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**A STUDY OF THE ELECTROSTATIC INTERACTION BETWEEN INSULATORS
AND MARTIAN/LUNAR SOIL SIMULANTS**

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ABSTRACT

Using our previous experience with the Mars Environmental Compatibility Assessment (MECA) electrometer, we have designed a new type of aerodynamic electrometer. The goal of the research was to measure the buildup of electrostatic surface charge on a stationary cylindrical insulator after windborne granular particles have collided with the insulator surface in a simulated dust storm. The experiments are performed inside a vacuum chamber. This allows the atmospheric composition and pressure to be controlled in order to simulate the atmospheric conditions near the equator on the Martian surface. An impeller fan was used to propel the dust particles at a cylindrically shaped insulator under low vacuum conditions. We tested the new electrometer in a 10 mbar CO₂ atmosphere by exposing two types of cylindrical insulators, Teflon (1.9 cm diameter) and Fiberglass (2.5 cm diameter), to a variety of windborne granular particulate materials. The granular materials tested were JSC Mars-1 simulant, which is a mixture of coarse and fine (<5 μ m diameter) particle sizes, and some of the major mineral constituents of the Martian soil. The minerals included Ottawa sand (SiO₂), iron oxide (Fe₂O₃), aluminum oxide (Al₂O₃) and magnesium oxide (MgO). We also constructed a MECA-like electrometer that contained an insulator capped planar electrode for measuring the amount of electrostatic charge produced by rubbing an insulator surface over Martian and lunar soil simulants. The results of this study indicate that it is possible to detect triboelectric charging of insulator surfaces by windborne Martian soil simulant, and by individual mineral constituents of the soil simulant. We have also found that Teflon and Fiberglass insulator surfaces respond in different ways by developing opposite polarity surface charge, which decays at different rates after the particle impacts cease.

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1. INTRODUCTION

When spacecraft, landers, and the spacesuits of future astronauts come into contact with either the lunar or Martian soil, it is believed that triboelectric charge generation on their man-made material surfaces may result in potentially disastrous situations. The absolute lack of humidity on the lunar surface, and the extremely arid conditions on the Martian surface have raised concerns that electrostatic charge buildup will not be dissipated easily. If triboelectrically generated charge cannot be dissipated or avoided, then dust will accumulate on charged surfaces and electrostatic discharge may destroy electronic components. Solar panels and thermal radiators that accumulate dust over time will have decreasing efficiency. Moving parts, such as joints in spacesuits, will also be affected as soil accumulation inhibits their motion.

There are two mechanisms by which a surface can become triboelectrically charged. The first method is through frictional contact by rubbing the surface over the soil. The second is through collisions between windborne dust particles and a surface. Although the second method of charge generation is not possible on the moon, dust storms occur on a frequent basis on Mars. Major Martian dust storms are easily visible from Earth, and satellites orbiting Mars have also observed the occurrence of so-called dust devils that can drive soil high into the atmosphere.

The Mars Environmental Compatibility Assessment (MECA) electrometer was designed jointly by the Jet Propulsion Laboratory and Kennedy Space Center to be a flight instrument on a 2001 unmanned Mars lander mission [1, 2], which was later cancelled. The MECA electrometer was designed primarily to characterize the electrostatic interaction between insulating materials and the Martian soil by rubbing the insulators simultaneously over the soil. The five insulators chosen for the MECA Electrometer were Fiberglass/Epoxy (G10), a Polycarbonate (Lexan™), Polytetrafluoroethylene (Teflon™), Rulon J™, and Polymethylmethacrylate (Lucite™, also called PMMA). The MECA electrometer also contained an ion gauge for detecting charged particles in the Martian atmosphere, and an electric field sensor for detecting the local electric field on an object's surface.

Our research goal last year [3] involved testing and evaluating the MECA electrometer and its four types of onboard measurement sensors: (1) a triboelectric sensor array, (2) an ion gauge (charged particle sensor), and (3) a local electric field sensor. These goals were accomplished by (1) bringing the MECA electrometer into physical contact with Martian and lunar soil simulants [4, 5], (2) using a weak alpha particle source to create atmospheric ions under low vacuum conditions, and (3) applying a known voltage to a metal plate above the electric field sensor.

In 2001, our summer research evolved into measuring the effect of windborne dust particles on insulator surfaces. Martian dust storms were simulated in a vacuum chamber using an impeller

fan to propel dust particles at an insulator-capped electrometer. The electrometer sensor was embedded below the surface of a cylindrically shaped insulator. The insulator target had a cylindrical shape for aerodynamic reasons. Less turbulence would be created as wind encounters a cylinder. Hence, windborne dust particles would more likely impact the windward side of the cylinder in head-on collisions at higher speeds than they would under more turbulent conditions, thus maximizing the triboelectric charge they can produce.

The experiments and data taken using our new electrometer are described and presented in the following sections. We conclude with a discussion of the results of the experiments, and present conclusions about the new electrometer.

2. EXPERIMENTAL

In this section, we describe the design and development of the new aerodynamic electrometer. We also present data taken with the electrometer under conditions that attempt to simulate a Martian dust storm.

2.1 Design of the Aerodynamic Electrometer

The purpose of this research was to measure the amount of electric charge that is generated triboelectrically when windborne dust particles strike an insulator surface. A cylindrical geometry was chosen for the design of the electrometer based on its aerodynamic shape. When wind encounters a cylinder under non-turbulent conditions, the atmospheric molecules in the wind will follow streamlines around the cylinder. Any turbulence that might occur would be found on the side opposite the windward face of the cylinder. By contrast, a planar surface that is perpendicular to the wind will create turbulence everywhere over the surface. Any turbulence at the surface is likely to diminish the effect of an impact between a windborne dust particle and the surface. For these reasons, a cylindrical shape was chosen for the electrometer in order to maximize the chances for a windborne dust particle to make an impact with the electrometer. In addition, it was expected that an aerodynamic design would more likely produce consistent and reproducible results.

Dust particles that are carried by the wind will also tend to follow the streamlines unless the streamlines begin bending too sharply around an obstacle such as a cylinder. Since the dust particles are much more massive than the atmospheric molecules, there is high probability that they will cross streamlines due to their momentum and strike the cylinder's surface. This is especially true for particles that are on a head-on collision with the cylinder.

When a dust particle makes contact with the cylindrical insulator's surface, electric charge can be transferred between the two materials even if both are originally neutral. The physical reason for this is well known from solid state physics. Charge transfer is necessary in order for the two dissimilar materials to reach equilibrium. If the two materials that are brought into contact have different Fermi energies, then electrons will try to move from the material with the higher Fermi energy to the other material in order to equalize their Fermi energies.

2.2 Experimental Procedure

Figure 1 shows the aerodynamic cylindrical electrometer system that was constructed to perform the experiments. A dc power supply (not shown) is normally attached below the electrometer's electronics housing.

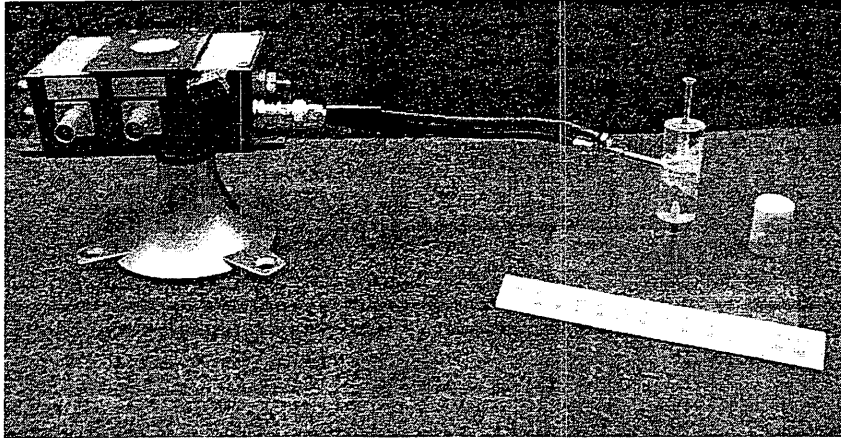


Figure 1. Lucite and Teflon cylinders are shown on the right. An electric field sensor probe is embedded in the Lucite cylinder to within 0.1 inches of the surface. A planar Teflon-capped electrode is mounted on the top of the electronics housing shown on the left. The BNC connectors attached to the respective outputs of the cylindrical and planar electrometers are shown together on the housing. An external dc power supply (+/-5V and +12V) is contained in a separate housing, but is not shown.

Figure 2 shows the cylindrical electrometer placed in the vacuum chamber along with the dust impeller fan that was used to propel dust particles towards the cylinder. A fixed volume of granular material is placed on the aluminum foil that covers an audio speaker. The speaker is used to force the dust to move in a vertical direction above the foil so that the wind that is generated by the impeller fan can carry the particles to the cylinder. The atmosphere within the chamber consists of carbon dioxide at a pressure of 10 mbar. Before an experiment is performed, the chamber is first evacuated to <5 mbar and then backfilled with carbon dioxide to over 133 mbar. The chamber is pumped down again and backfilled with CO₂ once more before being pumped down to a final pressure of 10 mbar CO₂.

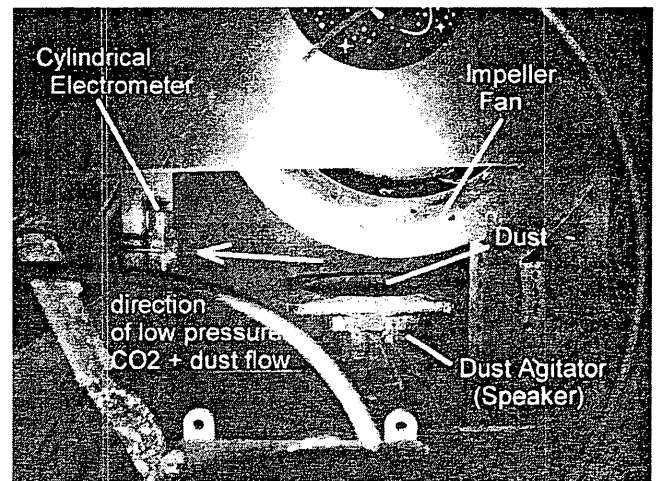


Figure 2. The cylindrical electrometer and dust impeller apparatus shown in the small vacuum chamber where experiments were performed.

When the impeller fan is turned on and the Martian soil simulant is propelled towards a Teflon cylinder, the dust coverage on the windward face of the Teflon surface is shown as in Figure 3. The electrometer probe is able to measure the residual charge at a location near the middle of the cylinder and below the dust-covered side of the Teflon cylinder.

The cylindrical insulator is removed from the electrometer probe for cleaning. Dust from a previous experiment is partially removed from the insulator surface using compressed air, followed by rinsing the insulator with alcohol and using compressed air to dry the surface.

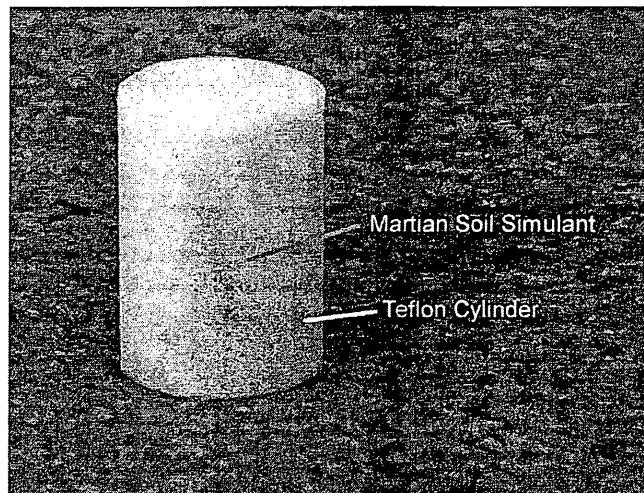


Figure 3. Windward side of a Teflon cylinder that was partially coated with Martian soil simulant. The soil was blown at the cylinder in a vacuum chamber by an impeller at 10 mbar CO₂ pressure.

A dry-vac is used to vacuum up any loose dust that is present on objects located in the vacuum chamber and on the chamber walls prior to conducting an experiment.

2.3 Data

A Lecroy Waverunner Digital Storage Oscilloscope (DSO) model LT364L (500MHz, 1GS/sec, 4 channels) was used to collect the data. A DSO probe type PP006 (10 MW, 12 pF, 500 MHz, 10:1) was used to pick up the output voltage coming from the cylindrical electrometer located in the vacuum chamber. The DSO was configured using Channel 1 to monitor the electrometer output signal, and with Channel A providing a filtered view of Channel 1 using the DSO's "Enhanced Resolution Filtering" mode.

Data was stored on a removable hard drive on the DSO after each experiment that could be later downloaded to a networked PC. Data was saved in ASCII format, which allowed the data to be easily imported into Microsoft Excel. The data shown in Figure 4 was generated in this manner.

Figure 4 shows data that was taken by the aerodynamic electrometer in the vacuum chamber at 10 mbar CO₂ pressure using the impeller fan to propel granular materials at Teflon and Fiberglass cylinders in separate experiments. The experiments were performed using Martian soil simulant (<5 μ m diameter particles), and three of the mineral constituents of the Martian soil: Fe₂O₃, SiO₂, and MgO. It should be noted that only the change in voltage is important over the course of a particular experiment. The zero voltage level is arbitrary for that reason, and the Teflon/Fiberglass data could be shifted in each graph so that the data for the two materials could be overlaid. However, the voltage offset for the electrometer circuit was approximately 20 mV. The electrometer circuit gain is based on resistor components, and was set at 0.25 pC/mV.

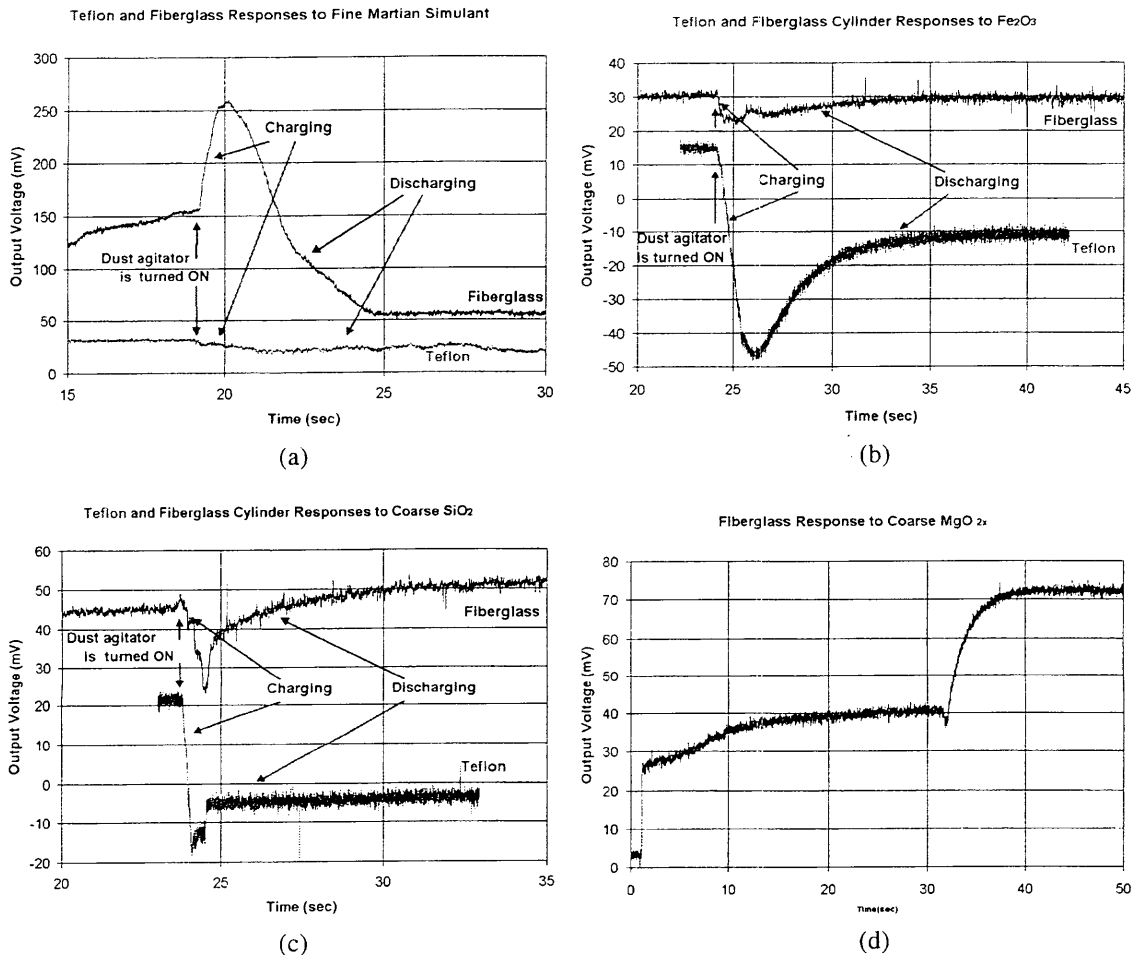


Figure 4. Electrometer output voltage response versus time for Teflon and Fiberglass being struck by windborne granular materials. The materials used were (a) fine ($<5 \mu\text{m}$) Martian soil simulant, (b) Fe_2O_3 ($17 \mu\text{m}$), (c) coarse SiO_2 . The response of Fiberglass to MgO is shown in (d). The electrometer output voltage is related to the amount of surface charge according to the conversion factor 0.25 pC/mV .

3 DISCUSSION

The data presented in Figures 4 (a), (b), and (c) clearly show that a Teflon cylinder will respond in a different manner to a given type of windborne granular material than does a Fiberglass cylinder. This observation has favorable implications for the possibility of modifying our design by combining individual cylindrical electrometers into a single multisensor electrometer that can be used to identify the mineral composition of windborne dust particles. The amount and polarity of surface charge produced on a cylindrical material's surface might generate a signature that is characteristic of the interaction between the cylindrical material and the type of incident dust particle. For example, Fiberglass charged to $(-8\text{mV}) \times (0.25\text{pC/mV}) = (-2\text{pC})$ in response to the windborne iron oxide (Fe_2O_3) before this charge began to decay through leakage across the

surface, whereas the Teflon cylinder charged to $(-62\text{mV}) \times (0.25\text{pC/mV}) = (-15.5\text{pC})$. Furthermore, the charge decay rates for Fiberglass and Teflon are not the same. In contrast to iron oxide, some materials, such as magnesium oxide (MgO), cause Fiberglass to charge positively. These different responses provide encouragement that a multisensor approach to mineral determination is possible. Additional experiments are clearly needed in which many more types of cylindrical insulators are used in addition to Fiberglass and Teflon, and other mineral compositions are used.

The present electrometer is limited by having to perform separate experiments for different types of cylinders. Ideally, an array of electrometer sensors that are attached to different types of cylindrical materials would allow their simultaneous responses to the same windborne particles to be studied. Thus, a follow-up to this research would be to construct a multisensor electrometer based on the cylindrical geometry that was utilized here.

One of the complicating factors associated with the method of charge measurement used here is that the windward side of the cylindrical insulator may accumulate a layer of granular materials on it (see Figure 3). The apparent reason for this is that the presence of a charged surface can allow an incident particle to be attracted to the surface, and to adhere to the surface. Further investigations are needed to understand the effect of the presence of a dust layer on the insulator surface on the measurement of charge by the electrometer sensor.

4 CONCLUSIONS

This research has demonstrated that a cylindrically shaped electrometer can be developed to measure the amount of electrostatic charge produced when windborne dust particles collide with the surface of an insulator. We were able to conduct experiments under controlled atmospheric conditions in a small vacuum chamber using a high-speed impeller fan to produce the windborne dust particles.

The cylindrical electrometer and its associated circuitry were constructed at NASA KSC during the summer 2001 research, and initial data was taken. The sensitivity of the electrometer is 0.25pC/mV , but the sensitivity can be adjusted by changing resistors in the circuit that we built. The cylindrical electrometer was tested using Teflon and Fiberglass cylinders. The dust particle composition consisted of JSC Mars-1 simulant, which is a mixture of coarse and fine ($<5\mu\text{m}$ diameter) particle sizes, as well as some of the major mineral constituents of the Martian soil. These other materials included Ottawa sand (SiO_2), iron oxide (Fe_2O_3), aluminum oxide (Al_2O_3) and magnesium oxide (MgO). An atmosphere consisting of carbon dioxide at 10 mbar was used in the vacuum chamber to simulate the Martian atmosphere. The atmospheric temperature was not controlled, and remained at ambient room temperature.

The data taken by the cylindrical electrometer shows that Teflon and Fiberglass cylinders charge differently when exposed to the same type of windborne granular material under similar pressure conditions and atmospheric composition. With further testing of the instrumentation using other types of cylinder materials, it is believed that a cylindrical multisensor can be constructed that will provide simultaneous measurements of charge by the different sensors. This approach may

make it possible for a multisensor electrometer to identify the mineral composition of the windborne granular particles by a unique electrostatic charging signature that multisensor output produces in response to the dust particles that collide with it. The next step that we intend to pursue in this research is to construct a prototype multisensor cylindrical electrometer.

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