Removal of Dye (Blue 56) From Aqueous Solution via Adsorption onto Pistachio Shell: kinetic and isotherm study of removal process

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Abstract: In the present investigation, shells of pistachio are used as adsorbents and they have been successfully used for the removal of Blue 56, from water samples. The effect of various parameters such as: pH, amounts of adsorbents, size of adsorbent particles and contact time on removal processing were investigated. In this study Freundlich absorption isotherms and Langmuir were investigated. The experimental data were correlated reasonably well by the Freundlich adsorption isotherm and isotherm parameters were calculated. In order to investigate the efficiency of Blue 56 adsorption on the pistachio shell, pseudo-first-order, pseudo-second-order, Elovich and intra-particle diffusion kinetic models were studied. The model that had good correlation to attract Freundlich was chosen as the model. Its kinetics follows the pseudo second order reaction.

Keywords: Blue 56; Adsorption; Isotherm; Pistachio shell; Kinetics

INTRODUCTION

Approximately 700,000 tones and 10,000 different types of dyes and pigments are produced annually across the world and are extensively used in many industries including textile, leather, pulp, paper, food and plastics (Sadettin and Dönmez, 2006; Kiran et al, 2009; Aksakal and Ucun, 2010). Among all the chemical available dye classes, direct azo dyes are water-soluble molecules containing one or more ionic groups (most often sulfonic acid and/or amino groups) and are considered to be recalcitrant, non-biodegradable and persistent (Mohan et al, 2008; Akar et al, 2009). A significant proportion of these dyes is lost in manufacturing and processing units and entering the environment in wastewater. The colour dye effluents are considered to be highly toxic to the aquatic biota and affect the symbiotic process by disturbing the natural equilibrium through reducing photosynthetic activity and primary production due to the coloration of the water in streams (Aksu and Tezer, 2005). Physico-chemical processes such as electro-coagulation, ozonation, photocatalysis, membrane filtration and adsorption have been employed for the treatment of dye containing wastewater (Patel and Suresh, 2008). Among these technologies the adsorption method is widely used in the removal of synthetic dyes from the industrial effluent (Calvete et al, 2009; Liang et al, 2010). Through great variety of adsorbents, activated carbon and ion exchange resins have been investigated for removing the dye from wastewater. Although they have a good adsorption capacity, their high costs limit the commercial application (unit cost of virgin material is about 1 US dollar/kg) as well as activated carbon can not be regenerated easily (thermal regeneration costs are about 1-2 US dollar/kg) (Russo et al, 2010).

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Therefore, new, low-cost and highly effective sorbents need to be investigated. Biosorption process employing biopolymers (such as sawdust, wood chips, chitin/chitosan, starch, cyclodextrin and cross linked chitosan/cyclodextrin) and non-viable microbial (fungi, algae and bacteria) biomass has emerged as one of the powerful and attractive options since it is inexpensive.

The adsorption mechanism and the activation parameters were investigated for the adsorption of some dyes such as blue 56 on pistachio shell. The present work aimed to study a convenient and economic method for blue 56 removal from water by adsorption on a low cost and an abundantly available adsorbent, to gain an understanding of the adsorption kinetics, to describe the rate and mechanism of adsorption, to determine the factors controlling the rate of adsorption and to calculate the activation energy of system. The effects of initial blue 56 concentrations, solution pH, amount of adsorbent, particle size and temperature on blue 56 adsorption rate have been evaluated.

\[
R\% = \frac{C_0 - C_t}{C_0} \times 100
\]

Where \(C_0\) and \(C_t\) are the initial concentration and dilute phase concentration of the dye, respectively.

RESULTS AND DISCUSSION

The effect of pH

Textile dyes are complex organic compounds having different aromatic rings and functional groups; the latter have different ionization potentials at different pH and therefore their interaction with microbial biomass depends on the chemistry of a particular dye and the specific chemistry of the bio sorbents. The ionic forms of the dye in solution and the surface electrical charge of the biomass depend on the solution pH. Therefore, pH significantly influences the dye biosorption. The effect of the pH on dye biosorption is presented in Fig. 2.

As seen from the figure, the maximum dye biosorption was observed at pH 2-4 and as the pH increased, the biosorption decreased. Since its chemical structure is hidden, the pKa values of the functional groups of dye molecule cannot be
known. Therefore, it’s estimated that at lower pH values there may be an electrostatic attractions between charged dye molecules and charged cell surface. The optimum pH was used to remove the blue color of 56 (3.5).

When the adsorbent dose was increased from 0.1 to 0.4 gr, it can be seen that increase the absorption increases and then remains constant, it was a possible reason for that is the increasing amount of adsorbent concentration to the optimum color for empty and unoccupied adsorption sites are more accessible. And the rate of adsorption to remove color and high color, and then remains constant. However, a further increase in the adsorbent mass from 3.0 to 4.0 g, did not yield a significant difference in the efficiency. The optimal value is 0.3 gr.

The effect of adsorbent amount

The amount of adsorbent, the effect of adsorbent dosage on the adsorption efficiency. Adsorbent dosage is an important parameter because it determines the capacity of an adsorbent for a given initial concentration of the adsorbate. The adsorption of blue 56 onto pistachio shells was measured at three concentration dye (60, 70, 80) mg/l for different adsorbent dosage (0.1-0.4) gr. effect amount of adsorbent on the removal of the blue color of 56 is shown in Figure (3).

The effect of particle size

Removal is directly related with surface area of adsorbent; therefore, the effect of particle size (figure 4) was studied. It was found that percent removal of reactive dye was decreased with increasing particle size of adsorbent. The size of the adsorbent has a greater influence on the rate of adsorption. The influence of particle size (mesh size) was studied with 40, 60 and 100 mesh sizes in three concentration (60, 70, 80) mg/l. it is observed that the reduction in size results in increased efficiency of adsorption with maximum reduction of 99.5% in mesh (100).

The effect of concentration of dyes

The effect of dye concentration on its adsorption was studied by pistachio shells. The concentration ranges of dyes were 50 mg/L to 100 mg/L. The concentrations at which Blue 56 and fast Blue dyes show maximum adsorption were 50 mg/L and 70 mg/L, respectively. (Fig. 5)
In some cases, equilibrium was almost attained in 5 or 8 min, depending on the values of operating variables. These results indicate that the adsorption process can be considered very fast. To summarize, take into account the cost of energy consumed in agitation, longer contact times (>12 min) unnecessarily prolonged the process to obtain similar result.

**KINETIC EXPERIMENTS**

Kinetic experiments were performed using flasks containing 25 mL of Blue 56 solutions at concentrations of 80 mg/L. The procedure used in kinetic tests was similar to those conducted in the first part of the study. In each test, 25 mL of Blue 56 solution with the desired concentration was added to each flask and the pH was adjusted to 3.5. After the adjustments, 0.3 g of PHP was added and the resultant suspension was stirred at 2000 rpm for 1–11 min at 25 °C. The results were analyzed for fitness with pseudo-first and -second order models.

**Pseudo-first-order model**

The pseudo-first-order rate expression based on solid capacity is generally expressed as follows (Lagergren, 1898):

$$ \frac{dq}{dt} = k_{ad}(q_e - q) $$  \hspace{1cm} (2)
Values of adsorption rate constant \((k, \text{ad})\) for the dye blue56 adsorption onto pistachio shells were determined from the straight line plot of \(\log(q_e - q)\) against \(t\). The data were fitted with a poor correlation coefficient (Table 1), indicating that the rate of removal of dye blue 56 onto pistachio shell does not follow the pseudo-first-order equation.

Table 1. Adsorption kinetic parameters for the adsorption of Blue 56 at temperature 25 ± 0.5 °C on condition optimum: PS amount 0.3 g/25 mL, contact time 11 min and pH=3.5.

<table>
<thead>
<tr>
<th>Model</th>
<th>Concentration (60 mg/L)</th>
<th>(q_e) (mg/g)</th>
<th>(K_1) (min(^{-1}))</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudo first-order</td>
<td></td>
<td>4.85</td>
<td>0.511</td>
<td>0.960</td>
</tr>
<tr>
<td>kinetic model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo second-order</td>
<td></td>
<td>5.291</td>
<td>0.1641</td>
<td>0.997</td>
</tr>
<tr>
<td>kinetic model</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraparticle diffusion</td>
<td></td>
<td>0.844</td>
<td></td>
<td>2.203</td>
</tr>
<tr>
<td>model</td>
<td></td>
<td></td>
<td></td>
<td>0.957</td>
</tr>
<tr>
<td>(q_e) (exp) (mg/g)</td>
<td></td>
<td>4.77</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The pseudo-second-order equation is also based on the sorption capacity of the solid phase. It predicts the behavior over the whole range of data. Furthermore, it is in agreement with chemisorption being the rate controlling step and is expressed as (Ho et al, 2000):

\[
\frac{dq_e}{dt} = K_{2,\text{ad}} (q_e - q)^2
\]  

Where \(K_{2,\text{ad}}\) is the rate constant of second order-adsorption (g/mg. min). For the same boundary conditions the integrated form of equation (4) becomes:

\[
t = \frac{1}{k_{2,\text{ad}}q_e^2} + \frac{1}{q_e} t
\]  

The initial sorption rate, \(h\) (mg/ g. min), at \(t = 0\) is defined as:

\[
h = k_{2,\text{ad}}q_e^2
\]  

Where \(k_{2,\text{ad}}\) and \(h\) values were determined from the slope and intercept of the plots of \(t/q\) against \(t\) (Fig. 8).
The values of the parameters and correlation coefficients are also presented in Table 1. The correlation coefficients of all examined data were found very high ($R^2 > 0.99$). This shows that the model can be applied for the entire adsorption process and confirmed that the sorption of blue 56 onto PHP follows the pseudo-second-order kinetic model.

**ISOTHERM DATA ANALYSIS**

The parameters obtained from the different models provide important information on the adsorption mechanisms, the surface properties, and affinities of the adsorbent. The most widely accepted surface adsorption models for single-solute systems are the Langmuir and Freundlich models. The correlation with the amount of adsorption and the liquid-phase concentration was tested with the Langmuir and Freundlich isotherm equations. Linear regression is frequently used to determine the best-fitting isotherm, and the applicability of isotherm equations is compared by judging the correlation coefficients.

**Langmuir isotherm**

The Langmuir adsorption isotherm is based on the assumption that all sites possess equal affinity for the adsorbate. It may be represented in the linear form as follows (Langmuir, 1916):

$$\frac{c_e}{q_e} = \frac{1}{K_L Q_m} + \frac{C_e}{Q_m}$$

(7)

Where $Q_m$ is the maximum dye blue 56 uptake, mg/g, $K_L$ the Langmuir adsorption constant, L/mg. The model provides the maximum values where they could not be reached in the experiments. The values of $K_L$ were increased with increasing the dose of adsorbent for PHP, respectively. High $K_L$ values indicate high adsorption affinity. The monolayer saturation capacity, $Q_m$, were 19.46 mg/L for PHP, respectively.

**Freundlich isotherm**

The empirical Freundlich isotherm is based on the equilibrium relationship between heterogeneous surfaces. This isotherm is derived from the assumption that the adsorption sites are distributed exponentially with respect to the heat of adsorption. The logarithmic linear form of Freundlich isotherm may be represented as follows (Freundlich, 1906):

$$\log q_e = \log K_F + \frac{1}{n_F} \log C_e$$

(8)

Where $K_F$ (L/g) and $1/n_F$ are the Freundlich constants, indicating the sorption capacity and sorption intensity, respectively. The magnitude of $K_F$ shows a high dye blue 56 adsorptive capacity of PHP from studied aqueous solution. Table 3 also indicates that $0 < 1/n_F < 1$, which indicating that the dye blue 56 is favorably adsorbed by PHP at all studied parameters.
Fig. 9. Langmuir isotherm models plot for the adsorption of BLUE 56 with concentrations 10–130 mg/L, at temperature 25 ± 0.5 °C on optimum condition: PHP amount 0.3 g/25 mL, contact time 11 min and pH=3.5

Table 2: Comparison of the coefficients isotherm parameters for BLUE 56 adsorption onto PHP.

<table>
<thead>
<tr>
<th>Isotherm Models</th>
<th>Parameters</th>
<th>Qe (mg g⁻¹)</th>
<th>K (L mg⁻¹)</th>
<th>R²</th>
<th>1/n</th>
<th>Kf (L mg⁻¹)</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langmuir</td>
<td></td>
<td>35.9</td>
<td>0.146</td>
<td>0.969</td>
<td>0.724</td>
<td>1.68</td>
<td>0.995</td>
</tr>
<tr>
<td>Freundlich</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 10. Freundlich isotherm models plot for the adsorption of BLUE 56 with concentrations 10–130 mg/L, at temperature 25 ± 0.5 °C on optimum condition: PHP amount 0.3 g/25 mL, contact time 11 min and pH=3.5

CONCLUSIONS

The results of present investigation show that PHP has considerable potential for the removal of BLUE 56 from aqueous solution over a wide range of concentration. Equilibrium and kinetic studies were conducted for the adsorption of blue 56 from aqueous solutions onto PHP in the concentration range 10–130 mg/L at pH 3.5 and 298 K. The equilibrium data have been analyzed using Langmuir and Freundlich isotherms. The characteristic parameters have been determined for each isotherm and related correlation coefficients. The Freundlich isotherm was demonstrated to provide the best correlation for the adsorption of blue 56 onto PHP. The adsorbed amounts of blue 56 increased with increase in contact time and reached the equilibrium after 11 min. The equilibrium time is independent of initial blue 56 concentrations. The kinetics of adsorption of blue 56 onto PHP was studied by using pseudo first- and second-order equations. All findings presented in this study suggest that blue 56 /PHP system cannot be described by a first-order reaction model. For the examined system, the pseudo second-order kinetic model provided the best correlation of the experimental data.

REFERENCES


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