Unique Properties of Lunar Soil Lead to Unexpected ISRU Discoveries

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Abstract. Returning humans to the Moon in the near-future necessitates designs and construction for many engineering projects for lunar exploration and In-Situ Resource Utilization activities. One factor common to all activities on the Moon is the ever-present, sharp, abrasive, glassy dust – the <20 μm portion of the lunar regolith, making up ~20 wt% of the soil (Taylor et al., 2005). Various ISRU activities will entail large-scale transport of lunar regolith, but conventional means will launch huge amounts of dust to produce numerous deleterious effects, for example, as it falls back covering installations such as solar cells. The <5 μm portions can remain suspended in electrostatic levitation around the Moon – possibly negating effective astronomy [Stubbs et al., 2005]. But, can this dust portion of the soil be kept from having such show-stopping effects? This is the subject of our study – to mitigate against the deleterious effects of the omnipresent lunar dust.

The unique properties of lunar regolith make for the extreme coupling of the soil to microwave radiation. Space weathering of lunar regolith has produced myriads of nanophase-sized metallic Fe grains (as in an iron nail) set within silicate glass, especially on the surfaces of grains, but also within the abundant agglutinitic glass of the soil. **It is possible to melt lunar soil (i.e., 1200-1500 ^{o}C) in minutes in a normal kitchen-type 2.45 GHz microwave, almost as fast as your tea-water is heated.** Using real Apollo 17 soil has demonstrated the uniqueness of the interaction of microwave radiation with the soil. The applications that can be made of the microwave treatment of lunar soil for *in-situ* resource utilization (ISRU) on the Moon are unlimited (Taylor and Meek, 2005) as illustrated in Figures 1 and 2.

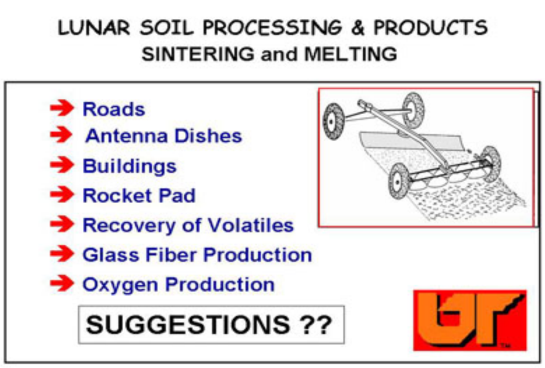

Figure 1. Multiple Uses for Lunar Microwave Technology

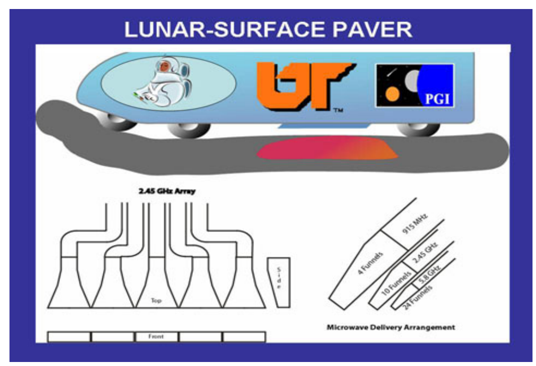

Figure 2. Microwave Lunar Paver

For many ISRU endeavors, it is imperative that methods of handling and collecting lunar regolith be developed that mitigate against the possibility of stirring too much dust into the lunar "exosphere". We have devised a potential scheme to minimize the dust problem utilizing its ferromagnetic properties, due to the presence of nanophase metallic Fe in the ~40-50% impact glass of the lunar soil (Figures 3 & 4). The presence of 80-90% glass in the dust makes this portion of the soil totally capable of being attracted by a simple magnet [Taylor et al., 2005] and called a **Lunar soil MAgnectic Collector- LSMAG**. The presence of this np-Fe bearing glass in larger agglutinates also renders a magnetic susceptibility to the larger grain-sized soil particles. It should be possible to effectively "suck-up" the regolith using magnetic fields. This can be done in a similar fashion to the way maglev trains and coil guns (or gauss weapons) work [Taylor & Eimer 2006]. **These two developing technologies *use consecutive electro-magnets to pull an object along.*** The largest advantage of these technologies is that there are no moving parts in the device. Most importantly, such an attracting systems applied to the Moon would not only pull the soil along, but effectively capture the dust as well.

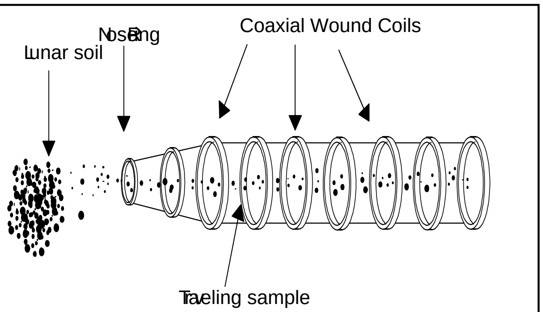

Figure 3. Diagram of our **"Lunar Soil MAgnetic Collector" - LSMAC.** Coaxial rings are sequentially powered up and down in a rippling effect to move ferromagnetic lunar soil to the right.

The operation of this 'coil vacuum' is conceptually simple (Fig. 3). This device consists of a series of wound coils individually controlled to generate magnetic fields in sequence. Soil is picked up by a 'nose coil' and pulled through the center of the coil. As this moving soil approaches this first coil, the coil is powered down, and the next coil in the sequence is powered up and attracts the particles of soil further into the tube. As the soil approaches this second coil, it too is powered down, and the next coil in the sequence is powered up to tractor the soil further down the line. This process of turning coils on and off continues in a "caterpillar/millipede effect" moving the soil particles along this electronic-conveyor belt (Figure 4).

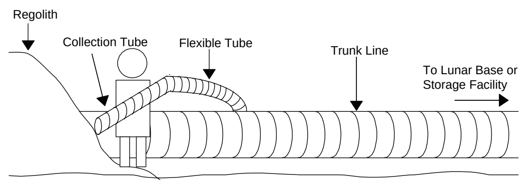

Figure 4. Conceptual drawing of possible method of collecting lunar soil using the **"Lunar Soil MAgnetic Collector" (LSMAC).**

The astronaut/robot uses a slightly flexible coil 'sucker tube' to collect soil, which is in turn fed into a hard mounted "Trunk Line" that is capable of higher flow rates and is transported to be used at a relatively stationary facility. Multiple collection branches would feed into one trunk line. This allows for several areas to be excavated simultaneously, and as the regolith is exhausted in one large area, the Trunk Line can be extended to new areas.

However, even using the LSMAC to mitigate the dust that is suspended above the lunar surface, contamination of any pressurized module is inevitable and will be a persistent problem for any human presence on the moon. To reduce the health threat to anything living in these locations, it is necessary to have an air purification system that is able to effectively remove particulate contaminants from the air. This will require a multi-stage system to reduce the need for consumable HEPA filters (Fig. 5), and presents another opportunity for the magnetic properties of the lunar regolith to be used.

The **Lunar Air Filtration with a Permanent-Magnet System – LAF-PMS** – uses magnetic fields to attract particles out of the air. From fundamental electromagnetic theory, it is known that the force on a ferromagnetic particle due to a magnetic field is proportional to the gradient (change) of the field at the particle. Therefore, large field gradients are needed to trap the lunar dust within the filter. Using electromagnets, as in the case of the LSMAC, is not energy efficient due to the field strength required and the long duration that the fields would have to be on. Instead, it is more advantageous to use strong permanent magnets to generate the needed fields, requiring energy only to destroy the gradients to allow for cleaning Plastic columns slide vertically, indicated by the fine arrows. To turn the filter off, the iron inserts in the plastic column are slid into the gap between the magnets (Figure.5)

To achieve the large field gradients needed for the LAF-PMS with permanent magnets, much care must be taken in choosing a layout to prevent canceled, wasted, or stray fields. By placing opposite poles of two long permanent magnets close together a region with large field gradients is formed around the resulting gap (Fig. 5 Insert). This concept has been used previously on the nano-scale to attract paramagnetic gas particles, however, this concept is fundamental to magnetic fields and is independent of scale [4]. The technical challenge of this design is to incorporate the ability to destroy the gradients, reversibility, and on command. This can be accomplished by either: (1) changing the susceptibility of the material or (2) by generating a independent flux, within the gap between the magnets.

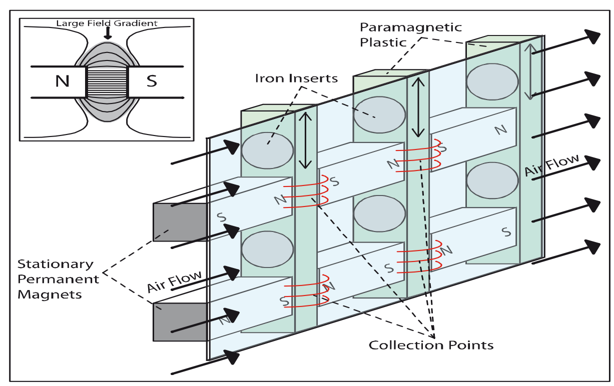

Figure 5. Schematics of the **LAF-PMS.**

Magnetic field gradients are shown by representative flux lines. These are the collection points for ferromagnetic dust. Insert: Sketch of the flux lines between two long magnets.

The LAF-PMS is made up of a plates of magnets that are arranged in rows with spaces between them (Figure 2). When the filter is 'on', the material between the magnets is paramagnetic and, therefore, has no effect on the magnetic fields. Air passes on both sides of each plate with particles being attracted to each gap. Turning 'off' the LAF-PMS for cleaning involves the simple exchange of the material between the magnets. If a soft magnet (i.e., Fe) is inserted into these gaps, the gradient between the magnets, disappears and the trapped dust is freed. Cleaning can then agitation or wiping. The filter is then reactivated by pulling the Fe out from between the magnets, thereby restoring the localized, intense fields.

The dust of the Moon is one of the major environmental challenges that we face in returning to the lunar surface. However, this dust can be of great use in making life on the Moon possible. It is a matter of perspective and attitude that can change this pest and curse into an invaluable tool and resource. By using properties that are inherent in the lunar soil, it is possible to eliminate the potential hazard of having this dust suspended above the surface.

References: [1] Taylor, L.A., and Meek,T., Jour. Aerospace Engr. **18,** 188-196(2005); [2] Taylor, L.A., Schmitt, H.H., Carrier, W.D., III, and Nakagawa, N., AIAA, 1st Space Explor. Conf., Orlando, FL, CD-ROM(2005); [3] Taylor, L.A., and B.C. Eimer, *Space Resources Roundtable VIII.*(2006); [4] Eimer, B.L. and Taylor, L.A., Space Round Table VIII (2006).