

Adsorption of Pb²⁺ Ions Aqueous Environment Using the Novel Cao-Cdo/Zsm-5 Zeolite Nanocomposite Adsorbent

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Abstract

ZSM-5 is a porous zeolite material that reveals good activity for the adsorption of heavy metals and other contaminants for effluent purification. In this scientific research, we synthesized the novel CaO-CdO/ZSM-5 zeolite nanocomposite adsorbent and studied the effects of different parameters on the adsorption of Pb²⁺ ions from water media for the first time. About 99.2% adsorption removal efficiency was obtained after contact time of 60 min and adsorbent amount of 0.1 g/L for initial Pb²⁺ concentration of 200 mg/L at pH8 and temperature of 60°C. The adsorption kinetic fit well via the pseudo-second order model. Furthermore, the adsorption results were reproduced using the Langmuir isotherm with a maximum adsorption capacity of mg/g. The thermodynamic data displayed that the adsorption of Pb²⁺ ions over the CaO-CdO/ZSM-5 nanocomposite were endothermic and spontaneous.

Keywords: CaO-CdO/ZSM-5, zeolite, nanocomposite, Pb²⁺ ions, adsorption.

Introduction

NanoComposite

Nanocomposite is a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm) or structures having nano-scale repeat distances between the different phases that make up the material (Song et al., 2020).

The idea behind Nanocomposite is to use building blocks with dimensions in nanometre range to design and create new materials with unprecedented flexibility and improvement in their physical properties.

In the broadest sense this definition can include porous media, colloids, gels and copolymers, but is more usually taken to mean the solid combination of a bulk matrix and nano-dimensional phase(s) differing in properties due to dissimilarities in structure and chemistry (Rane et al., 2018).

The mechanical, electrical, thermal, optical, electrochemical, catalytic properties of the nanocomposite will differ markedly from that of the component materials. Size limits for these effects have been proposed.

1. <5 nm for catalytic activity
2. <20 nm for making a hard magnetic material soft
3. <50 nm for refractive index changes

4. <100 nm for achieving superparamagnetism, mechanical strengthening or restricting matrix dislocation movement (Lopez et al., 2004).

Nanocomposites are found in nature, for example in the structure of the abalone shell and bone. The use of nanoparticle-rich materials long predates the understanding of the physical and chemical nature of these materials. Some researchers investigated the origin of the depth of colour and the resistance to acids and bio-corrosion of Maya blue paint, attributing it to a nanoparticle mechanism. From the mid-1950s nanoscale organo-clays have been used to control flow of polymer solutions (e.g. as paint viscosifiers) or the constitution of gels (e.g. as a thickening substance in cosmetics, keeping the preparations in homogeneous form). By the 1970s polymer/clay composites were the topic of textbooks, although the term “nanocomposites” was not in common use.

In mechanical terms, nanocomposites differ from conventional composite materials due to the exceptionally high surface to volume ratio of the reinforcing phase and/or its exceptionally high aspect ratio. The reinforcing material can be made up of particles (e.g. minerals), sheets (e.g. exfoliated clay stacks) or fibres (e.g. carbon nanotubes or electrospun fibres). The area of

the interface between the matrix and reinforcement phase(s) is typically an order of magnitude greater than for conventional composite materials. The matrix material properties are significantly affected in the vicinity of the reinforcement. Some scientists be aware that with polymer nanocomposites, properties related to local chemistry, degree of thermoset cure, polymer chain mobility, polymer chain conformation, degree of polymer chain ordering or crystallinity can all vary significantly and continuously from the interface with the reinforcement into the bulk of the matrix. This massive quantity of reinforcement surface area means that a relatively small amount of nanoscale reinforcement can have an observable effect on the macroscale properties of the composite.

Zeolite

Zeolites are a group of crystalline materials made up of evenly sized pores and tunnel systems. When purifying VOCs and hydrocarbons, we use a synthetic hydrophobic zeolite. When the contaminated air passes through the material, the hydrocarbons are adsorbed. The material can adsorb a certain amount of hydrocarbons before needing to be regenerated.

A smaller flow of hot air is then directed through the material so that the hydrocarbons release from the zeolite in a higher concentration. This enables more cost-effective incineration. One of its strengths is that it is non-combustible—meaning it can withstand very high temperatures. This means that we are also able to purify volatile hydrocarbons such as fumes emitted from vulcanization, plastic smoke and styrene, all of which require very high temperatures during regeneration. The resistance to high temperatures and the structure of the material also allows the zeolite to be completely regenerated – meaning that the VOCs completely release from the zeolite when heated. This means that the system maintains its high purification rate year after year and that the material does not have to be replaced, which gives it a long lifespan and a minimal need for maintenance. Our systems have an availability of over 99% and a lifespan exceeding 25 years. Combining the benefits of zeolite with our 30 years of experience in working with air purification gives our customers a supremely sustainable and customized system with low operating costs and high availability.

Reversible hydration and dehydration

During drying it comes to the removal of free and bound water from the crystal grid, which is then counterbalanced back in contact with materials such as stored grain and feed, pet litter, in flue gas to prevent condensation and the like. Clinoptilolite stabilize moisture at a low dose of volume and avoid the adverse effects of water.

Ion exchange

Grid structure allows clinoptilolite to operate as Ion exchanger and as a selective adsorbent. Adsorption and exchange of ions depends on their charge and size. The more the size of the ion matches the size of the entering grid of clinoptilolite, the easier it will be captured and kept. Entry pore diameter is approximately 4 angstrom, which corresponds to the average

ammonium ions NH_4^+ , H_2O , ^{134}Cs & ^{137}Cs . These compounds exhibit the greatest affinity to bind to clinoptilolite, which operates as a selective adsorbent for a wide range of pollutants.

Result and Discussion

FESEM

The morphology and particle size of the as-synthesized CaO-CdO/ZSM-5 by the ultrasonic-assisted hydrothermal method was studied applying the FESEM analysis. Fig.1 illustrates the FESEM image of the CaO-CdO/ZSM-5. From the FESEM image, the hexagonal structure of the ZSM-5 zeolite and sphere-like shapes of the CaO-CdO NPs were all clearly confirmed. The aforementioned obviously display the successful fabrication of the CaO-CdO NPs within the ZSM-5 structure without any destructive changes in its crystalline properties. Furthermore, the average length and diameter of the ZSM-5 were achieved to be $\sim 3 \mu\text{m}$ and $2 \mu\text{m}$, while for the CaO-CdO NRs were determined to be 15 nm, respectively.

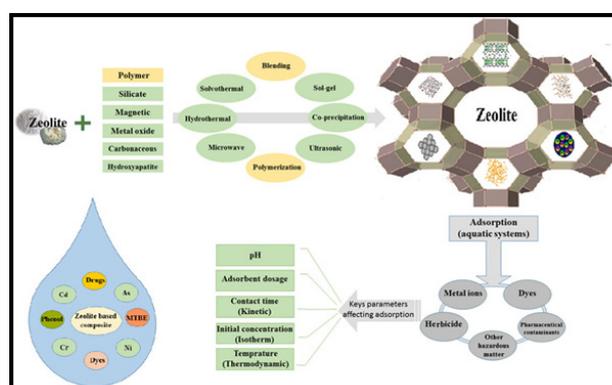


Figure 1: Graphical abstract Zeolite-based composites for the adsorption of toxic matters from water (Song et al., 2020).

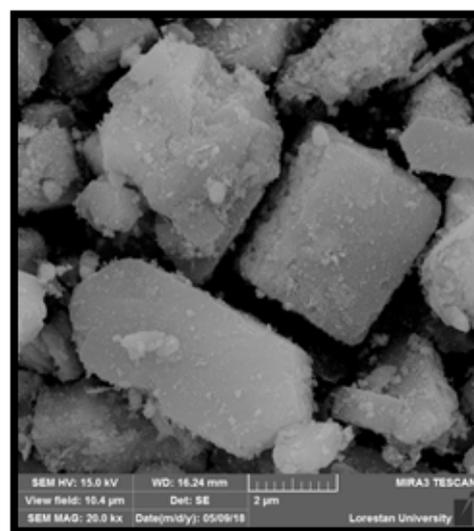


Figure 2: FESEM of the CaO-CdO/ZSM-5.

Conclusion

The present research was aimed to investigate the adsorption of Pb^{2+} ions from water media on the CaO-CdO/ZSM-5 zeolite nanocomposite. The outcomes illustrated that 0.1 g/L of CaO-CdO/ZSM-5, pH 8, initial Pb^{2+} concentration of 200 mg/L

and contact time of 60 min were optimized for maximum adsorption of Pb^{2+} ions. The kinetic evaluate displayed that the adsorption of Pb^{2+} ions on the CaO-CdO/ZSM-5 nanocomposite follows the pseudo-second order model. Also, this study follows the Langmuir isotherm with a q_{max} amount of 125.7 mg/g. Furthermore, the thermodynamic data demonstrated that the adsorption of Pb^{2+} ions on the CaO-CdO/ZSM-5 nanocomposite were endothermic and spontaneous in nature. Additionally, CaO-CdO/ZSM-5 adsorbent was regenerated up to 4 runs revealing its suitability to be used repeatedly in Pb^{2+} adsorption.

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