Solid-gas carbothermal reduction for water production from lunar regolith simulant: experimental results

M.Lavagna[1], I.Troisi[1], A.Dottori[1], A.Colagrossi[1], J.Prinetto[1], R.Freddi[2], I.Pretto[2]
michelle.lavagna@polimi.it, ivan.troisi@polimi.it, alice.dottori@polimi.it, andrea.colagrossi@polimi.it, jacopo.prinetto@polimi.it
[1]Politecnico di Milano, Aerospace Science & Technology Dept, Via Giuseppe La Masa 34, 20156, Milano-Italia,
[2]OHB Italia S.p.A., Via Gallarate 150, 20151, Milano-Italia

A long-term human exploration, currently focus of important space programs, shall be sustainable to be achievable. To this end, the capability to exploit local resources to support the crew planetary staying in their primary needs is a mandatory step to gain. Among those, in situ water and oxygen extraction\production represents a turning point, therefore the primary targeted goal to address enabling technologies development [1]. The Moon is expected to be the first-in-time human space outpost, which drives the mineralogical resources to consider to assess their manipulation and processing viable strategies.

Among those, Politecnico di Milano (PoliMi) proposed and deepened, from design to in-lab experiments, a revisited carbothermal reduction, financed by the ESA ISRU-Demo study, in collaboration with OHB-I [2]. The demo plant is shown in Figure 1.

The effectiveness in extracting oxygen from the lunar regolith minerals simulant whenever the reaction temperature is kept low to avoid any phase change in the feedstock has been successfully demonstrated. The demo plant, designed and built to run the experiment [3], consists of a main furnace, heated at 1000-1100°C – below the feedstock melting point - and fed with the simulant over which a methane\hydrogen mixture flows: oxygen is extracted as carbon oxide [4]; a methanator reactor follows to output a water\methane\hydrogen vapour mixture. Water separation happens thanks to mixture flowing in a condenser, kept at temperature lower than the water liquefaction. The gaseous and solid products are such that the cycle can be closed with a limited need of refilling. Experimental tests focused on characterizing this solid-gas reaction sensitivity to many tuneable parameters, both process and feedstock dependent. In particular, the process temperature, the inlet gas mixture, the processes different phases duration, the regolith particles size, the solid gas ratio and others have been considered in the test plan run on the implemented demo plant in PoliMi labs. The process, as expected, revealed to be temperature and solid gas ratio sensitive, while no need of grain size selection emerged. As the carbon plays a crucial role in the oxygen extraction, with particular attention to the coke deposition side effect, which slows the feedstock reduction, a peculiar hydrogen based washing phase has been inserted between contiguous reduction reactions [5], to expose fresh material to the ingested methane.

Up to a 12% yield in feedstock mass and 25% in oxygen mass trapped in the dry simulant as oxides has been obtained.

Gas mixture composition along the lines is sampled before and after each reactor by means of a gas-cromatographer. The condensed water is also quantified, and the processed feedstock analysed through Scanning Electron Microscopy (SEM) and X-Rays powder Diffraction (XRD) to map the mineralogy changes and, therefore identify the most reactive components in the feedstock.

The intensive experimental campaign allowed settling a starting database to be exploited for process model identification and future flight pilot plant design.

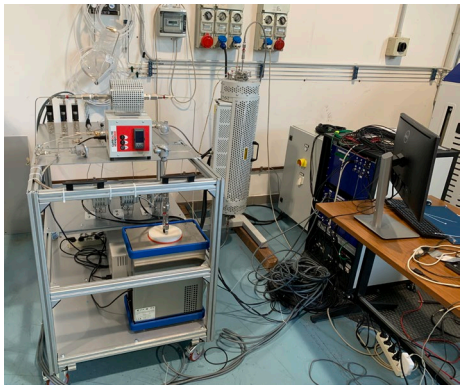

Figure 1 ISRU demo plant @PoliMi

Acknowledgements the lab demo plant has been realized under the ESA-E3P-ISRU-SOW-001-AO/1-9183/NL/JK.

References

[1] Landgraf M., et al. (2021), Lunar surface concept of operations for the global exploration roadmap lunar surface exploration scenario., *IAC 2021*. **[2]** Lavagna M.R., et al. (2021), Water production from lunar regolith through carbothermal reduction modelling through ground experiments, *EPSC 2021* **[3]** Prinetto J. et al (2023), *Planet. Space Sci.*, 225, Terrestrial demonstrator for a low-temperature carbothermal reduction process on lunar regolith simulant: Design and AIV activities, 10.1016/j.pss.2022.105618 **[4]** Troisi I. et al (2022), *Acta Astronaut.*, 199, 113-124, Oxygen extraction from lunar dry regolith: Thermodynamic numerical characterization of the carbothermal reduction, 10.1016/j.actaastro.2022.07.021. **[5]** Li X., et al. (2015), Carbothermal reduction of quartz in methane–hydrogen–argon gas mixture, *Metall. Mater. Trans. B*, pp. 2384-2393, 10.1007/s11663-015-0407-x