Demonstration of a Piloted Mars Mission Scale RWGS System.

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Abstract: In the summer and fall of 2017 a team consisting of Pioneer Astronautics and the R&D group at Pioneer Energy, a spinoff company of Pioneer Astronautics, built and demonstrated a combined Reverse Water Gas Shift-Methanol system scaled to meet the requirements of a piloted Mars mission. The program, which was done for a private customer seeking to demonstrate commercial applications of its CO_2 capture technology and to win the Carbon Capture X-Prize, culminated on November 14-15 a conducted a 24 hour non-stop demonstration of an integrated RWGS-Methanol system in the presence of the X-Prize judges. In addition, the team performed a 5 hour demonstration of an additional module transforming the methanol into dimethyl ether.

The Reverse Water Gas Shift (RWGS)[1] was run at an average rate of 70 liters per minute CO_2 and hydrogen feed. It averaged about 99% efficiency in reducing CO_2 to CO, producing an exhaust that was roughly 99% CO and 1% CO_2. Conversions as high as 99.8% were achieved, but system parameters were adjusted to decrease efficiency to 99% because 1% CO_2 is desired in the methanol synthesis feed to improve system kinetics. Approximately 81 kg of water was produced by the RWGS in the course of the 24 hour run.

The CO from the RWGS was then fed into the methanol synthesis unit, where it was reacted with hydrogen to produce approximately 105 kg of methanol in the course of the 24 hour run. Some of the methanol product was then taken to the dimethyl ether synthesis unit, where it produced and captured in liquid form 11.8 kg of DME over a 5 hour period, for a daily production rate of 57 kg per day. Approximately 17.7 kg net of methanol was consumed to make the 11.8 kg of DME, for a combined conversion and capture efficiency of about 93%. (A 100% efficiency would have resulted in 12.72 kg DME, because two methanols react to produce one DME and one H_2O.)

It may be noted that if the water produced by the system were electrolyzed, it would produce 72 kg of oxygen per day, or 36 metric tons over a 500 period. The methanol system would produce 52.5 metric tons of methanol. The DME system would produce 28.5 tons of DME.

Oxygen burns with DME at a stoichiometric ratio of 2.087. So if the 28.5 tons of DME produced were combined with 59.5 tons of oxygen, a total of 88 tons of useful bipropellant would be available. Alternatively, if oxygen is viewed as the limiting propellant, by combining the 36 tons of oxygen with 20 tons of DME (to run slightly fuel rich) 56 tons of useful bipropellant would be available. If the oxygen product were used in a LOX/RP engine burning at 2.8:1, at total of 49 tons of useful bipropellant would be available.

In any case, more propellant would be produced by such a system than that required for the ascent vehicle in the NASA design reference mission. Finally, it may be noted that if the RWGS system were run in parallel in a Sabatier Electrolysis (S/E)[1] system sized to produce 48 kg of CH_4 and 96 kg of O_2 per day, a total of 24 tons of methane and 84 tons of oxygen would be produced, which is sufficient to fly the Mars Direct mission.[1]

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Fig. 1 Piloted Mars mission scale RWGS unit.

Fig. 2 Program team together with RWGS/Methanol system.

References

[1] R.Zubrin with R. Wagner, "The Case for Mars: The Plan to Settle the Red Planet and Why We Must," Simon and Schuster, NY, 1996, 2011.