Microchannel CO Methanation Reactors for NASA In-situ Resource Utilization

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Introduction

Microchannel process technology offer significant advantages as a highly effective route to process intensification. NASA applications where size, weight, and process efficiency are key performance metrics, are very suitable applications. In situ resource utilization (ISRU) technologies are one such example [1-3]. For use in a lunar carbothermal reduction process system a catalytic microchannel CO methanation reactor was developed.

For the lunar ISRU process maximum CH_4 effluent concentration is desired. From a thermodynamic perspective, lower operating temperature is desired. The performance benefits – enhanced methane output at lower temperatures - as dictated by thermodynamics are clear. However, the key to processing efficiency lies within in the kinetics and reactor design. A catalyst with the fastest possible kinetics is desired. The faster the rate of reaction the smaller the reactor needs to be. Furthermore, exploitation of these thermodynamic considerations in the design of the methanation reactor can offer considerable size and weight benefits [4].

Catalyst considerations for this methanation process were evaluated. Reactor design characteristics and operating performance for a multichannel reactor was investigated. Temperature, throughput, and modes of operation, including the use of counter-flow air-cooling, were variables explored.

Materials and Methods

A Ru/Al_2O_3 powder catalyst prepared by incipient wetness impregnation was chosen as the catalytic active component after an initial screening evaluation [5]. To achieve low pressure drop and improve heat transfer, structured catalysts were prepared using FeCrAlY intermetallic alloy. The felt substrates were wash-coated with catalyst slurry prepared from ball-milled powder catalyst. Reaction was carried out in the flow-by mode. An electrically heated multi-channel reactor was fabricated utilizing these structured catalysts. Interleaved channels allow for air cooling offering controllable process conditions. Catalytic activity was studied for the methanation reaction using conditions required for the ISRU program. A model feed mixture composition of H_2=54.1%, CH_4=25.2%, and CO=20.3%, and CO_2=0.4% was used.

Results and Discussion

Design characteristics and operating performance evaluation for a multichannel reactor, approximately 4.5 in. X 0.5 in. X 1.0 in. in size (Figure 1), was investigated. Reactant throughputs were varied ranging from GHSV=36,000 hr^{-1} to GHSV=3,600 hr^{-1}. Temperatures were varied from 300°C to 500°C. Two modes of operation were investigated: 1) under adiabatic conditions and 2) utilizing counter-current air cooling.

Benefits of counter-flow air cooling are described in Figure 2. Operating at a GHSV=3600 hr^{1}, the inlet and exit reactor temperature were approximately 430°C and 410°C, respectively, prior to adding air cooling. The data on the right-hand side of Figure 2 depicts this initial condition. At these temperatures and throughput the reactor was operated under an equilibrium-controlled regime. CO conversion was 97.4% and the CH_4 and CO dry effluent compositions were 66.2% and 0.9%, respectively. Counter-current air cooling was gradually introduced, offering a differential temperature operating profile. Maintaining the inlet reactor temperature at 430°C, the methane effluent composition output increased from 66.2% to 79.9% by introducing counter-flow cooling. This allowed the *exiting* reactor temperature to decrease by ~100°C (from 410°C to 310°C). Equilibrium-control of the reaction was maintained throughout. By comparison, when the reactor was operated isothermally at 310°C, without differential temperature operation, only 25.7% CO conversion was achieved, even at a throughput 3 X slower (GHSV=1,200 hr^{1}). Operating under such temperature differential conditions offer exploitation of high kinetics at the hot front-end of the reactor while utilizing favorable thermodynamics at the cooler back-end.

Figure 1: Multi-channel catalytic CO methanation reactor.

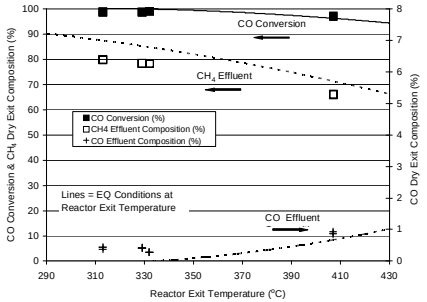

Figure 2: Catalytic reactor activity results utilizing counter-flow air cooling, maintaining the reactor inlet temperature at 430°C (GHSV=3600 hr^{-1}, feed composition: H_2=54.0%, CH_4=25.4%, CO=20.2%, CO_2=0.4%).

Significance

Highly process intensive microchannel technology can offer significant size and weight as well as energy efficiency advantages. Such highly efficient and compact reactors are uniquely suitable for NASA ISRU missions.

References

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