Thermal mining of icy regoliths: production decline mitigation.

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Introduction: Extraction of ice in Permanently Shadowed Regions of the Moon using the thermal mining method may follow distinct production phases closely related to the build-up of a sublimation lag and loss of bulk thermal conductivity [1]. Negative feedbacks in lunar water production, capture and processing need to be closely studied and mitigated using operational and technological methods. Two novel production methods are especially promising: (1) continuous thermal mining, utilizing fast removal of the sublimation lag, and (2) fracking thermal mining, utilizing injection of a high thermal conductivity material into icy regolith porous space and fractures. These two methods are studied in homogenous and heterogenous icy deposit conditions using combined heat and mass transfer model, and are compared with the baseline thermal mining method yields. Technical feasibility of those methods is also discussed. Production improvements are observed across different production scenarios. This proves that maintenance of bulk high-thermal conductivity in the mined deposit may improve water production in PSRs, while new systems and operational strategies have to be included in the development of ice extraction infrastrcucture. Thermal mining once again proves that it is a very promising architecture for development of the cislunar econosphere, showing yields of thousands of metric tonnes of water per extraction.

Modelling: Based on the previous time-dependent combined heat and mass transfer model found in [1] and [2] (baseline scenario A), an extended variability was introduced to investigate different extraction scenarios, with addition of bulk regolith depth-dependence (scenario B), ice content depth dependence (scenario C), lowered ice density (scenario D), and continuous sublimation lag removal (scenario E). As in the baseline investigations, focus is set on the phase change interface and its behaviour, as it can be easily translated to water production and production rates. The continuous lag removal is modelled with mesh movement governed by the limit on icy fraction in nodes. The lag removal is consistent with continuous scraping or blow-off of the hot sublimation lag, as the extraction progressed deeper.

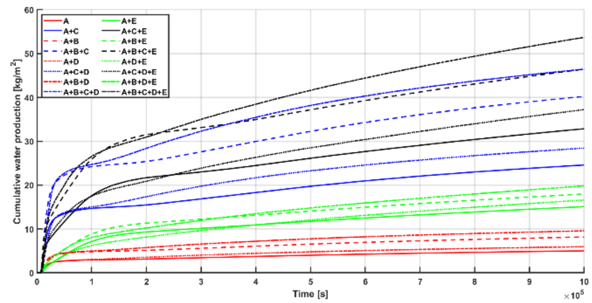

Figure 1. Cumulative production across different scenarios.

Discussion: Across the different scenarios, yields are increased relatively to the baseline. Such observations can be made:

- Bulk thermal conductivity is the main production factor during thermal extraction of ices – the extraction systems should aim to keep this parameter high, whenever possible. Introduction of non-icy high-TC materials in the deposit (through fracking) may be advantagous;
- Heterogenous, depth-increasing distribution of ice and regolith density positively affects production yields;
- Exposure of ‘fresh’ ice, especially in heterogenous deposit, is advantageous;
- Regardless of the scenarios, production still follows distinct production phases, with high production rates at the beginning, and slow decline in time.

References:

[1] T. G. Wasilewski, "Lunar thermal mining: Phase change interface movement, production decline and implications for systems engineering," *Planetary and Space Science,* vol. 199, 2021.

[2] T. G. Wasilewski, T. Barciński and M. Marchewka, "Experimental investigations of thermal properties of icy lunar regolith and their influence on phase change interface movement," *Planetary and Space Science,* vol. 200, 2021.