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Application of Induction Furnace Dust as an Adsorbent for the Removal of Ciprofloxacin from Contaminated Water

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A B S T R A C T

Background: The high production and consumption of various drugs have resulted in severe environmental problems. This study investigates the removal of the antibiotic ciprofloxacin (CIP) from contaminated water using Electric Arc Furnace Dust (EAFD). Environmental contamination by antibiotics can adversely affect the environment, especially living organisms. Such contamination contributes to the development of microbial resistance to drugs and hinders the treatment of diseases using established antibiotics.
Methods: Batch experiments were designed to evaluate the effects of initial ciprofloxacin concentrations (1-100 mg L^{-1}), solution pH (1-11), and amount of adsorbent (0.5-15 g).
Results: The results revealed that optimal conditions for removing ciprofloxacin from contaminated water were achieved at an initial CIP concentration of 10 mg L^{-1} (50 mL), with a pH of 7 and a yield of 83 ± 5%, using 5 g of EAFD adsorbent. The pseudo-second-order and Temkin models were more consistent in predicting the kinetics and isotherms of the adsorption process, respectively.
Conclusion: The findings of this research demonstrate that EAFD is an effective adsorbent for removing CIP from contaminated water. Furthermore, this approach concurrently addresses two critical issues: CIP contamination and EAFD pollution.

1. Introduction

Over the last two decades, pharmaceutical products and waste have emerged as significant global contaminants, causing environmental destruction, particularly in wastewater (Thiebault, 2020). Even low concentrations of these pollutants in the environment can seriously damage ecosystems, making them a significant potential threat to aquatic habitats. Recent studies have indicated that pharmaceutical compounds are classified as toxic pollutants. More than sixty types of these compounds can be found in aquatic systems, such as sewage, surface water, groundwater, and drinking water, with concentrations ranging from 10^{-1} to 10^{5} ng L^{-1} (Ghemit et al., 2019; Lancheros et al., 2019). Pharmaceutical compounds have been released into the water through effluents from wastewater treatment plants, hospitals, private farms, landfills, and animal excreta (Puszkarewicz et al., 2017). Antibiotics are used for various purposes, including the treatment of bacterial infections in both animals and humans and high doses are also being used in poultry feeding and aquaculture (Xing et al., 2015; Mehrani et al., 2016). On the other hand, the extensive use of CIP in medical treatment, coupled with its significant increase in consumption, is causing the persistence or pseudo-persistence of these antibiotics in the environment. Recent studies have reported that the CIP is highly stable in aqueous solutions and the concentrations range from 1 μg L^{-1} to 30 mg L^{-1} in

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water/surface water and wastewater of pharmaceutical factories, respectively. Several studies have concluded that even a low concentration of CIP can cause serious harm to the environment and human health. Recent researchers have demonstrated that the presence of CIP in drinking water negatively impacts humans, leading to symptoms such as nausea, nervousness, vomiting, diarrhea, headaches, and tremors (Vasudevan et al., 2009; Van Doorslaer et al., 2014; Khazri et al., 2017). Additionally, higher concentrations of CIP may lead to serious adverse effects, including acute renal failure, thrombocytopenia, change in the DNA of clams, and the elevation of liver enzymes (Milan et al., 2013; Yoosefian et al., 2017). Thus, the removal of CIP from water sources has garnered significant interest in physical, biochemical, and chemical processes. Various methods have been developed to eliminate pharmaceuticals from aquatic solutions such as photocatalysis (using light as catalysis for degradation), ultrasonic or electrochemical degradation (using sound waves or electricity power for degradation), Fenton process (using the hydroxyl radical for degradation), Ozonation (using the ozone for degradation), or adsorption by different adsorbents (Tarpani & Azapagic, 2018; Martín et al., 2019).

In all of these methods, except for the adsorption, the materials produced during degradation may be secondary contaminants with hazardous effects. In contrast, pollutants are only separated from the water using the adsorption method, while degradation can occur afterward, externally. Additionally, adsorption is considered one of the low-cost, easy-to-operate, simple-to-design, and high-efficiency methods to remove pharmaceutical contaminants from wastewater. This technique is not affected by the toxicity of antibiotics and is applicable for eliminating both organic and inorganic pollutants (Mohan et al., 2014; Liang et al., 2018). Some studies were carried out to indicate ciprofloxacin adsorption with various adsorbents such as bentonite (Genç et al., 2013), montmorillonite (Jalil et al., 2015), and coal fly ash (Zhang et al., 2011). In this research, we present a novel and low-cost adsorbent for the removal of ciprofloxacin from water: EAFD, a byproduct of the steelmaking process. The EAFD dust has been classified as hazardous waste (da Silva Magalhães et al., 2017). Producing a ton of steel can generate approximately 10 to 30 kg of dust. Generally, EAFD contains up to 40% zinc, and 50% iron and is often mixed with harmful heavy metals in very low percentages (da Silva Magalhães et al., 2017; Sinaga et al., 2019). Approximately 8.5 million tons of EAFD dust is generated worldwide each year, with an estimated increase to 18 million tons by 2050 (Almeida et al., 2023). The disposal of EAFD dust is prohibited in most countries due to the risk of leaching hazardous heavy metals such as zinc (Zn), cadmium (Cd), and lead (Pb). An additional challenge is the accumulation of EAFD itself. Therefore, identifying alternative uses for this waste can be beneficial. Although dust has been introduced as a hazardous waste due to the presence of heavy metals, It was confirmed that toxic metals were not leached beyond permissible limits at any pH (Singh et al., 2021). Therefore, this waste can be utilized to remove organic substances from contaminated water, thanks to its appropriate magnetic properties and ability to adsorb these substances. Our current study results show that EAFD can be introduced as an efficient adsorbent for wastewater treatment (Shamsi et al., 2021). The current study aims to employ the mentioned dust as an effective adsorbent for removing ciprofloxacin from water samples and to evaluate the impact of key parameters on the uptake procedure.

2. Materials and Methods

2.1 Chemicals reagents and materials

All chemical reagents of analytical purity were sourced from Sigma-Aldrich (Darmstadt, Germany), Merck (Darmstadt, Germany), and Fluke (Buch′ s, Switzerland), and were used in their original form without further purification. Ciprofloxacin (98%) as a model of used pharmaceutical and an adsorbate were prepared from Alborz Darou factory, Iran. EAFD along with sodium hydroxide (≥ 97.0%), and hydrochloric acid (37%) were utilized to prepare the adsorbent. In all designed experiments, ultra-pure distilled water was prepared using the Zolalan system (ZUD101). The specific resistance of the ultrapure water used was measured at 12 megohm cm^{-1} at 25 °C.

2.2 Instruments

Fourier transform infrared spectroscopy (FT-IR) analysis was conducted to identify the functional group of the adsorbent using an FT-IR spectrometer (Bruker, model Vector 22, Germany) in the wavelength range of 4000-400 cm^{-1}. The prepared mixture was stirred with an IKA KS 260 BASIC (United States) stirrer. The pH of the solutions was measured using a pH meter (Metrohm 620, Germany) equipped with a combined glass electrode (Metrohm 6.0210.100, Germany). Three standard buffer solutions (Metrohm USA pH buffer 4, 7, 9, 10X30MLPH BUF), 4, 7, and 10, were used to calibrate the pH meter. A forceful magnet (N42 50X20 magnet; surface field 4123 Gauss, China) separated the magnetic adsorbent from the sample solution. All materials and chemical reagents were weighted by an Ohaus GA200D (United States) analytical balance (± 0.00001 g). To assess the removal efficiency, the concentration of CIP before and after the batch adsorption procedure was measured using a UV/VIS spectrophotometer (Analytik Jena, Specord 205, Germany) at the maximum absorption wavelength ciprofloxacin of 278 nm. Blank solutions, which contained all sample components except for the drug itself, were used in all determinations and experiments. The accuracy and precision of the measurements were validated through the use of standard solutions and the standard addition method with real water samples, yielding approximately 95% recovery and less than 5% error and relative standard deviation.

2.3 Preparation of adsorbent

The EAFD as adsorbent was prepared from the Esfarayn steel industries complex-IRAN. The city of Esfarayen has a geographical coordinates Latitude of 40°36′′ - 17°37′′ and a Longitude of 57°56′′ - 58°7′′ located in northeastern Iran and southern Bojnourd. Due to the production of 81,000 tons of steel per year and 120,000 tons of steel pieces per year, this is an important industry. Electric arc furnace dust (3 kg) was sampled randomly from the three sampling points (from the arc furnace and the depot location) and then mixed. Initially, the EAFD was rinsed several times with ultra-pure water. To ensure that the adsorbent is pure from other adsorbed impurities, the pH of the mixture of EAFD and water was adjusted to 7 using HCl (1M) or NaOH (1M) solutions, and then it was dried for 24 hours at 100 °C (Singh et al., 2021).

2.4 Adsorption procedures

In this research, a one-at-a-time method was employed to optimize the effective parameters in the removal procedure, while a batch method was chosen to investigate the associated parameters affecting the adsorption process. Initially, different amounts of the prepared adsorbents (ranging from 0.05 to 15 g) were dispersed into 50 mL of real water samples (that were contaminated by the addition method) or standard samples containing CIP (5-100 mg L^{-1}). The mixture of CIP as the adsorbate and EAFD as the adsorbent was then shaken at 300 rpm for 30 minutes. Real samples were taken from wells and tap water. The matrix of these real samples is significant to the authors. In this manuscript, the real water samples were collected from the well and the Golabar reservoir, as well as from tap water in the environmental science research laboratory. The standard sample was prepared by diluting a ciprofloxacin standard solution with deionized water. An external magnet (N42, 50X20 magnet; surface field 4123 gauss) was then placed at the bottom of the beaker to separate the adsorbent from the sample solution. HCl and NaOH solutions were used for pH adjustments. The effect of pH on CIP removal was studied in the pH range of 1-11. The equilibrium time for kinetic studies was investigated in 1-60 min. A spectrophotometry technique at the maximum absorption wavelength of CIP assessed the CIP concentration before and after adsorption procedures. To ensure adequate separation and prevent measurement errors, phase separation was performed by centrifuge at 2000 rpm for 5 min (Shamsi et al., 2021). Calculating the amount of CIP adsorbed on the EAFD surface in terms of mg g^{-1}, is very useful and essential for water treatment management procedures.

3. Results and Discussion

3.1 The adsorbent characterization

FT-IR technique was applied to characterize EAFD. This technique can identify functional agents that are possible predictions of the adsorbent ability. The FT-IR spectrum is given in Figure 1 a. The appeared peaks at 3423 cm^{-1}, 2900 cm^{-1}, 1640 cm^{-1}, 1010 cm^{-1}, 873 cm^{-1}, and 592 cm^{-1} confirmed the presence of O-H, C-H, C-O, C-C, C=C, and Fe-O functional groups on the EAFD surface, respectively (Noor et al., 2010; Ahmad et al., 2011). A scanning electron microscope (SEM) technique was performed to indicate the EAFD surface morphology as the studied adsorbent (Figure 1 b). As shown in the SEM of EFAD, basic and chemical properties of EFAD include 1) the shape of EAFD particles is spherical, and dimensions study of particles indicates the presence of nano-scale particles, 2) EAFD adsorbent is granular and grain shape, 3) porosity of dust shell can be a help to its adsorbent ability. Alsheyab (2013) has reported similar results in the SEM analysis of EAFD particles. The surface area of EAFD was determined by nitrogen adsorption. The Brunauer-Emmet-Teller (BET) analysis (Figure 2) verified that the surface area, the total pore volume, and the mean pore diameter of EAFD are 4.86 m^2 g^{-1}, 1.12 cm^3 g^{-1}, and 23.57 nm, respectively. The surface area of EAFD was declared 3.93 m^2 g^{-1} in the literature (Ferreira et al., 2018). These properties confirm that this material can be an effective adsorbent for water treatment.

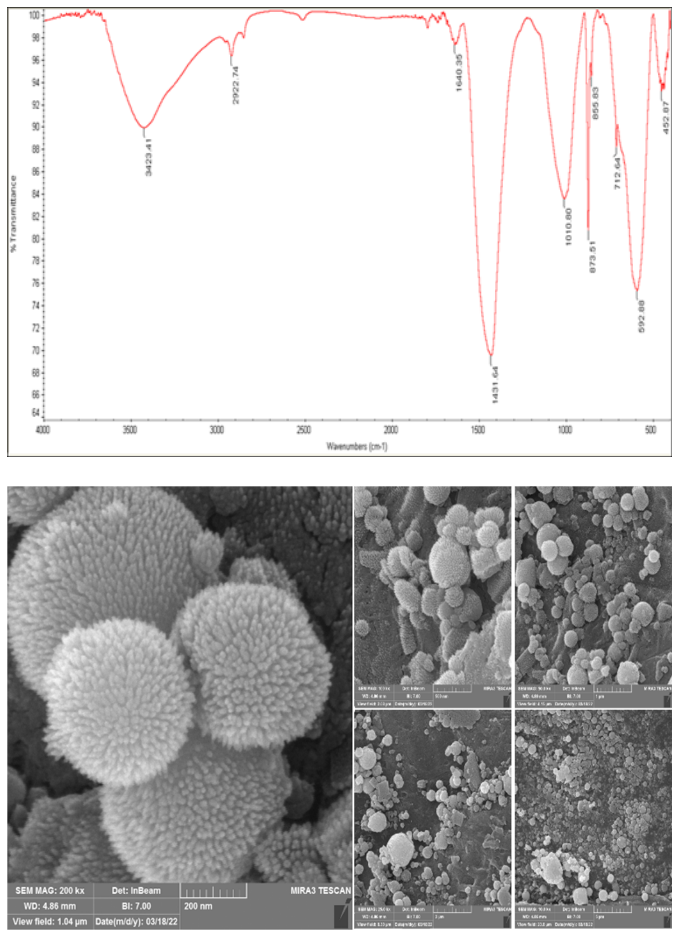

Figure 1. a) FT-IR-spectrum of EAFD b) SEM images of EAFD

3.2 Surface charge assessment of EAFD (pH_{pzc})

One of the significant adsorbent surface properties is pH_{pzc} because the reason for the interactions and their existence can be guessed in the region of solution pH. To detect pH_{pzc}

value of the EAFD, initial pH values (pH_i) of 50 mL of ultra-pure water were set to a range of 2-10 using diluted solutions of HCl or NaOH. Then, a mass of 1 g of EAFD as the adsorbent was added to each solution. The mixture samples of EAFD in ultra-pure water that was adjusted to its initial pH were stirred for 48 h at 25 ± 2°C. The graph of the final and initial pH of the solutions was drawn and used to assess the final and initial pH of the solutions and equal points (Zaghouane-Boudiaf et al., 2014). According to the results, the pH_{pzc} value of the EAFD is around 8.5. This means that the EAFD surface at pH 0-8.5 has a positive charge, causing an electrostatic attraction between the surface and the negative ions. When pH > 8.5, the EAFD surface is negatively charged, and while this condition favors the interaction between positive ions and the negative surface surface charge is not suitable for absorbing negative ions.

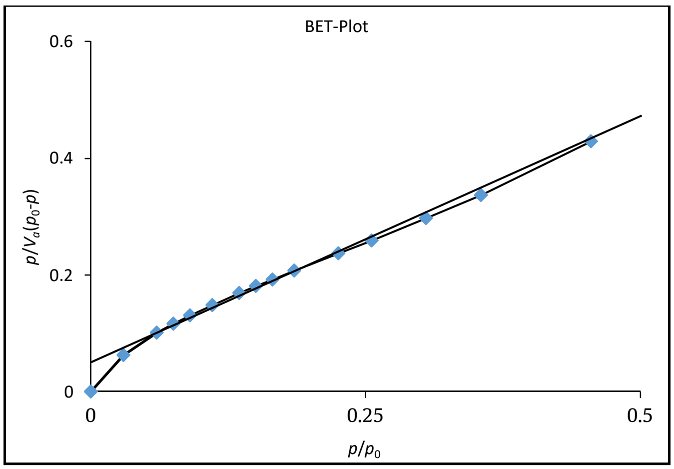

Figure 2. BET plot of N_2 adsorption

3.3 Optimization of the adsorption procedure

3.3.1 Ciprofloxacin adsorption efficiency in different pH

The following Equations 1 and 2 were used to calculate the adsorption capacity and uptake percentage of the CIP, respectively:

$$q_t = \frac{(C_0 - C_t) \times V}{W} \quad (1)$$

$$\text{Uptake Percentage} = \frac{(C_0 - C_t) \times 100}{C_0} \quad (2)$$

Where the t subtitle is used to display values at any time and "q" (in term mg g^{-1}) shows the CIP adsorbed amounts on the EAFD surface as adsorbent, "V" (in L) was used for showing the volume of sample solution, "W" indicates the weight of adsorbent (g), "C_0" and "C_t" (in mg L^{-1}) were used for the CIP concentrations in aqueous solution at the beginning of the designed experiment and at any time of experiment, respectively. Investigation of the pH effect on the efficiency of the adsorption process is significant because it can impact on species of adsorbates as well as the charge of the adsorbent surface and the ionic type of adsorbate. The influence of solution pH on the removal of ciprofloxacin by EAFD was investigated in the range of 2-10. Ciprofloxacin has a pK_a of 8, which means that the abundance of its positive species at pH less than 8 is higher due to the adsorption of hydronium ions. It exists in nutrient and negative species at pH 8 and above 8, respectively (Wang et al., 2010). Figure 3 indicated adsorption efficiency notably decreased by increasing the pH of the solutions. While pH was increased, the surface of the adsorbent became more negative, and the interactions between CIP and the surface of the adsorbent increased. Although the highest q_e was achieved at the pH of 1, the experiments were performed at pH = 7 because the pH of surface and groundwater is in this area. It is noteworthy that the adsorbent efficiency will be higher in acidic environments.

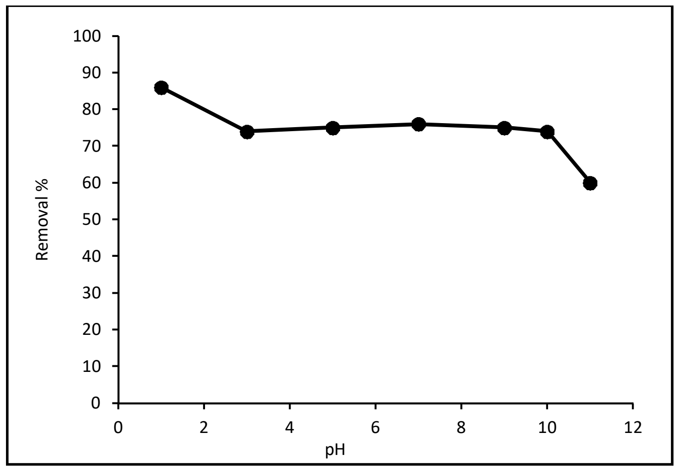

Figure 3. Effect of pH value on CIP uptake by the EAFD
* Experimental conditions: CIP initial concentration 10 mg L^{-1} (50 mL), EAFD as adsorbent 5 g, time of shaking 30 min, shaking rate 200 rpm, temperature 25 °C.

3.3.2 Ciprofloxacin adsorption efficiency in different EAFD dosage

The effect of EAFD dosage on the CIP uptake was investigated using different amounts of EAFD in the range of 0.5 - 15 g, 50 mL of CIP initial concentration of 10 mg L^{-1} at pH 7. The concentration of the CIP was measured before and after the adsorption, and the adsorption efficiency was calculated. The results confirmed that increasing the adsorbent quantity improved the uptake efficiency from 24% to 83%. An increase in the adsorption efficiency is because of the access of the drug molecules to a broader adsorbable surface. The adsorption efficiencies did not change significantly after increasing the adsorbent contents to 5 g.

3.3.3 Ciprofloxacin adsorption efficiency in different ciprofloxacin concentrations

The initial contaminant concentration is one of the variables that can influence the adsorption capacity. To examine the impact of the initial concentration of CIP on the adsorption efficiency, 5 g of EAFD was added to CIP solutions with different concentrations (5, 10, 20, 25, 50, 100 mg L^{-1}). Outcomes in this experiment revealed the removal value increased with the increase in initial concentration of CIP from 5 to 10 mg L^{-1}, which is due to the interaction between the EAFD and ciprofloxacin. The highest removal was recorded at the initial concentration of 10 mg L^{-1}. Then the removal decreased for the concentrations above 10 mg L^{-1}, which can be confirmed by reducing the EAFD surface area.

3.3.4 Ciprofloxacin adsorption efficiency in different contact time

The experiment indicates the influence of shaking time on CIP adsorption with the initial CIP concentration of 10 mg L^{-1}, Volume of CIP solution 50 mL and pH = 7, and EAFD amount of 5 g in the time range of 1 to 60 min. The removal efficiency was improved from 57% to 78% by increasing the 5 to 60 min contact time. After 30 minutes, the amount of absorption did not increase significantly. The interaction between CIP molecules and functional agents on the EAFD surface rises when the contact time increases. However, the adsorption process reached relatively steady at some point in time, and the adsorption amount remained approximately constant.

3.3.5 Kinetic Study of Ciprofloxacin adsorption on the EAFD

The kinetic models presented help describe the mechanism of the CIP adsorption process and investigate the time necessary for reaching equilibrium. Numerous kinetic models have been developed to predict the behavior of the experimental data (Keshvardoostchokami et al., 2017; Phasuphan et al., 2019). In this study, the kinetic of CIP adsorption on the EAFD adsorbent was investigated by applying four different kinetic highly used models:

Simple Elovich (Eq. 3): $$q_t = a + 2.303b \ \log t \qquad (3)$$

Power function (Eq. 4): $$\log q_t = \log k_p + v_p \log t \qquad (4)$$

pseudo-first-order (Eq. 5): $$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303} \qquad (5)$$

pseudo-second-order kinetics (Eq. 6): $$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \qquad (6)$$

Kinetics of liquid-solid adsorption and chemisorption of gasses on solids are described mostly with Pseudo-first-order (or Pseudo-second-order) and the Elovich models, respectively. However, the Elovich kinetic model is also used to investigate liquid-solid adsorption systems (Gamboa et al., 2016). In equation 3, a (in term mg g^{-1} min^{-1}) and b (in term g mg^{-1}) are the chemisorption rate and the CIP's desorption constant, respectively. q in term mg g^{-1} shows the amount of CIP adsorbed on the EFAD surface, subscripts t, e demonstrate the procedure's any time and equilibrium time, respectively. k_p (in term mg g^{-1}) and V_p (in term min^{-1}) are constants in the Power function model, and k_1 (in term min^{-1}) and k_2 (in term g mg^{-1} min^{-1}) show the rate constants of pseudo-first-order, and pseudo-second-order models, respectively (Tu et al., 2012). The obtained kinetic parameters for simple Elovich, pseudo-first-order, and pseudo-second-order kinetic models are given in Figure 4. Also, in Table 1, the kinetic parameters are shown. These parameters were assessed based on the kinetics models (Eq. 3- Eq. 6) in CIP adsorption onto the EAFD procedure. The comparison of the correlation coefficient (R^2) of the models (as a criterion to indicate the kinetic model) proved that the pseudo-second-order kinetic model (R^2 = 0.99) has a high correlation coefficient. Adherence to the pseudo-second-order model shows that the rate of the adsorption process is related to the amount of both CIP and EAFD. Other researchers also agreed with the pseudo-second-order kinetic model for CIP removal, in which modified montmorillonite, magnetic sorbents, and ZIF-67 prepared by hollow cobalt sulfide were applied as adsorbents (Avcı et al., 2019).

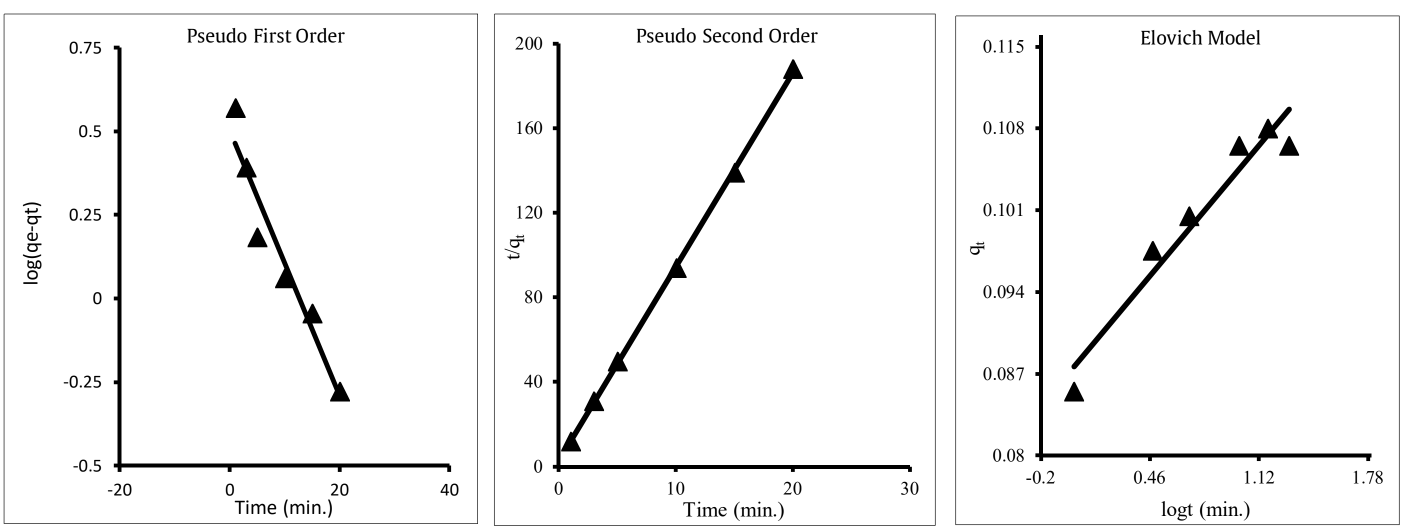

Figure 4. The kinetic models for ciprofloxacin adsorption
* Experimental conditions: CIP initial concentration 10 mg L-1 (50 mL), EAFD as adsorbent 5 g, initial solution pH 7, shaking rate 200 rpm, temperature 25 °C

Table 1. The kinetic parameters for ciprofloxacin adsorption on EAFD

Model name	Power function			Simple Elovich			Pseudo first-order		Pseudo second-order		
Parameter	k_p	v	R^2	a	b	R^2	k_1	R^2	k_2	q_e	R^2
Ciprofloxacin	0.555	0.299	0.853	0.088	0.088	0.796	0.0053	0.93	8.405	0.115	0.99

* k_p (mg g-1), v (min-1), a (mg g-1 min-1), b (g mg-1), k_1 (min-1), k_2 (g mg-1 min-1), h_0 (mg g-1 min-1), qe (mg g-1)

3.3.6 Adsorption isotherms

In this study, the Langmuir, Freundlich, and Temkin isotherm models were utilized to examine the adsorption isotherms. Based on the Langmuir isotherm, each active adsorption site only accepts an adsorbate molecule, and they are arranged in a monolayer and fixed positions (Gamboa et al., 2016). In contrast to the Langmuir model, the Freundlich model claims multilayer adsorption of adsorbate molecules on heterogeneous surfaces. Temkin isotherm assumes that the adsorption heat decreases linearly due to the interactions between adsorbate and adsorbent surfaces (Pérez-Marín et al., 2007). The linear models of these models are given in equations 7-9.

Freundlich isotherm model: $$\frac{C_e}{q_e} = \frac{1}{Q_{max} b} + \frac{C_e}{Q_{max}} \quad (7)$$

Langmuir model: $$\log q_e = \frac{1}{n_F} \log C_e + \log K_F \quad (8)$$

Temkin isotherm: $$q_e = \frac{RT}{b_T} \ln(a_T C_e) \quad (9)$$

C_e in term mg L^{-1} shows the concentration of the CIP as adsorbate on the EAFD as an adsorbent in equilibrium time, q_e (in term mg g^{-1}) was used for indicating the amount of the CIP in mg on the EAFD in g, Q_{max} (mg g^{-1}) show the maximum adsorption capacity of the adsorption that mean mg of CIP on the EAFD in optimization condition, and b in L mg^{-1} denotes the Langmuir equilibrium constant dependent on the free energy and affinity of binding sites. K_F is the Freundlich constant related to adsorption capacity (mg g^{-1}), and $1/n_F$ indicates adsorption intensity. b_T in kJ mol^{-1} is the Temkin constant for adsorption heat, R (in term 0.0083 kJ K^{-1} mol^{-1}) shows the gas constant, a_T in g^{-1} is the Temkin isotherm constant, and T denotes the absolute temperature (K) (Khazri et al., 2017; Rafati et al., 2018). In the current study, regarding Table 2 and Figure 5, the removal mechanism of CIP on EAFD is well-fitted to Temkin adsorption isotherm with the correlation coefficient R^2 = 0.98.

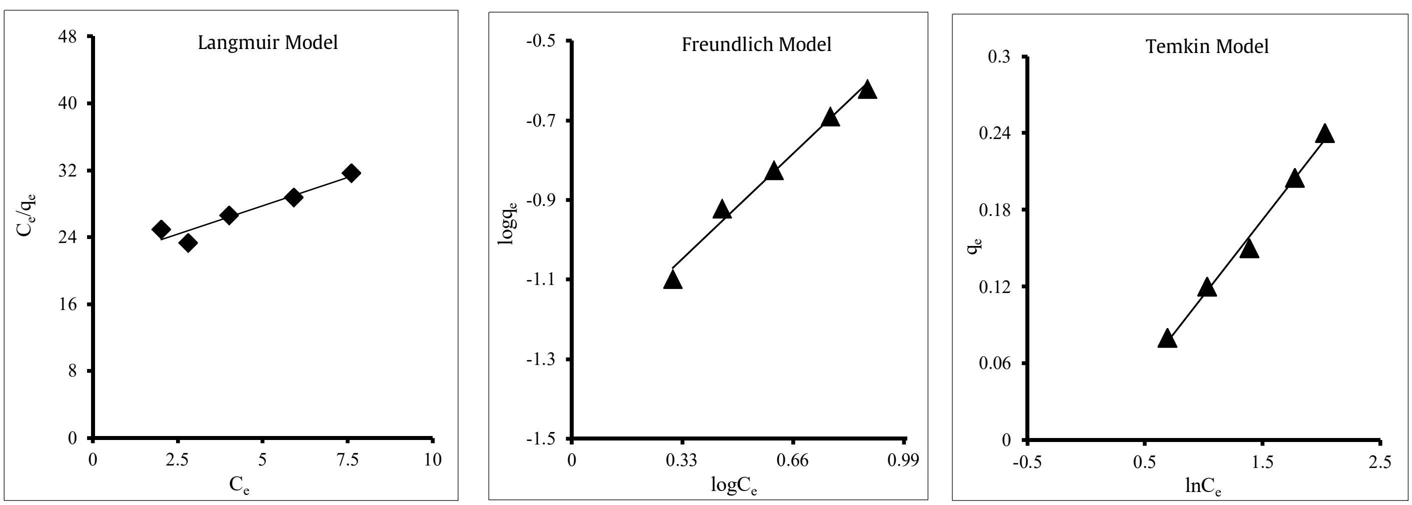

Figure 5. Isotherm adsorption models to study of CIP adsorption onto EAFD
* Experimental conditions: CIP initial concentration 10 mg L-1 (50 mL), initial solution pH 7, time of shaking 30 min, shaking rate 200 rpm, temperature 25 °C

Table 2. The parameters of Langmuir, Freundlich, and Temkin isotherm models for Ciprofloxacin adsorption on EAFD

Model	Langmuir				Freundlich			Temkin			
Parameter	Q_{max}	b	R_L	R^2	k_f	n	R^2	a	b	B_T	R^2
Ciprofloxacin	0.478	0.050	2.006	0.937	0.234	0.803	0.868	0. 806	18.83	16.272	0.984

* Q_0 (mg g^{-1}), b (L mg^{-1}), k_f (mg g^{-1}), a (L g^{-1}), b (kJ mol^{-1}), B_T (kJ mol^{-1})

3.3.7 Maximum adsorption capacity

The maximum amount of CIP that adsorbed on the EAFD surface was 0.320 mg g^{-1}, indicating the maximum adsorption capacity of EAFD for the uptake of CIP. This capacity was achieved using 3 g of EAFD in 50 mL CIP solution (10 mg L^{-1}) with the mixture shaken at 200 rpm for 24 hours. The maximum adsorption capacity can also be calculated using the Langmuir equation. It can be obtained by drawing the slope of graph $1/q_e$ relative to $1/c_e$. The value obtained from this method was equal to 0.478 mg g^{-1}. It is important to note that this is a theoretical value. Although the adsorption capacity with EAFD is relatively low, this adsorbent is easier to use. The critical point is that EAFD is a unique industrial waste that must be collected and managed sustainably to protect the environment. This adsorbent can also be used multiple times. The adsorption capacities of the other materials for the removal of CIP are listed in Table 3. Therefore, EAFD can effectively treat water, particularly for adsorbing CIP residues from contaminated water. This adsorbent is inexpensive and capable of removing organic compounds, providing a solution to the solid waste problem in the steel industry.

Table 3. Comparison of the studied adsorbents and other different adsorbents for removal of Ciprofloxacin

Type of Adsorbent	q_e (mg g^{-1})	Kinetic model	Isotherm model	Reference
Modified Montmorillonite	1.15	pseudo-second order	-	(Avcı et al., 2019)
Magnetic Biosorbents	527.93	pseudo-second order	Langmuir	(Zheng et al., 2020)
ZIF-67 Derived Hollow Cobalt Sulfide	471.7	pseudo-second order	Langmuir	(Liang et al., 2018)
Zeolitic Imidazolate Framework-8 Derived Nanoporous Carbon	416.7	pseudo-second-order	Freundlich	(Li et al., 2017)
Bentonite	147.06	pseudo-second-order	Langmuir	(Genç et al., 2013)
EAFD	0.478	pseudo-second-order	Temkin	Present study

3.3.8 Effect of real water matrix

To evaluate the adsorbent's performance for CIP uptake from real samples, several experiments were conducted using water samples from three stations in Zanjan Province, Iran. Various substances and complex mixtures of organic and inorganic compounds, including nutrients and salts in wastewater, may influence the outcome of adsorption processes (Giannakis et al., 2015; Adityosulindro et al., 2017). Table 4 presents some characteristics of these samples. Ciprofloxacin solutions (10 mg L^{-1}) with pH equal to 7 were prepared from these samples, and the removal percentage was calculated after 15 min shaking. As shown in Table 4, EAFD significantly removed CIP from the samples. As shown in Table 4, the CIP concentrations in the actual samples post-treatment are lower than the values reported in various standards for agricultural, adsorbent, and surface water applications, indicating that the treated water can be used in multiple applications. Under optimal conditions, ciprofloxacin removal by the adsorbent was 83% for distilled water, 91% for university tap water, 75% for well water, and 85% for Golabar dam water. In all samples, the drug concentration was 10 mg L^{-1}, added manually. The results indicated that electric arc furnace dust has a high potential for adsorption. Magnetic separation offers distinct advantages for the use of EAFD as an adsorbent compared to the other adsorbents. This method is straightforward and user-friendly. Additionally, magnetic separation enables the reuse of the adsorbent without compromising its properties. Figure 6 shows that the EAFD magnetic particles could be separated toward the magnet within 30 s. More than 90% of EAFD particles can be retrieved from the solution using a magnet. The main advantages of the introduced adsorbent are its short processing time, the absence of a filtration or centrifugation step, and its high effectiveness in water treatment (Shamsi et al., 2021). After separating, the adsorbent can be easily recovered by applying 0.5 M sodium hydroxide or 1 M hydrochloric acid.

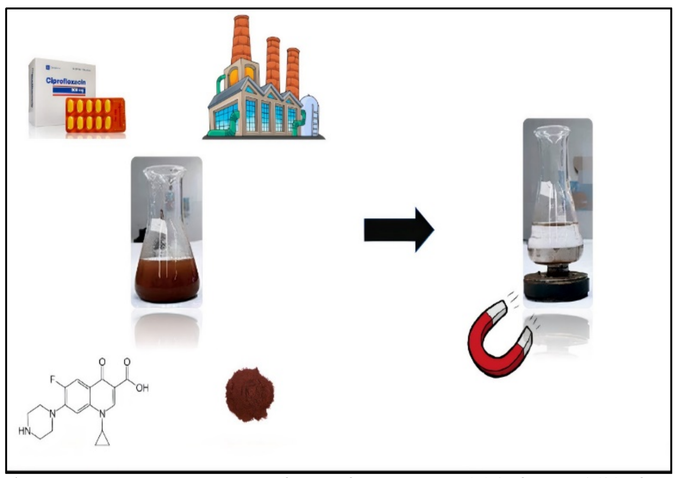

Figure 6. Magnetic separation of EAFD from mixture (a) before and (b) after using the magnet

Table 4. Applicability of the proposed method in the treatment of real samples and some physical and chemical characteristics of the examined real samples

Sample	Adsorbent	pH	Concentration of CIP (mg L^{-1})	Amount of adsorbent (g)	DO [a] (mg L^{-1})	TDS [b] (mg L^{-1})	EC [c] (µS cm^{-1})	Uptake (%)
1	EAFD	7.74	10	5	3.3	140	395	91
2	EAFD	7.5	10	5	8.1	300	564	75
3	EAFD	7.7	10	5	0.5	160	782	85

[a] Dissolved Oxygen, [b] Total Dissolved Solids, [c] Electrical Conductivity

4. Conclusion

In this research, EAFD was utilized as a magnetic adsorbent to uptake ciprofloxacin from aqueous solutions. The effective parameters for this process were studied, and optimal conditions were determined to achieve maximum removal efficiency of CIP. A dosage of 5 g of the EAFD removed 88% of CIP from 50 mL of the diluted solution with a concentration of 10 mg L^{-1} at pH = 7 after a 30-minute exposure time. The results indicated that the pseudo-second-order kinetic model best fits the adsorption kinetic data. Additionally, the analysis of the adsorption isotherms models demonstrated a high correlation with the Temkin model. The findings revealed that the adsorbent efficiently removed CIP even from real samples, and the presence of other molecules did not negatively affect CIP removal. In the future, the potential of the adsorbent for removing other pollutants can be explored.

Authors' Contributions

Arezoo Mehdikhani, Zahra Shamsi: Methodology; Formal analysis; Investigation; Resources; Writing (Original Draft). **Mina Keshvardoostchokami, Mohamad Abadi:** Resources; Writing (Review and Editing). **Abbasali Zamani:** Methodology; Conceptualization; Supervision; Resources; Writing (Review and Editing). **Abdolhossein Parizanganeh:** Formal analysis and Resources; Supervision; Writing (Review and Editing).

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethical considerations

This article does not contain any studies with human participants or animals performed by any authors. Project number: 23059. Project duration: 9 months (15 May 2017 to 10 February 2018).

Using artificial intelligence

All authors have stated that their research didn't use any artificial intelligence (AI) techniques.

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