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Title

Lunar pilot plant payload design toward in situ demonstration of oxygen extraction by carbothermal reduction

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Abstract

In the coming years the surface of the Moon is foreseen to be crowded by crewed and robotic missions. The capability to exploit local resources, with particular attention to regolith, is a key point to make sustainable the lunar exploration long-term. In this context, In-Situ Resource Utilisation (ISRU) processes to either extract or produce oxygen from the lunar regolith are primarily being studied: some of them, such as the carbothermal reduction process of molten/solid regolith (1) (2) and the FFC Cambridge process (3), are being characterized on terrestrial labs with dedicated pilot plants. The natural next step entails their demonstration in representative environment such the lunar surface is, as happened for the MOXIE experiment on Mars (4); to this end, the NASA Commercial Lunar Payload Services (CLPS) program offers a unique opportunity towards such class of technologies enhancement, making available a ride to the Moon for small size payloads. Therefore, the challenge to face stays in miniaturizing a complex chemical plant keeping its representativeness while being compliant with the CLPS constraints.

The roadmap towards feasibility for the carbothermal reduction plant for oxygen extraction adopted by the ASTRA team in Politecnico di Milano (PoliMi) is discussed in the paper, taking advantage of the experience gained in the tests campaign on the demo plant built at the PoliMi Lab financed by an ESA study (5). The carbothermal reduction proved at PoliMi is a two-stage solid-gas reaction which gets water from a mixture of methane and hydrogen fluxed on lunar simulant. That gaseous mixture reduces the feedstock at temperatures lower than the simulant melting point, still effective to trigger the oxygen tearing as carbon oxides; the following methanation stage converts the gases into water vapor, methane and hydrogen residuals; water is then extracted by condensation, and the loop can be closed exploiting byproducts as reactants again. No feedstock beneficiation is requested, greatly simplifying the plant operations automation; moreover, the solid phase favors the carbothermal reactor automatic and easy discharge, whenever the plant is seen working at regime. The lab plant -to be miniaturized towards flight- includes two reactors, two feeding lines and tanks dedicated to reactants, a condenser, actuators and sensors to regulate and monitor the flow and quantify the gaseous species content.

The major challenge to face stays in complying with the tight volume, mass and electrical power limitations imposed by CLPS while keeping the process feasible, its performances measurable and the plant technologically affordable. The tradeoffs run about the plant architecture, e.g. reduced wrt complete plant, to freeze the lunar payload baseline are presented and discussed; the technological criticalities entailed in the main reactor and its thermal control design according to the sealing and operational requirements are shown together with the preliminary solution identified. The proposed solution to get rid of the feedstock charge into the plant is also highlighted, considering the environmental and interface requirements imposed by the complex flight scenario. The expected yield and operational profile of the preliminary lunar demo plant designed so far are also presented.

References

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