Spent Lithium Cobalt Oxide Batteries: Heterogeneous Catalyst for Upcycling Lignocellulosic Biomass

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Significance and Relevance

This study adopts a waste-to-resource approach by repurposing spent lithium cobalt oxide ($LiCoO_2$ or LCO) batteries, part of a growing waste stream exceeding millions of units annually, as a heterogeneous catalyst for upcycling lignocellulosic biomass. The cobalt content, a high-value transition metal with remarkable catalytic properties for reductive reactions, is effectively utilized, offering a sustainable alternative to traditional catalysts. The findings highlight a dual benefit: reducing the environmental burden of hazardous battery waste while transforming it into a valuable resource for biomass conversion into high-value chemicals, promoting circular economy principles.

Preferred and 2nd choice for the topic: Green chemistry and biomass transformation, renewable resources conversion
Preferred presentation: (Oral only)

Introduction and Motivations

The rapid proliferation of lithium-ion batteries, fueled by their extensive use in electronic devices and electric vehicles, has led to a growing challenge in managing spent lithium cobalt oxide (LCO) batteries.[1] These batteries not only contribute to environmental hazards due to toxic components but also represent a wasted resource, as cobalt is a critical and valuable metal known for its catalytic properties in various chemical processes.[2] Addressing this dual concern, the repurposing of spent batteries into heterogeneous catalysts aligns with sustainable waste management and circular economy principles, enabling both environmental remediation and resource recovery.[3] This innovative approach can unlock new pathways for converting lignocellulosic biomass into value-added products, thereby contributing to renewable energy and material production goals.

Materials and Methods

The cathodic material, also known as “Black Mass” (BM), was obtained through the direct recovery of spent LCO batteries. BM was further processed using a simple mechano-thermal treatment to convert it into an efficient heterogeneous Co-catalyst, which was subsequently fully characterized through XRD, FT-ATR, in-situ DRIFT, XPS, SEM-EDX and TEM analysis.

Reactions were performed in a stainless-steel autoclave reactor (100 mL). In each reaction, 40 mL of a 0.1 M furfural (FUR) solution and 0.25 g of the BM catalyst were loaded into the autoclave, both in the presence and absence of added hydrogen.

Results and Discussion

The performance of spent LCO batteries, as heterogeneous catalysts for the hydrogenation of furfural (FUR) was evaluated under reductive conditions, using 2-propanol as both solvent and hydrogen donor. The study revealed promising catalytic activity, with significant conversion of furfural to furfuryl alcohol (FAL).

In fact, under optimized conditions (2-propanol, H_2 pressure of 10 bar, 210 °C, and 180 minutes of reaction), a conversion of 65% to FAL was achieved. Extending the reaction time further improved FUR conversion to 90%, although a decline in catalyst stability was observed due to cobalt leaching (Figure 1).

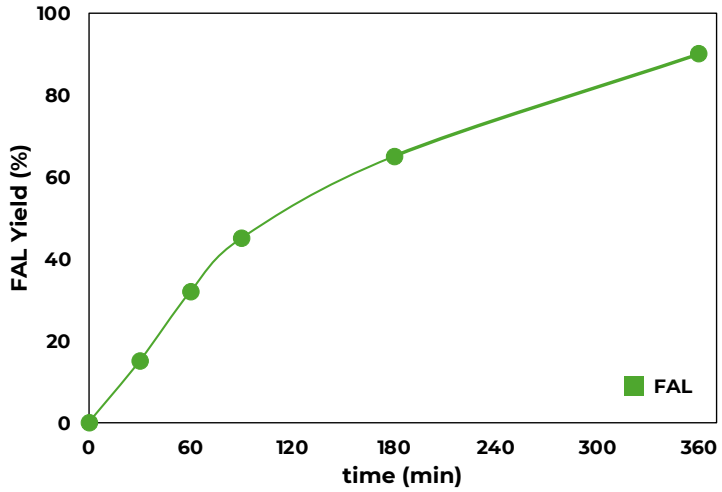

Figure 1. Reaction time effect on furfural hydrogenation [reaction conditions: FUR 0.1 M; 2-PrOH, H_2 10 bar; 210 °C]

Higher reaction temperatures, up to 240 °C, enhanced conversion rates and selectivity, but also exacerbated catalyst degradation, as indicated by increased cobalt leaching (Figure 2).

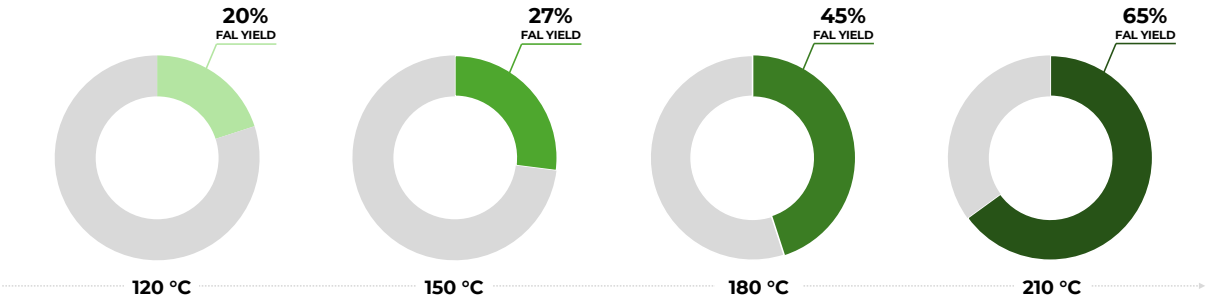

Figure 2. Reaction Temperature effect on furfural hydrogenation [reaction conditions: FUR 0.1 M; 2-PrOH, H2 10 bar; 180 min]

Importantly, no by-products were detected under any of the tested conditions, demonstrating the catalyst's high selectivity. These findings highlight the effectiveness of BM-derived catalysts in biomass upcycling while emphasizing the need for strategies to mitigate catalyst degradation during prolonged and high-temperature reactions.

High furfural conversion can also be obtained under transfer hydrogenation conditions by using 2-propanol as solvent/H-donor. Finally, in order to extend the substrate scope, hydrogenations of other lignocellulosic derived molecules were also tested, clearly show that spent LOC can be efficiently used as a heterogeneous catalyst for their reductive upgrading. In this contribution, we present a novel approach to re-use spent LCO as a stable and efficient Co-based heterogeneous catalyst, demonstrating its high activity for the selective reductive upgrading of biomass-derived molecules.

References

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3. E. Paone, M. Miceli, A. Malara, G. Ye, E. Mousa, E. Bontempi, P. Frontera, F. Mauriello, *ACS Sustainable Chem. Eng.* **2022**, *10*, 2275−2281.