Determining the triboelectric charging characteristic of fine calcite and quartz

A. Oberrauner and H. Flachberger

Abstract

The Chair of Mineral Processing at Montanuniversitaet Leoben is deeply involved in research and development of electrostatic separation technologies. Research activities on this field cover fundamentals as well as application topics by using various electric-field-separators such as a hamos free-fall-separator and unique equipment to characterize triboelectric charging of powders, all being established in a fully air conditioned 7 m high climatic chamber to guarantee reproducible test-results. Lately a testing unit for investigating the triboelectrostatic charging behaviour of minerals was developed and constructed with the support of an industrial partner. Systematic tests on various monomineralic samples done in conditioned atmosphere show e.g. a strong relation of the charging behaviour to the surrounding atmosphere's relative humidity and the strength and polarity of an applied external electrostatic field. Some results of detailed investigations performed on calcite and quartz are presented. Furthermore a concept of a new electrostatic laboratory-separator is shown.

Keywords: *Triboelectric charging, Electrostatic separation*

1. Introduction

The Chair of Mineral Processing at Montanuniversitaet Leoben has been working on methods of electrostatic separation of mixed mineralic powders for many years. One of the main research focal points of the Chair for the coming years is electrostatic separation. At the moment the focus of the experiment-oriented research – which is being carried out by the first author in the framework of his dissertation – is on the exploration of possible applications and limits of electrostatic separation for sorting of fine and very fine-grained material.

An important part of this comprehensive area of research is the concerted, controlled and reproducible influencing of the triboelectric charging behaviour of materials, since this concerted charging by friction is the prerequisite for the further electrostatic separation of primary and secondary raw materials. However because triboelectric chargeability depends on many influences, an intense scientific examination of the various aspects is needed to determine which of these are responsible for the changes in the electrostatic properties of the surfaces of mineral phases.

A testing apparatus – a triboelectric charging unit – was designed and built at the Chair, in cooperation with a partner from the industry, which is able to take specific measurements related to the triboelectric charging behaviour of fine and finely dispersed materials under controlled and changeable conditions. From the results of these measurements triboelectric charging characteristics were then derived which should allow predictions about the electrostatic sortability of powders. Furthermore a concept of a new laboratory separator for separating fines should be shortly presented.

2. Theoretical basis

Triboelectric charging, which is the underlying principle of electrostatic separation of nonconductors/nonconductors, occurs through the contact friction of particles rubbing against each other or against a surface. The polarity and level of the charge reached on the materials concerned depends on many, complex, interacting factors. Triboelectric charging is based on the exchange of charges between surfaces which touch each other, whereby the direction of the charge transfer is related to the relevant level of the work function.

The contact partner which can transfer electrons more easily to the other – and thus has the lower electron work function – remains positively charged after the quick separation of the surfaces; the negative charge which has been given up creates a negative polarity in the contact partner. Similarly there is a rough correlation between the dielectric constants of the contact partner, which is described in the form of the Coehn-rule. According to this rule of thumb, the contact partner with the higher dielectric constants gets a positive electric charge[1] . The charging characteristic can be influenced greatly by the use of reagents on the surface, a principle which has been used for some decades for the utilization of electrostatic separation for large scale processing of potash[2].

According to investigations[3], the size of the charge achieved depends significantly on the kinetic intensity of the contact among other things. The harder the particles hit against each other, the higher their opposite charge. The higher the size of the difference in the charge, the easier it is to achieve the consequent separation in the electrostatic field, as, for example in a free-fall separator.

The triboelectric chargeability of a mineral can be determined by bringing it into contact with a material with known triboelectric properties, then separating the two and subsequently measuring the electric charge on the surface of the mineral. For powders such "electrisators" can be, for example, diagonally arranged vibrating troughs, fluidised beds, pipes with pneumatic propulsion of the particles, rotors of various shapes or other constructions.

A well known method to determine the charge of a sample is the measurement in a Faraday cup which is attached to an electrometer or a somewhat simpler designed (nano-) Coulomb-meter. The advantages of this unit are, among other things, a simple and quick measurement as well as the easily repeatable test of the exactness of the charge measurement. The method using a discontinuously operated Faraday cup was used in the present investigations to measure the charges in the materials in the triboelectric charging unit.

3. Triboelectric charging unit

3.1 Design and construction

A triboelectric charging unit has been developed at the Chair of Mineral Processing for the examination of the triboelectric chargeability of different materials, which consists of an electric-powered, cylindrical rotor in a cylindrical steel housing. Fig.1 shows the construction drawing.

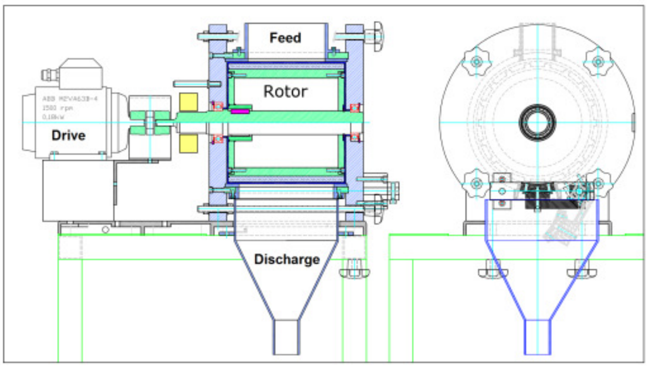

Figure 1. Technical construction drawing of the triboelectric unit developed

The speed-controlled electrical driven rotor is operated using a frequency converter. A replaceable plastic casing is fitted onto the cylindrical surface of the rotor and on the inner walls of the steel housing (stator) so that the influence of different contact materials can be investigated in relationship to their charging effect on the samples. Polyethylene (PE) was selected as the material for the rotor and stator casings in the experiments. By applying an electrical potential to the insulated stator housing, it is possible to build up a radial electric field which the triboelectric charge in the gap between the grounded rotor and the housing can be superimposed on. The exterior diameter of the plastic casing on the rotor is 200 mm, the inner diameter of the stator covering is 206 mm. The triboelectric charge occurs in the 3 mm wide gap between the rotor and the stator. The length of the rotor is 200 mm.

The sample is fed to the charging unit via an oscillating conveyor and a steel chute. The high voltage for the electrical field is produced by a "fug HCP 35-6500" high voltage generator. The rotor is grounded by graphite brushes on the driveshaft.

To be able to investigate the influence of different atmospheric conditions, the triboelectric charging unit was placed in an adjustable climate chamber, which was provided by the Chair of Subsurface Engineering.

3.2 Measuring the charge

The Faraday cup for measuring the triboelectric charge, which was positioned underneath the triboelectric charging unit, consists of two concentric metal cylinders which are very well isolated from each other by foamed polyethylene. The outer cylinder is grounded and protects against external influences. Charged grains which pass through the triboelectric charging unit and fall into the Faraday cup create an opposite electrical charge on the surface of the inner cylinder which reaches a "Monroe 284“ Coulomb-meter via a shielded connecting cable.

The input of the Coulomb-meter consists of an integrating operational amplifier. The charge carriers reaching the operational amplifier via a resistor charge up the degenerating condenser C_{Mess} to a voltage U_{Mess} which is dependent on the size of the charge. Thanks to the known size of the measuring condenser, the total charge of the grains in the Faraday cup can be derived using the equation $Q_{Mess} = U_{Mess} \cdot C_{Mess..}$ This is shown appropriately signed on the Coulomb-meter’s display. After measuring the total charge the sample in the Faraday cup is weighed to be able to determine the mass-specific charge in nC/g and, through the knowledge of the particle’s specific surface, to determine the surface charge density σ_P in nC/m².

4. Measurements

To judge the triboelectric chargeability of mineral phases in a raw material it is necessary to carry out charge measurements on pure mineral samples, since the presence of several mineral phases with different chargeabilities will only render a sum of the charges of the mixed sample.

For this reason reference samples of calcite and quartz of the purest possible quality were prepared.

The charge characteristics of the minerals examined are determined by changing the testing parameters. These parameters are:

- Rotor speed
- Feed rate
- Grain size distribution
- Relative humidity of the surrounding atmosphere
- Temperature
- Intensity of the external electrical field
- Rotor and stator materials

4.1 Description of the samples

Hand-picked calcite with a percentage of HCl-insolubles of < 1 % and pure, iron-free ground quartz were used for the tests to determine the triboelectric charging characteristics. The average grain size of the samples was 35 µm, the maximum was 200 µm.

In contact charging of calcite against polyethylene a positive charge to the calcite was expected due to the higher electron work function of polyethylene ($\Phi_{(PE)} = 4.25$ eV [*]; $\Phi_{(Calcit)} \sim 3,2$ eV), while with quartz against polyethylene, a negative triboelectric charge was expected due to the somewhat higher electron work function of $\Phi_{(Quarz)} \sim 4.39$ eV.

4.2 Results of the triboelectric tests

The tests on triboelectric chargeability were carried out in the electronically controlled, walk-in climate chamber of the Chair of Subsurface Engineering. Before testing the samples were conditioned for several hours in each case to reach the same conditions as the surroundings.

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[*] eV…electron-volts

After checking the feed rate of the vibrating chute and a five-minute start-up time of the unit, several charge measurements were carried out for each of the designated parameters.

4.2.1 Influence of the rotor speed

By raising the speed of the rotor the centrifugal and shearing forces affecting the particles were increased. Because of the more intense contact between the grains and the surface of the rotor and stator, a higher triboelectric charge would be expected. Fig. 2 shows the dependence of the charging on the rotor speed as well as (for better generalization of the values) the dependence of the charging on the peripheral velocity of the rotor.
From the tests it can be seen that there is a clear dependence of the chargeability on the speed of the rotor. Although below a peripheral velocity of 10 m/s there is nearly no triboelectric charging of the grains, with a velocity starting about 12 m/s there is a distinct rise in the charge.

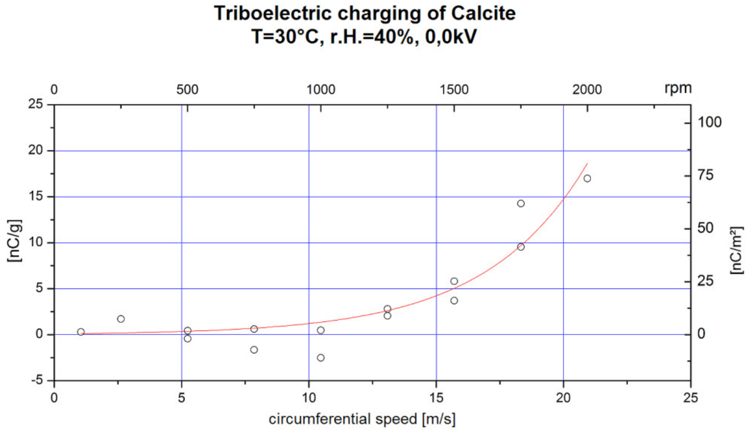

Figure 2. Dependence of the triboelectric chargeability of calcite in Nanocoulomb per gram and Nanocoulomb per m² of particle surface on the rotor circumferential speed of the triboelectric charging unit.

4.2.2 Influence of the humidity of the surrounding atmosphere

The thickness of the layer of water molecules on the grain surfaces depends strongly on the humidity of the surrounding air. Water on the grain surfaces changes the electrical properties of the particles and, because of changed surface conductivity and work function, this then leads to a changed triboelectric charging behaviour of the grains. In the course of the tests a strong dependence between the triboelectric chargeability and the relative humidity of the surroundings was seen. While calcite could be charged up to +9,5 nC/g in a dry atmosphere, the chargeability dropped continuously with rising humidity. At a relative humidity of 50% the specific charging was only +2 nC/g, at 60% the zero charging point was reached. At a humidity of 70% there was even a negative chargeability of -2 nC/g.
Quartz always charged negatively to -3 to -5 nC/g, but no significant relationship could be measured between the set humidity and the triboelectric charge. Fig. 5 illustrates these trends. (Continuous line at the stator potential 0,0 kV).

4.2.3 Influence of the process temperature

Separation in an electrical field after previous triboelectric charging usually works best with pre-warmed feed, whereby the origin and the composition of the raw material call for different optimization of the process temperature. These optimal operating points are in the range above 80 °C and are thus, in many processing situations, an economically relevant factor for the use of electrostatic separation.

Ciccu et al. [5] made charging tests on different minerals in an aero-cyclone and determined, in a free-fall separator attached behind the cyclone, the mass yield (r_m) of the minerals on the negative electrodes dependent on the feed temperature. The extreme values of r_m represent the optimal operating temperature for the individual mineral. Baryte, which is positively chargeable, for example, reached the highest r_m of 88% at a feed temperature of 120 to 150 °C. Higher and lower temperatures yielded lower r_m values. Quartz, which also charges negatively against steel, reached lower r_m on the negative electrodes the higher the feed temperatures were. While the r_m was still 10% at a temperature of 75 °C, it decreased to 4% at a temperature of 150 °C; at 200 °C only 3 % was transmitted to the negative electrode[4]. The graphic illustration of the results can be seen in Fig. 3. The reasons for these temperature dependences lie in surface effects which will not be treated in this paper.

In the course of the tests in the triboelectric charging unit in the range of +10 °C to +50 °C a temperature influence could only be proven when at 30 °C a certain optimum of chargeability for both calcite and quartz was recognized.

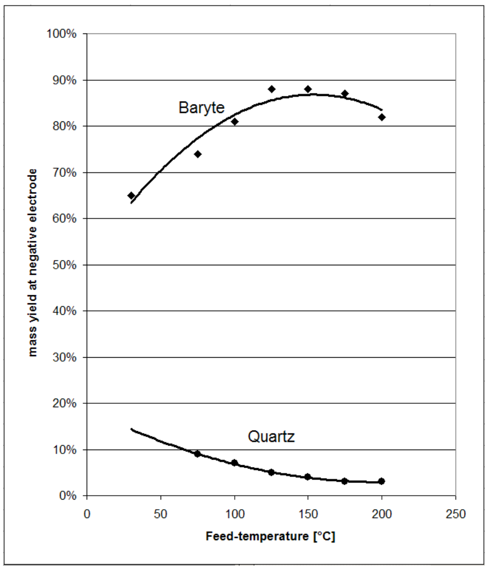

Figure 3. Temperature dependence of the triboelectric chargeability of baryte and quartz in an aerocyclone (Ciccu)

4.2.4 Influence of the feed rate

In several test series the dependence of triboelectric particle charging on the feed rate was examined in the triboelectric charging unit. At increasing feed-rate there was a clear drop in the specific chargeability of the samples. This effect can be plausibly explained by the stronger hindrance of the grains to touch the rotor or stator surfaces. An increasing quantity of grains per time unit in the air gap of the unit leads to increasing particle-particle-contacts and – contrarily – to a reduction of the contacts of particles with the PE surfaces which however would be necessary for triboelectric charging.

Fig. 4 shows the curve for the chargeability of calcite. While the feed rate of 50 g/min achieved a specific charging of 52 nC/g, the chargeability sinks hyperbolically with higher feed rates. At a feed rate of 400 g/min., only 8 nC/g was measured. Hangsubcharoen carried out measurements of the triboelectric chargeability of coal and quartz and arrived at similar measurement results using a so-called “in-line mixer“[5]

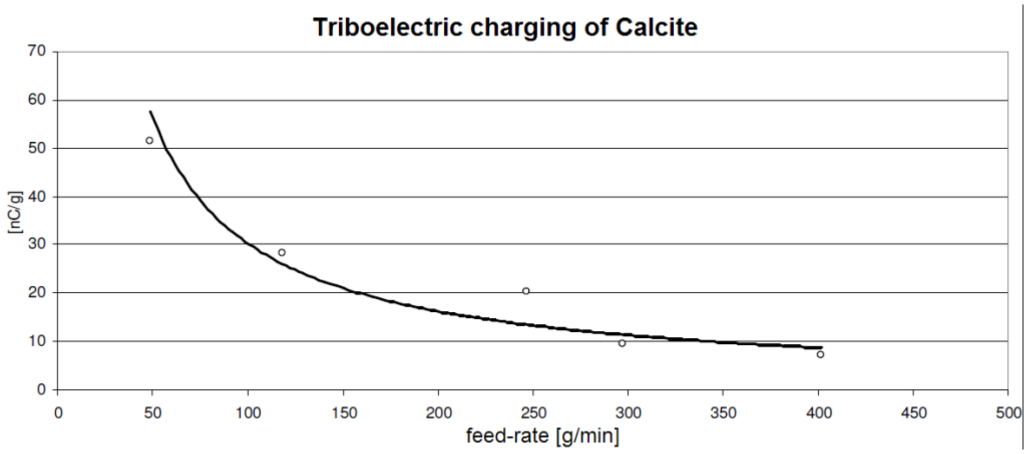

Figure 4. Dependence of the triboelectric chargeability on the feed rate in the triboelectric charging unit, taken from the measurements of calcite

4.2.5 Influence of an electrical potential applied to the stator housing

If an electrical potential is applied to the triboelectric charging unit while the test is in progress, this influences the charging of the grains in such a way that a higher potential causes a higher specific charging. An applied positive potential strengthens positive particle charging, negative potential causes stronger negative charging. This behaviour is visible in both the tests with calcite and with quartz.

The dependence of the particle charge on the applied voltage shows a linear relationship, the gradient of the change in the charging, however, varies. Quartz changes its specific charge from -9,14 nC/g at a starting potential of -6,0 kV to -6,3 nC/g at a starting potential of +6,0 kV. Consequently the change of the specific charge is about 0,24 nC/g per kV. With calcite the change rate is about 1,35 nC/g per kV.

The results of the triboelectric chargeability in environments of different humidity and at different levels of the applied stator potential are termed triboelectric charging characteristics. A clear graphic illustration of these material properties with the relative humidity on the x coordinate and the specific triboelectric charges reached on the y coordinate can be made by grouping the measuring points of the same electric potentials at different atmospheric humidity and labelled as “iso-potential curves”.

As can be seen in Fig. 5, when the conditions are dry there is almost no influence on the chargeability from the applied voltage in the case of calcite; the higher the relative humidity was set, however, the greater was the possibility to change the chargeability of both calcite and quartz. It is interesting here that the controllability – visible in the fanning out of the iso-potential curves in Fig. 5 – rises linearly for calcite with the relative humidity of the environment because of the applied electrostatic potential. The possibility to influence quartz rises significantly only after the humidity has exceeded 40% and then remains constant until 70% humidity is reached (see the parallel iso-potential curves). From this behaviour it can be directly concluded that the number of water molecules present on the surfaces of the grains is not only responsible for the chargeability, but also that it is an important parameter for the controllability by an electrostatic field.

This knowledge is essential for the selection of the best processing method in electrostatic separation plants. When the triboelectric charging takes place under the influence of an electrical field, the results of the separation are immediately affected because the chargeability of the mineral phases involved change in relation to the relative humidity.

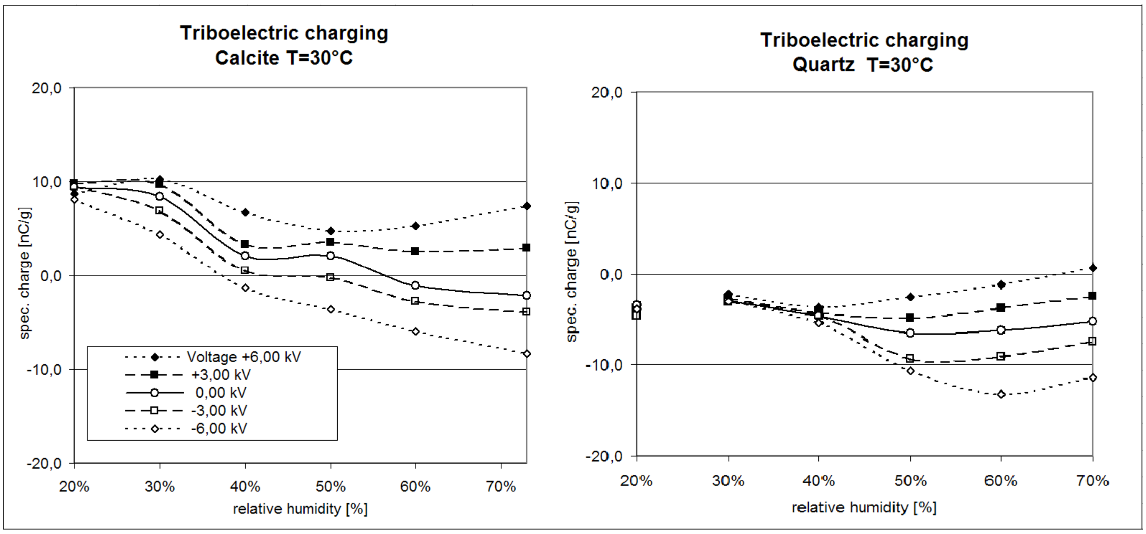

Figure 5. Triboelectric charging characteristics of calcite and quartz

5. Concept for an electrostatic fines-separator

The separation of fines in electrical fields is a widely unsolved task. The finer particles get the harder it is to separate them in an electrical field. Especially occurring agglomeration and air-turbulences are parameters which significantly lower the quality of the separation when particles (minerals) are smaller than ~63 µm. For this reason a concept of a new electrostatic separator is currently being developed at the Chair of Mineral Processing. The idea is to mix the primarily charged particles with air after passing the triboelectric charging unit and to guide them into a laminar air flow before they are finally separated in a coaxial separation chamber. In order to determine possible troubles concerning turbulences in air-flow the separator has been simulated by “Flow” 3D simulation software before construction. Fig. 6 shows the planned flowsheet of the new separator.

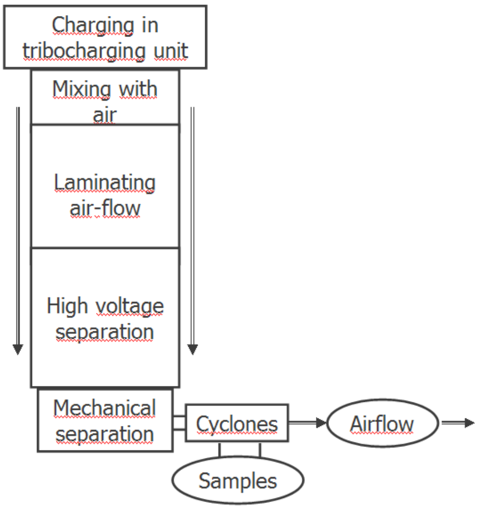

Figure 6. Electrostatic fines-separator: flow-sheet

6. Conclusion

The construction of a triboelectric charging unit set up in a climate chamber made it possible to determine the triboelectric charging characteristics of diverse fine grained minerals and, from that, to make conclusions about the basic suitability for separation in an electrostatic field and necessary climatic and electrostatic factors in the surroundings. The results available from the tests on calcite and quartz against polyethylene show a strong dependence of the triboelectric chargeability of these minerals on the humidity of the surrounding air and on the electrical fields present. Furthermore, the results indicate the necessity for surroundings with controlled dry conditions.

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