INTEGRATED MARS IN-SITU PROPELLANT PRODUCTION SYSTEM. Anthony Muscatello, Robert Zubrin, Claire Ohman, and Sam Booth, Pioneer Astronautics, 11111 W. 8th Ave., Unit A, Lakewood, CO 80215, tony.muscatello@pioneerastro.com.

Introduction: Although it has a high leverage in the production of rocket propellant for the exploration of Mars, the Sabatier-Electrolysis Process (S/E) suffers from the disadvantage of producing only half of the oxygen needed to fully burn all the methane fuel produced. This situation leads to the need to either discard half the methane or, more realistically, add a second process to make more oxygen, such as carbon dioxide electrolysis or the Reverse Water Gas Shift process (RWGS). Integrating the S/E and RWGS processes into a single unit would greatly reduce equipment mass and complexity.

Accomplisments: The goal of the six-month NASA SBIR 2005 Phase I Integrated Mars In-Situ Propellant Production System (IMISPPS) project was to establish the feasibility of converting carbon dioxide and hydrogen to methane/carbon monoxide fuel according to the reaction:

$$3CO_2 + 6H_2 \rightarrow CH_4 + 2CO + 4H_2O.$$

The enthalpy of the combined reaction is exothermic at -22 kcal/mol.

As desired, the process produces oxygen in the proper ratio for use in Mars Sample Return missions or human Mars missions. A Phase II project would build a prototype flight unit. The purpose of the Phase I research was to design and build a machine for converting carbon dioxide to methane and carbon monoxide fuel using a combined Sabatier/Reverse Water Gas Shift (S/RWGS) reactor, and enough oxygen to oxidize the fuel as rocket propellant. The IMISPPS process allows the production in a single unit of all the rocket propellant needed for a Mars sample return mission or human missions using *in-situ* resource utilization to make bipropellant for Earth return. The amount of CO can be tuned to improve the specific impulse of the methane fuel. An additional goal was to investigate the feasibility of converting the CH_4/CO product to higher hydrocarbons with lower hydrogen content to reduce the amount of hydrogen imported from the Earth. Although some small conversions were found with various catalysts, none were deemed practical for Phase II investigations.

The research completed in this project included:

- Literature reviews to determine the current status of RWGS and methane/carbon monoxide conversion technology; preparation of catalysts based on the literature review results;
- Testing of the catalysts on a small scale to determine their activity;
- Scale-up of successful catalysts and previously known Sabatier and RWGS catalysts in a full scale brassboard reactor to make CH_4/CO fuel with a total propellant production rate of ~1kg/day;
- Recycling of the unreacted CO_2 and hydrogen to effect near complete conversion;
- Demonstration of electrolysis to recycle hydrogen and produce oxygen oxidizer;
- Investigation of methods such as temperature variation to modify the CH_4/CO ratio; and
- Scouting experiments into cryogenic distillation to remove CO from CH_4/CO product.

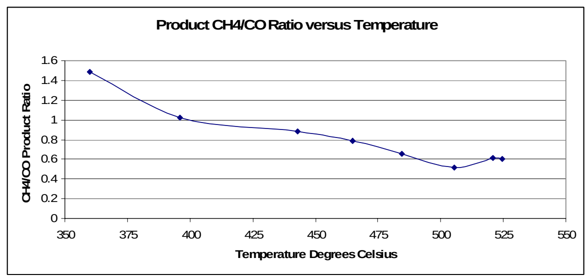

Figure 1. CH_4/CO Product Ratio versus Temperature

We prepared active RWGS catalysts, but chose to combine previously established Sabatier and RWGS catalysts that were adequate to make the CH_4/CO fuel. We scaled up the system and produced CH_4/CO/O_2 at rates approaching the goal of 1 kg of bipropellant per day with a leverage up to 20. We determined that reaction temperature can be used to vary the CH_4/CO ratio (Figure 1), thus allowing optimization of how much oxygen is produced. The recycling system allows near complete conversion of CO_2 and H_2 feed to fuel and oxygen. Cryogenic distillation of the CH_4/CO product is effective in removing excess CO from the CH_4, resulting in a fuel with an improved Isp.

This project has successfully demonstrated the feasibility of the S/RWGS process, showing that an integrated system could be used for a Mars Sample Return mission or human missions to Mars.

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