Use of Incinerated Rice Husk for Adsorption of Reactive Dye from Aqueous Solution

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Abstract

Rice husk was incinerated in a muffle furnace at 300ºC for 4 h and the incinerated rice husk was characterised in terms of surface area, micropore area, micropore volume, average pore diameter and surface morphology. Adsorption of a textile dye, Reactive Yellow 15, by the incinerated rice husk was examined. Batch adsorption tests showed that the extent of dye adsorption depended on initial concentration, contact time and pH. Equilibrium adsorption was achieved in 240 min, while maximum dye adsorption occurred at pH 2. Equilibrium adsorption data were fitted to the Langmuir and Freundlich isotherms and the data fitted well to the Freundlich isotherm model. Adsorption of Reactive Yellow 15 by incinerated rice husk followed pseudo-second-order kinetics. Being a low-cost adsorbent, incinerated rice husk can be applied for the adsorption of reactive dyes from aqueous solution and wastewater in developing countries.

Keywords: Adsorption, rice husk, Reactive Yellow 15, Freundlich Isotherm, Langmuir Isotherm

1. Introduction

dyes generally have complex aromatic molecular structure with synthetic origin, which make them more stable and difficult to biodegrade. Commercially, there are more than 10,000 dyes available (Gong et al., 2007). Many industries such as food, paper, carpet, rubber, plastics, cosmetics and textiles use dyes for various purposes (Robinson et al., 2002). Reactive dyes are generally used for cotton and other cellulosic fibers but are also used to a small extent on wool and nylon. These dyes form a covalent bond with the fiber and contain chromophoric groups such as azo, anthraquinone, triarylmethane, phtalocyanine, formazan, and oxazine. Their chemical structures are simpler, have narrower absorption bands, and dyeings are brighter making them advantageous over direct dyes (Gupta & Suhas, 2009). About 45% of all textile dyes produced annually belong to the reactive type. Reactive dyes have been listed as compounds of concern in textile effluents because they are water-soluble, found in the wastewater at higher concentrations than other dyes and cannot be easily treated by conventional treatment methods. The main techniques practiced for the treatment of dye-containing effluents are adsorption, oxidation–ozonation, biological treatment, coagulation/flocculation, and membrane processing. The problems associated with these techniques are incomplete removal of reactive dyes and high initial and operational costs, thus they constitute an inhibition to dyeing and finishing industries (Tunc et al., 2009).

Adsorption process is one of the most effective methods used for the removal of various pollutants and textile dyes from wastewater. Activated carbon is the most widely used adsorbent for the removal of colour and treatment of textile effluents but the high price of activated carbon limits its use on a larger scale (Malik, 2003; Lakshmi et al., 1994; Aksu & Kabasakal, 2004). Hence, there is a need to develop low-cost adsorbents that are effective for adsorptive removal of dyes. Rice husk is an agricultural waste. It consists of cellulose (32.23%), hemicelluloses (21.34%), lignin (21.44%) and mineral ash (15.05%) (Rahman et al., 1997) with high percentage of silica (96.34%) in the mineral ash (Rahman & Ismail, 1993). rice husk-based adsorbents are therefore expected to be effective in adsorbing textile dyes from water. However, the rice husk needs to be modified or treated before being applied for adsorption of dyes (Chakraborty et al., 2011). Chemical or thermal treatment reduces cellulose, hemicelluloses and lignin crystalinity, leading to an increase of specific area for adsorption (Daffala et al., 2010).

In this study, adsorption capacity of incinerated rice husk for Reactive Yellow 15 (RY 15) was studied. The aim of the study was to develop a low-cost adsorbent for inexpensive dye removal.

2. Materials and Method

2.1 Incinerated Rice Husk

Rice husk was washed several times with distilled water in order to remove dust and dried in an oven at 105°C for 24 h. The washed and dried rice husk was then incinerated in a muffle furnace at 300°C for 4 h. The resulting incinerated rice husk was ground to a finer size of 212- 500 µm and used in various adsorption studies.

2.2 Adsorption Studies

Batch adsorption studies were carried out by shaking 100 mL of dye solution of desired concentration with 0.2 g of incinerated rice husk in a conical flask at room temperature (22°C), using an orbital shaker at 150 rpm. After a predetermined contact time, the flask was removed from the orbital shaker and the supernatant was filtered through 0.45 µm membrane filter and analysed spectrophotometrically for residual dye concentration. The effects of contact time (10-260 min), dye concentration (20-40 mg/L) and pH (2-9) on adsorption were determined by batch adsorption test. The pH of the solution was adjusted by 0.1 N NaOH or 0.1 N HCl.

Adsorption isotherm was determined by batch equilibrium test using optimum contact time and pH for adsorption. Kinetic study was conducted.

3. Results and Discussion

3.1Characterisation of Incinerated Rice Husk

The BET surface area, micropore area, micropore volume and average pore diameter of inerated rice husk are 76.47 m^2/g, 14.29 m^2/g, 0.006967 mL/g, and 40.20 Å, respectively. Scanning electron micrograph of incinerated rice husk (Figure 1) shows presence of macro- and micro-pores.

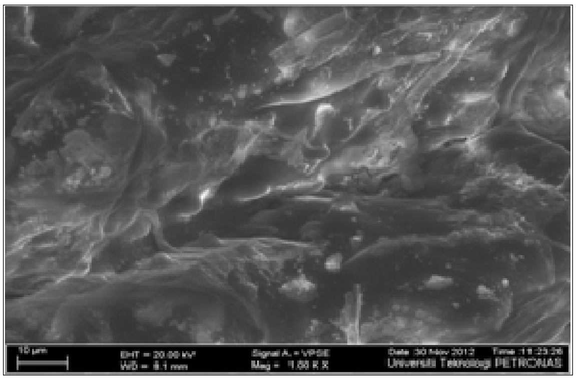

Figure 1. Scanning electron micrograph of incinerated rice husk

3.2 Effect of pH

Effect of pH (2–9) on adsorption of RY 15 for an Incinerated rice husk dose of 2 g/L, contact time 24 h and RY 15 concentration of 20 mg/L was studied, and the results are shown in Figure 2. Maximum adsorption of 83.3% occurred at pH 2. Similar observation has been found by Khan et al., (2010) for adsorption of RY 15 by coconut coir activated carbon.

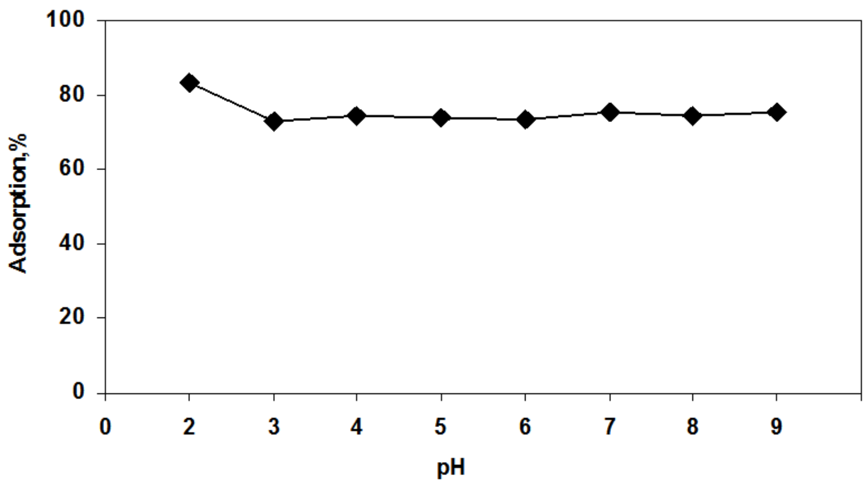

Figure 2. Effect of pH on adsorption of RY 15 by incinerated rice husk

3.3 Effect of Contact Time and Initial Concentration

Effect of contact time and initial RY 15 concentration on adsorption by incinerated rice husk is shown in Figure 3. The contact time was varied in the range 10-260 min at RY 15 concentration 20 and 40 mg/L, incinerated rice husk dose of 2 g/L and pH 2. Equilibrium was attained in 240 min. A contact time of 240 min has also been reported for the adsorption of RY 15 by coconut coir activated carbon (Khan et al., 2010). A contact time of 240 min was used in subsequent adsorption tests.

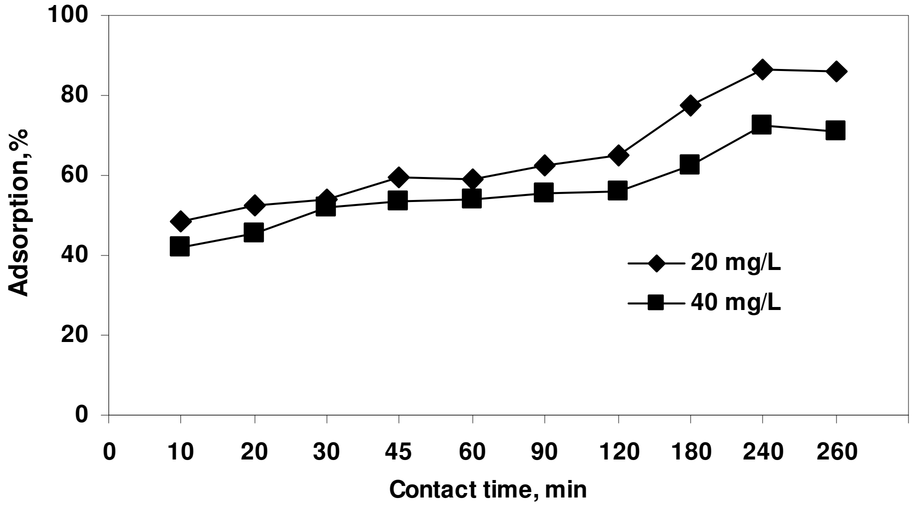

Figure 3. Effect of contact time on adsorption of RY 15 by incinerated rice husk

3.4 Adsorption Isotherm

In adsorption in a solid-liquid system, the distribution ratio of the solute between the liquid and the solid phase is a measure of the position of equilibrium. The preferred form of depicting this distribution is to express the quantity q_e as a function of C_e at a fixed temperature; q_e being the amount of solute adsorbed per unit weight of the solid adsorbent, and C_e the concentration of solute remaining in the solution at equilibrium. An expression of this type is termed an adsorption isotherm (Weber, 1972). The Langmuir adsorption isotherm and its linear form are:

$$q_e = \frac{Q^\circ b C_e}{1 + bC_e} \tag{1}$$

$$\frac{C_e}{q_e} = \frac{1}{bQ^\circ} + \frac{C_e}{Q^\circ} \tag{2}$$

where, $Q°$ is the amount of solute adsorbed per unit weight of adsorbent in forming a monolayer on the surface (monolayer adsorption capacity) and b is a constant related to the energy of adsorption.

The Freundlich adsorption isotherm and its linear form are:

$$q_e = K_f C_e^{1/n} \tag{3}$$

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \tag{4}$$

where, K_f is the Freundlich constant (adsorption capacity) and *1/n* represents the adsorption intensity or surface heterogeneity.

Linear form of Langmuir (Figure 4) and Freundlich (Figure 5) adsorption isotherm were fitted to the adsorption data for RY 15 adsorption by the incinerated rice husk. Freundlich isotherm model fitted better than Langmuir isotherm model to the adsorption data. The values of Langmuir constants ($Q°$ and b) and Freundlich constants (K_f and *1/n*) for RY 15 adsorption by incinerated rice husk are shown in Table 1.

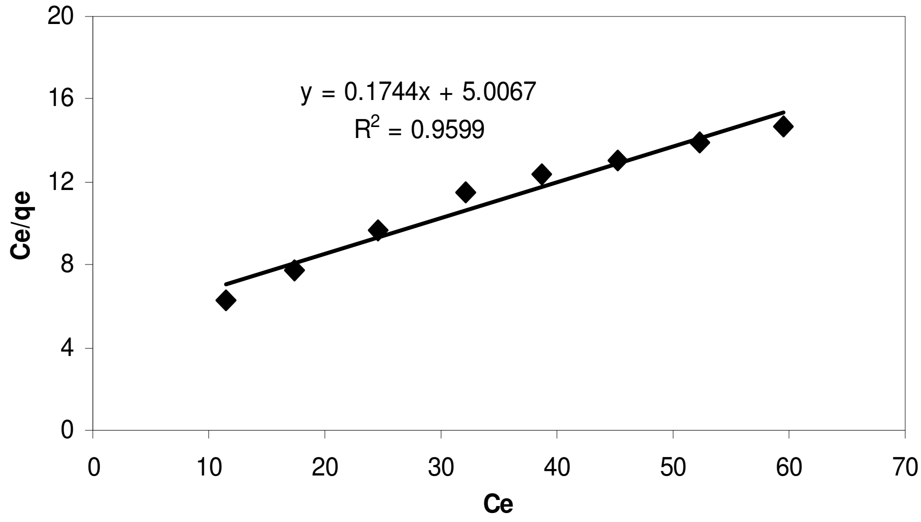

Figure 4. Langmuir isotherm for RY 15 adsorption

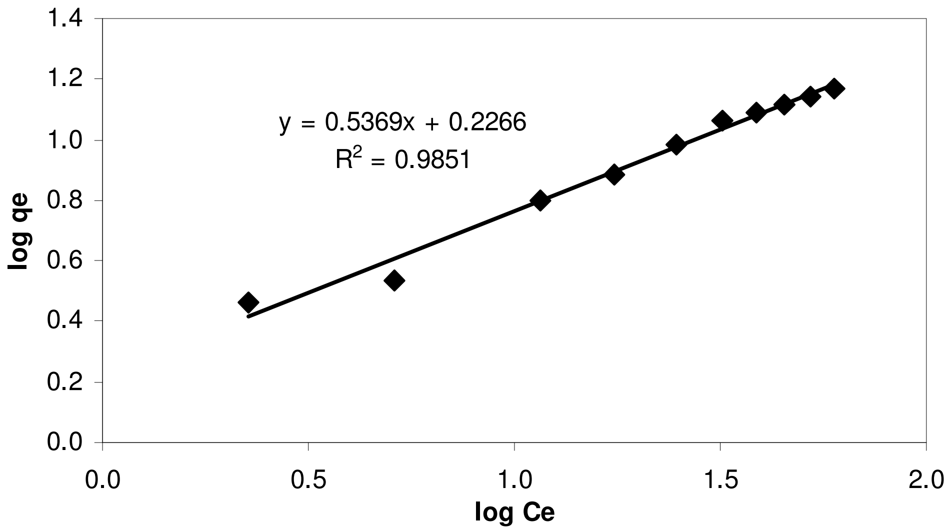

Figure 5. Freundlich isotherm for RY 15 adsorption

Table 1. Values of Langmuir and Freundlich Constants

Langmuir		Freundlich	
$Q°$ (mg/g)	b (L/g)	K_f (mg/g)	$1/n$
5.73	0.034	1.68	0.5

3.6 Adsorption Kinetics

Attempts were made to model the kinetic data for adsorption of RY 15 from aqueous solution by incinerated rice husk using two models, viz., the pseudo-first-order and pseudo-second-order kinetic models.

The pseudo-first-order model and its linear forn may be written as

$$\frac{dq_t}{dt} = k_1(q_e - q_t) \quad (5)$$

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \quad (6)$$

and the pseudo-second-order model and its linear form may be written as

$$\frac{t}{q_t} = \left(\frac{1}{k_2 q_e^2}\right) + \left(\frac{t}{q_e}\right) \tag{7}$$

$$\frac{dq_t}{dt} = k_2 (q_e - q_t)^2 \tag{8}$$

where, q_e and q_t are the amounts of dye adsorbed (mg/g) at equilibrium and any time t, respectively, k_1 is the equilibrium rate constant for pseudo-first-order kinetics (min^{-1}) and k_2 is the equilibrium rate constant for pseudo-second-order kinetics [g/(mg.min)]. Plots of $log(q_e - q_t)$ versus t and of t/q_t versus t are presented in Figures 6 and 7, respectively. Comparatively higher values of R^2 for the pseudo-second-order kinetic model than those for the pseudo-first-order kinetic model indicated that the pseudo-second-order kinetic model gave a better fit to the experimental data, indicating chemical adsorption of RY 15. Similar observation has been reported for the adsorption of RY 15 by coconut coir activated carbon (Khan et al., 2010).

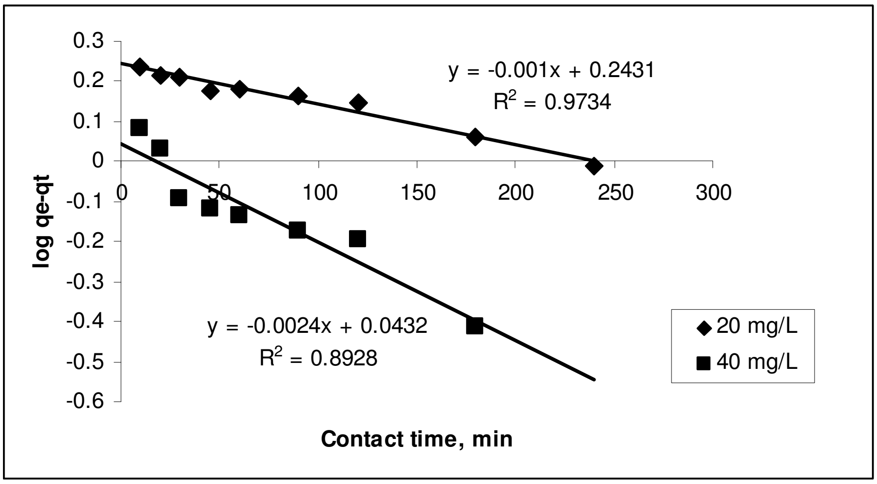

Figure 6. Pseudo-first-order kinetic plot of RY 15 adsorption by incinerated rice husk

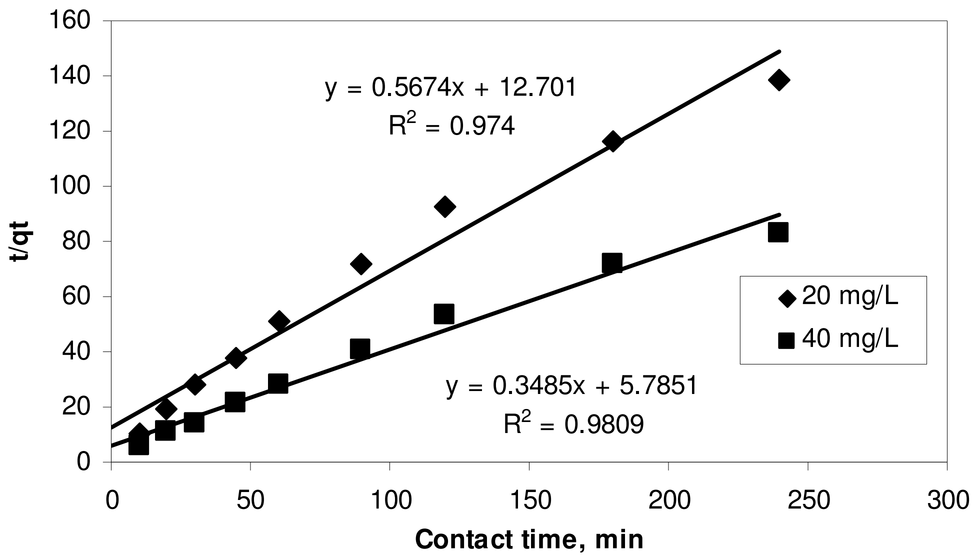

Figure 7. Pseudo-second-order kinetic plot of RY 15 adsorption by incinerated rice husk

4. Conclusions

Incinerated rice husk was found effective in the adsorption of RY 15 from aqueous solution and maximum adsorption occurred in 240 min at pH 2. Freundlich isotherm model fitted better than Langmuir isotherm model to the experimental data. Langmuir constants $Q°$ and b were 5.73 and 0.034, and Freundlich constants K_f and $1/n$ were 1.68 and 0.5, respectively. The pseudo-second-order kinetic model gave the better fit to the experimental data, indicating chemical adsorption of RY 15. Rice husk being a low-cost agricultural by product, the incinerated rice husk can be applied as an effective adsorbent for the removal of reactive dyes from aqueous solution and wastewater in developing countries.

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