SUBSYSTEM TESTING AND RESULTS OF THE PLANETARY VOLATILES EXTRACTOR (PVEx). V. Vendiola[1], K. Zacny[1], P. Morrison[1], A. Wang[1], R. Huddleston[1], R. Mendoza-Axle[1], A. Hattori[1], A. Paz[2], [1]Honeybee Robotics, 398 W. Washington Ave, Suite 200, Pasadena, CA 91103, kazacny@honeybeerobotics.com, [2]NASA Johnson Space Center.

Introduction: In Situ Resource Utilization (ISRU) or "living off the land" relies on exploiting local resources and in turn reducing the burden of transporting supplies. NASA has determined that ISRU will be critical for both robotic and human exploration of the solar system as well as for establishing a permanent human presence on the Moon and Mars [1]. Honeybee Robotics has a long history of developing prototype and flight surface-preparation, sampling, and sample-processing systems. More recently, Honeybee Robotics has explored several ISRU concepts including the Mobile In-Situ Water Extractor (MISWE) [2], the World Is Not Enough (WINE) water-extraction system [3], and various low-TRL designs [4].

Among these ISRU concepts, the most mature is the Planetary Volatiles Extractor (PVEx). PVEx (Figure 1) is an integrated ISRU architecture which combines excavation and volatile processing. A sublimation and distillation batch process is used to recover volatiles (e.g., water) by heating the interior of a coring auger and condensing volatiles in a condenser (cold trap). Dry regolith is discarded at the end of each operation. The current corer has an inner diameter of 50 mm and can drill a maximum depth of 0.5 m. The Corer Assembly includes a thin-walled copper tube with a resistive heater, a drill auger having three flights at a ~25-degree pitch angle, and a cutting bit with percussive-grade tungsten carbide teeth.

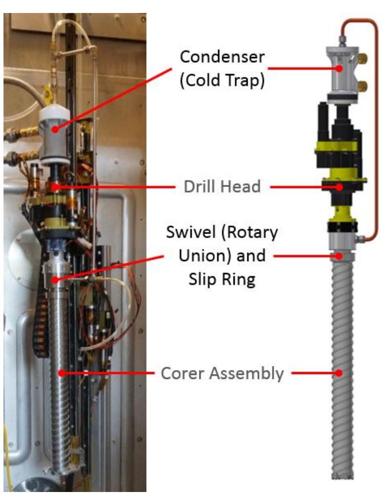

Figure 1. PVEx Subsystems

PVEx can be scaled depending on the volumes of the material required. As such, it can serve as either an initial reconnaissance tool or production system. For example, a production purposed PVEx could be 20 cm in diameter and 1 m long, capable of capturing 3 kg of water/hour (assuming 5% water by weight 2 g/cc regolith density). A Curiosity-size rover with four PVEx systems will, therefore, capture 12 kg water/hour or 50 MT water per year (assuming 50% duty cycle: 50% water extraction and 50% driving, drilling).

The main attribute of the PVEx approach is that it can perform well in dry and ice-cemented regolith. If the subsurface strength is unknown, this type of drilling-based ISRU system is one of the few that would be effective. Based on testing at Honeybee Robotics, even a small fraction of water (1%) is sufficient to sinter soil grains together forming a competent and strong material that cannot be broken up by a scoop [5].

The initial testing of PVEx revealed mechanical problems related to the robustness of drill components and interference between the drilled core and Corer Assembly. Material and geometry changes were made and have addressed these issues. Modifications were also made to help prevent dirt from entering the annular space between the sleeve and auger and from entering the volatile capture subsystem. These updated designs were procured and tested to verify their effectiveness. An end-to-end demonstration and further performance testing will be conducted.

Drill Performance Tests: Four types of drilling tests were performed: ice-bearing regolith simulant under vacuum conditions, Texas Cordova Creme (TCC) Limestone drilling tests under ambient conditions, ice block drilling tests in a large freezer, and Indiana Limestone drill tests under ambient conditions. Vacuum tests were conducted within Honeybee Robotics' large vacuum chamber. The internal dimensions of the chamber are approximately 1 square meter by 3 meters tall. The chamber can achieve absolute pressures as low as 3 Torr. During all tests, the weight on bit was kept less than 100 N.

The initial vacuum tests, limestone drill tests, and ice block drill tests were conducted with an in-house drilling system developed for the Life in the Atacama (LITA) project. The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT) drill was used for Indiana Limestone tests and will be used for future testing.

In the initial vacuum chamber testing, PVEx penetrated to its full depth of 50 cm and then turned on its heater until the temperature measured by the thermocouple located in the center of the core began to rise sharply. This rapid temperature increase is taken as evidence that endothermic sublimation or evaporation was no longer occurring in the core and that the sample must, therefore, be dry. Additional subsystem vacuum tests were also conducted showing that at around 75 minutes, the core would be dry (Figure 2).

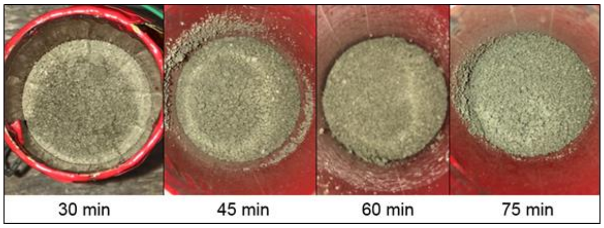

Figure 2. Volatile Capture Subsystem Testing

The TCC Limestone and ice block tests were conducted to investigate issues that were encountered during initial vacuum chamber testing (e.g., core binding, inability to drill to full depth, and restricted vapor flow path). The ice block tests (Figure 3) provided an opportunity to visually observe cuttings transport out of the borehole through the clear ice as well as to investigate the extent to which thermal issues might have affected the initial tests.

Figure 3. Ice Block Drill Test Setup

These tests also prompted geometry changes within the Corer Assembly. The components were procured; PVEx, with the TRIDENT drill was used to drill in Indiana Limestone. The drill performance data is shown below (Table 1). PVEx has been shown to be mechanically robust and capable of efficiently collecting near-surface and subsurface water in various forms.

Table 1. Drill Performance Data

Material		*	+	x	x
Drill		LITA		TRIDENT	
UCS#	MPa	5	23	45	45
ROP^	cm/ min	5.70	4.98	1.80	1.92
Power	W	246	242	142	141

\# Unconfined Compressive Strength
^ Rate of Penetration
***** Ice at -20C
\+ Texas Cordova Creme Limestone
x Indiana Limestone

Next steps: The next series of tests will include an end-to-end demonstration. Several drill tests will be conducted in a test bed of NU-LHT-3M Lunar Highlands simulant. The test bed will be prepared like previous NASA preparations [6]. The regolith will be wetted in 5% water by weight, compressed per ASTM D4253 to 1.5 g/cc, and frozen in a -20C freezer overnight. The test bed will then be moved to Honeybee's large vacuum chamber in preparation for the subsequent drill and volatile capture test at ~3 Torr. After drilling to depth, the heater sleeve will be activated for approximately 75 minutes at 50W. The temperature of the volatile capture components (e.g., heater sleeve, cold trap), the drill performance, and the water collected per batch will be measured.

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