Process intensified CO_2 conversion to sustainable aviation fuel (SAF) via a zeolite membrane reactor

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Highlights

- Zeolite structural integrity and crystal purity is maintained after ultrasonication.
- Micron sized zeolites were synthesized.
- Crystal growth is unordered under the synthesis conditions.

1. Introduction

The power-to-liquids (PTL) process converts captured carbon dioxide (CO_2) and green hydrogen (H_2) to sustainable aviation fuel (SAF). PtL process steps include Reverse Water Gas Shift (RWGS) converting CO_2 into syngas (or other CO_2 to syngas pathways), and Fischer Tropsch (FT) fuel synthesis from syngas. Aviation currently contributes 2% to global greenhouse gas (GHG) emissions and PTL is a critical pathway estimated to reach ~19% of 2030 aviation decarbonization measures. PTL SAF reduces aviation emissions by up to 80% and is a drop-in fuel, easy to integrate in existing airline fleets. However, CO_2 conversion reactions involved in the PTL process yield water (H_2O) by-product. Reaction thermodynamics and the H_2O by-product limit productivity, selectivity, and catalytic activity, which are essential contributors to optimum process efficiency, output, and techno-economics, especially as SAF costs are currently 2-5x higher than conventional aviation fuel. In-situ H_2O removal via a membrane reactor shifts the equilibrium to the product side, increases reaction rate by higher partial pressures, mitigates catalyst deactivation, and reduces energy, catalyst, and end-product separation requirements [1]. In this process intensification approach, reaction and separation are integrated, as the reactor walls are lined with hydrophilic, nanoporous zeolite membrane material prepared through secondary growth method and ultrasound (US) assisted deposition. The membrane selectively separates H_2O molecules (kinetic diameter=2.65 Å), preventing passage of larger gas molecules including H_2 (2.89 Å), CO_2 (3.30 Å), and CO (3.76 Å). Zeolitic membrane reactors have increased methanol conversion from 61% in a traditional reactor to 85% [2]. However, there are no commercial membranes which achieve appropriate hydrophilicity, employ fast and cheap synthesis, maintain high thermal stability at FT reaction conditions >200°C.

2. Methods

Hydroxy Sodalite (HSOD) and Linde Type A (LTA) zeolite membrane powders were prepared by direct *in situ* approach. For the HSOD membrane, aluminate solution was prepared using sodium aluminate, sodium hydroxide and deionized water. The aluminate solution was then poured slowly into a silicate solution containing sodium metasilicate, sodium hydroxide and deionized water. The resultant solution was aged at room temperature for 30 minutes and repeated with an aging time of 6 hours. The solution was transferred to an autoclave at 140 °C for 3.5 hours of

hydrothermal synthesis. After hydrothermal synthesis, the zeolite membrane was washed with deionized water until neutral, and then dried at 100 °C overnight. For the LTA membrane, sodium aluminate, sodium hydroxide and deionized water was mixed, stirred vigorously, aged at room temperature for 30 minutes and repeated with a different aging time of 6 hour. Ludox colloidal silica was added into the solution dropwise. The solution was transferred into an autoclave for hydrothermal synthesis at 80 °C for 5 hours. After crystallization, the membrane was rinsed with deionized water until neutral, and then dried at 100 °C overnight.

3. Results and discussion

The formation of HSOD and LTA zeolites was confirmed by XRD measurements. SEM observation revealed ball like HSOD particles with particle size of 1.62 -14.88 μm and cubic LTA particles with particle size of 2.62 – 4.6 μm.

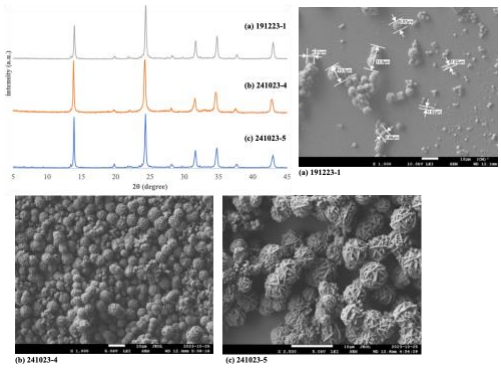

Figure 1. XRD and SEM images of HSOD membrane powders **(a)** aged for 30 minutes (**b)** aged for 6 hours **(c)** aged for 30 minutes

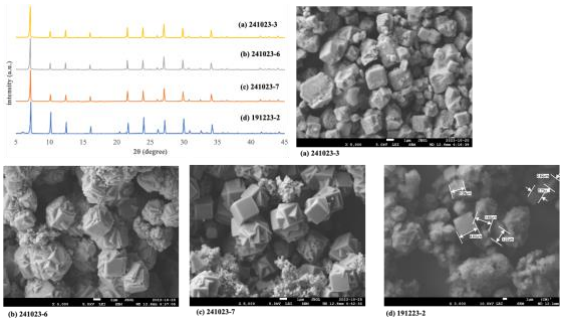

Figure 2. XRD and SEM images of LTA membrane powders. **(a)** Standard LTA after ultrasound treatment **(b)** aged 6 hours **(c)** aged 30 minutes **(d)** aged 30 minutes

4. Conclusions

HSOD and LTA zeolites were successfully synthesized. Further research is ongoing to apply ultrasound and secondary growth in the membrane synthesis to deposit nano thick membrane layer on a substrate; and to test its performance in a membrane reactor. Ultrasound anchors nanoparticles to the surface of the substrate by forming chemical bonds/interactions and minimizes effects of process conditions such as temperature and synthesis solution concentration in the final membrane formation, resulting in detect free and high-quality membranes [3]. The membrane will be paired with the FT catalyst developed in our lab composed of non-noble metals to convert syngas into C_{5+} paraffins and SAF.

References

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Keywords

CO_2 conversion: Process intensification: Zeolite membrane: Sustainable Aviation Fuel