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A kinetic study of the adsorption of reactive Yellow 21 dye on flamboyant shells activated carbon

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ABSTRACT

Activated carbon prepared from flamboyant shells was used for the removal of reactive yellow 21 dye from aqueous solutions. The kinetics of reactive yellow 21 dye adsorption on flamboyant shells activated carbon adsorbent is best described by the pseudo second order kinetics model with a correlation coefficient (R^2) of 0.999. The rate constant of pseudo-second order kinetics increases with increase in temperature; whereas, the amount of adsorbed reactive yellow 21 dye on the adsorbent decreases with increase in temperature. Adsorption of reactive yellow 21 dye on flamboyant shells activated carbon adsorbent is found to be strongly dependent on the pH of the medium.

Keywords: Activated Carbon, Flamboyant Shells, Reactive Yellow 21 Dye, Adsorption

INTRODUCTION

Textile industries are generally characterized by high water consumption. Textile wastewater is released from spent dye bath sand dye rinse operations that contains unfixed dyes and are often highly colored. The non-biodegradable nature of the spent dye baths poses serious environmental problems [1, 2]. Textile wastewater compositions are not simple solutions of dye in water, but include many other materials such as particulates, processing additives, salts, surfactants, acids and alkalis as such several difficulties are encountered in removal of dyes from textile waste waters. There are a number of methods for dye removals which include chemical coagulation, flocculation, chemical oxidation, photochemical degradation, membrane filtration, including aerobic and anaerobic biological degradation but all of these methods suffer from one or other limitations. Among several chemical and physical methods, the adsorption has been found to be superior compared to other techniques for wastewater treatment in terms of its capability to efficiently remove a broad range of pollutants and its simplicity of design [2]. Adsorption is a process by which certain components of a fluid phase are attracted to the surface of a solid adsorbent via physical or chemical bonds, thus removing the component from the fluid phase. In general, adsorption processes may be classified as physical or chemical depending on the nature of forces involved. Many physico-chemical factors influence the adsorption process and these include; adsorbate/adsorbent interaction, adsorbent surface area and pore structure, chemistry of the surface, nature of the adsorbate, effect of other ions, particle size, pH, temperature, contact time, etc. Adsorption processes provide a feasible treatment especially if the adsorbent is inexpensive and readily available [1-3].

Among commercial adsorbents, activated carbon is the most commonly used adsorbent [3]. The use of activated carbon has been highlighted as an effective technique for dye removal due to its unique molecular structure, high porosity and an extensive surface area which make them effective adsorbents for several toxic materials in wastewater treatment. Activated carbons are widely used as adsorbents in both gas-phase and liquid-phase separations processes and are produced from various carbonaceous materials such as coal, coconut shell, wood, and polymer scrap [4]. This paper presents a kinetic study of the adsorption of reactive yellow dye 21 on flamboyant shells activated carbon adsorbent prepared by Isah et al [5].

MATERIALS AND METHODS

Stock solution of reactive yellow dye 21 was prepared by mixing 400mg of the dye in 500ml of distilled water. Working solution of desired concentrations was prepared by dilution. The pH of the stock solution was tested using a digital pH meter and found to be 7.3. Fresh dilution was used for each study. Detailed synthetic procedure for the preparation and characterization of the flamboyant shells activated carbon adsorbent has been published elsewhere by Isah et al [5]. The flamboyant shells activated carbon adsorbent has surface area of 595 m^2/g [5],

Batch adsorption was carried out in 250ml beaker by mixing 100ml of the 50mg/L of reactive yellow dye solution with 1g of flamboyant shells activated carbon. The beaker flask is then placed on a hot plate and stirred at 320rpm at room temperature (29 ^{0}C) for the desired period of time. The procedure was repeated at 50 ^{0}C and 60 ^{0}C in order to determine the effect contact time and temperature on the adsorption process. At the end of each adsorption experiment, the mixture was quickly separated using vacuum pump filtration. The residual concentration of the reactive yellow 21 dye in the supernatant solution was determined using UV/Vis spectrophotometer.

To study the effect of pH on the absorption process, the pH of the working solution was adjusted using HCl or NaOH solution.

RESULTS AND DISCUSSION

The Removal efficiency of reactive yellow dye was calculated using the equation below

Removal efficiency = $[C_0 – C_t / C_0] \times 100$

Where C_0 is initial concentration and C_t is the concentration of reactive yellow 21 dye after adsorption for a period of time, t. Table 1 presents data on the effect of contact time and temperature on the removal efficiency of reactive yellow 21 Dye by flamboyant shells activated carbon. From the table it is seen that the removal efficiency of reactive yellow 21 Dye by flamboyant shells activated carbon increases with increase in contact time and temperature.

Table 1 Effect of contact time and temperature on the removal efficiency of reactive yellow 21 Dye by flamboyant shells activated carbon

Temperature (^{0}C)	Time (minutes)	C_o (mg/L)	C_t (mg/L)	Removal efficiency (%)
29	10	50	38.18	23.6
	20	50	36.36	27.3
	30	50	34.54	30.9
	40	50	31.81	36.4
	50	50	28.18	43.6
50	10	50	31.80	36.4
	20	50	30.00	40.0
	30	50	27.30	45.5
	40	50	23.60	52.8
	50	50	20.00	60.0
60	10	50	29.10	41.8
	20	50	26.40	47.2
	30	50	23.60	54.6
	40	50	20.90	58.2
	50	50	18.20	63.6

To investigate the adsorption mechanism, the two most widely used models to describe adsorption kinetics curves were considered i.e. Lagergren pseudo first-order kinetic model and pseudo second-order kinetic model.

The integral form of the Lagergren pseudo first-order equation is given by [6]:

$\log(q_e - q_t) = \log q_e - (k_1/2.303)t$

Where q_e is the amount of adsorbed adsorbate on the adsorbent at equilibrium (mg adsorbate/g adsorbent), q_t is the amount of adsorbed adsorbate on the adsorbent at time, t, k_1 is the adsorption rate constant for pseudo first-order kinetics. A plot of log(qe - qt) versus time, t, and a plot of log(qe - qt) against t is a straight line. $K_{1,}$ and $_{qe}$ can be determined from the slope and intercept of the plot, respectively.

The integral form of the pseudo-second order kinetic is expressed as [6]:

t/qt = 1/h + t/qe

Where k_2 is rate constant of Pseudo-second order kinetics (g/mg-min), and h = k_2qe^2 . The plot of (t/qt) against t using equation 2.8 gives a linear relationship from which qe and k_2 can be determined from the slope and intercept of the plot, respectively.

The plots of log(qe - qt) vs. t, and t/qt vs. t, from figures. 1 and 2 for both Lagergren pseudo first-order and pseudo second-order kinetic models were linearly fitted at 29°C, 50°C and 60°C, respectively. The derived parameters such as, qe, k_1, $k_{2,}$ and h, for the two kinetic models are presented in table 2. The R^2 values and rate constants determined from the plots are shown in table 2. The R^2 values were found to be in the range of 0.975 and 0.995 for pseudo first-order model, and 0.994 and 0.999 for the pseudo second-order model. Hence, the higher correlation coefficient (R^2) values for the pseudo second-order model suggest that the kinetic sorption data is best described by the pseudo second-order kinetics. As seen in table 2, the rate constant of pseudo-second order kinetics (k_2) increases with increase in temperature; whereas, the amount of adsorbed adsorbate on the adsorbent at equilibrium (q_e) decreases with increase in temperature.

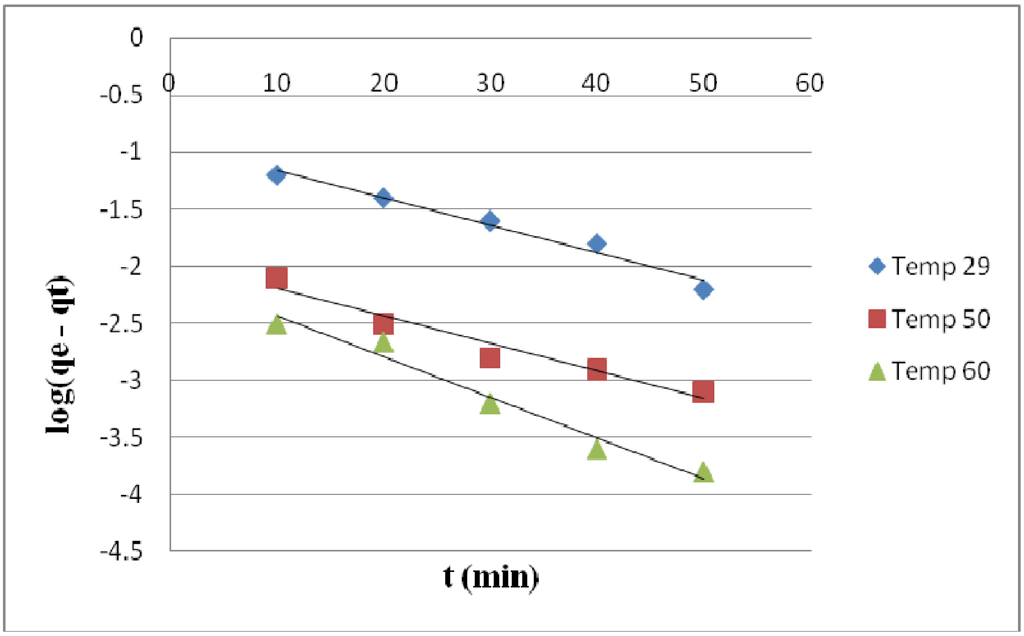

Figure 1 Lagergren pseudo first-order plot for reactive yellow dye adsorption on flamboyant shells activated carbon at 29^{0}C, 50^{0}C, and 60^{0}C.

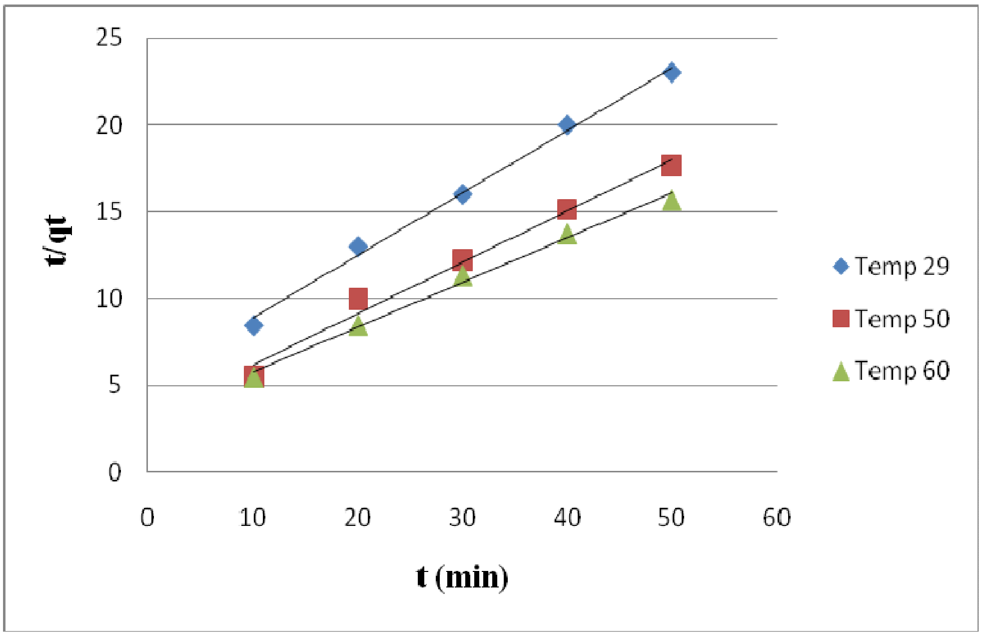

Figure 2 pseudo second-order plot for reactive yellow dye adsorption on flamboyant shells activated carbon at 29^{0}C, 50^{0}C, and 60^{0}C

Table 2 Pseudo first order and Pseudo second model parameters

Type	Parameter	Temperature (K)		
		302	323	333
Pseudo 1st order	q_e	0.123	0.015	0.0074
	k_1	0.0575	0.0598	0.0806
	R^2	0.995	0.975	0.990
Pseudo 2nd order	q_e	0.365	0.289	0.283
	h	0.183	0.259	0.412
	k_2	1.375	3.13	5.148
	R^2	0.994	0.997	0.999

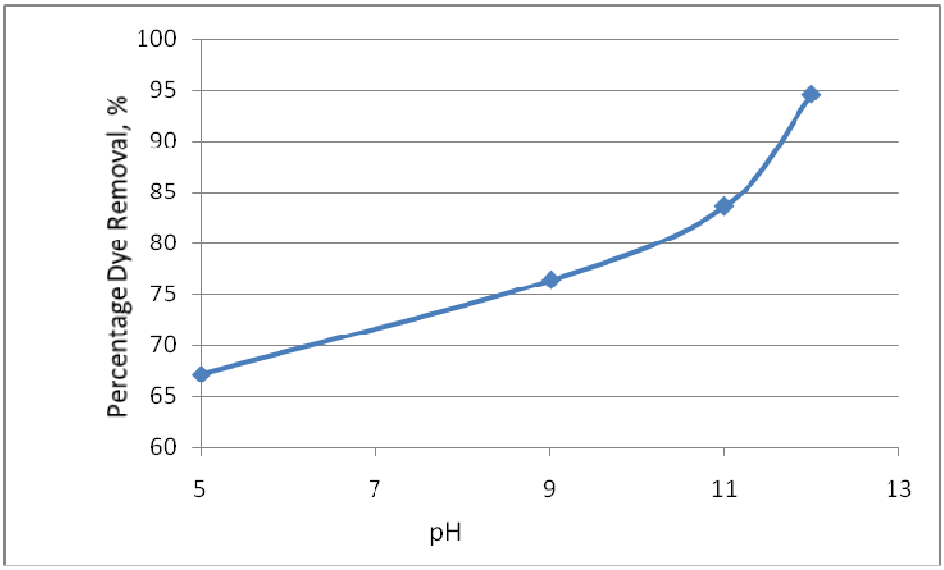

Figure 3. Effect of pH on the removal efficiency of reactive yellow 21 Dye by flamboyant shells activated carbon

The effect of pH on the removal efficiency of reactive yellow 21 dye by flamboyant shells activated carbon is shown in table 3 and figure 3. As shown in the figure 3, the adsorption process increases with increase in the pH. The highest removal efficiency is achieved in the alkaline medium. This observation indicates that the unprotonated form of the dye is more readily adsorbed on the surface of flamboyant shells activated carbon adsorbent.

Table 3 Effect of pH on the removal efficiency of reactive yellow 21 Dye by flamboyant shells activated carbon

pH	Removal Efficiency, (%)
5.0	67.2
9.0	76.4
11.0	83.6
12.0	94.6

CONCLUSION

The kinetics of reactive yellow 21 dye adsorption on flamboyant shells activated carbon adsorbent is best described by the pseudo second order kinetics model with correlation coefficient of 0.999. The rate constant of pseudo-second order kinetics (k_2) increases with increase in temperature; whereas, the amount of adsorbed adsorbate on the adsorbent at equilibrium (q_e) decreases with increase in temperature. adsorption of reactive yellow 21 dye on flamboyant shells activated carbon adsorbent is better in the alkaline medium.

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