2.1. Introduction

Dyes and pigments are widely used as colouring agents. The total dye consumption in textile industry worldwide is more than 10,000 tonnes/year and approximately 100 tonnes/year of dyes discharged into waste streams. Dye effluents are aesthetic pollutants that contain chemicals which exhibit toxic effect towards microbial populations and can be toxic and carcinogenic to organisms and mammals [1, 2]. Congo red (CR) is a benzidine-based anionic bisazo dye known to metabolize to benzidine, a known human carcinogen [3]. CR is toxic to animals and plants and thus its introduction to water stream is of potential health, environmental, and ecological concern. Therefore, CR containing effluents have to be adequately treated before they are discharged into the environment. Owing to structural stability, CR is difficult to biodegrade. Physicochemical or chemical treatment of such wastewater is, however, possible [4].

Adsorption techniques for wastewater treatment have become more popular in recent years owing to their efficiency in the removal of pollutants than other conventional methods. Although activated carbons are used abundantly throughout the water and wastewater treatment industries. Carbon adsorption is an expensive process because of high cost of producing activated carbons. Over recent years, this has attracted considerable research into low-cost alternative materials for the production of carbon from agricultural wastes for dye removal, such as coir pith [5], bamboo dust, coconut shell, groundnut shell, rice husk, straw [6], coconut coir [7], euphorbia rigida [8], cedar wood [9], corncob [10] etc. These residues from agricultural and agro-industries are valuable materials because their current economic values are less than the apparent cost of collection, transportation and processing for beneficial use [11]. Bael (Aegle marmelos) is an indigenous fruit of India. It is grown throughout Southeast Asian countries like India, Sri Lanka, Pakistan, Bangladesh, Burma, and Thailand. The peel of bael fruit comprises of a very hard shell which is
about 30% of total fruit weight [12]. Therefore, bael shell is a byproduct of its fruit and considered to be a waste.

In this study, the adsorptive removal of CR dye from aqueous solution onto bael shell carbon (BSC) was investigated. The effect of different parameters such as pH, temperature, contact time and initial dye concentration were investigated. The adsorption kinetics and isotherms for CR adsorption onto BSC were also studied and the mechanism of CR adsorption was discussed.

2.2. Materials and Methods

2.2.1. Preparation of Bael Shell Carbon

Bael shell was collected locally. It was washed with the distilled water and dried in sunlight for ten days. The dried shell was crushed and sieved to 150 BSS mesh particle size before subjecting it to carbonization for 1 h at 450 °C in muffle furnace. The carbonized sample was washed with hot distilled water and dried at 60 °C for 24 h and subsequently used as such for further studies.

2.2.2. Characterization of BSC

2.2.2.1. Elemental, SEM and FTIR Analysis

The elemental analysis of bael shell and bael shell carbon was performed using EA1108 (Carlo-Erba). The surface morphology of BSC was studied by the scanning electron microscopy using Leo 435 VP model. FTIR analysis of BSC before and after adsorption was carried out in the range of 400-4000 cm\(^{-1}\) by Inter-spec 2020, Spectro lab, UK, in KBr pellets.

2.2.2.2. Determination of Surface Active Groups

Surface functional groups on BSC were evaluated by Boehm acid-base titration method [13]. The amount of oxygen-containing groups (carboxyl, lactonic and phenol) on BSC was determined by neutralizing with 0.1 N NaHCO\(_3\), 0.1 N Na\(_2\)CO\(_3\), and 0.1 N NaOH solutions, respectively. The basic groups of BSC were neutralized with 0.1 N HCl. The acidic and basic sites were determined by adding 50 ml of 0.1 N titrating solution and 1 g of BSC into 250 ml volumetric flask. The flasks were left for 5 days at 30 °C. Afterward, a sample of 10 ml was titrated with 0.1 N HCl or NaOH solutions. The carboxylic and lactonic sites were titrated with a 0.1 N Na\(_2\)CO\(_3\) solution, while the carboxylic sites were determined with 0.1 N NaHCO\(_3\)
solution and the phenolic sites were subsequently estimated by difference [14].

### 2.2.2.3. Determination of Zero Point Charge of BSC

The point of zero charge (pHz) was determined by the salt addition method. In the procedure, 0.1 M KCl solutions were prepared and its initial pH was adjusted between 2.0 to 11.7 using NaOH and HCl solution. Then, 20 ml of 0.1 M KCl was taken in a 150 ml flask and 0.02 g of BSC was added to each flask. These flasks were kept for 24 h and the final pH was measured. The graph was plotted between initial and final pH. The pHz was then calculated from this graph at the point where \( \Delta \text{pH} = 0 \) [7].

### 2.2.3. Batch Adsorption Studies

The batch experiments were carried out by taking 20 ml of CR dye solution of known concentration in a 125 ml flask. 0.02 g of BSC was added to each flask and mixture was agitated in water bath shaker at 80 rpm until equilibrium was achieved. Then, the concentration of CR in the supernatant solution was analyzed using Elico SL 164 spectrophotometer (double beam) at the \( \lambda_{\text{max}} = 496 \text{ nm} \), except at pH 3 (\( \lambda_{\text{max}} = 580 \text{ nm} \) showed colour change). The percent adsorption of CR and equilibrium adsorption capacity, \( q_e \) (mg/g), was calculated by the following relationships, respectively:

\[
\% \text{ adsorption} = 100 \left( \frac{C_0 - C_e}{C_0} \right)
\]

\[
q_e = \frac{(C_0 - C_e) V}{m}
\]

where, \( C_0 \) and \( C_e \) are the initial concentration and equilibrium concentration of CR (mg/l), respectively. \( V \) is the volume of the dye solution (l), and \( m \) is the mass of BSC (g).

### 2.2.3.1. Effect of pH and Kinetic Studies

Adsorption of dye is strongly dependent on the solution pH. This can be attributed to the chemical form of dye in solution and functional groups present on the adsorbent surface at a specific pH [15]. CR is a diazo anionic dye. The effect of pH on CR adsorption onto BSC was studied from 3 - 9.5. Adsorption kinetics was studied at different pH 5.7- 9.5 by agitating 20 ml of CR solution of concentration 50 mg/l with 0.02 g of BSC to the different time intervals (5, 15, 30, 45, 60, 90, 120, 150 and 180 min).
CR is a pH sensitive dye and exposure to HCl causes colour change from red to blue, due to $\pi-\pi^*$ transition of azo group shift to higher wavelength because of protonation [16]. Yermiyahu et al. [17] have performed the potentiometric titration of CR and revealed that at lower pH, it become cationic and shows two tautomeric form of protonated CR, i.e. ammonium rich variety and azonium variety. The fresh solution shows the predomination of ammonium rich variety whereas after 1 h, azonium rich variety predominated and the isoelectric point of CR is near pH 3 [18].

2.2.3.2. Effect of Concentration

The effect of the initial dye concentration was determined by introducing 0.02 g of adsorbent in 20 ml of dye solution of different initial concentrations 40 to 80 mg/l at pH 5.7 for 180 min at 30 °C. The concentration of CR left in the supernatant solution was determined by spectrophotometer.

2.3. Results and Discussion

2.3.1. Characterization

2.3.1.1. Elemental and SEM Analysis

The elemental analysis of bael shell and BSC is shown in Table 2.1. As depicted in Table 2.1, the carbon content in the BSC has significantly increased compared to the raw material which may be attributed to high carbonization temperature. On the other hand, the hydrogen and nitrogen contents are lower than the raw material. A slight decrease in the nitrogen content can be explained by lose of nitrogen containing groups like amides and amines which decomposed at temperature above 400 °C. The decrease in hydrogen content was caused by its removal in the form of moisture during carbonization process.

The textural structure examination of BSC particles can be observed from the SEM photograph. SEM of BSC taken before and after dye adsorption is shown in Fig. 2.1. The SEM image shows irregular and porous texture surface morphology. The pores were prominent on the surface of BSC before adsorption but after adsorption the pores were filled by the dye (CR), whereby the adherence to the surface of adsorbent.
Table 2.1. Elemental analysis of beal shell and bael shell carbon.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Bael shell</th>
<th>Bael shell carbon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture at 110 °C (%)</td>
<td>9.5</td>
<td>5</td>
</tr>
<tr>
<td>Ash content at 715 °C (%)</td>
<td>26.8</td>
<td>32</td>
</tr>
<tr>
<td>Volatile content at 930 °C (%)</td>
<td>52.7</td>
<td>32</td>
</tr>
<tr>
<td>C content (%)</td>
<td>45.81</td>
<td>68.67</td>
</tr>
<tr>
<td>H content (%)</td>
<td>7.03</td>
<td>3.07</td>
</tr>
<tr>
<td>N content (%)</td>
<td>0.50</td>
<td>0.42</td>
</tr>
</tbody>
</table>

Fig. 2.1. SEM image of BSC (a) before CR adsorption and (b) after CR adsorption.

Fig. 2.2. Initial vs final pH plot for determination of zero point charge of BSC.
2.3.1.2. Surface Active Groups and Zero Point Charge

The concentrations of total acidic and basic sites on BSC determined by the Boehm titration method are 0.64 mequiv/g (carboxylic and lactonic site - 0.52 mequiv/g and carboxylic site - 0.12 mequiv/g) and 0.3 mequiv/g, respectively. The combined influence of all the functional groups of BSC determines pH\(_z\). Fig. 2.2 shows that at 6.28, \(\Delta pH = 0\). Therefore the pH\(_z\) of BSC is 6.28.

2.3.2. Effect of pH

The complexation of dye with the adsorbent surface is significantly affected by the solution pH. The adsorption of CR was studied in the pH range 3-9 and the maximum adsorption was observed at pH 3. The percentage adsorption of CR at pH 3, 4, 5, 6, 7, 8 and 9.5 was 92, 88, 85, 83, 82, 48, and 44, respectively. The maximum adsorption onto BSC at lower pH may be due to the more positive charge on the adsorbent surface. Similar kinds of results were also reported for the adsorption of CR by Binupriya et al. [19] and Chowdhury et al. [20]. The adsorption of CR onto BSC can be explained via van’der Waals, electrostatic, H-bonding and hydrophobic-hydrophobic interactions. The role of these interactions can be explained as follows:

(i) In acidic medium, the protonation of –OH and –COOH groups present at BSC surface (i.e. \(C_x\)-OH + H\(^+\) \(\leftrightarrow\) \(C_x\)-OH\(_2\)^\(+\), \(C_x=\) Carbon) occurs (since pH\(_z\) of the adsorbent is 6.28, below which the adsorbent surface is positive). Generally, the carboxyl groups presented a pKa value between 3.0 and 5.0 [21]. At pH lower than pKa, carboxylate groups carry positive charge resulting electrostatic interaction between negatively charged SO\(_3\)^\(–\) groups and positively charged adsorbent surface.

(ii) H-bonding between oxygen and nitrogen containing functional groups of CR and BSC surface.

(iii) Hydrophobic - hydrophobic interaction between hydrophobic parts of CR and BSC [22].

(iv) In basic medium, the carboxylic groups of BSC are expected to ionize completely. Therefore, electrostatic repulsion between anionic CR and anionic BSC surface which lowers adsorption capacity.

In support of the above explanation, FTIR spectra of BSC before and after CR
Adsorptive Removal of Congo Red

Adsorption are presented in Fig. 2.3. The major differences are: the absorption band at 3387 cm$^{-1}$ (Fig. 2.3a), corresponding to the stretching vibration of O-H and N–H on BSC, diminishes after adsorption with CR and shifts to lower wave number 3378 cm$^{-1}$ (Fig. 2.3b) and 3149 cm$^{-1}$ (Fig. 2.3c). This difference indicates the hydrogen bond formation between the hydroxyl groups of BSC and the amine group of dye molecules at pH 5.7 (Fig. 2.4a). At the lower pH, protonation of adsorbent’s carboxylic and hydroxyl groups occurs which leads to the increase in electrostatic interaction with the dye (Fig. 2.4b). The appearance of two new peaks at 2889 cm$^{-1}$ and 2834 cm$^{-1}$ can be assigned to the –CH stretch (Fig. 2.3c). A significant shift of C = O from 1689 cm$^{-1}$ to 1691 cm$^{-1}$ and 1694 cm$^{-1}$ confirms the interaction with the dye molecule. Furthermore, the peak at 1590 cm$^{-1}$ can be attributed to amine group, showing the lower wave number 1577 cm$^{-1}$ and 1587 cm$^{-1}$ after CR adsorption indicates the formation of hydrogen bond between the O-H group of BSC and N–H groups of the dye molecules. Moreover, the IR spectra of BSC taken before and after dye adsorption shows that the absorption band at 1256 cm$^{-1}$ (Fig. 2.3a), corresponding to –SO$_3$ group, broadened and strengthened after adsorption (Fig. 2.3b and 2.3c). A new absorption peak at 797 cm$^{-1}$ was observed on BSC after CR adsorption assigned to characteristic adsorption of aromatic skeletal groups. Fig. 2.4 shows the proposed mechanism of CR adsorption onto BSC. Wang and Wang [23] also reported that the NH$_2$, –N=N–,–HN–N= and –SO$_3$ groups of CR were involved in the adsorption.

Fig. 2.3. FTIR of BSC (a) before CR adsorption (b) after adsorption of CR at pH 5.7 and (c) after adsorption of CR at pH 3.
Fig. 2.4. Proposed mechanism of CR adsorption (a) at pH 5.7 and (b) at pH 3.

2.3.3. Effect of Contact Time and Kinetics

The effect of contact time on the CR adsorption onto BSC at different pH is depicted in Fig. 2.5. The adsorption of CR decreases and the equilibrium time increases when the initial solution pH is increased. The adsorption of CR on BSC
Adsorptive Removal of Congo Red

showed two phases: (i) an initial rapid phase where adsorption capacity sharply increased within the first 50 min due to the rapid surface adsorption (external surface adsorption) and (ii) a slower phase whose contribution to the total dye adsorption was relatively small (internal surface adsorption) [24]. Adsorption equilibrium can be achieved within 100 min, after which the adsorption of dye was negligible.

![Graph showing adsorption kinetics](image)

**Fig. 2.5. Kinetics of CR adsorption onto BSC at 30 °C.**

The adsorption kinetics was investigated for better understanding of reaction pathways and dye uptake rate. Fig. 2.5 represent to the kinetics of CR adsorption onto BSC. First-order reversible model, pseudo-first order model and pseudo-second order model were applied to the experimental data obtained. The linear equations for the applied model were:

First-order reversible model: \[ \ln (1-U) = -k t \] (3)

Pseudo-first order model: \[ \log (q_e - q_t) = \log q_e - \left(\frac{k_1 t}{2.303}\right) \] (4)

Pseudo-second order model: \[ \frac{t}{q_t} = \left(\frac{1}{k_2 q_e^2}\right) + \left(\frac{t}{q_e}\right) \] (5)

where \( k \) is the rate constant of first-order reversible adsorption, \( U_t \) is fraction attainment of equilibrium, \( k_1 \) and \( k_2 \) are the rate constant of pseudo-first order and pseudo-second order rate constants, respectively. \( q_e \) and \( q_t \) are adsorption capacity at equilibrium (mg/g) and at any time, respectively. The parameters obtained from the kinetics models are listed in Table 2.2. It is evident from Table 2.2 that a more precise fit of kinetics data was shown by the pseudo-second order model at pH 5.7, 7 and 8.
The values of calculated adsorption capacity are much closer to the experimental adsorption capacity for pseudo-second order kinetic model and the values of regression coefficients ($R^2$) are higher (0.9983) than that of first-order reversible and pseudo-first order kinetic model. At pH 9, the values of $k$ calculated from the first-order reversible model is found to be closer to that of the values of $k_1$ computed from Lagergren equation, indicating that the adsorption of CR follows the pseudo-first order kinetic model [6].

### Table 2.2. Constants for the kinetic adsorption of CR onto BSC using different models.

<table>
<thead>
<tr>
<th>Order Reaction</th>
<th>Parameters</th>
<th>pH-5.7 (l/min)</th>
<th>pH-7 (l/min)</th>
<th>pH-8 (l/min)</th>
<th>pH-9.5 (l/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-order reversible model</td>
<td>$k$</td>
<td>0.034</td>
<td>0.048</td>
<td>0.103</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>$R^2$</td>
<td>0.9818</td>
<td>0.9714</td>
<td>0.9797</td>
<td>0.9433</td>
</tr>
<tr>
<td>Pseudo-first order model</td>
<td>$k_1$ (l/min)</td>
<td>0.056</td>
<td>0.048</td>
<td>0.0718</td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td>$q_e$ (mg/g)</td>
<td>2.952</td>
<td>4.732</td>
<td>16.994</td>
<td>15.624</td>
</tr>
<tr>
<td></td>
<td>$R^2$</td>
<td>0.9563</td>
<td>0.9978</td>
<td>0.9998</td>
<td>0.9409</td>
</tr>
<tr>
<td>Pseudo-second order model</td>
<td>$k_2$ (g/mg min)</td>
<td>0.492</td>
<td>0.029</td>
<td>0.005</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>$q_e$ (mg/g)</td>
<td>42.37</td>
<td>41.32</td>
<td>27.63</td>
<td>3.66</td>
</tr>
<tr>
<td></td>
<td>$R^2$</td>
<td>0.9999</td>
<td>0.9999</td>
<td>0.9983</td>
<td>0.911</td>
</tr>
</tbody>
</table>

2.3.4. Effect of Concentration and Equilibrium Modeling

The dye adsorption capacity of BSC at equilibrium increases from 31 to 68 mg/g when the initial concentration was increased from 40 to 80 mg/l. The larger adsorption capacity at higher concentration was possibly due to the greater driving force created by the concentration gradient ($\Delta C = C_0 - C_e$).

The surface property, affinity of adsorbent and adsorbate can be characterized by the different equilibrium models. The equilibrium data obtained for the adsorption of CR onto BSC were fitted into three isotherm models namely Langmuir, Freundlich and Temkin, to determine the most suitable model that represent the adsorption process.

The Langmuir model [25] that assumes monolayer adsorption onto adsorbent surface containing finite number of identical sites and no transmigration of the adsorbate in the plane of the surface is given by the following equation:
1/ q_e = (1/ \Theta^0 b C_e) + (1/ \Theta^0) \tag{6}

The Freundlich model [26] assumes multilayer adsorption and heterogeneous system, characterized by the heterogeneity factor 1/n. Freundlich model is expressed by the following equation:

\[ \ln q_e = \ln K_F + (1/n) \ln C_e \tag{7} \]

The Temkin model [27] is represented by the following equation:

\[ q_e = B \ln A + B \ln C_e \tag{8} \]

where q_e (mg/g) is the dye amount adsorbed at equilibrium, C_e (mg/l) is the equilibrium concentration of dye, \( \Theta^0 \) (mg/g) and b (l/mg) are the Langmuir constants. K_F and n are the Freundlich constants denoting adsorption capacity and intensity of adsorption, respectively. A and B are the Temkin constants. The values of these parameters were calculated from slope and intercept of their respective plots as shown in Fig. 2.6, 2.7 and 2.8.

Fig. 2.6. Langmuir isotherm plot for the adsorption of CR onto BSC.
The values of Langmuir, Freundlich and Temkin adsorption isotherm parameters are listed in Table 2.3. It was found that the correlation coefficients of Langmuir, Freundlich and Temkin were 0.9679, 0.972 and 0.9399, respectively. This revealed that the data were better fitted by Freundlich model than Langmuir and Temkin model. The magnitude of the Freundlich constants, $K_F$ and $n$ indicate that the uptake of CR dye from aqueous solution onto BSC was feasible. The value of Freundlich exponent $n$ is 1.84 which lies in the range of 1–10, indicating the favorable
adsorption of CR onto BSC. Similar results were also observed for the removal of CR onto rice husk ash [20]. The maximum monolayer adsorption capacity of the BSC was found to be 98.03 mg/g. The comparison of the maximum monolayer adsorption capacities of the various carbonized adsorbents with BSC is shown in the Table 2.4.

Table 2.3. Langmuir, Freundlich and Temkin constants for CR adsorption.

<table>
<thead>
<tr>
<th>Langmuir model</th>
<th>Freundlich model</th>
<th>Temkin model</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Theta^0 = 98.039$ (mg/g)</td>
<td>$K_F = 5.243$ (mg/g)(mg/l) $^{-1/n}$</td>
<td>$A = 0.111$ (l/g)</td>
</tr>
<tr>
<td>$b = 0.016$ (l/mg)</td>
<td>$n = 1.840$</td>
<td>$B = 25.8$</td>
</tr>
<tr>
<td>$R^2 = 0.9679$</td>
<td>$R^2 = 0.972$</td>
<td>$R^2 = 0.9399$</td>
</tr>
</tbody>
</table>

Table 2.4. Comparison of maximum monolayer adsorption capacity of various carbons for CR removal.

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Adsorption capacity (mg/g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coir pith carbon</td>
<td>6.7</td>
<td>[5]</td>
</tr>
<tr>
<td>Bamboo dust carbon</td>
<td>101.9</td>
<td>[6]</td>
</tr>
<tr>
<td>Coconut shell carbon</td>
<td>188.4</td>
<td>[6]</td>
</tr>
<tr>
<td>Groundnut shell carbon</td>
<td>110.8</td>
<td>[6]</td>
</tr>
<tr>
<td>Rice husk carbon</td>
<td>237.8</td>
<td>[6]</td>
</tr>
<tr>
<td>Straw carbon</td>
<td>403.7</td>
<td>[6]</td>
</tr>
<tr>
<td>Commercial activated carbon</td>
<td>493.8</td>
<td>[6]</td>
</tr>
<tr>
<td>Rice husk ash</td>
<td>7.047</td>
<td>[20]</td>
</tr>
<tr>
<td>Carbon slurry waste</td>
<td>272</td>
<td>[28]</td>
</tr>
<tr>
<td>Beal shell carbon</td>
<td>98.03</td>
<td>this work</td>
</tr>
</tbody>
</table>

2.3.5. Thermodynamic Studies

The adsorption of CR onto BSC was studied at 25, 40 and 55 °C as shown in Fig. 2.9. The adsorption was found to increase from 40-46 mg/g with increase in temperature. Increase in temperature may increase the rate of diffusion of the adsorbate molecules into the internal pores of adsorbent particle and may decrease the viscosity of the solution [29].

Thermodynamic studies were performed to find the nature of adsorption process. Thermodynamics parameters i.e. free energy ($\Delta G^0$), enthalpy ($\Delta H^0$) and
Adsorptive Removal of Congo Red

entropy ($\Delta S^0$) were calculated using Van’t Hoff and Gibb’s –Helmholtz equations:

$$\Delta G^0 = -RT \ln K_c$$  \hspace{1cm} (9)

$$K_c = \frac{C_{ae}}{C_e}$$  \hspace{1cm} (10)

$$\ln K_c = \left(\frac{\Delta S^0}{R}\right) - \left(\frac{\Delta H^0}{RT}\right)$$  \hspace{1cm} (11)

where $C_{ae}$ and $C_e$ are the equilibrium concentration of dye (mg/g) on the adsorbent and solution, respectively. $K_c$ is the equilibrium constant, $T$ is the solution temperature (K) and $R$ is the gas constant. The value of $\Delta H^0$ and $\Delta S^0$ was calculated from the slope and intercept of plot of $\ln K_c$ vs $1/T$ (Fig. 2.9, inset). The negative $\Delta G^0$ values 3.986, 4.46 and 5.781 kJ/mol at 25, 40 and 55 °C, respectively indicates the spontaneous nature of CR adsorption onto BSC. The positive $\Delta H^0$ value 13.613 kJ/mol, confirmed the endothermic nature of CR adsorption, while the positive value of $\Delta S^0$ (58.8 J/mol K) reflect the affinity of the CR towards BSC.

Mattson and Mark [30] have reported that the enthalpy changes for the adsorption of organic molecules from aqueous solution onto activated carbon are usually within the range 8-65 kJ/mol. The enthalpy change due to chemisorption falls between 84 and 420 kJ/mol whereas enthalpy change of less than 84 kJ/mol associated with physical adsorption. [31]. The enthalpy change for CR adsorption is 13.613 kJ/mol. Therefore, the adsorption of CR onto BSC is is likely to be physisorption.

![Fig. 2.9. Effect of Temperature on CR adsorption onto BSC](image-url)

2.4. Conclusion

The aim of this work was to study the adsorption of CR onto BSC and to find the proper adsorption mechanism. From the results, following conclusions can be drawn:

- The adsorption of CR onto BSC was strongly pH dependent. In acidic medium adsorption occurs by electrostatic, hydrogen bonding and hydrophobic–hydrophobic interactions. The maximum adsorption (92%) was observed at pH 3.
- Oxygen containing functional groups on BSC plays an important role in the CR adsorption.
- It was found that pseudo-second order fitted well at pH 5.7, 7 and 8 whereas at pH 9.5, pseudo-first order was the rate limiting step.
- Freundlich model was found to provide the best fit to the experimental data indicated heterogeneous and multilayer adsorption.
- Thermodynamic studies showed the spontaneous and endothermic nature of CR adsorption onto BSC. The positive $\Delta H^0$ value 13.613 kJ/mol indicating the physical forces were involved in the adsorption of CR.
References


