Phase 1 Project Summary

Firm: Orbital Technologies Corporation

Contract Number: NNX10RA67P

Project Title: Advanced Carbothermal Electric Reactor

Purpose of the Research:

The overall objective of the Phase 1 effort was to demonstrate the technical feasibility of the Advanced Carbothermal Electric (ACE) Reactor concept. Unlike state-of-the-art carbothermal reactors that use concentrated solar energy and/or laser energy to heat the regolith, the ACE Reactor uses an innovative method to electrically heat the regolith to temperatures over 1800ºC within a thermally insulted environment, either with or without a crucible. Commercial high-temperature heating elements made from molybdenum disilicide ($MoSi_2$) are designed to only operate in oxidizing atmospheres where a protective layer of silicon dioxide (SiO_2) will form. In Phase 1, the ACE reactor used $MoSi_2$ heating elements with a protective coating to allow them to operate in any type of environment (oxidizing, reducing, or vacuum). The ACE Reactor concept eliminates the problems encountered with traditional carbothermal hot-wall reactors and offers significant advantages over current carbothermal reactor approaches. By eliminating the need for a concentrated solar energy system, the ACE reactor offers a significantly lowers system mass and removes the need to keep optical surfaces clean. In addition to efficiently producing oxygen, the ACE reactor separates the processed regolith into metallic iron and a silicate glass that can be formed into structural components or shielding materials.

Description of the Research Carried Out:

Design requirements were defined for the two prototype ACE Reactors that were built and tested in Phase 1, an ACE Reactor Engineering Unit that will be built and tested in Phase 2, and a ACE Reactor spaceflight unit. A process was developed to apply a protective coating to $MoSi_2$ heating elements. Multiple carbothermal reduction experiments were conducted in the Primary Prototype ACE Reactor using a single crucible. A coated $MoSi_2$ heating element was immersed in molten JSC-1A simulant during a carbothermal reduction experiment in the Alternate Prototype ACE Reactor and destructively analyzed. A second coated $MoSi_2$ heating element was operated under carbothermal reduction conditions while in direct contact with JSC-1A lunar regolith simulant in the Alternate Prototype ACE Reactor. Finally, a preliminary design for an ACE Reactor Engineering Unit was developed.

Phase 1 Results;

Six carbothermal reduction experiments were performed without any degradation of the crucible due to contact with the molten regolith, the reducing atmosphere, or thermal stresses. The processed regolith was successfully poured out of the crucible at the end of each test allowing the crucible to be reused. A method to separate the metallic iron from the silicate glass in the processed regolith was also demonstrated. Analysis of the iridium-coated heating element immersed in the molten regolith during carbothermal reduction processing showed that the coating failed allowing the heating element to react with the melt and degrade. However, the portions of the coated heating element outside the melt region but still in a reducing environment were completely intact. Another coated heating element was able to create a melt pool through direct contact with JSC-1A lunar regolith simulant and then be removed from the melt while it was operating. In addition, the conceptual design for an ACE Reactor Engineering Unit was developed.

Justification for Phase 2 Continuation:

The Phase 1 project demonstrated the technical feasibility of the ACE Reactor concept by meeting all of the technical objectives and answering the technical questions. The Primary Prototype ACE Reactor demonstrated that regolith can be processed with 80-85% less thermal energy than state-of-the-art carbothermal reduction reactors (SOA reactors) with fully reusable hardware (no consumables). This means that an ACE Reactor can process at least 12 times more regolith than a SOA carbothermal reactor given the same thermal energy. The Primary Prototype ACE Reactor demonstrated that the processed regolith can be poured out of a crucible after processing and the crucible reused many times. It also demonstrated that the processed regolith can be separated into metallic iron and silicate glass. The metallic iron or silicate glass can then be poured out of the crucible into a mold to make structural components or shielding materials. The ACE Reactor technology is an efficient, lightweight method for NASA to produce oxygen, iron and glass from regolith to support future human exploration of the Solar System.