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THE EFFECT OF AIR FRICTION IN ELECTROSTATIC SEPARATION

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ABSTRACT

This paper presents the results of a Ph.D. research program undertaken by the Author at the Mining Engineering Department of Oporto University. This was a part of a continuing team effort to develop modelling and computational ideas and tools for the mineral processing industry, based on mathematical descriptions of the state of liberation of a comminuted mineral mass. It focuses on the effects of air friction on the metallurgical parameters affecting an electrostatic separation process and on their practical implications, mainly as regards the needs for previous sizing of the feed.

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INTRODUCTION

A minimally realistic mathematical modelling of an electrostatic separation operation obviously needs to take into account not only the size distribution of the feed but also - and perhaps mostly - its grade distribution. The description of the joint distribution of grade and size is computed as the size distribution multiplied by the grade distribution conditional on size as described by Madureira et al. [1]. For most purposes, the former may be described by a Schumann-Gaudin distribution. For the case of undiscriminating, transgranular breakage of a granitoid (i.e. Voronoi polyhedral) ore texture, Cavalheiro [2] has show the latter to be describable by means of a beta distribution function the parameters of which can be related to the average grade and average grain size of the texture. The resulting type of joint size and grade distribution has been used as the starting point for the present work of investigation that consisted basically on the developpement of a mathematical model [3] of an electrostatic separator. The type of equipment chosen for this demonstration was the simple and well-known drum separator with particle charging by induction (Fig. 1); in the near future both the corona and the triboelectrification mechanisms will be modelled. All the results of the computational experiments described in this paper refer to a single set of regulation parameters, namely:

$V_0 = -30\,kV$, the electrode voltage; $R = 165 \times 10^{-3}\,m$, the drum radius; $r = 25 \times 10^{-3}\,m$, the electrode radius; $d_p = 195 \times 10^{-3}\,m$, the distance from the rotor surface to the electrode centreline; $\alpha = 35^\circ$, the angle between the drum-

electrode centrelines and the horizontal; $w = 5\,rad/s$, the drum angular velocity; $h = -350 \times 10^{-3}\,m$, the ordinate of the septum's edge, measured from the drum centreline.

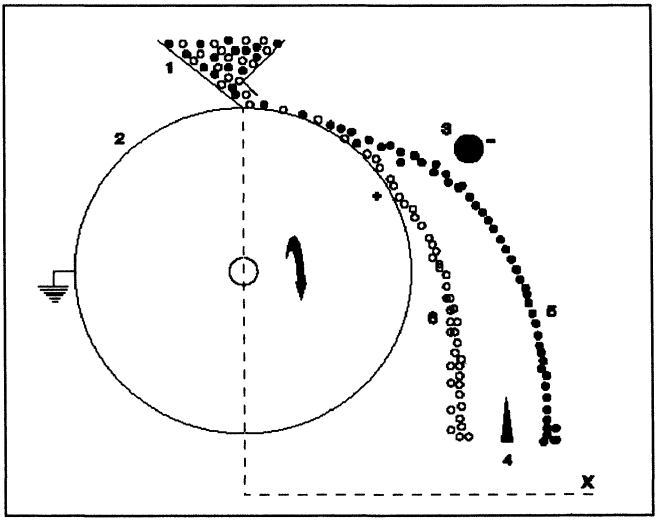

Fig. 1 Schematics of an induction separator: 1) feed hopper; 2) rotor; 3) charged electrode; 4) septum (product cut-off); 5) conducting particles; 6) insulating particles.

The lamelar flow regime around particles was adopted. A coefficient of dynamic viscosity of $181 \times 10^{-7}\,kg\,m^{-1}\,s^{-1}$ was selected for the friction of the air on the mineral particles [4]. As the two mineral species to be separated, cassiterite (a conductor) and scheelite (an insulator) were chosen as representative of a typical industrial application [5]. Specific gravities were taken as *7.0* and *6.0*, respectively [6], and relative permittivities as *27.75* and *5.75*, respectively, at *20° C* and *60 Hz* [7]. Extensive research notwithstanding, no reliable conductivity data were found available for scheelite [8]. The value of $10^{-7}\,\Omega^{-1}\,m^{-1}$ was taken as typical of insulator minerals of similar behaviour and smaller enough than the conductivity of cassiterite ($\approx 10^{-3}\,\Omega^{-1}\,m^{-1}$) [9] to make an effective contrast.

ABSCISSAS vs. PARTICLE SIZE PLOTS

For a given separator regulation, the abscissas vs. particle size plots of Figs. 2 and 3 represent the abscissas *x* (see also Fig.1) of the falling point of the particles (at ordinate *h*) for mineralogically pure particles.

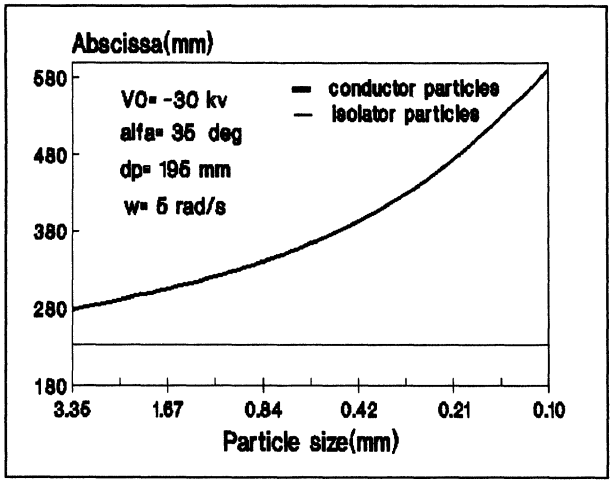

Fig. 2 - Abscissas vs. particle size plot (without air friction)

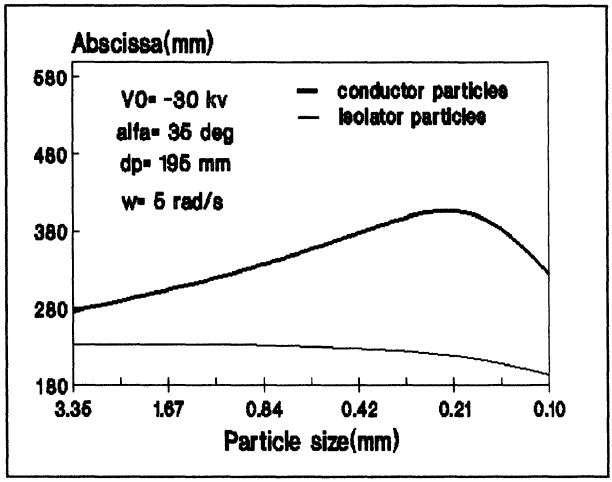

Fig. 3 - Abscissas vs. particle size plot (with air friction)

Fig.2 refers to particle behavior without air friction, the condutors giving a roughly parabolic plot (*i.e.,* showing high sensitivity to size) and the insulators giving a horizontal plot (*i.e.,* being size insensitive).

By comparison with the former, Fig. 3 shows the effect of air friction: conductors now give a complex plot, concave for the higher particle sizes and steeply falling past a maximum at about *0.21 mm*; contrastingly, for the insulators the plot starts horizontally and starts falling gently past about *0.59 mm*.

MARGINAL PARTICLE SIZE, PARTICLE GRADE AND ABSCISSA DISTRIBUTIONS

Although Cavalheiro's liberation model (*op. cit.*) predicts both volume and surface grades, the latter was not considered in this study because:

i) surface grade, although important for the separation mechanism, is industrially irrelevant.

ii) the separation model results for separation grade were shown to be too complex for an abridged statistical analysis such as the present one.

The study of a trivariate statistical distribution size (ϕ_i) - volume grade (t_{v_k}) - abscissa (x_j) is, thus, the main object of the present paper. The results of simulations with and without air friction were grouped into classes according to the three chosen variates, the centrepoints of which are shown in Table I.

Table I

i, j, k	1	2	3	4	5	6	7	8	9	10	11	...	20	...	25
ϕ_i (mm)	3.35	2.37	1.67	1.18	0.84	0.59	0.42	0.30	0.21	0.15	0.10				
t_{v_k} (%)	2.5	7.5	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	...	97.5		
x_j (mm)	198	214	230	246	262	278	294	310	326	342	358	...	502	...	582

For each simulated situation, grouped results corresponding to the 11 size classes may be represented as follows:

$$\left\{\begin{array}{ccc} \phi_i & x_j & t_{v_k} \\ 1 & 1 & 1 \\ \vdots & \vdots & \vdots \\ 1 & 1 & 20 \\ \vdots & \vdots & \vdots \\ 1 & 25 & 1 \\ \vdots & \vdots & \vdots \\ 1 & 25 & 20 \\ \vdots & \vdots & \vdots \\ 11 & 25 & 20 \end{array}\right\} \left\{\begin{array}{c} f_{ijk} \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \\ \vdots \end{array}\right\} \tag{1}$$

f_{ijk} representing relative frequencies for each class. If n_i is the size of the representative sample for each size, and n is the size of the whole sample, the (sampling) size-grade distribution of the feed may be defined, according to Exp. (1) as

$$f_r\,(t_{v_k}, \phi_i) = \frac{\sum_{j=1}^{25} f_{ijk}}{n}\,, \quad i = 1, 2, \ldots 11\,;\; k = 1, 2, \ldots 20 \tag{2}$$

n being given by

$$n = \sum_{l=1}^{11} n_l \tag{3}$$

and represented as in Fig. 4, according to Cavalheiro's model predictions.

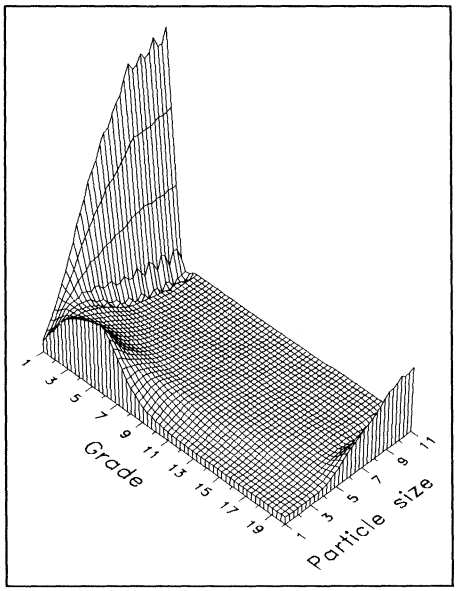

Fig. 4. Bivariate size-grade distribution of the feed.

To render the simulation results easier to interpret, an exhaustive statistical study of distribution represented by Exp. (1), was undertaken and the following representations were retained:

a) the marginal distribution of the abscissas (*i.e.*, independently of both size and grade);

b) the marginal-conditional distribution of the abscissas conditional on size (*i.e.*, independently of grade alone);

c) the three bivariate marginal distributions.

For simplicity's sake the bivariate abscissas-size and abscissas-grade distributions were chosen to be described here because, in our view, these provided the most significant plots. Similarly to Exp. (3), these may be defined as

$$f_r(x_j, \phi_l) = \frac{\sum_{k=1}^{20} f_{ijk}}{n}, \quad i = 1,2,\ldots 11; \; j = 1,2,\ldots 25 \tag{4}$$

and

$$f_r\,(x_j, t_{v_k}) = \frac{\sum_{i=1}^{11} f_{ijk}}{n}, \quad j = 1, 2, \ldots 25\ ;\ k = 1, 2, \ldots 20 \tag{5}$$

and computed from the simulation results. Figs. 5 to 8 represent these bivariate distributions.

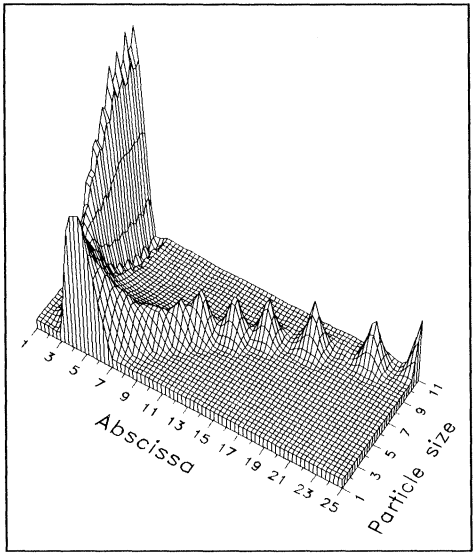

Fig. 5 - Bivariate abscissas-size marginal on grade (without air friction)

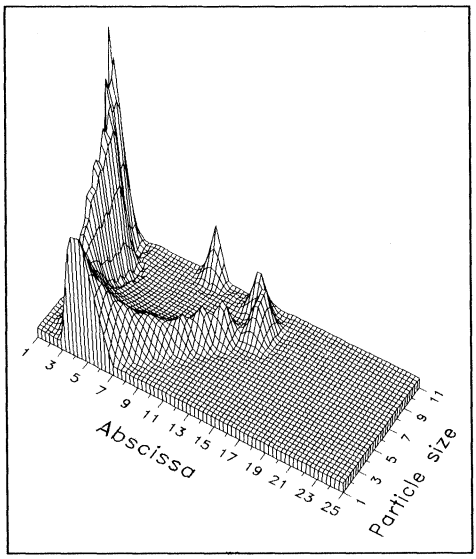

Fig. 6 - Bivariate abscissas-size marginal on grade (with air friction)

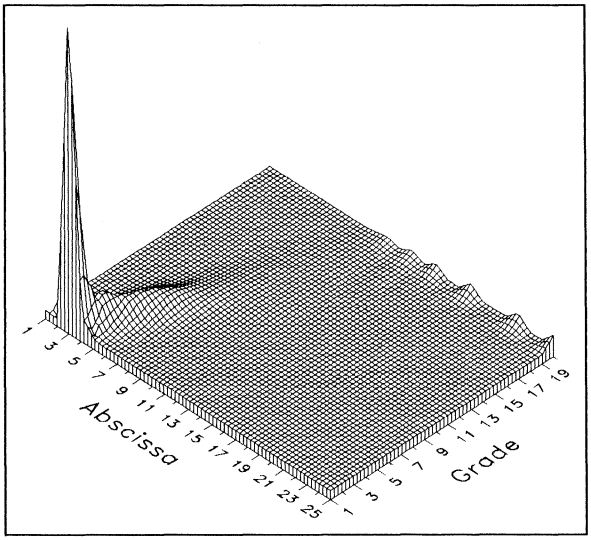

Fig. 7 - Bivariate abscissas-grade marginal on size (without air friction)

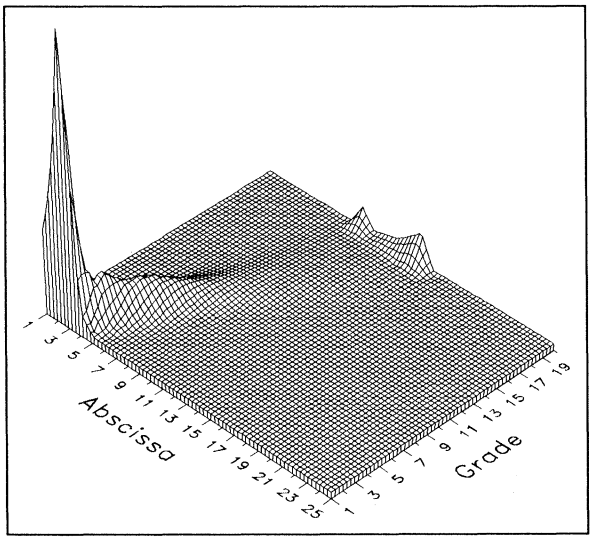

Fig. 8 - Bivariate abscissas-grade marginal on size (with air friction)

The analysis of these results strongly emphasises the fact that coarse (*i.e.* larger than size class *5 ≈ 0.84 mm*) particles of these minerals are almost impossible to separate, either with or without air friction. A significant material accumulation at the abscissa class 3 (which corresponds to the gravitational jump), is formed mainly by particles or low grade and broad size distribution that behave electrically as poor conductors. From this size downwards, the

abscissas-size distribution becomes forked, clearly showing an increasing separation effect. Air friction, however, strongly attenuates this effect from *0.59 mm* downwards, meaning that the poor conductors still follow the gravitational jump, while the better conductors now fall nearer to the drum than in the frictionless case; from *0.21 mm* downwards this effect becomes strongly marked, and below *0.10 mm* separation again becomes impracticable.

WASHABILITY CURVES

Given the lack of reliable data about the electrical properties of minerals that are extremely sensitive to the ever present impurities, an experimental validation of the present model was not decisive. For this presentation, we resort to the computation of washability curves, the widely used instruments of the minerals processing industry for the evaluation of separation efficiency [10]; in fact, the general shapes of these curves are well known to us, even for such quantitatively ill-studied processes such as electrostatic separation. Thus, we regard qualitative agreement between the shapes derived from model predictions with those to be expected from experience.

These curves represent yield (*i.e.*, the fraction of the feed that goes into the concentrate) vs. cut-off grade or, as in our case, yield vs. the abscissa of the cut-off point (*i.e.*, the position of the septum that defines the separation between concentrate and waste).

Figs. 9 to 18 show washability curves corresponding to the most significant size classes, for both the frictional and frictionless cases; it should be noticed that between the abscissa labels we indicate the volume grade of the material caught in the corresponding slot.

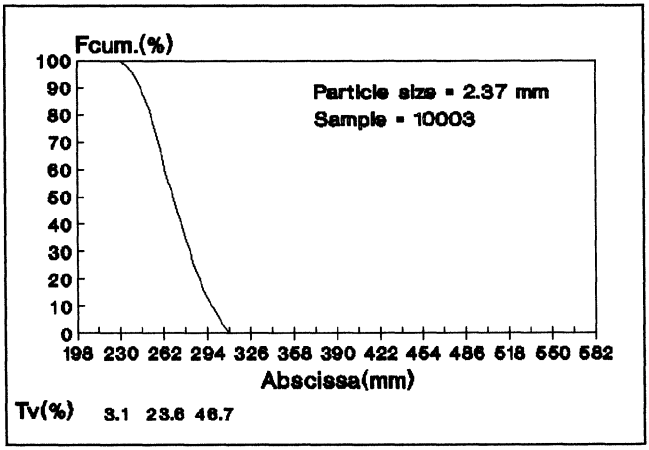

Fig. 9 - Washability curve - without air friction

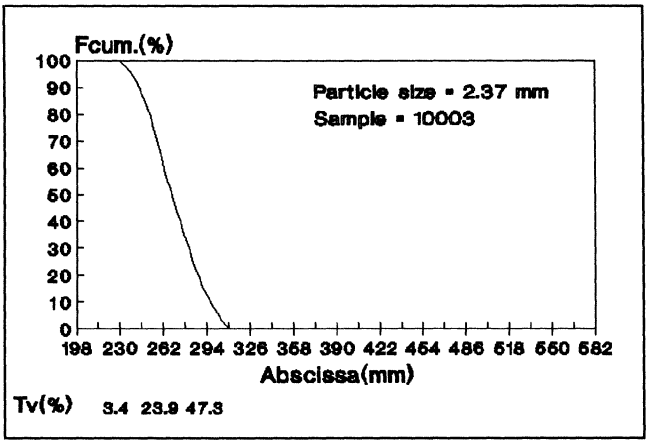

Fig. 10 - Washability curve - with air friction

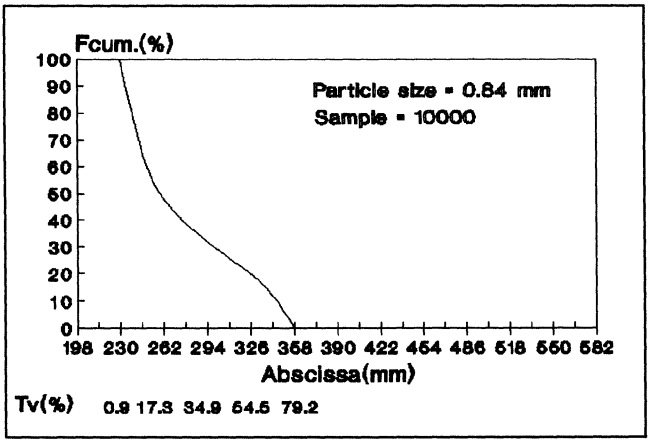

Fig. 11 - Washability curve - without air friction

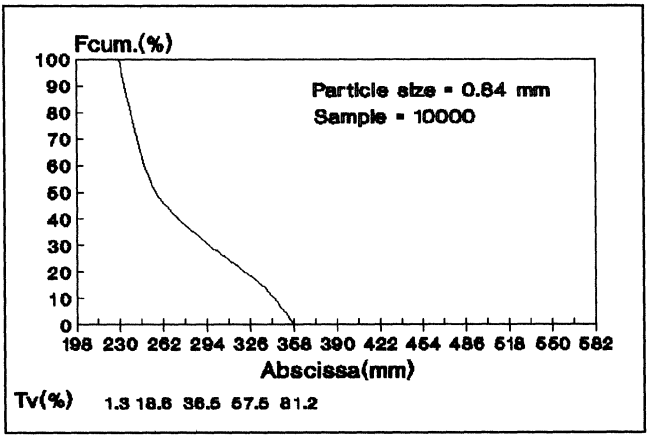

Fig. 12 - Washability curve - with air friction

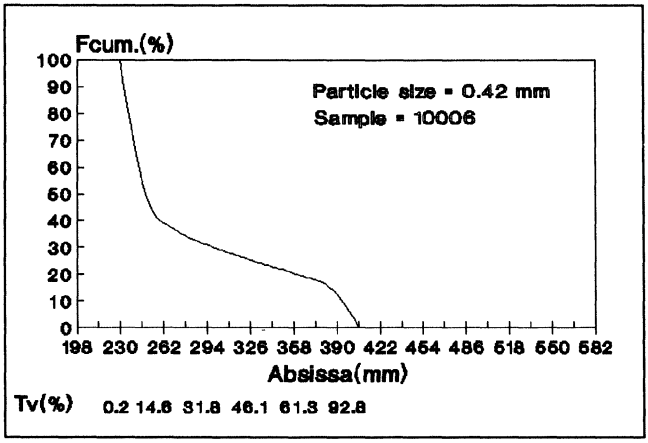

Fig. 13 - Washability curve - without air friction

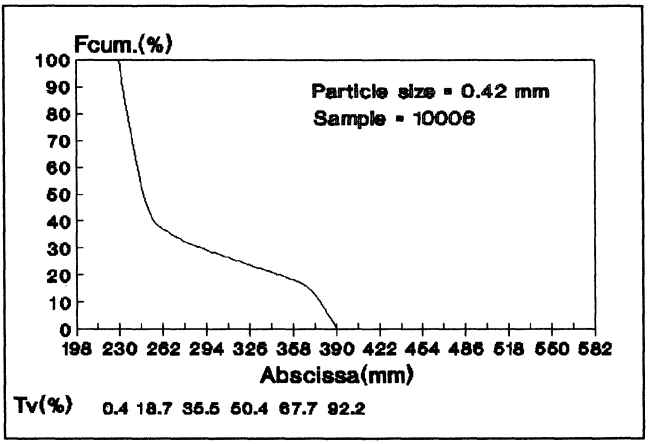

Fig. 14 - Washability curve - with air friction

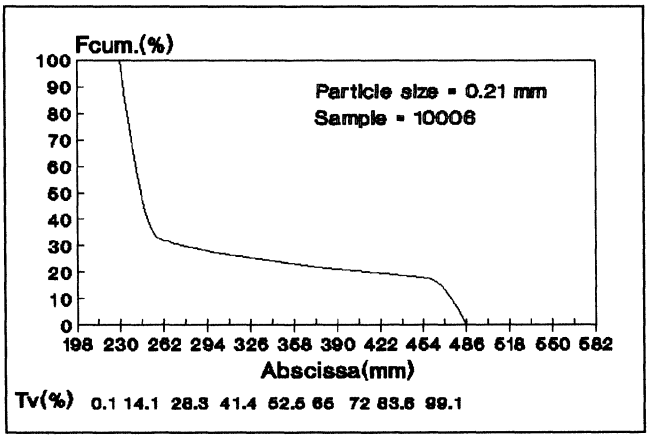

Fig. 15 - Washability curve - without air friction

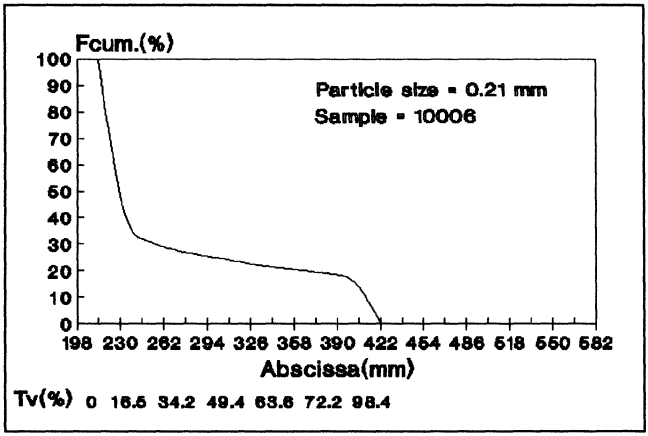

Fig. 16 - Washability curve - with air friction

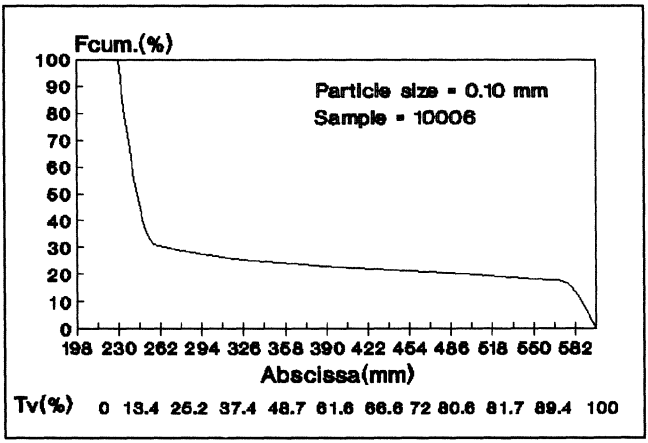

Fig. 17 - Washability curve - without air friction

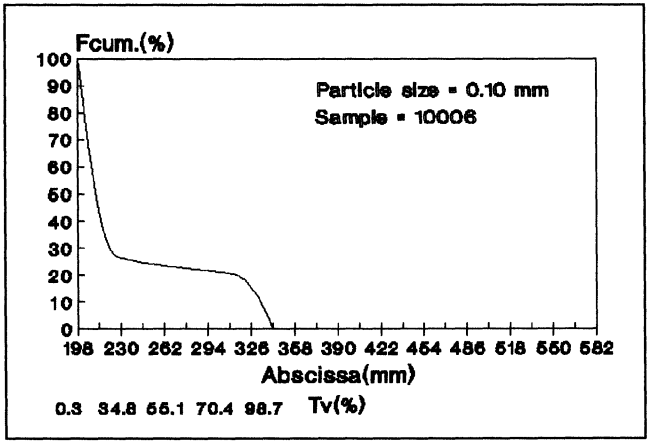

Fig. 18 - Washability curve - with air friction

The analysis of these curves allows us to examine the behaviour of particles in electrostatic separation. Specifically, we may notice that size *0.84 mm* is a transition point between two characteristic shapes of the washability curves and, thus, of the ore behaviour: a horizontal stretch starts to develop from this size downwards, meaning a separation gradually more efficient and easier to control. This may be confirmed by the grades indicated for each slot.

This type of behaviour is generally similar for the case where air friction disturbs the separation, the differences being merely quantitative: the spatial separation shortens and grade decreases in corresponding slots. These observations agree and expand those previously obtained from the bivariate distributions.

CONCLUSIONS

The analysis of the bivariate distributions demonstrated the fact that coarse (*i.e.,* larger than *0.84 mm*) mineral particles are almost impossible to separate, either with or without air friction. For smaller sizes the effect of air friction is progressively emphasised and below *0.10 mm* electrostatic separation again becomes impracticable.

It was shown that the present model of an electrostatic indutive separator is able to cause plausible washability curves. The analysis of these curves allow us to confirm the observations obtained from the bivariate distributions, pointing out that in the frictional case, there is a sizing feed that optimises the behaviour of particles in electostatic separation.

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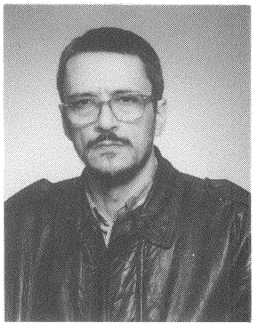

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Keywords: Air friction, electrostatic separation, modelling, simulation