Recent Progress in Enhancing Catalytic Performance for Methanol Synthesis via Carbon Dioxide Hydrogenation

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Abstract

Against the backdrop of escalating global Carbon Dioxide (CO_2) emissions and the urgent need for carbon neutrality, catalytic hydrogenation of CO_2 to methanol (CTM) has emerged as a promising strategy for carbon recycling and renewable fuel production. However, this process is constrained by inherent thermodynamic limitations, including low CO_2 conversion, moderate methanol selectivity, and catalyst deactivation at high temperature, which hinder its large-scale application. This review systematically examines strategies for enhancing catalytic activity in CO_2 hydrogenation to methanol from the perspectives of catalyst component regulation, reaction mechanisms, water effects, reaction conditions, and thermodynamic equilibrium. Results show moderate improvements via component regulation and mechanism studies (up to 10% CO_2 conversion, 90% methanol selectivity). Notably, zeolite membrane reactors—addressing thermodynamic limitations by timely water removal—dramatically boost activity (up to 49.1% CO_2 conversion, 90.2% methanol selectivity). Additionally, water sorbents (*e.g.*, 13X molecular sieves), dehydrants (*e.g.*, propylene oxide), and hydrophobic agents (*e.g.*, poly(divinylbenzene)) also achieve favorable outcomes. Future research on heat transfer intensification and thermodynamic limitations remains critically important, and this review is expected to provide practical insights for researchers to overcome challenges in the CTM reaction and accelerate near-term advances in the field.

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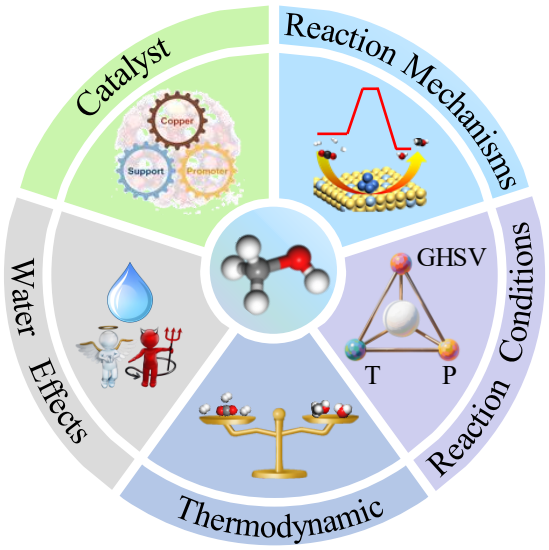

Innovative Description: It is reported that zeolite reactors, sorbents, dehydrants/hydrophobes overcome Carbon Dioxide to methanol thermodynamics via water removal.