

## KINETIC CHARACTERIZATION OF Cd<sup>2+</sup> ADSORPTION ON $\gamma$ -Al<sub>2</sub>O<sub>3</sub> BASED NANOCOMPOSITES

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The adsorption isotherm was analyzed to describe the equilibrium behavior of Cd<sup>2+</sup> ions on the synthesized adsorbents. The experimental data were fitted to the Langmuir model to evaluate the adsorption capacity and surface characteristics. The results revealed that the adsorption of Cd<sup>2+</sup> ions followed the Langmuir isotherm, indicating monolayer adsorption on a homogeneous surface. The study was conducted using  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> nanoparticles and  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/CuO nanocomposite as adsorbents.

**Keywords:** adsorption, Cd<sup>2+</sup> ions, Langmuir isotherm,  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/CuO nanocomposite.

### INTRODUCTION

It is known that heavy metals are one of the hazardous environmental pollutants due to their persistence, migration and bioaccumulation character. They enter the environment from both natural and anthropogenic sources worsening the quality of air, soil and aquatic systems [1-3]. Among heavy metals, Cd is more harmful to all the ecosystem components, including human health. The use of water containing over 0,006 mg/l of Cd can damage fetal brain, lungs, livers and nervous systems [4]. The removal of heavy metals from aquatic environment is one of the urgent problems of nowadays. Traditional methods for treatment of metal polluted wastewater have some disadvantages due to insufficient metal removal, high energy consumption, and the production of waste products requiring proper disposal. Therefore, it is necessary to use efficient and environmentally friendly methods for reducing heavy metal content in water [5-7].

Adsorption is one of the methods widely used for the removal of pollutants from wastewater. Various types of adsorbents have been applied to remove oil and oil products, heavy metals, dyes, antibiotics and other toxic substances from industrial and domestic effluents. Nanomaterials have distinct advantages for recovering heavy metals from fluid systems because of their small size, large surface area and enhanced reactivity.

The studies have shown that the efficiency of the adsorption process is dependent on several parameters, primarily on the amount of adsorbent and the contact time. Sometimes low-cost adsorbents represent low adsorption capacity that requires increased amounts of adsorbents to achieve efficient removal of pollutants. However, it is possible to achieve high adsorption efficiency at low-concentrations of high-cost adsorbent and minimum contact time by developing appropriate experimental conditions. Optimization of adsorbent mass involves precise mathematical calculations that rely on theoretical adsorption kinetics and adsorption isotherms [8].

In this study, the Langmuir empirical model was applied to analyze the adsorption behavior of Cd<sup>2+</sup> ions

from aqueous solution onto  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> nanoparticles and a  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/CuO (12 wt% CuO) nanocomposite. The  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and CuO nanoparticles used in our experiments were synthesized by sol-gel method. The crystallite sizes of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and CuO nanoparticles were calculated from XRD data using the Scherrer equation [9].

### EXPERIMENTAL RESULTS

Figure 1 shows the removal of Cd<sup>2+</sup> ions from an aqueous solution using equal quantities of  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> (0.0058 g) and the  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/12% CuO nanocomposite.  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> exhibits moderate Cd<sup>2+</sup> uptake, whereas the  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/CuO nanocomposite achieves significantly faster and higher adsorption; most of the Cd<sup>2+</sup> ions are removed within the first 30 minutes. The Langmuir isotherm was then constructed using these equilibrium data, enabling the maximum adsorption capacity (q<sub>m</sub>) and the Langmuir constant (K<sub>L</sub>) to be determined for both adsorbents.

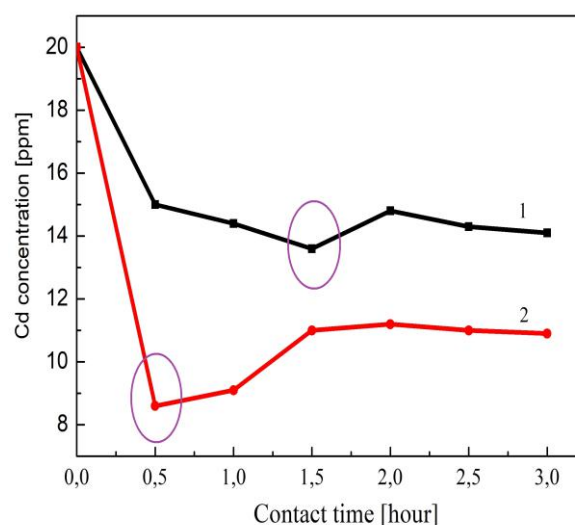


Fig. 1. Removal of Cd<sup>2+</sup> ions from solution using the same dose (0.0058 g) of (1)  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> nanoparticles and (2)  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/12% CuO nanocomposite as a function of contact time.

**ADSORPTION KINETIC ANALYSIS**

The Langmuir empirical model is most frequently used by authors for describing the heavy metal adsorption process [8]. The Langmuir theory proposed to describe the adsorption of gas molecules on metal surfaces has found successful applications in many other processes of monolayer adsorption. The Langmuir model finds application in solid-liquid systems, expounding that all sites on the surface of the adsorbent have equal opportunities to be occupied by heavy metals. The isotherm equation further assumes that adsorption takes place at specific homogeneous sites within the adsorbent. It is then assumed that once a Cd(II) ion occupies a site, no further adsorption will take place at that site. The amount of adsorbed heavy metal onto the adsorbent material per unit mass of adsorbent was defined by the following equation:

$$q_e = \frac{C_0 - C_e}{W} V \tag{1}$$

Where ions uptake at equilibrium,  $q_e$  (mg/g),  $C_0$  and  $C_e$  (mg/L) were the initial and equilibrium concentrations of the ion solutions, respectively.  $V$  (L) identifies the volume of the solution, and  $W$ (g) indicates the mass of adsorbent.

Langmuir’s isotherm model suggests that the uptake occurs on homogeneous surface by monolayer sorption without interaction between adsorbed ions. The linear form of Langmuir isotherm equation is represented by the following equation:

$$\frac{C_e}{q_e} = \frac{1}{Q^0 b} + \frac{1}{Q^0} C_e \tag{2}$$

Where  $Q^0$  is the maximum metal ions uptake per unit mass of adsorbent (mg/g) related to adsorption capacity and  $b$  is Langmuir constant (L/mol) related to energy of sorption. Therefore, a plot of  $C_e/q_e$  versus  $C_e$ , gives a straight line of slope  $1/Q^0$  and intercept  $1/(Q^0 b)$ .

The Langmuir isotherm data for Cd<sup>2+</sup> ions adsorption onto  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> NPs and  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/12%CuO composite are presented in figure 5a and b.

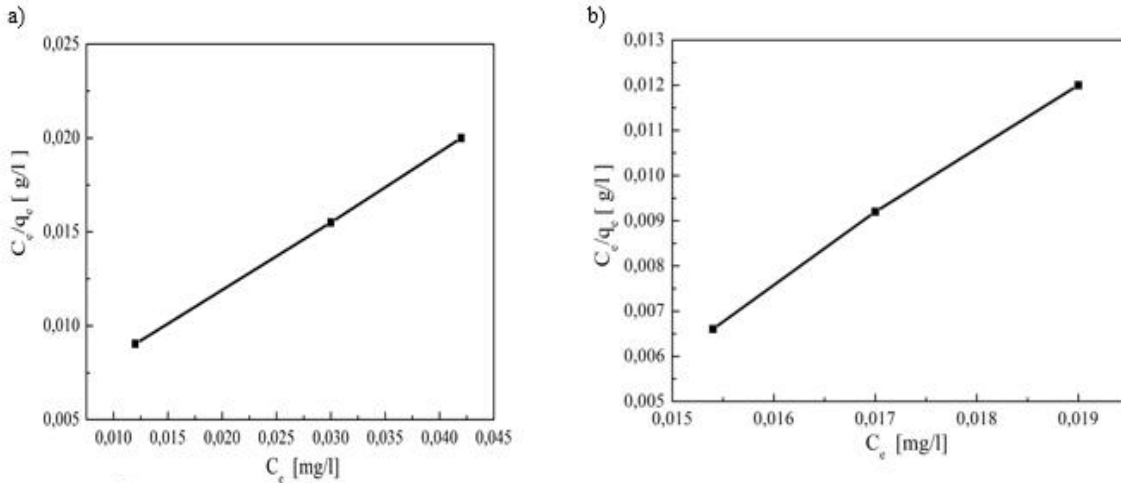


Fig. 2. Langmuir isotherm of Cd<sup>2+</sup> ions adsorption onto: a)  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>; b) Al<sub>2</sub>O<sub>3</sub>/12%CuO composite.

One of the essential characteristics of the Langmuir isotherm was a dimensionless constant of separation factor or equilibrium parameter  $R_L$ . The value of  $R_L$  being between 0 and 1 indicates good adsorption efficiency. The value of  $R_L$  was found using the following equation:

$$R_L = \frac{1}{1 + R_L C_0} \tag{3}$$

Where  $K_L$  is the Langmuir constant and  $C_0$  is the initial concentration of the Cd ions [10].

The calculated values of  $Q^0$  and  $R_L$  are given in the table below.

Table. Langmuir isotherm model for the removal of Cd ions from water using  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> and  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/(12%) CuO composite powders

Isotherm model parameters	Adsorbent	
	$\gamma$ -Al <sub>2</sub> O <sub>3</sub>	$\gamma$ -Al <sub>2</sub> O <sub>3</sub> /CuO (12%)
$Q^0$ (mg g <sup>-1</sup> )	136	167
$R_L$ (L mg <sup>-1</sup> )	0.933	0.954

## CONCLUSION

The results of this study demonstrate that the adsorption of Cd<sup>2+</sup> ions from an aqueous solution onto  $\gamma$ -Al<sub>2</sub>O<sub>3</sub> nanoparticles or the  $\gamma$ -Al<sub>2</sub>O<sub>3</sub>/CuO nanocomposite can be well described by the Langmuir isotherm. This indicates that the adsorption of Cd<sup>2+</sup> ions by both materials occurs predominantly as a monolayer on a homogeneous surface, where all active sites are energetically equivalent and can accommodate one

Cd<sup>2+</sup> ion each. The high correlation with the Langmuir model suggests that the interactions between the adsorbate and the adsorbent are uniform across the surface and that multilayer adsorption or significant ion-ion interactions are negligible. These findings provide important insights into the adsorption mechanism and confirm that both materials offer well-defined active sites for the effective and predictable removal of Cd<sup>2+</sup> ions from aqueous solutions.

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