The application of the electrodynamic separator in minerals beneficiation

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Abstract. The aim of presented paper is elaboration of methodology of upgrading natural minerals in example of chalcocite and bornite sample. The results were obtained by means of laboratory drum separator. This device operates in accordance to properties of materials, which in this case was electrical conductivity. The study contains the analysis of the forces occurring inside of electrodynamic separator chamber, that act on the particles of various electrical properties. Both, the potential and electric field strength distributions were calculated, with set of separators setpoints. Theoretical analysis influenced on separator parameters, and hence impacted the empirical results too. Next, the authors conducted empirical research on chalcocite and bornite beneficiation by means of electrodynamic separation. The results of this process were shown graphically in form of upgrading curves of chalcocite considering elementary copper and lead.

1. Introduction
Static electric fields are used in technological processes, among which electric separation can be found. The argument of separation is defined through differences of magnetic properties or/and electrical conductivity. The advantage of electrodynamic separation is the possibility of obtaining efficient separation of individual components in dry conditions. This eliminates many operations such as thickening, dewatering, hydrotransportation, additional drying which cause higher energy consumption and higher processing costs [1-3].

The materials treated by electrodynamic separation require proper preparation, such as crumbing and classification – with purpose of being sure that final products will be properly extracted. Products can be fine-grained, mixed including various ingredients. It often happens that those ingredients are pretty similar to each other in terms of their characteristics, so it is necessary to proceed with further separation processes.

The aim of this paper is to demonstrate possible laboratory applications of electrodynamic drum separator in mineral processing of chalcocite and bornite ores supported with statistical analysis of received results. For the experimental research, the difference in electric susceptibility was chosen as a separation feature.
2. The principle of particles separation in electric field

Electrical separation methods are based on differences between time traces of electrical particles on seeds with different conductance, and, basing on that, different time constants for triboelectric effect. This solution has been applied in electrodynamic drum separator, constructed by Huff in 1905.

The mixture of particles is poured from feeder to coronal zone, where they are electrified with negative charge, and then passed down to the surface of the drum. Particles with low resistivity become electrified positively and are thrown outside by electrical field forces. At the same time, particles of high conductivity keep their charge received in coronal zone and they are transferred by means of electric field and specular reflection forces to another part of the receiver. Then, they fall off or are scraped with a brush. The structure and scheme of the separator are shown on the Figure 1.

![Scheme of drum separator working](image)

**Figure 1.** Scheme of drum separator working

2.1. Mineralogical characteristics of copper minerals

The materials used for empirical research are ores of chalcocite and bornite. Chalcocite is a most common mineral in all three types of ore found on the motherlodes form Lubin to Sieroszowice. The maximum density of chalcocite, up to 90% of total volume, can be found close to nested sandstone structures with anhidrite binders. The average percentage share can vary up to 94% of the total sum of all sulfides.

Bornite (Cu₅FeS₄) – according to quantity, bornite is the second ore mineral in the motherlode after chalcocite. It can be found in all lithological types of ore. In sandstones, the average percentage share of this mineral varies from 0.2-0.7% of volume, in slates – 0.4-1.6%, whereas in dolomites one can notice the variation from 0.1 to 1.0% of total volume. Bornite creates mainly dispersed, nested and veiny structures in all layered rocks. Bornite’s chemical composition is very mixed. Bornite taken from Lubin and Polkowice area usually contains more silver.
3. Microscopic model separation with using of drum separator

Figure 2 below shows forces affecting the conductive particles – particle A is located on the drum’s surface and particle B has been thrown away from it. As one can see on the forces distribution presented on Figure 2, the main role in terms of conductive particles’ separation is played by the sum of electric ($F_e$) and centrifugal ($F_o$) force, while looking into the movement of non-conductive particle, the effect of distribution is made by higher electrical ($F_e$) and specular reflection ($F_i$) forces [4].

![Figure 2. Distribution of forces acting on conductive particles [4]](image)

To determine the dispersion effectiveness of various electrical characteristics, it’s necessary to determine the particles’ trajectory after leaving the drum’s surface, and as it follows – to create the microscopic separation model. The trajectory of separated particles is affected by many factors, amongst which the most important ones are: the electrodes’ arrangement, the high voltage value (both of those factors determine the field distribution between the drums), the drum’s angular velocity, the granularity of separated particles and the relative air humidity [4], [5].

The shape of particles’ trajectory in drum separator is connected with the affection of forces on the particle while the particle is located on the drum’s surface, as well as after being thrown away from it in the area of electric field.

General equation representing acting forces is in form [6], [7]:

$$ m \frac{dv}{dt} = \Sigma F $$

where:

- $m$ – mass of particle [g],\[\frac{dv}{dt}\] – particle’s acceleration [m/s²], $\Sigma F$ – sum of forces acting on particle [N].

In time in which a particle is located on drum’s surface the forces act on it (their modules are presented).

- of electrical field:

$$ F_e = QE $$

- of reflection:

$$ F_i = \frac{Q^2}{4\pi\varepsilon_0(d^2)} $$

where:

- $Q$ – particle’s charge [C], $E$ – intensity of electrical field [Vm⁻¹], $d$ – drum’s diameter [m].
- centrifugal:
\[ F_\omega = \frac{mv^2}{r} = m\omega^2 r \]  
\[ F_g = mg \]  
(4)  
(5)

where:
- \(\omega\) – drum’s axial velocity \([s^{-1}]\), \(g\) – gravity \([ms^{-2}]\).
- dynamic medium’s drag force:
\[ F_w = \Psi S \frac{\rho v^2}{2} \]  
(6)

where:
- \(\Psi\) – coefficient of dynamic medium drag \([-]\), \(S\) – surface of particle’s projection on surface perpendicular to motion \([m^2]\), \(\rho\) – density of medium in which particle is moving \([kgm^{-3}]\), \(v\) – particle’s velocity \([ms^{-1}]\).

4. Numerical analysis of the electric field distribution

The potential distribution and electric field density in drum separator system have been observed using Finite Elements Method using COMSOL Multiphysics environment. This software is a simulation pack, solving sets of partial, non-linear differential equations in one, two or three dimensions [4].

The computed model consist of rotating, grounded cylinder with loader placed above, which aim is to supply the system with particles to separate. The model consist also of two electrodes: the aberrational, motionless, cylinder-shaped one and movable, corona, comb one, which aim is to increase the electric field among its limit.

Figure 3. Distribution of the electric potential and electric field for \(\Theta = 60^\circ\), \(\varphi = 45^\circ\), \(V = 11\ kV\)

Figure 3 shows distribution of electric potential for following angles of corona electrode: \(\Theta = 60^\circ\), \(\varphi = 45^\circ\) and voltage \(V = 11\ kV\). On the figure 3 the distribution of electric field density for corona electrode described above is presented. The highest density of field can be found around the edge of corona electrode. However, the surface of drum is also affected by high field density, which means that particles located on the drum, in this area, are under the influence of this field as well.

5. Methodology of research

The investigation of electrostatic separation was performed by means of laboratory drum separator by constant voltage of 11 kV and constant drum rotaries (Figure 4). The samples of chalcocite and bornite were separated which granulation was 0.040–0.063 mm. Chalcocite contained 25.6% of Cu and 16% of Pb and bornite – 20.5% of Cu and 0.9% of Pb. These were minerals of copper ore, selected especially to research and mineralogically qualified as chalcocite and bornite. The materials to investigation were comminuted in laboratory crusher and then the narrow particle fraction 0.063–0.040 mm was sieved with maintained constant conditions of temperature and humidity of area. The
separation products were collected in containers and each of them was weighed and marked for contents of individual elements by means of spectrometer XRF.

![Figure 4. Photo of electrodynamic drum separator](image)

6. Elaboration of research results
Tables 1 and 2 present shares and distributions of copper and lead contents in sample of chalcocite and bornite of granulation 0.063-0.040 mm after electrostatic separation.

| No. box | Share [%] | Cu [%] | Pb [%] |
|---------|-----------|--------|--------|
| 1       | 1.80      | 50.40  | 5.30   |
| 2       | 4.90      | 45.20  | 4.60   |
| 3       | 10.29     | 44.50  | 4.50   |
| 4       | 10.95     | 44.80  | 4.90   |
| 5       | 8.66      | 40.40  | 6.20   |
| 6       | 7.35      | 31.30  | 13.90  |
| 7       | 6.54      | 32.10  | 16.10  |
| 8       | 3.10      | 36.40  | 10.80  |
| 9       | 0.98      | 36.50  | 10.50  |
| 10      | 0.98      | 30.40  | 15.40  |
| 11      | 0.98      | 9.00   | 22.40  |
| 12      | 43.46     | 6.30   | 25.40  |
| 13      | 10.90     | 31.30  | 11.50  |
| 14      | 0.10      | 37.80  | 6.90   |
Table 2. Contents of copper and lead in bornite separation products

| No. box | Share [%] | Cu [%] | Pb [%] |
|---------|-----------|--------|--------|
| 1       | 0.00      | 0.00   | 0.00   |
| 2       | 1.42      | 42.60  | 0.36   |
| 3       | 3.46      | 33.74  | 0.63   |
| 4       | 5.51      | 27.90  | 0.76   |
| 5       | 4.25      | 33.50  | 0.60   |
| 6       | 3.46      | 31.90  | 0.65   |
| 7       | 2.05      | 33.90  | 0.57   |
| 8       | 1.42      | 29.90  | 0.73   |
| 9       | 0.79      | 26.70  | 0.81   |
| 10      | 0.31      | 20.00  | 1.01   |
| 11      | 4.41      | 14.30  | 0.95   |
| 12      | 62.36     | 17.20  | 0.99   |
| 13      | 10.55     | 17.70  | 0.93   |

The electrostatic separation is commonly applied in purpose of separating conducting and nonconducting particles [8]. Such separation is usually associated with concentration (beneficiation) of certain elements in certain products (containers) while others will be depleted for certain component. In this paper the attempt of evaluating beneficiation of separated materials divided in drum separator was done on the basis of methods being applied in mineral engineering. To this purpose, coordinates were calculated for Halbich’s upgrading curve (called also as Hall’s curves) and then the graphs were plotted [9]. It is obtained on the basis of the balance of separation products as dependence of cumulated recovery in function of useful component’s contents in concentrate [10]. The cumulated recovery is calculated according to the formula:

\[
\sum \varepsilon = \sum \gamma \frac{\beta}{\alpha}
\]

where: \(\varepsilon\) – recovery of analyzed element, \(\gamma\) – yield of product (in his case related to share), \(\beta\) – contents of useful components in concentrate, \(\alpha\) – contents of useful component in feed.

On Figure 5 the Halbich’s upgrading curves are presented for copper and lead in chalcocite and on Figure 6 in bornite. Halbich’s upgrading curves for copper in chalcocite and bornite are similar with growth of copper contents in concentrates. Analogical beneficiation curves for galena in these minerals have course of the same type in chalcocite and bornite, respectively but show growing tendency with growth of lead contents in concentrate. That means that in case of copper in electrostatic beneficiation for containers of lower numbers (close to drum) not much material is transferred but it is rich in copper. For these containers is possible to achieve high quality copper concentrates by small yields. However, in case of lead in tested minerals its cumulation is observed in containers of higher numbers and lead is carried outside the drum. Such distribution of selective cumulation of copper and lead in individual containers is related to many factors, among others to such as: materials granulation, level of components liberation and possibility of absorbing and giving electrical charge on particles’ surface in time of acting electric field forces. The electrical properties of elements, such as conductance and specific resistance decide precisely about possibility of absorbing of surface electrical charge by particles which causes that selective transfer of particles to various containers (products) occurs, constructed of elements of characteristic sign being parts of it. For copper the conductance is equal to 58.5 [MS/m] and resistance 0.02 [\(\mu\Omega \cdot m\)]. However, for lead the conductance is equal to 4.8 [MS/m] and resistance to 0.02 [\(\mu\Omega \cdot m\)]. Various values of these material
features for copper and lead decide about various ability to absorb and give electric surface charge and this causes its selective separation.

![Graph](image1)

**Figure 5.** Halbich’s upgrading curves: a) for copper – chalcocite, b) for lead – chalcocite

![Graph](image2)

**Figure 6.** Halbich’s upgrading curves: a) for copper – bornite, b) for lead – bornite

It’s becoming more and more common that Fuerstenau’s curves are used for mineral processing of the material consisting of two different ingredients. To compare the selectivity of the two ingredients’ division, the separate balances are made and curves – as the gain relations of one of the ingredients in the concentrate in function of second analyzed ingredient in waste [10] – are drawn. On the Figures 7 and 8 the Fuerstenau’s curves – as the relations of gain relations of copper in function of lead loss in waste – are presented for tested minerals. In both cases, the mineral processing curves for chalcocite and bornite are angled from line of coordinates (0,0) and (100,100), which corresponds to situation where there are no reasons to use the particular method of mineral processing due to lack of differences conditioning the separation. The selection indicator $F$, based on Fuerstenau’s curves, has been related to the point of curve’s maximum camber point – its value for chalcocite equals to 78/78 and for bornite – to 64/64. This indicator tells about the average lead from copper division in chalcocite and weak lead from copper division in bornite.
7. Conclusions
It’s possible to use electrostatic separation to divide the conductive from non-conductive elements from the mix of different ingredients or from one material consisting of elements of different electrical features. The experiments done on chalcolite and bornite samples proved that it’s possible to use electric separation for dividing copper and lead concentrates with satisfying final effects. However, those conclusions are the result of basic-level experiments and it’s necessary to proceed with further works on this subject.

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