CONCENTRATED SOLAR DRIVEN *IN-SITU* RESOURCE UTILIZATION ON THE MOON

A. R. Clendenen[1], B. M. Jones[2], T. M. Orlando[2], and P. G. Loutzenhiser[1]. [1]George W. Woodruff School of Mechanical Engineering and [2]School of Chemistry and Biochemistry, Georgia Institute of Technology.

Introduction: An external power source is essential for driving *in-situ* resource utilization (ISRU) processes. Since technologies are limited due to launch costs, readily available resources must be leveraged. Sunlight is a readily available resource and thus concentrated solar irradiation is ideal for driving lunar ISRU, including ISRU extraction of oxygen or water from the lunar regolith.

Solar Resources on the Moon: The moon has no atmosphere to attenuate solar irradiation, resulting in direct-normal solar irradiation of ~1365 W/m^2 compared to ~1000 W/m^2 on Earth. The lunar declination angle is only ~1.5° compared to ~23.5° on the Earth [1], resulting in small seasonal variations in solar resources. The lunar day is also ~14 earth days with regions of permanent illumination. Thus, the moon is ideally situated for using concentrated solar irradiation.

Concentrating sunlight offers a viable pathway towards efficiently capturing sunlight as process heat to drive ISRU processes. There are three main types of solar concentrating technologies: (1) trough systems, (2) tower systems, and (3) dish systems. Trough systems use single axis sun tracking while tower and dish systems use two axis sun tracking [2]. Each system is capable of concentrating solar irradiation for use in different applications; trough systems 30-100 suns (where 1 sun is equal to 1000 W/m^2, the direct-normal solar irradiation at the surface of the earth), tower systems 500-5000 suns, and dish systems 1000-10000 suns [3].

Oxygen Extraction from Lunar Regolith: One ISRU process that could utilize concentrated solar irradiation is the extraction of oxygen from the lunar regolith.

Equilibrium Predictions. Chemical equilibrium modeling was performed to forecast chemical compositions as a function of temperature and pressure for lunar regolith. Gibb's Free Energy minimization ($\Delta G = 0$) was used to predict equilibrium compositions for isobaric processes [4]. The pressure on the moon was ~ 3×10^{-15} bar, and the equilibrium composition of each species was normalized per unit mass of regolith. The regolith compositions were taken from [5]. Equilibrium predictions for oxygen are shown in Figure 1. A small temperature range is present for favorable O_2(g) evolution due to the extremely low pressure. A dramatic increase in O_2(g) favorability occurs at ~800°C and peaks at ~ 950 °C before dissociating to O(g).

Experimental Results. Thermogravimetric analysis (TGA) was performed to assess performance in a non-equilibrium system. Figure 2 shows the results for a TGA experiment using the Lunar Mare regolith simulant LMS-1 that demonstrate oxygen extraction is possible in a range of temperatures between 800-1300 °C. The mass loss isn't accounted for purely by oxygen indicating other gasses are released upon heating as well.

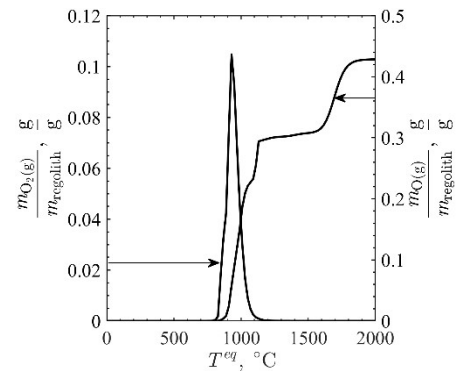

Figure 1. Equilibrium predictions for O(g) and O_2(g) as a function of temperature for Low Titanium Mare.

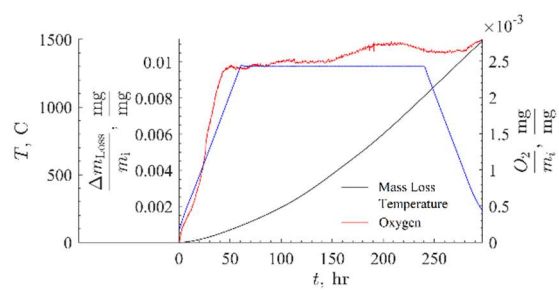

Figure 2. TGA results of the extraction of O_2(g) (black line) from LMS-1 graphed with the temperature program (blue line) and the total mass loss (red line).

Water Extraction from Lunar Regolith: Similar predictions were made for water extraction in shadowed craters.

References: [1] Burke (2012) In: Badescu (eds) Moon. [2] Steinfeld and Meier, (2004) E*ncy of Energy* 5, 623-637. [3] "Concentrating Solar Power" *SEIA*. [4] White, et al., *J CHEM PHYS*, 28(5): 751-755. [5] Stoeser, et al. 2010. [6] Colaprete, et al., *Science*, 2010. 330(6003): 463-8.

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