Cross Contamination of Martian Rock Samples

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ABSTRACT

This paper presents the results of theoretical analyses conducted to investigate potential of various particle removal techniques. The purpose is to limit the extent of cross contamination caused by the small particles generated through in situ handling and processing of the simulated Martian rock. Since the same hardware would be used to process several rocks, the cross contamination is defined as particles transferred from sample to sample as a particulate contaminant. For the purpose of analysis, we assume that during handling and processing step, rock is crushed using a jaw crusher set at 1 mm gap. The particle distribution of crushed rock is estimated by a Weibull technique. The estimated mass distribution shows that particles in the range of 10 to 100 μm are approximately 0.5 weight percent and they are the major source of the cross contamination. Particles larger than 100 μm are large and easily removed by gravity alone. Removal can be further improved by use of a conductive mechanical brush. Particles less than 10 μm are approximately 0.0001 weight percent. These particles do not cross contaminate because they are generally held strongly at the surface. Therefore, maximum possible cross contamination is 0.5 weight percent if we do not use a cleaning technique other than a mechanical brush. Our theoretical analysis has shown that a high pressure CO_2 jet set at delivery pressure of 13.5 Torr and ultrasonic vibration techniques have potential to remove particles in this size range from a grounded conductive surface and may limit cross contamination to less than 0.1 weight percent.

INTRODUCTION

A 2009 Mars Science Laboratory (MSL) mission is being planned by the National Aeronautics and Space Administration (NASA), which will feature a precision landing capability to get to within approximately 5 km of a target site and collect Martian rock for scientific analysis. The collected Martian rock samples will be subjected to processes that involve coarse and fine crushing followed by various physical and chemical analyses. The sample crushing will be accomplished using a jaw crusher set at a gap of 1 mm to provide particles in the size range of 1 μm to 1 mm. In between each processing step, the sample is transported by means of a conveyor belt and gravity assisted chute. After the first sample is processed and analyzed, the same hardware will be used to process the next sample. In this process scheme, the concern is the transfer of material from sample to Sample as a particulate contaminant.

There are two sources of particulate contaminants. The first source is small particles generated through handling and processing of Mars rock samples. The second source is airborne particles. In this paper, we will address only the first source of particulate contaminants. The approach used is as follows.

1. Theoretically predict mass distribution in the particle size range of less than 10 μm, 10 to 100 μm and larger than 100 μm particles when a Martian rock is crushed using a jaw crusher set at 1mm gap.

2. Theoretically evaluate the potential of mechanical particle removal techniques that may help limit the cross contamination of samples to less than 0.1 weight percent.

ANALYSES

SIZE DISTRIBUTION OF CRUSHED ROCK

We estimate the size distribution of particles where the maximum size is 1mm, which corresponds to a 1mm separation of jaws of the crusher. The particle distribution is described by a Weibull distribution with respect to the fragmentation process, which is in the nature of a fractal process [1]. Crushing produces a tree of cracks and repeated crushing produces similar cracks in each size. Ultimately, every size starting from the maximum to the smallest exists and is described by

$$n(m) := \frac{N_T}{m_1} \cdot \left(\frac{m}{m_1}\right)^{\gamma} \cdot \exp\left[\frac{-\left(\frac{m}{m_1}\right)^{\gamma+1}}{\gamma+1}\right]$$

Where, m_1 is the mass of the maximum particle size corresponding to 1 mm diameter (for 1mm jaws), which is equal to 1.6 mg. γ is a number between 0 and –1 and is taken to be –0.75 in this sample case considered. n(m) is the number density, which means that n*dm is the number of particles in the mass interval dm. The mass distribution is given by n*m*dm and integration over all sizes gives the total mass of the sample. The following plot shows the cumulative percent distribution in bins of equal mass interval as a function of particle size. The distribution below contains 6mg in the range from 0 to 100 µm for a sample of total mass equal to 2 gm.

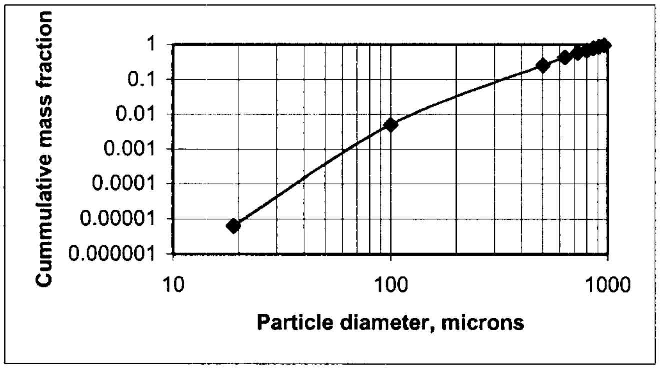

Figure 1. Particle distribution.

In this case, the particles less than 100 µm are 0.5 weight percent of the total. This particle distribution depends on the types of rock and the corresponding γ value.

PARTICULATE CONTAMINANT REMOVAL TECHNIQUE

Based on size distribution analysis, various mechanical cleaning techniques were investigated to determine which technique offers a good chance to remove 10 to 100 µm particles and limit cross contamination to less than 0.1 wt.%. This analysis was conducted based on the following assumptions.

1. All crushed rock samples are dry.
2. Fine crushed Martian rock has similar particle size distribution.
3. Electrostatic force is the only mechanism considered for particle adhesion to the surface.
4. Particles larger than 100 µm are easily removed because for the large size particles, Martian gravitational force is larger than electrostatic force.
5. Particles mechanically trapped in conveyor belt, dead space, and on rough surfaces will not be removed by the techniques considered in this paper. The release of these trapped particles is a random process which can seriously influence the cross contamination.

<u>Gravity Assist Brush Cleaning</u>

During the Viking mission, the sample handling surfaces were cleaned using gravity assisted brush cleaning[2]. This technique is excellent for gross cleaning and works well when the gravitational force is larger than the electrostatic force. For vertical or inclined surfaces, the gravitational force along with force generated by the movement of a brush is utilized to overcome the electrostatic force. While in the case of horizontal surface, the force generated by the action of the brush has to overcome both gravitational and electrostatic forces.

It is stated [3] "that non conducting grains (glass, Sic, and the regolith simulants) have a large initial triboelectric charging potential (up to + 10 V) with a distribution approximately centered on zero. The no conducting grains are weak photoemitters and attain a negative floating potential when dropped past a photoemitting surface. We can assume that a particle can charge to 10 V. This corresponds to 3468 electronic charges on a 1-µm particle and proportionally (with diameter) more charges on larger particles.

The steady field above the surface is assumed to be the normal field expected on Mars. The magnitude of this is estimated from the information suggesting that roughly 50 V/cm may be produced, along with electrical spark discharges and glow discharges, in a simulation of a dusty, turbulent Martian surface environment [4]. In the calculations, a field equal to 100V/cm has been assumed.

To conduct this analysis, the electrostatic force was calculated for the following two cases.

Case 1. Electrostatic force on a particle deposited on the conductive surface.

$$\mathbf{force2}(\mathbf{d_p}) := \frac{\left(\mathbf{N3}\cdot\mathbf{e}\cdot\frac{\mathbf{d_p}}{1\cdot\mathbf{mic}}\right)^2\cdot 9\cdot 10^9\cdot\mathbf{N}\cdot\mathbf{m}^2}{\mathbf{d_p}^2\cdot\mathbf{C}^2}$$

Where,
N3= 3468, the number of electrons required to charge 1 µm particle to 10 volts
e=1.6 x10^{-19} C, and **C** is a Coulomb,

This force does not depend on particle size and is equal to 2.778 x 10^{-9} Newtons.

Case 2. Electrostatic force on the charged particle pinned down (on a conductive surface) by an external Martian field **E** is the product of the field and charge[5].

$$\mathbf{force3}(d_p) := E \cdot [(N3) \cdot e] \cdot \frac{d_p}{1 \cdot mic}$$

Where,
E= electric field on Mars=100 V/cm

The gravitational force is calculated by the following equation.

$$F_{gra}(d_p) := \frac{4 \cdot \pi}{3} \cdot \left(\frac{d_p}{2}\right)^3 \cdot g_{Mars} \cdot \rho_p$$

Where,
d_p is particle size,
g_{Mars} = gravitation force on Mars, 3.77 m/s^2,
ρ_p = particle density, 3 gm/cc.

The results are shown in Figure 2. In the second case, the forces are compared for the case of particles charged to 10 V (which requires 3470 electrons on a 1 µm particle and proportionally more for larger particles) in an external field equal to 100V/cm above a grounded conducting plate. The force due to an external field can either pin the particle down or lift it depending on the polarity. For large particles, this will exceed the electrostatic force induced by the image charge.

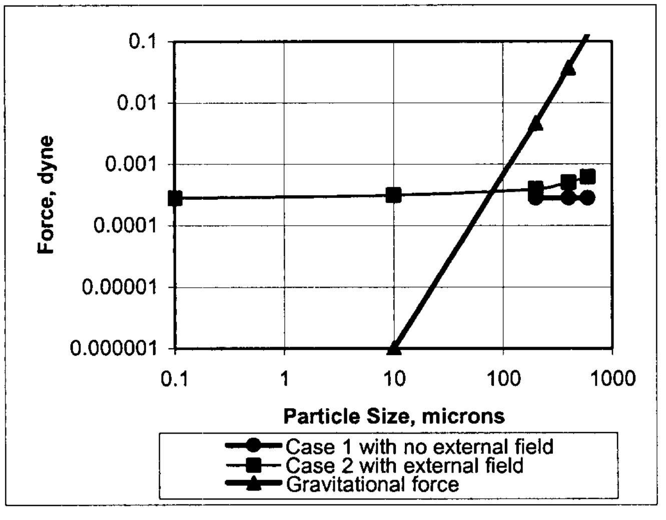

Figure 2. Electrostatic and gravitational forces on an insulated particle (1) attracted by its image and (2) pinned by an external field on a grounded conductive surface.

Gravity and electrostatic forces balance at approximately 100 µm. Particle above 100 µm can be easily removed by the brush, while particles below 100 µm will not be dislodged by gravity alone. Use of conductive (carbon, copper doped) brush is essential. Brushing may also electro statically charge the surface and enhance electrostatic attraction of the fine particles. In case of nonconductive surface, the electrostatic force will be significantly larger than the values calculated for the grounded conductive surface because local fields can be very large.

Ultrasonic Vibration

This technique uses ultrasonic vibration to dislodge particles both physically trapped and/or electro statically attached to a surface. The sonic system supplies electrical energy to the transducer at a desired frequency. The supplied electrical energy is converted by the transducer into the mechanical energy in the form of vibration. Since, Martian atmospheric density is low, the transducers have to be in direct contact with the surface to transfer energy. Transducer locations are determined by the surface geometry and density of particles.

High frequency vibrations of low amplitude produce large **g** forces and can easily dislodge small particles. This force is calculated by the equation below where the role of **g** is replaced by acceleration **a ω^two,** representing the second derivative of a sinusoidal displacement of amplitude **a** [5].

$$F_{acou}(d_p) := a \cdot \omega^2 \cdot \frac{4 \cdot \pi}{3} \cdot \left(\frac{d_p}{2}\right)^3 \cdot \rho_p$$

A surface vibrating at an amplitude "**a**" produces an acceleration equal to **a∗ω^two** which is large at high frequencies. The Figure 3 compares electrostatic force for the insulated particle pinned on the grounded conductive surface with ultrasonic vibration force at 10^7 radians/s. Calculations indicate that for this case, the ultrasonic vibration has a potential to remove particles as small as 2 µm in size.

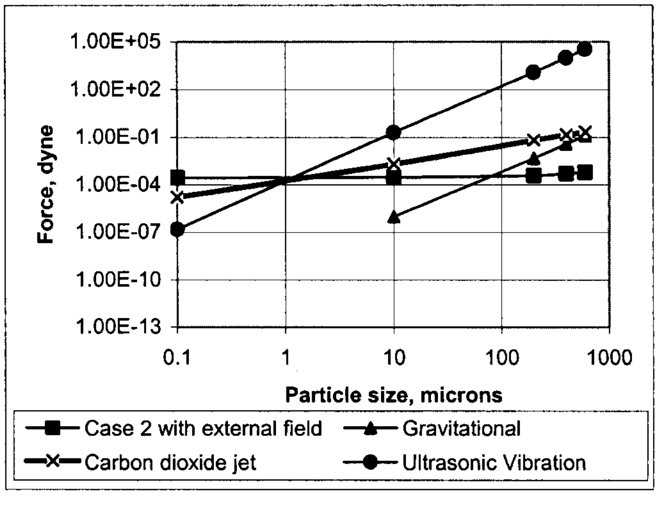

Figure 3. Forces generated by ultrasonic vibration and CO_2 wall jet to remove particles

High Pressure CO_2 Jet

In this technique the force of high velocity jet is utilized to over come the electrostatic and gravitational forces holding particle on a surface. This system is composed of two parts: 1) a Martian CO_2 acquisition system, and 2) jets critically placed around at all locations or surfaces to be cleaned. A study is required to evaluate various Martian CO_2 acquisition devices such as CO_2 pump [6] developed for Mars 2001 Surveyor but never used, cryogenic cooler, and CO_2 mechanical compressor.

Wall jets of carbon dioxide issuing from narrow slots located at a height of few mm and at a velocity, 100 m/s selected to estimate the drag forces on a particle pinned on the surface. For a given slot size and jet velocity, aero dynamic calculations can be performed to determine the flow field downstream of the slot. The boundary layer at any station x resembles a typical boundary layer in a free stream except that in the wall jet there is a half-jet instead of a free stream. Semi empirical equations exist to determine the maximum velocity, thick nesses of the inner boundary layer and outer jet layers for a specified momentum flux at the slot. The aerodynamic force is calculated using Stokes equation with the local velocities at the location of the center of a particle at a typical distance equal to 15 cm downstream of the slot, in the inner boundary layer of the turbulent wall jet. These compared to electrostatic and gravity forces and is described below [7]:

$$D(d_p,\xi) := 3\cdot\pi\cdot\mu\cdot d_p\cdot\left(\frac{d_p}{2\cdot\delta_{in}(\xi)}\right)^n\cdot U_{max}(\xi)$$

where,
μ is the viscosity of the jet,
U_{max} is maximum velocity in the boundary layer of a wall jet, can easily be several tens of m/s on Mars,
δ is boundary layer thickness
ξ is a jet travel distance (assumed 15 cm) divided by the viscous length as defined below

$$\xi(x) := \frac{x}{\left(\rho\cdot\frac{\nu^2}{M}\right)}$$

Where,
M is the jet momentum per unit length and
ν is the kinematic viscosity.

The results are shown in the Figure 3. This technique also has a potential to remove particles as little as two µm in size.

DISCUSSION ON HOW TO MAINTAIN LESS THAN 0.1 WEIGHT PERCENT CROSS CONTAMINATION

When a rock sample is ground, a particle distribution is produced containing various sizes including particles below 100 µm, arbitrarily called "fine particles". Mechanical brushing can sweep particles above this size and leave the fine particles. Brushing may also electro statically charge the surface (if non-conducting) and enhance electrostatic attraction of the fine particles. The fine particles are held to the surface if external fields are present and if they are charged. Gravity is weaker than electrostatic forces and the particles will not fall off. Typical mass fractions in these sizes can be about 0.5 weight percent. If they are not removed, a part may be carried from one sample to the next and cause cross contamination.

Particles below 10 µm are less than 0.0001 wt.percentage. These particles do not cross contaminate because they are generally stay attached to the surface. Gravity assist and brushing will leave only 0.5 weight. percent (10 to maximum100 µm), which should be removed by one or more techniques discussed in this paper. Suggested particulate removal techniques in this size range are combination of ultrasonic vibration and high pressure CO_2 jet at 13.5 torr for an insulated particle pinned on the grounded conductive surface.

CONCLUSION

Various mechanical cleaning techniques were investigated to evaluate their potential to remove particles in the size range of 10 to 100 µm. The theoretical analysis presented in this paper has shown that the high pressure CO_2 jet and ultrasonic vibration techniques have potential to remove particle in this size range and limit cross contaminant to less than 0.1 weight percent.

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