

Characterization of copper-based nanocatalysts supported on metal oxides for the selective hydrogenation of furfural

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Abstract

Furfural is a biomass-derived platform molecule of growing interest for the production of renewable fuels and value-added chemicals, such as furfuryl alcohol (FOL) and 2-methylfuran (2-MF), via catalytic hydrogenation. In this work, copper-based nanocatalysts supported on ZnO, MgO, and Al₂O₃ were synthesized through a co-precipitation method adapted from the literature, aiming to provide an environmentally friendly alternative to the traditional copper chromite catalyst, known for its toxicity. The synthesized materials were characterized by transmission electron microscopy (TEM), nitrogen adsorption-desorption (BET method), and Fourier transform infrared spectroscopy (FTIR). TEM analysis revealed distinct morphologies depending on the support, including nanowire structures and core-shell configurations. The catalysts exhibited relatively low specific surface areas, ranging from 8 to 37 m²/g, consistent with reports for similar metal oxides.

Keywords: Furfural; Hydrogenation; Copper; nanocatalysts

Introduction

Furfural is an aldehyde derived from the acid hydrolysis of pentosans present in lignocellulosic biomass. With an estimated global production of approximately 250,000 tons per year, it is traditionally employed as a solvent in various chemical industries. In the context of modern biorefineries, however, furfural has emerged as a key platform molecule for the synthesis of renewable fuels and high-value-added chemicals, particularly furfuryl alcohol and 2-methylfuran¹.

The catalytic hydrogenation of furfural is the primary route for producing these biofuels. Currently, copper chromite (CuCr₂O₅) is the most commonly used catalyst for this process. Despite its widespread use, this material presents significant limitations, including moderate catalytic performance and the environmental and health hazards associated with chromium compounds, which are classified as toxic².

In light of these concerns, the present work aims to develop and characterize copper-based nanocatalysts supported on ZnO, MgO, and Al₂O₃ as alternative, environmentally benign materials for the catalytic hydrogenation of furfural. These nanostructured systems are expected to provide improved performance and reduced ecological impact, contributing to the advancement of sustainable catalytic technologies in biomass valorization.

Experimental

The synthesis procedures were adapted from the methodology reported by Brady et al. (2023).

Synthesis of CuO nanoparticles:

CuO was synthesized by dissolving 6.111 g of Cu(NO₃)₂·3H₂O in 100 mL of deionized water under continuous heating at 50 °C. A 0.5 mol/L NaOH solution was then added dropwise until the pH reached 8, and the mixture was stirred for 4 h. The resulting precipitate was vacuum-filtered, washed three times with deionized water and once with absolute ethanol, then dried at 70 °C for 2 h and calcined at 500 °C for an additional 2 h.

Synthesis of Cu-based nanocatalysts:

A dispersion containing 0.2 g of the synthesized CuO in 40 mL of deionized water was sonicated for 30 min. Separately, aqueous solutions of the respective support precursors (Zn²⁺, Mg²⁺, or Al³⁺ salts) were prepared and combined with the CuO dispersion. After 15 minutes of stirring, 0.5 mol/L NaOH was added until the pH reached 10–11. The suspension was stirred for 6 h, followed by drying at 70 °C for 2 h and calcination at 500 °C for 2 h.

Characterization techniques:

The samples were characterized by transmission electron microscopy (TEM), nitrogen physisorption and Fourier transform infrared spectroscopy (FTIR).

Results and discussion

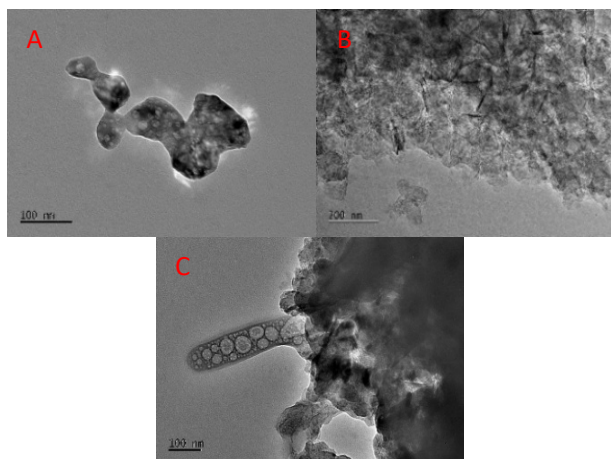


Figure 1. TEM images. (A) Cu/ZnO, (B) Cu/MgO, (C) Cu/Al₂O₃

TEM micrographs of the samples supported on ZnO, MgO, and Al₂O₃ revealed distinct morphologies depending on the support. For the Cu/MgO sample, nanowire-like copper structures were observed dispersed across the oxide matrix. In contrast, the Cu/ZnO and Cu/Al₂O₃ catalysts exhibited a core-shell morphology, in which copper nanoparticles appeared encapsulated by a thin layer of the respective support material consistent with structures previously described by Brady et al. (2023).

Textural properties of the catalysts were determined using nitrogen adsorption-desorption isotherms, applying the Brunauer-Emmett-Teller (BET) method. The specific surface areas were measured as follows: 36 m²/g for Cu/MgO, 37 m²/g for Cu/Al₂O₃, and 8 m²/g for Cu/ZnO. These relatively low surface areas are typical for metal oxides and are in agreement with previous studies^{4,5}. Lower surface area in the ZnO-based sample may be associated with particle aggregation or lower porosity.

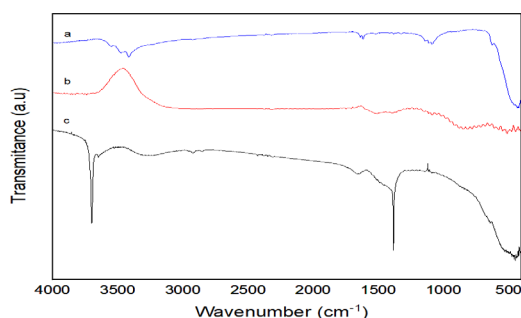


Figure 2. FTIR spectra. Curve a: Cu/ZnO. Curve b: Cu/Al₂O₃. Curve c: Cu/MgO

In the FTIR spectrum of the Cu/ZnO sample, absorption bands between 400 and 480 cm⁻¹ were attributed to Zn–O bond vibrations. For Cu/Al₂O₃, a weak band at 570 cm⁻¹ was attributed to Al–O stretching. In the Cu/MgO catalyst, a band at 441 cm⁻¹ corresponded to Mg–O bond vibrations. These spectral features are consistent with the expected structural for the respective oxide phases

Conclusion

The synthesized Cu-based nanocatalysts displayed favorable nanostructures, such as nanowires and core-shell morphologies, that may enhance catalytic performance despite their low specific surface areas, typical of metal oxides. FTIR analysis revealed characteristic vibrational bands associated with the oxide supports, supporting the success of the synthesis procedure. Overall, the results indicate that these materials are promising candidates for application in furfural hydrogenation.

Acknowledgments

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