Prototype Low-Pressure Advanced Thermal Mining System with Vapor Extraction, Ionization and Electrostatic Transportation, and Deposition of Ice in an Engineered Cold Trap

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Project Objective

To develop and demonstrate an advanced thermal mining prototype capable of collecting 1 kg of ice in approximately 11 hours from icy Lunar regolith that integrates engineered extraction, vapor ionization and electrostatic transportation of sublimated vapor to a cold trap, and deposition of water vapor on an engineered cryogenic heat pipe with periodic delamination of ice, and system-level scale-up analysis.

Introduction

The ongoing in-situ resource utilization (ISRU) project at cSETR is focused on the design, development and demonstration of a lab-scale advanced thermal mining prototype. There are significant uncertainties in estimating the thermophysical properties of icy Lunar regolith such as effective specific heat and thermal diffusivity. Moreover, the vapor sublimates in an ultra low-pressure environment that makes it difficult to transport the rarefied vapor to the cold trap. Furthermore, the limitation of power in lunar south pole and poor thermal conductivity of de-posited ice in the cold trap makes the ice re-capture system less efficient. Therefore, this work presents an engineered vapor ionization, transportation and deposition system.

Project Concept

This work experimentally measures the thermophysical properties of icy regolith, experimentally compares the sublimation rates at various concentrations and depths from capture tent and thermal drill simulators, and presents the design, development and demonstration of an advanced thermal mining prototype that integrates vapor ionization and transportation to the cold trap by electrostatic field, and re-capture 1 kg of ice on the evaporator of an engineered cryogenic heat pipe. Figure 1 presents cSETR advanced thermal mining concept.

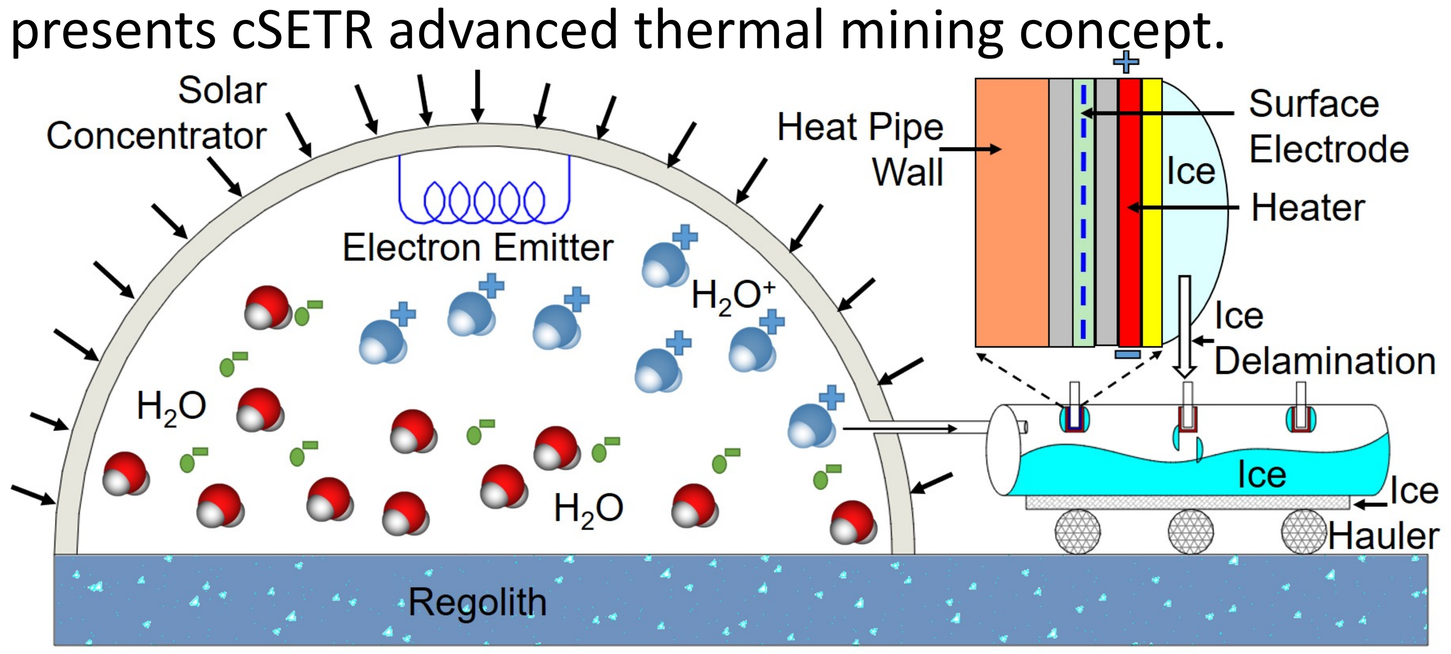

Figure 1. cSETR advanced thermal mining concept

Acknowledgments

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Vapor Sublimation from Icy Regolith

This task focuses on the experimental characterization of vapor sublimation rate from the icy lunar regolith. Experiments are performed in the cSETR Thermal Vacuum (T-Vac) chamber (Fig. 2a) at 10^{-5} Torr base pressure and -100 °C temperature. 1000 grams of JSC-1A is uniformly mixed with 64 grams of water (6 wt.%) and placed inside the T-Vac (Fig. 2b). Patch heaters underneath a 23 cm × 23 cm wetted lunar regolith sample controls vapor sublimation (Fig. 2c) rates. The test results are compared with the pure ice model in Andres (2007) model in Fig. 2d. Average sublimation rate was achieved as 5.95×10^{-5} kg/m²s.

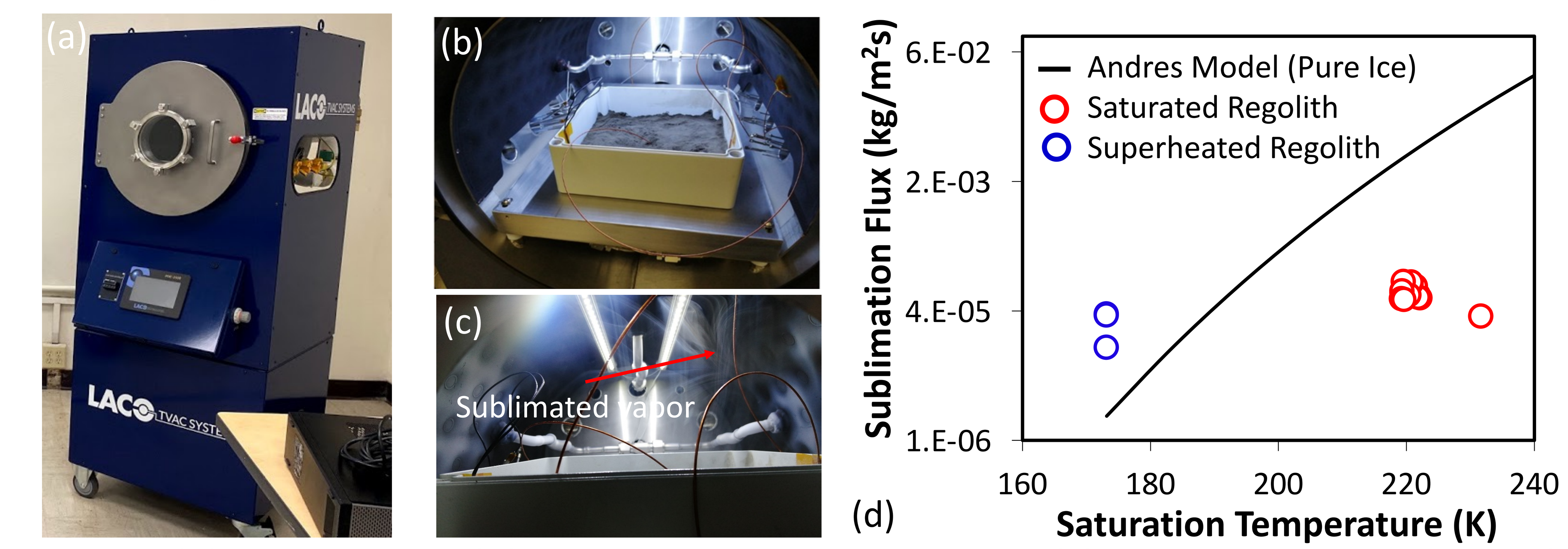


Figure 2. (a) cSETR T-Vac, (b) icy regolith sample in T-Vac, (c) vapor sublimation, and (d) sublimation test results compared with Andres (2007) model.

Vapor Ionization and Transportation

The rarefied vapor transportation system focuses on the ionization of sublimated low-pressure vapor and transportation to the cold trap in three different electrostatic field: (i) a tungsten filament electron emitter (Fig. 3a), (ii) a radio-frequency plasma source, and (iii) a tungsten filament with applied magnetic field for electron trapping. More than 450% increase in water collection rates has been estimated analytically as shown in Fig. 3b. This work presents the preliminary experimental results for sublimated vapor ionization using a tungsten filament electron emitter (Fig. 3c).

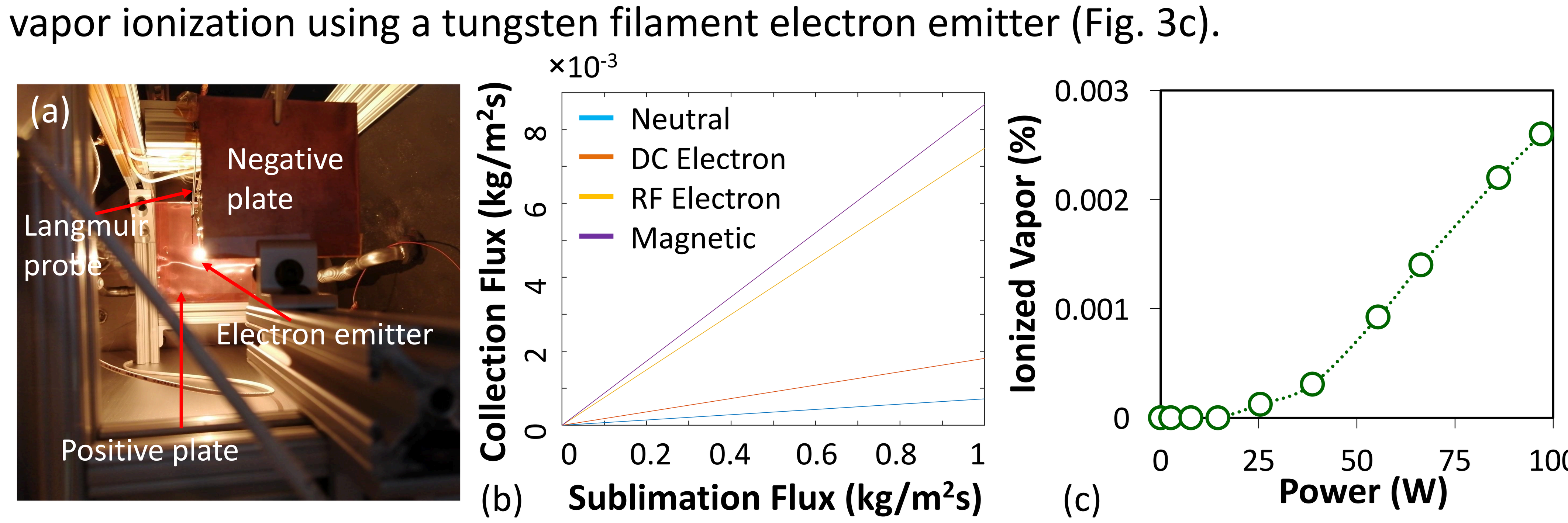


Figure 3. Vapor ionization and electrostatic transportation: (a) ionization system with a tungsten emitter, (b) analytical, and (c) experimental ionization rate.

Engineered Heat Pipe

This work focuses on developing a LN_2 heat pipe utilizing the 3D printed titanium micro-scale surface engineering.

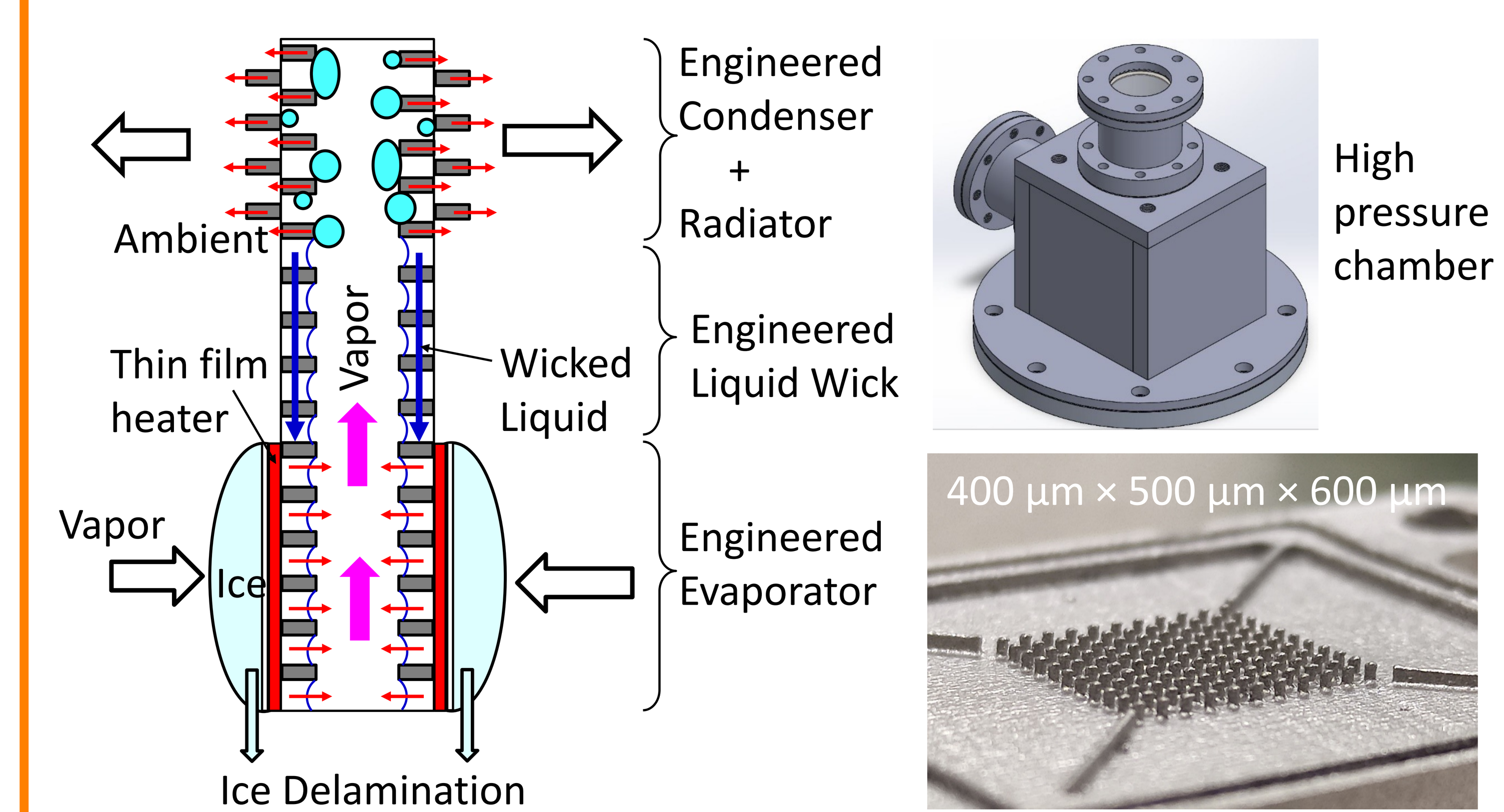
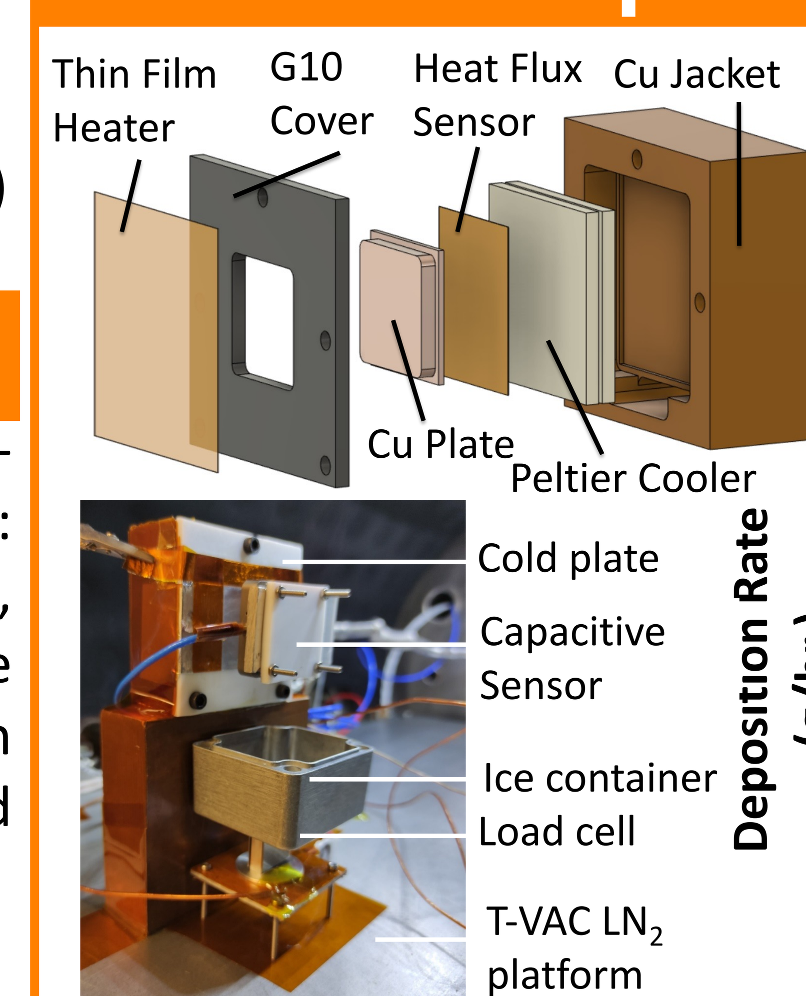


Figure 4. Engineered cold plate concept and test facility

Ice Deposition Rate



The engineered cold plate design and preliminary ice deposition test results are presented here measured using capacitive sensor and load-cell.

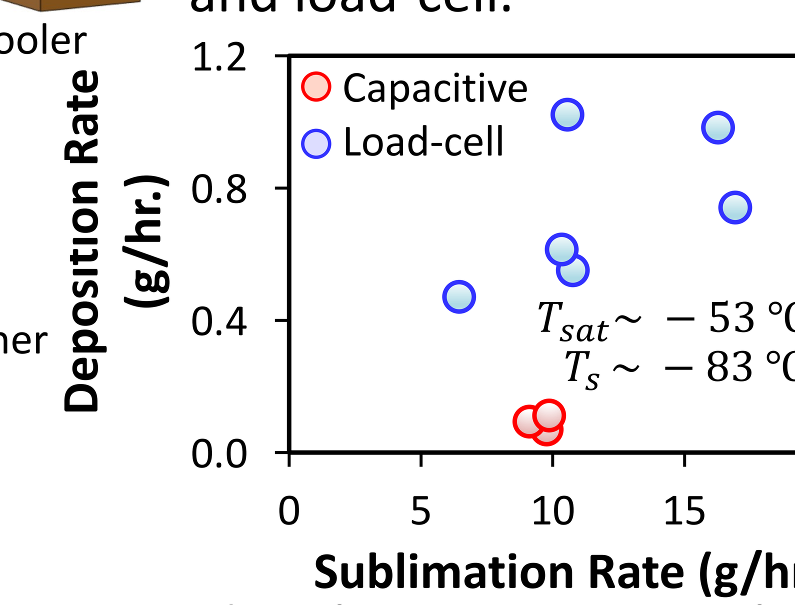


Figure 5. Ice collection system and preliminary test results.

Conclusions

This research aims to develop and demonstrate an advanced thermal mining technology of 1 kg ice collection capacity integrating engineered extraction, transportation, and deposition of water vapor from lunar regolith. The project is now at the engineered heat pipe design and testing, and exploration of various ionization systems stage.