NASA now looks to Mars as the next step in human space exploration. A couple of challenges of such a destination include affordability and weight/volume limitations. As a way to solve these issues NASA is looking into the practice of In-Situ Resource Utilization (ISRU). Instead of manufacturing and bringing all the supplies necessary for a Mars mission and return trip, the goal is to send a preliminary mission to produce reserves of propellant, water, and oxygen on site. Part of this effort includes the Atmospheric Processing Module (APM). The APM is part of a lander that is composed of multiple compartments, each having a unique function; regolith collection/processing, water processing, atmospheric processing, and product storage. The overall goal is to develop the capability to produce methane (CH₄) and oxygen as a fuel/oxidizer combo via a Sabatier reaction using resources from the Martian environment. The APM still must undergo modifications in design, and perhaps method, to become flight-ready to produce methane at the level of purity and quantity needed for a vehicle.

**BACKGROUND**

Martian atmosphere is composed of 95.32% carbon dioxide (CO₂), which is what the APM is designed to process in order to produce CH₄ and water.

CO₂(g) + 4 H₂(g) → CH₄(g) + 2 H₂O(l) (ΔH= -165.4 kJ/mol)

Water produced from the reaction will later be electrolyzed and the oxygen (O₂) will be stored and used as oxidizer, and the H₂ is recycled back to the Sabatier reactor.

4 H₂O(l) → 4 H₂(g) + 2 O₂(g)

**MARCO POLO**

MARCO POLO is a joint effort between NASA centers, with the APM based at the Kennedy Space Center (KSC). The APM is one compartment of a multi-function lander. There are also regolith and water processing units. Regolith processing includes excavating and transporting it back to the lander for water extraction via a "baking" process. The water modules are responsible for cleaning up and processing the water produced by both the APM and regolith units. Currently, the configured APM is 1/20 the size of an actual mission scale.

**METHODS:**

**CO₂ FROZEN SUBSYSTEM**

This subsystem consists of 2 Sunpower Cryotol cryocoolers (see Figure 2) that alternate freezing cycles. The process begins with bringing the cryocooler to a pressure of <1 torr, using a vacuum pump. The temperature is then set to 150 K. When the chamber reaches required conditions, gas is sent in (using a mass flow controller) at 1.2 SPM from either a k-bottle of pure CO₂ or Martian simulant gas (3% nitrogen, 1.6% argon and 95.4% CO₂). The cryocooler vessel is kept at Mars pressures. The CO₂ freezes to a specially designed chilling head made of copper. A "Ferris wheel" configuration (see Figure 3) was selected due to its low thermal mass and large surface area. This chilling head has the capability of collecting 88 g CO₂/hr. After one freezing cycle, which lasts 1.4 hrs., the gas is shut off and gaseous impurities are evacuated from the chamber and vents to the atmosphere. The CO₂ sublimes at ~193 K with the aid of a heater and since the chambers of the cryocoolers weren’t designed to handle the pressurization of the CO₂ sublimation process, a KNF pump is used to compress the CO₂ into 2 10-l storage tanks to a pressure up to 100 psi. The pressure in these tanks always needs to be 60-100 psi for the Sabatier subsystem to function properly. A pressure differential of ~20 psi is required for uni-direction flow from the tanks to the reactor.

**Sabatier Reactor Subsystem**

The Sabatier reactor (see Figure 5) was based on a design by Pioneer Astronautics. It is a 30 cm long stainless steel tube, with an outer diameter of 2.54 cm, and wall thickness of 0.21 cm. The reactor is filled with a catalyst of ruthenium on alumina with 0.635 cm (0.25 in) pipe running through the center. Before the gases (CO₂ and H₂) enter the catalyst bed they’re run through this pipe to preheat. During nominal operation, the gases flow through the preheat loop and enter the reactor at Gas Re-entry #1. The reactor is primed with H₂ while preheating and when it’s at temperature (210°C) CO₂ from the tanks flows to the reactor at a ratio of 4.5 H₂:CO₂. The reaction elevates the temperature in the reactor to ~450°C where after a few minutes, the reaction is producing enough heat to sustain itself and the heater can be turned off.

**RESULTS**

Currently, one of the biggest goals is to obtain more data on the Mars gas operations. While the APM was going through a troubleshooting period, most of the runs were performed with pure CO₂. Many components of the APM have yet to be upgraded to flight hardware. The cryocoolers must be altered and a more efficient way to cool the subsystems is being worked. The chillers are too heavy and power consuming to be part of the final configuration. On the software side, the LabVIEW code is in the process of being modified. Procedures, such as the freezing cycles, are being updated to function autonomously. This is essential to operations once it’s in the Martian environment. The centers are also starting to look at virtual integration. While one module at a center is operating, teams at the other centers will be able to view the data in real time. A related action item is the integration of the APM with the other modules on the lander. Johnson Space Center recently sent KSC the water cleanup module. It’s capability to interface with the Sabatier subsystem and process the water produced from the reaction will be evaluated.

**REFERENCES**