Electrodes for Free-fall Electrostatic Separators

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Abstract: *The efficiency of electrostatic separation process depend on the intensity of the electric field generated by an appropriate electrode system. The aim of this paper is to evaluate a novel electrode design for free-fall electrostatic separators. The experiments were carried out on three laboratory-scale models, energized from a low-ripple DC high-voltage supply. The charge simulation method was then used for the numerical analysis of the electric field generated by each of the three models. The computed data confirmed the experimental results: the novel design generates a more intense, though less uniform electric field.*

1 INTRODUCTION

Electrostatic separation is defined as the selective sorting of charged or polarized particles under the action of an external electric field [1], [2]. During recent years, new electrostatic separation processes have been developed for ore processing and waste recycling [3-8].

The simplest electrostatic separators are those in which the material to be sorted falls freely in an electric field and the charged particles are attracted to electrodes of opposite polarities. The electrode system of any such free-fall electrostatic separator consists in two vertical plates connected to a D.C. high voltage supply and generating a uniform electric field (Fig. 1, a and b). Other electrode arrangements, such as two parallel horizontal cylinders, can also be effectively employed (Fig. 1, c). In any of these cases particles are tribo-charged prior to their admission in the electric field that performs the selective sorting.

The charged non-conductive particles that come in contact with an electrode are likely to stick to it, due to the image force [1]. Therefore the electrodes should be provided with means to prevent the build-up of an insulating layer on their surface.

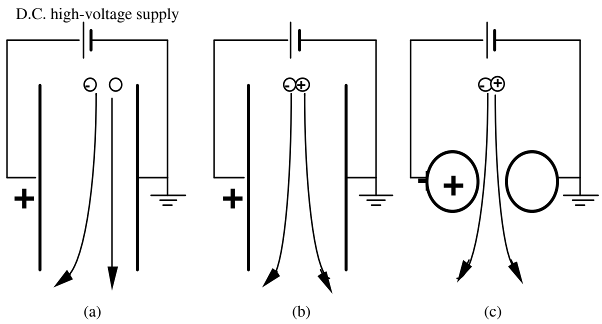


Figure 1. Principle of free-fall electrostatic separators; separation of negatively-charged and neutral particles **(a)** or negatively- and positively-charged particles **(b, c)** in the electric field generated between vertical parallel plate electrodes **(a, b)** or horizontal cylinder electrodes **(c)**, energized from a D.C. high-voltage supply.

The present paper is aimed at evaluating an electrode design that reduces the need for cleaning. The experiments and the numerical simulations presented hereafter will point out an additional advantage over "standard" designs: the electric field is higher at any value of the applied high voltage.

2 THEORETICAL ASPECTS

2.1 Particles in contact with electrodes affected by DC electric fields

The electric field E between two parallel-plate electrodes is roughly expressed as:

$$E = V/s, \quad (1)$$

where V is the applied high voltage, and s is the spacing between the electrodes. An insulating spherical particle of radius r, which carries a charge Q (assumed to be concentrated in its center) and is in contact with one such electrode (Fig. 2), in air (dielectric constant ε_0) will be subjected to an electric force:

$$F = F_C + F_i \quad (2)$$

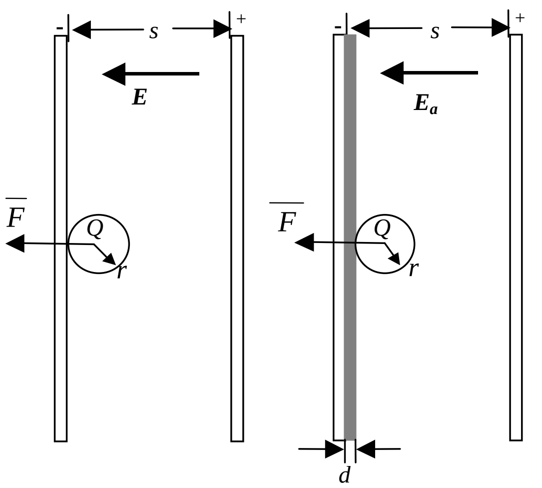
where F_C is the Coulomb force:

$$F_C = QE, \quad (3)$$

and F_i is the electric image force:

$$F_i = Q^2/[4\pi\varepsilon_0(2r)^2]. \quad (4)$$

This force will stick it to the electrode surface, if the gravitational force is not enough to drag it to the collector of the electrostatic separator.



a. b.

(a) $$\overline{F} = Q\overline{E} + \frac{Q}{4\pi\varepsilon_0(2r)^2} \bullet \frac{\overline{r}}{r}$$

(b) $$\overline{F} = Q\overline{E}_a + \frac{Q}{4\pi\varepsilon_0\left[2(r+d)\right]^2} \bullet \frac{\overline{(r+d)}}{(r+d)}$$

Figure 2. Forces acting on a spherical insulating particle in contact with a plate electrode **(a)** or with a dielectric-coated plate electrode **(b).**

Under the similar circumstances, a conductive sphere would acquire an electric charge of the same polarity as of the electrode with which it is in contact by electrostatic induction process. As a consequence, they will be attracted to the electrode of opposite polarity and directed to a different compartment of the collector. This effect significantly diminishes the efficiency of the electrostatic separation.

2.2 Particles in contact with dielectric-coated electrodes affected by DC electric fields

The intensity of the electric field E_a in the air gap between two parallel-plate electrodes, with one electrode covered by a dielectric layer of width d, characterized by a relative permittivity ε_r, can be expressed from the following system of equations, derived from Gauss law and the definition of the electric voltage V:

$$E_a\, \varepsilon_0 - E_d\, \varepsilon_r\varepsilon_0 = 0 \quad (5)$$

$$E_a\,(s - d) + E_d\, d = V \quad (6)$$

where E_d is the electric field strength in the dielectric layer. Thus:

$$E_a = V/[s - d(\varepsilon_r - 1)/\varepsilon_r] > V/s \quad (7)$$

which means that, at a given voltage, the electric field strength in the air gap between plate electrodes increases in the presence of a dielectric layer.

This is the first advantage of such an electrode arrangement. The second obvious advantage is that conductive particles in contact with a dielectric- covered electrode will not change their sign, and hence will be recovered in the appropriate collecting compartment of the electrostatic separator.

The third advantage of dielectric coating is the drastic diminution of the electric image force that "pins" the charged insulating particles on the surface of the electrode. Indeed, in this case:

$$F_i = Q^2/\{4\pi\varepsilon_0\,[2(r + d)]^2\} \quad (8)$$

which means that the particles are less likely to stick to the surface of the electrode.

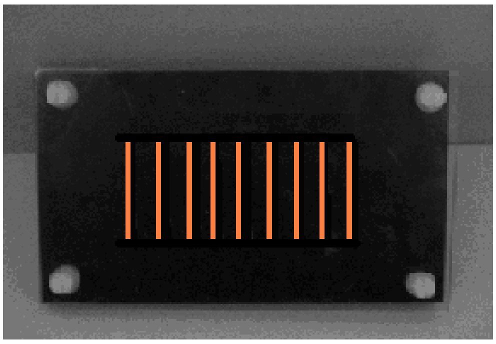
The experiments described hereafter confirm the effect of the dielectric coating and suggest the possibility of reducing the weight of this kind of electrode by using a metallic mesh, instead of a plate.

3 EXPERIMENTAL STUDY

3.1 Electrode models

The "standard" electrode (model #1)) consisted in a metal plate (88 mm × 44 mm × 0.5 mm), attached to a dielectric support (160 mm × 100 mm × 10 mm). Model #2 is obtained by attaching a transparent polycarbonate plate (160 mm × 100 mm × 4 mm) to the "standard" electrode, as shown in Fig. 3, a. In model #3, the metal plate is replaced by 9 copper wires of diameter 1 mm, spaced at an interval of 11 mm, and connected to the same high-voltage supply.

(a)



(b)

Figure 3. Figure 3. Photographs of electrodes model #2 **(a)** and model #3 **(b)**.

3.2 Experimental procedure

The electrodes were suspended at variable distances s = 30, 40 and 50 mm from a horizontal plate electrode, connected to the ground (Fig. 4). They were energized from a fully-adjustable, low-ripple, DC high voltage supply (Spellman, SL 300, 60 kV, 5 mA).

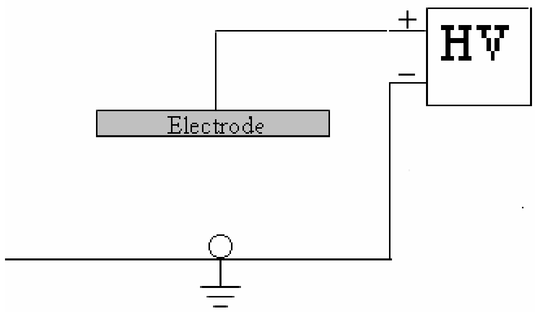


Figure 4. Schematic representation of the experimental setup.

A graphite cylinder (diameter: 0.5 mm; length: 5 mm) was placed on the grounded electrode. The applied voltage was progressively increased, at the rate of 1 kV/s, until the graphite particle was lifted-off from the electrode by the electric field forces. Félici showed that for a particle of known nature, shape, and size lift-off occurs at a well-defined intensity of the electric field [9, 10].

Let V_1, V_2 and V_3 be the average values of lift-off voltage recorded for the models, at a given inter-electrode spacing s. If $V_1 > V_2 > V_3$ then, at a given voltage V, $E_1 < E_2 < E_3$, with E_i representing the respective electric field strengths for the three models. This observation will be used for assessing the effect of electrode design on the strength of the electric field generated by each of the three models.

3.3. Experimental results

The lift-off voltages, recorded for the three models are given in Table 1. As predicted, the lift-off voltages were higher for model #1 than for model #2 and model #3.

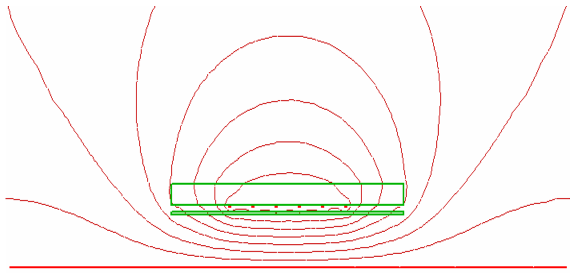
The difference between the average lift-off voltages of model #2 and model #3 are not statistically significant. However, the dispersion of the measured values is higher for model #3 than for model #2. This can be explained by the slight non-uniformity of the electric field produced by an array of wires, instead of a metallic plate.

Table 1. Lift-off voltage measured for the three electrode models at *s* = 25 m.

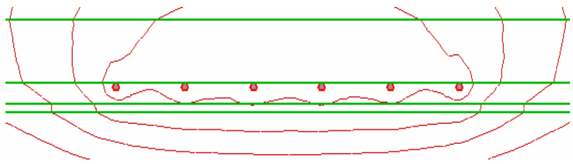
Electrode Model	**Lift-off Voltage [kV]**	
	Average value [kV]	Standard deviation [kV]
#1	15,92	0,98
#2	13,63	0,63
#3	13,2	0,72

4 NUMERICAL MODELING

The numerical analysis of the electric field generated by the three models of electrodes was carried out using the "Superficial Charge Simulation Program" (SCSP), which had been described elsewhere [11]. The simulations were done for three electrode configurations similar to those employed for the experimental study.



(a)



(b)

Figure 5. General aspect **(a)** and a zoom of the wire electrodes **(b)** of the .SCSP-plotted equal-potential lines for model #1.

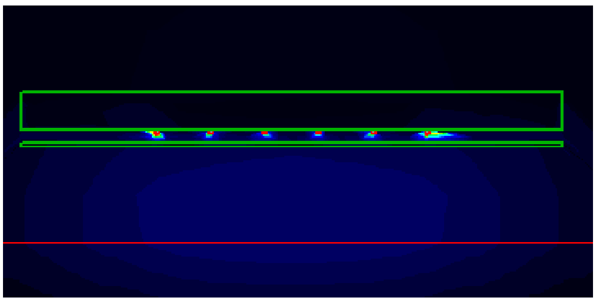
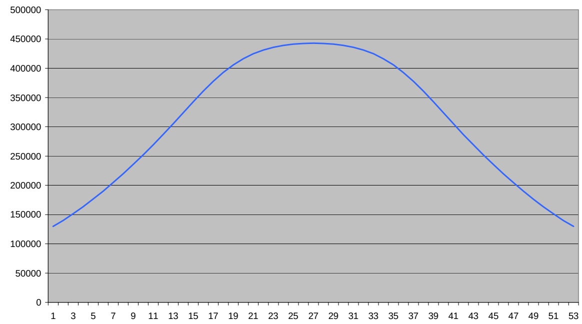
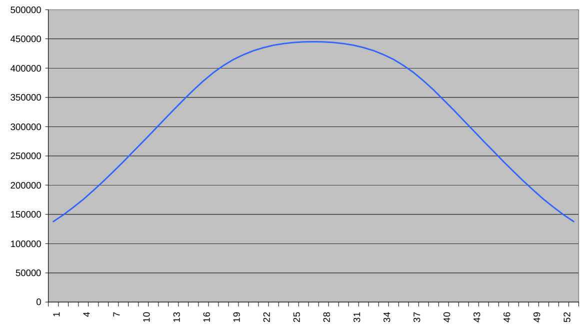


Figure 6. Map of SCSP-computed electric field strength for model #3.

Some typical results (the equi-potential lines and the intensity of the electric field) are represented in Fig. 5 and Fig. 6. The curves $E(x)$ plotted in Fig. 7 show that the intensity of the electric field at the surface of the grounded plate electrode is higher for the electrodes model #2 and model #3, compared to the electrode model #1.



(a)



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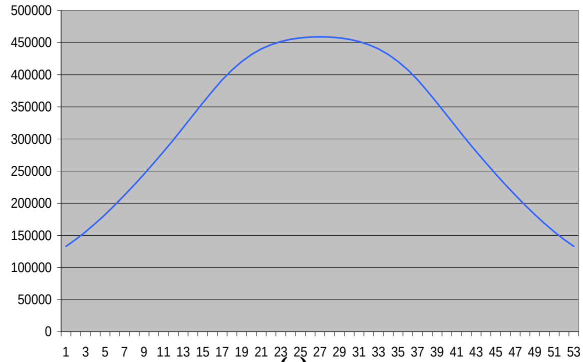

(c)

Figure 7. SCSP-computed intensity of the electric field at the surface of the grounded plate electrode for models #1 **(a)**, #2 **(b)** and #3 **(c)**.

5 CONCLUSIONS

The experimental results confirm the theoretical predictions regarding the intensification of the electric field in the presence of a dielectric layer at the surface of the plate electrode. Using a mesh of metallic wires instead of the plate would be a good solution, as this would be accompanied by a reduction of the electrode mass. The numerical simulations indicate that the non-uniformity of the electric field generated by such an electrode is fairly low and would not affect the output of an electrostatic separation process significantly.

Acknowledgments

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