Alqalam Journal of Medical and Applied Sciences. 2025;8(2):1032-1038
https://doi.org/10.54361/ajmas.258277

Original article

Effect of Contact Time and Adsorbent Dosage on Removal of Copper Ions from Aqueous Solutions by Iron Slag

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Abstract
This work aims to study the effectiveness of iron slag in removing copper ions from aqueous solutions, depending on different parameters such as contact time, particle diameter, pH, initial concentration, sorbent dosage, and temperature. In this research, some variables such as contact time, dosage, and particle size were studied based on room temperature. The results indicated that the best removal of copper ions was at contact time (90 min), sorbent weight (3.5 g), and sorbent particle size (200 µm). With the initial concentration of the solution, the best removal percentage was 99.55%, and the maximum adsorption capacity was 96.08 mg/g. From these results, it is clear how suitable it is to use iron slag in reliably removing copper ions from wastewater and industrial wastewater.

Keywords. Absorption, Copper Ions, Iron Slag.

Introduction

Water is an essential component of all plant and animal life, its pollution is generally considered more significant than soil and air pollution [1]. This liquid has special properties: it is the best dissolving agent available and can suspend or absorb a wide range of substances [2]. Surface water (freshwater lakes, rivers, and streams) and groundwater (borehole and well water) are the main natural water resources. Water pollution is one of the most significant environmental issues [3,4]. Heavy metals are among the main pollutants of water sources [5]. Between two and three billion people worldwide lack access to basic sanitation, and more than one billion people do not have access to safe drinking water. Each year, water-related diseases cause between three and five million deaths [6].

These heavy metals may be present on the water's surface as a result of man-made or natural processes. As a result of natural processes, rocks that include elements such as metals, volcanic eruptions, forest fires, and naturally occurring weathering processes. Metal penetrates the various areas of the ecosystem as a result of these actions. Sulphates, hydroxides, oxides, phosphates, and silicates are among the compounds that include heavy metals [7,8]. The primary causes of the massive buildup of heavy metals in the water are both natural and human-caused. Additional natural sources of heavy metal contamination in water include the wet and dry deposition of atmospheric salts, the contact of water with rocks, and the interaction of water with While one example of a human cause of tainted water is the abrupt rise in urbanization and industrialisation [9].

Copper is classified as a priority pollutant because of its adverse health effects [10]. Cadmium is regarded as the most serious contaminant of the modern age [11]. Zinc and iron are essential elements and are generally considered to be non-toxic below certain levels [12]. Lead is not an essential trace element in any organism and has no known biological function. It can cause a variety of harmful health effects [13].

Heavy metals from wastewater can be recovered using a variety of treatment methods. While some of them are relatively modern inventions, others are tried-and-true techniques that have been in use for decades. Precipitation, ion exchange, membrane processes, and adsorption are the most often employed [14.15]..

Methods

Preparation of Adsorbent

In the adsorption tests, iron slag served as the absorbent material. It was acquired from the Misurata-based Libyan Iron and Steel Company. After that, it was cleaned and left to dry for an entire night at 100°C in an air oven. After that, it was mashed with a disc machine and sieved through a laboratory test sieve to get the desired volume.

Preparation of Adsorbed Solution

A copper stock solution was produced by dissolving a carefully balanced quantity of water, copper sulphate ($CuSO4.5H2O$), in 100 ml of purified water. The stock solutions were then diluted to the required concentrations (1000, 1500, 2000, 2500, and 3000 ppm) using deionised water. The spectrometer that was utilised to measure the amounts of copper in a variety of samples, both before and after treatment Maker of the spectrophotometer was made by Labmod, inc, USA.

***Received**: 28-04-2025 - **Accepted**: 01-06-2024 - **Published**: 09-06-2025*

Figure 1. Iron Slag

Parameters Affecting Copper Removal

The purpose of the experiment was to determine the factors affecting the extraction of *Cu(II)* ions from the synthetic solution and to assess the ideal adsorption process settings. This is accomplished by altering the temperature, pH of the solution, initial concentration of adsorbate, contact time, adsorbent dose, and particle size. The balancing principle (Eq 1) calculates the calculated sorption capacity of Cu(II), and (Eq. 2) calculates the per cent removal of *Cu(ll)* ions**.**

Experimental Studies

The purpose of the experiment is to identify and verify the parameters that influence the removal of copper(II) from a standard solution. Additionally, it involves assessing the ideal conditions for the adsorption process, looking at particle size, contact time, and the impact of PH, dose for the starting concentration and temperature. The mass balance equation (1) was utilized to compute the quantity of copper adsorbed onto iron slag:

$$q = \frac{V(C_0 - C_e)}{W} \qquad (1)$$

where: (V) is the volume of solution in liters, (W) is the mass of the adsorbent in grams, (C_o) is the initial metal ion concentration in solution, and (q_e) is the amount of copper adsorbed on the adsorbent. The percentage removal of metal ions is also calculated and reported using Eq (2) :

$$\%R = \frac{(C_0 - C_e)}{C_0} * 100 \qquad (2)$$

Contact Time

order to determine the equilibrium time, the removal % of *Cu(II)* from the tanning solutions is examined for 100 ml of solution, adsorbent dose of 3.5 g, particle size (d=200) µm, pH value of 5, temperature of 25 °C, and time durations of (30, 60, 90, and 120 min). The impact of contact time on the removal of *Cu(II)* from wastewater for five batches is displayed in Figure (2). For both samples, an ideal contact duration of 90 minutes corresponds to a percentage elimination of *Cu(II)* reaching for each batch of tanneries (99.55 , 93.18 ,85.87 , 75.186 , 65.02), respectively .

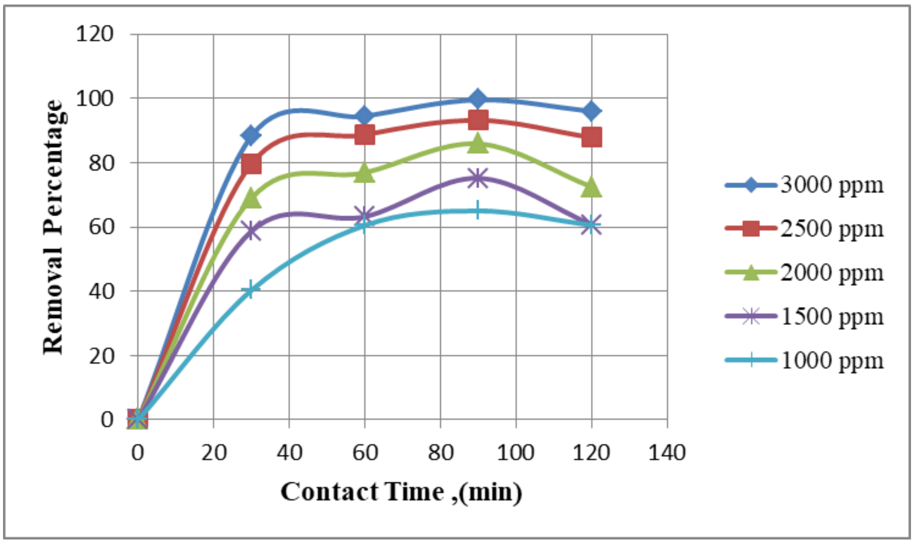

Figure 2. Effect of Contact time on copper adsorption
Condition:(adsorbent dosage =3.5 g/100 ml, pH=5 , particle size=(d=0.200 mm), and temperature 25 ℃)

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Effect of Adsorbent Dose Variation

This study was conducted at 25 °C with a pH of 5, a contact time of 90 minutes, and adsorbent dosages of 0.5, 1, 2.5, 3.5, and 5 g/L. The initial concentration of the solution was (3000,2500,1500,1000 ppm). The results show that the removal efficiency increases with the adsorbent dosage. The copper removal was 99.55 % when the dose was 3.5 g/L (Figure 3). It can be observed that the available sites at low adsorbent doses are insufficient to capture all the available ions in the solution, resulting in poor removal efficiency. Therefore, it can be concluded that the optimum adsorbent dosage for maximum copper removal was 3.5g/L.

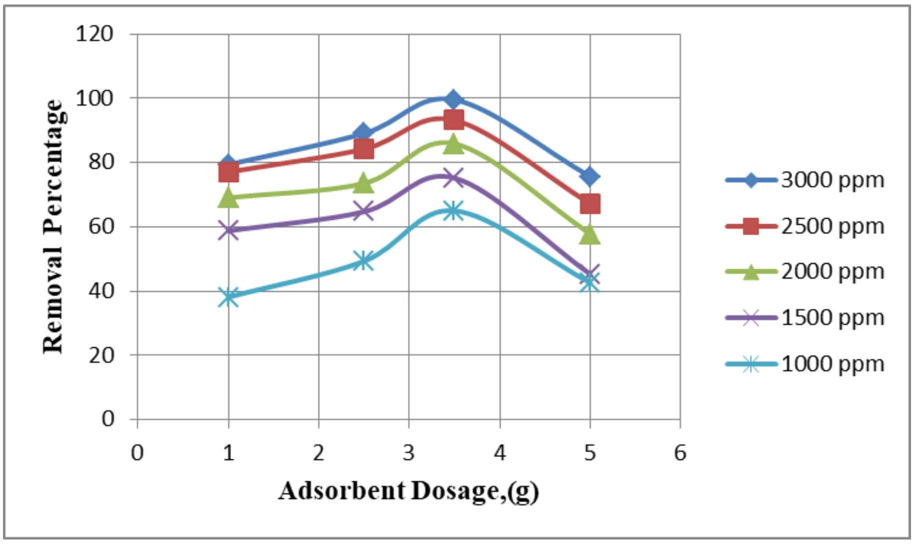

Figure 3. Effect of adsorbent dosage on copper adsorption
Condition:(adsorbent dosage =3.5 g/100 ml, pH=5, contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃)

Effect of Adsorbent Particle Size

In the removal of copper ions, experiments with copper removal using iron slag have used sorbents with different particle sizes of 200, 500, and 600 µm. It is performed at room temperature (25 °C). Adsorbed slag: A dose of 3.5 g was added to react with a solution of copper ions for a 90-minute contact time and pH 5. Keep all other parameters constant. Results obtained from impact Average size of adsorbed particles upon removal of copper, shown in Figure 4. It can be seen that the average particle size is 200 µm. Iron slag is capable of removing a high percentage of copper from aqueous solutions. The removal rates were 99.55%. For copper. Moreover, the copper removal rates decrease with increasing particle size. Iron slag, the removal rate at a particle size of 500 µm was 42.75%. At a size of 600µm, the removal rate was 15.09%. These results can be attributed to. It is clear that the smaller the particle size, the higher the adsorption capacity, because this leads to the creation of more sites Available on the outer surface of iron slag for adsorption. On the other hand, low particle size would increase high rate of the ion exchange process. According to theory, decreased particle size also results in increased ion exchange.

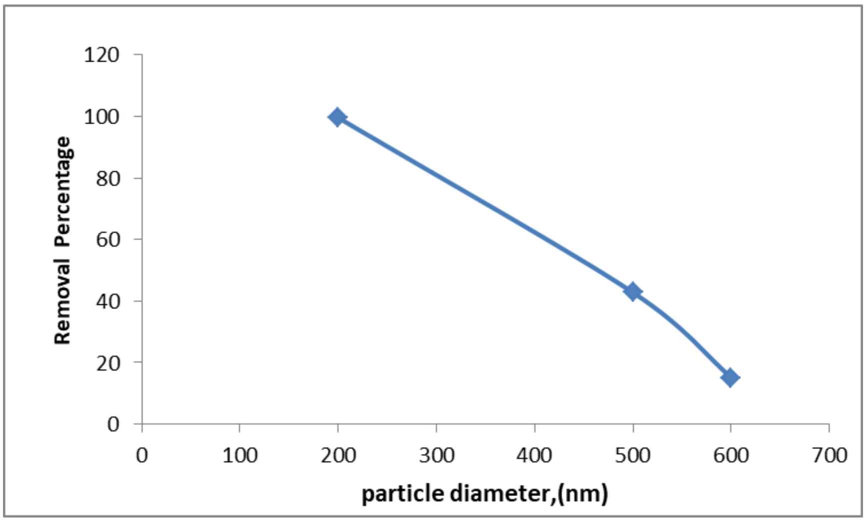

Figure 4. Effect of particle size on copper adsorption
Condition:(adsorbent dosage =3.5 g/100 ml, pH=5, contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃)

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Adsorption Kinetics

The solute uptake rate is explained by the field of adsorption dynamics, which studies adsorption kinetics. The residence period of adsorbate uptake at the solid-solution interface is regulated by this rate. 3.5g Iron slag was added to 100 ml of *Cu(II)* tanning solutions in two batches to determine the adsorption kinetics through a batch procedure. The solution at temperature 25 °C, with a particle size of (d=0.200) mm, an initial pH of 5, and known time intervals (30, 60, 90, and 120) minutes, the concentration of leftover *Cu(II)* ions was measured in the supernatants. Using a spectrophotometer, the initial concentration (C_o) and equilibrium concentration (C_e) of *Cu(II)* ions were found.

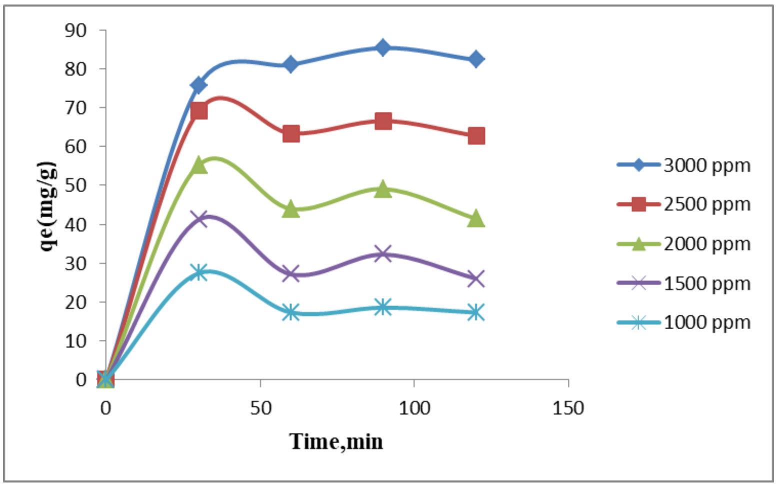

Figure 5. Adsorption kinetics of Cu(II)on iron slag at different initial concentrations Condition:(adsorbent dosage =3.5 g/100 ml, pH=5, contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃)

Simple First Order Model

A straightforward order equation can explain the sorption kinetics [17]. The first-order simple equation that follows explains the shift in the bulk concentration:

$$log(C_t) = \frac{K_1}{2.303}t + log(C_0) \qquad (3)$$

Where C_t and C_o are the concentration of metal ions at time / and initially (mg/l), respectively, and k_1 is the first-order rate constant (1/min). Moreover, it was suggested that the adsorption system with solid surfaces is not suitable for simple kinetic models like the first- or second-order rate equation. Figure 6 displays the experimental results, demonstrating how the ln (C_t) vs (t) for a single batch of tanning solution differs significantly from the theoretical values. A comparison between the results derived from this model and the other subsequent models displayed in Table 2 reveals that the simple first-order kinetics is unable to adequately describe this adsorption process.

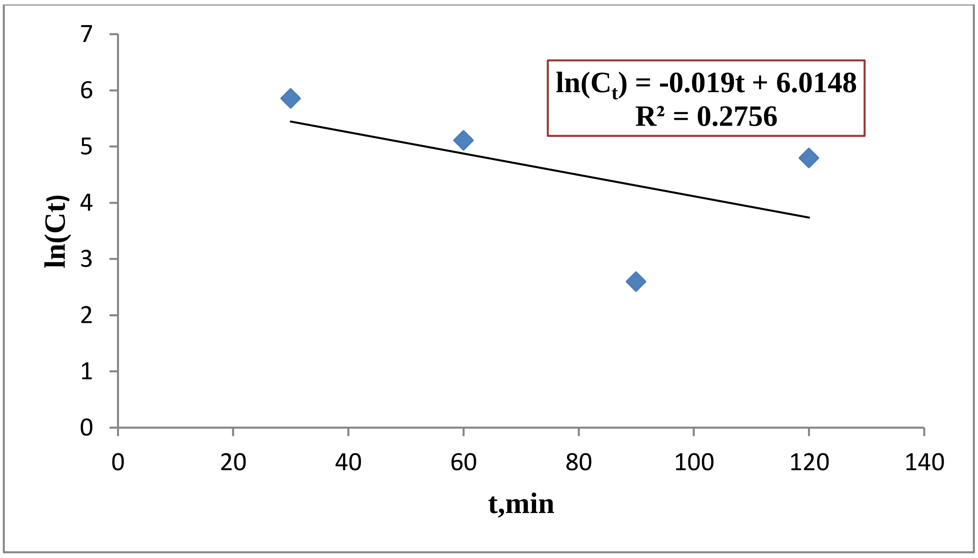

Figure 6 Plot of the simple first-order adsorption kinetics of Cu(II) Condition:(adsorbent dosage =3.5 g/100 ml, pH=5, contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃).

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Pseudo-First-Order Model

Lagergren's model, pseudo-first-order, outlines the adsorption process in solid-liquid systems based on the adsorption capacity of solid adsorbent materials [18]. It is postulated that one *Cu(II)* ion is adsorbed onto one adsorption site on the iron slag surface. It is described in Eq:

$$log(q_e - q_t) = log(q_e) - \frac{K_1}{2.303}t \qquad (4)$$

Where q_e and q_t are the amount of metal ions adsorbed at equilibrium and at time t (mg/g), K_1 is the equilibrium rate constant of pseudo-first-order adsorption (l/min). The slopes and intercepts of plots of log(q_e-q_t) versus t, are used to determine the pseudo-first-order constant K_1 and equilibrium adsorption qe [19].

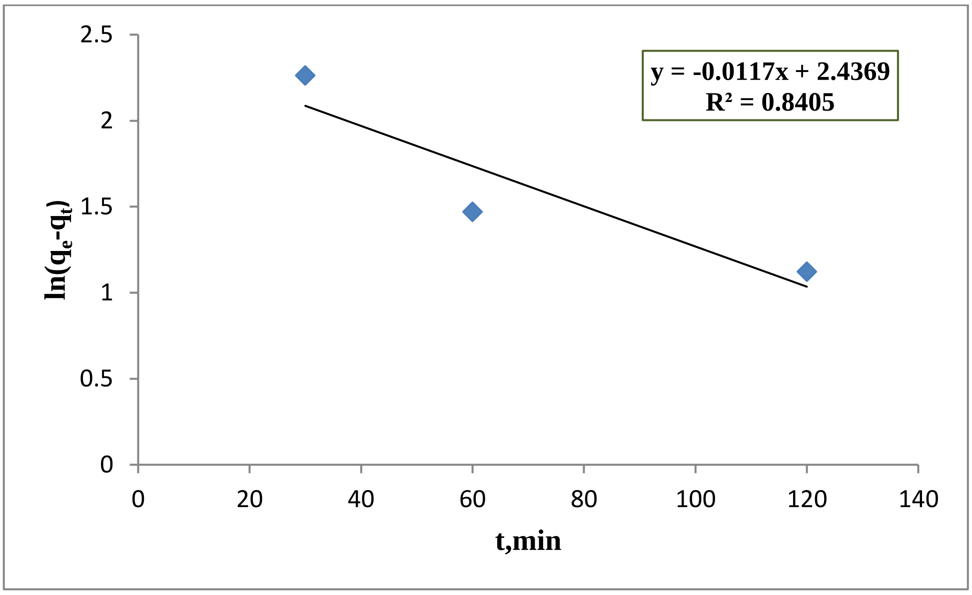

Figure 7. Plot of pseudo-first-order adsorption kinetics
Condition:(adsorbent dosage =3.5 g/100 ml, pH=5, contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃).

Pseudo-Second-Order Kinetics

This model assumes that one *Cu(II)* ion is adsorbed onto two adsorption sites on the iron slag surface. The slope and intercept of plots t/q_e versus t.

It functions for a single chemical layer onto the sorbent grain in the absence of chemical species reactions. The non-linear form of this model is as follows:

$$\frac{t}{q_t} = \frac{1}{K_2 q_e^2} + \frac{1}{q_e}t \qquad (5)$$

Where k_2 is the equilibrium rate constant of pseudo-second-order adsorption, (g/mg · min). The slopes and intercepts of plots (t/q_t) versus (t) are used to calculate the pseudo-second-order rate constants k_2 and q_e [19]. Figure 8 is used to calculate the pseudo-second order constant K_2 and q_e.

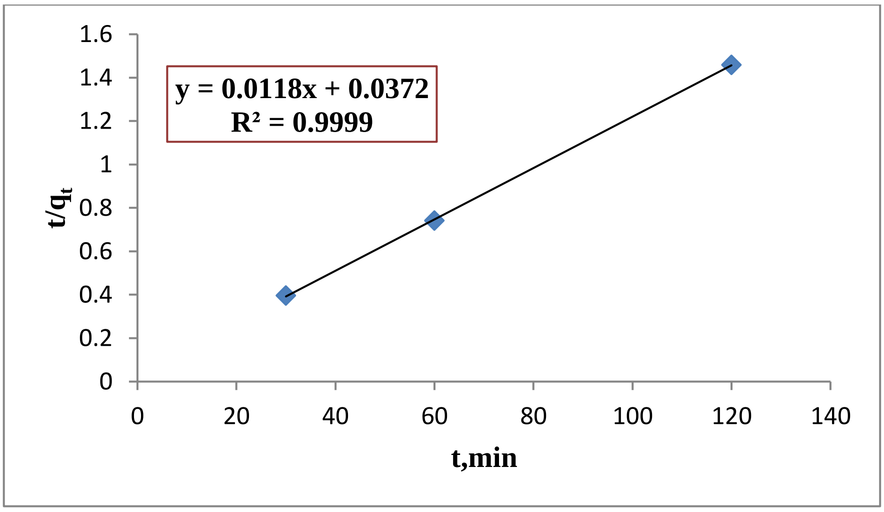

Figure 8. Plot of pseudo-second order adsorption kinetics.
Condition☹adsorbent dosage =3.5 g/100 ml, pH=5,contact time=90 min, particle size=(d=0.200 mm),and temperature 25 ℃).

Received*: 28-04-2025 -* ***Accepted****: 01-06-2024 -* ***Published****: 09-06-2025*

Tables 1-3 show a comparison of the experimental and theoretical results for the sample. This figure shows that the pseudo-second-order kinetic model has a better correlation with the whole adsorption process. Therefore, a pseudo-second-order kinematic model can be made that is the limiting

Table 1. Simple First Order Model

C_o (ppm)	K_1(min^{-1})	R^2
1000	-0.0045	0.5645
1500	-0.0018	0.0898
2000	-0.0028	0.0976
2500	-0.0068	0.345
3000	-0.019	0.2756

Table 2. Pseudo-First Order Model

C_o (ppm)	q_e(exp)	K_1	R^2
1000	7.047	0.0162	0.5714
1500	6.40	0.0007	0.0446
2000	7.84	0.0012	0.0278
2500	8.77	0.0083	0.4166
3000	11.4375	0.0117	0.8405

Table 3. Pseudo-Second Order Model

C_o (ppm)	q_e(exp)	K_2	R^2
1000	20.16	0.00283	0.9796
1500	26.11	-0.1790	0.9985
2000	41.67	-0.0820	0.9969
2500	64.52	0.0055	0.9989
3000	84.75	0.00374	0.9999

Conclusions and Discussion

Adsorption of Cu(II) by iron slag is investigated in batch experiments, and kinetics and equilibrium experiments are conducted for a synthetic feedstock solution simulating industry effluents. The following conclusions are drawn from the data: The optimal parameters for removing Cu(II) are: AC dosage = 3.5 g/100 ml, particle size (d = 200 µm), starting pH = 5, temperature = 25 °C, and 90 minutes of contact time. The method is chemisorption and (pseudo-second order). Therefore, the current study demonstrates the viability of using iron slag as a readily available, low-cost adsorbent for the efficient removal of Cu(II) from aqueous solution under ideal circumstances.

Results showed a comparison of the experimental and theoretical results for the sample. pseudo-second-order kinetic model has a better correlation with the whole adsorption process.

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Received*: 28-04-2025 -* ***Accepted****: 01-06-2024 -* ***Published****: 09-06-2025*