High Vacuum Metallurgy: Opportunities in Lunar Resource Processing

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ABSTRACT

The effect of low-pressure environments on metal compound stability is a well-known but scarcely used phenomenon even though reduction processes operating at sub-atmospheric pressures offer significant benefits in terms of the energy requirements for metal compound reduction. At industrial scales, some vacuum metallurgical processes such as silicothermic reduction to produce magnesium metal via the Pidgeon process, routinely operate under low vacuum conditions (1 to 10^{-5} atm). However, more often in terrestrial industry, the benefits of these vacuum conditions are counteracted by equipment availability and production rates. The use of high vacuum conditions ($<10^{-10}$ atm) to promote the production of metals at significantly lower temperatures is rendered unviable by the lack of industrial scale vacuum pumping apparatus capable of attaining these pressures. The difficulty in obtaining ultra-low pressures at industrial scales combined with the seeming lack of need to focus on the reduction of energy requirements for metal compound reduction, results in vacuum metallurgical processes being overlooked for terrestrial applications. In contrast however, the challenge presented by the likely need for metal production in space for supplying future off-earth activities has the opposite requirements. In space, and specifically on the Moon, access to electrical energy is significantly limited and extremely costly, and instead of high vacuum conditions requiring extremely specialised pumping equipment, these conditions represent the natural ambient conditions found at the lunar surface. We predict that the development of low-pressure metal production technologies for use in space will heavily favour the field of vacuum metallurgy. In this talk we present a set of calculated Ellingham diagrams that demonstrate the effects of vacuum conditions on oxide stability and highlight the significant advantages these vacuum conditions can provide in the field of Astrometallurgy.