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Synergistic Effect of Zr-Modified Cu-ZnO-Al_2O_3 and Bio-Templated HZSM-5 Catalysts in CO_2 Hydrogenation to Methanol and DME

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Abstract : The conversion of CO_2 into versatile, useful compounds such as fuels and other chemicals remains a challenging frontier in research, demanding the innovation of increasingly effective catalysts. In the present work, a catalyst-incorporating zirconium (Zr) modification within CuO–ZnO–Al_2O_3 (CZA) was synthesized via a co-precipitation method to convert CO_2 into methanol. Furthermore, bio-HZSM-5 was used to promote methanol dehydration to produce dimethyl ether (DME). We prepared the porous hierarchy bio-HZSM-5 with remarkable pore connectivity by utilizing an economical loofah sponge and rice husks as biotemplates. The synthesized catalysts were characterized using Field Emission Scanning Electron Microscopy (FE-SEM), X–ray diffraction (XRD), N_2 adsorption (BET), temperature-programmed desorption (NH_3-TPD) and thermogravimetric analysis (TGA). The Zr addition improved the performance of the CZZA catalyst as a structural promoter, leading to increased DME selectivity and total carbon conversion by enhancing active sites, surface area, and the synergistic interfaces between CuO and ZnO. The presence of silicon in the biomass, notably from the loofah sponge (0.016 wt %) and rice husks (8.3 wt %), also performed a pivotal role in the preparation of bio-HZSM-5. Furthermore, contrasted to the CZZA/com-ZSM-5 catalyst, the integration of CZZA with bio-HZSM-5-L bifunctional catalyst achieved the highest DME yield (12.1 %), DME selectivity (58.6%), CO_2 conversion (22.5%) at 280 °C and 30 bar. The payback time for 5 and 10-tons per day (5 and10-TPD) DME formation using the catalytic process of CO_2 from petrochemical refinery plant waste gas emissions was 2.98 and 2.44 years, respectively.

Keywords : Cost assessment, Dimethyl ether, low-cost bio-HZSM-5, CZZA catalyst, CO_2 hydrogenation
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