

Study of Sabatier Catalyst Performance for a Mars ISRU Propellant Production Plant

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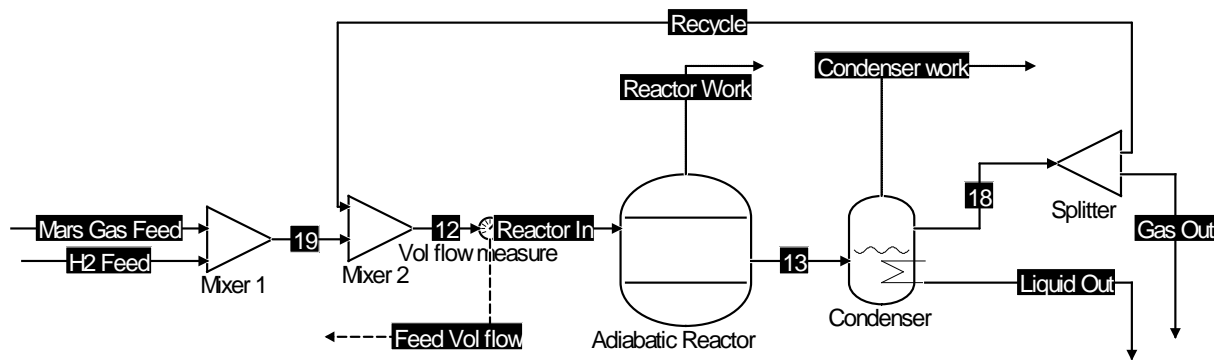
Background

- CO₂ gas from Mars atmospheric simulant gas was taken and condensed in a cryocooler (Muscatello et al.)
 - Condensed CO₂ was allowed to sublime and used as feed gas for the reaction
 - 7 hour runs for 4 days
 - Obtained reaction efficiency with nickel-based catalyst
- New Ru/Al₂O₃ catalyst was used (Meier et al.)
 - Reactant rates and temperature were increased to characterize reactor design and to determine catalyst performance limits and durability
 - Unable to run at off-nominal conditions – catalyst damaged



Background

- Different Sabatier designs and configuration to maximize CH₄ while meeting purity requirements for a Mars ISRU Propellant Production Plant (Hintze et al.)
 - None met purity requirements
 - Advantages of adiabatic vs. isothermal systems
 - Optimization of reactors and condensers

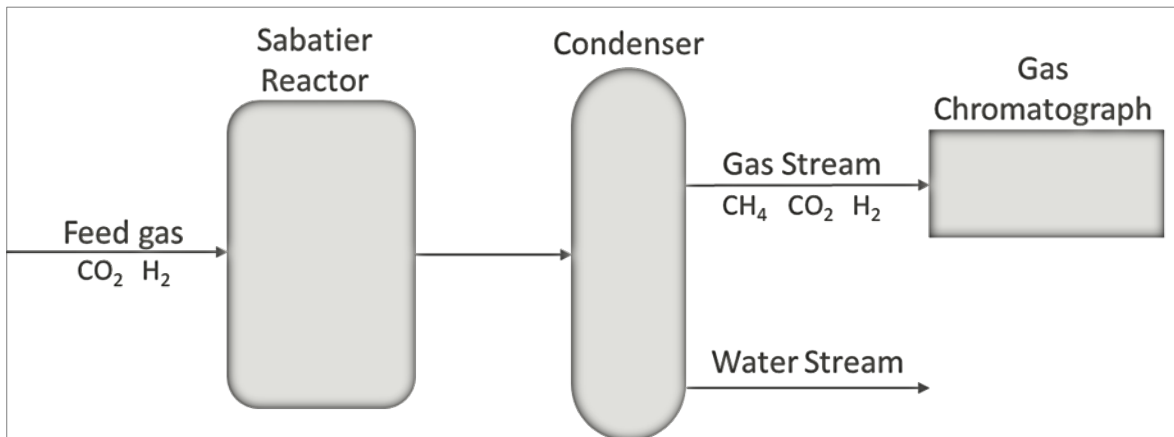


Overview

- Catalyst Screening: Catalysts tested in their capacity for continuous production of CH₄ gas via the Sabatier reaction and possible effects of:
 - Launch vibration loads
 - Liquid water
 - Particulate contamination
 - Chemical contamination



Testing Method



Testing Method

- Catalysts used
 - Clariant® (Nickel monoxide, impregnated through Al₂O₃ base)
 - 0.5% Ru coating on Al₂O₃ base
 - 2% Ru coating on Al₂O₃ base

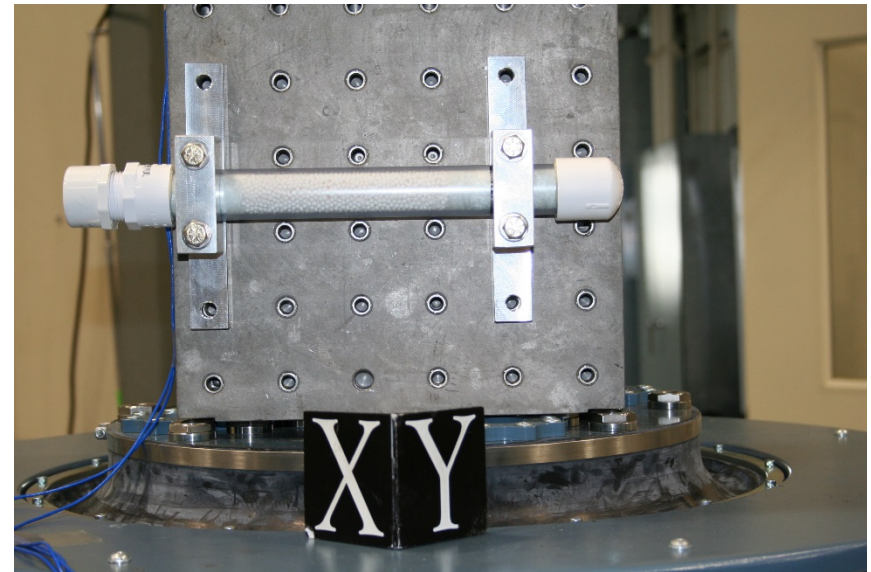
	Clariant® (g)	0.5% Ru (g)	2.0% Ru (g)
Mass (g)	27.9 ± 0.5	20.0 ± 0.6	14.3 ± 0.3

- Clamshell heater, with CO₂ and H₂ gas feeds supplied through flow controllers connected on top of reactor
- Condenser cooled to 3°C
- Water collected at exit of reactor as byproduct



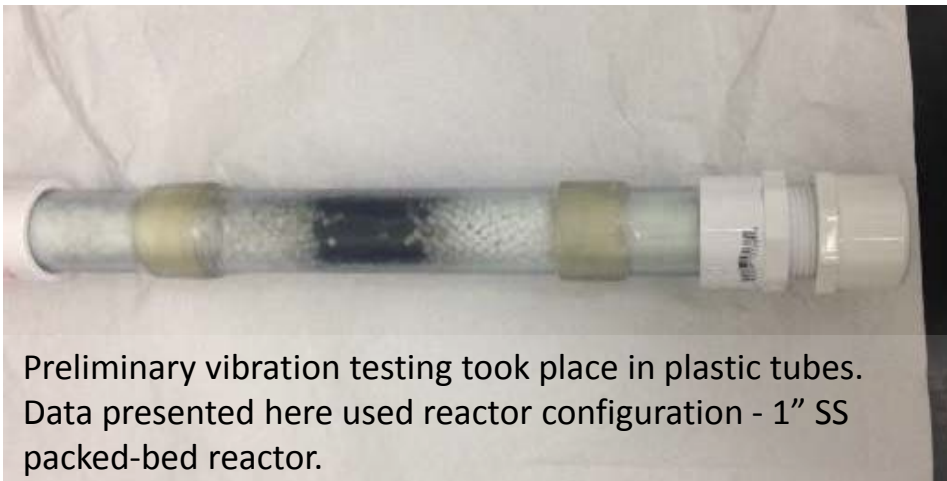
Vibration Test

- Background run for each reactor to determine baseline performance
- Reactors were affixed to shaker table and exposed to vibration profile – simulated launch environment (20 Hz – 2000 Hz, overall vibration force of 14.1 g_{rms})
- Vibration tests using clear plastic tubes were carried out to evaluate packing methods



Vibration Test

- Performance of reactors measured after exposure to vibrational forces
- Test data compared before and after exposure to launch vibration to determine impact of vibration on each catalysts used



Vibration Test

Catalyst pellets before (left) and after (right) vibration tests



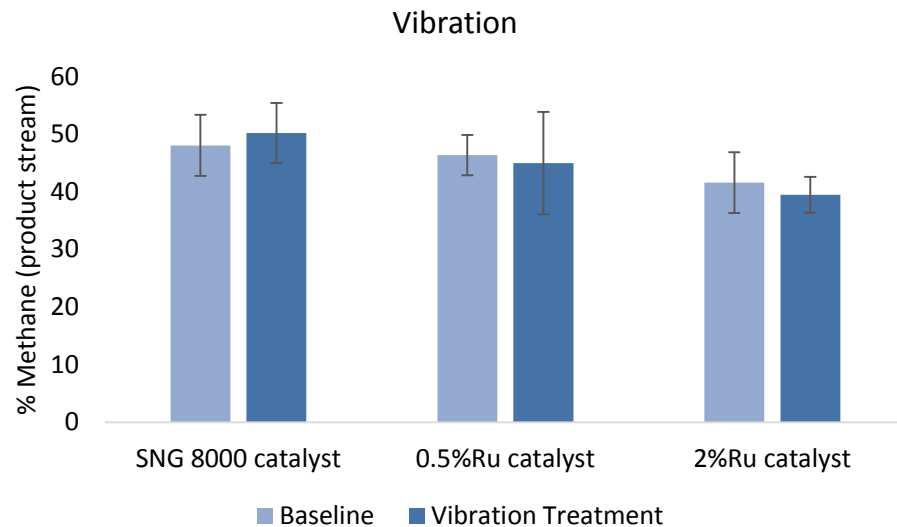
Clariant®



0.5% Ru



2.0% Ru



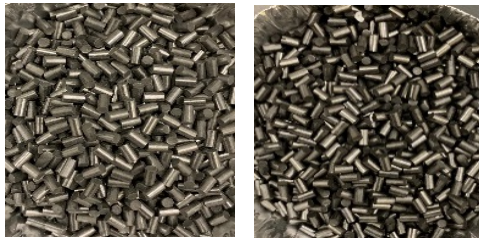
Liquid Water Test

- Background run for each reactor to determine material's baseline performance
- Reactors were filled with water to maximum capacity through the top to ensure catalyst was completely submerged
- Water was left inside of reactors for a approximately 18 hours, emptied, and placed in a vacuum oven over night to ensure catalyst dried prior testing
- Measured production of CH₄ gas after catalyst was subjected to liquid water exposure
- Test data processed and compared before and after to determine impact of water exposure on each of the catalysts used

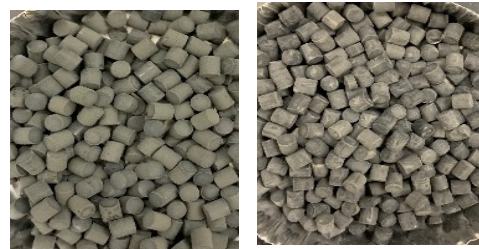


Liquid Water Test

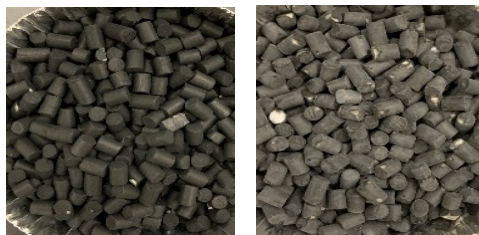
Catalyst pellets before (left) and after (right) liquid water tests



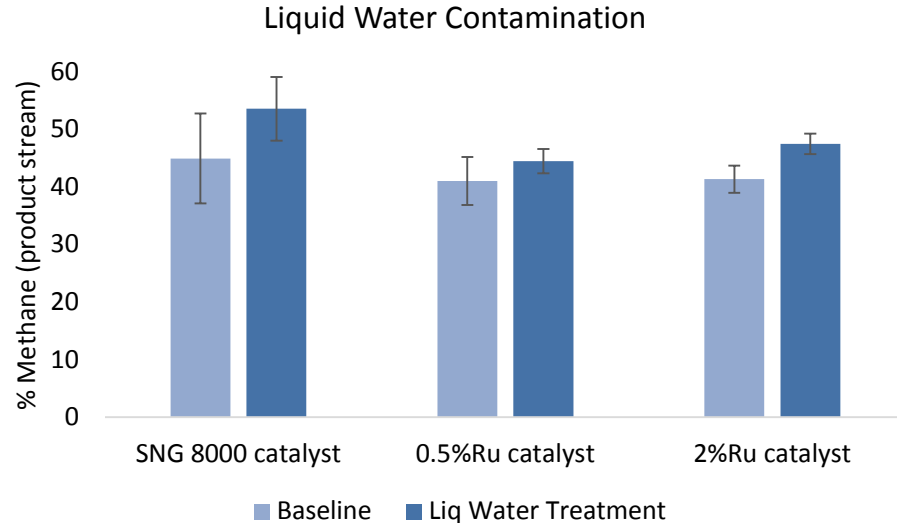
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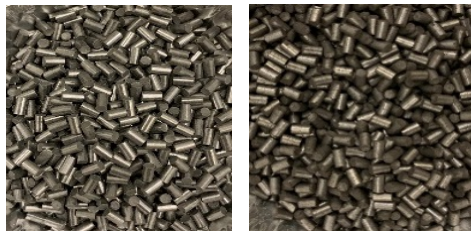
Particle Contamination Test

- No backgrounds performed
- Performance of reactors compared to average of previous background runs
- Mars JSC-1 simulant sieved to 5 μm used for particle contamination of catalysts
- Amount of particulate to be added determined, taking into consideration total flow and filtration efficiency
- Test data compared to determine impact of dust particles on each catalyst used

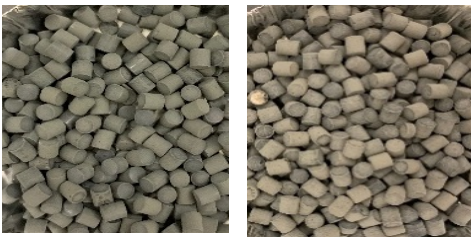


Particle Contamination Test

Catalyst pellets before (left) and after (right) particle contamination tests



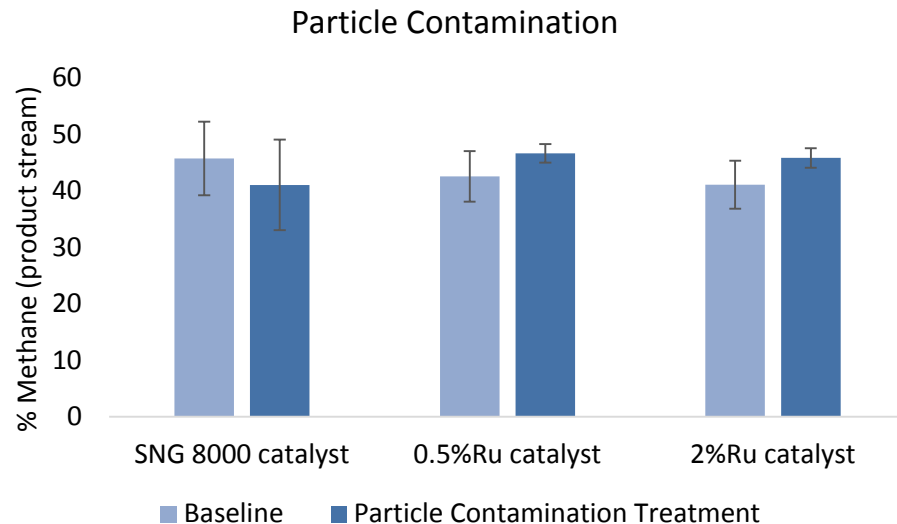
Clariant®



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2.0% Ru



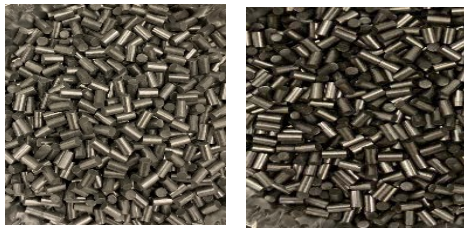
Chemical Contamination Test

- No backgrounds performed
- Performance of reactors compared to average of previous background runs
- HCl and FeSO_4 used as surrogates; added to reactor upstream to allow contaminants to flow over reactor bed during reaction
- Calculations performed to determine amount of chemicals to be added
 - ferrous sulfate heptahydrate ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$), 4.2wt%
 - hydrochloric acid (0.1M HCl), 0.6wt%
- Test data compared to determine impact of chemicals on each catalysts used



Chemical Contamination Test

Catalyst pellets before (left) and after (right) chemical contamination tests



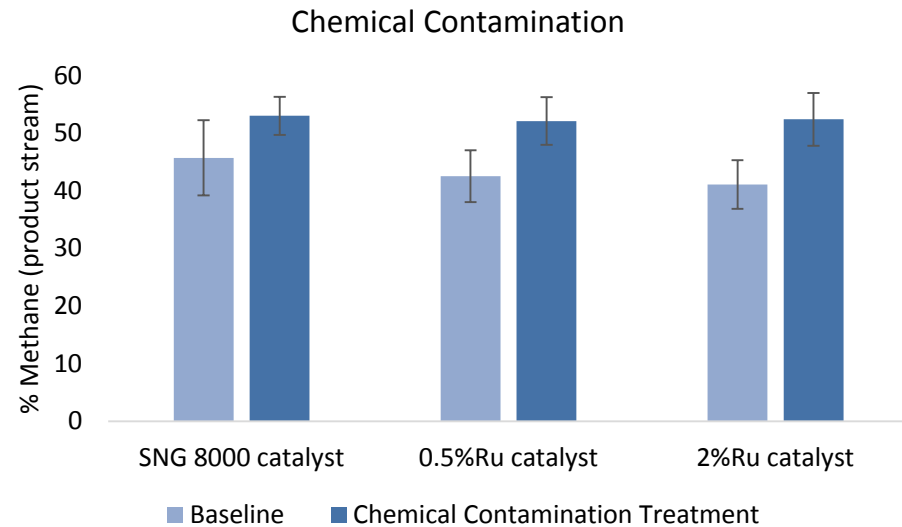
Clariant®



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Conclusion

- Clariant[®], 0.5% Ru/Al₂O₃, and 2.0% Ru/Al₂O₃ catalysts tested to evaluate capacity for production of CH₄ gas via Sabatier reaction and possible effects of harsh conditions encountered on a Mars mission
 - Vibrational forces did not have a significant effect on the catalyst performance
 - Liquid water exposure appears to have slightly increased CH₄ formation for the 2% catalyst but otherwise did not show significant effects
 - Particulate and Chemical contamination exposure did not have a significant effect on the catalyst performance.
(Vibration and Liquid water baselines were used)



Conclusion

- All catalysts continued to perform, with minimal change, regardless of circumstances; none were largely affected either physically or chemically
- Disparities in testing results likely stem from variation in thermocouple placement from one test to the next – causing inconsistencies in reactor operating temperature
- Any of these catalysts will be an adequate choice for the overall design study of the Mars IRSU Propellant Production Plant



Future Work

- Effective size and mass scaling for the reactor and product separation required for a successful system
- Determine how the water condenser will perform in a reduced gravity environment
- Sabatier reaction is also being targeted for lunar oxygen liberation via the carbothermal route
 - Volatile separation to avoid poisoning Sabatier catalyst
 - Operating conditions to meet reactant and product requirements
 - Carbon monoxide as key reactant
 - Minimize CH_4 loss and carbon deposition in reactor system



Acknowledgements

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**THANK
YOU!**



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