RARIFIED WATER VAPOR DEPOSITION FROM ICY LUNAR REGOLITH ON AN ENGINEERED COLD PLATE

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ABSTRACT

This work presents the fundamental ice collection experiments conducted under rarefied flow regime to develop a high-capacity cryogenic heat pipe for ice recollection on the Moon's surface. Preliminary ice collection experiments are conducted under cryogenic vacuum environment of 1.5×10^{-2} Torr and -60 °C. The characterization of water vapor sublimation rates from icy lunar regolith (JSC-1A) at various heating powers is established by utilizing a cryogenic thermal vacuum chamber (T-VAC). A custom-built engineered cold plate is designed, manufactured and tested at various degrees of subcooling and vapor sublimation rates. A thin film heater is embedded within the cold plate to generate thin vapor lubrication layer and delaminate bulk ice from the cold plate. A capacitive sensor is used to determine the rate of ice growth in real time. The delaminated ice is collected on a load cell to measure the ice collection rates. The maximum ice collection rate achieved is 1.02 grams per hour on a 2.5 cm × 2.5 cm cold plate area with a subcooling of 31.4 K and sublimation mass flux of 5.95×10-5 kg/m2 s. Vapor deposition heat flux data is collected and plotted to reveal relationship between subcooling and ice collection rates. The maximum ice deposition heat flux of 1200 W/m2 has been achieved at the subcooling of 31.4 K. Ice collection experiments continued to improve upon the 1st generation of ice characteristic studies in a cryogenic vacuum environment. A cryogenic vacuum system is designed specifically to find the correlation between ice collection rates and degree of sub cooling and also vapor deposition heat flux. Ice data is collected in efforts to develop a high-capacity cryogenic heat pipe with thermal delamination component. Tests are performed in cold vacuum at 2.0×10^{-3} Torr and -50 °C, to study ice growth rates, deposition heat flux, and the power and duration requirements for delaminating ice. A maximum ice collection rate of 2.9 grams per hour is observed on the 40mmx40mm cold plate for a subcooling of 95 K, and 7.5×10^{-5} kg/m^2s sublimation mass flux. The redesigned cold plate demonstrated a maximum ice collection efficiency of 83% which a significant improvement from the 9.6% efficiency from the 1st generation of ice collection. The correlation between vapor deposition heat flux and degree of

subcooling is found to be directly proportional. The maximum deposition heat flux seen is 6100 W/m^2 which will be basis for designing the evaporator section of the engineered heat pipe. The ice growth rates as a function of degree of subcooling appears to stagnate after 50 K subcooling. Some ice density measurements are taken using a photograph scaling method achieve a max frost density of 92 kg.m^3. Furthermore, this study experimentally demonstrates the concept of ice re-capture which is vital to developing a successful water collection unit on the Moon.

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CHAPTER 1: INTRODUCTION

1.1. MOTIVATION AND BACKGROUND

As the interest in exploration and life sustainability in space increases, so does the research on the development of new technologies for in-situ resource utilization (ISRU). Among the resources available in space, water is vital for space exploration as it can be decomposed into propellant or utilized as a potable drinking source. According to the data collected from the LCROSS mission, the permanently shadowed lunar poles contain approximately 5 percent water by mass (Colaprete 2012). NASA's ARTEMIS program, along with different partners, are currently developing methods of extraction and collection such as thermal drilling or solar concentrators in conjunction with ice collection tanker. Challenges arise when collecting the ice in a storage facility under the rarified flow regime. The ultra-low pressure on the lunar surface restricts the use of traditional pressure driven fluid flow methods which results in random diffusion of water vapor molecules and other volatiles from the extractor to the collector. Through a Cooperative Agreement with the NASA Johnson Space Center (JSC) (NASA JSC and UTEP 2019), UTEP Aerospace Center (cSETR) team has performed a feasibility study of a novel electrostatic transportation of sublimated vapor and high-capacity cold plate to recapture ice in a low-pressure condition. Following the understandings from the feasibility studies, the team is currently developing an advanced thermal mining technology that integrates engineered extraction, low pressure vapor transportation through electrostatic field, and deposition of water vapor from lunar icy regolith using engineered cryogenic heat pipe with thin film resistance heater, as shown in Fig. 1-1, under NASA Lunar Surface Technology Research (LuSTR) grant (Advanced 2021).The water vapor is extracted from the lunar regolith using a solar concentrator or an array of thermal auger drills. UTEP developed a novel method to transport the vapor from the extraction

site to the collection unit by using an ionization method coupled with electrostatic fields. Using electron bombardment, the water molecules are ionized, and the use of electric fields gives the vapor particles a controllable path to the collector. This concept limits the vapor loss due to random particle walk and increases the collection flux to the collector (JSC and UTEP 2019).

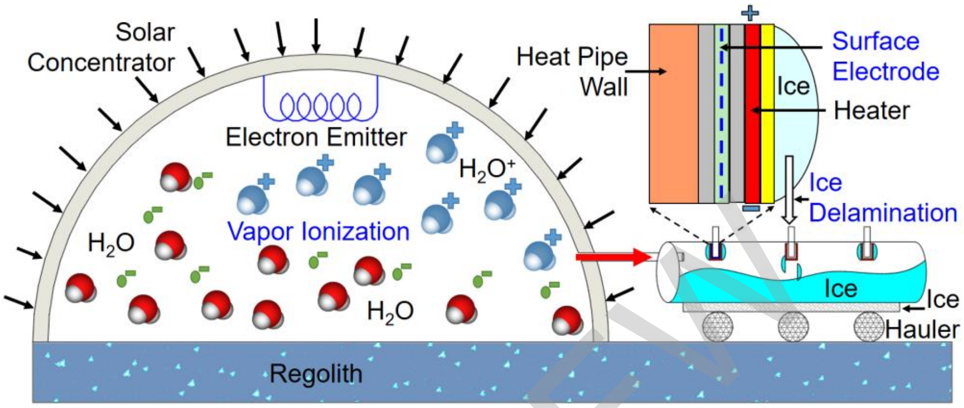

Figure 1-1: UTEP CSETR advance lunar mining concept (Advanced 2019)

Inside the ice collection facility, such as an ice tanker, sublimated water vapor deposits on the walls as frost. The heat rejected from the water vapor is conducted through the walls and radiates out to the lunar environment. However, the accumulation of frost growth degrades heat rejection rates to the collection facility walls due to the low thermal conductivity of ice. The vapor deposition rate decreases as the frost layer builds until eventually all ice growth stagnates. To overcome this obstacle, a cryogenic heat pipe with thermal ice delamination is proposed. Heat pipes are heat transfer devices that utilizes fluid phase change to efficiently conduct energy between two bodies. Heat pipes are typically used in electronic cooling applications with water as the working fluid. Incorporating a cryogenic heat pipe into the ice collection facility would collect the water vapor on the evaporator section and release heat to the condenser section which would extend to the lunar environment. By integrating a thin film heater onto the evaporator section of