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Dielectrophoresis in the Microgravity Environment

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Abstract

Microgravity and vacuum, singly or combined, are uniquely advantageous media for the use of dielectrophoresis as a materials separation technology. In order to assess these advantages a free-fall vacuum dielectrophoretic separator was designed and constructed for use at the earth's surface.

Introduction

"Dielectrophoresis" is the motion induced by the presence of nonuniform electric field. The field equations describing this phenomena are

$$\vec{F} = (\vec{P} \cdot \vec{\nabla}) \vec{E} \quad (1)$$

$$\vec{P} = \overleftrightarrow{\alpha} \cdot \vec{E}\, v \quad (2)$$

$$\vec{F} \sim K_1 \frac{(K_2 - K_1)}{(K_2 + 2K_1)} \vec{\nabla} (E)^2 \quad (3)$$

where F is the resulting force on the particle, P the induced dipole, E the applied field, and K_1 and K_2 the relative dielectric constants of the medium and the particle, respectively. Because dielectrophoresis is so often confused with electrophoresis, Table I is presented for the reader. (This is a somewhat more elaborate presentation of an earlier comparison by Pohl.[1])

As Equation 1-3 and Table I together indicate, the dielectrophoretic effect has several remarkable features, at least in principle. The effect depends principally on the complex electrical permittivity and the acceleration is independent of particle size and shape; thus it can (at least potentially) be used for separations based on materials properties only, as in the classical mineral separation technologies based on density which are used at the earth's surface. The principal disadvantage is that it is a second-order effect and the resulting forces are weak unless high fields (and gradients) are used. At the earth's surface, particularly when a suspending medium is used, the fields will be limited by the properties of the medium and convection will usually wipe out the effect or at least render the separation irreproducible, difficult or both. These problems are completely eliminated by use of the microgravity/vacuum environment. The remaining problem is the presence of relatively strong, first-order forces due to residual static electrical charge on the particles to be separated. This problem is effectively dealt with by utilization of the effect implied by Eq. (3), that is, that the effect is independent of the sign of the applied field; the dielectrophoretic force always has the sense of the more intense field, regardless of field direction. Thus, alternating fields, in which the forces due to direct

Table I. A Comparison of Electrophoresis with Dielectrophoresis

	Electrophoresis	Dielectrophoresis
Induced Force and Velocity:	Depends on sign of charge and sign of field. Field reversal reverses motion.	Independent of sign of applied field. Particle moves to more intense field.
	Force depends on charge; does not depend directly on volume.	Force is proportional to volume of particle.
Induced Acceleration:	Acceleration α $1/r^2$ Excellent at molecular level.	Acceleration independent of size or shape. Feeble at molecular level unless large gradients are used.
Field Requirements:	Homogeneous or inhomogeneous fields.	Inhomogeneous fields only. Usually requires strong field gradients to overcome convection, diffusion.
	High (eg., 1 kV/m) fields, typically.	High to very high, typically 1-10 kV/m.
	Steady (DC) fields only.	Steady (DC) or alternating fields.

effects are oscillatory, do not affect the direction of the dielectrophoretic force at all. In an operating separation system the direct forces would be dealt with by the use of AC fields, and the primary technical problem in this connection would be to insure that the amplitude of oscillation induced by direct forces would be reasonable compared to the dimensions of the system. For some classes of materials the effect may be optimized by using the frequency dependence of the dielectric constants.

Additionally, because recent advances have occurred in the understanding of gravitationally-driven and capillarity-driven (i.e., Marangoni-Levich) convection, the prospect for substantial progress in separation technology as the earth's surface may exist as well. To begin with a test was desired of the feasibility of vacuum/microgravity separations by dielectrophoresis. The instrumentality elected was free-fall separation in vacuum.

Design Considerations

In order to achieve maximum separation with simple electrode geometry, coaxial cylinders were decided on, at the expense of uniformity of acceleration. (Later modification to isomotive electrode geometry was allowed for.) A preliminary assessment of lateral oscillatory amplitude at audio frequencies indicated that a system width in the range 1 – 10 cm would probably suffice; in any case, the amplitude could be decreased by increasing particle size and thereby decreasing the charge/mass ratio, assuming static charging. The amplitude would of course depend on the frequency, which was limited by practical considerations to the audio range, i.e., 20 Hz – 20 KHz. At such frequencies voltages on the order of 10 KV may be attained by pushing the state of the art of transformer design, which we did. For concentric cylindrical electrodes with 150 mm and 3 mm diameters, lateral accelerations were calculated to be in the 0.001 – 0.01 g range, depending on dielectric properties. A six-foot free-fall (dictated mainly by ceiling height in our laboratory) would then result in lateral displacements of at least a few mm, easily observable. Even small differences in dielectric properties should then result in particulate segregations which are observable at low magnification and analyzable by, e.g., the EDXA method.

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Construction of the Free-Fall Separator

The final form of the device is shown in Figures 1 and 2. The outer electrode is an evaporated

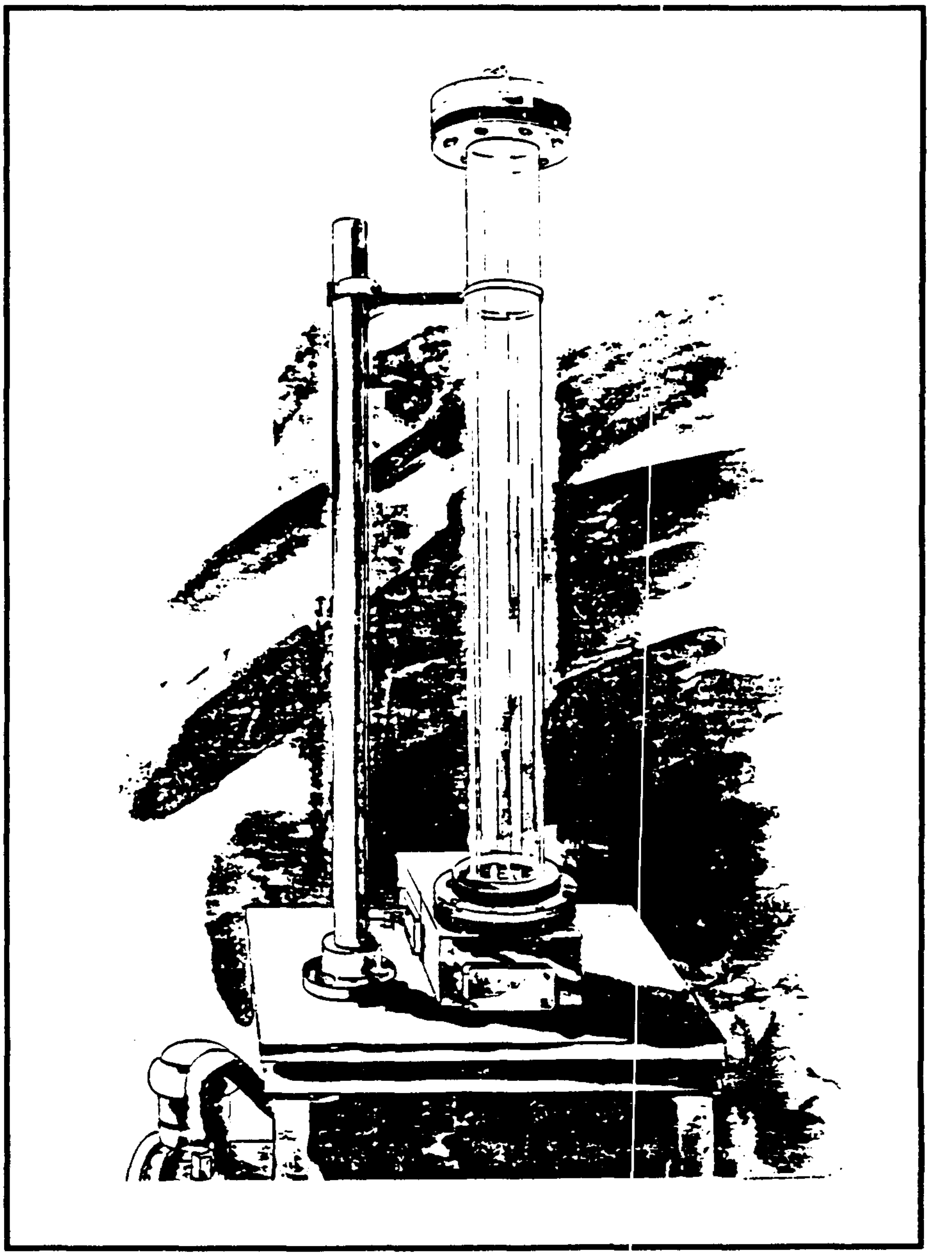

Figure 1. Free-fall Separator.

gold film deposited on the interior of the Pyrex tube; the inner electrode is polished stainless steel. At the top is a concentric mechanical iris, motor-driven for the sake of safety and to avoid vibration of the column. At the bottom is a platform supported by a removable access plate. Mixed powders will be dropped through the iris and collected on adhesive-coated slides or even small containers for examination. Below the platform and access plate is the vacuum plenum. The system is pumped through this plenum by a water-cooled, two-inch diffusion pump backed by a 5 cfm mechanical pump. Vacuum instrumentation consists of a Bayard-Alpert ionization gauge and a thermocouple gauge. The system has been pumped out and is usually kept under vacuum. The ultimate vacuum is slightly above 10^{-8} torr.

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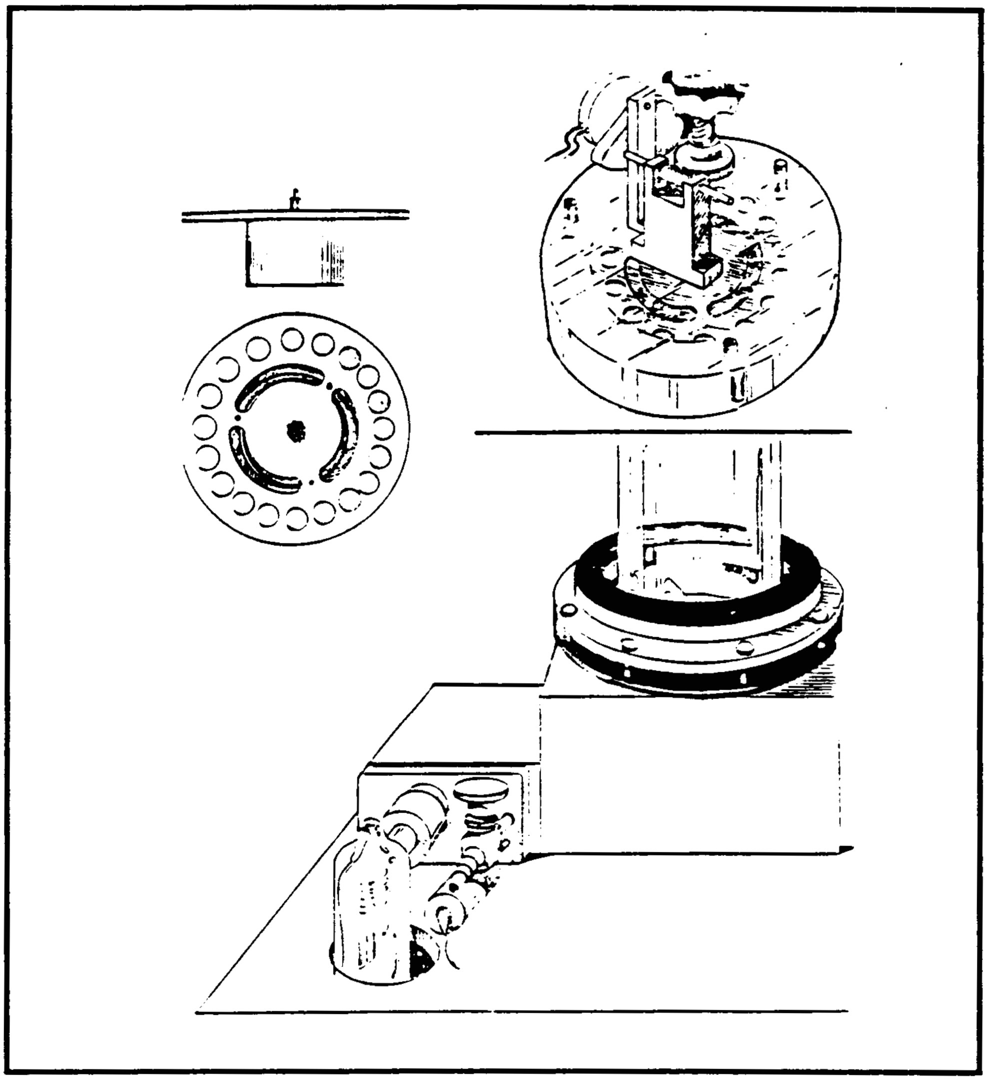

Figure 2. Detail of the Free-fall Separator.

The system is designed to be driven at 20 Hz - 20KHz at voltages up to 10 KV (RMS) by a 250 watt audio amplifier coupled to the electrodes by a transformer. Performance at the high-frequency end of this range will be limited by the capacitance of the separator (about 26 pF); the characteristics of the transformer, including the capacitance and inductance of the secondary; and, related to these concerns, by nearby resonances. Considerable difficulty was encountered obtaining adequate designs and hardware for this purpose, which we now have from two sources. At this time we do not expect to be able to drive this system to 10 KV at the highest frequencies, but in general, the performance should be more than adequate for our experimental objectives.

Utilization

The system is now ready for use. The general scheme is to evaluate the separation of "model" powder mixtures (ceramics, polymerics, metallics) and develop quantitative models applicable to microgravity conditions. Some analysis of dynamic effects, particularly those resulting from relaxations, will be attempted.

Reference List

1. H.A. Pohl, "Dielectrophoresis," (Cambridge University Press, 1978).