Slope Stability of Electropacked Beds

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Abstract—**The mechanics of packed or fluidized beds of semi-insulating particles are substantially altered by strong applied electric fields. The angle of repose of a loosely packed bed of glass beads increases with the applied electric field; a sufficiently intense field will freeze the bed. An extensive series of angle of repose measurements are reported which suggest three distinct regimes of critical slope equilibria: *infinite slope* equilibrium for low electric field intensities; *finite slope* equilibrium for somewhat stronger fields, and the frozen bed limit for strong electric fields. The failure of an infinite slope equilibrium is characterized by individual particle motions confined to a thin layer near the surface. This regime is amenable to analysis, and the electrically induced cohesion can be inferred from the experimental data. The results are compared to Dietz's published expression for the cohesive electrical force acting between two contacting spherical particles. SEM photographs of the particles used experimentally provide evidence that surface asperities and very fine particles may be more important than previously suspected.**

INTRODUCTION

THE MECHANICS of packed or fluidized beds of semi-insulating particles are substantially altered by strong applied electric fields. Recent investigations suggest that these electromechanical effects can be utilized in a wide variety of applications including air filtration [1], [2], fine particle separation [3], commercial drying processes [4], heat transfer [5]-[7], and bulk bed control [8]. In this work, an extensive series of experiments using an electropacked bed (EPB) is reported. The angle of repose of a loosely packed bed of glass beads increases with the applied electric field. Measurements of repose angles are used to infer the electric stress acting in the EPB. The experimental results support the assertion that the same electromechanical forces exist in both electrofluidized beds (EFB's) and EPB's. The effects of several parameters on the electrical force are studied. These parameters include particle size, experimental cell dimensions, electric field orientation, surface conductivity, and the surface roughness. A dc electric field is used in all of the experiments reported here.

BACKGROUND

Spontaneous electrostatic interactions due to triboelectrification in fluidized beds of insulating particles have been reported by several workers [9]-[13]. In earlier works [9]-[11], an electrode positioned in an air fluidized bed was used to measure the buildup of electrical charge. Spontaneous voltages as high as 5 kV [10] were measured. Particle concentration was reported to be maximum in regions where the maximum potential occurs [11] and particle agglomeration was widely observed [9]-[13]. Increasing the particle conductivity was found to reduce substantially electromechanical effects. The reduction of electrostatic charge was attributed to a decrease in the time required to discharge bed particles [12], [13].

Several investigations are reported in which an electric field is imposed on a fluidized bed [8], [13]-[15], and particle chaining is reported in each of these works. Boland *et al.* [13] observed particle chains aligned with a spontaneously generated electric field in an experiment using a bed fluidized by kerosene. A streaming current caused by the dissociation of ions within the kerosene gives rise to a separation of bulk charge, and an electric field parallel to the flow is generated. Electrodes are used to impose electric fields on air fluidized beds [8], [14], [15]. An observation common to all these investigations is the surprisingly strong electromechanical interaction. Katz and Sears [14] were able to prevent a bed from fluidizing at flow rates up to 15 times the zero field incipient fluidization rate. In the thorough investigation by Johnson and Melcher [8], the electrical stress variation with the applied electric field is found to be essentially linear. This is in contrast to variations proportional to the square of the applied field, as would be expected from conventional electric force calculations [16].

A model for the strong interparticle electrical force is developed in a series of works by McLean [17]-[19] and Dietz [6], [15], [20]. Fig. 1 illustrates the essential details of this model. The applied electric field induces currents which are confined to the surface of the semi-insulating particles. The current can flow from particle to particle only in the immediate vicinity of the contact point. This constriction of the current and the high surface resistivity of the particles create large potential differences across the interparticle gap near the contact point. The surface charges on opposite sides of the gap are of opposite signs and account for the electrostatic attraction. Under reasonably general conditions, Dietz [6], [20] calculates the electrostatic force acting between two semi-insulating particles to be

$$f^e \cong (0.415)4\pi\epsilon_0 R^2 E_{\max}{}^{0.8} E_0{}^{1.2}. \tag{1}$$

The electric field in the immediate vicinity of a particle contact is assumed to be limited to a maximum value $E_{\max}$ by a nonlinear charge transport mechanism. Robinson and Jones [21] report that Townsend discharge is unlikely to occur within the interparticle gap and that field emission is the most plausible candidate for this nonlinear charge transport mechanism.

Paper IUSD 81-62, approved by the Electrostatic Processes Committee of the IEEE Industry Applications Society for presentation at the 1981 Industry Applications Society Annual Meeting, Philadelphia, PA, October 5-9. Manuscript released for publication May 26, 1983. This work was supported by the National Science Foundation.

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0093-9994/84/0200-0253$01.00 © 1984 IEEE

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