Removal of brilliant green (BG) from aqueous solution by using low cost biomass Salix alba leaves (SAL): thermodynamic and kinetic studies
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ABSTRACT
The removal of brilliant green dye (BGD) from aqueous solution by using Salix alba leaves (SAL) was carried out via batch studies. The maximum removal efficiency was found to be 95.2% with initial dye concentration 50 mg/L at 0.15 g adsorbent dosage, pH = 6, and 298 K temperature, and the equilibrium was observed within 3½ hours. The adsorption capacity increased (2.21–15.89 mg/g) from 10 to 50 mg/L of dye concentration. Kinetic and isotherm studies were also carried out. The results showed that pseudo-second order model better describes the adsorption mechanism. The isotherm equilibrium data analysis was carried out by using Freundlich and Langmuir models and the sorption process was observed to conform with the Langmuir isotherm with linear correlation coefficient \( R^2 = 0.99 \). The thermodynamic properties \( \Delta G^\circ \), \( \Delta H^\circ \), and \( \Delta S^\circ \) delineated that BGD adsorption over SAL was feasible, spontaneous, and endothermic between 303 and 323 K temperature.

INTRODUCTION
Dyes are color organic compounds which are discharged in sewage water of many industries, such as paper, fabrics, leather, cosmetics, and printing. The long-time adverse environmental effects caused by discharging these dyes change water color, sunlight permeation, and are unpleasant for drinking and domestic uses. Annually, a huge amount of dyes and pigments (over \( 7 \times 10^5 \) tons) are being produced throughout the world (Machado et al. 2012) and 90% of this production is used in the textile industry (Mane & Babu 2011). Wastewater discharge increases with the development of printing, textile, and tanning industries (Nandi et al. 2009). The textile industry is responsible for two-thirds of the production of total dye stuff and effluent discharges (10–15%) of the used dyes in water bodies (Mittal et al. 2008). The treatment of dye wastewaters is difficult due to their organic molecular composition, dye resistance to aerobic digestion, stability to oxidizing agents, heat and light (Ertugrul et al. 2009). In recent years, different technologies have been developed for efficient dye removal from wastewater (Daneshvar et al. 2012). The physical and chemical methods coagulation/flocculation, adsorption (Calvete et al. 2009), oxidation (Ahmad & Alrozi 2011; Foo & Hameed 2012), and membrane-based separation (Amela et al. 2012) are used in dye removal from wastewater. The most feasible, efficient, and low-cost technique is the adsorption process among all the above-mentioned methods (Crini 2009; Tan et al. 2008; Elwakeel et al. 2016, 2017a, 2017b). Many common dyes are removed by adsorbents (biomass) (Dogan et al. 2007; Nandi et al. 2009; Oladoja et al. 2009; Chen et al. 2012;
Ioannou et al. 2013; Liu et al. 2013), such as congo red, methylene blue, brilliant green, and methyl orange. The most widely used adsorbent for dye removal is activated carbon, but its use is restricted due to higher cost and regeneration problems (Mall et al. 2006). Nowadays scientists are focusing on low cost nonconventional and efficient adsorbents as an alternative for costly adsorbents. Some of these include bagasse fly ash (Aroguz et al. 2008), powdered peanut (Gong et al. 2005), raw pine cone (Dawood & Sen 2012), and palm kernel coat (Oladoja & Akinlabi 2009).

Brilliant green dye (BGD) appears as a golden crystal and organic dye that belongs to the triphenylmethane family. It has many uses, for example, dermatological agent, biological stain, veterinary medicine, to inhibit mold propagation in poultry feed, fungus, and intestinal parasites (Nandi et al. 2009). Brilliant green .comis toxic when injected into humans and animals. Common harmful effects of BG on humans are irritation to the gastrointestinal tract with long-time exposure resulting in organ damage (Mittal et al. 2009). As a result of its decomposition, sulphur oxides, nitrogen oxides, and carbon dioxide are produced which further pollute the environment (Kismir & Aroguzet 2011).

In this study, Salix alba leaf (SAL) powder has been investigated as an adsorbent for BGD removal. SAL is an easily and freely available biomass. SAL has not been used for adsorption of BG previously. However, in this work, batch adsorption studies have been used for the removal of BGD from aqueous solution. Different parameters such as the effect of temperature, contact time, effect of pH, initial dye concentration, and adsorbent dosage have been studied for efficient removal of dye from wastewater. The kinetic and thermodynamic mechanism of adsorption has also been studied.

MATERIALS AND METHODS

Preparation of stock solution

Brilliant green (C27H34N2O4S) by BDH Chemicals was used as received. The standard solution of BG (1,000 mg/L) was prepared by mixing 1 g of BG per 1,000 mL of distilled water. Further dilution of the mixture was carried out to prepare 10–50 mg/L solutions.

Preparation of adsorbent

Locally collected Salix alba leaves from the village Rairban, Bagh Azad Jammu and Kashmir, Pakistan were washed with deionized H2O to eliminate dirt and dried in a thermostatically controlled oven at 100 °C for 24 hours. The desiccated biomass was crushed and ground with a mortar and pestle then passed through sieves to obtain particles of 70 mesh size.

Characterization of Salix alba leaves

The SAL powder was characterized by different techniques such as Fourier transform infrared (FTIR) spectrophotometer and UV-vis-spectrophotometer. A scanning electron microscope (SEM) was applied for the delineation of surface morphology. TGA/DSC studies were done by using instrument universal V 4.5A TA, SDT Q600 V 20.9. The surface area of the SAL powder was delineated by employing Quatachrome Novawin V. 11.04. The bulk density and moisture contents were also calculated and the acquired results are presented in Table 1.

Desorption

Desorption studies were also carried out for the determination of regeneration of the used adsorbent. The experiments were conducted using 0.1 molar solutions of desorbing agents (distilled water, KCl, NaOH, and HCl) for the used SAL regeneration possibility. The BG solution (50 mL of 50 mg/L) was treated with 0.15 g of SAL for 3½ hours. The dye loaded adsorbent was shaken with 25 mL of desorbing agents for 5 hours. The desorption percentage was calculated by employing a relation:

\[
% \text{Desorption} = \frac{m_d}{m_a} \times 100
\]

where \(m_a\) (mg/L) denotes adsorbed and \(m_d\) (mg/L) desorbed amounts of BG.

| Salix alba | Surface area (m²/g) | Water contents % | Bulk density g/cm³ |
|-----------|---------------------|------------------|-------------------|
| 180.72    | 1.94%               | 1.53 g/cm³       |

Table 1 | Physical characteristics of Salix alba leaves
**Batch equilibrium and kinetic studies**

The batch studies were carried out by preparation of 50 mL dye solution in 250 mL conical flasks with 0.15 g of the adsorbent (SAL). The three flasks were agitated and heated at 303, 313, and 323 K, respectively. The samples were filtered and the absorbance of the filtrate was determined with UV-Vis spectrophotometer at $\lambda_{max} = 625$ nm for brilliant green. The samples' equilibrium concentrations were determined by the application of the Beer–Lambert law while adsorption capacity was found using the following equation:

$$q_e = \frac{(C_o - C_e)V}{m}$$  \hspace{1cm} (2)

where $m$ denotes SAL mass in (g), $C_o$ initial, $C_e$ initial, and equilibrium concentrations of BG (mg/L) and $V$ designates volume of solution (L). The removal efficiency was found using a relation given below (Ahmad & Kumar 2010):

$$\% R = \frac{(C_o - C_e)}{C_o} \times 100$$  \hspace{1cm} (3)

The data analysis was carried out by employing the isotherm adsorption models (Langmuir and Freundlich) using the relation:

$$\frac{C_e}{q_e} = \frac{1}{Q_o} + \left(\frac{1}{Q_o}\right)C_e$$  \hspace{1cm} (4)

where $Q_o$ is the adsorption capacity.

The dimensionless factor of Langmuir isotherm is expressed as:

$$R_L = \frac{1}{1 + bC_e}$$  \hspace{1cm} (5)

where $C_o$ (mg/L) denotes the initial concentration of adsorbate (BG). The $R_L$ value is helpful in the determination of the nature of the adsorption process. The process is favorable if $R_L$ (0 < $R_L$ < 1), unfavorable ($R_L$ > 1), irreversible ($R_L$ = 0), or linear ($R_L$ = 1). The Freundlich model is used for determination of heterogeneity of system using an empirical isotherm:

$$\ln q_e = \ln K_F + \frac{1}{n} \ln C_e$$  \hspace{1cm} (6)

where $K_F$ (mg/g (L/mg)$^{1/n}$) and $n$ in the above equation are Freundlich constants. The thermodynamic studies were carried out for determination of the nature of the adsorption process by using various mathematical relations such as entropy change ($\Delta S$ J/K mol), free energy change ($\Delta G$ kJ/mol), and enthalpy change ($\Delta H$ kJ/mol) (Equations (7) and (8));

$$\Delta G = -RTlnK_c$$  \hspace{1cm} (7)

$$\ln K_c = \frac{-\Delta G^o}{RT} = -\frac{\Delta H^o}{RT} + \frac{\Delta S^o}{R}$$  \hspace{1cm} (8)

In the above equation, equilibrium constant is $K_c$, $R$ stands for gas constant (8.314 J/K mol) and $T$ (Kelvin).

**RESULTS AND DISCUSSION**

**Characterization of Salix alba leaves**

**FTIR analysis**

The FTIR analysis was carried out from 4,000 and 500 cm$^{-1}$ using FTIR spectrophotometer (Perkin Elmer spectrum 100 series) to investigate surface functional groups. The prominent peaks before adsorption spectra at 3,417 cm$^{-1}$ is due to stretching vibrations of amine and water on the adsorbent surface, the peak observed at 1,620 cm$^{-1}$ represents the presence of aromatic C= C bendings, the prominent peak at 1,041 cm$^{-1}$ is due to carboxylic acids, C-O stretching of alcohols, esters, and ethers present on the adsorbent surface. The stretching vibrations of C-S appeared at 611 cm$^{-1}$ (Figure 1(a)). After the adsorption of BG on the SAL (adsorbent) surface, significant changes in the frequencies were observed at 1,620 cm$^{-1}$ and 1,382 cm$^{-1}$ (Figure 1(b)). The changes reflect the functional groups' participation in the adsorption process either due to linkage by physical van der Waals forces or through chemical bonds (Ergene et al. 2006; Haafiz et al. 2015). SEM analysis of SAL powder before
The differences in both the photographs delineate the adsorption of BG onto SAL.

**Thermal analyses**

Figure 3 (thermogram) presents the plot between the loss of mass and temperature. TGA analysis showed three phases. In the first phase (30–230 °C), the decomposition occurred due to slow loss of initial mass due to water contents and the evaporation of volatile compounds (Klim et al. 2010; Poletto et al. 2011). The mass loss obtained at this phase was 18.18%. This phase ended at 230 °C. The second phase (230–450 °C) showed a quick loss of weight during the roasting of samples. The results showed that the mass loss obtained was 47.99%. The mass loss was maximum for the sample in this phase and the mass loss is mainly due to the decomposition of organic matter and other hydroxyl groups-containing components of biomass. For the third phase (450–780 °C), the percent mass loss observed was 12.01% and it might be due to decomposition of solid-residue (Sullivan & Ball 2012; Trache et al. 2014). Two main phases were observed according to DSC analysis. The first negative peak showed that the evaporation of different volatile compounds and moisture contents occurred and these processes consumed energy so the endothermic phase was observed below 100 °C (Figure 3). The positive peak was observed above 100 °C and showed an exothermic phase, because in this phase there was decomposition of cellulose, hemicelluloses, and lignin which is an exothermic reaction (Azubuike & Okhamafe 2012).
**Effect of contact time**

Variations in the time of contact between adsorbent and dye are useful in understanding the adsorbed volume of dye at different times by taking the constant adsorbent dosage. In the process of wastewater treatment, equilibrium time is of great importance. The contact time effect shown in Figure 4 was carried out by taking the contact time from 10 to 250 minutes, 50 mg/L BG concentration, 0.15 g adsorbent dose, and pH = 6 at room temperature. The dye uptake capacity (2.217–15.8 mg/g) and removal efficiency (95.2%) increased from 10 to 250 minutes and equilibrium was attained at 210 minutes. This is due to accretion of dye ions’ positions on the adsorbent surface, and further diffusion process diminished at higher contact time. The maximum adsorption percentage was observed at 210 minutes, then there was slow change up to 250 minutes. The reason is that at the start of adsorption, the sites for adsorption are exposed which accelerates the adsorption due to diffusion from the dye solution to the sites of the adsorbent (Yunus 2006; Royer et al. 2009).

**Effect of biosorbent dosage**

An important parameter for the adsorption of BG onto SAL is the adsorbent dosage. The dye uptake capacity of an adsorbent is determined by the dosage of an adsorbent for the fixed initial dye concentration. This parameter was studied on the removal of BG by keeping all other experimental conditions constant. As shown in Figure 5, the adsorption percentage increased as the concentration of adsorbent increases and reached maximum (95.56%) at 0.45 g (adsorbent concentration). However, an inverse effect was observed for the adsorption capacity because of the increasing adsorbent dose (0.15–0.45 g) causing the dye uptake capacity to be reduced (13.11–5.29 mg/g). The decrease in adsorption capacity is because of remaining unsaturated sites for the adsorption of dye onto adsorbent (Mahir et al. 2005).

**Effect of preliminary dye concentration**

The dye uptake capacity also affected initial dye concentration. The effect of preliminary dye concentration was
studied by taking adsorbent dosage 0.15 g, initial BG concentration 10–50 mg/L at equilibrium time (210 minutes), and pH = 6 at 298 K. Figure 4 shows that the removal efficiency (41.75–95.35%) and adsorption capacity (6.95–15.89 mg/g) increased from 10 to 210 minutes. The removal of dye by the adsorption process depends mainly on the initial dye concentration for mass transfer. This is because the high driving force for mass transfer is responsible for the increased adsorption capacity with dye ions, so better adsorption is attained with highly concentrated dye (Colak et al. 2009).

Effect of pH

The pH of the solution affects greatly the BG percentage removal of SAL, as shown in Figure 6. The maximum removal efficiency (95.56%) was obtained at pH = 6 with 50 mg/L initial dye concentration for the equilibrium time of 210 minutes. 0.1 M HCl and NaOH were employed for adjusting pH of the BG and SAL mixture. The removal efficiency was increased with increasing pH up to 6 and then decreased. This is because the number of positive charges on the surface of SAL increases due to which the adsorption process is not favorable because of repulsive electrostatic forces (Tam et al. 2002; Aksu & Tezer 2005). The low adsorption capacity at very low pH may be due to the competition of protons with dye molecules available at the active sites of adsorbent (Tien 2002). The surface of SAL may become negatively charged, due to which, cationic species increase the adsorption through electrostatic attraction, thus resulting in increased adsorption. Hence, the dye uptake capacity (15.897 mg/g) was obtained at pH = 6 and then started to decline at pH = 13.

Effect of temperature

The effect of temperature on the process of adsorption was carried out by taking 50 mg/L initial dye concentration, 0.15 g adsorbent dose, pH = 6, and equilibrium time of 210 minutes. The temperature varied from 293 to 323 K, as shown in Figure 7. It was observed that the increase in temperature enhanced the adsorption capacity and percentage removal which shows that the adsorption process is endothermic in nature. The increase of removal efficiency at higher temperatures demonstrates the endothermic nature of the adsorption process (Colak et al. 2009). The mobility of dye molecules increases, hence the surface functional groups and dye molecules react more rapidly at a higher temperature (Kim et al. 2010).

Adsorption thermodynamics

The adsorption process can be characterized by thermodynamic parameters such as enthalpy change (ΔH° kJ/mol), change in free energy (ΔG° kJ/mol), and entropy change (ΔS° J/mol). These parameters can be calculated by
Equations (9) and (10):

\[ \Delta G = -RT \ln K_L \]  

(9)

In Equation (9), \( R \) (8.314 J/mol K) is the universal gas constant, \( T \) (K) absolute temperature of the solution, and \( K_L \) (L/mg) isotherm constant of the Langmuir equation. The plot of \( \ln K \) versus \( 1/T \) (Figure 8) was used for the determination of \( \Delta H^\circ \) (kJ/mol) and \( \Delta S^\circ \) (J/mol) by using Equation (10):

\[ \ln K_L = -\frac{\Delta G^\circ}{RT} = -\frac{\Delta H^\circ}{RT} + \frac{\Delta S^\circ}{R} \]  

(10)

The positive \( \Delta H^\circ \) (kJ/mol) (56.634) indicated that adsorption of BG onto SAL is an endothermic process. The negative values of \( \Delta G^\circ \) (kJ/mol) in Table 2 gives a clear indication of the feasibility and spontaneity of the adsorption process. The positive \( \Delta S^\circ \) J/mol (241.77) shows the affinity of SAL for BG and also infers that the randomness increases at the interface of solid and solution.

**Equilibrium studies**

The equilibrium isotherm describes the amount of dye (adsorbate) taken up by the adsorbent (biomass) and the adsorbate concentration that remains in the solution. The measured adsorption equilibrium data are analyzed by many equations. The equations of the equilibrium models give us the information about the surface characteristics, adsorption capability of adsorbent, and mechanism of adsorption. In the present study, the isotherm models (Langmuir and Freundlich) were used to calculate the dye uptake capacity \( q_e \) of SAL for the percentage removal of BG from aqueous solutions (Ghaedi et al. 2011). The isotherm of adsorption of BG onto SAL was carried out at 303, 313, and 323 K. The Langmuir model specifically explains the homogeneous sites of adsorption. This model is applied in numerous monolayer adsorption mechanisms (Langmuir 1918). Isotherm studies data for adsorption of BG on SAL follow the isotherm model of Langmuir as given in the equation:

\[ \frac{C_e}{q_e} = \frac{1}{Q_o b} + \left( \frac{1}{Q_o} \right) C_e \]  

(11)

where \( Q_o \) is monolayer formation adsorbate amount, \( C_e \) is equilibrium concentration (mg L\(^{-1}\)), \( Q_e \) is adsorbed amount (mg) per adsorbent amount (g), and \( b \) is Langmuir constant. Hence, the straight-line plot of \( C_e \) versus \( C_e/q_e \) (Figure 9) is obtained having slope \((1/Q_o)\) and an intercept \((1/Q_o b)\); the calculated values are presented in Table 3.

**Table 2 | Thermodynamic results for BG adsorbed on SAL**

| Temperature (K) | \( \Delta G \) (kJ/mol) | \( \Delta H \) (kJ/Mol) | \( \Delta S \) (J/mol) |
|-----------------|--------------------------|-------------------------|-----------------------|
| 303             | -17.921                  | 56.634                  | 241.77                |
| 313             | -19.907                  |                         |                       |
| 323             | -23.650                  |                         |                       |

**Figure 8 | The plot of adsorption thermodynamics for BG adsorbed SAL.**

**Figure 9 | Langmuir isotherm model results at various temperatures for BG adsorbed SAL.**
The \( Q^0 \) values drawn from the Langmuir plot showed a decrease with increase in temperature and \( b \) \((\text{dm}^3/\text{g})\) Langmuir constant also decreased and hence showed the exothermic nature of adsorption. The adsorbent surface homogeneity is delineated by the Langmuir isotherm. The small adsorption patches with equivalent energy levels were developed on the adsorbent surface during the adsorption process (Weber & Chakkravorti 1974). The best fitting of the Langmuir isotherm is delineated by the correlation coefficient \((R^2)\) value (0.9957). The value of \( R^2 \) showed that the adsorption data of BG dye onto SAL best fits the Langmuir isotherm.

The dimensionless factor of the Langmuir isotherm is expressed as:

\[
R_L = \frac{1}{1 + bC_0}
\]  

(12)

where \( C_0 \) \((\text{mg/L})\) denotes the adsorbate (BG) initial concentration. The \( R_L \) value is helpful in determination of the nature of the adsorption process. The process is favorable if \( R_L (0 < R_L < 1) \), unfavorable \((R_L > 1)\), irreversible \((R_L = 0)\), or linear \((R_L = 1)\).

The heterogeneous or non-ideal adsorption is determined by the Freundlich model. The model is applicable for a multilayer adsorption system (Ghaedi et al. 2011). This model is expressed by the relation:

\[
\ln q_e = \ln K_F + \frac{1}{n} \ln C_e
\]

(13)

where \( n \) and \( K_F \) are empirical constant and Freundlich equilibrium constant, respectively. As such, the straight-line plot of \( \ln \) \( C_e \) versus \( \ln \) \( q_e \) (Figure 10) is drawn where \( 1/n \) is slope and \( \ln K \) intercept. The parameters determined for SAL adsorption are shown in Table 3 (Hagsheresht & Lu 1998). In the Freundlich isotherm \( n \) represents the sorption intensity generally and \( n > 1 \) shows the favorable adsorption of adsorbate on adsorbent. Adsorption intensity increases with the increase in \( n \) value.

### Adsorption kinetics

The mechanism and rate of adsorption process can be found by three kinetic models, namely, intraparticle diffusion, pseudo-first order model (PFO), and pseudo-second order model (PSO). Lagergren (1898) proposed the PFO and it is written as:

\[
\log (q_e - q_t) = \log q_e - \left( \frac{K_1}{2.303} \right)t
\]

(14)
$q_e$ (mg/g) is adsorbed amount of BG by SAL at equilibrium and the pseudo-first order model rate constant is $k_1$ (1/min). The graph (Figure 11) of ln($q_e$ – $q_t$) versus $t$ is used to calculate the $k_1$ given in Table 4. The PFO model has a linear relation as shown below (Ghaedi et al. 2010):

$$\frac{t}{q_t} = \frac{1}{k_1 q_e^2} + \left(\frac{1}{q_e}\right) t$$ (15)

The slope and intercept obtained from $t$ versus $t/q_t$ (Figure 12) are utilized for the determination of PSO model to determine the PSO rate constant ($k_2$; g/mg min) and $q_e$ (adsorption capacity) (Figures 11 and 12). Adsorption kinetics of BG by SAL were calculated at different conditions from respective plots as shown in Table 4. The correlation coefficient ($R^2 \geq 0.98$) values of the PSO model are higher than PFO. $q_e$ cal values increased as the initial dye concentration increases. $q_e$ Exp. are best fitted with $q_e$ Exp. for the PSO model, where the possibility of rate-limiting step was provided by the PSO model which controlled the dye adsorption onto activated carbon also delineated from hydrogen sulfide-treated bagasse (Mittal et al. 2008) and Euphorbia rigida (Aroguz et al. 2008). The uptake behavior of BG described by the kinetic models suggested that these models do not account for the mechanism of diffusion.

Error analysis

The statistical analysis, sum of squared error (SSE) was employed for error analysis. The following relation was used for error analysis:

$$SSE = \sum_{i=1}^{n} (q_{e \text{ calc}} - q_{e \text{ meas}})^2$$ (16)

The $q_{e \text{ (meas)}}$ and $q_{e \text{ (calc)}}$ in the aforementioned equation are the values of experimental and calculated adsorption capacity (mg/g), respectively. The low values of SSE demarcate best match with experimental data (Tables 3 and 4).

The comparison of $q_{\text{max}}$ with different adsorbent is also given in Table 5.

Intraparticle diffusion

The Weber and Moris plot was used for the determination of the intraparticle diffusion process (Weber & Morris 1963).
The relation is expressed as:

\[ q_t = K_i t^{1/2} + C \]  

(17)

where \( C \) is the intercept which can be calculated from the slope of the linear plot of \( t^{1/2} \) against \( q_t \) and \( k_i \) (mg/g) denotes the diffusion intraparticle rate constant (Azbubuike & Okhamafe 2012). According to this model, the involvement of diffusion in the adsorption mechanism, the plot between \( q_t \) and \( t^{1/2} \) (Figure 13), should be linear. The process will be rate controlling when the lines cross through the origin. The slope in a linear portion of the plots from Figure 13 is used for calculation of intraparticle rate constant and intercept (C) (Table 3). The mass transfer rate difference between two stages (initial and final) of the adsorption process deviated the straight lines from the origin (Figure 13). Moreover, this deviation also indicated that the pore diffusion is not a sole rate step.

Desorption

Desorption studies were also carried out for the determination of regeneration of the used adsorbent. The experiments were conducted using various kinds of molar desorbing agents (distilled water, KCl, NAOH, and HCl) for used SAL regeneration possibility. The maximum desorption (53.10%) was observed with 0.1 M KCl. The percentage desorption of different reagents of BG loaded SAL powder is presented in Table 6.

CONCLUSIONS

The current study shows that low-cost adsorbent SAL (biomass) can be effectively used for the removal of brilliant green from its aqueous solutions. The removal efficiency of \textit{Salix alba} increased as the contact time, initial dye concentration, adsorbent dosage, and temperature increased. The adsorption capacity of adsorbent was found to be increased with the rise in initial dye concentration, contact time, and temperature, but with the increasing adsorbent dosage, a decrease was observed. The adsorption kinetics results showed a good correlation coefficient \( R^2 > 0.98 \) with pseudo-second order kinetics. Equilibrium isotherm results conformed well with the Langmuir isotherm equation. The adsorption capacity (13.71 mg/g) of BG over SAL confirmed the monolayer adsorption capacity. The dimensionless separation factor \( (R_L) \) also denotes SAL adsorbent capacity for the BG removal from aqueous solutions. Thermodynamic parameters such as \( \Delta H^o \), \( \Delta S^o \), and \( \Delta G^o \) of adsorption were also calculated and indicated the BG adsorption process over SAL is spontaneous and physical in nature. The adsorbent (SAL) is very cost-effective and easily available in large amounts. This adsorbent gives

| Adsorbents                  | \( q_m \) (mg/g) | Reference                      |
|-----------------------------|-----------------|--------------------------------|
| Luffa cylindrical sponge    | 18.2            | Olaseni \textit{et al.} (2014) |
| Activated carbon (prepared from Acron) | 2.11 | Ghaedi \textit{et al.} (2011) |
| Rice husk ash              | 26              | Zolgharnein \textit{et al.} (2015) |
| Saklikent mud              | 1.18            | Kismir & Aroguz (2011)         |
| \textit{Salix alba} leaves (SAL) | 15.89 | This study                     |

Table 5 | Comparison of maximum adsorption capacity \( q_m \) of BG with previous studies

Desorption studies were also carried out for the determination of regeneration of the used adsorbent. The experiments were conducted using various kinds of molar desorbing agents (distilled water, KCl, NAOH, and HCl) for used SAL regeneration possibility. The maximum desorption (53.10%) was observed with 0.1 M KCl. The percentage desorption of different reagents of BG loaded SAL powder is presented in Table 6.

| Desorbing reagents | % Desorption |
|--------------------|--------------|
| 0.1 M KCl          | 53.10        |
| 0.1 M HCl          | 24.13        |
| 0.1 M NaOH         | 2.06         |
| Distilled water    | 7.58         |

Table 6 | The BG loaded SAL % desorption studies
better removal efficiency and adsorption capacity even at very low dye concentration and at other moderate experimental conditions (contact time from 10 to 250 minutes, 50 mg/L BG concentration, 0.15 g adsorbent dose, and pH = 6 at 298 K). 0.1 M KCl was found to be the best desorbing agent for BG loaded SAL with percent desorption of 53.10%. It may be used for the removal of other hazardous dyes such as methylene blue, crystal violet, congo red, etc.

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