Advanced Powder Technology 25 (2014) 1800–1807

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

# Electrostatic collection of tribocharged lunar dust simulants

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ARTICLE INFO

*Article history:*
Received 24 May 2014
Received in revised form 9 July 2014
Accepted 12 July 2014
Available online 27 July 2014

*Keywords:*
Lunar dust
Particle collection
Electrostatic field
Tribocharging
Vacuum
Particle charger

ABSTRACT

Levitation and consecutive deposition of naturally charged particles on lunar surface were troublesome in previous NASA explorations. Protecting sensitive surfaces from dust deposition in the limiting condition of the lunar atmosphere is imperative for future space exploration. This study reports experimental investigation of the collection efficiency of an electrostatic lunar dust collector (ELDC). A dual-functional remotely controlled particle charger/dropper was designed for tribocharging 20 μm lunar dust simulants, and a system of Faraday cup connected to an electrometer working in the nC range was used to measure the particle charges. Tribochargeability of two lunar dust simulants was studied, and the process was found to be the most effective with the JSC-1A samples. Aluminum was verified to be a more effective plate material than stainless steel. For the tested range of electrostatic field strength (0.66–2.6 kV/m), the mass-based and charge-based collection efficiencies were in the range of 0.25–1% and 0.45–1.45% for the low vacuum ($10^{-1}$ Torr), and 8–35% and 12–54% for the high vacuum ($10^{-5}$ Torr) conditions. The linear relationship between the applied voltage and ELDC collection efficiency predicted by the theoretical model was confirmed, and the collection pattern of the collected particles over the collection plate was consistent with the previously computed charge distribution on the collection plate. Aside from validating the predictability of the theoretical model, this study offers a novel method of particle charging inside a vacuum chamber with a variety of applications for studying chargeability of particles at different temperatures and pressures.



## 1. Introduction

Protection of solar panels and optical systems installed on lunar surface from depositing charged lunar dust is a great concern to the National Aeronautics and Space Administration (NASA) for future lunar, a steroidal and Martian explorations. Charging of lunar dust is due to exposure to intense high energetic solar radiation on the dayside of the moon, as well as exposure to low energetic electrons impingement on the nightside of the moon [1,2]. Astronauts in Apollo 17 mission reported a layer of micron-sized and submicron-sized lunar dust levitated from the surface because of repelling forces between the like-charged particles [3]. This was imaged by the lunar orbiter as a horizon glow over the lunar terminator [4].

Strong adhesion of charged lunar dust to all surfaces, rise and fall cycles of the particles and consequent dust deposition on mission-critical equipment have been studied within the past two decades leading to development of different control technologies. However, only electrostatic- or electrodynamic-based methods seem practical which have gained the most acceptance in the literature [5,6]. Electrodynamic dust shield (EDS) technology introduced by Calle et al. [7] and Kawamoto et al. [8,9] is based on electric curtain concepts developed by Tatom et al. at NASA [10] and Masuda et al. at University of Tokyo [11]. The EDS consists of embedded electrodes inside a transparent insulator film installed on the solar cell surfaces, and it utilizes standing or traveling waves to lift and transport both charged and uncharged particles deposited on the surface. However, according to a study by Qian et al. [12] the rate of electric power required for the EDS operation may be significantly higher than that provided by a solar panel, although the cleaning operation is infrequent.

Inspired from industrial electrostatic precipitators (ESP) [13], an electrostatic lunar dust collector (ELDC) was suggested by Afshar-Mohajer et al. [14]. The ELDC provided electric potential between a parallel set of conducting and transparent thin plates normal to the protected surface to attract incoming like-charged particles to the oppositely charged collection plate. The proficiency of the ELDC

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http://dx.doi.org/10.1016/j.apt.2014.07.010
0921-8831/

running at relatively low applied voltage has been investigated numerically (~170 V needed for 100% collection efficiency of 20 μm lunar dust for plate dimensions of $L = W = 10$ cm and $D = 5$ cm) [15,16]. Although the application of ELDC is limited to the sufficiently charged falling lunar dust, ELDC has the advantages of negligible power consumption for efficient dust collection before the deposition [17].

Alternatively, an electrostatic lunar dust repeller (ELDR) was proposed to protect surfaces by applying needle-shape electrodes that are connected to the same terminal of the power supply to repel the incoming like-charged lunar dust. Although the ELDR came with three advantages of less sunlight blockage, less weight and no need of electrode cleaning compared to the ELDC, power consumption of the ELDR is significantly higher, making its application limited to the surface areas smaller than 900 cm$^2$ [18].

While the EDS has been well studied experimentally, all previous studies on the ELDC offering two major advantages of low material cost and low electric power consumption have been theoretical with simplified assumptions of spherical particles, identical particles size and density, and uniformly distributed charges on the particles. Moreover, the perfect vacuum ($10^{-14}$ Torr) assumed in the theoretical model ignores the effect of vacuum level on the ELDC performance and particle chargeability required for ELDC applications in other environments (e.g., Martian atmosphere). The approximated electrostatic field and charge distribution on the ELDC plates using numerical models also need verification. Therefore, the current study was embarked to address the above-mentioned modeling limitations, to investigate tribochargeability of most common lunar dust simulants (JSC-1A and Chenobi), and to evaluate the collection efficiency of an ELDC experimentally using a novel remotely controlled tribocharging device. The reasons for selecting tribocharging as the charging method of lunar dust simulants were its productivity and ease of use for application inside the vacuum chambers [19]. For instance, application of UV source inside vacuum chamber requires an insulating coating layer on the chamber inner walls as well as conducting surfaces of other equipment to prevent photoemission [20], which interferes with the charge measurement and electrostatic field generation of this study.

Tribocharging of particles is a common technique for separating insulator particles in various industrial applications (e.g., treatment of ash from coal in power plants) [21]. In this charging mechanism (also known as triboelectricity or contact electrification), electrical charges are generated and exchanged due to the particles' contacts to the container wall as well as particles' slides on other particles. Such an exchange is due to the difference in energy levels (the energy required to release the outmost electron respect to the core of an atom) of the contacting materials until establishment of an equilibrium between the energy levels. Electrons flow from the material with a lower work function ($\Phi_1$) to the material with a higher work function ($\Phi_2$) until equilibrium is reached [22]. In contrast to conducting materials, there is no unified model for charge transfer between insulating materials. However, results of a study by Castle [23] showed that the total transferred charge is linearly proportional to the absolute difference between work functions of the contacting materials.

To choose the appropriate material for tribocharging, work function of lunar dust simulants should be available. The work function of Chenobi lunar dust simulants is still unknown, and there are only a handful of studies regarding the work function of JSC-1A lunar dust simulations. Sternovsky et al. [22] conducted tribocharging experiments inside a vacuum chamber on fine particles to infer the work function of JSC-1A by comparing the total measured charge of the JSC-1A sample compared to other particles made from known materials. Their result suggested 5.9 eV as the work function of JSC-1A lunar dust simulants [24]. Trigwell et al. [25] took a similar approach for determining the JSC-1A work function by adding inclined planes made of select materials between the dust dropper and Faraday Cup for strengthening the electrification. Their work identified the JSC-1A work function to be 5.4 eV.

In the first stage of this study, tribocharging properties of two selected lunar dust simulants (JSC-1A and Chenobi) were investigated. Then, the importance of plate conductivity in particle collection was investigated by comparing stainless steel and aluminum as the material for the ELDC plates. Finally, the collection efficiency of a customized ELDC as a function of applied voltage at low vacuum ($10^{-1}$ Torr) and high vacuum ($10^{-5}$ Torr) levels was determined.

## 2. Experimental

As shown in Fig. 1, the experimental set-up consisted of a chamber enclosing four key elements: particle tribocharger, particle dropper, particle collector (ELDC), and particle charge measurer (Faraday Cup and electrometer). First, the particle tribocharger rotating around its longitudinal axis charged particles for a preset period of time. Then, these charged particles were released from the tribocharger. The exact elevation of the tribocharger inside the chamber was set to attain the same particle velocity at the ELDC entrance determined in the previous modeling efforts [14–16,18]. Since the first set of experiments aimed to obtain charging properties of the lunar dust simulants as a function of time, falling particles directly entered the Faraday Cup (MONROE, diameter = 10 cm, depth = 15 cm) with the ELDC turned-off. The total charge of the ensemble particles inside the Faraday Cup was read using an electrometer (KEITHLEY, Model 6514 with 0.1 pC reading precision).

To study the effect of air pressure on tribocharging, experiments were conducted at three pressure levels: atmospheric, low vacuum and high vacuum. The low vacuum experiments were conducted at the vacuum level of about $10^{-1}$ Torr using a 2-stage rotary vane vacuum pump (Oerlikon Leybold TriVac D16B) connected to a transparent cylindrical chamber made of 1-in-thick PVC (see Fig. 2a). The high vacuum experimental set-up was designed using a turbo-molecular vacuum pump (Oerlikon Leybold TurboVac 361) added between the mentioned 2-stage rotary vacuum pump and a stainless steel vacuum chamber (HVB-100-N088171, RIBER Inc., Bezons, France) to achieve a vacuum level of about $10^{-5}$ Torr (see Fig. 2b).

Evaluating the influence of tribocharging duration on the created charge on particles was the main goal of the first set of experiments. In the second set of experiments, ELDC was turned on, and its

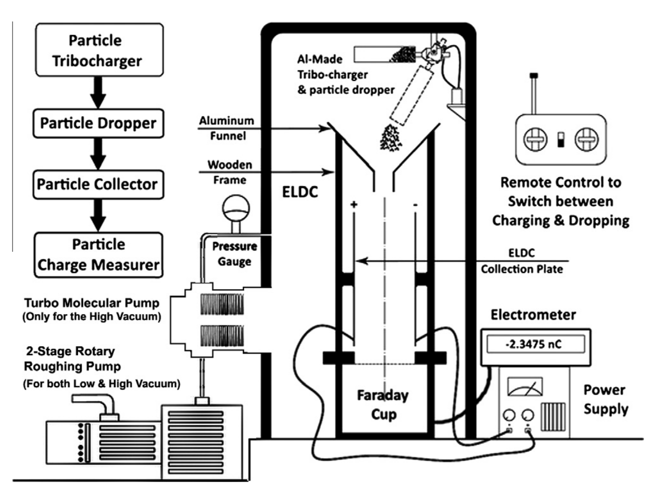


**Fig. 1.** Schematic of the experimental set-up.