Biosorbents prepared from pomelo peel by hydrothermal technique and its adsorption properties for congo red

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Abstract
A new kind of biosorbent was prepared from pomelo peel by using potassium hydroxide as activating agent and hydrothermal treatment method. The characteristics of materials were analyzed by SEM, BET and FTIR. Increasing the adsorbent dosage (from 2.5 to 17.5 g l\(^{-1}\)) and contents of congo red in solution (from 20 to 50 mg l\(^{-1}\)) cause the increment of removal rate of congo red. On the other side, the removal rate is decrement with rising of temperature and pH. The maximum adsorption quantity of biosorbent was 144.93 mg g\(^{-1}\) at 303 K, which calculated by Langmuir model. The pseudo-first-order kinetic model, pseudo-second-order kinetic model and intra-particle diffusion model were used to explain adsorption process. The value of Gibbs free energy (\(\Delta G\)) is \(-7.63\) (kJ/mol) at 303 K and the enthalpy change (\(\Delta H\)) is \(-31.43\) (kJ/mol), meaning that adsorption behavior for congo red is spontaneous.

1. Introduction

Dyes are generally made by artificial synthesis and contain a variety of chemicals, which is widely used in industry. The use of a large number of dyes causes serious water pollution [1]. As one of the dyes, congo red has wider applications in textile, paper, leather, plastics and related industries [2]. Congo red wastewater brought serious problems because of its toxicity, which poses a major threat to people’s health and living environment [3]. Therefore, seeking an efficient way to remove congo red from the wastewater has received more and more attention.

At present, the water treatment methods commonly used in the world are reverse osmosis [4], biological oxidation [5], ion exchange [6], adsorption [7] and membrane filtration [8]. As one of the treatment methods, adsorption is widely used because of its high efficiency, sustainability and convenience [9]. Various adsorbents are used for sewage treatment, such as activated carbon [10], zeolite [11], carbon nanotubes [12], grapheme [13] and agricultural waste peels [14]. In recent years, various biosorbents have been investigated intensively for adsorption of wastewater due to its low cost, easy access and eco-friendly [15]. Orange peel [16], garlic peel [17], banana peel [18], potato peel [19] and pomelo peel were researched as biosorbents to adsorb different containments from wastewaters.

Pomelo trees are cultivated in all tropical and subtropical regions of the world [20]. A large amount of pomelo is consumed in people’s daily life and its peel is often thrown away as a waste [21]. The accumulation and decay of pomelo peel will cause environmental pollution and waste of resource. Up to now, the progress is slow for waster utilization of pomelo peel [22]. Pomelo peel has a porous structure. The components of cellulose and hemicellulose endow its various and abundant functional groups [20], which makes it a promising biosorbent in wastewater treatment. However, the finite adsorption capacity and removal efficiency of primitive pomelo limit its practical applications.
Activation and carbonation of pomelo peel to prepare activated carbon is an effective way to improve its adsorption capability. The chemical and physical methods commonly used to prepare activated carbon. The physical activation is to oxidize precursor using oxidizing gases such as O₂ [23], CO₂ [24] and H₂O [25]. The chemical activation is to treat the precursor using chemical reagents such as H₃PO₄ [26], H₂SO₄ [27], KOH [28], ZnCl₂ [29], and K₂CO₃ [30]. Both physical and chemical activation methods usually need high temperature (400 °C–1000 °C) to oxidize or etch the precursor to form multi-porous structure. The high temperature increases production cycle and cost.

In this work, pomelo peel was chemically modified with potassium hydroxide agent and then activated by a hydrothermal technique. Hydrothermal technique is widely used to dispose and transform organic solid waste into valuable resources [31]. Compared to conventional activation method, low temperature (200 °C) of hydrothermal processing not only decreases production cycle and cost, but also does not produce waste gases such as CO₂, NO, SO₂. The adsorption properties of hydrothermal treated pomelo peel for congo red were obtained by batch experiments. The physical properties of hydrothermal treated pomelo peel were researched by FTIR, SEM and BET.

2. Materials and methods

2.1. Materials
Congo red (C₃₂H₂₂N₆Na₂O₆S₂, >99% in purity) was supplied by Tianjing Dengke Chemical Reagent Co., Ltd. Potassium hydroxide agent was supplied by Sinopharm Chemical Reagent Co., Ltd. The solution preparation all uses the deionized water. The other reagents were analytical grade.

2.2. Preparation of biosorbents
The pomelo peel was obtained in the local fruit market. The inner soft structure of pomelo peel was separated and dried in the air. 1 g air-dried primitive pomelo peel was put into the potassium hydroxide solution (20%wt). The mixture was subsequently transferred and sealed in a Teflon-lined stainless steel autoclave. Then put it into the oven for 2 h at 200 °C. After heating, the mixture was put into a beaker and washed to neutral. For the purpose of study the effect of different drying methods for adsorption of congo red, part of hydrothermal treated pomelo peel was naturally dried in the air and the other was dried by the vacuum freeze dryer (FD-1-50, Boyikang Laboratory Apparatus Co., Ltd., China).

2.3. Characterization of the biosorbents
The surface morphologies of the air-dried peel and two kinds of modified peel were studied by SEM (TM3000, HITACHI, Japan). Functional groups were detected by FTIR (Nicolet iS10, Thermo Scientific, USA). The specific surface area of the air-dried pomelo peel and freeze-dried modified pomelo peel were studied by BET (ASAP 2460, Micromeritics, USA).

2.4. Batch adsorption experiments
All adsorption experiments were placing 10 mg of freeze-dried modified pomelo peel and 20 ml of congo red solution in a conical flask. Then put the conical flask in the constant temperature gas bath shaker (SHZ-82A) for 48 h at 160 rpm to reach adsorption equilibrium. The UV-visible spectrophotometer was used to detect equilibrium concentration of congo red. The adsorption quantity of freeze-dried modified pomelo peel was obtained by the equation (1):

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

where \( C_0 \) (mg/l) is the initial concentration and \( C_e \) (mg/l) is the equilibrium concentration of congo red solution.

The effect of solution pH was researched by putting freeze-dried modified pomelo peel into the 20 ml congo red solution of 50 mg l⁻¹. And the pH value of congo red solution ranges from 4 to 10. The effect of adsorbent dosage was researched by putting varying dosage of adsorbent (5–35 mg) into the congo red solution of 50 mg l⁻¹, respectively.

The influence of temperature was investigated by putting adsorbent into the varying concentration (20–50 mg l⁻¹) of congo red solution, which adsorption process was proceeded at different temperature. The relationship between adsorption time and change of solution concentration was measured by the way that put the adsorbent (10 mg) into the dye solution of 50 mg l⁻¹. The adsorption ability \( q_t \) (mg/g) might be able to calculate with the equation (2):

\[ q_t = \left( \frac{C_0 - C_t}{m} \right) \times V \]
contains a peak at 1735 cm$^{-1}$. The FTIR was analyzed for pomelo peel and shown in Figure 1. To compare the difference of functional groups between air-dried primitive peel and freeze-dried modified peel, 3.1 Characterization of adsorbent

The FTIR spectrum of primitive peel (Figure 1(a)) contains a peak at 1735 cm$^{-1}$. It is because stretch of carboxylic acid groups of hemicellulose (C=O) [32]. After the modification (Figure 1(b)), this peak is disappeared due to the decomposition of hemicellulose around 453 K [33]. Additionally, the peak at 1414 cm$^{-1}$(C=C) also disappeared. It can be attributed to the effect of KOH activation. At around 3346 cm$^{-1}$ and 2918 cm$^{-1}$ for peaks are represented O–H groups stretching of cellulose and asymmetric C–H vibration, respectively. The peak at 1642 cm$^{-1}$ of modified peel may indicate the stretching of carboxylic groups (−COOH). The peak near 1371 cm$^{-1}$ of modified peel may refer the stretching vibration of −COO$^{-}$ of pectin [32]. And at around 1156 cm$^{-1}$ can be assigned C–O–C stretching vibration of cellulose [34]. At around 1060 cm$^{-1}$ reflects stretching vibration of C–OH [20].

After the adsorption process (Figure 1(c)), losing of some peaks or decreasing of transmittance (T %) could be thought as possible interaction of dye molecules and functional groups at these bands [35]. The peak of −COOH stretching at 1642 cm$^{-1}$ (Figure 1(b)) shifts to 1640 cm$^{-1}$ (Figure 1(c)) with decrement of intensity. This decrement may be due to the influence of dye molecules at this peak. The peaks of O–H (3346 cm$^{-1}$) and C–H (2918 cm$^{-1}$) have the similar change. These functional groups may play an important role in the adsorption process.

Figure 2 shows SEM images of the pomelo peel. The air-dried pomelo peel (Figure 2(a)) has the continuous and unbroken morphologies. After being modified by potassium hydroxide, both the air-dried (Figure 2(b)) and freeze-dried (Figure 2(c)) pomelo peel forms more folds and slits, which can increase total surface of pomelo peel.

Adsorption capacity of three kinds of pomelo peels was represented in Figure 3. The air-dried primitive pomelo peel is only 13.68 mg g$^{-1}$. After modification, it increases to 73.34 mg g$^{-1}$ for the air-dried modified pomelo peel and 85.41 mg g$^{-1}$ for the freeze-dried modified pomelo peel. It may be because the functional groups were introduced by potassium hydroxide treatment.

Nitrogen adsorption and desorption isotherm was shown in Figure 4(a). The specific surface area is only 1.3003 m$^{2}$ g$^{-1}$ for the primitive pomelo peel. After the modification, it increased to 4.0845 m$^{2}$ g$^{-1}$. The improvement of the specific surface area is attributed to the hydrothermal treatment and special drying method. Freeze drying method can form porous structure through subliming water molecules at the circumstance of vacuum and low temperature [36]. The BJH pore volume distribution curve (Figure 4(b)) shows that the number of pores of the freeze-dried modified peel is larger than that of the primitive pomelo peel. The larger specific surface area and pores provide more active sites in the adsorption process of congo red.

\[ q_t = \left( \frac{c_0 - c_t}{W} \right) \times V \]

where $c_t$ (mg/g) is the concentration of congo red at time $t$.

3. Results and discussion

3.1. Characterization of adsorbent

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3.2. Effect of temperature

Figure 5(a) shows the relationship of adsorption ability with temperature. At 303 K, the adsorption ability is $85 \text{ mg g}^{-1}$. At 323 K, it decreases to $64 \text{ mg g}^{-1}$. The lower adsorption capacity at higher temperature may be due to restrain hydrogen bonding of functional groups with dye molecules [37].

3.3. Effect of dosage

As the freeze-dried modified peel dosage rises, the removal rate gradually increases from 51% to 94% (figure 5(b)). It can be attributed to the increase of a great quantity of adsorption sites [38]. On the other side, the adsorption capacity ($q_e \text{ mg g}^{-1}$) decreases from 102 mg g$^{-1}$ to 26 mg g$^{-1}$ with rise dosage of adsorbent. This is because the quantity of dye which adsorbed by per unit weight of the adsorbent is reduced causing the decline of utilization rate of the active sites [39].
3.4. Effect of time

The impact of adsorption time for congo red onto the freeze-dried modified pomelo peel was shown in figure 5(c). It is obvious that the former 300 min of adsorption process is faster. It can be attributed any amount of activation sites on the adsorbents that can easily bind with dye molecules [40]. After then, adsorption process tends to be slow until the adsorption equilibrium has reached. This can be explained by the process that the adsorption of dye molecules shifts from surface area toward into the inner pores of the adsorbent [41]. The long adsorption equilibrium time is the consequence of long-range diffusion of congo red enter the inner porous of adsorbent.
3.5. Effect of pH
The process of congo red onto the freeze-dried modified pomelo peel is affected by pH of solution, which result was shown in figure 5(d). At pH = 4, removal percentage of congo red is 85.83%. However, at pH = 10, removal percentage of congo red reduces to 75.11%. This can be explained by the process that carboxyl groups of adsorbent bind with congo red molecules at acidic pH. Oxygen-containing functional groups have an important effect during the adsorption process [42]. At acidic pH, congo red molecules are cationic form, which can attach with carboxyl groups of the adsorbents. At basic pH, congo red molecules are anionic form and the carboxyl groups of adsorbent also become an anion (−COO−), which is not suitable for dye molecules binding with the adsorbents [38]. Therefore, at acidic pH, adsorbent has higher removal rate for congo red than at basic pH.

The dissolved organic matter such as fulvic acid (FA) and humic acid (HA) will affect the oxygen-containing functional groups of the adsorbents and affect the adsorption capacity [43]. Previous studies have shown that FA and HA were negatively charged in the pH range of 3.0–10.0 [44, 45]. At low pH values, the FA and HA easily bind to the surface of the adsorbents, providing more oxygen-containing functional groups to form complexes with cationic adsorbates, so the adsorption capacity is increased. At high pH values, the binding of FA and HA to the adsorbents becomes difficult due to electrostatic repulsion, and thereby change the adsorption capacity of adsorbents [46, 47]. On the other hand, the organic matter also competes with the dye molecules for adsorption sites, which also affects the adsorption capacity [48].

3.6. Adsorption mechanisms
Based on the study of pH and FTIR, the possible adsorption mechanism was discussed. After the adsorption process, The peaks of –COOH (1642 cm⁻¹) and O–H (3346 cm⁻¹) have changed with the decrease of intensity. This may indicate that these oxygen-containing functional groups play a role in the adsorption process. Through the study of pH, we can further analyze and discuss the adsorption mechanism. Congo red molecules are positively charged (CR⁺) under acidic conditions and negatively charged (CR⁻) under alkaline conditions [49]. With the increase of pH, oxygen-containing functional groups (−COOH) will be negatively charged due to deprotonation (−COO⁻) [50]. Therefore, we can conclude that there is electrostatic attraction between the congo red molecules and the carboxyl groups of the adsorbent at acidic pH, and electrostatic repulsion at basic pH. This conclusion is also consistent with the experimental results of pH. Electrostatic interaction has an important influence on the adsorption process. Figure 6 shows the possible adsorption mechanism of congo red adsorption onto adsorbent at acidic pH.

3.7. Effect of other co-ions
The adsorption of dyes is generally accomplished by hydrogen bonding, functional group interactions and electrostatic interaction with the adsorbent. They are affected by the ionic strength and pH in the aqueous solution [51]. The metal cations such as Na⁺, Cu²⁺ and Ca²⁺ may be combined with the active sites on the surface of the adsorbent and compete with the dye molecules, which will affect the adsorption efficiency of the adsorbent for dye molecules [52]. Previous studies have shown that pomelo peel has adsorption capacity for
Cd$^{2+}$ [53] and Cu$^{2+}$ [54], so the presence of some ions in the solution may reduce the adsorption capacity of pomelo peel for Congo red. In addition to the competitive effect of ions, the ionic strength also affects the electrostatic interaction. The electrostatic attraction can promote the adsorption of dye molecules by adsorbents. Some authors have found that the addition of NaCl solution can inhibit the electrostatic attraction and reduce the adsorption capacity of the adsorbent [55, 56]. This is mainly because Na$^+$ ions and Cl$^-$ ions can shield the charged sites of the adsorbent. And ionic strength may also affect the hydrophobic interactions. Therefore, the influence of ionic strength on the adsorption process is complicated.

3.8. Kinetic studies

In order to evaluate the adsorption kinetics, the pseudo-first-order model, pseudo-second-order model and intraparticle diffusion model were used to fit the experimental data. The degree of data fitting is represented by $R^2$ and sum squares errors (SSE).

The pseudo-first-order kinetic model is expressed as: [57]

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2.303}t$$

Where $k_1$ is the adsorption constant, $q_e$ represents adsorption ability of adsorbent at equilibrium concentration and $q_t$ indicates specific concentration at time $t$. The $q_t$ and $q_i$ obtain by fitting $\log(q_e - q_t)$ with $t$ (figure 7(a)). The accurate values were shown in table 1. The $q_t$ (59.17 mg g$^{-1}$) is lower than the 85.41 (mg/g) of experimental date. The value of $R^2$ is only 0.8667. The value of sum squares errors (SSE) is 0.56446.

The pseudo-second-order kinetic model is expressed as: [58]

$$\frac{t}{q_t} = \frac{1}{2k_2q_e^2} + \frac{t}{q_e}$$

Table 1. The kinetic constants of adsorption of congo red on adsorbent.

| Kinetic model          | Parameters | Values          |
|------------------------|------------|-----------------|
| Pseudo-first-order     | $k_1$ (min$^{-1}$) | 2.95 × 10$^{-3}$ |
|                        | $q_e$ (mg/g)   | 59.17           |
|                        | $R^2$         | 0.8667          |
|                        | SSE           | 0.56446         |
| Pseudo-second-order    | $k_2$ (g/mg min) | 1.37 × 10$^{-4}$ |
|                        | $q_e$ (mg/g)   | 89.37           |
|                        | $R^2$         | 0.9968          |
|                        | SSE           | 0.47052         |
| Intraparticle diffusion model | $k_{ad1}$ (mg/g min$^{1/2}$) | 4.50 |
|                        | $C_1$ (mg/g)   | -3.46           |
|                        | $R^1_2$       | 0.9923          |
|                        | $k_{ad2}$ (mg/g min$^{1/2}$) | 0.41 |
|                        | $C_2$ (mg/g)   | 68.66           |
|                        | $R^2_2$       | 0.6840          |

Figure 7. Adsorption kinetics of congo red onto adsorbent: (a) pseudo-first-order kinetic model, (b) pseudo-second-order kinetic model and (c) intraparticle diffusion model.
where $k_2$ (g/mg min) is the adsorption constant, which obtained by fitting $t/q_t$ with $t$ (figure 7(b)). And the values of $k_2$ and $q_e$ were shown in table 1. The value of $R^2$ (0.9968) is higher than the $R^2$ (0.8667) of the pseudo-first-order kinetic model. The value of sum squares errors (0.47502) is lower than the pseudo-first-order kinetic model. The experimental date of $q_e$ is 85.41 mg g$^{-1}$, which is closer to the fitting data of Pseudo-second-order (89.37 mg g$^{-1}$). These indicate that the pseudo-second-order kinetic model is more suitable adsorption process of congo red onto the freeze-dried modified pomelo peel.

The intraparticle diffusion model is expressed as:

$$q_t = k_{id}t^{1/2} + C_i$$

where $k_{id}$ (mg/g min$^{1/2}$) is the intraparticle diffusion constant and $C_i$ is the parameter related to the boundary layer of molecules. The $k_{id}$ and $C_i$ were obtained by fitting $q_t$ with $t^{1/2}$ (figure 7(c)). And the values of $k_{id}$ and $C_i$ were shown in table 1. It is clearly evident that the adsorption by freeze-dried modified pomelo peel has two stages. Consequently, internal diffusion is only one of the conditions affecting the adsorption rate. It is a complicated process [39]. In the first stage of adsorption, the faster removal rate can attribute to sufficiently combine the dye molecules with surface area of adsorbent. Subsequently, the adsorption rate slows down as the concentration of dye molecules decreasing.

### 3.9. Equilibrium modeling

The experimental data was fitted by Langmuir and Freundlich models. The Langmuir model considers that the adsorption process can be evenly distributed throughout the surface of adsorbent. The Langmuir model is expressed as: [60]

$$\frac{c_e}{q_e} = \frac{c_e}{q_{max}} + \frac{1}{q_{max}k_L}$$

where $k_L$ is the Langmuir parameter, $q_{max}$ is the maximum adsorption capacity and the $q_e$ represents adsorption ability of adsorbent at equilibrium concentration. The $k_L$ and $q_{max}$ can be acquired by fitting $c_e/q_e$ with $c_e$ (figure 8(a)). The table 2 was represented the values of $k_L$ and $q_{max}$. Comparing maximum adsorption capacity of modified pomelo peel and other adsorbents (table 3) illustrates that modified pomelo peel is the excellent adsorbent in wastewater treatment. The values of $R^2$ and sum squares errors were shown in table 2.

The Langmuir model also can express as:

$$R_L = \frac{1}{1 + c_0k_L}$$

where $c_0$ is the initial concentration of congo red solution. The $R_L$ can be calculated by $c_0$ and $K_L$. The figures of $K_L$ are all less than 1, which indicates that modified pomelo peel is the appropriate adsorbent in the process of removing dye.

The Freundlich model considers that adsorption is the heterogeneous distribution on surface of adsorbent. The Freundlich model is expressed as:

$$q_e = k_{fmax}c_e^{1/n}$$

where $k_{fmax}$ is the Freundlich constant, $q_e$ is the equilibrium adsorption capacity, and $c_e$ is the equilibrium concentration of congo red solution. The Freundlich model is expressed as: [60]

$$\ln q_e = \frac{1}{n} \ln c_e + \ln k_f$$

where $k_f$ is the Freundlich constant, and $n$ is the adsorption intensity parameter. The Freundlich model is expressed as:

$$c_e = \frac{q_{max}}{k_{fmax}} n^{1/n} c_e^{1/n}$$

where $c_e$ and $q_{max}$ are the equilibrium concentration of congo red solution and the maximum adsorption capacity, respectively. The $q_{max}$ can be acquired by fitting $q_e/c_e$ with $c_e$ (figure 8(b)). The table 2 was represented the values of $k_{fmax}$ and $n$. Comparing maximum adsorption capacity of modified pomelo peel and other adsorbents (table 3) illustrates that modified pomelo peel is the excellent adsorbent in wastewater treatment. The values of $R^2$ and sum squares errors were shown in table 2.

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where \( k_F \) and \( n \) are Freundlich equilibrium constant and adsorption intensity, respectively. The values can be obtained by plotting \( q_l \) versus \( c_l \) (figure 8(b)). The table 2 was illustrated the specific values of \( n \). Compared with Freundlich model, Langmuir model has higher values of \( R^2 \) and lower values of sum squares errors. It can evidence that experimental data is more appropriate the Langmuir model and adsorption process of the dyes molecules onto the freeze-dried modified pomelo peel is monolayer adsorption process.

### 3.10. Thermodynamic study

The temperature has the obvious effect for the congo red molecules onto the freeze-dried modified pomelo peel. The parameters (\( \Delta G, \Delta H, \Delta S \)) can be calculated by following the equation at different temperature: [67]

\[
\ln q_e = \ln k_F + \frac{1}{n} \ln c_e
\]

\[
\ln \left( \frac{q_e}{c_e} \right) = -\frac{\Delta H}{RT} + \frac{\Delta S}{R} \quad \text{(8)}
\]

\[
\Delta G = \Delta H - T \Delta S \quad \text{(9)}
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where \( k_F \) and \( n \) are Freundlich equilibrium constant and adsorption intensity, respectively. The values can be obtained by plotting \( \ln q_e \) versus \( \ln c_e \) (figure 8(b)). The table 2 was illustrated the specific values of \( n \). Compared with Freundlich model, Langmuir model has higher values of \( R^2 \) and lower values of sum squares errors. It can evidence that experimental data is more appropriate the Langmuir model and adsorption process of the dyes molecules onto the freeze-dried modified pomelo peel is monolayer adsorption process.

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\]

where \( K \) is the absolute temperature and the \( R \) is the universal gas constant (8.314 J mol\(^{-1}\) K). The \( \Delta H \) and \( \Delta S \) can be obtained by fitting \( \ln \left( \frac{q_e}{c_e} \right) \) with \( 1/T \). The table 4 was indicated the specific figures of \( \Delta G, \Delta H \) and \( \Delta S \).

The specific figures of \( \Delta G (-7.63, -6.85 \text{ and } -6.06 \text{ kJ mol}^{-1}) \) represent that adsorption process is the spontaneous reaction and not require external energy. At 303 K and 323 K, the values \( \Delta G \) are \(-7.63 \text{ (kJ/mol)}\) and \(-6.06 \text{ (kJ/mol)}\), respectively, suggesting that lower temperature is more favorable for congo red onto freeze-dried modified pomelo peel. The value of \( \Delta H (-31.43 \text{ kJ mol}^{-1}) \) represents process that congo red molecules onto the freeze-dried modified pomelo peel is an exothermal reaction. The value of \( \Delta S (-78.48 \text{ J mol}^{-1} \text{ K}) \) indicates that randomness of adsorption onto freeze-dried modified pomelo peel is reduced at the solid-solution interface [68].
4. Conclusions

In this work, a new kind of biosorbent was prepared from pomelo peel by hydrothermal treatment method. The surface morphology, functional groups and specific surface area of the adsorbent were studied by SEM, FTIR and BET methods, respectively. The influences of temperature, pH, adsorbent dosage and time for adsorption were researched by batch experiments. The maximum adsorption capacity (144.93 mg g\(^{-1}\)) was calculated by Langmuir model at 303 K, which illustrates that pomelo peel is the excellent adsorbent in wastewater treatment. The kinetic studies indicate that the adsorption process is more suitable for pseudo-second-order kinetic model. The research of thermodynamics evidences that adsorption process is an exothermal and spontaneous reaction. Results of this study show that modified pomelo peel has the bright prospect to adsorb congo red.

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