



Analysis of the Triboelectrostatic Charging Behaviour of a Synthetic Sulfidic Copper Ore

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Abstract: In this study, several tests were performed to analyse the triboelectrostatic charging behaviour of an artificially mixed sulfidic copper ore consisting of quartz and chalcopyrite. To check the surface charge of the pure mineral samples, they were analysed in a self-developed triboelectrostatic charging unit. After that, the artificially mixed sulfidic copper ore was sorted by using a triboelectrostatic belt separator.

The objective of the study is to generate basic knowledge about the triboelectrostatic charge behaviour and furthermore the sortability by using electrostatic separation. All separation tests were carried out under controlled ambient conditions.

Keywords: Electrostatic separation, Mineral processing, Sulfidic copper ore, Triboelectrostatic charging behaviour, Dry processing investigations

Untersuchungen zum triboelektrostatischen Aufladeverhalten eines synthetisch hergestellten sulfidischen Kupfererzes

Zusammenfassung: Im Rahmen dieser Studie wurden mehrere Versuchsreihen durchgeführt, um das triboelektrostatische Aufladeverhalten eines synthetisch hergestellten sulfidischen Kupfererzes, bestehend aus Quarz und Chalkopyrit, zu untersuchen. An den Reinmineralproben wurde mithilfe einer selbst entwickelten triboelektrostatischen Aufladeeinheit die Oberflächenaufladung gemessen. Anschließend wurde das synthetisch hergestellte Erz mit einem triboelektrostatischen Bandscheider sortiert. Ziel der Studie ist es, Basiswissen über das triboelektrostatische Aufladeverhalten und in weiterer Folge auch die Eignung zur elektrostatischen Sortierung zu generieren. Alle Sortierversu-

che wurden unter kontrollierten Umgebungsbedingungen durchgeführt.

Schlüsselwörter: Elektrostatische Sortierung, Mineralaufbereitung, Sulfidisches Kupfererz, Triboelektrostatisches Aufladeverhalten, Trockene Sortierverfahren

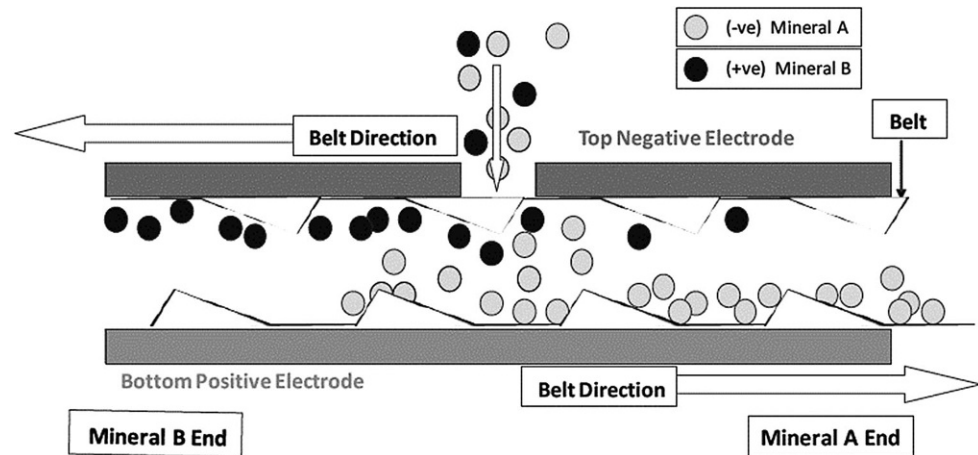
1. Introduction

The profitability of copper extraction and processing depends on numerous factors. Of course, the most important information is the copper grade of the ore and the overall extent of the deposit, but also the existing infrastructure and the availability of water. Copper ores are extracted in both underground and open-pit mining. In the past, a deposit with at least 1–2% copper content was considered worthy of mining. Today the minimum content for large open-pit mines is 0.3%. Before the mined copper ore can be used for metallurgic processes, the accompanying minerals have to be separated by mineral processing. The ore is first crushed and then ground in mills, whereby the individual mineral phases are often only liberated at grain sizes below 100 µm. In the case of sulfidic copper ores, the beneficiation towards marketable copper concentrates takes place using flotation. In this way, ore concentrates are obtained, the copper content of which is usually between 20 and 30%. Since the copper content of the raw ores is very low and large amounts of tailings created during flotation, the processing plants are located near the deposits for economic reasons. The use of flotation inevitably involves large amounts of water in the separation process and the dumping of the tailings as slurry [1, 2].

The implementation of a dry sorting process can be an important approach in order to make copper processing sustainable and resource-saving in the long term.

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Fig. 1: Operating principle of a triboelectrostatic belt separator [7]



2. Triboelectrostatic Separation

One such dry process is electrostatic separation, a surface-controlled process. The separation features in the electrostatic field are charge differences of the grain surfaces as large as possible. These charge differences are generated by the so-called tribo-polarization. As a result of electron transfer between the contact partners, they receive opposite surface charges. The intensity of this electron transfer depends on the size of the contact surface as well as on the contact duration, frequency, and strength. The charging mechanism is activated by intense interparticle and wall-particle contacts. Often this is realized in upstream units that are not part of the separation process itself, for example vibro feeders, fluid bed dryers, or cyclones [3–6].

The operating principle of a triboelectrostatic belt separator is shown in Fig. 1.

3. Triboelectrostatic Charging Unit

In this research, the charging behaviour of a synthetic sulfidic copper ore is studied to check the possibility of a successful separation in the electrostatic field. The tests for this are carried out in a specially constructed triboelectrostatic charging unit.

This unit was designed for providing a clearly delimited system in which the triboelectrostatic charging is carried out and recorded by measurement of the specific surface charge. This system is intended to offer further parameters for influencing the charging behaviour. These parameters should be precisely defined and monitored during the charging process so that the process can be better understood and subsequently influenced [8].

A 3D illustration of the triboelectrostatic charging unit is shown in Fig. 2.

At the beginning of the dimensioning work, the conditions of the in-house compressed air network determined the maximum available compressed air volume flow rate and the maximum available volume flow rate and operating pressure for the charging unit. The relative humidity of the air supply is about 20% [8].



Fig. 2: 3D illustration of the triboelectrostatic charging unit [8]

The grain size range and density for the analysed raw material samples were then defined. In order to fluidize as many different industrial minerals as possible, a density of between 2 and 4 g/cm³ was assumed. The desired grain size range lies between 40 μm and 1 mm. A possible loss of the fine fraction (<20 μm) in the filter system is accepted, since this fraction often has a negative impact on the selectivity in the electrostatic separation process anyway. The fluidized bed consists of three chambers, which are connected to each other by detachable flange connections. The feed weight is about 1.5 kg, the inside diameter

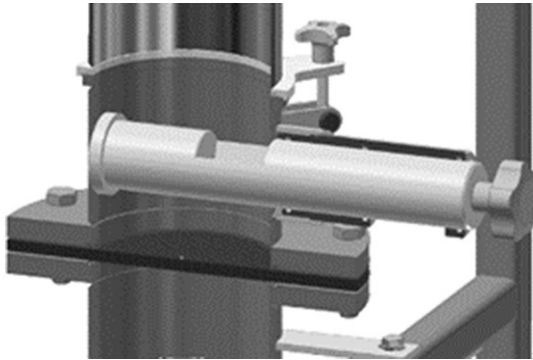


Fig. 3: 3D model of the sampling unit (filling) [8]

is about 14 cm. Operation is possible at air temperatures ranging from 20–150 °C [8].

In order to measure the charging success of the raw material samples under consideration, a possibility for taking a sample and measuring its surface charge is integrated into the triboelectrostatic charging unit. The charge measurement is carried out with an electrostatic voltmeter and Faraday cup. This measurement is discontinuous and enables simple and quick measurement [6, 8].

3.1 Sampling Unit

For understanding the charging mechanism, it is necessary to detect the total charge of the fluidized samples. For this reason, a sampling unit is integrated into the process chamber of the charging unit.

This allows to take samples during the fluidization process to check the charge growth over the time [8].

Figs. 3 and 4 show the principle of the sampling unit in a 3D model.

In Fig. 3 the sampling unit is positioned in the fluidization chamber, where the sample is collected in the sampling cavity [8].

In Fig. 4 the sample is extracted transferred into the Faraday cup [8].

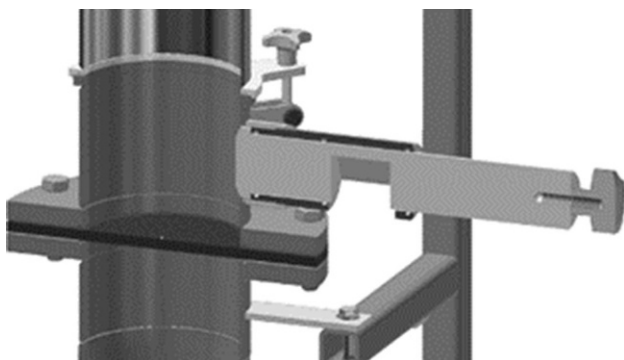


Fig. 4: 3D illustration of sampling unit (emptying) [8]

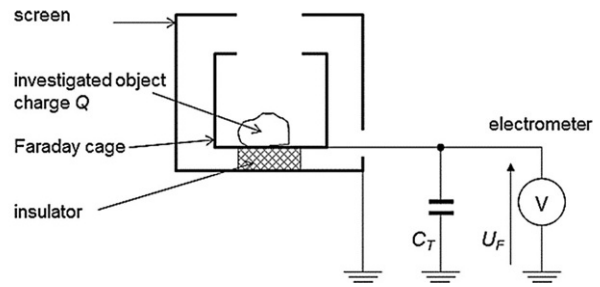


Fig. 5: Principle of charge measurement with Faraday cup and electrostatic voltmeter [9]

3.2 Charge Measurement

To measure the efficiency of the triboelectrostatic charging during the fluidization tests, a Faraday cup was positioned below the sampling unit of the triboelectrostatic charging unit. The Faraday cup consists of two concentric metal cylinders well insulated from each other. The two cylinders are fixed by polyethylene foam. The outer cylinder is used for shielding from external interference. The particles charged via tribocharging are transferred by the sampling unit into the inner cylinder of the Faraday cup. The principle of the charge measurement with Faraday cup and electrostatic voltmeter is shown in Fig. 5 [8].

After the fluidization in the triboelectrostatic charging unit, the grains generate an electrical charge on the surface of the inner cylinder according to the principle of influence charge. The inner cylinder is connected to a Coulomb meter of the type "Monroe 284". The connection to the Coulomb meter is realized via a BNC connector. The total charge of the sample is shown with the correct sign on the display of the Coulomb meter. After the total charge has been measured, the collected sample in the Faraday cup is weighed and the mass specific surface charge is calculated [8, 10, 11].

The equation for the calculation of the mass specific surface charge is given below [8]:

$$q_m = \frac{Q}{m}$$

q_m [nC/g] = mass specific surface charge

Q [nC] = total charge

m [g] = sample mass

4. Sample Description

The synthetic copper ore was blended from pure quartz and chalcocopyrite, which were prepared without using any chemicals. The particle size distribution of these two mineral phases was determined and is shown in Fig. 6.

To create the feed sample for the tests, quartz and chalcocopyrite were blended. The quartz to chalcocopyrite ratio was selected as 90:10 based on the example of a real ore. The re-

Fig. 6: Particle size distribution of pure quartz and chalcopyrite in the linear grid

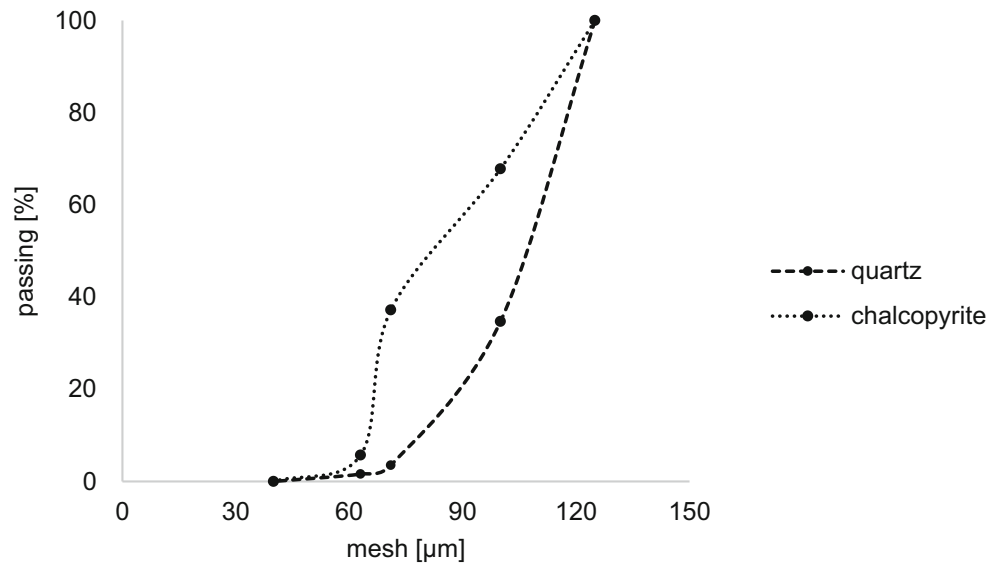
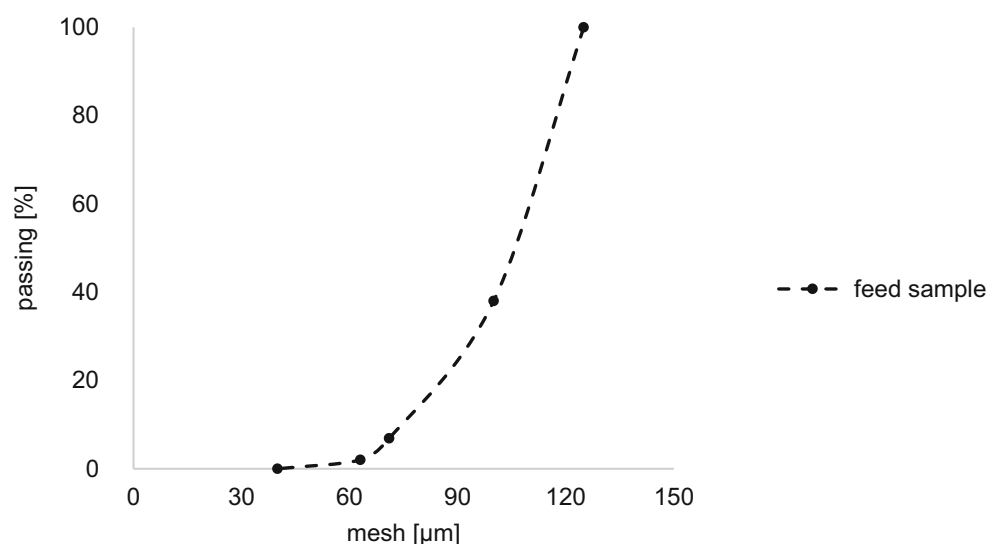


Fig. 7: Particle size distribution of the feed sample in the linear grid



sulting particle size distribution of the feed sample is shown in Fig. 7.

For a quick and easy assessment criterion of the 2-phase mineral mixture, the density was determined by the means of a helium pycnometer. The results of the density measurement of quartz, chalcopyrite and the feed sample are summarized in Table 1.

	Density
Sample	[g/cm ³]
Quartz	2.65
Chalcopyrite	4.15
Feed sample	2.75

5. Experimentation

5.1 Charge Measurement of the Pure Minerals in the Triboelectrostatic Charging Unit

To get an impression of the size and polarity of the triboelectrostatic surface charge, the pure mineral samples are fluidized for 60 min in the charging unit. Samples are taken every 15 min and measured immediately in the faraday cup to check the mass specific surface charge over time. The result of these tests is the time course of the surface charge, the so-called basic charging curve of pure minerals. This curve can be used to predict how long the charging process will take and from which other minerals the phase can be separated.

In order to investigate the influence of the fluidisation temperature, the minerals were preheated at different temperatures for 12 h in a drying oven and then fluidized at the same air temperature in the triboelectrostatic charging unit.

Fig. 8: Mass specific surface charge of pure quartz over time at different temperatures

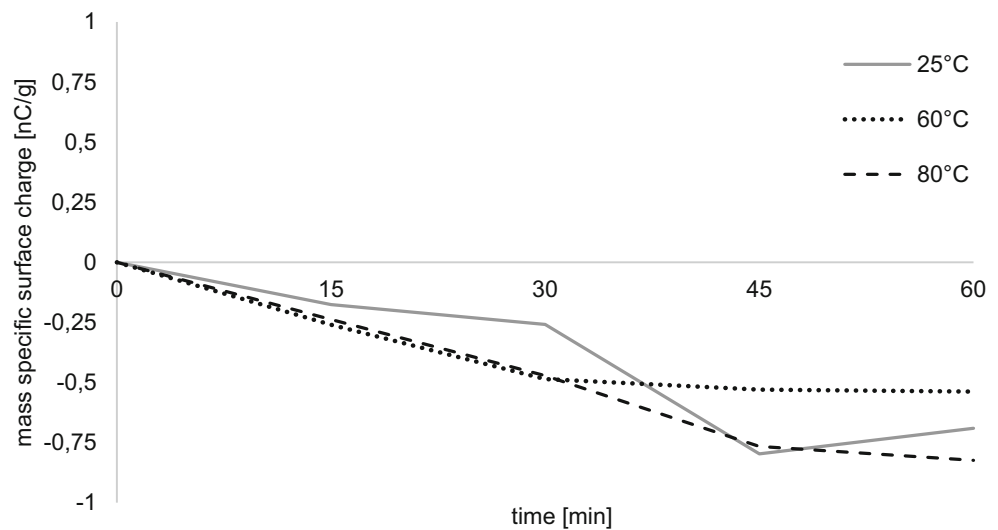
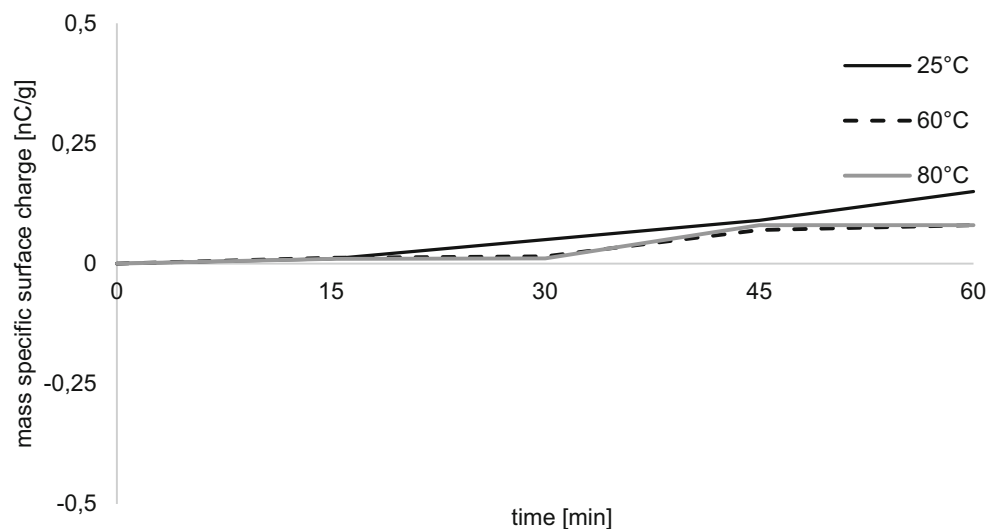


Fig. 9: Mass specific surface charge of pure chalcopyrite over time at different temperatures



The results of the time and temperature dependent mass specific surface charge of pure quartz and chalcopyrite are shown in Figs. 8 and 9.

The curves show that quartz is charged negatively at all tested temperatures, whereas chalcopyrite charges positively. The opposing charging of the two minerals is an important basis for sorting by the triboelectrostatic belt separator. The negative charging of quartz is most pronounced at 80°C and least at 60°C. In the case of chalcopyrite, the positive charge is strongest at 25°C and less, but approximately the same at 60°C and 80°C.

5.2 Triboelectrostatic Belt Separation

To check the significance of the charge curves, the pure minerals were then blended as a synthetic copper ore with a quartz to chalcopyrite ration of 90:10 based on the example of a real ore and then fed to the triboelectrostatic belt separator. Both feed and air temperature were set to 25°C,

the relative humidity during the separation tests was about 30%.

The experiments were carried out on a lab scale triboelectrostatic belt separator. The operational principle has already been shown in Fig. 1. The feed passes from above via a vibrating unit into the separation area with electrodes arranged one above the other. The polarity of the electrodes can be reversed on both sides. Product discharge takes place on the left and right side of the separator after leaving the separation chamber. The two products are collected in plastic bags [3].

5.2.1 Influence of Machine Parameters

The lab scale belt separator enables the variation of numerous parameters. In order to find out about the influence of these parameters, these and their interactions with each other were analysed. For the execution of the experiments, a partial factorial design of type "2⁵⁻¹" was chosen [3].

The separation success was assessed by determining the density of the concentrates and tailings.

TABLE 2
Machine settings at the best separation result

Belt speed [fps]	Gap between the electrodes [mm]	Applied voltage [kV]	Polarity of the top electrode (+/–)	Feed rate (1–10)
35.2	14	6	(+)	10

The following machine parameters can be changed on the lab scale belt separator [3]:

- applied voltage
- electrode distance
- belt speed
- polarity of the top electrode
- feed rate

Ad (a) The voltage applied to the electrodes can be infinitely adjusted from 0–6 kV. For the tests, the levels for the applied voltage were set at 3 and 6 kV [3].

Ad (b) The electrode distance is limited by the geometric conditions. For the maximum distance a value of 14 mm is determined, for the minimum it is 9 mm. These two extremes are chosen as levels in the experimental design plan [3].

Ad (c) A belt speed of 11 m/s is defined as the upper level in the design plan. For the lower level 5.2 m/s fps are selected [3].

Ad (d) The polarity of the top and bottom electrode can be set to positive or negative. In this case, one electrode must always be positive and one negative for the generation of an electrostatic field at the triboelectrostatic belt separator. For the experiments, both variants were implemented. Further information on the polarity always refer to the head electrode [3].

Ad (e) The intensity of the vibro feeder can be adjusted from 1–10. The values 5 and 10 are defined as levels [3].

The parameters (a)–(e) listed above were taken over into a partial factorial design of the type “2⁵⁻¹” [3, 12].

5.2.2 Results of the Triboelectrostatic Belt Separation

The influence of the five parameters on the separation success of quartz against chalcopyrite was assessed by average values of the concentrate density and the mass yield of concentrate. For every parameter, these values were averaged from all tests with the same setting for the respective parameter. As all parameters were set at two distinct levels, this results in two averages for each in this design. The difference between the lowest and highest average (if more levels are tested) indicates the influence of this parameter on the separation result—in this case on the yield and the quality of the concentrate [3]. The settings of the most successful test within this design are presented in Table 2, the associated balance is summarised in Table 3.

At the best sorting test, a chalcopyrite grade of 79.0% with a recovery of 81.2% was achieved in the concentrate. The possibility of triboelectrostatic sorting of quartz and chalcopyrite is clearly demonstrated, as was indicated by

TABLE 3
Balance sheet for the best separation result

	Mass [%]	Density [g/cm ³]	Calculated chalcopyrite grade [%]	Chalcopyrite recovery [%]
Chalcopyrite-concentrate	10.3	30.3	79.0	81.2
Quartz-tailings	89.7	20.7	2.1	18.8
Feed	100.0	20.8	10.0	100.0

the charging curves (Figs. 7 and 8). However, 18.8% of the chalcopyrite content are lost in the tailings by a one-stage separation.

6. Conclusions

The present study gives detailed information about the triboelectrostatic charging behaviour of a synthetic sulfidic copper ore and its potential of using triboelectrostatic belt separation. With the examined separation tests, an enrichment of chalcopyrite in the concentrate was possible. However, 18.8% of the chalcopyrite content was lost in the tailings. For a more efficient separation, additional separation stages should be considered.

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