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In situ oxygen extraction from lunar regolith materials with the SELENA experiment of the Barcelona Moon Team

I. Casanova (1,2, 3), E. F. Aymerich (2), M. Soler (3) and the SELENA Team
(1) Dept of Construction Engineering, UPC-Barcelona Tech, Barcelona, Spain (ignasi.casanova@upc.edu), (2) Institute of Energy Technologies; (3) Center for Research in Nanoengineering

Abstract

The SELENA experiment on board the Barcelona Moon Team mission is designed to demonstrate for the first time in situ the feasibility of extracting oxygen from common lunar regolith materials. A quantitative evaluation of oxygen extraction yields has been carried out by reduction of a lunar regolith simulant. Results prove the suitability of an experimental procedure based on temperature-programmed reduction to find the most efficient conditions to treat lunar basalts.

1. Introduction

In situ resource utilization (ISRU) is certainly a requirement for long-term missions in planetary bodies due to high cost of transportation from Earth. Oxygen is and abundant lunar resource, present in oxides and silicates, and vital for life support and spacecraft propulsion systems[1]. More than 20 different processes have been so far proposed to extract oxygen from lunar rocks, being reduction of ilmenite ($FeTiO_3$) present in high-Ti basalts the one that has probably been paid more attention due to the relative simplicity and productivity [2]. However, ilmenite-rich basalts are not ubiquitous on the Moon, and beneficiation of the mineral would be a necessary first step to actually take advantage of its potential. Hydrogen reduction of real lunar materials has also been carried out, demonstrating oxygen extraction yields of over 3% from lunar soil samples and almost 5% from lunar pyroclastic glasses at temperatures of 1050 ºC [3]. Oxygen relase (in the form of water) proved to be strongly temperature dependent. In this work, we present the optimization of the time-temperature conditions to achieve the maximum rate of extraction at the minimum cost on the surface of the Moon, based on temperature programmed reduction micro-nanotechnologies that will be implemented on the BMT payload to demonstrate, for the first time, the feasibility of in-situ oxygen extraction from lunar materials.

2. Available lunar resources

Lunar regolith (also referred to as lunar “soil”) is the fine-grained fraction of lunar materials formed by continuous meteorite bombardment. Undoubtedly, it is the most abundant and readily available resource on the surface of the Moon. In addition to utilization for radiation protection purposes, its chemical and mineralogical composition, together with its fine-grained nature, provide a wide range of exploitation possibilities. Furthermore, the relatively recent confirmation of the presence of water on the lunar surface, opens a wide range of combined utilization of these materials for oxygen production. Common lunar silicate materials contain between 45-55% by weight of oxygen, bound mainly with silicon, iron and magnesium in basalts (maria) and with silicon, calcium and aluminum in anorthosites (highlands). The so-called mafic (dark) basaltic materials, contain variable amounts of iron oxides, amounting on average about 10% of the total mass. Extraction of oxygen from these silicate materials is based on the reduction of such iron oxides (essentially FeO) through the reaction

$$FeO + H_2 \rightarrow Fe + H_2O$$

where the original hydrogen can be obtained by electrolysis of lunar water (initially though, transported from Earth), and water produced can be subsequently electrolyzed to recycle hydrogen. In a first approximation, 2 grams of hydrogen transported from Earth are necessary to produce about 56 grams of pure (metallic) iron and 16 grams of oxygen.

3. Preliminary results

A few grams of lunar stimulant JSC-1 have been reduced in an argon (90%) – hydrogen (10%) atmosphere, at temperatures ranging from 600 to 1000 ºC, yielding molecular water (and OH), identified through mass spectrometric analyses. Hydrogen consumption measurements have provided further evidence that the main contributor to oxygen release from basalts is reduction of iron (mainly Fe^{2+}) in the crystalline and glassy phases.

The SELENA experiment is based on the miniaturization of a temperature programmed reduction apparatus. A series of runs have been carried out to demonstrate the feasibility of the process and, most importantly, show that the kinetics (time-temperature dependent processes) can be calculated to optimize the oxygen extraction process at temperatures substantially lower that those required in previous experiments, and aims to be the first in situ demonstration of in situ resource utilization on the Moon.

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