). Most of these dyes are of synthetic origin and toxic in nature with suspected carcinogenic and genotoxic effects (Chatterjee et al., 2005; Daneshvar et al., 2007). The presence of these dyes even at a very low concentration is highly observable and undesirable. Therefore dye removal has been a very important but challenging area of wastewater treatment (Hu et al., 2006). The effluents containing dyes are highly coloured and cause serious water pollution. Many health related problems such as allergy, dermatitis, skin irritation, cancer, and mutations in humans are associated with dye pollution in water (Bhattacharyya and Sharma, 2004). Today there are more than 100,000 dyes with different chemical structures available commercially (Robinson et al., 2001). Dyes are broadly classified as anionic, cationic and non-ionic depending on the ionic charge on the dye molecules. Cationic dyes are more toxic than anionic dyes (Hao et al., 2000). From the environmental stand point, it is challenging to treat dye effluents because of their synthetic origins and their mainly aromatic structures, which are biologically non-degradable and may be toxic to health. In order to remove dye from industrial effluents, several processes have

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been adopted by researchers worldwide. Among several chemical and physical methods available, the adsorption process is one of the effective techniques that have been successfully employed for colour removal from wastewater.

Several adsorbents have shown good promise for dye removal from wastewater. Activated carbon is an effective but expensive adsorbent due to its high costs of manufacturing. Similarly polymers have proven to be efficient in dye adsorption due to their high regeneration capacity but lack economy in terms of cost. In view of these many natural adsorbents have been tested to reduce dye concentrations from aqueous solutions (Deniz and Saygideger, 2011; Yagub et al., 2011). Among the natural materials used as adsorbents for synthetic dyes, biomass and agricultural wastes are considered to be low-cost products. They have proved very efficient for dye removal from waste water due to high ligno-cellulose material which is part of their constituent (Annadurai et al., 2002; Chen et al., 2011; Sen et al., 2011; Wang and Yan, 2011). These wastes are renewable, available in large amounts and less expensive as compared to other materials used as adsorbents. They are better than other adsorbents because the agricultural wastes are usually used without or with a minimum of processing (washing, drying, grinding) and thus reduce production costs by using a cheap raw material and eliminating energy costs associated with thermal treatment (Franca et al., 2009). Different low cost sorbents have been explored by various researchers for dye removal from wastewater. These include Palm kernel fibre (El-Sayed, 2011), rice husk (Gupta et al., 2006; Lakshmi et al., 2009), sawdust (Batzias and Sidiras, 2007; Khattri and Singh, 2009), tea waste (Uddin et al., 2009), peanut shell (Tanyildizi, 2011), orange peels (Khaled et al., 2009; Arami et al., 2008), wheat shell (Bulut and Aydin, 2006), pineapple stem (Hameed et al., 2009), and coconut based sorbent; babassu coconut mesocarp (Vieira et al., 2009), coconut husk (Jain and Shrivastava, 2008; Low and Lee, 1990; Gupta et al., 2010), coconut shell fibre (de Sousa et al., 2010; Babel and Kurniawan, 2004), coconut copra meal (Ho and Ofomaja, 2006), coconut coir pith (Namasivayam et al., 2001), coconut bunch waste (Hameed et al., 2008) to mention a few.

In the extraction of coir fibre from the coconut husk and in the production of finished materials from the extracted fibre, a large amount of coir dust is produced. Coconut coir dust is described as that brown, spongy particle of low weight which falls out when the fibre is shredded from the husk. The coir dust is about 70% of the weight of the coconut husk (Tejano, 1985). Coir dust is rich in lignins and tannins. It is reported to be composed of cellulose, pentosan, furfural, and lignin (Gonzales, 1970; Joachim, 1930). Whilst a great deal has already been learned about the solid parts of the coconut, coir dust has, up to now, the least use and is still considered waste and nuisance for which no important industrial uses have been developed, and they are normally incinerated or dumped without control (Meerow, 1997; Vidhana Arachchi and Somasiri, 1997). It is known to have no commercial importance except, may be, in applications where sawdust is used in a very limited amount. However, in an effort to find an immediate solution to the perennial problem of coir dust disposal, several product development activities were undertaken that may bring about large scale utilization of this waste material. For sometime, coir dust was used in the tropics as a locally available material for preparing soilless growing media for containerized crop production (Reynolds, 1973; Chweya et al., 1978). Only during the past few years has this material become commercially popular and it is now being successfully used in different parts of the world as an environmentally sound peat substitute for container-grown ornamental plants (Offord et al., 1998; Noguera et al., 1998).

Researchers who have utilized coconut-based adsorbents for water treatment used them in modified forms as reported in a review work by Bhatnagar et al. (2010). The present study is undertaken to investigate the efficiency of raw coconut coir dust (without physical/chemical modification or activation) as a low cost adsorbent for the removal of methylene blue from aqueous solution. The effect of contact time, concentration of the dye, amount of adsorbent, pH and temperature on MB adsorption was studied. Adsorption isotherm and kinetics parameters were also evaluated, presented and discussed.

2. Experimental methods

2.1. Materials

The adsorbent, coconut (*Cocos nucifera* L.) coir dust was obtained from a local coconut processing mill in Ukanafun Local area of Akwa Ibom State. Methylene blue (MB) was purchased from Smerck fine chemicals, Onitsha, Nigeria. MB has molecular formula $C_{16}H_{18}N_3ClS$ (Mol. wt. 319.85 g/mol). It was used without further purification. Other reagents include concentrated H_2SO_4 and dilute NaOH solutions. All reagents were of analytical grade. De-ionized water was used throughout the experiment. Instruments employed for the work include UV–visible spectrophotometer (Unicam Heλ105 model), FTIR spectrophotometer (model 8400S), electric (platform shaker 20-880), mottle P165 weighing balance, pH-meter-16, and 10 ml clinical syringe and sieves of about 50–100μm size.

2.2. Preparation of adsorbent

Coconut coir dust was soaked in de-ionized water for 3 days and washed several times with water until all the coloured extract was removed and clean water obtained. It was oven dried at 60 °C for 24 h. It was sieved using a 50–100 μm sieve to obtain particles in this range. This was stored in a plastic container prior to use for adsorption studies. No chemical or physical treatments were performed prior to adsorption experiments.

2.3. Preparation of adsorbate

The dye stock solution was prepared by dissolving 1.0 g of dye in deionized water in a 1 litre volumetric flask and made to a concentration of 1 g L^{-1}. The working solutions were obtained by diluting the dye stock solution in accurate proportions to needed initial concentrations (5–60 mg L^{-1}) and were used to obtain a calibration curve (Fig. 1).

2.4. Adsorption experiments

2.4.1. Time optimization

For the optimization of shaking time, 50 mL of aqueous solutions 50 mg L^{-1} of methylene blue was taken in a 250 ml conical flask and a fixed amount of adsorbent (0.1 g) was added. The absorbance of the residual dye solution was recorded at λ_{max} (650 nm) at different time intervals. It was observed that