Mars Atmospheric Sample Return Instrument Development

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Introduction: The isotopic and chemical composition of the Mars atmosphere holds important clues to that planet's evolution and climate history. Our current knowledge of the Mars atmospheric composition comes from several sources. The Viking landers [e.g., 1] measured the overall composition, but isotopic compositions are known to greater precision from measurements of gas trapped in the SNC meteorites [e.g., 2]. Better measurements are planned to be made on the Mars Science Laboratory, but it is very likely that some measurements will not be made to the precision necessary for scientific interpretation. Clear examples of this are $^{18}O/^{16}O$ and $^{17}O/^{16}O$ (needed to better than ±1‰) and $^{14}C/^{12}C$. The latter would be used to constrain recent exchange of atmospheric CO_2 with buried CO_2 [3]. Accurate measurement of isotopologues [e.g., 4] represents another class of measurements not likely to be attained in-situ on Mars.

Atmospheric sample return instrumentation was an integral part of the SCIM mission, a Mars Scout mission which was proposed for the collection and return of atmospheric dust samples. The Atmospheric Collection Experiment (ACE) was a dual-component apparatus consisting of a passive and a cryogenic sorption gas collection system. Each of the two systems possessed a collection vessel that was initially under high vacuum. At the time of entry into the martian atmosphere, valves on SCIM were to open to allow gas to flow into the parallel-plumbed passive and cryogenic sorption gas collection systems. The passive system simply allowed the incoming gas to fill an initially evacuated 1 Liter vessel. The cryogenic sorption system employed a Joule-Thompson cryocooler and sorption medium that would have initially condensed and captured a much larger amount of the incoming gas. As the SCIM spacecraft began to exit the atmosphere isolation valves would have closed and trapped the gas samples in their collection systems for the return journey back to earth. The minimum SCIM mission goal was to collect 100 cm^3 @STP(≈ 0.2 g) of martian atmospheric gas and the ACE was being designed to gather 1000 cm^3 @STP (≈ 2.0 g) using both the passive and cryogenic systems. The volumes referred to above correspond to standard temperature and pressure on Earth (i.e., STP).

During the SCIM feasibility study a benchtop prototype system was built and tested to determine the suitability of the design to collect gas samples under the atmospheric pressure conditions to be encountered by the SCIM aeroshell [5]. The results of these tests are given in this abstract. The benchtop prototype has recently been refurbished to do some additional preliminary tests for gas collection as part of the proposed Mars Sample Return (MSR) mission. These preliminary test results will be presented at the meeting.

Experimental Analyses: Figure 1 displays a schematic diagram of a prototype ACE system built to assess the design concept and test the performance characteristics of the passive and cryogenic gas collection systems. The basic mechanical design, including gas collection vessel sizes, gas line diameters and lengths, and instrumentation locations, were obtained from preliminary analytical calculations. The prototype ACE system possessed a different layout than the spacecraft version as additional hardware was required on the prototype to effectively simulate the atmospheric conditions that the spacecraft system would be exposed to.

To simulate the pressure conditions during the SCIM passage through the atmosphere of Mars (~200 seconds duration), the benchtop prototype ACE employed a 1 liter stagnation pressure simulation vessel (SPSV) connected to a gas flow meter and gas throttling valve. The SPSV inlet port valve was connected to either an N_2 or CO_2 gas bottle. The SPSV outlet port was connected to the gas collection system by a tube with an inner diameter of 9.5 mm (0.375 in.) and a length of 1.83 m (72 in.), based on flight design for the ACE.

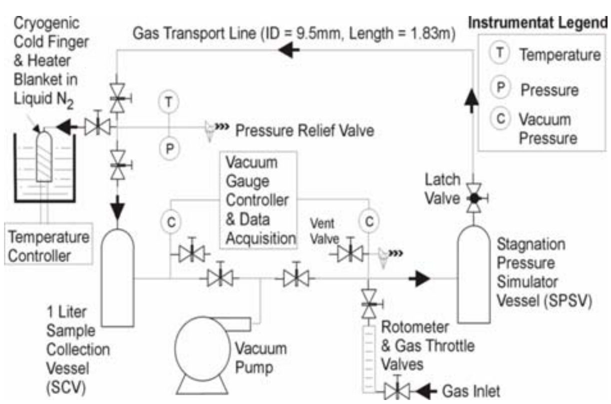

Figure 1: Schematic of the ACE prototype experiment.

To simulate the proposed Joule-Thompson cryocooler and cryogenic sorption system, a cylindrical copper cold finger (inner diameter = 14.3 mm, length = 152.4 mm), equipped with 15 grams of the Linde 13X zeolite, was immersed in a liquid nitrogen bath and isolated from the gas collection line via a ball valve. A heater, temperature sensor, and temperature controller were connected to the cold finger for regeneration of the zeolite material. The zeolite was used because it adsorbs gases at well above their condensation temperature, so that e.g., nitrogen, which is a major component of the Mars atmosphere, could be adsorbed using an apparatus that only cooled to 90ºK. Testing of the zeolite properties for, e.g., Ne and N_2 is a major goal of future work, as well as testing compact hardware that can achieve lower temperatures.

Initial tests of the cryogenic sorption gas collection system used CO_2 as the test gas, with other gases found in the Mars atmosphere to be used in later tests. The procedure for the cryogenic gas collection system began with evacuating the entire system to a pressure of 1.3 kPa and baking the cold finger at 160°C for 30 minutes. Next, the cold finger was pre-cooled to a temperature of –190°C by immersing it in liquid N_2. The next step was to isolate the SCV and vacuum pump from the rest of the gas collection system by closing the appropriate valves. The next few steps involved allowing the SPSV and cold finger to fill with gas following the overshoot pressure curve shown in Fig. 2 at the inlet to simulate the worst-case SCIM aeropass. Once the maximum stagnation pressure was reached, the valves between the SPSV and cold finger were closed. Next, the valves between the SCV and cold finger were opened and the cold finger was slowly warmed to approximately 20°C. Once the cold finger temperature stabilized for 30 minutes, the gas pressure and temperature in the SCV and cold finger were recorded and the mass of collected gas was calculated from the ideal gas law. Finally, the entire system was evacuated for the next test.

Results and Discussion: This study focused on the design, analysis, and testing of a benchtop prototype Atmospheric Collection Experiment, a device for collecting a sample of the Martian atmosphere.

Initial tests of the ACE prototype indicate that, when the testing the collection rate of CO_2, most of the incoming gas was condensed within the cold finger sorption material. For a 95 second test, 4.04 g (±0.23 g) of CO_2 was collected with the cryogenic sorption system. The uncertainty of ±0.23 g is a result of the limitations in the accuracy of the pressure and temperature transducers. The cryogenic sorption gas collection test was repeated several times to ensure reproducibility. The data from initial tests demonstrates that the cryogenic gas collection system possesses the ability to collect enough CO_2 to easily meet the mission requirement for SCIM.

Initial testing proved that the cryogenic sorption gas collection system far outperforms the passive system in gas collection ability for CO_2 (more than ten times) under the SCIM collection conditions. Cryogenic gas collection for MSR would have even greater advantages over passive collection, as the ambient surface pressure (~0.9kPa) is more than an order of magnitude lower than the peaks of the SCIM stagnation pressure profiles, which are greatly enhanced by the ram effect of the aeroshell. Atmospheric collection at the Mars surface would also differ from SCIM in that it would not be time constrained.

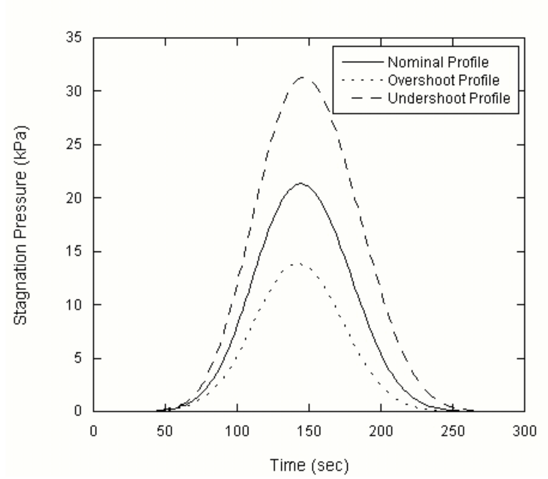

Figure 2: Stagnation pressure vs. time at the ACE inlet for the nominal, overshoot, and undershoot SCIM trajectories. Data provided by NASA Langley and Lockheed Martin Astronautics.

Ongoing Studies: The current instrument development strategy involves empirical measurement of gas adsorption efficiency of the cryogenic system zeolite for various gas species in the Martian atmosphere at Mars surface pressures (e.g., for the MSR mission). Results of these measurements will be presented at the meeting.

References: [1] Nier A and McElroy M.B. (1977) J. Geophys. Res. 82, 4341-4350. [2] Bogard D.D., et al. (2001) Spa. Sci. Rev. 96, 425-458. [3] Jakosky B.M. et al. (1996) JGR 101, 2247-2252. [4] Eiler J.M. and Schauble E. (2004) Geochim. Cosmochim. Acta 68, 4767-4777. [5] Bernardin, J.D., Konecni, Z., and Wiens, R., 2005, “Design and Testing of a Prototype Atmospheric Gas Collection Apparatus for a Mission to Mars”, Proceedings to The 2005 ASME International Mechanical Engineering Congress and Exposition, Orlando, FL