Carbon-Based Reduction of Lunar Regolith (CRLR)

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Introduction

ORBITEC is developing a new high-temperature processing technique to produce oxygen and metals from Lunar regolith via carbonaceous high-temperature reduction. The utility in this technique overcomes problematic issues inherent in traditional high-temperature processing methods that employ crucible-type containment vessels and hot-walled (i.e., resistance or inductive) furnaces. Crucible containment structures either crack from thermal and mechanical stress and/or react with the molten reaction mix, making it very unlikely that such a material could survive the repeated high-temperature thermal cycling in an economical LOX plant on the Moon. To enable *in situ* production of Lunar oxygen, high-temperature reduction of Lunar soil can be accomplished using an alternate heating source, achieving high oxygen yield and high carbon (or hydrogen, depending on the reducing source) recovery. The proposed method will allow extremely high processing temperatures (>2000 °C) and eliminate the difficult requirement of developing a containment vessel that withstands these temperatures, is impervious to prolonged chemical attack, and is capable of thermal cycling. Reduction of regolith using this heating approach will provide NASA with a manageable, practical, and efficient technique for extracting oxygen from indigenous Lunar resources for life support and propellant applications. In this effort, ORBITEC proposes to demonstrate new techniques for achieving high oxygen yield and high carbon or hydrogen recovery. It would also involve integrated designs for both a production plant and flight experiment, the latter being test-flown on a NASA reduced-gravity aircraft.

Objectives

The primary objective of this effort is to demonstrate a practical and feasible technique for heating to >2000 °C and the reduction of simulant by carbon and hydrogen, with very high recovery of carbon and hydrogen. This effort will look at both carbonaceous and hydrogen gas reduction of Lunar simulant, focusing on the first step, in either case, in the overall production of oxygen from metallic oxides. Furthermore, efficient demonstration in the first year will provide the foundation for a preliminary flight experiment designs. Demonstration of a flight experiment in 1/6-g on a NASA parabolic aircraft would further substantiate development of a technology demonstration experiment on the Moon.

As part of these overall goals, the CRLR design and development effort will focus on these technical objectives:

1. Design, develop, and fabricate a test chamber in which heating of Lunar simulant to temperatures greater than ~2000 °C can be demonstrated;
2. Determine temperature profiles, both experimentally and theoretically, within the regolith surrounding the processing zone, including transient and steady state behavior;
3. Evaluate the effects of the new heating approach on regolith heating profiles;

4. Demonstrate carbonaceous reduction of, at least, the silica, titania, and iron oxide components of Lunar simulant using three separate reducing agents, including carbon-based agents and hydrogen gas, heating to temperatures greater than ~2000 °C;
5. Design and develop a space flight experiment design that incorporates the new heating approach and is capable of acquiring samples from the Lunar surface; and,
6. Conduct low-g processing tests in a 1/6-g environment using a NASA reduced-gravity aircraft to assess the space flight experiment design, study the effect of low-g on the process, and provide data on the system's overall performance.

Project Status

It is envisioned that development of the proposed technique will ultimately lead to a scaled production plant on the surface of the Moon, providing an indigenous source of oxygen for propulsion and life support and the production of useful metal and ceramic byproducts. Before a production plant can be fully realized, several demonstrations of the technology and concept must be made in the Lunar environment. These demonstrations would most likely take the form of low-mass, low-power, experiment packages that would be part of an ISRU technology demonstration mission on the Moon that is envisioned by NASA and ORBITEC. However, the design of a space flight experiment package would require knowledge of the system's behavior and performance in the Lunar environment. Certain aspects of the Moon's environment could be simulated in the laboratory, such as the temperature extremes and its vacuum-like atmosphere. Simulation of the reduced gravity, however, would require flight-time on a NASA parabolic aircraft. Modeling of the processes also needs to be verified by experiments in 1/6-g.

It is highly desirable to investigate the proposed concept in a 1/6-g environment. It is presently unknown how the 1/6-g gravity will affect the processed regolith. It is also unknown how the transport mechanisms of carbon-based agents or hydrogen (depending on which reducing agent is used) to the hot sample surface will be influenced by 1/6-g. The lower gravity environment may affect the rate at which the reducing agent transports or diffuses into the reactant material. ORBITEC has considered the test environments available and believe that ~20 seconds, or more, of 1/6-g is sufficient time to allow for heating of small amounts of Lunar simulant material and subsequent reaction with either carbon-based agents or hydrogen gas. Drop tower tests with duration's in the 5 second time region are considered insufficient due to the initial disturbance conditions and very high cost. Thus, the environment provided by a NASA parabolic aircraft has been selected for 1/6-g simulation.

ORBITEC is currently designing and fabricating the experimental hardware for this project.