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Dispersive Solid Phase Extraction for the Preconcentration of Trace Moxifloxacin in Aqueous and Urine Samples Using β-cyclodextrin Functionalized Magnetic Nanotubes

Ali Moghimi[1]*, Hossein Anaraki-Ardakani[2]*

[1]Department of Chemistry, TeMS.C., Islamic Azad University, Tehran, Iran

[2]Department of Chemistry, Ka.C., Islamic Azad University, Karaj, Iran

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Abstract

This project presents a rapid method for the adsorption of low concentrations of Moxifloxacin in aqueous samples using *β*-cyclodextrin-functionalized magnetic nanotubes (Fe_3O_4/NT/M). The process involves two phases: the donor phase, which consists of the water containing Moxifloxacin, and the acceptor phase, which includes the functionalized magnetic nanotubes with β-cyclodextrin. The experiment consisted of two steps: extracting Moxifloxacin from the water sample and desorbing it using basic methanol. The adsorption process was described well by the Langmuir isotherm model, indicating a maximum Moxifloxacin adsorption capacity of 30.12 mg/g. The pseudo-second-order kinetic model suggests that the rate of adsorption of Moxifloxacin by Fe3O4/NT/M is limited and governed by a chemisorption process. To optimize the effective parameters, a Central Composite Design (CCD) approach was employed. This method yielded optimal conditions for the adsorbent dose (15 mg), ultrasonic treatment time (21.5 minutes), and elution volume (11.3 mL). The limits of detection and quantification for Moxifloxacin adsorption were determined to be 16.9 µg/L and 55.6 µg/L, respectively, with a linear range established between 1 and 10 mg/L. Ultimately, Fe_3O_4/NT/BD demonstrated significant potential for the adsorption of Moxifloxacin from biological samples.

Keywords: *β*-cyclodextrin, adsorption, Moxifloxacin, SPE, Nanoparticles.

[*]***Corresponding authors**: Ali Moghimi, Department of Chemistry, TeMS.C., Islamic Azad University, Tehran, Iran. Email: ali.moghimi@iau.ac.ir and Hossein Anaraki-Ardakani, Department of Chemistry, Ka.C., Islamic Azad University, Karaj, Iran. Email: Hossein.anaraki@iau.ac.ir.*

Introduction

Moxifloxacin is an antibiotic used to treat bacterial infections [1-4], such as pneumonia, conjunctivitis, endocarditis, tuberculosis, and sinusitis. The drug can be administered orally, intravenously, or as eye drops [5]. Common side effects of moxifloxacin include diarrhea, dizziness, and headache [4]. Moxifloxacin belongs to the family of fluoroquinolone drugs [4] and works primarily by inhibiting bacteria's ability to replicate DNA. It is also included on the World Health Organization's list of essential medicines [4]. *β*-Cyclodextrin is a class of oligosaccharides derived from starch, consisting of seven D-(+)-glucopyranose units linked together by α-1,4 bonds. Its cone-shaped structure and well-defined cavity create an ideal environment for various species to interact. Solid-phase extraction (SPE) is a widely recognized method for extracting analytes and species through adsorption.

Moxifloxacin is a broad-spectrum fluoroquinolone antibiotic that has been extensively studied analytically due to its widespread clinical use and potential adverse effects. Analytical methods for moxifloxacin are essential for quality control in pharmaceutical manufacturing, therapeutic drug monitoring, and pharmacokinetic studies, all of which are crucial for ensuring patient safety and treatment efficacy. Various analytical techniques have been developed and validated for detecting moxifloxacin in different matrices, including biological fluids, pharmaceutical formulations, and environmental samples. These methods include a wide array of approaches such as chromatography (HPLC, GC-MS), spectroscopy (UV-Vis, fluorescence, and mass spectrometry), and electrochemical techniques. Chromatographic methods, especially High-Performance Liquid Chromatography (HPLC), are commonly used due to their high sensitivity, selectivity, and versatility. When HPLC is coupled with mass spectrometry (LC-MS/MS), it provides exceptional sensitivity and specificity, allowing for the detection and quantification of moxifloxacin even at low concentrations within complex matrices. On the other hand, spectroscopic techniques like UV-Vis and fluorescence offer rapid and cost-effective alternatives for routine analysis, although they may have some limitations in selectivity and sensitivity compared to chromatographic methods [°].

Various drugs and insecticides are organic compounds that can be extracted from food, biological, and environmental materials using the solid-phase extraction (SPE) technique. Magnetic nanotube composites are recognized as effective adsorbents for removing non-ferrous wastewater due to their significant features, including a large specific surface area and layered, hollow structures. In this study, we used β-cyclodextrin-functionalized magnetic nanotubes as nanosorbents to remove Moxifloxacin from water solutions. We thoroughly investigated the effects of several parameters on Moxifloxacin sorption onto β-cyclodextrin-functionalized magnetic nanotubes. These parameters included the type of organic solvent, the pH of both the donor and acceptor phases, stirring speed,

extraction time, and the volumes of the donor phase. *β*-Cyclodextrin is a starch-derived oligosaccharide comprising seven units of D-(+)-glucopyranose linked by α-1,4 glycosidic bonds. Its unique conical structure, featuring a well-defined cavity, creates an ideal environment for various substances to interact [9].

Solid-phase extraction (SPE) is a widely recognized method for extracting analytes through adsorption, without dissolving them [10-13,8]. This technique allows for the temporary storage of these analytes without altering their concentration or chemical structure. Moxifloxacin[14,15], various medications[16], personal care products, and insecticides are examples of organic compounds that can be extracted from dietary, biological, and environmental samples using SPE. Magnetic nanotube composites, known for their significant specific surface area and unique layered, hollow structures, are effective sorbents for removing colored effluents from these sources [17,18].

Experimental

Chemicals

Moxifloxacin ($C_{21}H_{24}FN_3O_4$, Figure 1) were provided by Merck (Darmstadt, Germany). Other chemicals included NaOH (purity > %), acetonitrile (purity > 99%), $FeCl_2$ (purity > 99%), and $FeCl_3$ (purity > 99%). *β*-Cyclodextrin (purity > 99%) was purchased from Sigma-Aldrich (USA). Multi-walled carbon nanotubes (MWCNTs) were supplied by Carbon Structures Co. (Iran). Acetic, boric, and phosphoric acids were utilized to prepare buffer solutions, which were then adjusted to the required pH levels using a 2M NaOH solution. All compounds used in this study were of analytical grade and commercially available.

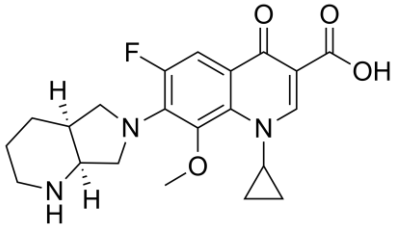

Figure 1. Chemical structures of Moxifloxacin.

Instruments

An Ultraviolet-visible (UV-Vis) spectrometer (Shimadzu, Japan) was used to measure absorption, store spectra, and record data, utilizing a 10 mL quartz cell. A pH meter, model ECHET P25, manufactured in Germany, was employed for pH measurements. Additionally, a magnetic heater paired with a digital scale from A&D, also made in Japan, was used in the experiments. Scanning electron microscopy (SEM) images were acquired using a TESCAN MIRA III. For further analysis, a Fourier-transform infrared (FT-IR) spectrometer, model Perkin Elmer RX1, was utilized. An X-

ray powder diffraction (XRD) investigation was conducted using a Philips instrument (plate number: PW1730).

Synthesis of magnetite nano adsorbent (Fe_3O_4@MWCNT)

In the initial step, a precise combination of 0.08 g of $FeCl_2$ and 0.21 g of $FeCl_3$ is mixed with 20 mL of deionized water, laying the foundation for an effective reaction. Next, the introduction of 0.04 g of multi-walled carbon nanotubes (MWCNT) enhances the solution's properties, after which it is heated at 50 ºC for 20 minutes to promote optimal interaction. Once cooled, the mixture undergoes ultrasonic dispersion for 20 minutes, ensuring uniformity. The addition of 1 mL of NaOH is crucial, followed by heating for 40 minutes to facilitate reaction completion. Finally, the solution is meticulously washed multiple times with distilled water and ethanol, culminating in a clean separation through magnetic methods, thereby achieving the desired results efficiently[19].

Synthesis of functionalized Fe_3O_4@MWCNT with β-cyclodextrin

0.5 g of β-cyclodextrin was dissolved in 50 mL of 1% acetic acid and stirred for 20 minutes at 400 rpm at a temperature of 25 °C. The precipitate obtained from the previous step was gradually added to the β-cyclodextrin solution. This mixture was then subjected to ultrasonic treatment for 5 minutes. Afterward, the product was separated using magnetic separation, following immersion in a water bath at 50 °C for 210 minutes [20].

Effect of pH on Moxifloxacin Removal

To investigate the impact of pH on the elimination of Moxifloxacin, we will follow these procedures. First, 1 mL of a 4 mg/L Moxifloxacin solution will be combined with 1 mL of a selected buffer, adjusting the pH within the range of 3 to 10. The mixture will then be distilled with deionized water. Following this step, 10 mg of the adsorbent will be added to the solutions, which will be agitated for 30 minutes before undergoing magnetic separation. Finally, the absorbance of the separated solution will be measured at a wavelength of 231 nm.

The effect of Fe_3O_4/NT/M amount

The effect of Fe_3O_4/NT/M amounts is analyzed by applying the optimal pH and conditions from the previous step to evaluate the varying amounts of Fe_3O_4/NT/M (10, 20, 30, 50, and 80 mg).

Adsorption time

The optimal conditions for the experiment, including pH and the amount of adsorbent, were determined. The solutions were then shaken for varying durations: 2, 5, 10, 15, 20, and 30 minutes. After shaking, the solutions were separated according to the previously established procedures, and their absorbance at the maximum wavelength was measured.

Determination of elution solvent

The selected solvent was added to the centrifuged solution balloon under optimal conditions, followed by shaking for 5 minutes before measuring the absorbance at the maximum wavelength.

Measuring of real samples

Urine samples from humans are collected, filtered, and stored in black glass containers. A specific volume of urine is obtained, and measurement procedures are conducted using the suggested approach. Additionally, a well water sample was collected from the Darband neighborhood in Tehran. A 50 mL sample of both urine and well water was placed into a flask, along with 30 mg of Fe_3O_4/NT/M and 1 mL of the chosen buffer. After shaking the mixture for 5 minutes, the sample was separated. It was then rinsed with 10 mL of methanol and shaken again.

Adsorption experiments

In the adsorption experiments, 30 mg of Fe_3O_4/NT/M was added to 50 mL of Moxifloxacin solution at various concentrations, adjusted to the optimal pH. The mixture was then shaken with a magnet for 5 minutes. The isotherms were examined for Moxifloxacin concentrations ranging from 10 to 100 mg/L[21].

Results and discussion

Characterization of the Fe_3O_4/NT/M

FTIR spectroscopy

The FTIR spectra of the carboxylated nanotube, Fe_3O_4/NT, and Fe_3O_4/NT/M after Moxifloxacin adsorption are presented in Fig. 2. In Fig. 2a, the peaks at 1030, 2927, 1620, and 3416 cm^{-1} correspond to multi-walled carbon nanotubes. The peak at 1030 cm^{-1} is associated with the C-O bond, while the peak at 1620 cm^{-1} is linked to the C=O stretching bond. In Fig. 2b, the peaks at 462 and 593 cm^{-1} are attributed to Fe-O bonds. In Fig. 2c, the unique absorption peak observed at 1633 cm^{-1} is attributed to the stretching vibrations of the C=O bond and C=C bonds within the graphite structure of Fe_3O_4/NT/M. The main band at 1118 cm^{-1} is associated with the C-O-C bond.

Additionally, the broad band at 3431 cm^{-1} is indicative of OH bending. The absorption band at 2920 cm^{-1} corresponds to the CH_2 vibrations of β-cyclodextrin[24].

Figure 2e presents the FTIR spectra of Fe3O4/NT/M following the adsorption of Moxifloxacin. The peak observed at 1624 cm–1 corresponds to the C=O functional group of the adsorbed Moxifloxacin on the Fe3O4/NT/M. Additionally, the peak at 1475 cm–1 is associated with the C–C vibrations of the aromatic ring from the adsorbed Moxifloxacin[25].

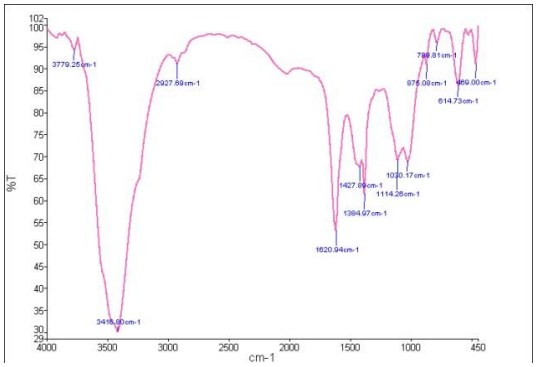

Figure 2a. FT-IR spectrum of carboxylated carbon nanotubes.

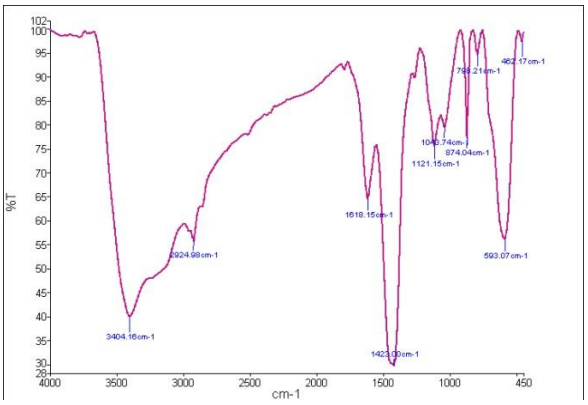

Figure 2b. FT-IR spectra of nano magnetic adsorbent.

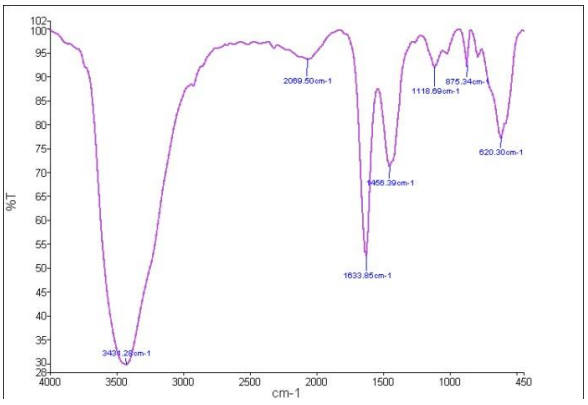

Figure 2c. FT-IR spectra of Fe_3O_4/NT/M.

SEM analysis

The SEM images of carbon nanotubes, nanomagnetic adsorbents, and Fe_3O_4/NT/M are presented in Figure 3. The carbon nanotubes have a width ranging from 14 to 23 nm and a length of several nanometers, exhibiting a random alignment (Figure 3a). The adsorption of β-cyclodextrin onto the nanomagnetic adsorbent is indicated by the brighter areas, which have a width of 24 to 68 nm (Fig. 3b).

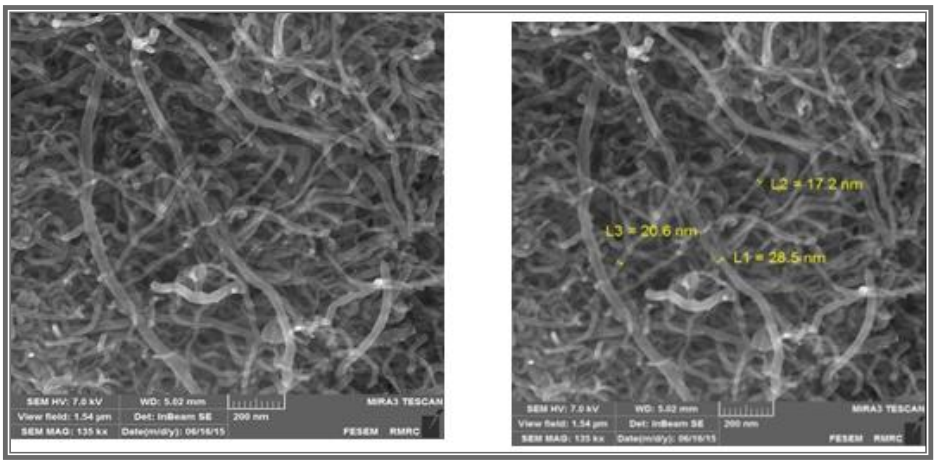

Figure 3a. SEM image of nanomagnetic adsorbent.

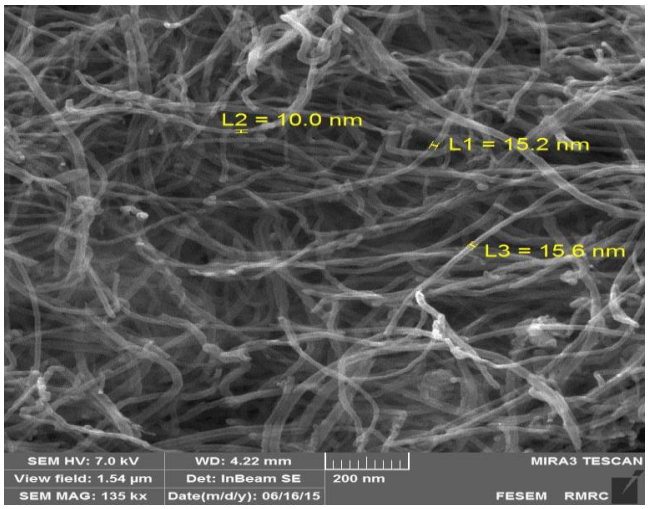

Figure 3s. SEM image of Fe_3O_4/NT/M.

XRD analysis

Figure 4 illustrates the XRD patterns of the adsorbent before and after the adsorption of Moxifloxacin. In panel 4a, the broad peak at 2θ = 26.5° is associated with the reflection of carboxylated carbon nanotubes. The distinct peaks observed at 30.2°, 35.5°, 43.2°, 53.6°, 57.1°, and 62.9° are attributed to the magnetite (Fe_3O_4). Following the adsorption of Moxifloxacin on the

Fe_3O_4/NT/M composite, there were noticeable changes in both the intensity and position of these peaks, as seen in panel 4d.

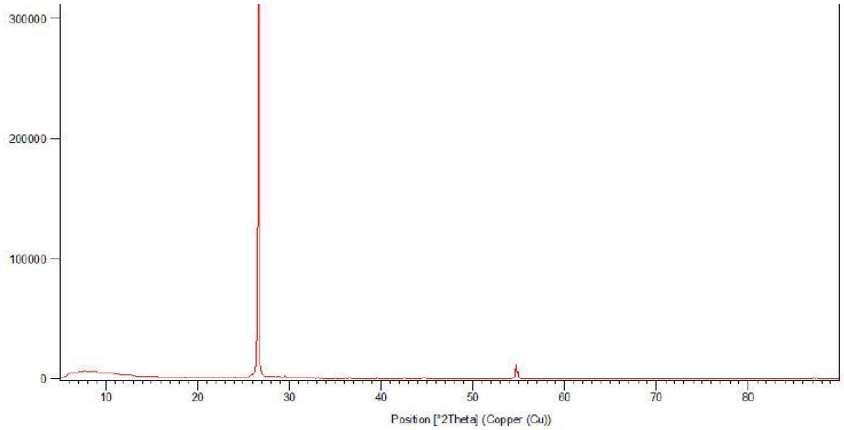

Fig 4a. XRD analysis of carboxylated carbon nanotubes

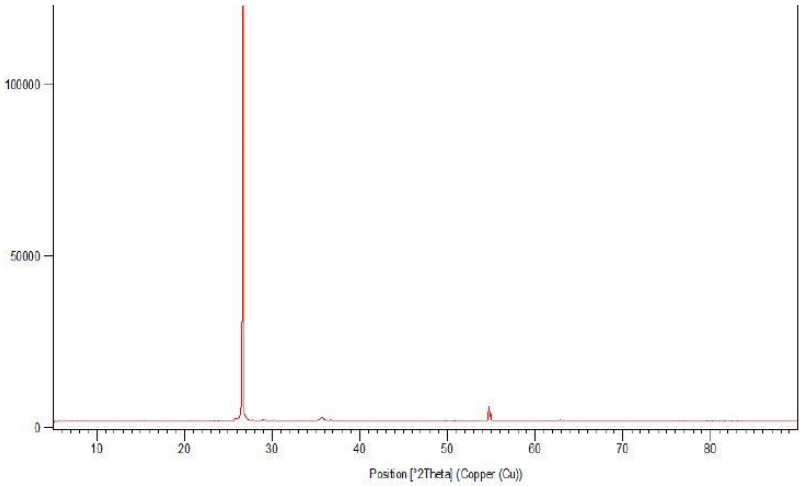

Figure 4b. XRD analysis of nano-magnetic adsorbent.

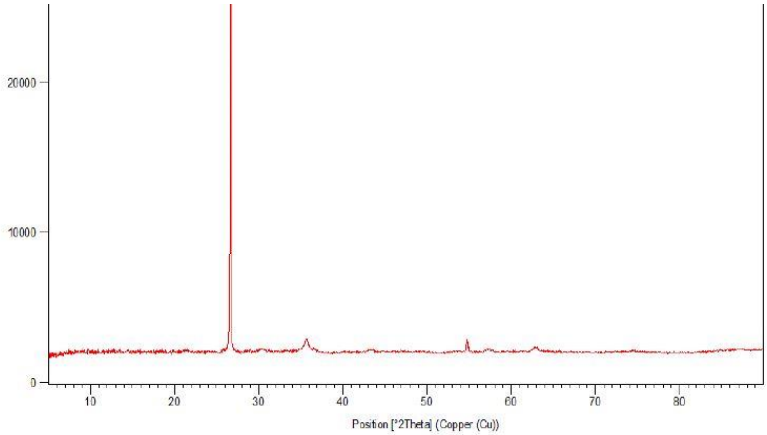

Figure 4c. XRD analysis of Fe_3O_4/NT/M.

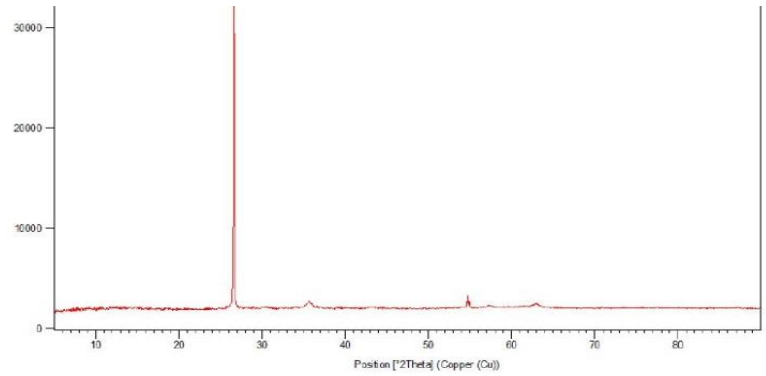

Figure 4d. XRD analysis of Fe_3O_4/NT/M with Moxifloxacin adsorption.

Factors influencing the measurement of Moxifloxacin extraction

The pH was adjusted using buffer solutions in the range of 3 to 10 to investigate the impact of pH on the extraction of Moxifloxacin. The results, shown in Figure 5, indicate that Moxifloxacin sorption is optimal at pH 6. At this pH, the conditions are favorable for the protonation of functionalized nanotubes, resulting in the highest uptake of Moxifloxacin on the carbon nanotubes operated by β-cyclodextrin. Thus, electrostatic interactions provide the best conditions for Moxifloxacin sorption at pH 6.

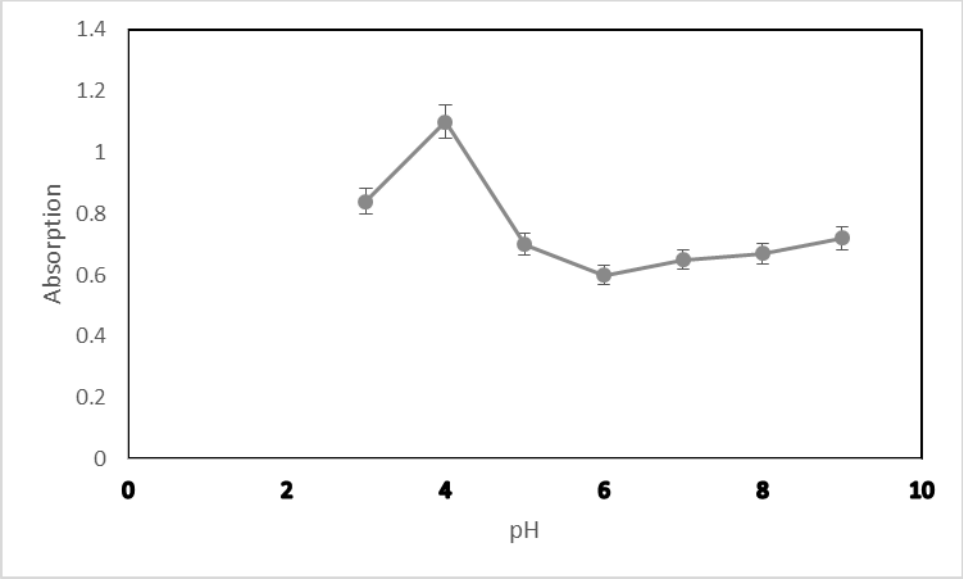

Figure 5. Influence of pH factor on Moxifloxacin extraction.

Another important factor examined in this study is the effect of salt. The UV-Vis spectra and the observed peak trends indicate that as the concentration of salt increases, the absorption of Moxifloxacin by Fe_3O_4/NT/M decreases. The results displayed in Figure 6 suggest that adding salt does not positively impact Moxifloxacin absorption, and therefore, its use should be avoided.

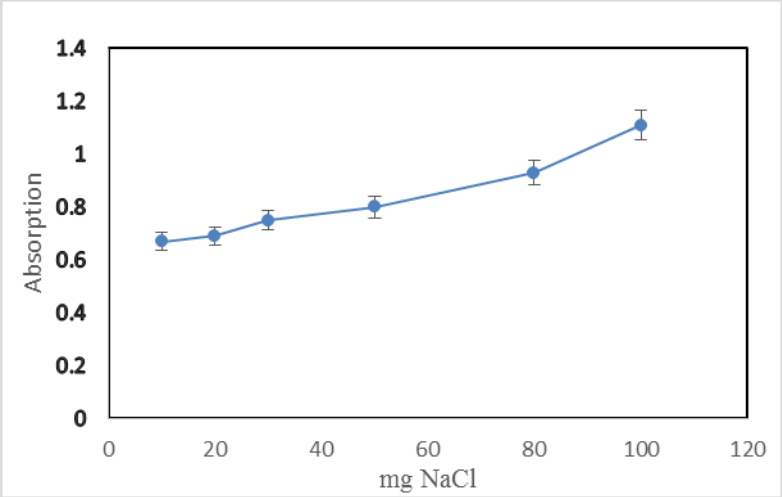

Figure 6. Investigation of the effect of salt concentration on the absorption intensity of moxifloxacin.

Investigating the elution solvent effect on Moxifloxacin extraction

The choice of elution solvent is a crucial factor that impacts the Moxifloxacin extraction process. In this study, various solvents such as ethanol, methanol, acidic methanol, and basic methanol were evaluated to determine the most effective solvent for Moxifloxacin extraction. Methanol was selected as the optimal solvent due to its maximal absorption properties. As indicated in Table 1, the best extraction conditions were achieved when a proper balance between Fe_3O_4/NT/M and the elution solvent was maintained, with methanol proving to be the most effective choice.

Table 1. Effect of various elution solvent on Moxifloxacin extraction.

Elution solvent	Recovery, %
Methanol	69
Acidic methanol	35
Basic methanol	62
Ethanol	45

To achieve optimal extraction, the volume of the elution solvent was investigated in this study. For the extraction of Moxifloxacin, various volumes of methanol were tested, with the best result obtained at a volume of 10 mL. The results are illustrated in Figure 11, which indicates that from a starting volume of 11.3 mL, all of the Moxifloxacin was successfully eluted.

Analysis of experimental design Moxifloxacin

The optimum conditions for maximizing the absorption of Moxifloxacin were investigated using the Central Composite Design (CCD) statistical method. A total of 20 tests were performed, as outlined in Table 2, which displays the experimental design conditions and the corresponding absorption percentages for each experiment. The absorption efficiency varied from 24.96% to 74.28%. The highest absorption percentage of 74.28% was achieved with an adsorbent dose of 15 mg, an absorption time of 20.8 minutes, and an eluent volume of 12.4 ml.

Table 2. Results of the CCD by experimental design CCD.

Run	adsorbent dose (mg)	Time (min)	Eluent volume (mL)	Recovery (%)
1	2	4	4	9
2	15	4	4	35
3	2	25	4	10
4	15	25	4	38
5	2	4	13	11
6	15	4	13	50
7	2	25	13	16
8	15	25	13	62
9	1	14.5	8.5	7
10	19.3	14.5	8.5	60
11	8.5	1	8.5	6
12	8.5	32	8.5	59
13	8.5	14.5	1	5
14	8.5	14.5	16	61
15	8.5	14.5	8.5	58
16	8.5	14.5	8.5	58
17	8.5	14.5	8.5	58
18	8.5	14.5	8.5	58
19	8.5	14.5	8.5	58
20	8.5	14.5	8.5	60

Analysis of variance

According to the CCD validation model, we analyzed variance (ANOVA) to assess the mutual influence of the variables and also performed ANOVA for the reciprocal variable (see Table 3). We obtained the optimal coefficients from the ANOVA table using equation 1.

$$R=-49.3347 +6.2015A+2.6659T +7.1843E+ 0.01648A.T + 0.13248A.E+ 0.03439T.E-0.26782A^2-0.07731T^2-0.38285E^2 \quad (1)$$

Table 3. ANOVA of the desipramine recovery for response quadratic model.

Source	**Sum of Squares**	**Degrees of freedom**	**Mean Square**	**F-value**	**p-value**	
Model	8897.86	9	988.65	5.94	0.0051	
A-adsorbent dose	4338.15	1	4338.15	26.08	0.0005	significant
B-time	964.15	1	964.15	5.80	0.0368	
C-Eluent volume	1452.80	1	1452.80	8.74	0.0144	
AB	10.12	1	10.12	0.0609	0.8101	
AC	120.13	1	120.13	0.7223	0.4153	
BC	21.13	1	21.13	0.1270	0.7289	
A^2	1206.12	1	1206.12	7.25	0.0226	
B^2	744.90	1	744.90	4.48	0.0604	
C^2	854.32	1	854.32	5.14	0.0468	
Residual	1663.09	10	166.31			
Lack of Fit	1659.75	5	331.95	497.93	< 0.061	**not significant**
Pure Error	3.33	5	0.6667			
Cor Total	10560.95	19				

The Model F-value of 5.94 indicates that the model is significant, as there is only a 0.51% chance that an F-value this large could occur due to random noise. P-values less than 0.0500 suggest that the model terms A, B, C, A^2, and C^2 are significant. Conversely, values greater than 0.1000 indicate that the model terms are not significant. If there are many insignificant model terms (excluding those necessary to maintain hierarchy), reducing the model may enhance its performance. The F-value for the misfit portion is 497.93, indicating that the misfit is not significant in comparison to the overall error. With a probability of 6.1%, the extent of this mismatch could likely be attributed to random noise.

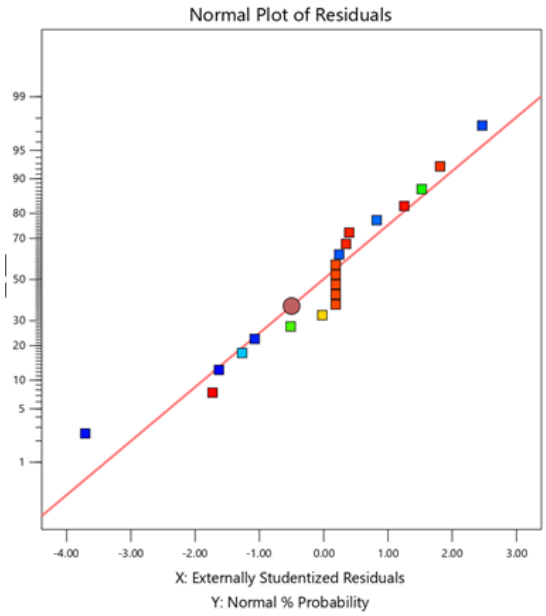

Figure 7. (a) Normal plot of residuals for desipramine recovery

In Figure 7, the random distribution of the residuals on both sides of the zero axis indicates that the variance of the original observations remains constant for all values of Y. This suggests that the figure is satisfactory. Therefore, we can conclude that the empirical model presented is appropriate for describing the extraction efficiency using the response sub-peaks.

Three-dimensional response surface plots

Figure 8-a illustrates the relative impact of time and detergent volume on recovery. A steeper slope along an axis indicates that the corresponding variable has a greater effect on the response. Additionally, the curvature of the surface around the peak provides insight into the process's sensitivity to changes in the variables. A smoother surface suggests that the process is less sensitive to small variations in the variables. Figure 8-b demonstrates the relative effect of time and adsorbent dose on percentage recovery. Again, a steeper slope along an axis indicates that the respective variable has a more substantial influence on the response. The curvature around the peak indicates the sensitivity of the process to changes in these variables. By increasing both the adsorbent dose and time, the absorption efficiency improves.

The Central Composite Design (CCD) optimization approach was employed as a versatile tool to investigate and enhance the effective parameters. Utilizing the CCD method, optimal conditions were determined, which included an adsorbent dose of 15 mg, an ultrasonic time of 21.5 minutes, and an optimal elution volume of 11.3 mL.

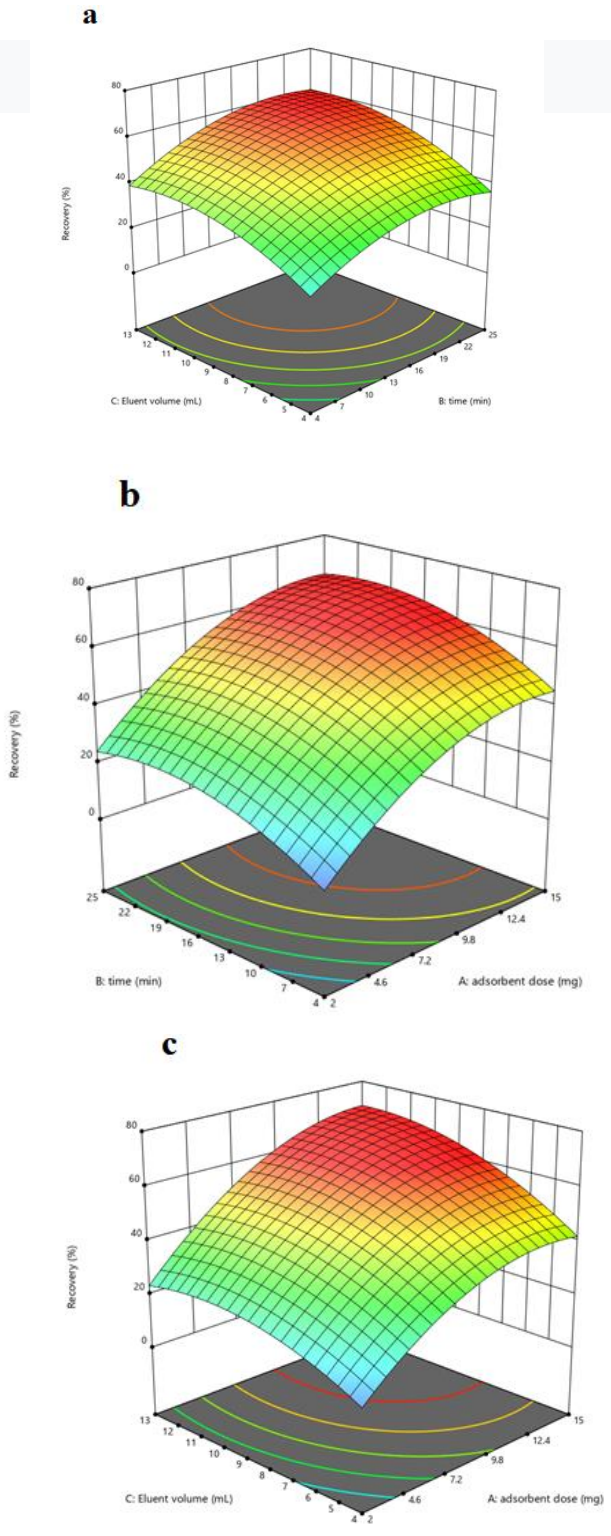

Figure 8. Response surface model for efficiency extraction of MOXIFLOXACIN a) eluent volume and adsorption time, b)adsorbent dose and adsorption time, and c) adsorbent dose and eluent volume.

Isotherm

To investigate how β-cyclodextrin-functionalized magnetic nanotubes (Fe_3O_4/NT/M) adsorb the drug Moxifloxacin on their surface, we applied the Langmuir and Freundlich isotherm models. The Langmuir model assumes that Moxifloxacin molecules are adsorbed uniformly and form a monolayer on the entire surface of the β-cyclodextrin-functionalized magnetic nanotubes. The Langmuir linear model is defined by Equation 2.

$$\frac{C_e}{q_e} = \frac{1}{k_L q_{max}} + \frac{C_e}{q_{max}} \qquad (2)$$

C_e represents the equilibrium concentration (mg/L), while q_e refers to the maximum amount (mg/g) of the Moxifloxacin drug adsorbed on the β-cyclodextrin-functionalized magnetic nanotubes (Fe_3O_4/NT/M). The maximum adsorption capacity (q_{max}) is measured in mg/g. K_L is the Langmuir constant (L/mg), which indicates the adsorption energy.

$$R_L = \frac{1}{1+(K_L c_0)} \qquad (3)$$

Equation 4 defines the parameter R_L as a dimensionless factor that indicates the favorability of the adsorption process. A low R_L value suggests better adsorption efficiency. Depending on the value of R_L, there are four possible adsorption modes: undesirable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$), and irreversible ($R_L = 0$). In the Freundlich model, it is assumed that the adsorption process is multi-layered and heterogeneous. The linear form of this model is represented by Equation 4.

$$\ln q_e = \ln K_F + \frac{1}{n} \ln c_e \qquad (4)$$

The constants K_F (L/g) and n in the Freundlich isotherm represent the adsorption capacity and intensity, respectively. Table 3 presents the results of the adsorption isotherms, which were found to fit well with the Langmuir model (R^2 = 0.98). This suggests that Moxifloxacin molecules are uniformly adsorbed onto the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M). According to the Langmuir model, the maximum adsorption capacity (q_{max}) and the adsorption energy constant (KL) for Moxifloxacin on the β-cyclodextrin functionalized magnetic nanotubes

(Fe_3O_4/NT/M) are 59.98 mg g^{-1} and 7.61 L mg^{-1}, respectively, at 25 °C. The separation factor (R_L) from the Langmuir model is 0.60, indicating that the adsorption of Moxifloxacin molecules by the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) is favorable. Additionally, the Freundlich model also shows a good fit with the data (R^2 = 0.96), suggesting that the adsorption of Moxifloxacin molecules occurs on the surface of the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) as well [20].

Table 4. Isotherms parameters of Moxifloxacin adsorption

Freundlich isotherm			Langmuir isotherm			
R^2	K_F (L/g)	n	R^2	K_L (L/mg)	R_L	q_{max} (mg/g)
0.95	7.66	1.68	0.98	0.13	0.60	59.94

Adsorption kinetics

Three kinetic models were employed to analyze the adsorption mechanism of Moxifloxacin onto Fe_3O_4/NT/M. These models include pseudo-first-order, pseudo-second-order[31], and intraparticle diffusion, with the pseudo-first-order kinetic model represented in equation 5.

$$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \quad (5)$$

The pseudo-second-order model [32] is written in follows:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (6)$$

The terms k_1 and $k_2$in equations (5) and (6) refer to the pseudo-first-order and pseudo-second-order rate constants, measured in units of 1/min and g/mg min, respectively. The sorption time, denoted as (t) is measured in minutes. The equilibrium sorption uptake, which occurs at (t= ∞), is represented as q_e, while the sorption uptake at time (t) is denoted as q_t, both measured in mg/g. The kinetic results were analyzed using the intra-particle diffusion model to illustrate the diffusion mechanism[33]. This is how the kinetic model is formulated:

$$q_t = k_p t^{1/2} + C \quad (7)$$

The rate constant in the intra-particle diffusion model is denoted as k_p (mg/g . $min^{1/2}$), with C representing the boundary layer width constant and (t) signifying the time of sorption in minutes. The sorption uptake, represented as q_t (mg/g), describes the amount of substance adsorbed over

time. In this study, three models were utilized to analyze the adsorption time and rate. The correlation coefficient (R^2) value for the pseudo-second-order model applied to Moxifloxacin sorption by Fe_3O_4/NT/M is 0.99, as shown in Table 3. This high(R^2) value indicates that the pseudo-second-order kinetic model can effectively predict Moxifloxacin adsorption by Fe_3O_4/NT/M. Furthermore, the model suggests that the rate of the Moxifloxacin sorption process is primarily controlled by the chemical sorption mechanism.

Table 5. Kinetics parameters for Moxifloxacin adsorption

Pseudo-first-order	q_{eq} (mg/g)	k_1 (1/min)	R^2
	6.240	0.064	0.88
Pseudo- Second-order	q_{eq} (mg/g)	k_2 (g/mg . min)	R^2
	14.534	0.002	0.99
Intra-particle diffusion	k_p (mg/g . $min^{1/2}$)	C	R^2
	0.25	11.05	0.97

Effect of interference species

The interference effect of various species on Moxifloxacin measurement was investigated under controlled conditions, taking biological matrices into account. Moxifloxacin samples were mixed with different concentrations of fluoxetine, with measuring conducted 60 minutes after the addition. The absorption intensities of these samples were then compared to those of a Moxifloxacin sample without any interfering substances. Moxifloxacin and fluoxetine were added at concentrations of 5, 10, and 15 mg/L. Table 6 illustrates the effects of adding interfering species on Moxifloxacin absorption. The interference effect becomes more pronounced with increasing amounts of fluoxetine, as shown in Table 6. Note that dilution reduces the absolute concentration of fluoxetine.

Table 6. Investigating the interference effect on drug absorption intensity.

The concentration of interference drug, mg/L	Drug absorption in ë$_{max}$	Changing the percentage of absorption
5	0.055	5.85
10	0.066	5.40
15	0.067	5.04

n = 3

Analytical performance

Calibration curve of Moxifloxacin extraction method

The calibration curve for the dispersive solid-phase extraction technique using Fe_3O_4/NT/M was developed after optimizing all parameters affecting the sorption of Moxifloxacin. In this procedure, various doses of Moxifloxacin were injected into 50 mL balloons, and Fe_3O_4/NT/M was applied under optimal conditions. The results of the Moxifloxacin drug extraction were plotted to create the calibration diagram. The correlation coefficient of the method (R^2) was 0.995. Under optimal conditions, the calibration curve demonstrated linearity within the 2 to 50 µg/L concentration range.

Calculation of the LOD method

The calculation was performed to measure the frequency of seven blanks using the wavelength of the Moxifloxacin drug. To determine the limit of detection (LOD), we first calculated the standard deviation of the data (S_b) and obtained the calibration curve slope (m). The LOD was then calculated using the formula provided (Eq. 9) [19]. The resulting LOD value is 16. 9µg/L.

$$LOD = \frac{3\ Sb}{m} \qquad (9)$$

Other analytical figures of merit have been calculated for the determination of Moxifloxacin using β-cyclodextrin-functionalized magnetic nanotubes (Fe_3O_4/NT/M) as a dispersive solid-phase extraction adsorbent in water samples. The limits of detection (LODs) for the dispersive solid-phase extraction method were determined based on the slope of the concentration curve, with a signal-to-noise ratio of 3, resulting in an LOD of 16.9 µg/L. Additionally, the limits of quantification (LOQ) were found to be 55.6 µg/L.

Precisions of method

The sorption quantities for four Moxifloxacin solutions were evaluated both intra-day and inter-day to assess the precision of the technique, using the relative standard deviation (RSD) as a measure. Standard solutions of optimal concentrations were prepared in four 50 ml balloons under identical conditions following the described procedures. The RSD based on intra-day measurements was 2.07 percent, and for inter-day measurements, it was 3.54 percent (n = 3). These values were obtained by measuring the maximum absorption intensity for Moxifloxacin.

Analysis of real samples

Measurement of real samples

The results of examining Moxifloxacin in real well water and urine samples are presented in Table 7. This was done after preparing the UV spectrum and calculating the concentration of Moxifloxacin in the solution using the calibration curve equation. Additionally, a T-test was conducted to compare the standard method of HPLC analysis with the method applied to real samples. The results indicate that the method used in this study is not significantly different from the standard drug analysis method.

Table 7. Concentrations of Moxifloxacin drug in real samples.

Sample	Spiked Moxifloxacin (ppm)	Moxifloxacin found (ppm)	Moxifloxacin concentration by HPLC (ppm)
Well water	0	N.D.[a]	N.D.
	5.00	5.68 (±0.81)	5.75 (±0.39)
Urine	0	N.D.	N.D.
	6.00	5.90 (±0.85)	5.92 (±0.6)

[a] Not Detection

Reusability

Using the adsorption-desorption cycle, the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) adsorbent is designed to be reusable, making it a cost-effective option. In this study, experiments were conducted on the adsorption and desorption of Moxifloxacin using the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) under optimal conditions over four sequential cycles. This was done to evaluate the feasibility of reusing the adsorbent (see Figure 9). Remarkably, the percentage of adsorption remained above 90% throughout all four cycles. Therefore, the β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) demonstrate exceptional effectiveness in extracting Moxifloxacin from water samples and can be reused up to four times.

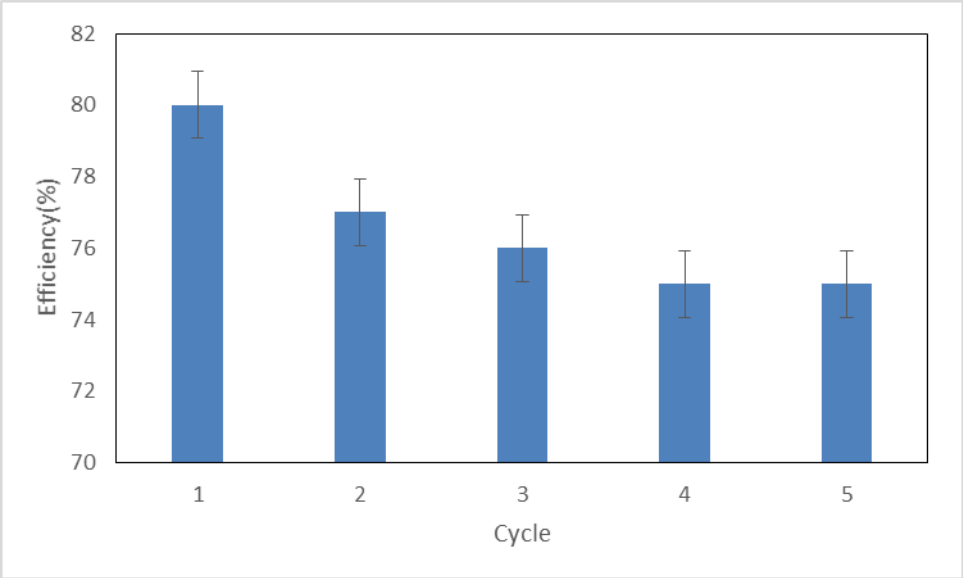

Figure 9. Reusability of β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) adsorbent.

Comparing the result of the technique with other methods

The results obtained from the analysis method for Moxifloxacin (see Table 8) demonstrate a broad linear range and a low detection limit. When compared to other methods used for extracting Moxifloxacin, the technique presented in this article stands out as simple and environmentally friendly. Therefore, it can be regarded as a valuable method for extracting desipramine. Table 8 presents the results of the current extraction procedure in comparison to another technique for determining Moxifloxacin. The findings highlight the differences between these two methods.

Table 8. Comparison of the results obtained from the current extraction procedure with another technique for determining Moxifloxacin

Method	Linear range ($\mu g\ L^{-1}$)	LOD ($\mu g\ L^{-1}$)	pH	RSD (%)	Ref
Solid Phase extraction	100–1000	80	5	6.3	[21]
Hollow fiber liquid–liquid–liquid microextraction	0.2–20	0.02	-	2.6	[22]
HPLC-MS/MS	63–956	5.4	-	<12	[°]
Dispersive Solid Phase Extraction	2-50	16. 9	6.0	2.07	This present method

Conclusion

This study presents the synthesis and use of β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) as an efficient adsorbent for the preconcentration of Moxifloxacin in water and urine samples before evaluation by HPLC. The β-cyclodextrin functionalized magnetic nanotubes exhibited excellent extraction performance due to their interaction with desipramine. Using Response Surface Methodology, we systematically studied the main parameters affecting the extraction percentage. This approach allowed us to interpret the results comprehensively and achieve acceptable outcomes with fewer experimental executions. Under optimal test conditions, the proposed method demonstrated linearity, reproducibility, sensitivity, and high extraction efficiency. The total time required for the adsorption and desorption of Moxifloxacin was less than 20 minutes, significantly reducing the time needed and accelerating the sample preparation process. Overall, the satisfactory results indicate that β-cyclodextrin functionalized magnetic nanotubes (Fe_3O_4/NT/M) are suitable for preconcentration and quantification of Moxifloxacin in biological and aqueous samples.

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