

Selective Adsorption Performance of Graphene Oxide Toward Norfloxacin and Moxifloxacin in Aqueous Solution

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Abstract

Norfloxacin (NFX) and moxifloxacin (MFX) are widely used fluoroquinolone antibiotics and are frequently detected as residues in water. Their persistent presence can increase the risk of antibiotic-resistant bacteria (ARB) emerging, making the selective removal of these compounds from the aquatic environment important. This study evaluates the adsorption selectivity of NFX and MFX using graphene oxide (GO) as a potential adsorbent. The results show that GO has a higher affinity for NFX than MFX, indicating selective interactions between GO functional groups and NFX molecules. These findings confirm the potential of GO as a selective adsorbent for removing specific antibiotics from aqueous solutions, which could provide a basis for developing wastewater treatment strategies.

Keywords

Graphene Oxide, Selective Adsorption, Norfloxacin, Moxifloxacin

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1. INTRODUCTION

Rapid population growth and economic development are increasing the need for better healthcare services. This condition is driving the growth of the pharmaceutical and drug manufacturing industries, which are becoming increasingly numerous. As a result, the volume of pharmaceutical liquid waste generated each year is also increasing. Pharmaceutical waste generally contains high concentrations of organic solvents, organic compounds that are difficult to degrade naturally, and antibiotic residues (Zhou et al., 2026).

The presence of antibiotic residues can pose serious challenges to the environment and public health due to their persistent nature, characterized by low biodegradability. These difficult-to-degrade pollutants can indirectly disrupt the structure and metabolic activity of microbial communities, while their bioaccumulation can exacerbate ecological risks by triggering the emergence of antibiotic-resistant bacteria (El-Aassar et al., 2025; Sun et al., 2026; Sun et al., 2025).

Norfloxacin (NFX) and Moxifloxacin (MFX) are synthetic fluoroquinolone (FQ) antibiotics that are increasingly detected in surface water, groundwater, and wastewater due to their widespread use (Mahmoud et al., 2025; Pham et al., 2025; Shaha et al., 2024; Yazidi et al., 2025). These antibiotics are difficult to digest and absorb completely, so most of their compounds are released into the environment in their original form (Ouyang et al., 2025). Additionally, their persistent, soluble, and ecotoxic nature makes

them dangerous emerging contaminants, as they have the potential to increase antimicrobial resistance and threaten aquatic ecosystems and human health (Li et al., 2025). Therefore, developing efficient methods for removing NFX and MFX from wastewater is crucial (Yazidi et al., 2025).

Various methods have been developed to eliminate the presence of these wastes, including adsorption, photolysis, microbial degradation, enzymatic transformation, and phytoremediation (Shaha et al., 2024; Yuan et al., 2025). Among these approaches, adsorption has received the most attention due to its effectiveness and simple application (Shabavi et al., 2024).

Graphene oxide (GO) is a single layer of graphite containing various functional groups on its surface, such as epoxy (–O–), hydroxyl (–OH), carboxyl (–COOH), and carbonyl (–C=O) groups at its edges (Amri et al., 2023; Berber et al., 2021; Widakdo et al., 2025). The distribution of these functional groups plays a role in enhancing adsorption capacity toward specific ions and expanding the potential applications of GO in water treatment (dos Santos et al., 2025).

Given the growing concern over FQ contamination in aquatic systems, this work explores the selective adsorption characteristics of norfloxacin (NFX) and moxifloxacin (MFX) on graphene oxide (GO) as a potential adsorbent material. This study is expected to provide initial information regarding the potential of GO as a selective material for removing FQ antibiotics from the aquatic environment.

2. EXPERIMENTAL SECTION

2.1 Materials and Instruments

This research utilizes chemical substances such as sulfuric acid (H_2SO_4), sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), sodium nitrate (NaNO_3), hydrogen peroxide (H_2O_2), potassium permanganate (KMnO_4), hydrochloric acid (HCl), distilled water (H_2O), graphite, and antibiotic compounds (Norfloxacin & Moxifloxacin). Material characterization was performed using a Rigaku Miniflex-600 X-ray diffractometer to analyze crystal structure and a Shimadzu Prestige-21 FTIR spectrophotometer to analyze functional groups. The absorbance of NFX and MFX solutions was measured using a Biobase UV BK-1800PC UV-Visible spectrophotometer.

2.2 Synthesis of Graphene Oxide

Graphene oxide (GO) was synthesized using the Hummers method according to the procedure reported in our previous study by Amri and Hanifah (2023) and Amri and Wibiyani (2024). In short, graphite (3 g) and NaNO_3 (1.5 g) were mixed in H_2SO_4 (69 mL) until homogeneous. Next, KMnO_4 (9 g) was added in portions at a temperature below 20°C and stirred at 35°C for 7 hours, then another 9 g of KMnO_4 was added and stirred for 14 hours. After standing at room temperature, 400 mL of distilled water and 3 mL of H_2O_2 were slowly added. The material obtained was then filtered, washed, and dried at 80°C for 3 days.

2.3 Selective Adsorption Experiments

The adsorption selectivity study of norfloxacin (NFX) and moxifloxacin (MFX) on graphene oxide (GO) was conducted by comparing the percentage removal of each antibiotic with time up to 60 minutes. In the selectivity experiment, both antibiotic solutions were mixed by adding 0.02 grams of GO and stirring at room temperature for 60 minutes. After the adsorption process, the solutions were separated by filtration, and the remaining antibiotic concentrations were determined from the absorbance values measured using a UV-Visible spectrophotometer at a wavelength range of 250-310 nm (Biobase UV BK-1800PC). Measurements were taken at 20-minute intervals, and the percentage of adsorption was calculated based on the difference between the initial and final absorbance values.

3. RESULTS AND DISCUSSION

3.1 Characterization of Graphene Oxide

The X-ray diffraction (XRD) pattern shown in Figure 1 indicates the successful synthesis of GO material. In the graph, there is a characteristic peak in the region around $2\theta = 9-11^\circ$, which indicates the (001) reflection plane of GO (Akintayo et al., 2025). Additionally, the simultaneous decrease in intensity around $2\theta = 26^\circ$ with the (002) reflection plane, which is characteristic of graphite (Vinsiah et al., 2020), confirms that the oxidation and exfoliation process of graphite into graphene oxide has been successful (Vietanti et al., 2025). This is due to the introduction of various oxygen-containing functional groups such as carbonyl, epoxy, hydroxyl, and carboxylate during the oxidation process

(Prasetya et al., 2025). The presence of sharp and intense peaks on the (001) plane indicates that the material formed has a high degree of crystallinity.

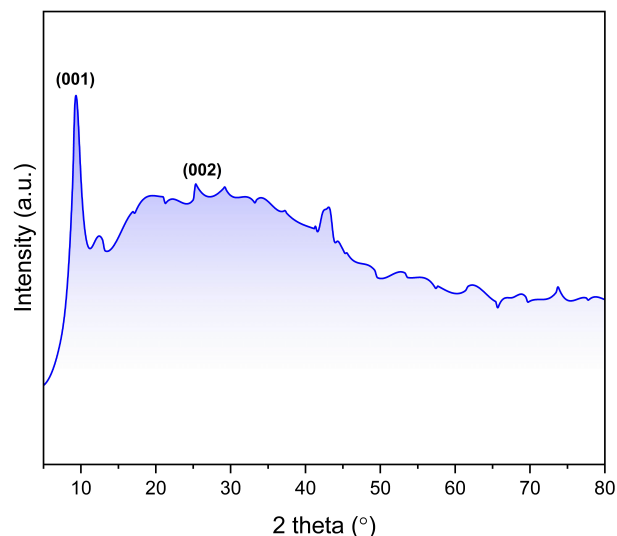


Figure 1. XRD Pattern of Graphene Oxide

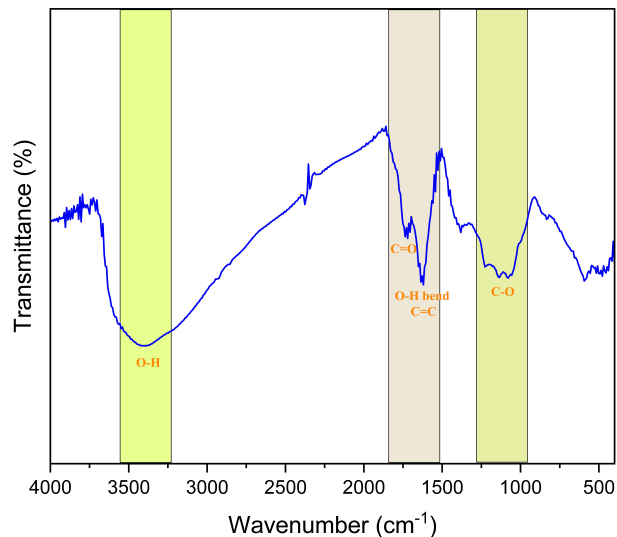


Figure 2. FT-IR Spectra of Graphene Oxide

Figure 2 shows the FT-IR spectrum of GO, which exhibits several characteristic absorption bands indicating the presence of various oxygen-containing functional groups on the surface of the graphene sheets. The broad absorption peak around $\sim 3400\text{ cm}^{-1}$ is attributed to the stretching vibration of the $-\text{OH}$ group, originating from hydroxyl and adsorbed water molecules (Podder et al., 2025). The absorption band appearing around $\sim 1726\text{ cm}^{-1}$ is related to the stretching vibration of the carbonyl group ($\text{C}=\text{O}$) from carboxylate or ketone groups (Aditi and Jindal, 2025). Meanwhile, the band around $\sim 1621\text{ cm}^{-1}$ is associated with the

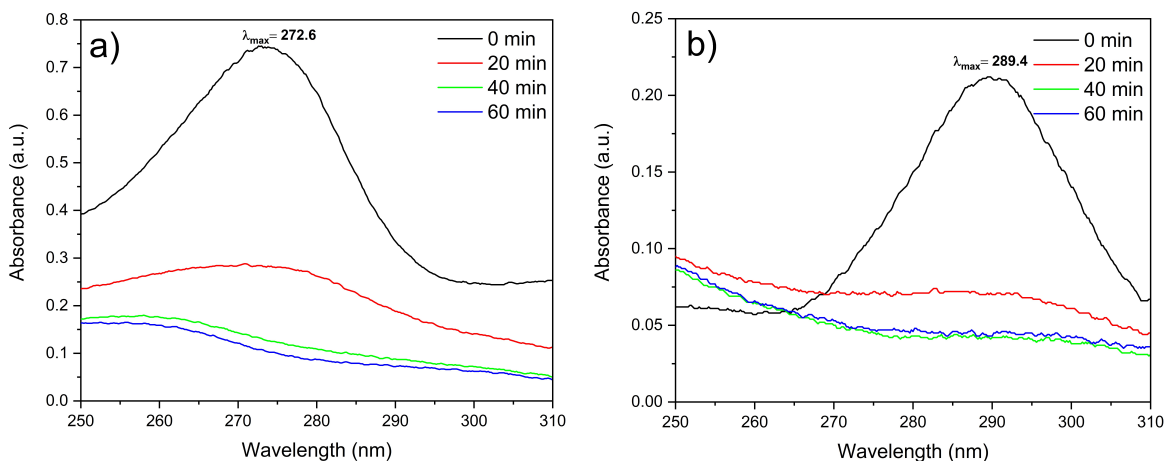


Figure 3. UV-Vis Spectra of (a) Norfloxacin (NFX) and (b) Moxifloxacin (MFX) on Graphene Oxide (GO) at Various Adsorption Times (0-60 Minutes)

O–H bending vibration and the C=C stretching vibration of the sp^2 aromatic framework in the graphene structure that remained after the oxidation process (Adawiyah et al., 2024; Prasetya et al., 2025). Next, the band around ~ 1140 – 1240 cm^{-1} can be attributed to the C–O stretching vibration of the epoxy group (C–O–C), while the band around ~ 1056 cm^{-1} indicates the presence of the C–O stretching vibration of an oxygen-containing functional group (Sharma et al., 2025). The overall presence of these peaks indicates that the graphite has been successfully oxidized to GO with a large number of oxygen functional groups bound to the surface and edges of the carbon sheets.

3.2 Selective Adsorption Studies

Figure 3(a) shows the UV-Vis spectra of NFX at various contact times (0-60 minutes) during the adsorption process. Based on the results obtained, the peak intensity of the main NFX absorption gradually decreased as the contact time between the adsorbent and the solution increased, indicating an effective adsorption process. At minute 0, the absorption peak shows the highest absorbance value of 0.745, representing the initial concentration of NFX in the solution before interaction with the adsorbent. After 20 minutes, the peak intensity decreases to approximately 0.284, and at minute 60, it further drops to around 0.108. Based on this value, the adsorption efficiency for NFX using GO adsorbent is 85.50%. This result indicates that the adsorbent surface has a good affinity for NFX molecules.

Additionally, adsorption efficiency tests were also conducted on the antibiotic MFX to evaluate the material's ability to remove other fluoroquinolone compounds, as shown in Figure 3(b). Based on the results of UV-Vis spectrum measurements, the absorption intensity of MFX showed a gradual decrease as the contact time increased from 0 to 60 minutes. At 0 minutes, the initial absorbance value was recorded at approximately 0.212, then decreased to 0.071 after 20 minutes, and reached 0.043 at

the end of the process (60 minutes). Based on calculations, the adsorption efficiency was found to be 79.72% after 60 minutes.

The rapid adsorption within the first 20 minutes for both antibiotic compounds indicates the dominance of the adsorption process involving electrostatic forces, hydrogen bonds, and π – π stacking interactions between the aromatic rings on NFX and MFX and the conjugated surface of GO (Zou et al., 2022). After that, the rate of decrease slowed down due to the limited active sites remaining on the adsorbent surface, indicating that the system was beginning to reach adsorption equilibrium.

The selectivity test was conducted to assess the ability of graphene oxide (GO) to simultaneously adsorb two types of fluoroquinolone antibiotics, namely NFX and MFX, in a mixed solution system. The change in absorption intensity over mixing time (0-60 minutes) is shown in Figures 4(a)-(b). The UV-Vis NFX spectrum shows a main absorption peak at around $\lambda_{\max} \approx 272.6$ nm, while MFX has an absorption peak that is slightly shifted toward longer wavelengths, namely $\lambda_{\max} \approx 289.4$ nm. These two distinct peaks remain clearly distinguishable, allowing for monitoring of the concentration decrease of each antibiotic as the adsorption process progresses.

After the process lasted for 60 minutes, it was observed that the absorption intensity of NFX decreased significantly compared to MFX. The percentage decrease in absorbance for NFX reached approximately 82.85%, while for MFX it was only about 81.82%. This indicates that GO has higher selectivity toward NFX compared to MFX. This difference can be attributed to the molecular structure and chemical properties of the two antibiotics. NFX has a smaller molecular size and more polar functional groups (such as –COOH and –NH) that interact more easily with the functional oxygen groups on the GO surface through hydrogen bonding and electrostatic interactions (Zhou et al., 2026). In contrast, MFX has a more complex structure that causes steric hindrance, making access to the GO active sites more limited

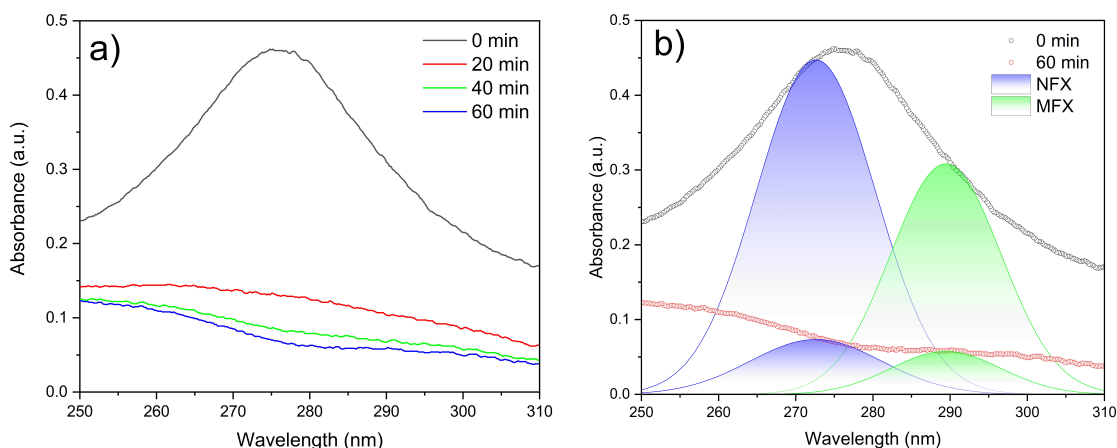


Figure 4. (a) UV-Vis Spectra of Norfloxacin (NFX) and Moxifloxacin (MFx) Adsorbed on Graphene Oxide (GO) at Various Contact Times. (b) Deconvolution Spectrum of The NFX-MFX Mixture at 0 and 60 Minutes

(Zhang et al., 2025). Additionally, the relatively small shift in the peak position of MFx adsorption during the adsorption process indicates that the interaction is weaker, likely dominated by π - π stacking interactions between the aromatic rings of MFx and the conjugated surface of GO.

This phenomenon of differing absorbance reduction confirms that GO not only functions as a non-specific adsorbent but also exhibits selective behavior toward molecules with specific chemical characteristics. This selective ability can be utilized in applications for separating or removing mixed antibiotics, which is useful in the wastewater treatment industry for handling pharmaceutical wastewater.

4. CONCLUSIONS

Graphene oxide (GO) has been successfully synthesized and exhibits different selectivity toward norfloxacin (NFX) and moxifloxacin (MFx). The results obtained show that the adsorption efficiency of NFX is higher than that of MFx. This difference in selectivity is likely influenced by the interactions occurring between the GO adsorbent and the two compounds. This finding confirms the potential of GO as a selective adsorbent for the removal of certain fluoroquinolone antibiotics from the aquatic environment.

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