Electrostatic Precipitation for Cleaning Mars Atmospheric ISRU Intakes. M.R. Johansen[1], J.R. Phillips III[1], J.J. Wang[1], J. Mulligan[1], B.A. Watson[1], J.E. Lane[2], J.G. Mantovani[1], P.J. Mackey[1], and C.I. Calle[1], [1]National Aeronautics and Space Administration, Kennedy Space Center, Mailcode: UB-R2, Michael.R.Johansen@nasa.gov, [2]SURA, Kennedy Space Center

Introduction: Future Mars ISRU atmospheric intakes are estimated to ingest several hundred grams of dust over their lifetime [1]. The Electrostatics and Surface Physics Laboratory at NASA's Kennedy Space Center is developing a dust removal system based on a mature terrestrial technology – electrostatic precipitation. In this technology, a high voltage and grounded collection electrode create a corona discharge which charges particles in a dust-laden flow. The resulting electric field between the high voltage and collection electrodes drive the charged particles toward the collection electrode. This paper presents the design of the electrostatic precipitator and preliminary results.

Theory: Particles entering a corona field are predominantly charged by Pauthenier field charging and diffusion charging. Pauthenier field charging defines a charge saturation limit. This limit is given as

$$Q_S = 12\pi\varepsilon_0 \frac{k}{k+2}\left(\frac{d}{2}\right)^2 E$$

where k is the relative permittivity of the particle, d is the particle diameter, and E is the electric field [2].

Diffusion charging is caused by thermal motion of ions causing random collisions with the dust particles. The particle charge can be estimated by

$$q = \frac{(4\pi\varepsilon_0 akT)}{e}\ln\left(\frac{aN_0e^2u_it}{4\varepsilon_0 kT}+1\right)$$

where a is the particle radius, k is the Boltzmann constant, N_0 is the ion number density, T is the gas temperature, and u_i is the mean ion velocity [3].

If the charge on the particles in the flow can be predicted, a free body analysis of the particle can be used to determine the collection length inside of the wire-cylinder precipitator geometry

Modeling and Simulation: The governing equations given in the preceding section can be modeled along with estimated particle atmospheric drag and other physical considerations. Using rigid body dynamics simulations through MATLAB and multiphysics analysis through COMSOL, the particle trajectories in the electrostatic precipitator can be estimated. This data will inform the optimal geometry of an electrostatic precipitator for Mars. Figure 1 displays preliminary results from COMSOL and MATLAB analysis.

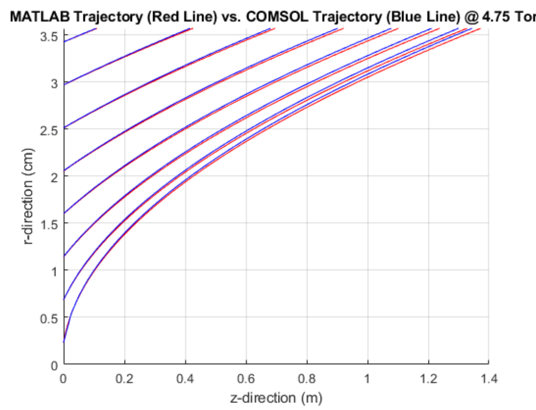

Figure 1 – Preliminary COMSOL and MATLAB analysis with estimated particle charge on a 1 μm diameter particle

Experimental Set-up: The Mars Electrostatic Precipitator Testbed was developed to characterize the physics of corona discharges, and thus particle collection efficiencies, in a flow simulating Mars atmospheric composition and pressure. The testbed maintains the pressure inside the high voltage (collection) region of the precipitator at the average Mars pressure of 4.75 torr of carbon dioxide. The testbed is able to generate flows of up to 2 SLPM. Though the actual composition of Mars atmosphere contains argon, nitrogen, oxygen, carbon monoxide, and other trace gases, previous studies have indicated that carbon dioxide gas serves as a good analog for electrostatic purposes [2]. The precipitator testbed uses an upstream flow controller and a downstream pressure controller to replicate the expected fluid properties of a Mars atmospheric ISRU processing plant. Figure 2 displays a simplified schematic of the Mars electrostatic precipitator testbed.

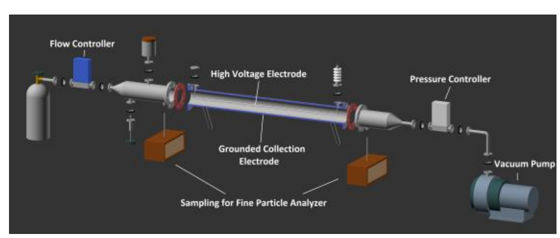

Figure 2 – A simplified schematic of the electrostatic precipitator testbed

A fluidized bed is used to introduce dust particles into the flow. A second flow controller is used to control the flow rate of carbon dioxide into the fluidized bed. This, along with the length of the introduction tube, can be used to fine tune the size distribution and quantity of particles that are entrained in the flow. A 60-degree nozzle is used to widely disperse the dust into the flow, obtaining a relatively uniform distribution of particles throughout the volume of the precipitator testbed. The fluidized bed is shown in Figure 3.

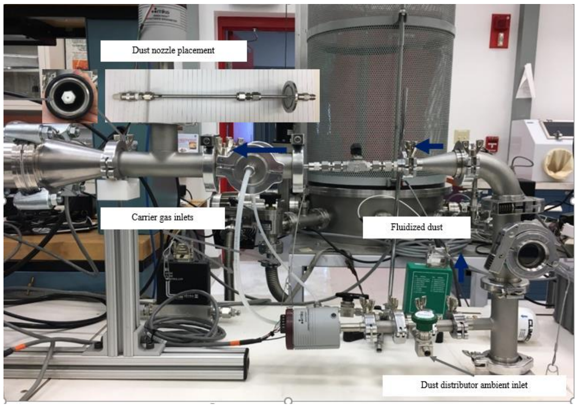

Figure 3 – Fluidized bed dust dispersion system

Preliminary Results: The electrostatic precipitator testbed enables the rapid test of new electrode geometries. One important characteristic that determines the dust clearing efficiency of an electrostatic precipitator is the current-voltage (IV curve) relationship. If the corona current associated with a known voltage on the precipitator is determined, the charge on the particles and thus the collection efficiency of the precipitator can be calculated. Figure 4 below shows an example of IV curve data in the electrostatic precipitator testbed.

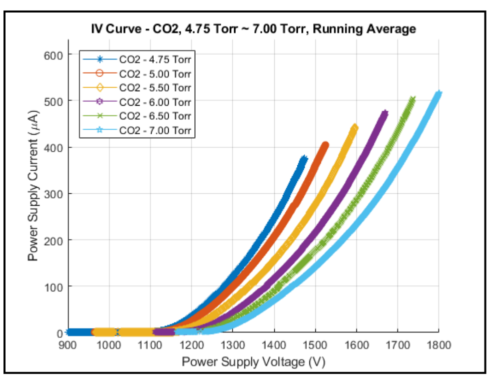

Figure 4 – IV curve data in carbon dioxide for a 7.13 cm tube ground electrode and 100 μm wire high voltage electrode

A commercial fine particle analyzer (FPA) is being modified to sample upstream and downstream of the collection region of the electrostatic precipitator. This tool enables the characterization of the size and shapes of particles in the flow and provides an estimate on dust clearing efficiency of the electrostatic precipitator. The device uses a microscope camera and a strobe light to image fine particles in a channel. The software automatically interprets and bins particles based on size. A sample image from the FPA is shown below in Figure 5.

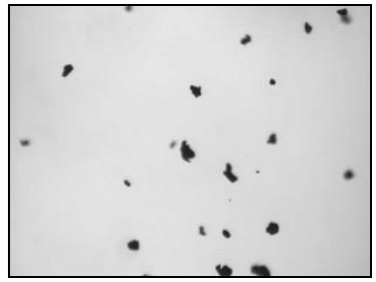

Figure 5 – Sample image of approximately 50 μm diameter particles

In addition to FPA analysis, laser scattering measurements are being used to determine flow properties in the electrostatic precipitator and can also be used to determine dust particle clearing efficiency. A 523 nm laser sheet and a DSLR camera are used to track particles in the precipitator downstream of the collection region to observe flow behavior and quantity of remaining particles. Figure 6 shows preliminary laser scattering images.

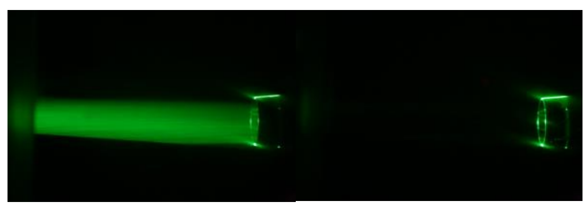

Figure 6 – Electrostatic precipitator off (left) and electrostatic precipitator on (right) indicating a high level of dust clearing efficiency

Future Work: The electrostatic precipitator testbed will be used to test a number of high voltage and collection electrode geometries. Laser scattering image analysis will be coupled with FPA analysis to determine particle clearing efficiency with initial data showing very promising results. Further development of a Mars electrostatic precipitator will be informed by operational constraints of the intended environment and long duration materials testing.

References:

[1] Phillips III, J. R. et al. (2016) *ASCE Earth and Space 2016* [2] Clements, J. S. et al. (2013) *IEEE Transactions on Industry Applications* [3] Cross, J. A. (1987) *Electrostatics: Principles, Problems and Applications*