Lunar Helium-3: Mining Concepts, Extraction Research, and Potential ISRU Synergies

Aaron D.S. Olson[1]
NASA Kennedy Space Center, FL, 32899, U.S.A
Email: aaron.d.olson@nasa.gov

Abstract. After reviewing Apollo soil sample analysis, researchers from the University of Wisconsin's Fusion Technology Institute (FTI) first proposed the use of Lunar ^{3}He to generate clean and economical nuclear power with the nuclear fusion reactions below:

$$D + {}^3He \rightarrow p\ (14.68\ MeV) + {}^4He\ (3.67\ MeV)$$

$${}^3He + {}^3He \rightarrow 2p + {}^4He\quad (12.86\ MeV)$$

They estimated that the Moon holds at least 1 million tonnes of ^{3}He, originating from the solar wind, within a 3 m depth of the lunar surface. The Wisconsin Center for Space Automation and Robotics (WCSAR) was formed in 1987, as one of NASA's Centers for the Commercial Development of Space, to study how ^{3}He could be mined from the Moon. WCSAR's researchers produced several mining concepts including mobile miners that excavate and process lunar regolith and in-situ volatile release and capture approaches. The most detailed of the mining concepts is the Mark-III (M-3) miner, completed in 2006.

The M-3 miner was designed to excavate 1258 tonnes/hr with a bucket wheel excavator and process 556 tonnes/hr (during the lunar daytime) of <100 µm regolith through a 12 MW solar concentrator powered heat pipe heat exchanger (HPHX). The HPHX was designed to heat the regolith up to 700°C to release the implanted solar wind volatiles and recuperate 85% of the input heat. Considering a 20 ppb ^{3}He concentration in the regolith, 66 kg of ^{3}He would be captured in onboard storage tanks over the course of one year. This mining effort would also result in the release hundreds of tonnes of other valuable volatile by-products, including water and hydrogen, that could be used to support sustainable lunar exploration. In the more near term, a mining operation to demonstrate the ability to collect 15 tonnes water for liquid oxygen/liquid hydrogen propellant from 5% water rich regolith may require ~400 tonnes of regolith to be excavated. This type of pilot scale operation could also demonstrate the ability to extract about 6 g of ^{3}He, assuming the ^{3}He concentration in permanently shadowed regions on the Moon is similar to that of equatorial regions.

Recent experiments at the FTI, in collaboration with NASA KSC's Swamp Works, investigated the flow induced agitation release of helium from JSC-1A lunar regolith simulant within a heat pipe heat exchanger. The Experimental approach included the implantation of helium-4 into 2 kg batches of lunar regolith simulant, the processing of the implanted simulant by flowing it through a heat pipe heat exchanger and, lastly the analysis of samples of the processed and implanted simulant for its remaining helium content with a vacuum furnace and mass spectrometer system. The experimental results constituted the first measurements and quantification of the amount of agitation loss from helium implanted regolith simulant in a heat pipe heat exchanger. The amount of agitation loss increased with regolith simulant flow rate. The implantation and extraction systems are shown in Figure 1.

[1] Research Engineer, NASA Kennedy Space Center

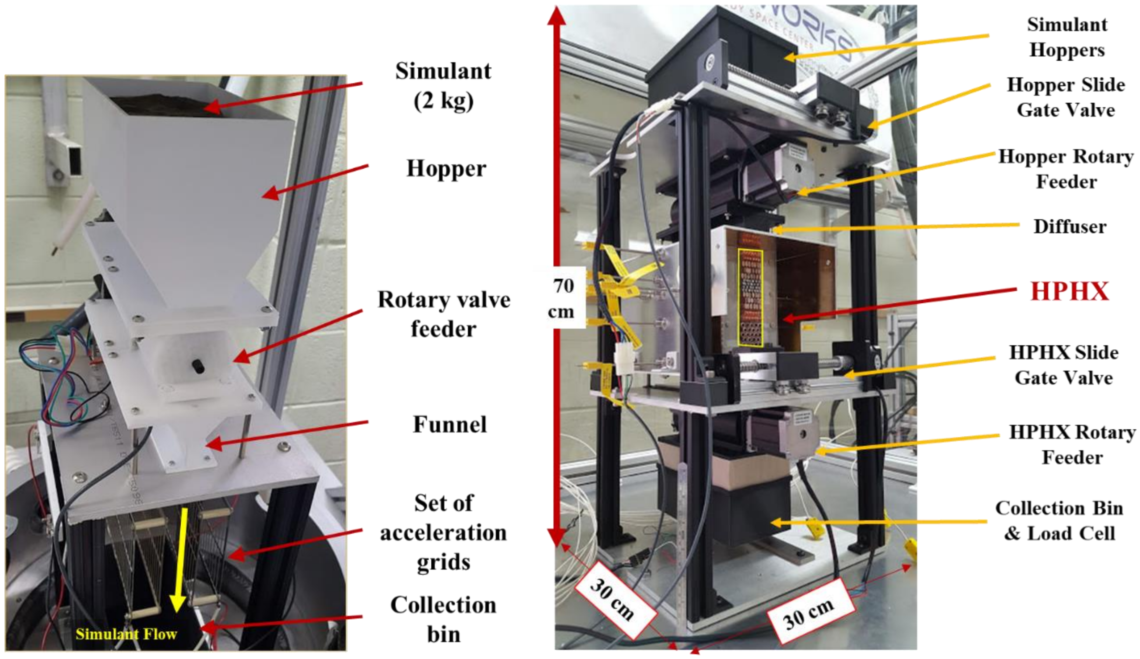

Figure 1. Primary components of the experimental helium implantation (left) and heat pipe heat exchanger extraction (right) systems

This paper describes and compares the various methods and designs specifically proposed for mining ^{3}He, and summarizes the methods, results and potential implications of recent research on helium extraction from lunar regolith simulant. This paper also touches on the potential synergy of lunar propellant production with ^{3}He mining and some of the recent advancements in fusion technology related to future ^{3}He fueled fusion reactors.

NOTE: This abstract is for the 5th of a 5 paper technical session organized for the ***Space Exploration*** track titled:

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