Effect of Sulfonation Conditions on Performance of Sulfonated Lignin-Based Porous Carbon Catalyst

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Significance and Relevance

This study develops lignin-based porous carbon catalysts (LPC) with adjustable sulfonation for efficient cellulose-to-C6 sugar conversion. The optimized LPC-S-200-12 catalyst showed high activity, recyclability, and stability due to its macroporous structure and sulfonic acid retention. Structural stability was confirmed via XPS and XRD. These findings advance understanding of lignin-derived catalysts and address biomass conversion challenges. The novelty lies in optimizing sulfonation conditions and integrating structural characterization to enhance performance and recyclability, driving green chemistry.

Preferred and 2nd choice for the topic: Green chemistry and biomass transformation, renewable resources conversion (Preferred choice); Sustainable and clean energy production and transport (2nd choice).
Preferred presentation: Oral preferred or Short Oral / Poster

Introduction and Motivations

The growing demand for sustainable energy and chemicals has highlighted the importance of lignocellulosic biomass as a renewable feedstock for bio-based products. Sugars derived from lignocellulosic biomass serve as critical intermediates in producing biofuels, bioplastics, and other sustainable materials, offering a pathway to reduce reliance on fossil resources.[1,2] However, efficient conversion of cellulose into value-added sugars remains a challenge due to the recalcitrance of biomass and the lack of robust catalytic systems.[3] Lignin, a major component of biomass, has gained attention as a precursor for designing advanced porous carbon materials with tunable properties.[4] By leveraging its unique structure, lignin-based porous carbon catalysts (LPC) offer a sustainable approach to enhance biomass conversion efficiency. This study aims to optimize sulfonation conditions for LPC synthesis, improving catalytic activity, recyclability, and structural stability, with the ultimate goal of advancing green biomass conversion technologies.

Materials and Methods

Preparation of Catalysts

Lignin-based porous carbon catalysts (LPC) were developed using lignin as a carbon precursor and Fe_3O_4 as a template, with sulfonation carried out under controlled conditions. The catalysts, named LPC-S-X-Y and LPC-SCL-X-Y (where X and Y represent the sulfonation temperature in °C and duration in hours, respectively), were synthesized using 98% H_2SO_4 or chlorosulfonic acid (SO_2Cl_2) as sulfonating agents. The synthesis procedure was illustrated in Figure 1.

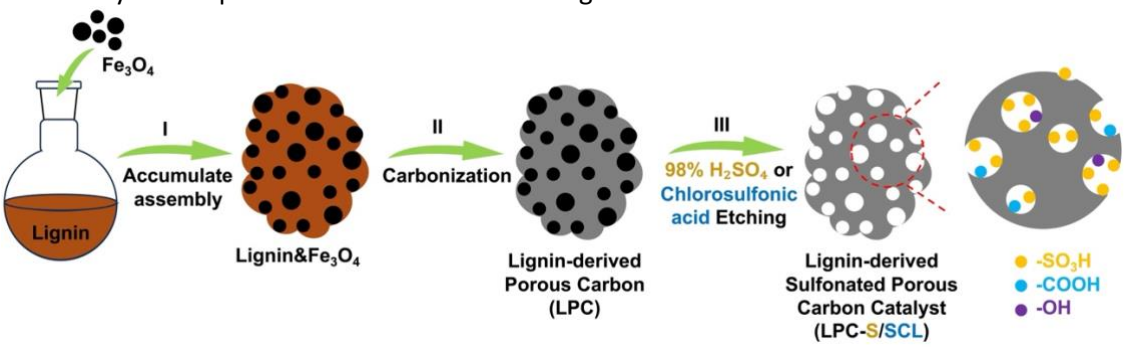

Figure 1 Schematic illustration of the preparation of LPC-S/SCL

Results and Discussion

Morphological of LPC and LPC-S/SCL

The SEM images (Figure 2) reveal distinct morphological features of LPC and sulfonated LPC samples. LPC shows a granular structure with uniform Fe_3O_4 nanoparticles, attributed to lignin adsorption onto Fe_3O_4 during suspension mixing, ensuring effective templating. Sulfonated samples, LSPC-200-12 and LPC-SCL-60-1, exhibit well-developed porous structures with mesopores and macropores. The removal of Fe_3O_4 created a hierarchical pore system. Macropores facilitate the diffusion of large oligosaccharides from cellulose degradation into the pore network, where active catalytic sites are located. This optimization enhances reactant accessibility and catalytic efficiency, emphasizing the importance of macroporosity in LPC-S/SCL performance.

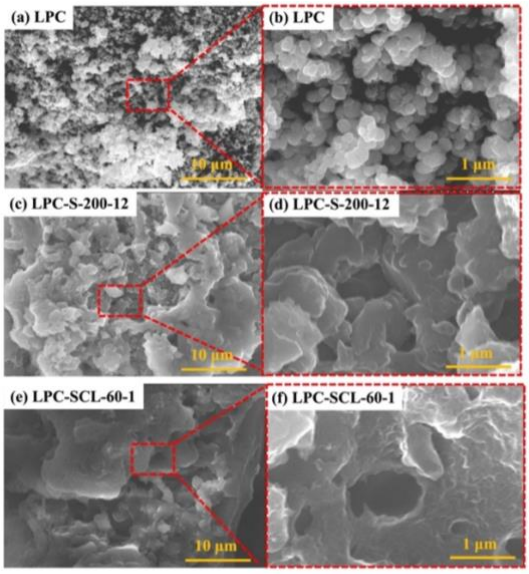

Figure 2 SEM images of (a) and (b) magnified surface structures of LPC; (c) and (d) magnified porous structures of LPC-S-200-12; (e) and (f) magnified porous structures of LPC-SCL-60-1

Catalyst performance and recyclability

The catalytic tests (Figure 3) demonstrate that LPC-S-200-12, synthesized with 98% H_2SO_4 at 200°C for 12 hours, exhibits superior performance in converting cellulose to C6 sugars, achieving the highest liquefaction efficiency among tested catalysts. Durability studies show that LPC-S-200-12 maintains its structural and chemical stability across multiple cycles, outperforming LPC-SCL-60-1 in recyclability. This exceptional performance and stability are attributed to the formation of stable sulfonic acid groups and an optimized pore structure, as confirmed by BET, XRD, and XPS analyses. These results highlight the importance of optimizing sulfonation conditions to enhance catalytic efficiency and long-term performance.

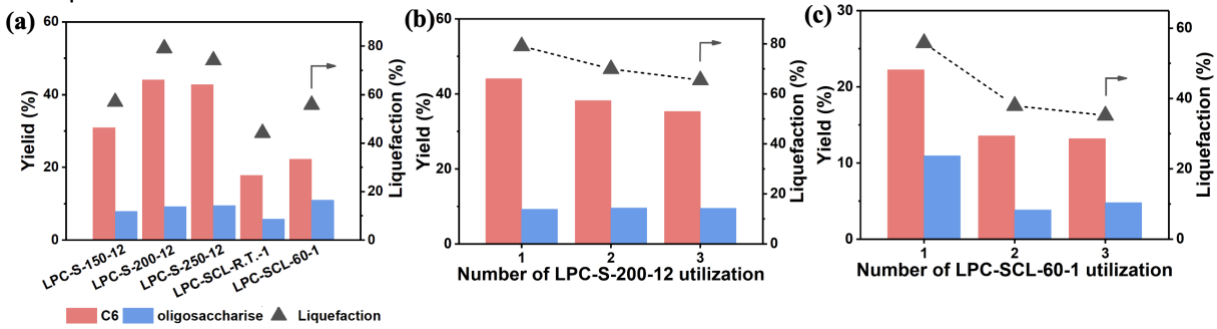

Figure 3 (a) Activity testing of the prepared catalysts;
Durability of (b) LPC-S-200-12 and (c) LPC-SCL-60-1

Conclusion

In summary, LPC-S-200-12, with its optimized pore structure and stable sulfonic acid groups, demonstrates excellent efficiency and durability, highlighting the importance of sulfonation conditions for lignin-derived catalysts in biomass conversion.

References

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