

NON-OHMIC DISCHARGE CHARACTERISTICS OF JSC MARS-1 MARTIAN REGOLITH SIMULANT. C. R. Buhler¹, C. I. Calle², A. Hirschmann³, D. Denning⁴, and A. W. Nowicki⁵. ¹Swales Aerospace, YA-F2-T, Kennedy Space Center, FL 32899, ² Electromagnetic Physics Laboratory, NASA, YA-F2-T, Kennedy Space Center, FL 32899, ³Florida Institute of Technology, 150 West Boulevard, Melbourne, FL 32901, ⁴Embry-Riddle Aeronautical University, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114, ⁵Dynacs Inc., DNX-15, Kennedy Space Center, FL 32899.

Introduction: Unlike Earth, Martian soil is highly resistive with little or no water content. This may lead to potentially dangerous situations in which large amounts of charge can buildup on the soil that can possibly discharge to astronaut suits and/or equipment [1]. An understanding of the soil charge decay properties is essential for the success of future manned/unmanned missions. In order to clarify this, the discharge characteristics of Martian regolith simulant were measured. It is known that the simulant is a good insulator [2] but its charge decay rate has never been measured. Here we show the decay rates of the simulant under various conditions including Earth/Mars atmospheres, temperatures, and pressures.

We used the JSC Mars-1 a Martian regolith simulant specifically developed for scientific research that is comprised of volcanic ash from Pu'u Nene, a cinder cone on the Island of Hawaii [2]. It was chosen based on its spectral similarity to Martian material and its characterization match with actual Martian soil.

Preparation: In order to replicate the conditions on Mars, the soil must first be baked out to remove excess moisture. This is crucial for electrostatic measurements that rely so heavily on water content that increases conductivity. Therefore, the soil was kept above 160°C continuously to keep moisture from entering it. Furthermore, most experiments were performed in a chamber under vacuum down to 10⁻¹ torr to prevent air/moisture from attracting to the regolith. The chamber was then backfilled with a CO₂ gas atmosphere.

I-V Measurements: In studying charge decay characteristics, normally one starts with an ohmic system in which $I=V/R$ and replaces I with $-dQ/dt$ and V with Q/C . This gives a standard charge (Q) decay relationship of $Q = Q_o \exp[-t/\tau]$ where $\tau = RC$ the time constant and Q_o is the initial charge. To measure the I-V characteristics of the Martian simulant, a Chilworth Volume Resistivity Kit was used. A voltage is supplied and the resulting current passing through the soil is measured. The results in Figure 1 at room temperature and room pressure suggest that the current-voltage relationship is non-ohmic (red curve) and has a quadratic behavior. This behavior is common in electronic components such as diodes and inductors.

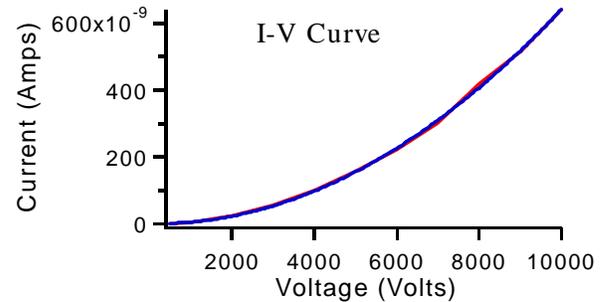


Figure 1. I-V curve of soil simulant at room temperature and pressure. Data is shown in red and the fit is shown in blue.

The fit of the data is also shown (blue curve in Figure 1) with the form $I = AV^2$ with $A=1.44 \times 10^{-14} (\Omega V)^{-1}$. Other terms in a polynomial fit are very small compared to the quadratic one. Using this form of the I-V relationship, the voltage decay with time curve can be found. Again, replacing I with $-dQ/dt$ and $Q=VC$, the voltage decay (not charge decay) now has the form

$$V(t) = \left(\frac{A}{C} t + \frac{1}{V_o} \right)^{-1} \quad (1)$$

where C is the capacitance of the soil and V_o is the initial voltage placed on the soil. Knowing the value of capacitance, A from the I-V fit, and the initial applied voltage, the voltage decay curve can be determined and compared with experiments.

Charge Decay Measurements: Charge decay measurements were performed with a JCI 155v4 Charge Decay Test Meter [3]. This instrument is capable of depositing a large amount of charge to nearly any surface via a corona discharge. Applying a voltage in excess of 10,000 volts to small discharge points creates this corona. The corona ionizes the air and the ions find their way to the surface. Within a few milliseconds after charging occurs the discharge points are removed exposing a field meter that records the electric field present on the surface.

The JCI 155v4 is placed about 3mm away from the regolith. The apparatus is placed inside a large vacuum chamber and evacuated to remove excess moisture. The soil is placed inside a metal dish with a thickness of about 2.5 cm and exposes an area of 4.5 cm × 5.5 cm. The JCI records the surface voltage immediately after the corona is applied.

Figure 2 shows the charge decay of Martian regolith at room temperature and room pressure. The JCI 155v4 provides up to 10,000V from its corona but the soil surface only receives up to about 2500V. This number depends on the number of ions present and the mobility of these ions. At lower pressures, as we will see later, the surface voltage is lower due to the fewer number of ions present.

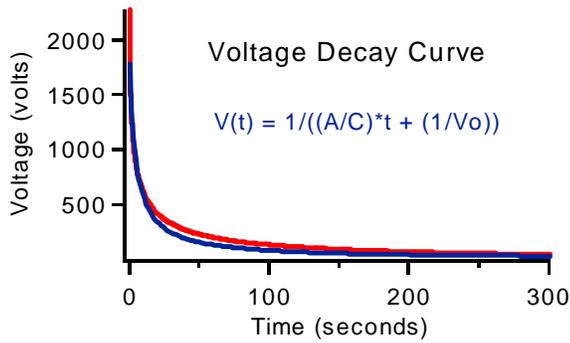


Figure 2. Voltage decay curve of Martian simulant at room temperature and pressure. Data is in red and the fit is the blue curve.

The fit to the decay curve gives a value of $A/C = 0.00011901$ and an error of 5.45×10^{-7} (not shown). This value correlates nicely with A measured from the I-V curve fit of $1.44 \times 10^{-14} (\Omega V)^{-1}$ divided by the measured soil capacitance of 1.75 pF which gives $8.2 \times 10^{-3} (\text{Vs})^{-1}$. (The simulant had a dielectric constant of 2.0 ± 0.1) The value of $1/V_o = 0.0005583 \pm 1.15 \times 10^{-6} \text{ V}^{-1}$ gives an initial surface voltage of 1791 volts compared with 2281 volts measured by the JCI 155v4. The fit is not exact but performs well above an exponential or power law fit. An exact fit would be extremely cumbersome considering the many complex factors such as temperature and pressure variations, soil packing, size and grain shape, actual moisture content, mineralogy composition, etc. We believe, however, that using the form of equation (1) and measuring A and the capacitance, a good fit to the voltage decay of the soil can be found.

Temperature effects: Similar comparisons were performed at a temperature of -10°C . The I-V curves gave a value of $A = 7.0 \times 10^{-15} (\Omega V)^{-1}$. Using the fit equation (1), $A/C = 2.12 \times 10^{-6} \pm 2.24 \times 10^{-8}$ yielding a capacitance of order 10^9 F . This increase in capacitance (most likely due to ice formation) was not anticipated, so measurements of the capacitance as a function of temperature were not taken. However, the fit of $1/V_o$ gave $0.017277 \pm 1.75 \times 10^{-5}$ which yields a $V_o = 58.8 \text{ V}$ while the measured V_o was 62.0 V .

For completeness, several voltage decay curves at different temperatures were taken and the average of the data is shown in Figure 3.

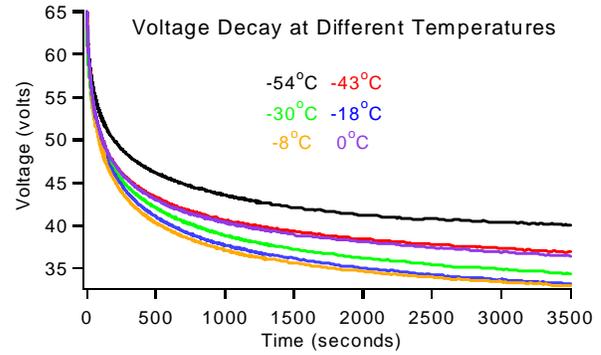


Figure 3. Voltage decay at various temperatures at 7 torr CO_2 .

The voltage decay curves shown in Figure 3 are actually averages of several runs with different initial voltages ranging from 65V to 75V at 7 torr CO_2 . To get a better feel of how temperature effects the decay time, the JCI also gives the time for the peak initial voltage to reach $1/e$ of this value. This time can be classified as a decay constant but this interpretation must be made loosely knowing that the system is non-ohmic. Average values of this decay time τ are shown in Table 1 for the various temperatures.

Temperature	τ (sec)
-54°C	62934.33
-43°C	51179.67
-30°C	38975.00
-18°C	34280.00
-8°C	29280.50
0°C	30655.67

Table 1. Decay times τ for the voltage to reach $1/e$ of its initial peak voltage at different temperatures.

Notice that in general the decay times (to reach $1/e$) increase with decreasing temperature. This indicates that charge transfer through the soil becomes more difficult at lower temperatures and that any charge deposited on the surface of Mars will stay for much longer periods than on Earth.

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References: [1] Sentman D.D., "Electrostatic Fields in a Dusty Martian Environment," *Sand and Dust on Mars*, NASACP-10074, pp. 53 (1991). [2] Allen C.C. et al., "JSC Mars-1: A Martian Soil Simulant", *Proc. Space 98*, pp. 469-476 (1998). [3] Chubb J.N., "Corona charging of practical materials for charge decay measurements" *J. Electrostatics* **37**, (1&2) pp. 53 (1996).