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ELECTRICAL SEPARATION OF METALS FROM MINERAL WASTES USING GRADIENT FORCES

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Abstract

This paper presents a method for recovery nonferromagnetic components (Au, Ag) in reduced concentration from mineral wastes, using gradient forces. First the main up-to-date electrical dry separation techniques for recovery useful materials from wastes are presented which are based on different electrical properties of the waste components.

INTRODUCTION

Electric dry separation is an ensemble of methods for recovery of useful materials from mineral and industrial wastes, based on the differences between their electrical properties. The wastes are heterogenous mixtures including milimetric or submilimetric particles of useful and basic materials being present in different proportions.

Usually these methods are used both for non-ferromagnetic material recovery (Au, Ag, Cu, Pb, Al) from mineral or electrotechnical wastes and for separation of different kinds of plastic materials, as in the following table:

Table 1: The present stage of electric dry separation

Separation Characteristics	Separation Processis	Separation Principles	Separation Types	Size of Particles
Electrical Conductivity	Eddy currents separation Electrostatic separation	Eddy currents in metals lead to the appearance of electromagnetic forces Different charging of particles leads to different electrical forces upon particles	Metal-nonmetal separation	>5 mm
Superficial electric conductivity	Corona separator	Corona discharge leads to different charging of particles and consequently to different electrical forces	Metal-nonmetal separation	0.02-2(4) mm
Dielectric permitivity	Free fall electrical high voltage separation	Tribocharging of the particles with different sign of charge leads to different forces upon particles	Plastic	<5(10) mm

The electrical gradient forces method (EGFM) presented in this paper has been used at West University of Timişoara for Au and Ag recovery, having a very low concentration in a mixture.

The material designed to separation was a mineral waste, a mixture containing useful particles with high electrical conductivity (corresponding to a high concentration of Au and Ag) and dielectric particles (SiO_2, calcite, pyrite), the mean size of mixture particles being about 75μm.

THEORETICAL CONSIDERATIONS

It is known that the electrical translational force $\vec{F}$, on a electric dipole $\vec{m}$ (induced or permanent) in a nonuniform electric field is [1]:

$$\vec{F} = (\vec{m}\nabla)\vec{E} \tag{1}$$

where $\vec{E}$ is the electric field strength and $\vec{m}$ the dipole moment of a dielectric particle embeded in a dielectric medium:

$$\vec{m} = v\vec{P} \tag{2}$$

where:
v – volume of particle,
$\vec{P}$ – polarization vector (dipolar moment density).
The polarization in the particle is [1]:

$$\vec{P} = N\varepsilon_0\varepsilon_{r_1}\alpha\vec{E}_i \tag{3}$$

where:
ε_0 – electric permitivity of free space,
ε_{r_1} – relative dielectric permitivity of the particle,
N – dipole concentration (dipole number per unit volume),
α – electrical polarizability of the particle,

$\vec{E}_i$ – internal electric field strength in the particle, in the direction of the external field [3]:

$$\vec{E}_i = (1 - k)\vec{E} \tag{4}$$

where:

$$k = \frac{\varepsilon_{r_1} - \varepsilon_{r_2}}{\varepsilon_{r_1} + 2\varepsilon_{r_2}} \tag{5}$$

is the depolarization factor and ε_{r_2} the relative dielectric permitivity of the medium.

Accordingly, the effective translational force $\vec{F}$ becomes:

$$\vec{F} = v(1 - k)N\alpha\varepsilon_1\vec{E}\nabla\vec{E} = \frac{1}{2}v(1 - k)N\alpha\varepsilon_1\nabla E^2 \quad (\varepsilon_1 = \varepsilon_0\varepsilon_{r_1}). \tag{6}$$

One observes that the force is proportional to the gradient of the square of the electrical field strength, therefore it can be called gradient force.

Equation (6) shows that the direction of the force is the same if the field is reversed in sign. Also, one observes that the existance of this gradient force requires a nonuniform field.

The specific volume force (force per unit volume of particle) is:

$$\vec{f}_v = \frac{\vec{F}}{v} = N\alpha(1 - k)\varepsilon_1\vec{E}\nabla\vec{E} \tag{7}$$

where N can be defined in accordance with mass density ρ of a particle as:

$$N = c\rho \tag{8}$$

c being a constante for each type of dielectric material.
The volume force (7) becomes:

$$\vec{f}_v = c\alpha\rho(1 - k)\varepsilon_1\vec{E}\nabla\vec{E}. \tag{9}$$

Because the mixture contains dielectric particles with close permitivities (metallic particles are in very low concentration and their contribution can be neglected), in (5) we can approximate $\varepsilon_{r_2} \simeq \varepsilon_{r_1} = \varepsilon_r$, therefore, the depolarization factor becomes $k = 0$. Thus, in (9) $\varepsilon_1 = \varepsilon_0 \varepsilon_r$ can be considered as a global dielectric permitivity of a entire medium placed in the electric field.

In the separator based upon the acting of gradient forces, the field is initially uniform, but the presence of many particles changes the field in their vicinity and leads to the appearance of gradient forces. [1] In this case we are proceed to modify (5), to adapt it to real conditions in a such separator.

Thus, taking into account the electric flux law in absence of free electrical charges $div\vec{D} = 0$ as in the EGFM separator, it results:

$$\nabla \vec{E} = -\frac{1}{\varepsilon_1} \vec{E} \nabla \varepsilon_r \tag{10}$$

and the expression (9) becomes:

$$\vec{f_v} = -c\alpha\rho E^2 \nabla \varepsilon_r. \tag{11}$$

It can observed that the presence of particles in the electric uniform field leads to appearance of gradient forces. These forces are independent of the sign of electric field and are always directed toward to the lowest value of the permitivity.
Eq. (11) is an appropriate form to express the behavior of particles from the surface of the mixture. Because inside the mixture the dielectric permitivity has the mean value ε_r, as was previously considered, here $\nabla \varepsilon_r = 0$. Also, because in a metallic particle $\vec{E_i} = 0$ (eq. 1, 2, 3), for the metallic particles from the surface do not act electrical gradient forces. Consequently, the forces (11) act only upon dielectric particles that are lying on the surface of the mixture.

Upon metallic particles which are lying on the surface of the mixture act superficial electric forces (force per unit surface of a particle) [2]:

$$\vec{f_s} = \frac{\varepsilon_0}{2} E^2 \vec{n} \tag{12}$$

[1] A mixture of different kinds of particles is placed in a uniform electric field: each particle is in a nonuniform field because of the presence of the other particles

like in Fig.1, where $\vec{n}$ is versor (unit vector) at the surface.

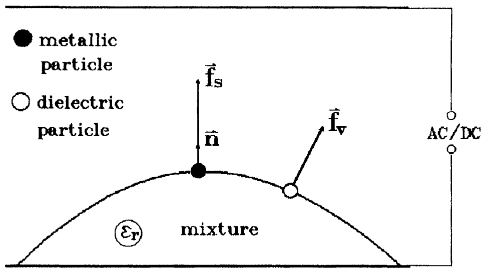

Figure 1: Mixture in electric field

Consequently, it can be considered that upon dielectric particles from the surface of mixture act electrical gradient forces (eq.11) and upon metallic particles from the surface act superficial electric forces (eq.12). For metallic and dielectric particles inside the mixture these forces are very small values.

In Fig.2 the action of the electrical forces given by (11) and (12) and the gravity force $\vec{G}$ on a dielectric and a metallic particle at the air – mineral waste interface is shown:

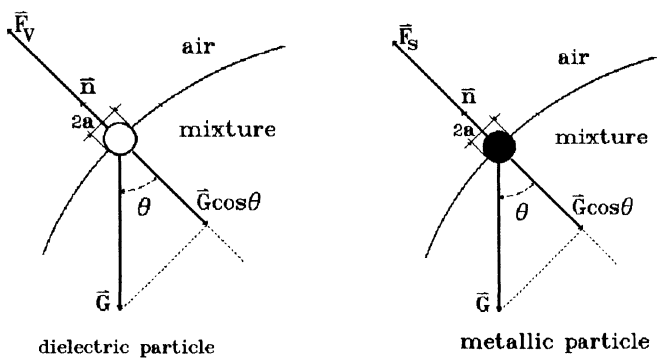

Figure 2: Particles at the interface

The condition for a dielectric particle to be moved from the air – mixture interface is:

$$|\vec{F}_v| \geq G\cos\theta \qquad (\vec{F}_v = v\vec{f}_v \quad v = \frac{4}{3}\pi a^3) \tag{13}$$

and for a metallic particle:

$$|\vec{F}_s| \geq G\cos\theta \qquad (\vec{F}_s = \frac{S}{2}\vec{f}_s \quad S = 4\pi a^2). \tag{14}$$

Accordingly, the repelling conditions for the particles which are lying on the surface of the mixture are:

– for a dielectric particle:

$$E^2 \geq \frac{g\cos\theta}{c\alpha\nabla\varepsilon_r} \tag{15}$$

– for a metallic particle:

$$E^2 \geq \frac{4}{3}\frac{\rho g\cos\theta}{\varepsilon_0}. \tag{16}$$

From (15) and (16) it results that for the same intensity of the electric field $\vec{E}$, the dielectric particles from the surface of the mixture will be firstly removed, because:

$$\frac{4}{3}\frac{\rho}{\varepsilon_0} > \frac{1}{c\alpha\nabla\varepsilon_r} \tag{17}$$

Consequently, it is thought that after applying the electrical field on the surface of the mixture the metallic particles will be concentrated.

EXPERIMENTAL RESULTS

The material to be separated (a mineral waste containing Au and Ag in low concentration having the size about 75 μm), was introduced in an AC electrical field (2 - 4 kV/cm).

At instant, a strong movement of the surface particles was observed and in a short time a dark layer with a high electrical conductivity (in comparison with that of the initial material) appeared at the surface of the mixture, accordingly with the previous theoretical considerations. After that the movement of the particles is diminished due the shielding effect produced by the metallic formed layer.

In Fig.3 it is represented a photo of a mixture after the voltage was applied.

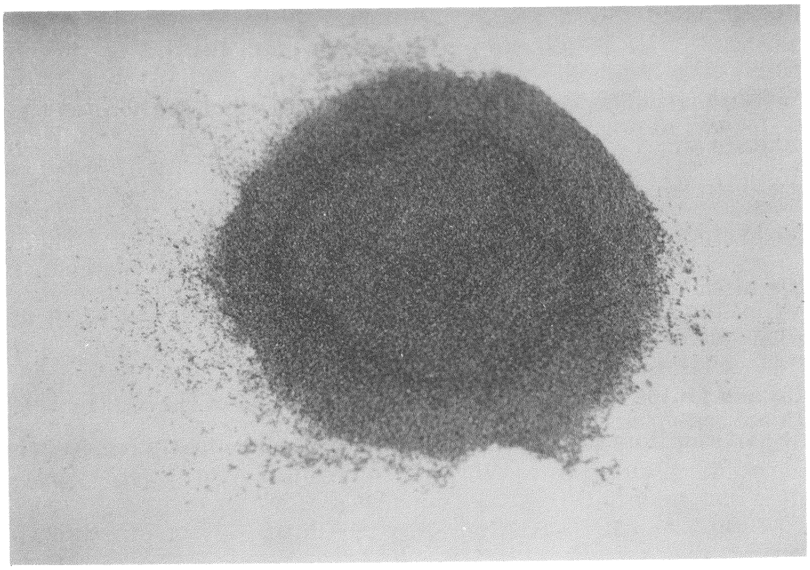

Figure 3: Mixture after applying the electric field

Turning off the electric field, the particles of the dark layer was collected and chemical analyzed. The contents of Au, Ag and Sulphur before and after the separation are presented in the following table:

Table 2: Experimental results using EGFM

Material	Before separation	After separation
Au[g/t]	1.3	10.1
Ag[g/t]	32.9	75.1
S[g/t]	4.28	34.32

CONCLUSIONS

As it was shown, the electrical gradient forces method (EGFM) is a dry separation technique, useful to recovery the nonferromagnetic metals having low concentration from mineral wastes.

The material subjected to the separation process is placed into an electrical field that is initially uniform, but the presence of particles changes the field in their vicinity, leading to the appearance of electrical gradient forces.

Owing to combined action of electrical and gravity forces, a superficial layer consisting in metallic particles on the surface of mixture was obtained.

The chemical analyse of particles from this superficial layer shows a growing of Au, Ag and S concentrations.

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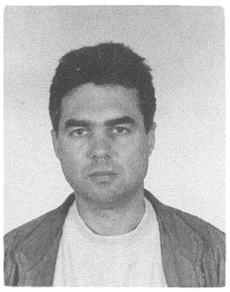
Keywords: gradient forces, electrical dry separation, nonuniform electrical fields, electrical gradient forces method, translational force, metallic formed layer.



Mihail Lungu was born in 1962 and graduated from the Faculty of Physics of the University of Timisoara, Romania, in 1986. In the period 1991 to 1995 he was associated with the Physics Faculty as a professor assistant and in 1995 he was appointed a lecturer. Since 1992 he has been working on his Ph.D thesis on recovery of useful components from mineral and industrial wastes. Mr. Lungu's further interests are solid state devices and plasma physics.

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