Banana Peel: A Low-Cost Adsorbent for Removal of Reactive Dye from Aqueous Solution

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Abstract—**A low-cost adsorbent was prepared from banana peel and adsorption of textile dye Reactive Yellow 15 by the adsorbent was examined. Batch adsorption test showed that extent of dye adsorption was dependent on dye concentration, contact time and pH. Equilibrium adsorption was attained in 180 min and maximum adsorption occurred at pH 2. Adsorption capacity of the banana peel adsorbent for the reactive dye was evaluated by batch equilibrium test. The adsorption data at optimum pH 2 was well described by the Langmuir and Freundlich isotherm models. Langmuir constants $Q°$ and b were 19.76 and 0.22, and Freundlich constants K_f and $1/n$ were 4.39 and 0.54, respectively. Adsorption of Reactive Yellow 15 by the banana peel adsorbent followed pseudo second-order kinetics. Banana peel is an effective adsorbent for removal of reactive dye from aqueous solution.**

I. Introduction

Dyes are synthetic aromatic organic compounds, which have extensive application as colourants for dyeing and printing in a variety of industries. There are more than 100,000 available dyes with an annual production of 7×10^5 metric tons and 5-10% of the dye is lost in the effluent [1]. Dye effluent contains a variety of organic compounds and toxic substances which are harmful to fish and other aquatic organisms. The coloured wastewater in the receiving streams reduces light penetration through the water and, as a result, reduces photosynthesis [2]. Reactive dyes are typically azo-based chromophores combined with different types of reactive groups. They differ from all other classes of dyes in that they bind to textile fibres such as cotton to form covalent bonds. They have the favourable characteristics of bright colour, water-fastness, simple application techniques and low energy consumption, and are used extensively in textile industries. A considerable amount of research on wastewater treatment has focused on the removal of reactive dyes from dye bath waste, because reactive dyes represent 20-30% of the total dye market, large fraction of reactive dyes (10-50%) are wasted during the dyeing process and conventional treatment methods are found to be inefficient for complete elimination of many reactive dyes [3], [4].

There is a need for effective treatment of wastewater containing dyes. Various techniques available for the treatment of wastewater containing dyes are reduction, ion exchange, evaporation, reverse osmosis and chemical precipitation. However, the disadvantages of using these techniques are high capital and operational cost and disposal of the residual sludge [5]. Adsorption appears to be one of the best techniques because it is simple to design, inexpensive compared to other methods and does not produce any sludge [6]. Many industries use activated carbon as an adsorbent for the treatment of coloured wastewater [7]. However, due to high cost use of such activated carbon is limited and, therefore, there is a need to produce low-cost adsorbents which are effective for adsorptive removal of dyes.

The purpose of this work was to assess the adsorptive potential of banana peel for removal of reactive dye from aqueous solution. Banana peel is a waste material and easily available in large quantity. The effects of various experimental conditions such as initial pH, contact time, initial dye concentration and adsorbent dose were examined and optimum experimental conditions were determined. Langmuir and Freundlich adsorption isotherms and pseudo first-order and pseudo second-order kinetic models were used to find out the most suitable models describing the experimental results.

II. Materials and Methods

A. Preparation of Banana Peel Adsorbent

Banana peel adsorbent was prepared according to a method used by Gupta et al. [8]. The waste banana peels were collected from the local market and restaurants and washed several times with tap water, followed by washing with distilled water so as to remove dust, soil and other materials adhering to the peel. Subsequently, the peels were dried in sun light for 5 days and then in a hot air oven at 80ºC overnight. The dried banana peels were then cut into small pieces, ground to a size of 200-400 µm and used in adsorption test.

B. Reactive Dye

A reactive dye, Sunzol Yellow GR (C.I. Reactive Yellow 15), was obtained from Arab-Malaysian Development Bhd. textile plant, Taiping, Perak, Malaysia. Concentration of the dye was determined by measuring the absorbance at the wavelength of maximum absorbance (420 nm) against a standard curve.

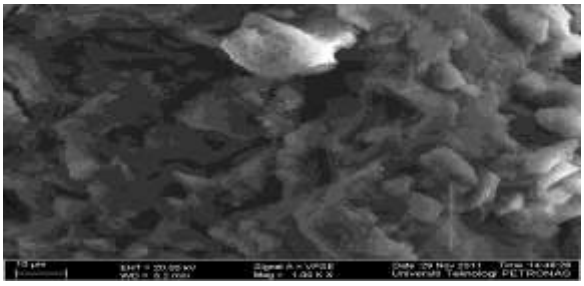

Figure 1. Scanning electron micrograph of banana peel adsorbent.

C. Adsorption Test

Batch adsorption test was carried out by shaking 100 mL of the dye solution of desired concentration with 0.5 g of the banana peel adsorbent 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 effect of contact time, dye concentration, pH and adsorbent dose 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.

III. RESULTS AND DISCUSSION

A. Scanning Electron Micrograph

Scanning electron micrograph of the banana peel adsorbent is shown in Fig. 1. The banana peel adsorbent appeared to contain more macro- and micropores, indicating good adsorption opportunity for dye.

B. Effect of pH

Fig. 2 shows the effect of pH on adsorption of Reactive Yellow 15. Maximum adsorption was achieved at pH 2. Similar observation was also made by Khan and Chaudhuri [9] for adsorption of Reactive Yellow 15 by coconut coir activated carbon. pH 2 was selected as the optimum pH for Reactive Yellow 15 adsorption and subsequent adsorption tests were conducted at pH 2.

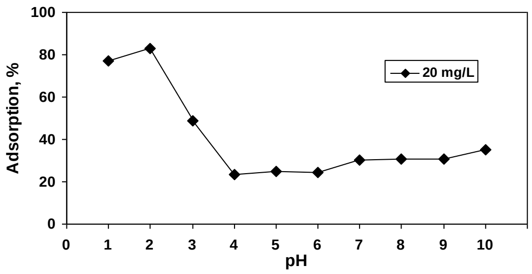

Figure 2. Effect of pH on adsorption of Reactive Yellow 15 by banana peel adsorbent.

C. Effect of Contact Time and Dye Concentration

Effects of contact time and dye concentration on adsorption of Reactive Yellow 15 by the banana peel adsorbent are shown in Fig. 3. Adsorption of dye increased with decreasing dye concentration and increased with increase in contact time. The equilibrium was attained in 180 min. A contact time of 180 min was used in subsequent adsorption tests.

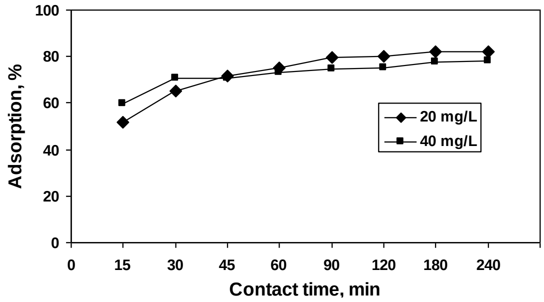

Figure 3. Effect of contact time and dye concentration on adsorption of Reactive Yellow 15 by banana peel adsorbent.

D. Effect of Adsorbent Dose

Fig. 4 shows the effect of adsorbent dose on adsorption of Reactive Yellow 15 from 20 and 40 mg/L solution by the banana peel adsorbent. Adsorption increased with adsorbent dose and attained 82 and 79% at 6 g/L for 20 and 40 mg/L solution, respectively.

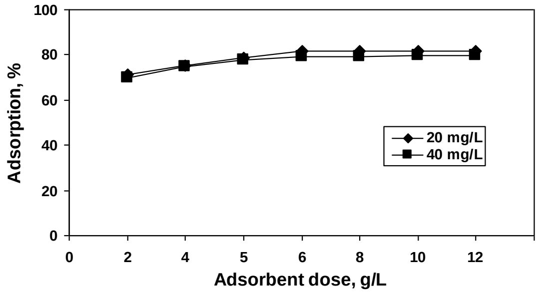

Figure 4. Effect of adsorbent dose on adsorption of Reactive Yellow 15 by banana peel adsorbent.

E. 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, the quantity 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 [10]. The Langmuir adsorption isotherm is

$$q_e = \frac{Q^\circ b C_e}{1 + bC_e} \qquad (1)$$

where, $Q°$ is the number of moles 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 is

$$q_e = K_f \, C_e^{\,1/n} \tag{2}$$

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

Adsorption isotherm for Reactive Yellow 15 adsorption by the banana peel adsorbent was fitted to the linear form of the Langmuir ($C_e/q_e = 1/bQ^\circ + C_e/Q^\circ$) (Fig. 5) and Freundlich ($\log q_e = \log K_f + 1/n \log C_e$) (Fig. 6) adsorption isotherm. The values of Langmuir constants $Q°$ and b, and Freundlich constants K_f and $1/n$ for Reactive Yellow 15 adsorption are shown in Table 1.

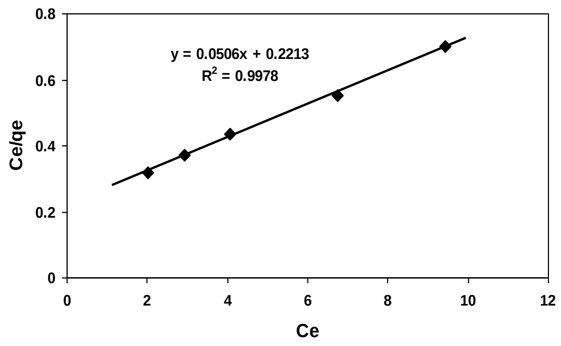

Figure 5. Langmuir adsorption isotherm for Reactive Yellow 15 adsorption.

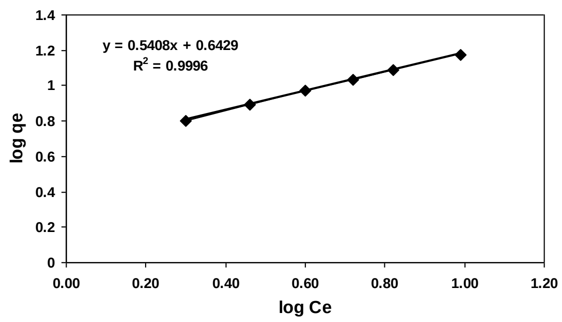

Figure 6. Freundlich adsorption isotherm for Reactive Yellow 15 adsorption.

TABLE I
LANGMUIR CONSTANTS $Q°$ AND b, AND FREUNDLICH CONSTANTS K_f AND *1/n*

$Q°$	b	K_f	*1/n*
19.76	0.22	4.39	0.54

F. Adsorption Kinetics

Attempts were made to model the kinetic data for adsorption of Reactive Yellow 15 by the banana peel adsorbent using two kinetic models, i.e. the pseudo first-order and pseudo second-order.

The linear form of the pseudo first-order model may be written as

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \tag{3}$$

and the linear form of the pseudo second-order model is

$$\frac{t}{q_t} = \left(\frac{1}{k_2 q_e^{\,2}}\right) + \left(\frac{t}{q_e}\right) \tag{4}$$

where, q_e and q_t are the amounts of Reactive Yellow 15 adsorbed (mg/g) at equilibrium and at 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 t/q_t versus t are presented in Fig. 7 and 8, respectively, and Table II and III list the values of k_1, k_2, and q_e for the two models. Comparatively higher values of R^2 implied better fit of the experimental data to the pseudo second-order kinetic model, indicating chemical adsorption. Similar observation has been reported for adsorption of Reactive Yellow 15 from aqueous solution by coconut coir activated carbon [9].

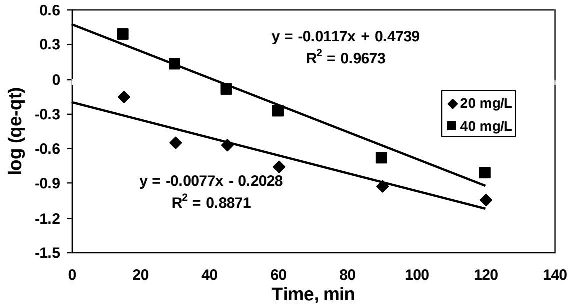

Figure 7. Pseudo first-order kinetic plot of Reactive Yellow 15 adsorption by banana peel adsorbent.

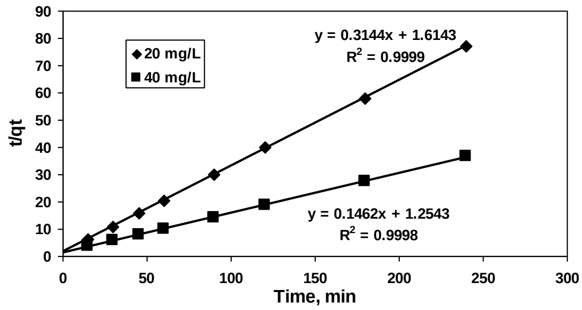

Figure 8. Pseudo second-order kinetic plot of Reactive Yellow 15 adsorption by banana peel adsorbent.

TABLE II
PSEUDO FIRST-ORDER KINETIC CONSTANTS AND EXPERIMENTAL AND CALCULATED q_e VALUES

Dye concentration	q_e (exp) mg/g	Pseudo-first-order	
		k_1 (min^{-1})	q_e (calc)
20 mg/L	3.1	0.01	0.62
40 mg/L	6.5	0.02	2.97

TABLE III
PSEUDO SECOND-ORDER KINETIC CONSTANTS AND EXPERIMENTAL AND CALCULATED q_e VALUES

Dye concentration	q_e (exp) mg/g	Pseudo-second-order	
		k_2 (g/mg·min)	q_e (calc)
20 mg/L	3.1	0.06	3.18
40 mg/L	6.5	0.01	6.83

IV. CONCLUSIONS

The banana peel adsorbent was found effective in adsorption of Reactive Yellow 15 from aqueous solution and maximum adsorption occurred at pH 2. Equilibrium adsorption data were well described by the Langmuir and Freundlich isotherm models. Langmuir constants *Q°* and *b* were 19.76 and 0.22, and Freundlich constants K_f and *1/n* were 4.39 and 0.54, respectively. The pseudo second-order kinetic model gave the best fit of the experimental data, indicating chemical adsorption. The banana peel adsorbent may be implemented as a low-cost adsorbent for reactive dye removal from aqueous solution.

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