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**MACHINES.
TECHNOLOGIES.
MATERIALS 2026
PROCEEDINGS**

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Kinetic investigation of copper ions adsorption onto corn stalks

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Abstract: Corn stalk was used as a biosorbent for the adsorption of copper ions from synthetic solutions. To examine the mechanism of the adsorption process and identify the potential rate-determining step, the following kinetic models were used in this study: the pseudo-first order kinetic model, the pseudo-second order kinetic model, the Elovich kinetic model, and the interparticle diffusion model. Kinetic studies show that copper ions adsorption followed the pseudo-second order kinetic model. The maximum adsorption capacity was 5.5 mg g^{-1} . The results indicate that corn stalk can be successfully used as a biosorbent for the adsorption of copper ions from synthetic solutions.

Keywords: CORN STALK, COPPER IONS, ADSORPTION, KINETIC INVESTIGATION

1. Introduction

The increasing discharge of heavy metals into aquatic environments poses a serious threat to ecosystems and public health, necessitating the development of efficient and sustainable wastewater treatment methods. Agricultural by-products, such as corn stalks, represent a promising class of low-cost, environmentally friendly adsorbents for removing metal ions from contaminated water.

Owing to their lignocellulosic composition and abundance of functional groups, modified or untreated corn stalks can effectively capture heavy metal ions through adsorption processes. To better understand the mechanisms and efficiency of these systems, kinetic modelling plays a crucial role. The application of kinetic models – such as pseudo-first-order, pseudo-second-order, and Elovich kinetic model – provides insights into the rate-controlling steps and adsorption dynamics, contributing to the optimisation of treatment parameters for practical applications.

2. Materials and methods

Corn stalks collected from agricultural fields near Bor were used as the adsorbent. The material was first ground and sieved, and the sieve fraction ($-1 + 0.4$) mm was used for adsorption experiments.

2.1. Adsorption of Cu^{2+} ions onto corn stalks – experimental procedure

Adsorption experiments of Cu^{2+} ions onto corn stalks were carried out in a stirred batch reactor with a magnetic stirrer operating at 300 rpm. Before the experiments, the adsorbent was washed with distilled water, and pH and conductivity were monitored.

A synthetic Cu^{2+} solution (0.2 g dm^{-3}) served as the aqueous phase, with 0.5 g of adsorbent mixed with 50 mL of solution. After a specified contact time, the suspension was filtered, and the filtrate was analysed for residual copper, alkali metals, and alkaline earth metals. The amount of adsorbed copper and the adsorption capacity were determined by mass balance, and pH variation was monitored during adsorption. All experiments were conducted at room temperature.

The adsorption capacity, defined as the amount of metal adsorbed per unit mass of adsorbent, was calculated using the following equation:

$$q_{(t)} = \frac{c_i - c_{(t)}}{m} V \quad (1)$$

where: $q_{(t)}$ is the adsorption capacity (mg g^{-1}); c_i and $c_{(t)}$ are the initial and time-dependent metal concentrations in solution (mg dm^{-3}); V is the solution volume (dm^3); m is the mass of adsorbent (g).

3. Results and discussion

3.1 Kinetics of the adsorption process

To investigate the adsorption mechanism and identify the rate-limiting step, the following kinetic models were applied: pseudo-first-order, pseudo-second-order, Elovich, and intraparticle diffusion models, commonly used for liquid–solid adsorption systems [1,2].

Adsorption experiments were conducted at an initial Cu^{2+} concentration of 200 mg dm^{-3} and stopped after 90 minutes, assumed sufficient to reach equilibrium [3].

The adsorption capacity increased rapidly during the first 10 minutes, reflecting abundant active sites on the corn stalks. Thereafter, the rate slowed as available sites decreased and Cu^{2+} concentration in solution declined, approaching equilibrium after ~ 60 minutes, when the amount of adsorbed copper remained constant.

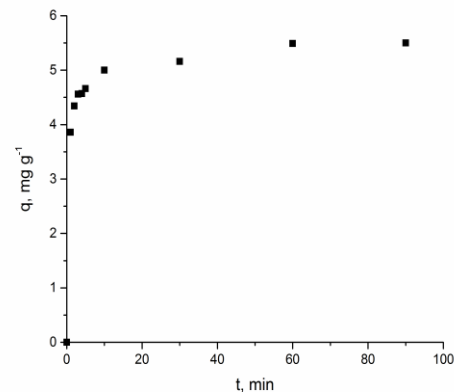


Fig. 1 Change of copper ion adsorption capacity with time on corn stalks.

3.1.1. Pseudo-first-order kinetic model (Lagergren model)

The pseudo-first-order kinetic model was proposed by Lagergren and is often referred to as the Lagergren model. This model assumes that the adsorption kinetics occur as a reversible process based on the adsorption capacity [4]. In differential form, the pseudo-first-order model can be expressed by equation (2):

$$\frac{dq_{(t)}}{dt} = k_1 (q_e - q_{(t)}) \quad (2)$$

where: $q_{(t)}$ is the adsorbent capacity defined as the mass of metal adsorbed per unit mass of adsorbent at time t (mg g^{-1}); q_e is the equilibrium adsorption capacity (mg g^{-1}); k_1 is the rate constant for the pseudo-first-order kinetic model (min^{-1}).

For practical application, the following equation can be used:

$$\log(q_e - q_{(t)}) = \log(q_e) - \frac{k_1}{2,303} \cdot t \quad (3)$$

A plot of $\log(q_e - q_{(t)})$ versus t provides a linear relationship, from which k_1 and q_e can be determined from the slope and intercept, respectively. Results are shown in Table 1.

As shown in Table 1, the pseudo-first-order model exhibits a correlation coefficient $R^2 = 0.89$, indicating a moderate fit. The calculated and experimental adsorption capacities differ significantly, suggesting limited applicability of this model.

Table 1: Pseudo-first-order kinetic parameters for Cu^{2+} adsorption.

Parameter/Ion	k_1 (min^{-1})	$q_{e,\text{exp}}$ (mg g^{-1})	$q_{e,\text{cal}}$ (mg g^{-1})	R^2
Cu^{2+}	0.082	5.5	1.76	0.89

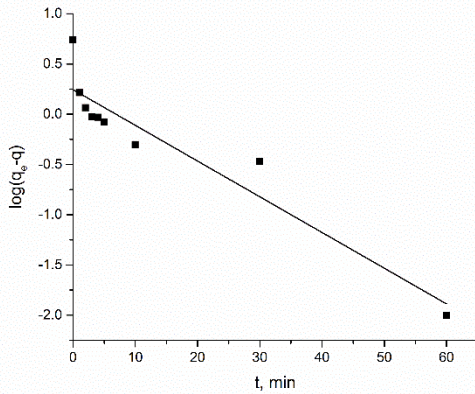


Fig. 2 Pseudo-first-order kinetic model for copper ion adsorption on corn stalks.

3.1.2. Pseudo-second-order kinetic model

The pseudo-second-order kinetic model assumes that both adsorption and ion exchange occur at the adsorbent surface, with chemisorption controlling the binding of the adsorbate [5]. The nonlinear form of the pseudo-second-order model is expressed as [6]:

$$\frac{dq_{(t)}}{dt} = k_2 (q_e - q_{(t)})^2 \quad (4)$$

where: $q_{(t)}$ is the adsorbent capacity defined as the mass of metal adsorbed per unit mass of adsorbent at time t (mg g^{-1}); q_e is the equilibrium adsorption capacity (mg g^{-1}); k_2 is the rate constant for the pseudo-second-order kinetic model ($\text{g mg}^{-1} \text{min}^{-1}$).

For practical application, the following equation can be used:

$$\frac{t}{q_{(t)}} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (5)$$

Values of k_2 and q_e were determined from the intercept and slope of the $t/q_{(t)}$ vs. t plot. The results are shown in Table 2.

Table 2: Pseudo-second-order kinetic parameters for Cu^{2+} adsorption

Parameter/Ion	k_2 ($\text{g mg}^{-1} \text{min}^{-1}$)	$q_{e,\text{exp}}$ (mg g^{-1})	$q_{e,\text{cal}}$ (mg g^{-1})	R^2
Cu^{2+}	0.205	5.5	5.5	1

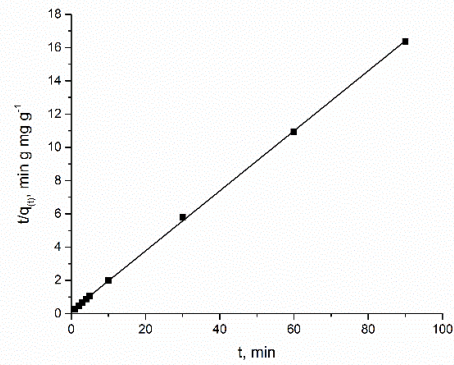


Fig. 3 Pseudo-second-order kinetic model for copper ion adsorption on corn stalks.

The perfect correlation ($R^2 = 1$) indicates excellent agreement between the experimental data and the pseudo-second-order model, confirming that chemisorption and ion exchange govern Cu^{2+} adsorption on corn stalks.

3.1.3. Elovich kinetic model

Originally developed for gas chemisorption on heterogeneous solid surfaces, the Elovich model is widely used for solution-phase adsorption [6]. It assumes that the adsorption rate decreases exponentially with increasing adsorbate coverage. In the literature, it is most commonly presented in the following form [7]:

$$\frac{dq_{(t)}}{dt} = \alpha e^{-\beta q_{(t)}} \quad (6)$$

where: α is the initial adsorption rate ($\text{mg g}^{-1} \text{min}^{-1}$); β is a parameter related to surface coverage and activation energy (g mg^{-1}); $q_{(t)}$ is the adsorbent capacity (mg g^{-1}).

For practical application, the following equation can be used:

$$q_{(t)} = \frac{1}{\beta} \ln(\alpha\beta) + \frac{1}{\beta} \ln t \quad (7)$$

The values of the parameters α and β were determined from the intercept and slope of the $q_{(t)}$ vs. $\ln t$ plot (Figure 4), and are presented in Table 3 together with the correlation coefficient R^2 for copper ions.

Table 3: Elovich kinetic parameters for Cu^{2+} adsorption.

Parameter/Ion	α ($\text{mg g}^{-1} \text{min}^{-1}$)	β (g mg^{-1})	R^2
Cu^{2+}	4.073	0.4	0.958

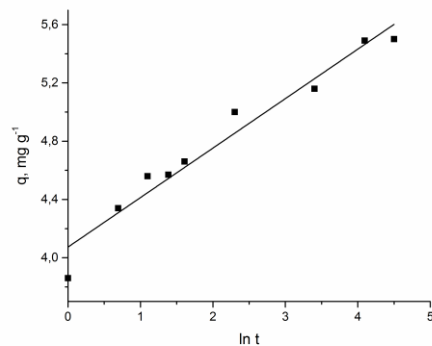


Fig. 4 Elovich kinetic model for copper ion adsorption on corn stalks.

From Table 3, based on the obtained value of the correlation coefficient $R^2 = 0.958$, it can be observed that the Elovich kinetic model describes very well the kinetics of copper ion adsorption onto corn stalks, indicating that copper ions bind to the adsorbent predominantly through chemisorption.

4. Conclusions

The kinetics of the copper ion adsorption process onto corn stalks were analyzed according to three theoretical kinetic models: the pseudo-first-order model, the pseudo-second-order model, and the Elovich model. Comparison of R^2 values for all models (Tables 1–3) demonstrates that the pseudo-second-order model provides the best fit ($R^2 = 1$), indicating that chemisorption is a possible mechanism of copper ion binding to the surface of corn stalks.

5. Acknowledgment

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