Graphene oxide edge grafting of polyaniline nanocomposite: an efficient adsorbent for methylene blue and methyl orange

Hefang Wang, Mengmeng Duan, Yong Guo, Cunyue Wang, Zetao Shi, Jidong Liu and Jianhua Lv

ABSTRACT

Polyaniline (PANI) chains were grafted at the edge of graphene oxide (GO) sheets by in-situ chemical oxidation polymerization. The obtained GO-PANI composite was used for the adsorption of cationic methylene blue (MB) and anionic methyl orange (MO) dyes from aqueous solutions. The structure of the GO-PANI composite was characterized by Fourier transform infrared spectroscopy (FT-IR), X-ray diffraction (XRD), scanning electronic micrograph (SEM), X-ray photoelectron spectroscopy (XPS) and zeta potentials. GO-PANI exhibited a high adsorption capacity for MB (962 mg/g) and MO (885 mg/g) compared with other reported absorbents, which was due to adsorption through strong π-π stacking and anion-cation interactions. The nanocomposite could be recycled five times without significant loss in removal abilities for MB (87.8%) and MO (75.0%), respectively. GO-PANI composite is a promising adsorbent for the adsorption of anionic and cationic dyes from aqueous solutions.

Key words | adsorption, dye, graft, graphene oxide, polyaniline

INTRODUCTION

Dyes are important water pollutants which are discharged by printing, textiles, dyeing, tanneries and paint industries (Ajmal et al. 2014; Sonai et al. 2016; Bordoloi et al. 2017). The untreated discharge of dye-containing waste water can cause great harm to aquatic organisms (Dey & Mukhopadhyay 2015). Therefore, removing dyes from waste water before discharge is an important challenge. Several physicochemical and biological methods, such as flocculation, catalytic degradation, reverse osmosis and adsorption by different materials have been used for the removal of dyes (Luo et al. 2010; Ghosh et al. 2015). Among the above methods, adsorption is considered an attractive method owing to its low cost, high efficiency and simple operation (Yao et al. 2015). Various adsorbents have been studied for the adsorption of dyes, such as metal oxides (SnO₂, Fe₃O₄, etc.), polymers and carbon-based materials (Pang et al. 2013; García et al. 2014; Thangavel & Venugopal 2014; Rajkumar et al. 2015; Lu et al. 2016). Recently, graphene-based materials such as graphene oxide (GO) have been intensively studied for adsorption, as they have a high surface area and abundant functional sites.

GO, with multiple hydrophilic hydroxyl and carboxyl groups, shows good adsorption for cationic dyes and heavy metal ions (Cu(II), Cr(III)) (Machida et al. 2006; Namvari & Namazi 2014; Yang et al. 2014; Kim et al. 2015; Dai et al. 2017). However, the strong π-π stacking interactions between graphene nanosheets can lead to serious aggregation and restacking, which decrease the adsorption activity (Li et al. 2013; Shang et al. 2014). Accordingly, modified GO at the edge or on the basal plane have received considerable attention. Many efforts have been devoted to the development of GO composites with good dispersion and hydrophilicity. For example, GO grafting polymers have been reported in in-situ polymerization approaches using aniline in the presence of GO (Goswami et al. 2011; Yu et al. 2012).

Chemical modification of functional groups on the surface of GO (which act as chemical anchoring sites) may improve their dispersion and adsorption capacity. Recently, polyaniline (PANI) has attracted more attention for its easy synthesis, low cost and excellent environmental stability as an adsorbent (Ai et al. 2010). PANI
has abundant amine and imine groups in the polymer chains, which makes it a promising material for composites with GO. With hydroxyl and epoxide in the basal plane and carboxyl at the GO edges, GO grafting polymers could weaken π–π interactions by augmenting the distance between the layers. Hence, covalent attachment of polymer chains from the edge functional groups could be an effective method to reduce the stacking of GO nanoplatelets, compared with uncontrolled GO composite materials (Georgakilas et al. 2012; Li et al. 2014b; Guo et al. 2015; Dutta et al. 2016).

In this study, PANI chains were grafted at the edge of GO sheets by in-situ chemical oxidation polymerization and the obtained composites (GO-PANI) were used for the adsorption of cationic methylene blue (MB) and anionic methyl orange (MO) from aqueous solutions. The effects of adsorbent dosage, pH, contact time and initial dye concentration were studied. Moreover, the adsorption was analyzed using isotherms, kinetic models, thermodynamics and adsorption mechanism. The results show that GO-PANI is an effective adsorbent for the removal of anionic and cationic dyes from aqueous solutions.

MATERIALS AND METHODS

Materials

MB, MO, sodium hydroxide (NaOH), hydrogen nitrate (HNO₃), and alcohol were purchased from Sinopharm Chemical Reagent Co., Ltd China. All the reagents were of analytical purity. The chemical structures of MB and MO are presented in Figure S1 (available with the online version of this paper). Different concentrations of MB and MO solutions were prepared by dissolving the required amounts of MB and MO in deionized water.

Preparation of GO-PANI

GO was prepared according to Staudenmaier method (Staudenmaier et al. 1898) and the detailed steps for preparing the GO-PANI was described in our previous study (Yang et al. 2016).

Adsorption study

The adsorption studies were carried out using MB and MO as the model dyes to investigate the adsorption ability of GO-PANI. The experiments was performed in a set of 150 mL Erlenmeyer flasks containing 50.0 mL MB or MO solutions and 0.6 g/L of the adsorbent. The flasks were placed in an isothermal water-bath shaker at 298 K for 90.0 min. The dye adsorption experiments were conducted in a set of Erlenmeyer flasks by batch process to study the influence of different parameters such as time (0–200 min), initial pH (2.0–11.0), and effect of the MB and MO concentration (25.0–250 mg/L). The initial and residual adsorbent concentrations were measured on a UV-vis spectrophotometer (INESA spectrophotometer) at a maximum wavelength of 664 nm for MB and 464 nm for MO. The amount of the absorption at equilibrium \( q_e \) (mg/g) was evaluated using Equation (1):

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

where \( C_0 \) and \( C_e \) (mg/L) are the concentration of the MB or MO initially and at equilibrium, respectively; \( V \) (L) is the volume of the solution; and \( m \) (g) is the mass of adsorbents used.

The pH-dependent experiments were carried out by adjusting the initial pH (in the 2.0–11.0 range) of the MB (100 mg/L) and MO solution (100 mg/L) using 0.01 M HNO₃ or 0.01 M NaOH solutions. For the kinetic adsorption experiments, 0.6 g/L of GO-PANI was ultrasonically dispersed into various concentrations of MB and MO solution. The desired pH 6.0 was adjusted by using a negligible volume of 0.01 M NaOH or HNO₃. A 5.0 mL aliquot was sampled and filtered at certain time intervals. For the adsorption isotherm experiments, 0.6 g/L of GO-PANI was ultrasonically dispersed into 100 mg/L of MB or MO solution. The entire process was repeated by varying the water-bath shaker temperature to 298 K, 308 K and 318 K. The suspensions were gently shaken for 90.0 min to obtain full equilibrium. The solid–liquid separation was carried out by centrifugation.

The amount of the adsorbent adsorbed on the adsorbent at time \( t \), \( q_t \) (mg/g) was calculated using a mass balance Equation (2):

\[
q_t = \frac{(C_0 - C_t)V}{m}
\]

where \( C_0 \) and \( C_t \) (mg/L) are the concentration of the MB or MO at initial and at time \( t \), respectively; \( V \) (L) is the volume of the solution; and \( m \) (g) is the mass of adsorbents used.
Regeneration studies

The recovered adsorbents from the 150 mL Erlenmeyer flask containing 50.0 mL (100 mg/L initial concentration) MB or MO solution used for batch adsorption studies were washed with 50.0 mL alcohol. After desorption, the adsorbents were lightly washed with distilled water to remove un-adsorbed dye on the surface, then dried and used for the next adsorption experiment. The cycle was repeated five times.

Characterization

Fourier transform infrared absorption spectra (FT-IR) were recorded on an FT-IR spectrometer (Bruker TENSOR 27) using the KBr pellet technique. Powder X-ray diffraction (XRD) patterns were characterized using XRD on a D8 Discover (Bruker AXS Ltd.) with Cu Kα radiation in a scanning range of 5–60° (2 theta) with a scan rate of 12°/min. The morphology of the composites was observed by scanning electronic micrograph (SEM; FEI Nova Nano SEM450). The zeta potential measurements were measured using a Nano Zeta Sizer (Nano-ZS90). X-ray photoelectron spectroscopy (XPS) was carried out on a Thermo ESCALAB 250XI spectrometer with a monochromatic Al Kα X-ray source.

RESULTS AND DISCUSSION

Characterization

The FT-IR spectra of GO-PANI are shown in Figure 1(a). The FT-IR spectra of GO-PANI show a broad peak at 3,432 cm⁻¹, attributed to the stretching vibrations of the OH group. The bands of doped PANI at 1,561 cm⁻¹ and 1,467 cm⁻¹ were attributed to C=C stretching in quinoid and benzenoid rings, respectively (Manivel et al. 2015; Jain et al. 2016). The adsorption peak at 1,292 cm⁻¹ may be related to C-N stretching of the secondary aromatic amine. The band at 802 cm⁻¹ is ascribed to the C-H out-of-plane bending vibration characteristic absorption peak of two substituted benzene (Liu et al. 2014). The FT-IR results suggest that PANI chains were grafted at the edge of GO sheets.

Figure 1(b) shows the powder XRD patterns of GO-PANI. For GO, the peak located at 12.5° (d = 0.71 nm) is attributed to (001) crystal plane of the layered structure of GO. The large interlayer distance is attributed to the formation of hydroxyl, epoxy and carboxyl groups, which increase the distance between the layers (Moussa et al. 2011). However, the disappearance of the peak at 12.5° and the presence of a new broad diffraction peak at 25° (d = 0.36 nm) in the spectra of GO-PANI indicate part of the GO sheets were reduced after the reaction with p-phenylene diamine (Matsuo et al. 2007). Compared with the patterns of pure PANI (Mahanta et al. 2008), the presence of typical peaks of PANI in the XRD patterns of GO-PANI indicated PANI could be successfully grafted onto the GO-PANI and its structure was preserved without being damaged.

SEM was used to investigate the morphology of the GO, PANI and GO-PANI. The GO has a good fold sheet structure and smooth surface (Figure 2(a)). The pure PANI particles show the rod-like nanostructures (Figure 2(b)) (Gui et al. 2014). As shown in Figure 2(c) and 2(d), the surface of GO-PANI is smooth, which is similar to that of
GO. However, compared with that of GO, the edges of GO-PANI are expanded with the rod-like particles, indicating PANI was successfully grafted at the edge of GO sheets. This result is consistent with the results of FT-IR and XRD.

XPS was performed to investigate the composition and chemical states of elements in the GO-PANI (Figure 3). The XPS wide-scan spectrum shows that GO-PANI is composed of the elements of C, O and N (Figure 3(a)). The C 1s XPS spectra of GO display four characteristic peaks at 284.8, 286.6, 287.4 and 288.3 eV (Figure 3(b)), attributed to C-C, C-O, C=O and O-C=O, respectively (Shao et al. 2014). Additionally, the C 1s spectrum of GO-PANI can be deconvoluted into four peaks at 284.7, 285.9, 286.5, 288.9 eV (Figure 3(c)), corresponding to the sp3-hybridized carbon atoms (C-C), carbon-nitrogen bond (C-N), hydroxyl groups (C-OH) and carbonyl groups (C=O), respectively. The presence of a peak at 285.9 eV assigned to C-N and the disappearance of the O-C=O peak further demonstrates that PANI was successfully grafted onto the edge of GO, which is in good agreement with the results of FT-IR, XRD and SEM.

Zeta potential is capable of giving an idea of surface charge. Thus, the zeta potential serves as another important adsorbent characteristic. Results of the zeta potential measurement at different pH explained the acid–base characteristic of GO and GO-PANI. As shown in Figure S2 (available with the online version of this paper), the zeta potential results showed that the GO-PANI surface charge was zero at pH 2.0. Therefore, the isoelectric charge of GO-PANI is pH = 2.0. In addition, the surfaces of GO have a certain degree of electronegativity in acidic and basic conditions (Shahabuddin et al. 2016). After grafting PANI chains at the edge of GO sheets, the zeta potential of GO-PANI slightly increased due to the presence of amine and imine groups in the PANI. This result is consistent with the results of FT-IR, XRD and XPS.

Effect of pH on absorption of MB and MO

The effect of pH on the adsorption of MB and MO is shown in Figure S3 (available online). The adsorption capacities present a significant change with the increase of pH values in the range of 2.0–10.0. Due to MB being a cationic
dye, the increasing pH may lead to increased electrostatic attraction, and therefore increased adsorption of MB on GO-PANI. Moreover, the zeta potential result showed that the GO-PANI surface charge was zero at pH 2.0 and the surface charge of GO-PANI is negative when the pH is greater than 2.0, which indicates that the high pH is beneficial for the adsorption of MB. In addition, a large amount of H\(^+\) released under low pH conditions might compete with the MB cation for the adsorption sites. As a result, high pH favors the MB adsorption onto GO-PANI by electrostatic attraction. Therefore, electrostatic attraction between MB cations and the negatively charged sites on the surface of GO-PANI is considered to be the major driving force for the adsorption. The adsorption rate of MO decreases with the increase of pH form 2.0 to 10.0. The pH affects the ionization of GO-PANI functional groups (such as amino and hydroxyl group), which are responsible for the adsorptions (Diagboya et al. 2014). At low pH, amino and hydroxyl groups on the surface of GO-PANI are protonated, thus leading to increases in electrostatic attraction between MO (anionic dye) and the positively charged sites of GO-PANI (Cui et al. 2015). As the pH of the MO solution increased from 2.0 to 10.0, the deprotonation of amino and hydroxyl groups on the surface of GO-PANI increased, leading to the decrease of MO removal efficiency. In particular, the adsorption capacity of GO-PANI for MO decreased rapidly in the pH range of 2.0–4.0, and then decreased gradually. However, when the solution pH value is 10.0, the adsorption capacity of GO-PANI for MO can still reach 113 mg/g. Therefore, the possibility of π–π interactions between MO and GO-PANI may also be taken into account for the adsorption process (Cheng et al. 2014). MB molecules can also provide π–π interactions and hydrogen bonding of adsorption complexes onto GO-PANI surfaces may be taken into account for the adsorption process (Cheng et al. 2014). These results agree with the zeta potential of GO-PANI shown in Figure S2. For the adsorption of MB and MO, GO-PANI exhibits almost the same adsorption ability at pH 4.0–6.0. The actual industrial dye waste water pH are generally close to neutral. Therefore, experimental data
for kinetic and isotherm experiments were performed at pH 6.0.

**Adsorption kinetics**

Figure 4 shows the effects of contact time on the adsorption capacity of MB and MO onto GO-PANI at different initial concentrations. The adsorption capacities of MB and MO onto the adsorbent drastically increase during the initial stage and this is followed by slow adsorption. It is obvious that the adsorption equilibrium is attained after 90.0 min. The results can be ascribed to the fact that most vacant surface sites are available for adsorption during the initial stage and the remaining vacant surface sites are hard to access due to repulsive forces between the dye molecules on GO-PANI and in the aqueous solutions (Fu et al. 2015). The fast adsorption for GO-PANI can be attributed to the nonporous nature of GO and the abundant surface functional groups on the nanocomposite, indicating the mass transfer resistance was minimal and the adsorbent had a strong affinity for cationic and anionic dyes. The equilibrium adsorption capacities of MB and MO at different concentrations present an increasing trend, which is due to the fact that the high initial concentration generated a strong driving force resulting from the concentration gradient. When the active adsorption sites of the adsorbent were almost completely occupied by MB and MO molecules, the adsorption amount reached the maximum and almost remained constant. It suggests that the adsorption process is highly dependent on initial MB and MO concentration.

To further analyze the adsorption kinetics, the adsorption kinetics data of MB and MO adsorption onto GO-PANI and PANI can be used for fitting to the Lagergren pseudo-first-order and pseudo-second-order equations, which are expressed as follows.

**Pseudo-first-order model:**

\[
\ln\left(\frac{q_e}{t} - q_t\right) = ln\frac{q_e}{C_0} - k_1t
\]  

(3)

where \(q_e\) and \(q_t\) are the amounts of MB or MO adsorbed at equilibrium and at time ‘\(t\)’ (mg/g), and \(k_1\) is the equilibrium rate constant of the pseudo-first-order equation (min\(^{-1}\)).

For the pseudo-second-order model:

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

(4)

where \(k_2\) is the rate constant of adsorption (g/mg·min) for the pseudo-second-order adsorption process. The fitting plots for the adsorption of MB and MO by GO-PANI and PANI are shown in Figure S4. Table S1 summarizes the values of kinetic parameters obtained from the two models of MB and MO adsorption onto GO-PANI and PANI, respectively. The values of correlation coefficients \((R^2)\) for the pseudo-second-order model are higher than for the pseudo-first-order adsorption, which indicates the pseudo-second-order model could reasonably describe the adsorption of MB and MO on GO-PANI. (Figure S4 and Table S1 are available online.)

Compared to \(q_m\) values of MB and MO adsorption on other adsorbents, GO-PANI has the highest adsorption...
Similarly, the adsorption band of MO at 1,607 cm$^{-1}$ could be involved in MB adsorption (Wang et al. 2016). The characteristic C$-\pi$ interactions as each carbon atom in GO-PANI has a $\pi$ electron orbit, which is perpendicular to the surface. In addition, MB and MO molecules containing C = C double bonds and benzene rings with $\pi$ electrons could form $\pi-\pi$ bonds with GO-PANI. The adsorption band of GO-PANI at 1,292 cm$^{-1}$ corresponding to C$-\pi$ shifts to 1,302 cm$^{-1}$, indicating that the amino of GO-PANI plays an important role in the adsorption process described as being protonated, which makes the surface of GO-PANI positively charged (Zujovic et al. 2011). Two bands at 1,369 and 1,193 cm$^{-1}$ are due to $S=O$ stretching of MO, and shift to wavenumbers 1,387 and 1,383 cm$^{-1}$, respectively. Thus, electrostatic attraction can be regarded as the adsorption force for MO onto GO-PANI. The molecule interactions between GO-PANI and MB or MO discussed above during the adsorption process are schematically represented in Figure 5.

Furthermore, when the MB and MO was adsorbed onto the GO-PANI, variations of C1s, O1s and N1s percentages in the XPS spectra of GO-PANI were observed (Figure S7, available online). Notably, the N1s of the MB-GO-PANI and MO-GO-PANI show an increased percentage area due to the presence of the amino groups of the dye. Moreover, the N1s signal shift to a lower BE value indicates the presence of slight electrostatic interactions between the positively charged amino groups on the GO-PANI surface and MB or MO (Sharma et al. 2014).

**Regeneration of GO-PANI**

A promising adsorbent should not only possess higher adsorption capacity but should also show good reusability properties, which will significantly reduce the overall cost for practical application. Thus, the recycling of GO-PANI for MB and MO removal are shown in Figure S8 (available online). The adsorption capacity of MB and MO using GO-PANI decreased slowly with increasing cycle numbers. However, the adsorption efficiency was still maintained about at 87.8% and 75.0% after the fifth cycle for MB and MO, respectively. In addition, an XRD investigation of GO-PANI adsorption for MB and MO before and after were performed to check the textural change in GO-PANI adsorption and desorption (Figure 1(b)). The structure of GO-PANI is unaltered after the adsorption and desorption of the dyes. This indicates that GO-PANI has a capacity (shown in Table 1). Such comparison suggests that GO-PANI may be an effective adsorbent for MB and MO removal from contaminated water.

**Mechanism of adsorption**

As discussed in the effect of pH on MB and MO adsorption, electrostatic attraction is regarded as the main adsorption force for MB. However, the adsorption process often includes a complex adsorption mechanism and various types of interactions may be involved in MB and MO adsorption onto GO-PANI. To verify the adsorption mechanism, the FT-IR spectra (Figure 1(a)) of GO-PANI, MB, MO, GO-PANI after the adsorption of MB (GO-PANI-MB) and GO-PANI after the adsorption of MO (GO-PANI-MO) were investigated.

For MB, the C-N stretching vibration at 1,327 and 1,387 cm$^{-1}$ shifts to 1,324 and 1,383 cm$^{-1}$, respectively (Liu et al. 2022c). The adsorption peaks at 3,432 cm$^{-1}$ for O-H for GO-PANI shift to 3,441 cm$^{-1}$. The shifts indicate that the existence of hydrogen bonding between the hydroxyl of GO-PANI and the nitrogen of MB. The characteristic adsorption peaks of MB at 828, 885 and 1,596 cm$^{-1}$ ascribed to the aromatic rings slightly shift to 827, 883 and 1,593 cm$^{-1}$, respectively, which suggest that $\pi-\pi$ interactions could be involved in MB adsorption (Wang et al. 2015). Similarly, the adsorption band of MO at 1,607 cm$^{-1}$ corresponding to C = C stretching of aromatic rings shift to 1,586 cm$^{-1}$. Furthermore, the adsorption peaks at 1,561 and 1,467 cm$^{-1}$ belonged to C = C for GO-PANI shift to wavenumbers 1,593 and 1,492 cm$^{-1}$ for MB, 1,586 and 1,498 cm$^{-1}$ for MO after adsorption, respectively (Zhang & Zhao 2022). This result confirms the presence of $\pi-\pi$ interactions as each carbon atom in GO-PANI has a $\pi$ electron orbit, which is perpendicular to the surface. In addition, MB and MO molecules containing C = C double bonds and benzene rings with $\pi$ electrons could form $\pi-\pi$ bonds with GO-PANI. The adsorption band of GO-PANI at 1,292 cm$^{-1}$ corresponding to C$-\pi$ shifts to 1,302 cm$^{-1}$, indicating that the amino of GO-PANI plays an important role in the adsorption process described as being protonated, which makes the surface of GO-PANI positively charged (Zujovic et al. 2011). Two bands at 1,369 and 1,193 cm$^{-1}$ are due to $S=O$ stretching of MO, and shift to wavenumbers 1,387 and 1,383 cm$^{-1}$, respectively. Thus, electrostatic attraction can be regarded as the adsorption force for MO onto GO-PANI. The molecule interactions between GO-PANI and MB or MO discussed above during the adsorption process are schematically represented in Figure 5.

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<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Dye</th>
<th>Adsorption conditions</th>
<th>$q_m$(mg/g)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>GNs</td>
<td>MB</td>
<td>293 K</td>
<td>154</td>
<td>Liu et al. (2012b)</td>
</tr>
<tr>
<td>3D-GO</td>
<td>MB</td>
<td>pH = 7, 298 K</td>
<td>390</td>
<td>Liu et al. (2012a)</td>
</tr>
<tr>
<td>Fe$_3$O$_4$/SiO$_2$/GO</td>
<td>MB</td>
<td>pH = 7, 298 K, 0.4 g/L</td>
<td>97.0</td>
<td>Yao et al. (2012)</td>
</tr>
<tr>
<td>mGO/PVA-CG</td>
<td>MB</td>
<td>pH = 7, 298 K</td>
<td>271</td>
<td>Cheng et al. (2015)</td>
</tr>
<tr>
<td>PANI/$\alpha$-ZrP</td>
<td>MO</td>
<td>pH = 4, 298 K</td>
<td>377</td>
<td>Wang et al. (2012)</td>
</tr>
<tr>
<td>Fe$_3$O$_4$@C@PANI</td>
<td>MO</td>
<td>0.2 g/L</td>
<td>120</td>
<td>Yao et al. (2013)</td>
</tr>
<tr>
<td>GOS/Fe$_3$O$_4$/PANI</td>
<td>MO</td>
<td>pH = 4, 298 K, 0.4 g/L</td>
<td>585</td>
<td>Li et al. (2014a)</td>
</tr>
<tr>
<td>MWCNTs/Fe$_3$O$_4$/PANI</td>
<td>MO</td>
<td>pH = 4, 298 K, 0.4 g/L</td>
<td>545</td>
<td>Zhao et al. (2015)</td>
</tr>
<tr>
<td>GO-PANI</td>
<td>MB</td>
<td>pH = 6, 298 K</td>
<td>544</td>
<td>Yang et al. (2016)</td>
</tr>
<tr>
<td>GO-PANI</td>
<td>MB</td>
<td>pH = 6, 298 K</td>
<td>962</td>
<td>This study</td>
</tr>
<tr>
<td></td>
<td>MO</td>
<td>0.6 g/L</td>
<td>885</td>
<td></td>
</tr>
</tbody>
</table>
good reusability and could be used repeatedly for the removal of MB and MO from waste water.

CONCLUSIONS

In summary, a novel GO-PANI composite was successfully prepared and used as an effective adsorbent to remove the cationic MB and anionic MO dyes from aqueous solutions. The effects of contact time, dye concentration, and initial pH on the removal of MB and MO were investigated through batch experiments. The adsorption process of MB and MO onto GO-PANI composites follows the pseudo-second-order kinetics model and the experimental results fitted well with Langmuir isotherm model, which suggest that the adsorption process is monolayer chemisorption. The monolayer adsorption capacity of GO-PANI composites was 962 mg/g for MB and 885 mg/g for MO, which is much higher than those of previously reported adsorbents. The mechanism of adsorption of MB and MO onto GO-PANI includes electrostatic attraction, π-π interactions and hydrogen bond interactions. Moreover, GO-PANI shows facile recovery and recycling properties and has the potential to be used as a good adsorbent for cationic and anionic dye removal.

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