Chicken feet yellow membrane waste as new bio-adsorbent for cationic methylene blue dye removal: adsorption, equilibrium, kinetic and thermodynamic studies

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Submission: 22 February 2020; Revision: 23 February 2020; Acceptance: 09 March 2020

Abstract

Background and objective: Dye molecules as an important type of organic pollutants are potentially toxic and have carcinogenic and mutagenic impact on living systems. Today, uncontrolled discharge of organic pollutants is environmental problem. Dissolution of synthetic dyes in aqueous media causes decreased light penetration into water and interferes photosynthesis reactions. This research introduces a new and eco-friendly adsorbent based on chicken feet yellow membrane (CFYM) for removal of cationic dye.

Materials and methods: Untreated CFYM was collected from slaughterhouse and prepared for analysis after washing by deionized water, drying at 90°C for 12-24 h and grinding to fine powders. The adsorbent was characterized by Fourier transform infrared spectroscopy, X-ray diffraction, Scanning electron microscopy and Emmett and Teller techniques. Functional groups of C=O, O–H, N–H, C–N, C–C and H–C–H could confirm that the pre-treated CFYM has mainly organic nature. Removal applicability and efficiency of bio-adsorbent were studied using cationic methylene blue (MB) as s model. To reach the best results, main parameters including pH, adsorbent mass, contact time and temperature were optimized by one-factor-at-a-time method through adsorption experiments in a batch system. The equilibrium adsorption experiments were evaluated by Langmuir, Freundlich, Tempkin and Dubinin-Raduskovich isotherm models. The adsorption kinetic models of pseudo-first order, second first order, Eloivich and intra-particle diffusion were also studied.

Results and conclusion: Results were in accordance to Langmuir isotherm model. Obtained kinetic and thermodynamic parameters confirmed that pseudo-first order model was the best kinetic model and adsorption process of MB on CFYM was exothermic and spontaneous. Based on the results, CFYM, as a novel natural adsorbent, was efficient for removal of cationic organic pollutant from aqueous solutions.

Keywords: Chicken feet yellow membrane; Isotherm; Kinetic; Methylene blue; Removal

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1. Introduction
In recent years, some methods were used to remove contaminants in environmental systems. In general, these methods are into three groups of physical, chemical and biological including chemical oxidation, coagulation, ion exchange, electrochemical, photochemical, reverse osmosis and adsorption process [1–4]. Adsorption-based method is one of the most convenient techniques for this purpose because of its simplicity, easy operation, compatibility with a variety of pollutants, degradability, reusability and low cost [5]. Up to date, this method has been utilized different adsorbent materials such as activated carbon [6], carbon nanotube [7], iron oxide [8], polymers [9] and molecular sieves [10]. Most synthetic and chemical adsorbents are unavailable, expensive, non-eco-friendly and might include complex synthetic process. Therefore, it is important to examine available and economical adsorbents in practice. Cost-effective adsorbents for water treatment and waste management include natural materials, agricultural by-products [11-13], industrials wastes [14], biomass materials [15] and biomass-based activated carbons [16] which were used for removal of various types of dyes. In this regard, chicken feet yellow membrane (CFYM) is safe and easy-prepared, low cost, eco-friendly, and available that highlights it over chemical adsorbents. Therefore, main goal of present work is fabrication of a novel, available and inexpensive natural adsorbent based on CFYM as an organic bio-waste for removal of methylene blue (MB) from aqueous solutions [17]. MB was selected as model because it is usually found in effluents of textile factories and may cause health concern [18].

2. Materials and methods
2.1. Chemicals
MB, Sodium hydroxide and hydrochloric acid were purchased from Merck (Darmstadt, Germany). Stock solution of MB was prepared at concentration of 1000 mg L⁻¹.

2.2. Preparation of bio-adsorbent powder
CFYM wastes were collected from a hen slaughterhouse (Tehran, Iran). A portion of 20 g CFYM was washed with hot deionized water for several times to remove fat content. Then, yellow membrane was dried in oven at 95°C for 24 h. The membrane was crushed and powered to obtain fine and homogeneous particles. Finally, it was washed with deionized water and dried in oven at 90°C for 12 h before use.

2.3. Characterization
CFYM was characterized by analytical techniques. The scanning electron microscopy images were obtained using a scanning electron microscope (SEM) model Mira 3 Tescan (TESCAN Electron Microscopy Inc., Brno-Czech Republic) [19]. X-ray diffraction (XRD) measurements were done by Bruker D8 Advance instrument (Bruker AXS, Karlsruhe, Germany) with Cu-Kα radiation source generated at 40.0 kV and 35.0 mA at room temperature [19]. Fourier transform infrared (FT-IR) spectra was achieved by FT-IR spectrometer (Bruker, Ettlingen, Germany) [19]. The specific surface area and pore volume of CFYM were analyzed by Brunauer, Emmett and Teller (BET) method with Gemini 2375 micrometric instrument. The powdered biomass was first degassed at 100°C and experiments were carried out by N₂ adsorption-desorption method [20]. The bio-adsorbent particles were separated from liquid phase by centrifugation at 958 xg for 15 min. Absorption experiments were carried out by UV-VIS spectrophotometer model T80 (Unico, USA).

2.4. Optimization of effective variables
Experimental design was carried out based on one-factor-at-a-time approach. In this regard, five variables of pH, absorbent mass, contact time, dye concentration and temperature were analyzed. Each time, one variable was studied within a common range that used in other studies and other four variables were constant. At the end, optimum points of variables were followed for characterization of adsorbent-dye interaction
in current study. To study influence of pH on adsorption process, MB dye solutions at 50 mg l\(^{-1}\) concentration were prepared at different pH ranged from 2 to 12 and absorption was read at 665 nm. Then, 100 mg of the adsorbent was added to solutions. Absorption of final solution was read by spectrophotometer at 665 nm. Similar experiments were done in range of 10-200 mg for absorbent mass, 10-125 min for contact time, 10-100 mg l\(^{-1}\) for dye concentration and 20, 30, 50, 70°C for temperature.

2.5. Analytical and efficacy experiments

To find the optimum wavelength at spectrophotometer, UV-VIS spectra of different concentrations of MB (10-100 mg l\(^{-1}\)) were recorded in range of 200-900 nm. and optimum wavelength of 665 nm was achieved. Therefore, average concentration and 665 nm wavelength were selected for further experiments. All data analysis was performed by Excel software. The adsorption tests of MB on CFYM was performed through a batch operational system. At the end of each experiment, 3 ml of solution was centrifuged at 958 ×g for 15 min. Concentration of residual dye in supernatant was detected using UV-VIS spectrometer at \(\lambda_{\text{max}}\) of 665 nm. Removal efficiency of bio-adsorbent (R\%) and amount of adsorbed dye per unit mass of the adsorbent at equilibrium \((q_e; \text{mg g}^{-1})\), were calculated through the following equations (Eq. 1 and 2):

\[
R (\%) = \left(\frac{C_o - C_e}{C_o}\right) \times 100 \quad \text{Eq. 1}
\]

\[
q_e = \frac{(C_o - C_e)V}{m} \quad \text{Eq. 2}
\]

Where, \(C_o\) and \(C_e\) are initial and equilibrium dye concentrations (mg l\(^{-1}\)) respectively, \(m\) is adsorbent mass (g) and \(V\) is volume of solution.

3. Results and discussion

3.1. Characterization of bio-adsorbent

In Figure 1, the FT-IR peak at 1239 cm\(^{-1}\) is related to stretching C–N of aliphatic amines, wagging C–H of alkyl halides and stretching C–O of carboxylic acids [20]. CH\(_2\) bending vibrations of alkanes (carbohydrates) and C–C stretching vibrations of aromatic groups in structure are detected at 1458 cm\(^{-1}\). Furthermore, peaks at 1542 and 1654cm\(^{-1}\) are related to bonds of amide II (from an out-of-phase combination of N–H in-plane bending and C–N stretching vibrations of peptide linkages) and amide I (C=O stretching vibration with minor contribution of C–N stretch), respectively. The peaks at 2853 and 2924 cm\(^{-1}\) are related to CH\(_2\) symmetric stretch vibrations of amide phases of collagen part. The band between 3200–3500 cm\(^{-1}\) is due to O–H and N–H stretch vibrations in amide structures [21].
The XRD pattern (Figure 2a) did not demonstrate well-defined and specific peaks which shows that there was no distinct mineral phase. Thus, CFYM can be considered as an amorphous structure, which is expected for organic materials. In SEM analysis, CFYM has a rough, bumpy and flex surface (Figure 2b and 2c). These images demonstrate some micro-pores on the adsorbent surface.

Figure 1- FT-IR spectrum of CFYM bio-absorbent

Figure 2- a) XRD pattern; b,c) SEM images of CFYM at different magnifications
Results of BET characterisation of CFYM are shown at Table 1. The specific surface area and pore volume were found to be 3.430 m² g⁻¹ and 0.007 cm³ g⁻³, respectively. Average diameter of adsorbent pores was 8.7 nm. With regard to IUPAC classification [22], CFYM considered as mesoporous adsorbent. BET surface area of CFYM is comparable with those of other natural adsorbents such as soy meal hull (0.76 m² g⁻¹) [23], ash gourd peel powder (0.48 m² g⁻¹) [24], garden grass (21.20 m² g⁻¹) [25], lentil shell (0.19 m² g⁻¹) [26], olive stone (0.18 m² g⁻¹) [27], rice shell (0.67 m² g⁻¹) [28] and sunflower hull (6.05 m² g⁻¹) [29].

Table 1. BET characteristics of CFYM

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BET surface area</td>
<td>m² g⁻¹</td>
<td>3.4321</td>
</tr>
<tr>
<td>Total pore volume</td>
<td>cm³ g⁻¹</td>
<td>0.0075</td>
</tr>
<tr>
<td>Mean pore diameter</td>
<td>nm</td>
<td>8.7530</td>
</tr>
</tbody>
</table>

3.2. Optimization of effective variables on adsorption process

3.2.1. Effect of pH
As can be seen in Figure 3a, adsorption efficiency of MB on CFYM was increased from pH 2 to 10 and then decreased up to pH 12. This may be explained by negatively surface charge of CFYM adsorbent in alkaline pH. This is due to CFYM composition that includes collagen and proteins. Therefore, functional groups of amine, amide and carboxylic acids play significant role [30]. In contrast, there is interfering effect of OH⁻ at very high pH (more than 10) on anionic bio-adsorbent that impairs the process. Based on the results, pH=10 was selected as the best in terms of increased removal efficiency of MB.

3.2.2. Effect of adsorbent mass
As can be seen in Figure 3b, removal percent of MB from solution increased with increasing CFYM mass from 10 to 75 mg and then was constant. Increased adsorption efficiency by increasing the adsorbent mass is due to availability of more surface area and active binding sites on the adsorbents that involved in MB interaction.

3.2.3. Effect of contact time
Removal efficiency increased from 93% to 98% by increasing the contact time from 10 to 50 min and then remained constant due to occupation of surface pores on adsorbent by MB (Figure 3c).

3.2.4. Effect of initial dye concentration
Amount of MB uptake by the adsorbent increased from 3.1 to 30.6 mg g⁻¹ by increasing MB concentration from 10 to 100 mg l⁻¹ (Figure 4). It may be attributed to enhanced driving force, decreased diffusion resistance for cationic dye transfer and increased collision of MB and adsorbent.

3.2.5. Effect of temperature
According to Figure 3d, inhibitory effect of temperature on dye removal suggests that the adsorption process of MB on CFYM is exothermic. Similar result was observed by Lin et al. on basic dye removal by fly ash [31].

3.3. Equilibrium studies
Influence of dye initial concentration on adsorption capacity was studied to find the adsorption isotherms. At this study, Langmuir, Freundlich, Tempkin and Dubinin-Radushkevich isotherms were followed [32–34]. Langmuir isotherm model corresponds to monolayer adsorption of adsorbate on adsorbent homogenous surface [32]. The linear equation of Langmuir isotherm can be represented as follows (Eq. 3):

\[
\frac{1}{q_e} = \frac{1}{(k_L q_m c_e)} + \frac{1}{q_m}
\]

Where, \(C_e\) is equilibrium concentration of dye in solution (mg l⁻¹), \(q_e\) is equilibrium capacity of dye on the adsorbent (mg g⁻¹), \(q_m\) is maximum monolayer coverage of adsorbate (mg g⁻¹), \(k_L\) is Langmuir constant corresponds to the energy of adsorption (l mg⁻¹), \(R_L\), separation factor, is a constant for describing the adsorption properties.
of Langmuir isotherm [35] which are derived from the following equation:

$$R_L = \frac{1}{1 + k_L c_o} \quad \text{Eq. 4}$$

At this study, all $R_L$ values were between 0.15 and 0.64 which shows that CFYM is appropriate adsorbent for MB removal [35] (Table 2, Figure 5).

Freundlich isotherm model assumes multilayer adsorption on heterogeneous surface. The equation is:

$$\ln q_e = \ln k_F + \left(\frac{1}{n}\right) \ln c_e \quad \text{Eq. 5}$$

Where, $k_F$ is Freundlich constant ($\text{mg}^{1-(1/n)} \text{g}^{-1} \text{L}^{1/n}$), $n$ is extent of deviation from linearity of adsorption process and used to determine type of adsorption. The obtained value of $n$ ($n>1$) indicated a desired physical adsorption process of MB on CFYM.

The Tempkin isotherm studies heat changes of adsorption [36] and the linearized equation is given as:

$$q_e = B \ln A + B \ln c_e \quad \text{Eq. 6}$$

Where, $B=RT/b$ and $b$ is Tempkin isotherm constant ($\text{J} \text{mol}^{-1}$), $A$ is equilibrium binding constant ($\text{L} \text{mg}^{-1}$) and $B$ is constant correspond to heat of sorption.

The Dubinin-Radushkevich (D-R) isotherm provides energetic information on type of adsorption [37] and the linear equation is expressed in Eq. 7.

$$\ln q_e = \ln q_m - K_{DR} \varepsilon^2 \quad \text{Eq. 7}$$

Where, $q_e$ is amount of dye adsorbed per unite weight of adsorbent (mg g$^{-1}$), $q_m$ is D-R adsorption capacity, $K_{DR}$ is a constant correspond to adsorption energy (mol$^2$ J$^{-2}$) and $\varepsilon$ is Polanyi potential which is given by following equation (Eq. 8):

$$\varepsilon = RT \ln \left(1 + \frac{1}{c_e^2}\right) \quad \text{Eq. 8}$$

$R^2$, $K_{DR}$ and $q_m$ values of D-R isotherm are given in Table 2. Parameter $E$ is defined as mean free energy of adsorption process for transferring one mole of adsorbate to adsorbent surface and its amount is calculated to evaluate the nature of adsorption process [38]. The value of $E$ is calculated from Eq. 9.

$$E = \frac{1}{\sqrt{2K_{DR}}} \quad \text{Eq. 9}$$

$E$ value was calculated 1.11 kJ mol$^{-1}$ that confirmed physical adsorption of MB on CFYM.

The predicted plots of isotherms were observed in Figure 6a-d. Calculated parameters of all investigated isotherms were summarized in Table 2. It can be found that correlation coefficient ($R^2$) from Langmuir isotherm model was the highest among all isotherms that suggests fitness of experimental data to Langmuir model and monolayer adsorption of MB on the adsorbent.

### 3.4. Kinetic studies

Various kinds of kinetic models were studied for MB adsorption on CFYM at room temperature. The linearized equation of pseudo-first-order kinetic is shown in Eq.10.

$$\log (q_e - q_t) = \log (q_e) - \frac{k_1 t}{2.303} \quad \text{Eq. 10}$$

Where, $q_e$ and $q_t$ are amounts of adsorbed dye per unit of adsorbent (mg g$^{-1}$) at equilibrium and certain time, respectively, and $k_1$ is adsorption rate coefficient of pseudo-first-order kinetic model (min$^{-1}$). Correlation coefficient of this isotherm model was 0.93 and significant difference between experimental $q_{exp}$ and calculated $q_{cal}$ showed that adsorption of MB on CFYM does not follow pseudo-first-order model. In pseudo-second-order kinetic model, rate control step is based on chemisorption [39]. This model is applied using equation 11.

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad \text{Eq. 11}$$
Figure 3- Effect of a) pH, b) adsorbent mass, c) contact time and d) temperature on adsorption of MB on CFYM.

Figure 4- Effect of initial dye concentration on adsorption capacity of MB on CFYM surface.

Figure 5- Values of obtained $R_L$ for Langmuir isotherm.
Figure 6- Plots of isotherms obtained for MB adsorption on CFYM: a) Langmuir, (b) Freundlich, c) Tempkin and d) Dubinin-Radushekevich isotherm models

Table 2. Isotherms parameters for adsorption of MB on CFYM

<table>
<thead>
<tr>
<th>Isotherms</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langmuir</td>
<td>$\frac{1}{q_e} = \frac{1}{q_m} + \frac{1}{q_m} \frac{1}{K_a}$</td>
<td>$q_m$ (mg g$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K_a$ (l mg$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R_L$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R^2$</td>
</tr>
<tr>
<td>Freundlich</td>
<td>$\ln q_e = \ln k_F + (1/n)\ln C_e$</td>
<td>$k_F$ (l mg$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R^2$</td>
</tr>
<tr>
<td>Tempkin</td>
<td>$q_e = B \ln (A) + B \ln (C_e)$</td>
<td>$A$ (l mg$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R^2$</td>
</tr>
<tr>
<td>D-R</td>
<td>$\ln q_e = \ln q'<em>m - k</em>{DR} \epsilon^2$</td>
<td>$q'_m$ (mg g$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$K_{DR}$ (mol$^2$ J$^{-2}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$E$ (kJ mol$^{-1}$)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$R^2$</td>
</tr>
</tbody>
</table>
An appropriate linear relationship with R²=1 for t/q against t showed that the adsorption process of MB on CFYM could be well explained by pseudo-second-order model (Figure 7b). It was further confirmed by slight difference between q_{cal} and q_{exp}. Evaluated equation of intra-particle diffusion was proposed by Weber-Morris model [10] (Eq. 12):

q_t = k_{dif} t^{0.5} + C ∂. Eq. 12

Where, k_{dif} is rate constant (mg g⁻¹ min⁻¹), and C is thickness of boundary layer (mg g⁻¹). Elovich kinetic model is expressed in Eq. 13.

q_t = \frac{1}{\beta} \ln (\alpha \beta) + \frac{1}{\beta} \ln (t) ∂. Eq. 13

Where, α (mg g⁻¹ min⁻¹) and β (g mg⁻¹) are rate constants for Elovich equation and represent initial adsorption rate and desorption coefficient, respectively.

Kinetic parameters of the four models were calculated from slope and intercept of the plots and are summarized in Table 3. As mentioned above, a good linearity and the highest correlation coefficient (R²), was observed for pseudo-second-order model.

3.5. Thermodynamic study
Thermodynamic parameters including change of Gibbs free energy (ΔG°, Kj mol⁻¹), enthalpy (ΔH°, kJ mol⁻¹) and entropy (ΔS°, kJ mol⁻¹K⁻¹) were studied to evaluate influence of temperature on adsorption process. Free energy change (ΔG°) as an important factor for spontaneity, is determined by following equations (Eq. 14 and 15) [40].

ΔG° = ΔH° - T ΔS° ∂. Eq. 14

ΔG° = -RT ln k_c ∂. Eq. 15

Where, R is gas constant (8.314 J mol⁻¹ K⁻¹), T is temperature (°K) and k_c (l mol⁻¹) is thermodynamic equilibrium constant that could be determined by following equation (Eq. 16).

K_c = \frac{q_e}{C_e} ∂. Eq. 16

ΔH° and ΔS° can be obtained from slope and intercept of ln k vs. 1/T plot (Figure 8). Calculated amounts of ΔG°, ΔH° and ΔS° are shown in Table 4.

Negative value of enthalpy confirmed the exothermic nature of adsorption. ΔG° was positive by increasing the temperature from 20 to 70°C which indicated the spontaneous nature of adsorption process. Furthermore, negative ΔS° showed a decreased randomness at adsorbent-solution interface during the process.
Figure 7- Kinetic modeling of adsorption of MB on CFYM; a) pseudo-first-order, b) pseudo-second-order, c) intra-particle diffusion, d) Elovich kinetic models

Table 3. Kinetic parameters for adsorption of MB on CFYM

<table>
<thead>
<tr>
<th>Model</th>
<th>Parameters</th>
<th>Value</th>
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<tr>
<td>Pseudo-first order</td>
<td>( q_{e,exp} ) (mg g(^{-1}))</td>
<td>16.400</td>
</tr>
<tr>
<td></td>
<td>( q_e ) (mg g(^{-1}))</td>
<td>1.342</td>
</tr>
<tr>
<td></td>
<td>( K_1 ) (min(^{-1}))</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.931</td>
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<tr>
<td>Pseudo second order</td>
<td>( q_e ) (mg g(^{-1}))</td>
<td>16.550</td>
</tr>
<tr>
<td></td>
<td>( K_2 ) (mg l(^{-1})min(^{-1}))</td>
<td>0.079</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>1</td>
</tr>
<tr>
<td>Intra-particle diffusion</td>
<td>( C )</td>
<td>15.304</td>
</tr>
<tr>
<td></td>
<td>( K_{dif} ) (mg g(^{-1})min(^{-0.5}))</td>
<td>0.117</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.835</td>
</tr>
<tr>
<td>Elovich</td>
<td>( \alpha ) (mg g(^{-1})min(^{-1}))</td>
<td>3×10(^{12})</td>
</tr>
<tr>
<td></td>
<td>( \beta ) (g mg(^{-1}))</td>
<td>2.433</td>
</tr>
<tr>
<td></td>
<td>( R^2 )</td>
<td>0.939</td>
</tr>
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Figure 8- Effect of temperature on adsorption kinetics of MB on CFYM

Table 4. Thermodynamic parameters for adsorption of MB on CFYM

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>ΔG° (kJ mol⁻¹)</th>
<th>ΔH° (J mol⁻¹)</th>
<th>ΔS° (J mol⁻¹ K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>-19.346</td>
<td>7.778</td>
<td>-23.678</td>
</tr>
<tr>
<td>50</td>
<td>-18.416</td>
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<td>70</td>
<td>-16.996</td>
<td>-22.398</td>
<td>-19.842</td>
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4. Conclusion
At this study, a novel, available, inexpensive and natural adsorbent was directly used for removal of organic pollutant from aqueous solutions. Isotherm, kinetic and thermodynamic studies were carried out in detail. As result, equilibrium data were best-fitted to Langmuir isotherm and confirmed a monolayer coverage of CFYM by MB. In addition, pseudo-second-order kinetic model was followed for the process. Some advantages such as safety and easy preparation, low cost, eco-friendly, and availability make this natural adsorbent preferable to chemical adsorbents in waste removal purposes.

5. Acknowledgment
The authors gratefully acknowledge Research Council of Shahid Madani University for financial support.

6. Conflict of interest
The authors have declared no conflict of interest.

References


