Role of polarization and charge on the levitation of a single particle in an electric field

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***Abstract*— Reports from the literature have shown that sand grains in a desert storm generate charges by contact electrification while wind transport of particles is related to charge separation. In most observations, electric fields of many kilovolts are measured during the dust storm. Authors have claimed that polarization of particle may be responsible for the lifting of particles from the ground as a result of the Earth's electric field. In this study, we report a preliminary result of the effect of charge and polarization on charged particle in an electric field. We observe that for a charged particle especially spherical polymer, polarization effect may not be solely responsible for the levitation whereas for a spherical metal particle, the lifting is only due to polarization.**

I. INTRODUCTION

The importance of granular charging in both nature and industry cannot be over emphasized. For example, is the fact that global warming and climate change have been linked to the presence of atmospheric dust. It has been suggested [1] that mineral dust aerosols influence the Earth climate through the process of radiation absorbance and scattering. The dust aerosols are normally lifted by a process called "saltation" [2, 3] which occurs naturally i.e. blowing dust, dust devils and dust storms. It has been reported that electric fields between 10 and 200 kV/m exist [4, 5, 6] as a result of charge transfer by collision of sand and dust particles. During the collision, the larger particles become positively charged while the smaller particles become negatively charged. The same observation was made by other researchers for different particles with different sizes [7, 8, 9]. The observed electric field is as result of charge separation which can be on the order of gravitational force [4]. According to Kok and Renno, the electric field at the earth surface induces charge in the soil particle (i.e. polarizes the soil particle) and the sign of the charge on the particle depends on the direction of the electric field.

The number of the saltating particles depends on the strength of the electric field leading to enhancement of emission of dust aerosols [1].

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In this paper, an experimental study was carried out to investigate the lifting of particles in an electric field. We envisage that the results from the study will enable us to examine the influence of charge and polarization on the levitation of the particle.

II. Experimental Procedure

We investigated the lifting of spherical polymeric and metal particles supplied by McMaster Carr Company in an electric field. The field was set up between two parallel circular copper discs separated from each other by 1" square glass spacers. The bottom disc was electrically grounded while the upper disc was connected to a high dc voltage. This geometry resulted in an electric field in the same direction as the gravity. The circuit was built such that we can change the polarity of the voltage difference. The electric field generated is given by the expression:

$$E = \frac{\Delta V}{d} \quad (1)$$

where ΔV is the voltage difference between the two copper discs and d is the spacing between them.

The polymeric particles, Teflon and Nylon were chosen based on their different positions in the triboelectric series. Particle samples were first dropped inside a glass bottle and shaken for a few seconds to induce a charge and then carefully placed at the center of the grounded copper disc. The electric field was then applied in steps of 0.5 V every 5 seconds until the particle was lifted; we referred to this as the threshold electric field Eth. We repeated the experiment many times changing incremental voltage but the result is not much different. The aluminum particle was not charged before being place at the center of the lower copper disc.

The charge acquired by the polymeric particles, Teflon and Nylon were measured using a Faraday pail apparatus. The Faraday pail was connected to an electrometer (Keithley model 6485) which is capable of being interfaced with a computer. The electrometer measured the current generated by the charged particle which was then integrated over a specific time to obtain the charge.

The measured threshold voltage for the levitation was compared to the theoretical threshold voltage Vth derived by Lebedev and Skalskaya [10] given by the expression:

$$V_{th}=d\left(\frac{mg}{1.37\pi\varepsilon_o D^2}\right)^{1/2} \quad (2)$$

where d is the separation between the two discs and D diameter of the particle, m is the mass of the particle, g is the acceleration due to gravity and is the electric permittivity of the air between the discs.

We calculated the electric field from the measured threshold voltage and by some study [3,4], the electrostatic force is equal in magnitude to the gravitational force on the saltating particle. From this relation, we determine the charge on the particle and then compare to the charge measured using the electrometer.

III. Experimental Result And Anaylsis

Our experimental results (Table 1) show that the two polymer particles investigated were lifted by different applied voltage polarity. The Teflon particle was lifted by a positive applied voltage while nylon particle was lifted by the opposite voltage (i.e. negative polarity). Conversely, the aluminum particle was lifted by both positive and negative polarity. The observation further confirms that Teflon always charges negatively on contact with other material whereas nylon mostly acquired positive charge from other body in contact. The measurement made using the Faraday pail connected to an electrometer confirmed that Teflon charged negatively and nylon charged positively as shown in Figure 1. The threshold voltage V_{th} measured for the polymeric particles was between 6 and 7 kV while that aluminum particle was about ±4.7 kV. The calculated value of the threshold voltage for Teflon and Nylon particles using equation 2 was lower than the observed value because the equation is meant for a conductive spherical particle [10]. The charge Q was calculated based on the theory that the electrostatic force was equal in magnitude to the gravitational force [3,4]. The charge density calculated was about one third of the electrometer value for the polymeric particles. Our investigation of this difference shows that the remaining induced charge on polymer particles after a few second on the copper plate was about half the initial value after the first jump. On the other hand, the same charge particle takes a longer time to discharge while in the Faraday pail. Of course, this cannot be avoided since the experiment was performed in the laboratory environment in which humidity and other factors played vital role.

Table 1: The measured average threshold voltage and the calculated parameters for the spherical particles.

	Teflon	**Nylon**	**Aluminum$_+$**	**Aluminum$_-$**
Average V_{th} (kV)	7.07 ± 0.03	-6.01 ± 0.02	4.72 ± 0.03	-4.68 ± 0.03
E_{th} (10^5 Vm^{-1})	8.03 ± 0.02	-6.80 ± 0.03	5.37 ± 0.02	-5.32 ± 0.01
Charge Q (pC)	56.7 ± 0.2	-36.2 ± 0.1	13.7 ± 0.2	-13.8 ± 0.2
Charge density σ (μCm^{-2})	7.17 ± 0.03	-4.57 ± 0.02	6.92 ± 0.03	-6.98 ± 0.03
V_{th} (equation 2) (kV)	6.06	4.46	4.87	-4.87
Electrometer σ (μCm^{-2})	20.57 ± 0.02	10.53 ± 0.03		

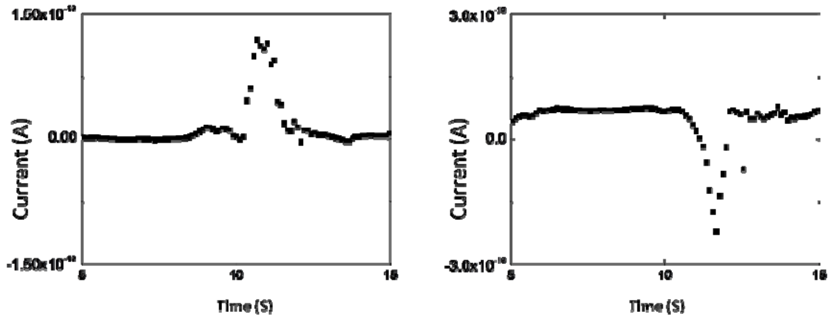

Figure 1: Current measurement of the charged spherical particle by Faraday pail. (left Nylon; right: Teflon).

IV. Conclusion

The result of our experiment to access the role of charge and polarization on the saltating particle can be summarized as follows:

1. For polymeric particles, the levitation in the electric field is caused by the pre-induced charge on the particle. The issue of polarization cannot be totally ruled out since some dielectrics can sometimes become conductive under environmental influence.

2. In the case of metal particle, polarization effect is the cause of the lifting in the electric field; we observed that aluminum particle jumps at both electric field polarity. This is in agreement with previous study where conductive spherical particles were investigated.

3. We have also observed the influence of laboratory environment especially relative humidity on the charging behavior of the polymeric particle studied. The next stage of our study is to build an apparatus which will make it possible to study the effect of humidity on the threshold electric field needed for lifting the particles.

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