Catalytic Microchannel Reactors for Martian In-Situ Propellant Production

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Introduction

The ability to use local resources to "live off the land", commonly referred to as In-Situ Resource Utilization (ISRU), is essential in expanding robotic and human extraterrestrial exploration, establishing a long-term human presence beyond low earth orbit, and enabling the commercial development of space. To reduce cost and risk and support human presence on Mars, the Martian atmospheric CO_2 can be converted to useful materials.

Catalytic microchannel reactors were designed for in-situ propellant production for Mars exploration. In the reactor system, Sabatier and reverse water-gas-shift reactions were carried out for methane and oxygen production using carbon dioxide and hydrogen as feed stock. The focus of the present study was on integrating structured catalysts into the design of multichannel reactor system, aiming at intensifying reactor operation. Demonstrated in this study were the catalyst development pathways and integration methodologies for microchannel reactor system. A chemically reacting flow model was used to assist experimental interpretation and to suggest microchannel reactor design approaches.

Materials and Methods

Structured catalysts were prepared using FeCrAlY intermetallic alloy obtained from Porvair. To achieve low pressure drop and improve heat transfer, porous FeCrAlY felt was used as substrate for Sabatier catalyst. Reaction was carried out in the flow-by mode. While for the RWGS reaction, FeCrAlY foam was selected as substrate. Therefore, reaction was carried at in the flow-through mode. The active components on RWGS catalyst consisted of Ru/ZrO_2-CeO whereas active components on Sabatier catalyst was made of Ru/TiO_2[1]. The configuration of the multichannle Sabatier reactor was described in reference [1].

Results and Discussion

When design structured Sabatier catalyst for multichannel reactor, the challenge remains in obtaining not only the physical property consistency but also identical catalytic activity. Essentially, it is desirable that each structured catalyst manufactured for multichannels should exhibit performance comparable with those prepared for a single channel.

After completion of preparing 140 strips of Sabatier catalyst, two strips were randomly picked and tested. The performance results are shown in Figure 1. About 81.3% CO_2 conversion at GHSV=36,000 h^{-1} was obtained, which was identical to those prepared for the single channel reactor. This means that the fabrication of structured catalyst can be scaled up from a single strip to large quantity of 140 strips without any activity deviations.

As shown in Figure 2, under the conditions tested, varying space velocity does not seem to have any effect on CO_2 conversion. This was probably because RWGS reaction was diffusion controlled at high temperature. Internal diffusion plays role in the RWGS reaction.

Significance

This work illustrates that it is possible to transfer the intrinsic kinetic performance obtained at powder catalyst level to structured catalyst system. With a proper design, the same kinetic performance can be transferred to multil-channel reactors. This study also presents a unique catalyst development methodology for microchannel reactors, which is different from those practiced in conventional reactors.
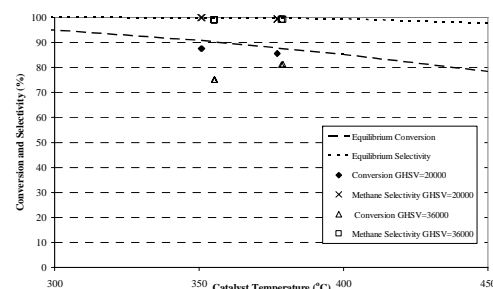

Figure 1. Performance of structured Sabatier catalyst prepared for multichannel reactor (Catalyst= 3% Ru/TiO_2 washcoated on FeCrAlY felt, CO_2/H_2=4:1, P= 0.1 MPa)
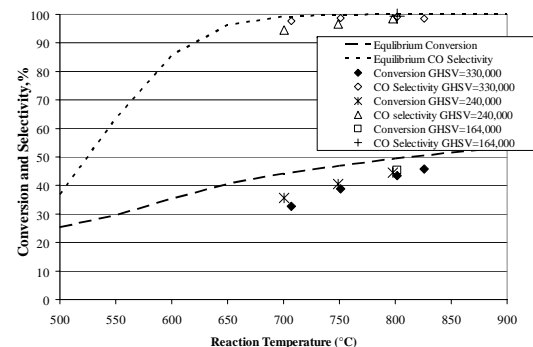

Figure 2. Performance of structured RWGS catalyst in a single channel reactor (6% Ru/ZrO_2-CeO washcoated on FeCrAlY foam, H_2/CO_2=1:1, P=0.1 MPa)

References
1.   Brooks, K.P., Hu, J., Zhu, H., Kee, R., Chemical Engineering Science, in press