Removal of hazardous Rhodamine dye from water by adsorption onto exhausted coffee ground

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Abstract Exhausted coffee ground powder (CGP) was proved to be an efficient adsorbent for the removal of Rhodamine dyes (i.e. Rhodamine B and Rhodamine 6G) from aqueous solutions by batch adsorption experiments. The morphology, chemical structure as well as the surface property of the as-prepared CGP adsorbent were investigated by using SEM, FT-IR and contact angle meter analytical techniques. The adsorption kinetics and isotherm behaviors of Rhodamine molecules onto CGP were studied and compared using pseudo-1st, pseudo-2nd and Langmuir/Freundlich models, respectively. The maximum adsorption capacities of Rh B and Rh 6G were calculated at 5.255 and 17.369 l mol g⁻¹ by Langmuir model fitting. The effects of temperature, ionic strength, solution volume and the co-existing anions on the sorption behavior were also investigated. Furthermore, the adsorption mechanism responsible for the efficient removal of dyes is discussed in terms of adsorption process caused by electrostatic and intermolecular forces.

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1. Introduction

The textile industry is one of the major sources, which discharges large amounts of industrial waste water. The discharge of such contaminated water into public streams is a great environmental challenge not only due to its treatment for reuse but also its toxicity to human beings and animals by contaminating underground water reservoirs [1]. The Rhodamine dye is one of fresh peach of synthetic dyes and it is widely used as a colorant in the manufacturing of textiles and food stuffs. It has been medically proven that drinking water contaminated with Rhodamine dyes could lead to subcutaneous tissue borne sarcoma which is highly carcinogenic [2]. In addition, others kinds of toxicity such as reproductive and neurotoxicity have been widely and intensively investigated and proved as well by exposure to these dyes [2].

Various natural or wasted materials have been extensively explored and investigated for the adsorption removal of different contaminants from aqueous solutions [3–6]. Coffee beans are now produced and used in significant quantities worldwide.
According to the data reported by United States Department of Agriculture (USDA), the annual global production capacity of coffee beans in the year 2012/2013 was estimated as exceeding 150 million of 60 kg bags and in future more production and waste of coffee ground are expected [7]. Therefore, the efficient utilization of the waste of coffee grounds has attracted considerable attention as millions of posts of coffee are brewed and millions of pounds of wet grounds are thrown every day all around the world. The carbonized form of coffee grounds has been attempted for soil remediation, adsorption removal of hazardous molecules from aqueous or gas phases or waste water desalination [8–10].

In this work, exhausted coffee ground powder (CGP) was used directly as a zero-cost adsorbent for the application of adsorption removal of Rhodamine dyes like Rhodamine B (Rh B) and Rhodamine 6G (Rh 6G) from aqueous solutions. The crystal and chemical structures of the as-prepared CGP were examined to understand the possible adsorption mechanism for removal of dyes. In addition, the adsorption kinetic, isotherm behaviors were compared and the thermodynamic parameters were calculated as well. Furthermore, the adsorption mechanism responsible for the efficient adsorption removal behavior is discussed in terms of adsorption caused by electrostatic and intermolecular forces.

2. Experimental

2.1. Materials

The coffee powders were purchased from local market in Saudi Arabia. To obtain the final CGP product, each 5 g of coffee powders was washed with 200 mL of boiled deionized water 3 times to get rid of any impurities. Salts of KCl and K2SO4 were purchased from BDH chemicals (Poole England) and K2HPO4 was purchased from Sigma–Aldrich (USA). The Rh B and Rh 6G dyes were purchased from Lambda Physik (USA) and Merek (Germany), and their properties are listed in Table 1. All the chemical reagents are of analytical grade and used without further purification.

2.2. Characterization

The crystal structure of the as-prepared CGP adsorbent was investigated by X-ray diffractometer (XRD, Bruker D8 ADVANCE) with 2θ scope of 10–90° using Cu-Kα X-ray source (λ = 0.15418 nm). The morphology of the as-prepared CGP was studied by a scanning electron microscope (SEM, FEI inspect F50). Fourier transform infrared spectra (FTIR) were recorded at room temperature using a FTIR spectrophotometer (NEXUS 670). The zeta potentials of the as-prepared adsorbent at different pHs were determined by a zeta potential instrument (Malvern, Great Britain). The water contact angle was measured by a contact angle meter (SL200B, Shanghai) at ambient conditions.

2.3. Batch adsorption experiments

Batch adsorption experiments were conducted to examine the adsorption kinetics, adsorption isotherm, the effect of temperature, solution pH and the ionic strength on the adsorption process as well as desorption and regeneration. A certain amount of CGP was mixed with Rhodamine dye aqueous solutions with a known initial concentration, and the mixture was stirred in a stir machine at a constant stirring speed and temperature. The mixture was centrifuged at 4000 rpm in a centrifugation machine after batch adsorption experiments so that the absorbance of Rh B and Rh 6G can be measured at 554 and 526 nm by means of UV–vis spectrophotometer (JASCO, V-570), respectively. The concentrations of the solutions were determined using linear regression equation.


Two kinetic models were used to fit the experimental data at different temperatures. The pseudo-first-order rate expression of Lagergren model is generally expressed as follows:

\[
\frac{dq}{dt} = k_1(q_{eq} - q)
\]

where \(q_{eq}\) and \(q\) are the amounts of adsorbed dye onto the CGP at equilibrium and at time \(t\), respectively. \(k_1\) is the rate constant of first-order adsorption. The integrated form of Eq. (1) is:

\[
\frac{1}{q} = k_1 t + \frac{1}{q_{eq}}
\]

The plots of \(1/q\) against \(1/t\) for the pseudo-first-order equation give a linear relationship and \(k_1\) and \(q_{eq}\) values can be determined from the slope and intercept of this equation, respectively. The pseudo-second-order kinetic rate equation is expressed as:

Table 1 Selected properties of Rh B and Rh 6G.

<table>
<thead>
<tr>
<th>Dyes</th>
<th>Rh B</th>
<th>Rh 6G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td><img src="image.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Chemical formula</td>
<td>C28H31N2O3Cl</td>
<td>C27H29ClN2O3</td>
</tr>
<tr>
<td>Mw</td>
<td>479.02</td>
<td>464.98</td>
</tr>
</tbody>
</table>
\[
\frac{dq}{dt} = k_2 (q_{eq} - q)^2 \tag{3}
\]

where \(k_2\) is the rate constant of second-order adsorption. After integrating, the following equation is obtained:

\[
t = \frac{1}{k_2 q_{eq}^2} + \frac{t}{q_{eq}} \tag{4}
\]

2.3.2. Thermodynamics [12]
The Gibbs free energy change \(\Delta G^o\), indicates the degree of spontaneity of the adsorption process. For significant adsorption to occur, the free energy changes \((\Delta G^o)\) of adsorption must be negative. The Gibbs free energy change of adsorption is defined as:

\[
\Delta G^o = -RT \ln K \tag{5}
\]

The other thermodynamic parameters, change in the enthalpy \((\Delta H^o)\), and entropy \((\Delta S^o)\), were determined by using following equations:

\[
K = \frac{C_A}{C_S} \tag{6}
\]

\[
\Delta G^o = \Delta H^o - T \Delta S^o \tag{7}
\]

where \(K\) is the equilibrium constant; \(C_A\), the amount of dye adsorbed on the adsorbent of the solution at equilibrium; \(C_S\), the equilibrium concentration of the dye in the solution. \(T\) is the solution temperature and \(R\), the gas constant.

2.3.3. Isotherms [13]
In this study, two classical adsorption models, i.e. Langmuir and Freundlich isotherms, were employed to describe Rh B and Rh 6G adsorption equilibrium. The Langmuir isotherm is valid for monolayer adsorption onto a surface with a finite number of identical sites. The Langmuir model is based on the assumption of adsorption homogeneity, such as equally available adsorption sites, monolayer surface coverage, and no interaction between adsorbed species. The Langmuir model can be expressed as:

\[
q_e = \frac{K_L q_m C_e}{1 + C_e} \tag{8}
\]

where \(C_e\) is the equilibrium concentration of the adsorbates in the solution, \(q_m\) the maximum adsorption capacity and \(K_L\) is the adsorption equilibrium constant.

The Freundlich equation is the empirical relationship whereby it is assumed that the adsorption energy of a protein binding to a site on an adsorbent depends on whether or not the adjacent sites are already occupied. One limitation of the Freundlich model is that the amount of adsorbed solute increases indefinitely with the concentration of solute in the solution. This isotherm can be described as follows:

\[
q_e = K_F (C_e)^{1/n} \tag{9}
\]

where \(q_e\) is the adsorption capacity at equilibrium, \(C_e\) the equilibrium concentration of adsorbates in the solution, and \(K_F\) and \(n\) are the physical constants of Freundlich adsorption isotherm which indicate the adsorption capacity and adsorption intensity, respectively.

2.3.4. Influence of solution volume
The Rhodamine dye solution volume was adjusted continuously and increased from 10 to 200 mL with the constant initial concentration of Rhodamine dye of 15 \(\mu\)mol L\(^{-1}\), corresponding to the simulation of the waste water basin where the solution volume varies with time and place [14].

2.3.5. Influence of ionic strength
To investigate the effect on ionic strength on the adsorption capacity, the ionic strength varied from 0.001 to 0.1 M by adding different amounts of \(K_2SO_4\) and the concentration of Rhodamine dye was 15 \(\mu\)mol L\(^{-1}\).

Figure 1 Representative SEM images (a, b) and FTIR (c) of the as-prepared CGP adsorbent. The inset figures a and c show the particle size distributions (sample size = 168) and the image of a water droplet on the surface of CGP surface demonstrating its hydrophobic property, respectively.
2.3.6. Influence of co-existing anions
The effects of co-existing anions on the Rhodamine dye adsorption were studied in 15 μmol L⁻¹ Rhodamine dye solution. Three kinds of salts of KCl, K₂SO₄ or K₂HPO₄ were selected to study the effect of co-existing anions on the adsorption capacity.

2.3.7. Regeneration by photolysis and reuse
The regeneration of saturated adsorbent by photolysis was carried out under a Xenon lamp irradiation with full arc (460 Watts, Oriel instrument). FTIR measurement suggested that the CGP adsorbent can be almost regenerated after irradiation for 2 h as no FTIR signals of Rhodamine dye molecules can be detected. The regenerated adsorbent was re-used in the next cycle of adsorption.

3. Results and discussion

3.1. Characterization of CGP adsorbent
The amorphous characteristic was proved by XRD measurement (not shown) as there is no apparent diffraction peak in the 2θ range of 1–90°. Fig. 1(a and b) depicts the SEM image of the as-prepared CGP adsorbent. The average particle size is calculated at 11.4 μm under the sample size of 168. Most of the particle sizes are ranged 1–20 μm. The enlarged image of the adsorbent is shown in Fig. 1(b), which suggests the hierarchical morphology of the as-prepared CGP adsorbent. As clear from Fig 1(b), the particles of adsorbent are of micrometer size and also consisted of numerous nanoparticles of hundreds of nanometers size. FTIR spectrum of the as-prepared CGP adsorbent was measured to study the surface chemical structure. As depicted in Fig. 1(c), the hydrophobic functional group of the C–H group was centered at wavenumbers 2921 and 2841 cm⁻¹, and the C–O group at 1741 cm⁻¹. The hydrophobic property of the CGP surface was also studied. The image of a water droplet on the surface of the CPG layer was captured and shown in the inset of Fig. 1(c). The contact angle of the droplet was measured at 113°, further suggesting the hydrophobic nature of the CPG surface.

3.2. Adsorption kinetics
As depicted in Fig. 2, a sharp increase can be observed by raising the adsorption temperature from 278 to 292 K. After adsorption for 2 h, the adsorption–desorption equilibrium can be reached and the adsorption capacity of Rh B was calculated at 3.02 and 1.66 l mol⁻¹ g⁻¹ at 292 and 278 K for Rh B, respectively. However the saturated adsorption capacity of Rh 6 G was found to be 4.16 and 5.45 times that of Rh B, which is calculated at 12.7 and 7.00 μmol g⁻¹ at 292 and 278 K, respectively. The fitted constants by the first-order and second-order kinetic models for Rh B and Rh 6G adsorption are listed in Table 2. The correlation coefficients for the first-order kinetic and the second-order kinetic models were 0.99, close to 1.0 for Rh 6G at 292 and 278 K, Rh B at 292 K. Therefore, the adsorption of Rh B and Rh 6G by the adsorbent CGP can be approximated favorably both by the pseudo-first-order model and the pseudo-second-order model.

3.3. Adsorption thermodynamics
It can be noticed clearly from Fig. 2 that the adsorption capacity of Rh B and Rh 6G on CGP are increased by increasing the adsorption temperature, demonstrating the endothermic nature of the adsorption process, which is further demonstrated by the calculated positive value of ΔH°. As shown in Table 3, the positive value of ΔS° indicates the reversible characteristic of the adsorption of Rh B and Rh 6G onto CGP. ΔG° values were positive indicating that the adsorption process led to an increase in Gibbs free energy. Positive ΔG° values of Rh B indicate the nonspontaneity of the adsorption process and the negative ΔG° value of Rh 6G indicates the adsorption process was spontaneous.

3.4. Adsorption isotherms
Fig. 3 depicts the adsorption amount of RhB and Rh 6G on the CGP adsorbent at different equilibrium concentrations, and the
corresponding fitted results are listed in Table 4. It can be seen that the adsorption isotherms of Rh B and Rh 6G on the CGP adsorbent can be fitted better by the Langmuir model than the Freundlich model, indicating the homogeneous (monolayer) adsorption characteristic. The monolayer adsorption capacity of Rh B and Rh 6G was theoretically calculated at 5.255 and 17.369 μmol g⁻¹ by Langmuir model fitting, respectively.

For different adsorbents, the saturated adsorption capacity for adsorbates can be compared by calculating the amount of adsorbates adsorbed on the adsorbents through adsorption isotherms. Some of the natural (waste) adsorbent materials and their adsorption capacities are given in Table 5. As shown in Table 5, the low cost natural (waste) adsorbent, such as kaolinite, wasted biological sludge had been used to remove RhB or Rh 6G, and the corresponding adsorption capacity can be reached to as high as 46 and ~16.3 mg g⁻¹, respectively. Some natural adsorbents, such as natural zeolite and Na⁺-Montmorillonite are not inexpensive, but nevertheless their adsorption capacities for Rhodamine molecules are low and the reuse of such exhausted coffee grounds is appealing in terms of resource utilization.

### 3.5. Influence of solution volume

Fig. 4 depicts the effect of solution volume on the adsorption capacity of Rh B and Rh 6G over the as-prepared CGP adsorbent. It can be found that the adsorption capacity of Rh 6G and Rh B decreases linearly from 15.2 to 9.3 l mol g⁻¹ C₀⁻¹, and 5.3 to 1.6 l mol g⁻¹ C₀⁻¹ with rising solution volume from 10 to

<table>
<thead>
<tr>
<th>Dye</th>
<th>Temperature (K)</th>
<th>K</th>
<th>ΔG° (kJ/mol)</th>
<th>ΔH° (kJ/mol)</th>
<th>ΔS° (J/(mol K))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rh B</td>
<td>292</td>
<td>0.369</td>
<td>2.420</td>
<td>52.185</td>
<td>170.429</td>
</tr>
<tr>
<td></td>
<td>278</td>
<td>0.125</td>
<td>4.806</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rh 6G</td>
<td>292</td>
<td>3.923</td>
<td>-3.318</td>
<td>52.246</td>
<td>190.286</td>
</tr>
<tr>
<td></td>
<td>278</td>
<td>1.327</td>
<td>-0.654</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 Langmuir and Freundlich isotherm constants for adsorption of Rh B and Rh 6G on CGP adsorbent.

<table>
<thead>
<tr>
<th>Dye</th>
<th>q_m (μmol g⁻¹ C₀⁻¹)</th>
<th>K_L (L μmol⁻¹)</th>
<th>r²</th>
<th>K_F (μmol⁻¹ L¹/ₙ g⁻¹)</th>
<th>n</th>
<th>r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rh B</td>
<td>5.255</td>
<td>4.364</td>
<td>0.958</td>
<td>1.190</td>
<td>2.062</td>
<td>0.884</td>
</tr>
<tr>
<td>Rh 6G</td>
<td>17.369</td>
<td>1.053</td>
<td>0.882</td>
<td>8.161</td>
<td>2.952</td>
<td>0.749</td>
</tr>
</tbody>
</table>

### Table 5 Comparison of adsorption capacity of a few natural (waste) adsorbents for Rh B and Rh 6G removal.

<table>
<thead>
<tr>
<th>Adsorbents</th>
<th>Adsorption capacity (mg g⁻¹)</th>
<th>Refs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolinite</td>
<td>46.1 (Rh B)</td>
<td>[15]</td>
</tr>
<tr>
<td>Bentonite</td>
<td>7.7 (Rh B)</td>
<td>[16]</td>
</tr>
<tr>
<td>Luffa cylindrical</td>
<td>9.9 (Rh B)</td>
<td>[17]</td>
</tr>
<tr>
<td>Na⁺-Montmorillonite</td>
<td>38.27 (Rh B)</td>
<td>[18]</td>
</tr>
<tr>
<td>Australian natural zeolite</td>
<td>2.12 (Rh B)</td>
<td>[19]</td>
</tr>
<tr>
<td>Coal ash</td>
<td>2.86 (Rh B)</td>
<td>[20]</td>
</tr>
<tr>
<td>Cellulosic waste orange peel</td>
<td>3.23 (Rh B)</td>
<td>[21]</td>
</tr>
<tr>
<td>Anaerobic sludge</td>
<td>19.52 (Rh B)</td>
<td>[22]</td>
</tr>
<tr>
<td>Cellulose-based wastes</td>
<td>20.6 (Rh B)</td>
<td>[23]</td>
</tr>
<tr>
<td>Biological sludge</td>
<td>~16.3 (Rh 6G)</td>
<td>[24]</td>
</tr>
<tr>
<td>Trichoderma harzianum mycelial waste</td>
<td>3.40 (Rh 6G)</td>
<td>[25]</td>
</tr>
<tr>
<td>Na⁺-Montmorillonite</td>
<td>0.4 (Rh 6G)</td>
<td>[26]</td>
</tr>
<tr>
<td>Coffee ground powder</td>
<td>5.26 (Rh B)</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>17.37 (Rh 6G)</td>
<td></td>
</tr>
</tbody>
</table>
100 mL, respectively. The adsorption capacity decrease might be due to the overlapping of adsorption sites as a result of overcrowding of adsorbent particles [27]. This procedure may correspond to simulation of the adsorption removal that takes place in a lake or river where the rate of solute and solvent are relatively constant and the solution volume varies with time and place.

3.6. Influence of ionic strength

It is well known that the ionic strength could affect the electrostatic interactions between adsorbents and adsorbates to a certain extent, meanwhile the electrolytes can affect the adsorption behavior by competing with adsorbate ions on the surface of adsorbent as well. The effect of ionic strength on the uptake of Rhodamine molecules by the as-prepared CGP is shown in Fig. 5. A negative correlation between adsorption capacity of Rh 6G molecules and ionic strength can be found. The reason could be possibly the fact that the increased concentration of K₂SO₄ could neutralize the surface negative charge, and an increase in the electrostatic repulsion between the negatively charged CGP adsorbent surface and the cationic Rh 6G molecules, inhibiting the adsorption of cationic Rhodamine molecules to the adsorbent surface. It is also interesting to find that there is almost no apparent effect of ionic strength on the adsorption capacity of Rh B, indicating the less important role of electrostatic force in the adsorption process of Rh B.

3.7. Influence of co-existing anions

The anions of chloride, sulfate and hydrogen phosphate which are considered to exist commonly in actual groundwater, were adopted to investigate the influence of anions on the adsorption capacity of Rhodamine dyes onto the as-prepared CGP adsorbent. As depicted in Fig. 6, it can be found that anions of hydrogen phosphate lead to the greatest decrease of the adsorption capacity of Rh B, but no apparent negative effect of chloride anions on the adsorption capacity was found for both Rh B and Rh 6G. The decrease of adsorption capacity could possibly be caused by the competition adsorption of anions with target model compounds (Rhodamine dye molecules) on the surface of adsorbent. Besides, an electrostatic field might form around the surface of adsorbent, which also can promote the electrostatic repulsion.

3.8. Regeneration by photolysis and reuse

The saturated CGP adsorbent can be regenerated easily upon UV light exposure. In our study, a simulated sunlight irradiated from Xenon lamp was used as light source for adsorbent regeneration. FTIR measurements (not shown here) clearly show that almost no Rh 6G and Rh B signals can be detected after 2 h of exposure, suggesting that the saturated CGP adsorbent was regenerated almost completely. The adsorption capacities of Rh B and Rh 6G in the successive five cycles are shown in Fig. 7. After the first cycle of reuse, the adsorption capacity of Rh B and Rh 6G decreases from 3.4 and 12.5 μmol g⁻¹ to 2.1 and 9.3 μmol g⁻¹, respectively. After five cycles of reuse, their capacities decrease to 0.9 and 5.5 μmol g⁻¹, respectively. The decrease in adsorption capacity...
after regeneration could be attributed to the unsuccessful regeneration sites on the as-prepared CGP adsorbent.

4. Possible mechanism

To understand the possible adsorption mechanism, the effect of pH condition on the adsorption capacity of Rh B and Rh 6G was investigated and results are depicted in Fig. 8(a). It can be found that the adsorption capacity is highly dependent on the pH of the solution which affects the degree of ionization of adsorbate. The maximum adsorption capacities of Rh 6G and Rh B were achieved at 25.1 and 7.18 μmol g⁻¹ under conditions of pH = 2. However, only adsorption capacities of 9.1 and 1.7 μmol g⁻¹ were obtained for the adsorption of Rh 6G and Rh B in aqueous solutions of pH = 10, respectively, indicating that the static electric adsorption mechanism occurred during the adsorption process. The zeta potentials of the CGP adsorbent surface under different pH conditions were measured. As shown in Fig. 8(b), it can be noticed that the zero point of zeta-potential (isoelectrical point, IEP) of the as-prepared CGP adsorbent was examined at 3.5, indicating the positive surface charge of samples at pH < 3.5. The initial pH value for Rh B and Rh 6G aqueous solutions with a concentration of 15 μmol L⁻¹ is around 6.0, therefore the negative charge of the CGP adsorbent surface can be expected. The electrostatic interaction might have occurred between the negatively charged surface of CGP and the positive charge of two kinds of Rhodamine molecules. It is worth noticing that CGP adsorbent exhibits a much higher adsorption capacity of Rh 6G than Rh B and threefold improvement of capacity can be found by the batch adsorption mentioned above. The reason should be possibly due to the repulsion forces that existed between the dissociated carboxylic (–COOH) group (pKa = 3.1 [28]) and the negatively charged surface of CGP adsorbent, which might inhibit the adsorption process through electrostatic forces. However, the adsorption can still be found under basic conditions, even though the adsorption capacity is much lower, indicating that the inter-molecular interaction might possibly be involved.

On the other hand one can expect, the hydrophobic interaction between the surface of CPG (which has been proved above) and the ester group (–COOCH₃) in Rh 6G molecules might took place in the adsorption process as well, which facilitates the efficient uptake on the surface of CGP adsorbent. Therefore, on the basis of the electrostatic and inter-molecular interactions, it can be preliminarily concluded that the much more higher adsorption capacity of Rh 6G should be caused by the repulsion forces from the dissociated carboxylic (–COOH) group in Rh B molecules, and the hydrophobic interaction forces from the ester group (–COOCH₃) in Rh 6G molecules (as illustrated in Fig. 9).

5. Conclusion

In this work, exhausted coffee ground powder has been proved to be an efficient adsorbent for the removal of Rhodamine dyes of Rh B and Rh 6G from aqueous solutions. The pseudo-
Removal of hazardous rhodamine dye from water by adsorption onto exhausted coffee ground

S127

do-2nd order adsorption kinetic model can describe best the adsorption process of both Rh B and Rh 6G on CGP adsorbent. Temperature-dependent adsorption experiments suggest that the adsorption process is of exothermic and endothermic nature. The maximum adsorption capacities toward Rh B and Rh 6G were estimated at 5.255 and 17.369 μmol g⁻¹ according to the Langmuir model. Anions of hydrogen phosphate were found to significantly interfere with Rh B and Rh 6G adsorption. Both the increase of ionic strength and solution volume could not be related to the improved uptake capacity. The saturated CGP can be regenerated easily by the photolysis method. The higher adsorption capacity of Rh 6G onto CGP adsorbent may be caused by the repulsion forces from the dissociated carboxylic (–COOH) group in Rh B molecules and through the hydrophobic interaction forces from the ester group (–COOCH₃) in Rh 6G molecules.

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References


