# Size Beneficiation of Regolith for Simplicity and Efficiency

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**Motivation**
NASA will process regolith at some point on the surface of an extraterrestrial body. If that process requires some sort of fluid-granular reaction, then control of particle size will be an essential process control for reaction success. This generally means a well bounded size range. Such process control is an ever more sophisticated effort in terrestrial industry. An anecdote from a former DOW Chemical employee describes a multi-billion dollar powder processing facility that failed and was scrapped because the control of powder feeding the reactor was inadequate. Even the Mars Phoenix lander already sought to control particle size for a science instrument. My charter from the In-Situ Resource Utilization (ISRU) program was to develop size sorting systems and characterize their performance.

The specific charge from the program was to develop a concept system that could produce about 13 kg of size sorted material per hour for the ROXYGEN reactor system. That shaped the initial sizing choices in some of what you see later. At this point size beneficiation is not a subsystem in reactor hardware that has to meet much smaller mass and volume constraints than ROXYGEN. A small size beneficiation system will be suggested in this paper.

**Criteria and Line of Reasoning**
Several issues were dominant in our hardware choices: (1) gravity independence, (2) simplicity and reliability, (3) energy efficiency, and (4) volume and mass. A background notion was that terrestrial granular handling industries often started with the simplest and most robust systems when doing things for the first time on the frontier. After surveying industry, the oldest and most trusted size beneficiation method, with clean size range cut-offs, used sieves in some fashion.

Knowing that granular flow in low-g is a problem, and sieves often blind with some particles getting caught in the small passages, solutions to these problems had to be found. De-blinding occurs by exerting forces on lodged particles to pop them out of the screen. Sometimes that is done by vibrations and sometimes by flexing the screen. Brushing is another method that was not explored here. To overcome low gravity it was realized that granular flow, including sieving, is facilitated by shearing motion and bearing forces. When particles are forced to rearrange in the vicinity of a small passage they increase their chances of orienting to get through the passage. Hence, a shearing-based sifter was sought.

Our first comparative experiments to examine the effects of low-g was on lunar-g parabolic flights in 2009. We built two home-grown concepts: (A) a horizontal vibratory sifter and (B) a rotary flat shearing sifter much like a flour sifter.**[PICS]** Vertical vibrations were not tried, expecting that low-g would only cause the particles to levitate off the screen too much to be effective. Testing the same equipment in 1-g in vacuum yielded the same comparative performance of the two systems. The message gained from that experiment was that the shearing sifter worked better.

In 2010 a University of Wisconsin team won a low-g flight opportunity for a sifter test. A thought was that an optimally designed commercial sifter would work better than what we built in-house. A commercial vibratory sifter was loaned to the team by Russell Finex. The qualitative report of results by the students was that the unit performed well. As a result there was a proposal for a low-g flight to repeat the student test with better instrumentation and experiment control. An ultrasonic deblinding feature was added for this flight as well, since we saw blinding in the Finex unit under 1-g at GRC. A vibratory sifter is very attractive from a wear life perspective. The continuous flow and batch configuration of these systems make them operationally simple and compact. Vibratory sifting would seem greatly affected by low-g and we have conflicting evidence of that so far. Careful measurements are the only way to make the right decision.

In the meantime a ROXYGEN-sized box-shaped shearing sifter was developed. **[PIC]** The box sifter allows two tiers of sifting in one system, which enables bounded particle size distributions. The rectangular geometry and motion enables three discrete exit paths, fore, aft, and bottom, of material with no extra mechanical parts. The bar shape was like a parallelogram with a vertex towards the screen in order to provide both shearing and normal forces on the material next to the screen, The screen support grating was aligned in the shear direction to avoid plowing larger particles against the screen and puncturing it, while flexure was possible in the transverse direction for de-blinding. The shear bar to screen clearance was kept small to assure optimal shearing motion of the granular material at the screen.

**Measurements to-date**

At this point we can report sifting results in 1-g using JSC-1a, OB-1, and LHT-2M for each of the box sifter and commercial vibratory sifter. However, the vibratory sifter showed blinding and ultrasonic de-blinding tests are yet to be run.

Given space limitations for this abstract, the reader should examine the symposium presentation for graphs of the results. However, some important observations are: (1) the box shearing sifter took less energy per unit mass produced than the vibratory sifter, (2) the ROXYGEN scaled box sifter was able to produce the the required rate of material while the vibratory sifter was too small or took much longer, (3) the area swept by the shear bars per mass produced was a good indicator of wear and was large enough that ultimate system designs will have to look at keeping system volume down while keeping area swept high, and (4) the percent efficiency of getting a size range from the feedstock relative to what is ideally possible was higher for the box sifter than the vibratory sifter but was never 100% in useful time scales for production.

**Other sifter candidates**

Systems considered have been: (1) vibratory sifter, (2) shearing sifter, (3) sonic sifter, and (4) barrel sifter. The testing of a commercial sonic sifter showed it to be slow for smaller particles and needed a gas pressure to operate. A simple barrel sifter was not tested because it has become clear shearing is valuable and a shearing barrel sifter being developed by Grainflow under an SBIR is the best test of this concept.**[PIC]**

**Conclusions**

The net conclusions from this work are that given low-gravity, vacuum, high quality size range control of product, simple robust hardware for long production life, and energy efficiency, then a shearing sieve-based system is a safe winner. Sieving has an industrial history that is well developed and trusted. Shearing does solve the low-g issues. Deblinding can be handled with built in modest screen flexure. It is long known that the lowest energy way to move granular material is a conveyor. In this sieving case the need for direct sliding surfaces is still less energy demanding than other high kinetic energy-based methods like vibratory methods. Wear does remain an issue and must be solved by development of wear-resistant materials. Note that wear resistant materials are an imperative for all usefully long-lived regolith handling machines. It is a gap in the ISRU program.

A good shearing sifter has design subtleties like shear bar shape and shearing clearance that matter.

Lastly, shearing sifters come in all sizes from a cup to as big as desired.**[PIC]** It all depends on the amount of product needed and modes of operation chosen.