Applications for Solar Thermal Processing on the Moon and Related Challenges

Conference Paper · December 2020

5 authors, including:

Matthew Shaw
Swinburne University of Technology

M Akbar Rhamdhani
Swinburne University of Technology

Mark I. Pownceby
The Commonwealth Scientific and Industrial Research Organisation

Applications for Solar Thermal Processing on the Moon and Related Challenges

Matthew Shaw[1], Geoffrey Brooks[1], M. Akbar Rhamdhani[1], Alan Duffy[2], Mark Pownceby[3]

[1] *Fluid and Process Dynamics Group, FSET, Swinburne University of Technology, Hawthorn, VIC 3122, Australia*
[2] *Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Hawthorn, VIC 3122, Australia*
[3] *CSIRO Mineral Resources, Clayton, VIC 3168, Australia*

Introduction

Space Resource Utilisation (SRU) is an emerging field of research that is rapidly expanding in scope. Solar thermal processing technology poses multiple significant advantages for SRU activities on the lunar surface. There are also some significant challenges related to the use of solar power that need to be addressed.

Space missions currently launch with all the required material to conduct their mission on board. The actual dollar cost of transport into space is hard to quantify as it changes depending on the total payload mass, transportation company, and a myriad of other factors; however, a recent study by Kornuta et al. investigating a lunar propellant infrastructure placed the cost at around USD 35k to deliver 1kg of material from Earth to the Lunar surface [1]. Whilst it is technically feasible to run longer operations and even establish bases on the Moon with these sorts of transport costs, a more economical solution is preferable.

In-Situ Resource Utilization (ISRU) is the concept of producing usable products from local resource sources. In a lunar context, this means the mining and processing of lunar native resources for use on the Moon. If materials can be processed on the lunar surface for a total cost of less than that of transport from earth to the lunar surface, then this can represent an economical way to lower the total operating costs of lunar based activity. One of the largest advantages of ISRU specifically, but SRU in general, is that one of the most significant costs for launch is that of the fuel load, and the majority of the fuel load is used simply getting into orbit from the surface of the earth. Once in orbit, the fuel requirements for navigating cislunar space, and indeed the solar system, are comparatively low. Resources produced on the lunar surface could conceivably be used throughout the solar system for a fraction of the cost of the same products shipped up from earth. This provides significant drive for light weight processing solutions to be developed. Considering the relative lack of material required to concentrate solar flux to useable levels for material processing operations, the use of solar thermal technology on the lunar surface is appealing.

Solar Thermal Processing of Lunar Materials

The Swinburne University of Technology is currently running multiple projects evaluating the potential use of solar thermal technology on the lunar surface.

A study run by Minogue et al. [2] designed a theoretical apparatus to produce solar thermally sintered regolith bricks for construction purposes. The schematic for this design can be seen in Figure 1, the design uses four 1.25m^2 Fresnel lenses to produce nine 3kg regolith bricks in a 5-hour cycle. The final mass of the apparatus was estimated to be 89kg. A prototype is going to be built to test out basic aspect of the concept and fundamental studies of sintering (using regolith simulant) and heat transfer modelling are underway to support the development of this concept.

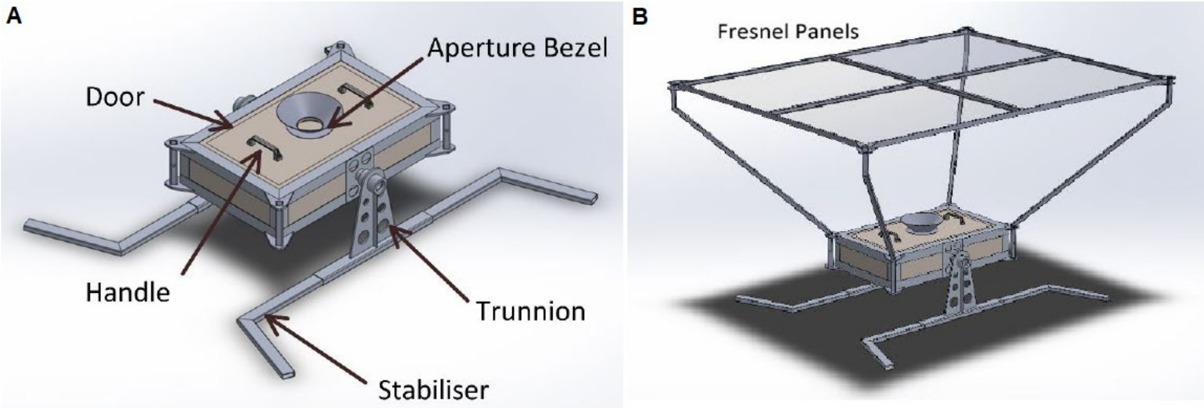

Figure 1 - Schematic of a solar thermal sintering apparatus for producing bricks from lunar regolith. Figure by Minogue et al. [2].

A current study by the authors [3] is evaluating a thermal decomposition and fractional deposition process for metal extraction from lunar regolith. Initial thermodynamic modelling has predicted that the low pressures on the lunar surface lower the required temperature for the sublimation and dissociation of the oxides present in the lunar regolith. These lower required temperatures (in the order of 800 to1200°C) for oxide dissociation result in direct solar thermal energy being a viable heat source for such a reactor. Figure 2 shows a basic schematic of the imagined ISRU process that utilises direct solar radiation as a heat source for a thermal dissociation reaction.

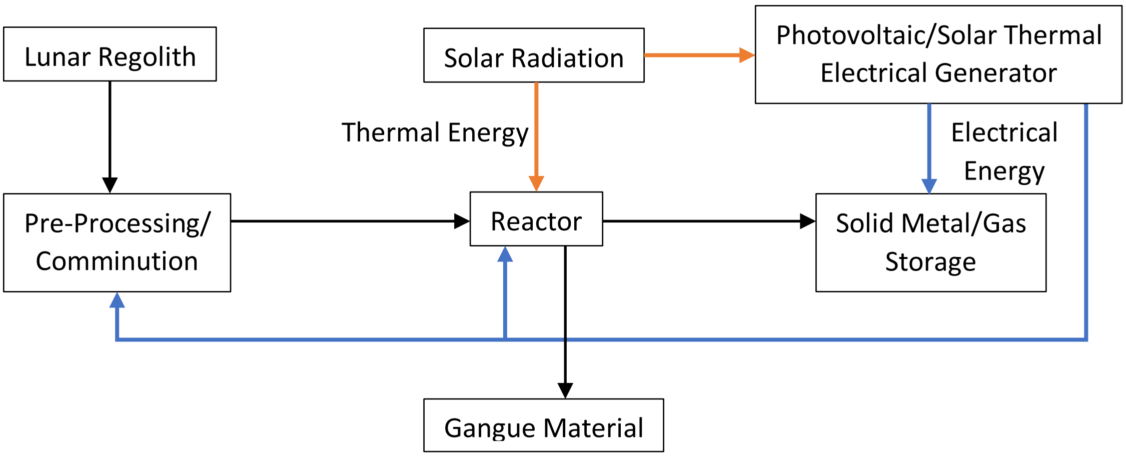

Figure 2 - Basic schematic of an ISRU process that uses solar radiation both directly and indirectly via electricity generation to produce usable resources on the lunar surface.

Currently, testing of a vacuum apparatus that utilises the Swinburne Solar Simulator developed by Ben Ekman et al. [4] is underway to validate the predicted effectiveness of this thermal dissociation and fractional deposition process for lunar metal production.

Other projects that are in initial phases include:

- Dust mitigation and ground stabilisation via the solar sintering of the lunar surface,
- Helium-3 extraction from the regolith using solar thermal power,
- Modelling of heat transfer through the regolith from a solar thermal concentration source.

Challenges for Solar Power Based Technologies on the Moon

For earth based solar processing technologies, the two main issues are the day/night cycle, and that of access to a steady solar flux. With an average steady solar flux of 1361W/m^2 [5] available for use during the lunar day, the issues encountered on earth due to the attenuation of the solar flux by the atmosphere and weather phenomenon are not an issue on the lunar surface. Whilst the available flux varies slightly through the year due to orbital paths, the local fluctuations are close to non-existent resulting in the potential for very thermally steady solar power based processes. An equatorial lunar day lasts for 708.72 hours, or around 29.5 earth days. This means that a processing facility utilising direct solar flux could run continuously with a steady flux for over two weeks at a time.

This would be followed by a second two-week period where there was no access to direct sunlight at all. This extreme duration without access to sunlight affects both photovoltaic power generation as well as any potential solar thermal processes and represents a significant issue in terms of the reliability of such processes in equatorial regions.

Due to the very shallow axial tilt of the Moon (1.54° versus the 23.44° of Earth [6]), there is a lack of seasonal variation in illumination conditions. This lack of major seasonal variation results in the existence of areas on the lunar poles that experience direct sunlight for greater than 50% of the lunar year. Using data from the Wide Angle Camera (WAC) on the Lunar Reconnaissance Orbiter, Speyerer et al. [7] mapped the illumination of the north and south pole areas for a full lunar year. They calculated that the area of maximum illumination on the south pole (89.740°S, 201.2°E) experienced direct sunlight for 71.7% of the year. An illumination map of the polar regions can be seen in Figure 3 displaying both the highly illuminated areas as well as the permanently shadowed craters in the vicinity.

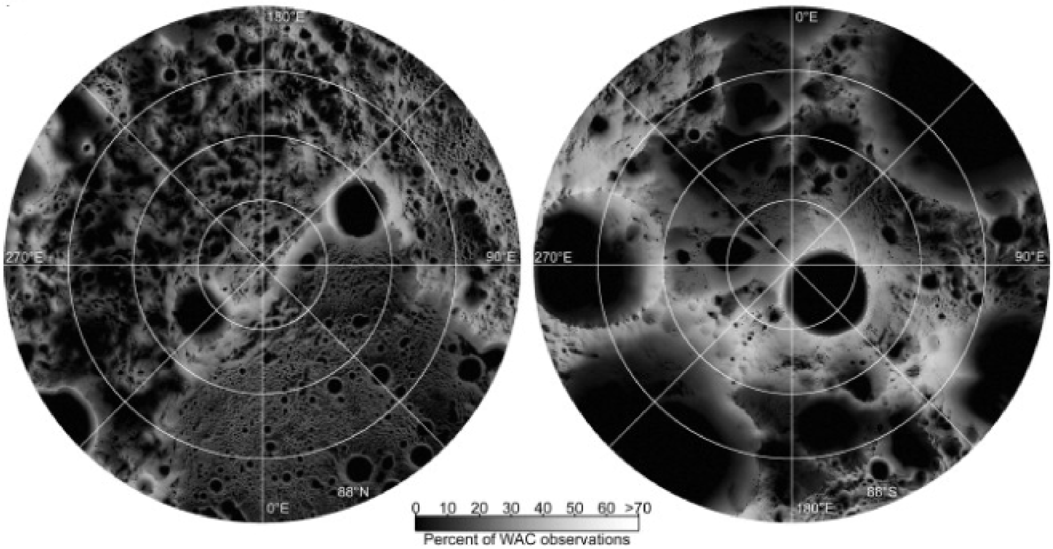

Figure 3- First order illumination map of the lunar north and south poles, data derived from the 3782 and 4036 WAC observations acquired of the north and south pole during a lunar year (15 February 2010 to 5 February 2011). Figure from Speyerer et al. [7].

In a similar earlier study Bussey et al. [8], using laser altimeter-derived topography from the Japanese Kaguya satellite, identified two areas less than 10 km apart from each other that were collectively lit for and estimated 94% of the year. It was identified that for periods of up to several months in the year these areas would have access to un-interrupted sunlight [8]. These regions, with combined access to sunlight of potentially 94% of the year have gained a lot of interest over the last decade. In terms of the applicability of solar thermal powered resource extraction processes, they provide a significant opportunity in terms of process feasibility.

An additional challenge for solar powered processes and energy generation on the lunar surface is that of the lunar dust. The dust on the Moon is both extremely abrasive and, due to the lack of atmosphere on the lunar surface, electrostatically charged. This dust presents significant issues in terms of materials selection and apparatus design for lunar based activities. Both active and passive solutions to the issue that the lunar dust will present need to be incorporated into all designs for lunar use to ensure complications are avoided. A simple design principle can be to avoid moving parts where at all possible, however this does not address the potential of dust build-up on photovoltaic panels and solar thermal concentrators. A potential alternative is the use of artificially generated electrodynamic dust shield that can utilise the charged nature of the dust to repel it from equipment [9]. The issue of the lunar dust is not isolated to solar based technologies; however, to ignore the potential hazards the dust will present to lunar equipment will cause issues in future endeavours.

Conclusions

Solar radiation is an abundant resource that has significant potential for terrestrial based processing technologies. This potential is even more amplified when considering the access to un-attenuated solar radiation in cislunar space and beyond. The research team at the Swinburne University of Technology aim to develop and prove technologies that will both help with the current global efforts to establish crewed settlements on the Moon but also help prompt new and interesting ways to utilise similar technology on earth for greener metals production. There are a number of challenges facing the use of solar based technology on the lunar surface however none are insurmountable, and solar thermal technology has many benefits over other technologies using electrical energy sources.

References

1. Kornuta, D., et al., *Commercial lunar propellant architecture: A collaborative study of lunar propellant production.* REACH, 2019. **13**: p. 100026.
2. Minogue, J., M. Shaw, and G. Brooks, *Solar thermal furnace for producing lunar regolith bricks, unpublished manuscript.* Swinburne University of Technology, 2020.
3. Shaw, M.G., et al., *Thermodynamic Modelling of Ultra-high Vacuum Thermal Decomposition for Lunar Resource Processing, Unpublished Manuscript.* Swinburne University of Technology, 2020.
4. Ekman, B.M., G. Brooks, and M.A. Rhamdhani, *Development of high flux solar simulators for solar thermal research*, in *Energy Technology 2015*. 2015, Springer. p. 149-159.
5. Kaczmarzyk, M., M. Gawronski, and G. Piatkowski. *Global database of direct solar radiation at the Moon's surface for lunar engineering purposes*. in *E3S Web of Conferences*. 2018. EDP Sciences.
6. Meeus, J., *Mathematical astronomy morsels*. 1997.
7. Speyerer, E.J. and M.S. Robinson, *Persistently illuminated regions at the lunar poles: Ideal sites for future exploration.* Icarus, 2013. **222**(1): p. 122-136.
8. Bussey, D.B.J., et al., *Illumination conditions of the south pole of the Moon derived using Kaguya topography.* Icarus, 2010. **208**(2): p. 558-564.
9. Calle, C.I., et al., *Active dust control and mitigation technology for lunar and Martian exploration.* Acta Astronautica, 2011. **69**(11): p. 1082-1088.