Journal of Farayandno – Vol. 19 – No. 88 (2025): pp. 51-74

National Iranian Oil Refining and Distribution Company (NIORDC)

Journal of Farayandno

Review Paper

DOI: 10.22034/farayandno.2025.2046473.1979

Catalytic Applications of Zeolites for Carbon Dioxide Conversion: A Review

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Received: 23 Aug 2024 **Accepted:** 25 Dec 2024

1. ABSTRACT

Zeolites, as acidic catalysts, play a pivotal role in enhancing the selectivity, efficiency, and stability of carbon dioxide (CO_2) conversion reactions. This study evaluates the performance of various zeolites in transforming CO_2 into dimethyl ether (DME), light olefins, hydrocarbons, and aromatic compounds. Results demonstrate that ZSM-5 zeolites, with their medium pore structure and strong acidity, achieve over 80% selectivity for aromatic production. H-MOR zeolites exhibit high thermal stability and hybrid catalytic activity, enabling 74% selectivity for DME synthesis. Modification of zeolites with transition metals (e.g., Fe, Zn, Ga, and Cu) significantly improves CO_2 conversion to aromatics; Fe_2O_3/KO_2-modified ZSM-5 enhances aromatic selectivity to 74.3%. Additionally, SAPO-34 combined with palladium under high-pressure conditions (50 bar, 350°C) achieves 40% CO_2 conversion to propane. Key factors influencing catalytic performance include the Si/Al ratio, metal doping strategies, and synthesis methods. These findings underscore the potential of zeolites as tunable catalysts for reducing greenhouse gas emissions and producing value-added chemicals in energy and chemical industries.

Keywords: Zeolite, Catalyst, Conversion, Carbon Dioxide, Aromatics.

2. INTRODUCTION

Carbon dioxide, a major greenhouse gas, necessitates innovative strategies for its conversion into valuable products [1]. Zeolites, with their porous structures, adjustable acidity, and thermal stability, have emerged as promising catalysts for CO_2 valorization. Previous studies highlight their role in methanol synthesis, Fischer-Tropsch reactions, and hydrocarbon upgrading. This work distinguishes itself by systematically analyzing zeolite modifications (e.g., metal incorporation, hierarchical structuring) and their impact on CO_2 conversion pathways. Current literature lacks comprehensive comparisons of zeolite frameworks (ZSM-5, MOR, SAPO-34) for diverse products like DME and aromatics, which this study addresses.

3. MATERIALS AND METHODS

Zeolites (ZSM-5, MOR, SAPO-34) were synthesized via hydrothermal methods. Metal modification involved wet impregnation with Fe, Zn, or Pd precursors. Catalytic tests were conducted in fixed-bed reactors under varying temperatures (200–350°C) and pressures (1–50 bar). CO_2 conversion and product selectivity were analyzed using GC-MS and XRD. Acidic properties were characterized via NH_3-TPD, while porosity was assessed through BET analysis.

3.1 Catalytic Testing

Please Cite This Article Using:
Bahmanzadegan, F., Ghaemi, "Catalytic Applications of Zeolites for Carbon Dioxide Conversion: A Review", Journal of Farayandno – Vol. 19 – No. 88, pp. 51-74, In Persian, (2024).

Reactions included CO_2 hydrogenation ($H_2/CO_2 = 3:1$) and methanol dehydration. Bifunctional catalysts combined metal oxides (Cu-Zn-Al) with acidic zeolites for direct DME synthesis.

4. RESULTS AND DISCUSSION

4.1. Aromatic Production

ZSM-5 exhibited 80% aromatic selectivity due to its medium pores and strong Brønsted acidity. Fe-modified ZSM-5 further enhanced selectivity to 74.3% by promoting oligomerization [2].

4.2. DME Synthesis

H-MOR achieved 74% DME selectivity at 250°C, attributed to its thermal stability and hybrid metal-acid sites [3].

4.3. Propane Formation

Pd/SAPO-34 yielded 40% propane at 350°C and 50 bar, leveraging Pd's hydrogenation activity and SAPO-34's shape selectivity [4].

5. CONCLUSION

Zeolites, particularly ZSM-5 and MOR, demonstrate exceptional potential for CO_2 conversion into high-value chemicals. Tailoring Si/Al ratios, metal doping, and hierarchical structures optimizes catalytic performance. Future work should focus on scaling these systems and improving long-term stability under industrial conditions.

6. REFERENCES

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