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Electrification of mineral particles by electron beam irradiation

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Abstract: A novel way for electrification of mineral particles by electron beam irradiation was proposed. The effect of irradiation dose on charge/mass ratio was investigated experimentally. The charge/mass ratio of electrified mineral powders after irradiation was measured by an instrument based on the principle of electrostatic induction. The experimental results showed that the charge/mass ratio is largely dependent on radiation dose and electric physical properties of minerals. The mechanism of electrification by electron beam irradiation is discussed. It is suggested that the essential of electrification by electron beam irradiation is a process of retardation and charge deposition of incident electrons in materials.

Key words: electrification; electron beam; irradiation; powder; mechanism

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Electrical separation is based on the electrical property differences of mineral particles. In the process, the electrification methods such as conduction, induction, corona and triboelectricity are commonly used [1]. A common characteristic of those traditional processes is that the electrical charges are distributed on surface of mineral particle with instantaneity, heterogeneity and dissipativeness.

Using ionizing radiation as an electrification method in electrical separation of minerals was proposed by I. M.Plaksin in 1964 [2]. Unfortunately, the high investment in radiation source establishment, high cost of operation and difficulty in waste source disposal become barriers for its industrial application. Such an electrification method was regarded not practical for its application.

With the development of particle accelerators and a deep understanding of the radiation processing technology, the cheap sources of high energy electron is readily available and expanding its application in various industrial fields [3]. This electrification method attracts attention and interest in mineral processing once again.

The application of electron beam irradiation in electrification of mineral particles has been investigated in this laboratory, and the mechanism and feasibility of this electrification method used for mineral electrical separation are also analyzed and discussed.

1 Experimental principle and materials

1.1 Principle and method for electrical charge measurement of particles

In electrical charge measurement of conductor particles, the key factor of the process is the charge transfer from tested conductor into instrument, then measured charge is obtained through measurement of electrostatic voltage. For insulators, however, the situation is different from conductors, the electrical charge of insulators cannot be transferred, and the charge is not always distributed evenly on the surface. The electrostatic voltage varies with the different parts of the surface. Therefore, it can't be measured by the contact or non-contact electrostatic voltmeter that commonly used for conductor. The measurement of electrical charge of insulators must be conducted indirectly based on principle of electrostatic induction by means of Farady pails [4]. The Farady pails can also be used for charge measurement of conductors. The principle diagram used for measurement of electrical charge of insulators is illustrated in **figure 1**.

Farady pails is made up of two metal pails which is insulated with each other. The outer pail is connected with ground, and the inner pail is insulated with the outer pail by polytetra fluoro ethylene or polystyrene insulating materials. The outer and the inner pails have metal covers with insulating hand knobs. If there were

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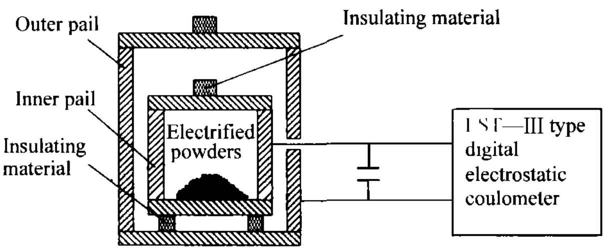

Figure 1 The principle of electric charge measurement by Farady pails method.

no metal covers, the height difference between the outer and the inner pails must exceed 10% of the height of the inner pail. When a measurement is conducted, the height that electrified body occupied in the inner pail should be less than 10% of height of the inner pail.

It can be known from Gauss theorem that opposite sign electric charge will be induced in the inner wall of the inner pail when electrified body is put in the inner pail. And simultaneously, the opposite sign and uniform sign electrical charge will be induced in outer wall of the inner pail and inner wall of the outer pail respectively, which include the induced charge in the capacitor of the instrument. Therefore, quantity and sign of electrical charge can be measured by an electrostatic coulometer. Or the electrostatic voltage between the outer and the inner pails can be measured by electrostatic voltmeter. The charge of the electrified body can be calculated by the following equation:

$$Q=(C_F+C_b)U \tag{1}$$

where C_F is the capacitance between the outer and the inner pails; C_b is the capacitance of the contact electrostatic voltmeter; Q is the quantity of electric charge of the electrified body; U is the potential difference.

If the mass and particle number of powder is known, then the charge/mass ratio is:

$$\frac{Q}{m}=\frac{(C_F+C_b)\cdot U}{m} \tag{2}$$

Suppose that powder is monodispersed, and the total numbers is n, the charge of each particle can be estimated by following equation:

$$q=\frac{Q}{n}=\frac{(C_F+C_b)\cdot U}{n} \tag{3}$$

1.2 Electrical properties of the experimental materials

Four samples including quartz, magnetite concentrate, calcite and pulverized iron ore with great difference in their dielectric constants were examined in experiments. The electric properties of the experimental materials are shown in **table 1**. All materials are ground to minus 180 μm, and then separated into subsamples weighing 5 g each for experiments. Every subsample is irradiated under a model GJ-5 high frequency and high voltage electron accelerator in Tianjin Institute of Technical Physics of China. The electrical charge of each subsample is measured by a model EST—III digital electrostatic coulometer according to principle illustrated in figure 1.

Table 1 The electrical properties of experimental materials

Name of materials	Main component	Resistance /Ω	Dielectric constant	Conductibility
Magnetite	Fe_3O_4	10^{-4}-10^{-3}	33.7-81.0	Conductor
Iron ore	Fe_2O_3	10-10^3	25.0	Conductor
Calcite	$CaCO_3$	10^7-10^{11}	7.8-8.5	Non-conductor
Quartz	SiO_2	10^{12}-10^{17}	4.2-5.0	Non-conductor

2 Experimental results and discussion

2.1 The charge/mass ratio of the particles after electron beam irradiation

Charge/mass ratio variations of the mineral particles after being irradiated by electron beam are illustrated in **figure 2**, **3**, **4** and **5** respectively. The experimental results show that the relationship of charge/mass ratio *vs* irradiation dose of different mineral particles are analogous. It is because of the difference of electric conductivity between mineral particles that results significant numerical differences in charge/mass ratio of mineral particles after electron beam irradiation.

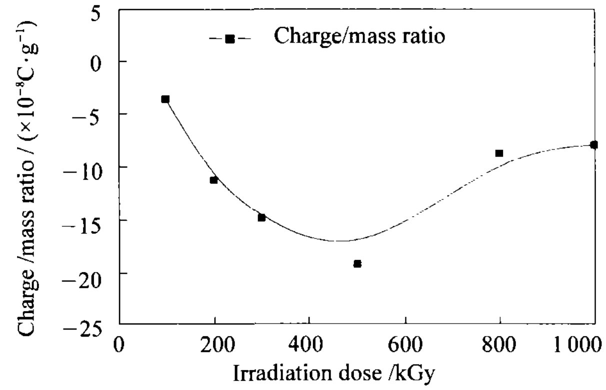

Figure 2 Effect of radiation dose on charge/mass ratio of iron ore.

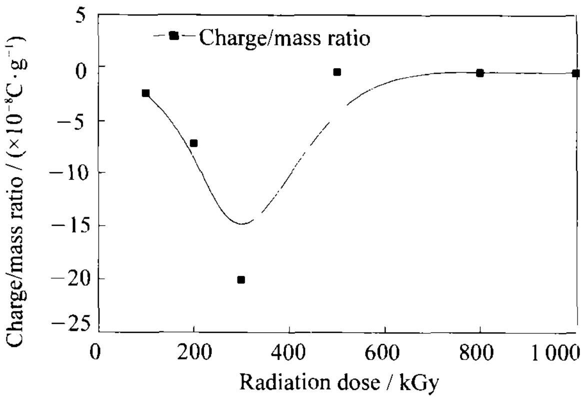

Figure 3 **Effect of radiation dose on charge/mass ratio of magnetite concetrate.**

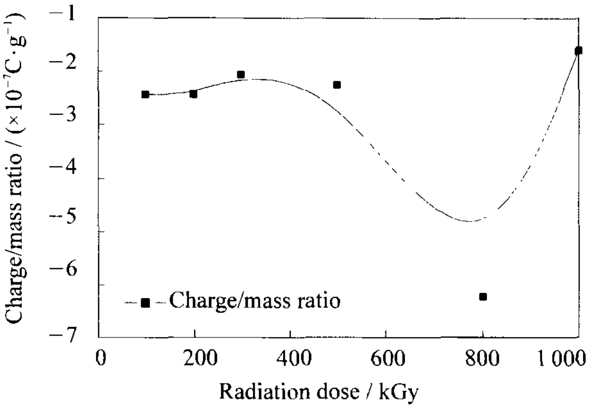

Figure 4 **Effect of radiation dose on charge/mass ratio of quartz.**

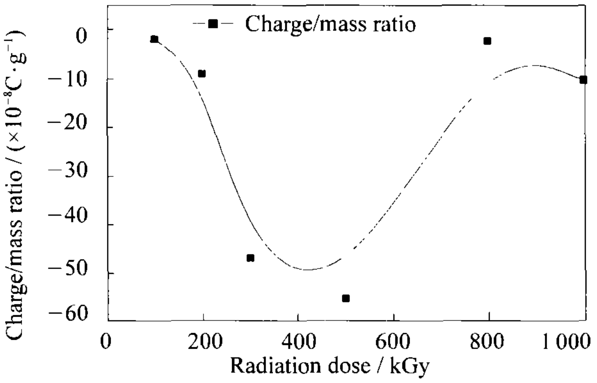

Figure 5 **Effect of radiation dose on charge/mass ratio of calcite.**

As shown in figure 2, charge/mass ratio of iron ore particle rises with increase of irradiation dose from zero to 500 kGy. When the radiation dose increases from 500 kGy to 1 000 kGy, the charge/mass ratio of iron ore particles decreases rapidly on the contrary. The maximal charge/mass ratio reaches to 1.92×10^{-7} C/g when radiation dose is 500 kGy.

Charge/mass ratio of magnetite concentrate as a function is illustrated in figure 3. The maximum of charge/mass ratio reaches to 2.0×10^{-7} C/g at radiation dose of 300 kGy. Then charge/mass ratio decreases when the radiation dose ranges between 300 kGy and 600 kGy. When the radiation dose exceeding 600 kGy, charge/mass ratio of magnetite concentrate maintains at a low value.

For the quartz particles, as shown in figure 4, the charge/mass ratio reaches their maximal value of 6.24×10^{-7} C/g when radiation dose increased to 800 kGy. And then it decreases rapidly. The maximum of charge/mass ratio of calcite particle reaches to 5.52×10^{-7} C/g at radiation dose of 500 kGy. And then it decreases to a low value.

From the comparison of above experimental results, one can find that the sequence of maximal charge/mass ratio of four particles is: quartz > calcite > iron ore > magnetite concentrate.

As shown in table 1, quartz and calcite are attributed to dielectric body, magnetite concentrate is a conductive body. Iron ore is made up of multi-components. Some of the components are metallic ores such as hematite, magnetite, chalcopyrite and *etc*. And others are gangue minerals. Generally speaking, iron ore is attributed to a conductive body. Magnitude sequence of dielectric constant and the resistance of four tested materials is as follows: quartz > calcite > iron ore > magnetite concentrate.

This is consistent with sequences of charge/mass ratio of four particles. It implies that charge/mass ratio of minerals electrified by electron irradiation is nearly correlative with their electroconductivity. The large the resistance is, the smaller the dielectric constant is, the larger the maximal charge/mass ratio of particles be.

From experimental results shown above, it can also be found that the radiation dose corresponding to the maximum of charge/mass ratio is interrelated with electroconductivity of materials. The smaller the dielectric constant of mineral is, the large the required radiation dose corresponding to maximal charge/mass ratio will be. Among four materials tested, the required radiation dose corresponding to the maximum of charge/mass ratio is 800 kGy for quartz, 500 kGy for calcite and iron ore, 300 kGy for magnetite concentrate respectively.

2.2 Mechanism of electrification by electron beam irradiation

(1) Retardation and deposition of incident accelerated electron in absorbing materials.

The most important process of incident high energy electron beam interacted with atoms of irradiated materials are elastic and inelastic scattering and emission of electromagnetic radiation (bremsstrahlung, or X radiation). This process involves the transfer of energy from incident electrons to atomic electron and energy loss due to inelastic collision [5]. In the course of slowing down of incident high energy electron, large numbers of electrons are being stopped and deposited their charge in medium. Generally, the maximum of deposited charges occurs in the position of all most incident electrons stopping [6].

When radiation ceased, the deposited charge will be dissipated. In the case of electrical conductor, the deposited charge is quickly ejected to surface up to fade away. The charge in medium has the characteristic of surface distribution. On the contrary, for dielectric material, partial charge will be held up in the inner part of medium. Dissipation time is dependent on dielectric constant of medium. In the other word, the charge in dielectric medium will be spacial or volumetric distributed.

(2) Limit of electrification by electron beam irradiation.

In case of real dielectrics, different dielectric mineral has its own breakdown voltage, namely withstand voltage. Limit quantity of electrified charge of dielectric minerals will dependent upon its breakdown voltage. As a rule, the breakdown voltage of dielectrics, expressed as E^*, is in the scope from hundreds keV to 1 MeV, *viz.* $E^* \approx 1$ MeV/cm. Breakdown voltage is the key factor which limits the electric charge accumulation in dielectrics [7].

Electric field strength generated by spacial charge layer in electrified dielectric can be expressed as the following equation [2,8]:

$$E = \rho \Delta x / \varepsilon \varepsilon_0 \tag{4}$$

where Δx is thickness of electrified charge layer, It's value approximate to the track of incident electron in the medium; ρ is average charge density; ε and ε_0 is absolute and relative dielectric constant respectively.

Suppose that the breakdown voltage of dielectric is E^*, the limiting charge density can be expressed as

$$\rho^* = \varepsilon_0 \varepsilon E^* / \Delta x \tag{5}$$

If charge accumulation is lower than the limit ofcharge density, electric field strength generated by spacial charge layer will be very small, and the conduction current induced by this electric field can be ignored. Under such a condition, the charge density ρ will be in direct proportion to charge deposited in medium. This will make the altering of charge density possible by changing radiation parameters (such as radiation dose and beam density). Practically, the relationship of maximal electrified charge of materials with radiation dose, which have been obtained from above experiment results, is an experimental verification on this theoretical explanation.

In the process of electrification by electron beam irradiation, the rate of electric charge accumulation in the medium is determined by the equilibrium between charge deposition and conductivity induced by radiation. The conductivity induced by radiation plays a very important role in the low conductivity medium. With the increasing of charge accumulation, the charge deposition will be affected by the electric field that generated by accumulated charges. The time required for reaching the maximum quantity of electric charge will be prolonged. In high-ohmic dielectric materials, the accumulated charge will produce a strong electric field that enough to reach the breakdown level. And then the new equilibrium will be established [9]. Therefore, the process of electrification by electron beam irradiation has the peculiarity of pulsating. The electric break down can produce micro-crack in inhomogenius materials, especially in multi-components ore [10]. This makes certainly the ore grinding process and the process of mineral separation more efficient [9,10].

3 Conclusion

Quantity of electric charge of mineral dielectrics electrified by electron beam irradiation is correlated to electric physical properties of materials, such as dielectric constant and resistance. The sequence of maximum charge/mass ratio of four tested materials is as follows: quartz > calcite > iron ore > magnetite concentrate. The rule shows good agreement with sequence of dielectric constant and electric resistance.

Radiation dose corresponding to maximum charge/mass ratio is interrelated with electroconductivity of materials. The smaller the dielectric constant of mineral dielectric is, the large the required radiation dose corresponding to the maximum of charge/mass ratio. For four tested mineral particles, the required radiation dose corresponding to maximum charge/mass ratio is 800 kGy for quarts, 500 kGy for calcite and iron ore, and 300 kGy for magnetite concentrate respectively.

Electrification by electron beam irradiation is a process of retardation and charge deposition of incident electron in materials. The maximum of deposited charges occurs in the position of all most incident electrons stopping. In practice, the maximum of electrified charge is predominantly determined by electroconductibility and electric field strength.

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