

TRIBOELECTRIC PHENOMENA IN MINERAL PROCESSING. THEORETIC FUNDAMENTALS AND APPLICATIONS

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INTRODUCTION

Surface-based ore processing methods, amongst which electric separation, are gaining increasing interest in mineral technology.

The Institute of Mining and Mineral Preparation of the University of Cagliari is engaged in this field with a broad research programme which started many years ago, (ref.1, and references cited therein, 2-6).

Three lines have been followed:

- theoretic investigation in order to define suitable models for the chemico-physical processes underlying the behaviour of minerals under varying environmental conditions;
- experimental tests, mainly with pure species, for the control and a better definition of the models adopted;
- finally, on the basis of the indications of theory and applied research, the solution of real processing problems at both laboratory and pilot plant scales, starting from crude ores.

As far as the theoretic studies are concerned, a unified model has been proposed as the result of the broad research carried out; this model is suitable for the description of the main surface-based phenomena involved in mineral processing. A large series of experimental checks have demonstrated its reliability in most cases.

In particular, the Fermi level has been assumed as the outstanding parameter for the condition between the behaviour of the various minerals in electric separation and flotation and their surface energy properties fully described by the Fermi-Dirac statistics.

The indications of the model are to be considered as very helpful for the improvement of the techniques and for the achievement of better practical results, as demonstrated by the applications, some of which are illustrated and discussed later in the paper.

THEORETIC FUNDAMENTALS

A simple model for the description of the interphase energy exchanges has first been studied in order to explain the triboelectric charging phenomena of mineral particles. The experimental research dealt with the measurement of the work function of the different minerals and with the detection, on a statistical basis, of the electric contact charges acquired by the single grains.

The work function was determined by means of the measurement of the contact potential difference with respect to gold, assumed as the reference metal, using the modified Kelvin methods (rotating or vibrating condenser). The contact potential measurements were carried out on specimens of natural crystals of different characteristics and origin, properly cut and smoothly polished. The data obtained with the methods adopted showed a satisfactory reproducibility.

Electric contact charges acquired by the single grains of the different mineral species after sliding on vibrating chutes made of various metals, ceramic materials glass and plastics, were detected using a Faraday well connected to a high input impedance electrometer. With the apparatus set-up, charges as small as 10^{-13} - 10^{-14} coulomb could be measured. It was revealed that the sign of the electric charges depend on the work function of the mineral with respect to that of the contact surface. More precisely, experimental results allowed to demonstrate the theoretic hypothesis regarding the transfer of electrons in triboelectric charging from the mineral to the "rubbing medium" and viceversa: the mineral is positively charged if its work function is higher, and negatively charged if it is lower than that of the contact surface.

Besides natural minerals, the model was also checked, after modification of the surface energy structure of the same minerals, with treatments such as X or γ irradiation, ionic or electronic bombardment, thermal processes.

This fact opens very interesting possibilities in order to assume the optimal conditions for a selective triboelectric charging of the different mineral species to be separated. Particularly important is the effect of temperature, which can be described by resorting to the energy band model in semiconducting solids.

The necessary data regarding the electrophysical parameters involved in the simplified band model were collected for the various minerals by measuring the electric conductivity σ and the Seebeck coefficient χ as a function of temperature. The gradient of the conductivity curve ($\log \sigma$ versus reciprocal absolute temperature) in the intrinsic field gives the width of the forbidden band E_g while the sign and value of χ in the so-called "transition zone" reveal the kind of conduction (n-type or p-type) and give the position of the Fermi level E_f with reference to the upper edge of the valence band.

Within the limits of the proposed goal, the model adopted, although simplified, is still very useful for a rough understanding of the phenomena involved in electric separation and in flotation. Moreover, on the basis of the indications made

available, it is possible to forecast the results obtainable in the processing of a crude ore containing two or more mineral components; the most suitable external actions for the improvement of the separations results can also be identified.

CHECK OF THE MODEL

The reliability of the model was ascertained on three mineral samples of fluorite, barite and calcite. The above indicated electrophysical parameters were systematically measured under different conditions in order to find the desired correlations with the separation results working with pure species or with synthetic mixtures of them.

At increasing temperatures, the Fermi level diminished continuously for n-type semiconductors like the fluorite and calcite minerals examined, as was expected, from a position corresponding to the energy levels of the "donor" states to the middle of the forbidden band. The opposite happened for the barite mineral examined for which conductance was p-type owing to the presence of "acceptor" states.

It is to be pointed out that minerals of the same species can be either n-type or p-type according to the impurities contained, and to the presence of distortions natural or induced, in the crystal lattice.

As the position of the Fermi level varies with temperature, the behaviour of the mineral grains in triboelectric separation alters accordingly. This was fully demonstrated by the experiments carried out using a cyclone as the charging device in order to achieve better contacts under the action of the centrifugal force.

INDUCED MODIFICATIONS

As demonstrated, the energy structure of minerals in surface layers can be modified through external actions in order to create the most favourable conditions for the surface-based mineral processing methods. Such a possibility is a step of outstanding importance for the improvement of the techniques available and for the set-up of new ones.

It is difficult to illustrate in a short space the different experimental results obtained. However, besides the effects of temperature, the modifications induced by mechanical actions, which produce distortions of the crystal lattice, giving rise to localized energy levels inside the forbidden band, are also worth mentioning. Therefore it is necessary to control with particular care the grinding phase before separation, in fact, as it is well known, the kind of grinding, wet or dry, and the particular environmental conditions during the mineral comminution affect to a great extent the final results.

A further modification can be accomplished by introducing doping elements into the crystal lattice; however, the practice of this technique is not yet satisfactory as regards the application in the field of ore dressing.

Very promising are the possibilities offered by the various techniques of irra-

diation in the surface-based mineral processes, notably in electrostatic separation. In fact, new energy properties can be acquired and maintained by the mineral grains, subjected to such actions, for a given time. It is thus possible to differentiate the behaviour of minerals which, practically, cannot be separated under normal conditions. Similar effects are produced by ionic or electronic bombardment at high field intensity.

In general the different kinds of irradiation and bombardment give rise to "acceptor" states thus increasing the tendency of the mineral substances to acquire negative contact charges. However, it is possible to take advantage of the different "decay" times, which are characteristic of each mineral, in order to attain the most favourable selectivity conditions.

The environment moisture is of great importance in triboelectric charging phenomena. In fact, it is evident that the adsorption of water molecules on the mineral surface modifies the energy structure thus influencing the exchange processes. Moreover, the water or vapour coatings increase the surface conductivity causing an easier leakage of the triboelectric charges.

INDUSTRIAL RESULTS

Following the indications of the basic research, many problems regarding the processing of crude ores by electrostatic separation could be satisfactorily resolved.

The separation tests were carried out with the "Electrociclojet" and the "Triboelectric cyclone separator", both designed and built at the Institute's workshop on both laboratory and pilot plant scales. In the case where the surface electric properties of natural minerals are already well differentiated under normal conditions, good separation results can generally be achieved through the appropriate selection of the material on which contact charging takes place. As demonstrated, the work function of such materials must be intermediate between the work functions of the mineral species to be separated.

Some examples are reported below:

- a) Upgrading of a barite crude ore with a quartzeous gangue. Suitable charging materials: perspex, grès. A two stage separation with the triboelectric cyclone separator gave a 97% BaSO_4 concentrate with a recovery higher than 95%, the BaSO_4 content in the reject being around 9%. Similar results were obtained with the Electrociclojet starting from a feed material finer than 0.5 mm including the finest sizes; the concentrate grade was higher than 98% BaSO_4 with a recovery of about 96% and very low losses in the refuse.
- b) Upgrading of a fluorspar ore with a complex gangue. Suitable charging material: stainless steel. The separation, with one cleaning and two scavenging stages was carried out with the Electrociclojet; a final product having a CaF_2 content higher than 97% was obtained with a recovery of about 90%.

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c) Cleaning and pyrite removal from coal. Suitable charging material: Stainless steel. The problem is of outstanding interest owing to the increasing consumption of coal in power stations. The reduction of the sulphur content below fixed limits is mandatory for ecological reasons. Tests have been carried out on laboratory and semindustrial scales on various samples of run of mine. The problem was satisfactorily solved as far as the removal of the free pyrite is concerned, whereas very little could be done for the elimination of the organic sulphur and of the finely dispersed pyrite particles. Anyway, it is to be pointed out that, notwithstanding the difficulty of the problem, inorganic sulphur was lowered to below 1.0% for the majority of the samples tested, with bearable losses. At the same time also the gangue minerals (calcite, quartz, silicates) were rejected in the refuse, owing to their well differentiated properties with respect to the main coal macerals.

Therefore, a low sulphur, low ash clean coal could be obtained with a single operation.

For instance, a 0.8% Sulphur, 5% ash clean product was obtained with a high recovery from a West Virginian raw coal with a single stage separation in the Electro-ciclojet; a further cleaning stage was sufficient to lower the Sulphur content to below 0.5%.

Similarly, from a West German raw coal having 20.3% ash and 0.82% pyritic sulphur, a 0.33% inorganic sulphur, 5% ash clean product was separated by effectively combining selective comminution and triboelectric separation.

In the case where the characteristics of the natural components are not sufficiently differentiated, it is practically impossible to achieve a satisfactory separation. In this case it is necessary to resort to suitable external actions in order to induce a selective modification of the surface electric properties.

A very interesting way is represented by the effect of temperature. The following examples are worth noting:

a) Electric separation with triboelectric charging of quartz from feldspar contained in a beach sand. Tests were carried out using a stainless steel cyclone for triboelectric charging. Both the feed material and the cyclone walls were heated to temperatures around 100°C. Besides the separation of a quartz product with a grade higher than 90% it was also possible to separate sodic from potassic feldspar with interesting efficiencies.

b) Upgrading of a Tunisian lean phosphate. The solution of this interesting problem is rather difficult owing to the very complex mineralogical structure of the ore. Preliminary tests of triboelectric charging clearly demonstrated the great sensitivity of the effect of temperature. A further series of systematic separation tests using a stainless steel cyclone for triboelectric charging revealed that both the concentrate grade and the recovery vary according to the temperature.

The optimum conditions could be found within a temperature interval ranging from 150 to 200°C; at higher temperatures the recovery continues to increase but the

grade becomes unsatisfactory.

According to the setting of the main geometric and operational parameters of the separator, $\text{Ca}(\text{PO}_4)_2$ grades higher than 75% could be obtained working with the Kalaa Djerda run of mine, an increase of about 10 % points with respect to the feed grade.

CONCLUSIONS

The values of the electrophysical parameters of the various mineral components present in a mixture, can be correlated with the separation results achieved in a high intensity electrostatic field, after triboelectric charging.

The correlations revealed allow a clearer explanation from the standpoint of solid state physics, of the mechanisms involved in surface phenomena.

Moreover, new and particularly beneficial techniques of ore dressing have been proposed; although these techniques were successfully tested with relatively simple separation problems, the future progress forecasted could render their application very profitable also for the treatment of difficult ores.

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