Particle Transport on the Mars Science Laboratory Mission: Effects of Triboelectric Charging.

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Introduction: One of the major challenges facing the 2009 Mars Science Laboratory (MSL) onboard analysis system is the ability to successfully transfer fine-grained powders from the sample acquisition unit to the analytical instruments that make the scientific measurements. Understanding how particles flow, especially ones that are less than 150 microns, in the Martian environment is crucial for the success of the science payload on the MSL rover. For MSL, two types of samples will be collected for scientific analysis: unconsolidated regolith using a scoop, and 150-micron or less particles created and collected in a rotary percussive drill. Both samples will utilize the Collecting and Handling for In-situ Martian Rock (CHIMRA) subsystem at the end of the robotic arm to sieve and portion the collected samples before being transferred to the sample inlets for the two analytical instruments that make up the MSL payload. During this collection and transportation phase, fine-grained particles will be in constant contact with the sample handling hardware and other particles as they move throughout the sample chain.

On Earth, moving particles cause electrostatic charging, specifically, triboelectric charging, which occurs when two particles are charged as they are moved when in contact with each other or other materials (i.e. rubbing). The presence of induced charges on particles causes individual particles to either stick together due to the attraction of opposite charges or repel each other due to the presence of like charges. On Earth, these charges are quickly dissipated by moisture in the atmosphere. But, in the low pressure, low humidity environment on Mars, charge dissipation is much slower and this effect has been shown to be problematic. Therefore, in order for MSL to be successful, it is important to understand how fine-grained samples will transfer on the surface of Mars, as well as what effects electrostatic charging may have on the quantity and quality of the material that is delivered to the science instruments, specifically understanding cross sample contamination is important to better understand scientific results. The goal of the current work is to characterize the charging effect of dry particle movement under ambient Martian conditions, using a suite of martian analog materials and possible flight hardware construction materials and to determine what effect electrostatic charging of fine-grained materials will have on the delivery of sample through the Sample Acquisition/Sample Processing and Handling (SA/SPaH) subsystem on the surface of Mars.

Experiment: All tests were performed at Martian environmental conditions (e.g. pressure, CO_2) in the Mars Chamber at the Extraterrestrial Materials Simulation Laboratory (EMSiL) at JPL. Four series of tests (TS1-TS4) were conducted to understand the effect of triboelectric charging.

Test Series #1 (TS1) - Aluminum Cup: TS1 was focused primarily on characterizing and validating our test setup configuration and functionality as well as providing a basic visual understanding of the induced charging environment. During this test series, the objective was to characterize the amount of induced electrostatic charge with one possible SA/SPaH construction material, namely aluminum. A 7.5cm diameter flat cup with an attached aluminum funnel and a pre-measured amount of powdered granular material was used. Once the prescribed dry low-pressure environmental conditions had been obtained within the chamber the sample was dumped onto the catch container and the current generated by dumping was measured. During TS1 we tested MMS (1) at different particle sizes (dust, fine and coarse grained sand-MMS) and masses (15g, 10g, 5g, 2g, 1g, 0.5g). The values of the six masses correspond to the amount of material that may be delivered to the CHIMRA from the drill or scoop. Results from these test showed that a significant amount of charge is created on the sample when it is moved from one location to the other. Additional testing using different particle sizes show that average grain size and size distribution plays an important role in triboelectric charging. The amount of particle adherence inversely varied with grain size, with the dust size fraction obtaining the greatest amount of charge and the amount adhesion while the course and sand sizes showed dramatically less adhesion.

Test Series #2 (TS2) - Titanium, Aluminum and Stainless Steel Tubes: The objectives of TS2 were similar to TS1 except we utilized three possible construction materials (stainless steel, Aluminum, Titanium). All three metals exhibited the capability for triboelectric charging with titanium displaying the largest charge generation and stainless steel the least. During these tests we added a vibrator to determine if material that adhered to the walls could be removed using vibration. While material fell from the tube, discrete packets were observed rather than as a continuous flow. A visual inspection of the tubes after a return to ambient pressure showed it was heavily coated with material adhering on the inner wall. Titanium displayed the highest capacity for charging.

Test Series #3 (TS3)-Vibration Titanium Tube. The objective of TS3 was to add flight like vibration to the experiments following the experience in TS2. For these experiments titanium and MMS dust were used. Each run in included a ~10g vibration lasting 3 to 5 sec., which was followed a 1-2 sec. rotation of the sample tube to the inverted position allowing the sample to fall onto the catch container. The rotation took ~2 sec. A quiet period (non-vibe) was employed followed by another multi-second vibration maneuver to determine if more material could be removed from the tube. During the vibration, a significant amount of current was generated, mainly due to fines moving in the bottom of the tube interacting with each other and the walls of the tube. However when the charge was integrated over the entire vibration duration, it resulted in zero net charge. This is most likely due to the process of inducing a charge on a grain, which exceeds the local breakdown voltage prescribed by Paschen's Law.

Test Series #4 (TS4)- Particle Transport and Adhesion in Martian Environmental Conditions. TS4 was designed to investigate and determine the amount of adhesion and the potential for passing material through the portioner on CHIMRA (~3 mm in diameter and 8 mm long tube). For these test, an end cap with a 3 mm hole was placed on one end to determine how much material passes to the catch container, and to determine whether this small hole would act as a clogging point. As in TS3, each run included the 5 sec vibration, a rotation of the tube, a quiet period, and post vibration as was used. During the first set of these tests, it was determined that a vibration was needed to pass material through the 3 mm hole because very little material passed. It should be noted that although enough material passed through the hole to eventually be analyzed by the instruments, a significant fraction remained in the tube, even after one hour of operation. To quantify the amount of adhesion two more tests were performed, one was to place similar material into the tube multiple times, and weigh the amount of material passing, and second was to experiment with different types of material to determine how much cross sample contamination was present. In the first adhesion tests ~0.5 g of material was placed in a capped Ti tube. The tube was vibrated, inverted, vibrated again. After an hour the tube was vibrated again. At this point the tube was rotated to the upright position and the chamber was brought up to ambient pressure. The amount of sample passed was weighed, and additional sample was placed into the tube without cleaning the tube. The chamber was pumped down and the experiment repeated. After three iterations, the amount of material passing through the hole was equal to the amount of material re-introduced and the amount of material adhering to the side became constant. We attributed this to the fact that similar materials do not produce a large amount of tribo-enduced charging when in contact with other "like" particles, so once the initial surface was covered with sample, no new adhesion occurs. Once the wall of the sample tube became coated with sample it does not readily removed any of the adhering material and acts like a buffer and does not impair the amount of material passing through the tube.

***Discussion*:** In the above experiments it is quite obvious that triboelectric charging is going to be a significant issue that needs to be taken into account when analyzing the scientific results on Mars. These testes were specifically carried out to add complexity as we get closer to the actual hardware testing that is expected to occur. During these tests, we have identified adhesion to be an important effect. This occurs when the charged material comes in contact with a metal surface. Because the charged particles are in a low energy state, charge does not pass onto them, but instead forms a mirror charge that causes the charged material to adhere to the surface. In our tests this adhesion is stronger than 10g that the vibrator exerts on the surface.

References: (1) Peters, G. H., W. Abbey, G. H. Bearman, G. S. Mungas, J. A. Smith, R. C. Anderson, S. Douglas and L. W. Beegle (2008). "Mojave Mars simulant - Characterization of a new geologic Mars analog." Icarus **197**(2): 470-479.