SIMULATING TRIBOELECTRIC CHARGING OF CHEMICALLY-IDENTICAL GRAINS UNDER NEAR-SURFACE MARTIAN CONDITIONS

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Introduction:

When a granular substance is fluidized, particles undergo collisions and charge frictionally [*Lacks and Sankaran*, 2011]. This *triboelectrification* is readily observable in Earth's natural systems, such as volcanic plumes [*Anderson et al.*, 1965; *Behnke and McNutt*, 2014; *Behnke and Bruning*, 2015], and is expected to be active in Martian dust devils and storms [*Eden and Vonnegut*, 1973; *Mills*, 1977; *Krauss et al.*, 2003; *Delory et al.*, 2006; *Forward et al.*, 2009b]. Electrification in Martian dusts systems may contribute to a global electric circuit on Mars [*Farrell and Desch*, 2001], localized discharge events (lightning) [*Eden and Vonnegut*, 1973; *Mills*, 1977], or chemical reactions that alter the surface and have implications for the presence of life as we know it [*Delory et al.*, 2006; *Kok and Renno*, 2009]. While on Earth the electric fields produced in dusty flows rarely reach the breakdown limit of 3 MV/m (volcanic plumes being the most obvious exception [*Cimarelli et al.*, 2014]), on Mars the low pressure CO2 environment requires smaller fields (~20 kV/m) to initiate breakdown [*Krauss et al.*, 2003]. Furthermore, the relatively large conductivity near the Martian surface suggests that discharge may manifest as glow discharge or small arcs, rather than kilometer-long sparks as observed in Earth thunderstorms [*Kok and Renno*, 2009].

Previous work has demonstrated a wide array of electrostatic phenomena occurring under Martian conditions. For example, *Eden and Vonnegut*, [1973] reported a faint glow in an agitated flask containing particles surrounded by a low-pressure CO2 environment. Similar experiments were conducted by *Mills*, [1977]. This last investigator also postulated that charging in Martian storms could lead to the breakdown of organic material at the surface. More recently, [*Krauss et al.*, 2003] conducted much more quantitative experiments on triboelectrification relevant to Mars in which discharges where produced either by stirring a volume of dust or by dropping a mixture of Mars simulant and glass beads through a tube.

While all these experiments have yielded valuable insight regarding electrification process on Mars, they also have important limitations. In all cases, for example, the Mars simulant was in direct contact with foreign objects (either the wall of the experimental vessel, a stirrer, or other types of particulates). Because frictional electrification is often enhanced in systems where two chemically distinct surfaces interact, such experiments may be overestimating the magnitude of electrification on Mars.

To counter these problems, *Forward et al.*, [2009b] used a novel spouted bed apparatus to restrict contacts between particles and other surfaces. This work showed that JSC M-1 simulant charged bipolarly, with smaller particles charging negatively and larger ones positively. In this case, the authors do not report discharge processes. This absence, however, may be due to the fact this investigation was conducted at pressures higher than those at the Martian surface and in a nitrogen environment where the breakdown limit was higher.

Here, we build upon the work of [*Forward et al.*, 2009b] to explore triboelectric charging of identical silicate insulators under near surface Martian conditions. In particular, this work aims to answer the following questions: 1) How does the energy of the granular flow affect charging? 2) What magnitudes of charge can be collected on micron-sized grains triboelectrically? 3) Do adhered salts influence the triboelectric behavior? and 4) Can electrolysis driven by electrostatic charging form the widespread perchlorates observed on the surface of Mars as has been recently postulated? [*Tennakone*, 2016]

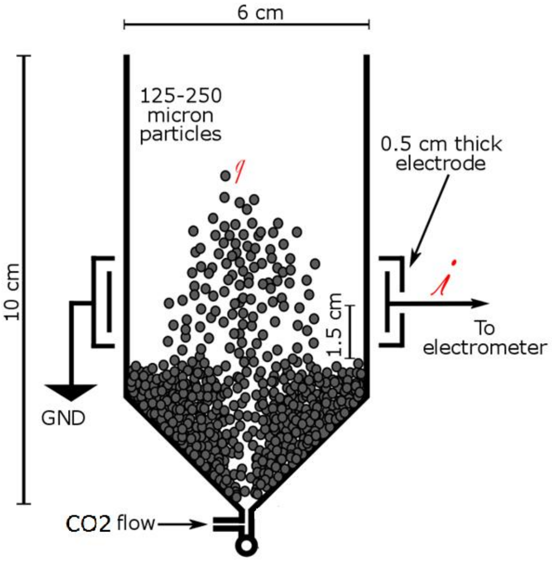

Figure 1: Schematic of experimental setup. Particles in the reactor a fluidized by a stream of CO2 and the charging is monitored by measured currents induced in a copper ring.

Methods and Preliminary Results

Based on the work of [*Forward et al.*, 2009a], we constructed an instrument capable of characterizing the triboelectric charging of ash arising from particle-particle collisions. The reactor (Fig. 1) consists of a glass tube fitted onto a machined aluminum distribution cup with a 200-micron hole milled into its bottom. The reactor can hold up 60 ml of a Mars simulant and is housed within a vacuum chamber. Before each experiment, the chamber is evacuated and then filled with CO2 to a pressure of 10 mBar. The sample is allowed to equalize with the low-pressure atmosphere for an hour.

To fluidize the bed and produce charging, a steady stream of nitrogen is forced through the 200-micron hole in the distribution cup for 60 minutes. In the resulting fountain, collide with each other and exchange charge triboelectrically. The design of the reactor is such to inhibit particle-wall interactions, ensuring that the triboelectrification of the ash parcel results primarily from particle-particle collisions.

To approximate Martian material, we use basaltic ash from the Xitle volcano (Distrito Federal, México). The material was sieved to obtain a size distribution of particles between 125-250 microns. Two sets of experiments were conducted. The first set used washed ash, while the second used ash coated with NaCl (obtained by submersing the ash in salt saturated water and then boiling off the fluid). Each sample was fluidized at 4 different driving pressures, thus modulating the energy and collision rate of particles in the system.

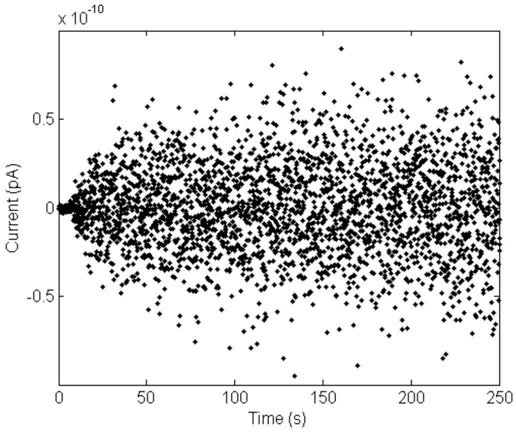

Figure 2: Raw data captured for 250 seconds at the onset of an experimental run. Each data point represents the net current induced by particles approaching and receding from the electrode. Notice that the data is centered about 0 amperes, but that the scatter of the data increases with time.

Time-dependent charging behavior: The fountain is capacitively coupled to a copper ring positioned 1.5 cm above the undisturbed bed level. When a charged particle enters the electrode, a current flows to ground through a picoammeter. As that same particle recedes, a current of equal magnitude but opposite polarity is produced. The overall current measured by the picoammeter reflects the sum of all the currents associated with charged particles moving in and out of the electrode at a given time. While the time-averaged current in the electrode is zero amperes (consistent with the closed system of the apparatus), the instantaneous current can attain magnitudes of several 10s to 100s of pA (superimposed on a noise floor ranging between 0.1 and 1 pA; see Fig. 2). The temporal behavior of particle charging is assessed by analyzing the change in the standard deviation of this instantaneous current across small timescales (every 5 sec) [*Forward et al.* 2009a]. At the onset of an experiment, the standard deviation of the current increases very rapidly as particles exchange charge. After a few minutes, however, the system reaches an electrostatic steady-state (this behavior is rendered in Fig. 3). At this point, the particles in the system have become fully charged.

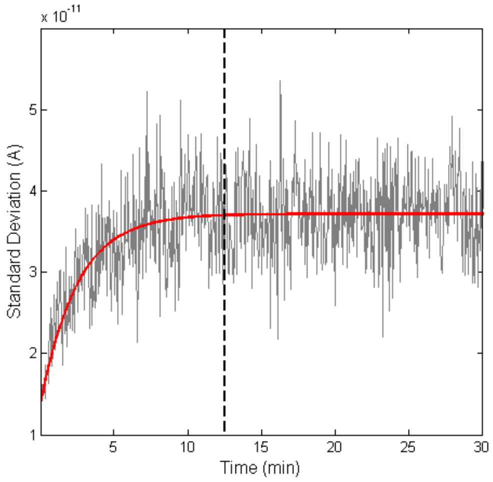

Figure 3: Electrostatic evolution of the system.

Absolute charge density measurements: Because the current signal recorded by the picoammeter is the superposition of many currents induced by particles of both polarities, it is difficult to estimate the surface charge density on individual grains. Thus, a second set of runs were conducted using the same fluidization parameters but with a micro-Faraday tube (inner diameter 5 mm and 5 mm in length), positioned above the fountain. After 60 minutes of fountaining (i.e. after the samples have reached electrostatic steady-state), the flowrate through the 200-micron hole is increased, jetting particles through the Faraday tube and the charge is measured by a charge amplifier. The operation of the charge amplifier can be described by the following transfer function:

$$V_0 = -\frac{q}{C_f} e^{-t/\tau_{RC}}. \quad (1)$$

The feedback capacitance is selected to detect charges smaller than 1 fC. Using this methodology, we can directly sample the distribution of charges in the fountain.

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