BIOSCIENCES BIOTECHNOLOGY RESEARCH ASIA, September 2015. Vol. **12**(Spl. Edn. 2), p. 657-670

Techniques and Equipment for Upgrading of Heat-treated Crushed Brown Coal For Energy Production and Utilities

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doi: http://dx.doi.org/10.13005/bbra/2246

(Received: 12 June 2015; accepted: 25 August 2015)

The article deals with the problems of increasing the efficiency of electric separators through developing new approaches to their design for upgrading of heat-treated crushed brown coal. The rational use of natural resources and efficient energy consumption are two basic requirements of EU Directive 2008/1/ÅC. It is expected that the techniques for brown coal pre-drying will result in increased energy efficiency of enterprises of up to 5% and upgrading of heat-treated brown coal will increase energy efficiency by the same value. To upgrade heat-treated brown coal it is necessary to design new equipment including high-efficiency electric separators. It was earlier found that the maximum value of coal particle charge was provided in a corona-electrostatic separator, a lower level of coal particle charge was observed in a triboelectrostatic separator and the lowest level of coal particle charge was established in a plate-type electrostatic separator. The basic efficiency constraint for drum-type corona-electrostatic separators is the diameter of a collecting electrode and one operating area. To select the directions for increasing the productivity and efficiency in separating heat-treated crushed brown coal in drum-type corona-electrostatic separators the results of studies of changes in force vectors affecting its charged particles, nature of their motion in the electric field resulting in separated products – organic and mineral components of brown coal, taking this into consideration the factors of the heating temperature, voltage across a corona-producing electrode (drum), diameter of a corona-producing electrode and its rotation speed, have been analyzed. The increased efficiency of a drum-type CES with a slight increase in its weight is associated with removing a constraint from design parameters – the diameter of a collecting electrode (drum). It is realized through the change of orientation of a collecting electrode from horizontal to vertical.

Key words: Heat-treated brown coal, upgrading, particle charge, A corona-electrostatic separator, efficiency, vertical corona-producing electrode (drum).

The rational use of natural resources and efficient energy consumption are two basic requirements of EU Directive 2008/1/ÅÑ. It is expected that the techniques for brown coal pre-drying will result in increased energy efficiency of enterprises of up to 5% and upgrading of heat-treated brown coal will increase energy efficiency by the same value. To upgrade heat-treated brown coal it is necessary to design new equipment including high-efficiency electric separators. After performing theoretical and laboratory researches of processes of effecting upgrading of heat-treated crushed brown coal HTCBC it has been proven that the basis for changing electrical conductivity in particles of crushed brown coal, which improves the efficiency of upgrading, is its heat treatment. Thus, electrical conductivity for semiconductors

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and dielectrics increases when the temperature rises, separation of charged particles of HTCBC is improved due to their drying, classification and dedusting (Olofinsky, & Novikov, 1974; Fraus, 1962; Mesenyashin, 1978). Fig. 1 shows the dependence of the charge of coal particles of different sizes on the heating temperature. The researches have identified the reasonability of heating up to 120-160°C with electric separation of coal particles for effective separation of a mineral component, for example, fractions "-0.5+0.0", 14% yield, 9.6% ash content.

Dependence of HTCBC charges and particles of non-heat-treated brown coal on the temperature is shown in Fig. 2. When particle sizes decrease the charge increases. Heating of particles up to 105^{0}Ñ is accompanied by condensation removal and reduced resistivity of a substance (from 10^{6} to 10^{3} MOhm) (Zimon, 1979; Volkova *et al.*, 1975; Lower-James, 1966). This results in increase of contact potential difference.

Before separating on drum-type separators sizing is recommended otherwise centrifugal forces, proportional to the cube of diameter of particles, can neutralize the effect of electric forces proportional to the square of the diameter of particles (Olofinsky, & Novikov, 1974; Mesenyashin, 1978).

It is known that in case of dedusting and classification of bulk materials, including coal, the disadvantage of sieves with a mesh smaller than 0.15 mm is hole clogging, wearability, expensiveness and low efficiency of sifting, excluding their commercial application. Therefore, corona separators used for dedusting and sizing of different materials are of practical interest (Plaksin, & Olifinsky, 1965; Kovalev, 1950). Working with the materials with fractions from 5 to 40%, sized less than 0.07 mm, it was found that extraction of this fraction on drum-type corona separators reaches up to 99%. When the content of fine fractions increases the number of treatment operations increases as well – when their content is from 5 to 20% one or two operations are required, when it is 20% and higher – three operations (Egorov, 1977; Kakovsky, & Revnitsev, 1962).

The surface electrical conductivity of minerals (especially that of dielectrics and semiconductors) depends on the amount of adsorbed moisture which dramatically increases electrical conductivity. Thus, when the ambient relative humidity is from 15 to 55% the charge value of particles remains almost the same, when the humidity changes by more than 55% the value of the coal particle charge will decrease dramatically. The dependence between the temperature and electrical properties in various minerals will differ therefore each mineral pair has its optimal temperature range in which the greatest difference in their electrical conductivity takes place (Olofinsky, & Novikov, 1974). Heat treatment is a basic method of material preparation. The values of contact charges are insignificant at room temperature, therefore before separation the material is usually heated to 50-300°C.

When developing design solutions for efficient separation it is necessary to take into account peculiarities of the particle charge in semiconductors and dielectrics. Mineral conductors are well separated from conductors and nonconductors. It is more difficult to separate semiconductors from nonconductors (mineral components of brown coal) which can complicate HTCBC upgrading and requires the intensified process of formation of electric charges with their increased values. It has been determined that charged particles are separated in the inhomogeneous electric field as a result of interaction of electric and mechanical forces which requires reasoning for selecting HTCBC separation techniques (Vereshchagin, & Levitov, 1974). In the course of theoretical and laboratory researches of triboelectrostatic upgrading of brown coal the following disadvantages were identified:

a) Reduced efficiency as compared to the corona-electrostatic process of upgrading;
b) Iin operation of the separator and free settling of clean coal the surface of plate electrodes must be free of dust which deteriorates separation;
c) The concentrate contains increased mineral components and the emerging tailings – increased organic components.

Method

Tribo adhesive separators process conductive and nonconductive, organic and nonorganic finely milled minerals and materials. Some components of adhesive forces under certain conditions prevail over others. Thus, if the air humidity is more than 70% adhesion of microscopic particles is increased by capillary forces (Simon, 1979). The upper limit of the size of particles, which can retain on the surface, differs in different conditions and may exceed 100 µm. In adhesive interaction of solids gravity forces, centrifugal forces and capillary forces are involved. The diversity of factors affecting adhesive interaction of coal particles indicates the complexity of the process concerned and the possibility of its adaptive management (Plaksin, & Olifinsky, 1965). The tribo adhesive method is limited by high energy consumption and necessity to operate the equipment U=20-60 kV. Therefore, this method of upgrading of heat-treated crushed brown coal will be unprofitable. When assessing the possibility of reliable separation of brown coal particles in terms of semiconductors from dielectrics when using a triboelectrostatic, tribo adhesive and corona-electrostatic methods of HTCBC separation drum-type corona-electrostatic method was selected as the most productive one. The studies of corona-electrostatic separators (CES) with horizontal and vertical drums showed that under equal conditions separators with a vertical drum are 2-3 times more productive. Therefore, to upgrade HTCBC it is recommended to design a CES with a vertical drum – collecting electrode. When developing design solutions of a CES with a vertical drum it is necessary to take into account the following:

a) The polarity of a corona-producing electrode affects the operation of separators with a corona discharge. The breakdown voltage is higher with a negative corona than that with a positive corona which is to be grounded (Fig. 3)
b) When the linear speed of a drum in constant electric field intensity is increased, the efficiency of a separator can be decreased.
c) The corona discharge emerges only in the inhomogeneous electric field in a small area near a thin conductor. This discharge does not extend to the opposite electrode and can be regarded as a partial gas breakdown (Plaksin, & Olifinsky, 1965).
d) One of the factors influencing the charge of HTCBC particles, sufficient for separation, is the corona discharge current. The corona current depends on the shape of a corona-producing electrode, voltage applied and structural features of the area of the separator corona discharge (Olefinsky, 1947).

These dependences (Fig. 4a) for the corona current are applied to the simplest cases when the current is determined only by the voltage across the electrodes, their dimensions and ion mobility, thus, without taking into account such factors as temperature, pressure, humidity, gas velocity and type and presence of suspended particles. Field intensity increases near a corona-producing electrode and remains almost the same in the rest interval between electrodes (Fig. 4b). To avoid sparking between cylindrical electrodes certain ratio between the wire radius r and the cylinder radius R must be ensured. For gas ionization without short circuit R: $r \geq 2.7$.

Based on the analysis of works of Russian and foreign scientists devoted to the charge and dynamics of separation of mineral particles in the course of corona-electrostatic separation (Egorov, 1977; Karnaukhov, 1966; Olofinsky, & Novikov, 1974; Fraus, 1962; Mammedov, 1979; Mesenyashin, 1978; Vereshchagin, & Levitov, 1974; Angelov *et al.*, 1978; Volkova *et al.*, 1975), one can conclude that mineral particles in the electric field are separated by means of retaining of charged particles on the surface of the grounded rotating electrode (retaining mode) or as a result of their turning towards the electrode with the potential opposed to that of particles (extraction mode).

Figs. 5a, 5b show that various forces affect the particle holding on the surface of a collecting electrode, and their resulting interaction determines the behavior of this particle in a corona-electrostatic separator (Olofinsky, & Novikov, 1974). According to the Newton's second law the equation of the trajectory of the particle gravity center is as follows (Olofinsky, & Novikov, 1974):

$$m\frac{d\overline{v}}{dt} = \sum \overline{F} = \overline{F}_{c} + \overline{F}_{G} + \overline{F}_{c.f.} + \overline{F}_{mir.} + \overline{F}_{pond} + \overline{F}_{ad.} + \overline{F}_{Arch} \quad ...(1)$$

where $_c$ is the Coulomb force caused by the effect of the electric field on the charged particle; $_G$ is the gravity force; $F_{c.f.}$ is the centrifugal force caused by rotation of a collecting electrode; $F_{mir.}$. is the mirroring force; F_{ad}. is the adhesive force of a particle to the collecting electrode, it is determined by interaction forces in the point of particle contract with the drum surface; F_{pond} is the ponderomotive force resulting from inhomogeneity of the electric field of the corona discharge and tending to withdraw the particle from the surface of a collecting electrode towards maximum field inhomogeneity, i.e. towards a corona electrode (Mesenyashin, 1982).

Equation (1) is the basic equation of forces affecting the particle in the electric drum separator. The researches of both foreign and Russian scientists addressed the forces affecting the particles with electric separation in the field of the corona discharge. Studies have shown that the forces in the equation of the trajectory of the particle gravity center in electric separation of materials, including HTCBC, must be neglected due to their small value.

These forces include $F_{pond, ad, Arch}$ (Olofinsky, & Novikov, 1974; Mesenyashin, 1978).

$$F_{pond} = 4\pi \cdot \varepsilon_0 \cdot r^3 \frac{\varepsilon_1 - 1}{\varepsilon_2 + 2} \cdot E \cdot gradE \quad ...(2)$$

where *gradE* is the gradient of field intensity of the corona discharge.

The value of F_{pond} is negligibly small and near the surface of a collecting electrode the electric field approaches to homogeneous $gradE \to 0$, and F_{pond} is important only in separation of fiber materials (Egorov, 1977; Olofinsky, & Novikov, 1974).

The direct proportionality between adhesive forces and particle sizes is experimentally observed (Karnaukhov, & Tarasova, 1963) in cases when there are no factors like roughness, electric field, moisture etc. The direct proportionality between adhesive forces and particle sizes indicates that for large particles the adhesive force is greater as compared to the adhesive force of small particles. Meanwhile, small particles retain more firmly. The relation between the adhesive force and the weight of particles rather than the absolute value of adhesive forces is of paramount importance in retaining particles.

The weight of particles is proportional to the cube of their radius:

$$F_{ad} = A \cdot r / 6H^2 \quad ...(3)$$

where *À* is a molar-attraction constant; *Í* is the clearance between the surface of a particle and the drum surface, m.

The weight of particles together with their sizes increases faster than adhesive forces – if the radius of particles is doubled, the adhesive force is doubled too, and the weight of particles increases by 8 times (Olofinsky, & Novikov, 1974; Mesenyashin, 1978).

The effect of adhesive forces on particles in the course of separation in drum-type CES, where materials larger than 50 – 70 μm are separated, can be neglected.

$$\overline{F}_{Arch} = \frac{4}{3}\pi \cdot r^3 \cdot \gamma_a \cdot g \quad ...(4)$$

where $_{Arch}$ is the Archimedes (buoyant) force; $\tilde{a}_a$ is air density.
This force in the air is 10^{-3} of the gravity force of particles and it must be considered in the course of separation in the liquid medium. Thus, basic forces determining the behavior of particles on the surface of a collecting electrode in a drum-type CES are F_k, F_T, $F_{c.f.}$, $F_{mir.}$:

$$\sum F = F_k + F_T + F_{cf} + F_{mir.} \quad ...(5)$$

$$\sum F = \pi\varepsilon_0 r^2 E_k^2 \cdot \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right) \cdot \left[4 + \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)\right] - \frac{\pi^2 r^3 \gamma_p R_1 n^2}{6{,}766} \quad ...(6)$$

where R_1 is the radius of a settling drum; *n* is a number of revolutions of a settling drum (Fraus, 1962; Mamedov, 1979).

Thus, particles being separated in the field of the corona discharge at the top of a collecting electrode will retain there if $\Sigma F \geq 0$.

When the drum rotates, the particle retained on it in the AB area, operating area of a corona-producing electrode (see Fig. 5b), moves to the BC area. The force retaining the particles on the collecting electrode reduces in this area as the field of the corona discharge in the BC area is weak and there is almost no force there (Karnaukhov, 1966) and the gravity force does not hold a particle on the drum like in the AB area but withdraws it from a collecting electrode. Therefore, the value of the resulting force in the BC area is as follows:

$$\sum F = F_{mir.} - F_{c.f.} - F_T \quad ...(7)$$

The particle retaining on the surface of a collecting electrode in the BC area discharges without the inflow of bulk charges from a corona-producing electrode, at that, its charge value is a function of the time this particle retain on the drum surface (Simon, 1979; Volkova *et al.*, 1975).

The formula defining the resulting force affecting the particle which retains on the surface of a collecting electrode, outside the operating area of the field of a corona discharge (Olofinsky, &

Novikov, 1974; Mesenyashin, 1978):

$$\sum F=\pi\varepsilon_0\cdot\left(1+2\frac{\varepsilon_1-1}{\varepsilon_1+2}\right)\cdot r^2\cdot E_c^2 f^2(R')\cdot e^{-\frac{2t}{\tau}}-\frac{4}{3}\pi\cdot r^3\cdot\gamma_p\cdot g-\frac{\pi^3 r^3\gamma_p R_1 n^2}{6{,}765}$$

or for nonconducting particles

$$\sum F=\pi\varepsilon_0 r^2 E^2{}_c\cdot\left(1+2\frac{\varepsilon_1-1}{\varepsilon_1+2}\right)^2-\frac{4}{3}\pi\cdot r^3\cdot\gamma_p\cdot g-\frac{\pi^3 r^3\gamma_p R_1 n^2}{6{,}765}\quad ...(8)$$

where R' is the contact resistance between a particle and a drum.

The above equations characterize the qualitative behavior on a CES horizontal collecting electrode of spherical particles and allow to assess the degree of influence of certain physical factors on the separation process (Plaksin, & Olifinsky, 1965; Degtyarenko, & Kashkarov, 1987; Belov, 1977).

Separation of HTCBC particles in a CES with a vertical drum is similar to that in a separator with a horizontal drum (Bachkovsky *et. al.*, 1968; Urvansev *et al.*, 2000; Revnivtsev, 1977). Unlike the diagram of forces in a separator with a horizontal drum, projection of the gravity force affecting the particle in a separator with a vertical drum, the axis of interaction of electrical pressing forces and a centrifugal separating force is equal to zero (see Fig. 6) (Levitov, 1966).

Fig. 6 shows the diagram of forces affecting the particles in a separator with a vertical drum. The effect of forces on particles retaining on the surface of a vertical collecting electrode:

$$m\frac{d\overline{V}}{dt}=\sum\overline{F}=\overline{F}_c+\overline{F}_{mir.}+\overline{F}_{pond}+\overline{F}_{ad}+\overline{F}_{c.f.}\quad ...(9)$$

where $_c$ is the Coulomb force of the effect of the electric field on the charged particle:

$$F_c = Q_e E_c \quad ...(10)$$

where Q_e is the equilibrium particle charge in the operating area of a corona-producing electrode; E_c is zero tension of the corona discharge near a collecting electrode.

$$F_c=4\pi\varepsilon_0\cdot\left(1+2\frac{\varepsilon_1-1}{\varepsilon_1+2}\right)\cdot r^2\cdot E_c^2\cdot f(R')\quad ...(11)$$

$F_{c.f.}$ is the centrifugal force affecting the particle retaining on the surface of a collecting electrode (drum) and is caused by rotation of the latter.

$$F_{c.f.}= m\cdot v^2/R \quad ...(12)$$

where v is a linear speed of drum rotation,

$$í = 2\pi\cdot R_1\cdot n/60 \quad ..(13)$$

where R_1 is the radius of a collecting electrode; n is the number of drum revolutions per minute

R is the distance from the drum center to the particle gravity center, $R = R_1 + r_1$, ...(14)
where r_1 is the distance from the drum surface to the particle gravity center. Since r_1 is very little as compared to R_1 we can assume that $R_1 = R$,
For spherical particles the weight is:

$$m = 4/3\pi\cdot r^3\gamma_p \quad ....(15)$$

Equation (12) with consideration of (13) and (14) is as follows:

$$F_{c.f.}=\frac{\pi^3\cdot r^3\cdot\gamma_p\cdot R_1\cdot n^2}{675},\quad ...(16)$$

$F_{mir.}$ is the mirroring force resulting from interaction of a particle resulting charge and induced to a collecting electrode of the electric charge equal in value to the resulting charge but opposed to it in its sign (Olefinsky, 1947).

It is known that the particle discharge to the grounding surface of a drum is expressed in the equation (Urvantsev *et al.*, 1995) :

$$Q_{RES}=Q_e\cdot e^{-\frac{t}{R'\cdot c}},\quad ...(17)$$

where Q_{RES} is the residual charge after t sec after a particle leaves the operating area of a corona-producing electrode; Q_e is the equilibrium particle charge which it receives in the corona field; R' is the contact resistance between a particle and a collecting electrode; C is the space between a particle and an electrode.

R and C values determine the time constant of charging and discharging of a particle τ and depend only on the properties of a particle itself and do not depend on the external field intensity (Kakovsky, & Revnivtsev, 1962):

$$\tau=\varepsilon_0\cdot\frac{\varepsilon_1 d_a+\varepsilon_2\cdot(1-d_a)}{\rho_{v_1}\cdot d_a+\rho_{v_2}\cdot(1-d_a)},\quad ...(18)$$

for the air at pv_2 = 0 and å$_2$= 1 this formula changes to (Kakovsky, & Revnivtsev, 1962):

$$\tau=\varepsilon_0\cdot\frac{\varepsilon_1+1-d_a}{d_a\cdot\rho_{v_1}},\quad ...(19)$$

where ε_1 is dielectric conductivity of the particle material; d_a is the depolarization coefficient determined by the ratio of main ellipsoid axes α, b, η (particle of a rotational ellipsoid shape); for a spherical particles $d_a = 0.5$; pv_1 is the specific bulk electrical conductivity of a particle which can be derived using the formula $pv_1 = 1/pv$, where pv is the bulk resistance of the particle material.

Taking into account particle discharge in the BC area based on equation (17) the formula for the mirroring force when the particle leaves the ionization area is as follows:

$$F_{MIR.} = \frac{\left(Q_0 \cdot e^{-\frac{t}{R \cdot c}}\right)^2}{16 \cdot \pi \cdot \varepsilon_0 \cdot r^2} = \pi \cdot \varepsilon_0 \cdot \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)^2 \cdot r^2 \cdot E_c^2 \cdot f^2(R) \cdot e^{-\frac{2t}{R \cdot c}} \quad \text{...(20)}$$

In practice, components - $\frac{2t}{Rc}$ of equation (20) are neglected since the value is close to 1 (Angelov *et al.*, 1978). In separation of particles larger than 0.05 mm in air by the medium resistance force, adhesive force, Archimedes (buoyant) force, the ponderomotive force can be neglected, the equation of balance of forces for a separator with a vertical drum is as follows (Urvantsev *et al.*, 1995):

$$\sum F = F_c + F_{mir.} + F_{c.f.} \quad \text{...(21)}$$

Equation for the resulting force [4, 8, 21, 39]:

$$\sum F_{res} = \pi\varepsilon_0 \cdot r^2 \cdot E_c^2 \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)\left(5 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right) - \frac{\pi^2 \cdot r^3 \cdot \gamma_p \cdot R_1 \cdot n^2}{675} \quad \text{...(22)}$$

With $\sum F_{res} \geq 0$ particles will be retained on a vertical collecting electrode, and with $F_{res} < 0$ they will be removed from the drum surface by the centrifugal force.

Therefore, the dependence of the size of nonconductor particles retained on a vertical collecting electrode in the area of the corona discharge:

$$r = \frac{675\varepsilon_0 \cdot r^2 \cdot E_c^2 \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)\left(5 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)}{\pi^3 \cdot r^3 \cdot \gamma_p \cdot R_1 \cdot n^2}, \quad \text{...(23)}$$

For example, for quartz particles with the density of $\gamma_p = 2.65 \cdot 10^3$ kg/m^3, dielectric conductivity $\varepsilon_1 = 4.5$, with field intensity of the corona discharge $E_{\hat{e}c} = 5 \cdot 10^5$ V/m:

$$r = \frac{0.721}{R_1 \cdot n^2} \quad \text{...(24)}$$

The content of the mineral component of HTCBC corresponds to the group of inertinite microcomponents – clay, sulfate sand, pyrite, and carbonates, i.e. analogue of quartz sand.

A number of HTCBC properties are similar to those of quartz sand:

dielectric conductivity 4.5, density of up to 1,500 kg/m^3, bulk density of up to 1.4 t/m^3, surface area of up to 5 m^2/kg, the diameter of a quartz sand particles is from 0.05 mm to 1 mm – with fraction particles "-1 mm" of HTCBC with the highest content of non-combustible components. The purpose of this work is to study the principles of separation of non-combustible components of HTCBC, the results of investigation of the quartz sand model can be used for the analysis of the quality of upgrading of HTCBC on a drum-type CES.

In the mode of retaining nonconductor particles when a particle leaves the corona area, only the mirroring force ($F_{mir.}$) and the centrifugal force ($F_{c.f.}$) affect the latter (Urvantsev *et al.*, 1995):

$$\sum F_{res} = 675 \cdot \varepsilon_0 \cdot r^2 \cdot E_c^2 \left(1 + 2\frac{\varepsilon_1 - 1}{\varepsilon_1 + 2}\right)^2 = \pi^2 \cdot r^3 \cdot \gamma_p \cdot R_1 \cdot n^2, \quad \text{...(26)}$$

For quartz particles with the density of 2.65’”10^3 kg/m^3 and dielectric conductivity å$_1$ = 4.5, the field intensity of the corona discharge is $E_c = 5 \cdot 10^3$ V/m

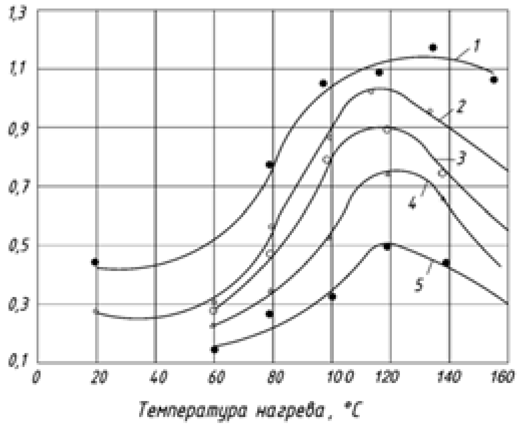
$$r = \frac{0.247}{R_1 \cdot n^2} \quad \text{...(27)}$$

By comparison, the size of quartz particles outside the corona area in separators with a horizontal drum is as follows:

$$r = \frac{0.247}{R_1 \cdot n^2 + 895.44} \quad \text{... (28)}$$

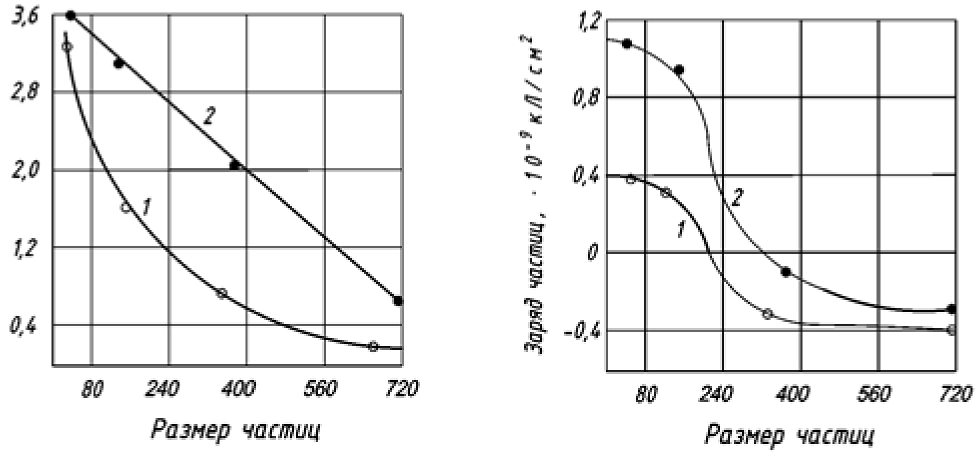
RESULTS

Calculation of the size of quartz sand particles retained on a vertical collecting electrode[27] and on a horizontal electrode is shown in Fig. s 7 and 8 for different values of the angular velocity of a collecting electrode and the linear



1-5 – sizes of particles 0.5-0.25; 0.25-0.175: 0.175-0.15; 0.15-0.1 and 0.1-0.074 mm

Fig. 1. Dependence of the charge of coal particles of different sizes on their preheating



1 – particles have been air-dried; 2 – particles have been heated up to 105^{0}C.
Fig. 2 – Dependence of particle charge on particle sizes and the heating temperature.

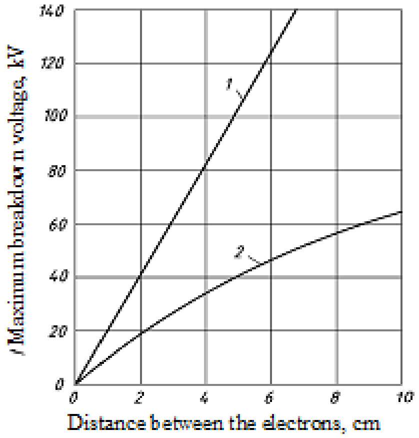


Fig. 3. Dependence of the breakdown voltage on the distance between the electrons with a negative (1) and positive (2) corona

speed of a drum (Simon, 1979). Increase in size of nonconductor particles retained on a vertical drum, as compared to a horizontal drum at the same linear speed, is due to change of the centrifugal force affecting the particles on a vertical drum based on equation[20].

Let us take the ratio of linear speeds (Fig. 7) of a horizontal collecting electrode of ϕ150 mm and vertical drums of ϕ0.5; 1.0; 2.0 m as an example. Linear speeds for a vertical drum of ϕ0.5 m – 2.7 and 3.6 m/sec; for a drum of ϕ1.0 m – 3.8 and 5 m/sec; for a drum of ϕ2.0 m – 5.3 and 7.2 m/sec correspond to the linear speed of a horizontal drum of 1.5, 2 m/sec (Urvantsev *et al.*, 1995).

Based on the diagrams of dependence of the diameter of particles retained outside the

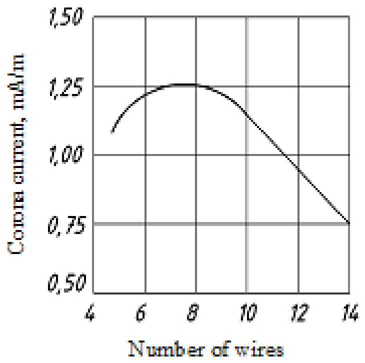
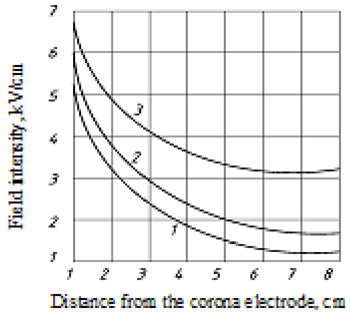


Fig. 4(a) Dependence of the corona current on the number of corona wires (Komlev, Urvantsev, Shikhov, & Zhuravsky, 1986)



1 – U_0 = 26 kV, I = 0.67’”10^{-6} A/cm; 2 – U_0 = 30 kV, I = 1.51’”10^{-6} A/cm; 3 – U_0 = 38 kV, I = 10^{-6} Å/cm

Fig. 4(b). The curves of field intensity distribution at different current values with the corona discharge between cylinders (cylinder “148 mm, wire “2 mm) (Plaksin, & Olifinsky, 1965) corona on the linear speed of a collecting electrode (Fig. 9), the size of nonconductor particles, retained on the drum, can be determined as follows (Urvantsev *et al.*,1995):

If the linear speed of a horizontal collecting electrode is less than 1 m/sec, the size of particles retained on the surface of a drum outside the corona decreases as compared to a vertical collecting electrode at the same centrifugal force. Based on the diagram of forces affecting the particles in a CES with a horizontal collecting electrode (Fig. 5b) outside the corona, the separating force increases by the value of the gravity force of particles. The gravity force of a particle in electric separators with a vertical collecting electrode does not affect the dynamics of separation of particles (see Fig. 6). Let us consider the diagram of dependence of the diameter of particles retained outside the corona on the linear speed of a collecting electrode (see Fig. 8) for a horizontal drum of ϕ240 mm and a vertical drum of ϕ0.5; 1.0 m. According to the diagram of correspondence of linear speeds (Fig. 9), the linear speed of a vertical drum of ϕ0.5 m – 1.0 and 1.5 m/

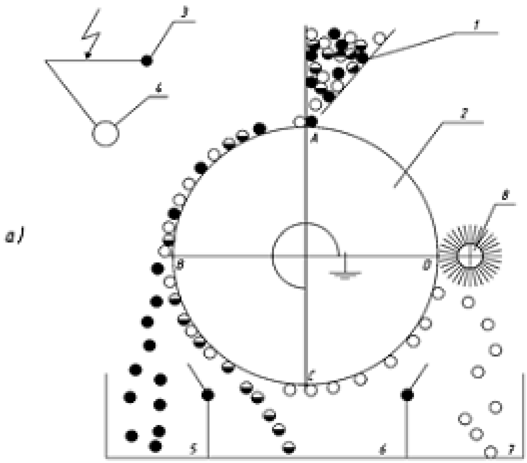


Fig. 5(a). Diagram of the operating area of a drum-type corona-electrostatic separator

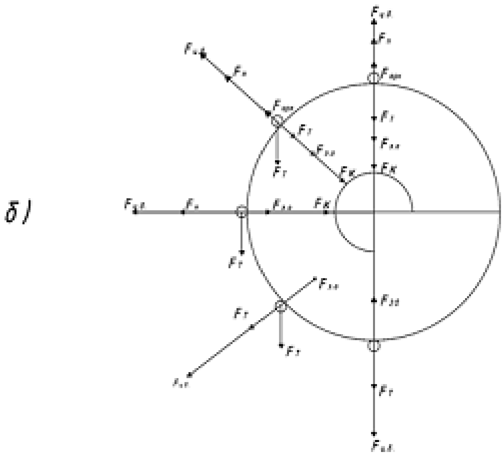


Fig. 5(b). Vector diagram of forces affecting the particle holding on the surface of a collecting electrode

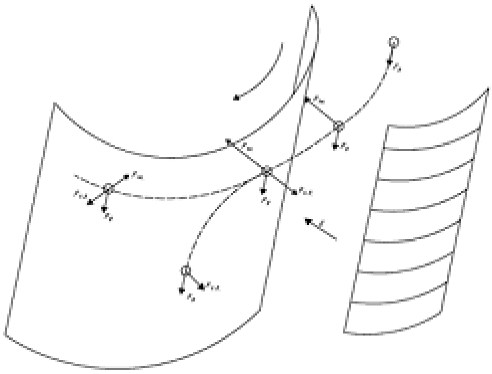
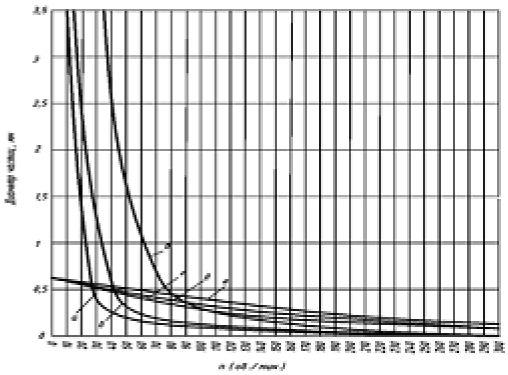


Fig. 6. Vector diagram of forces affecting the particles with a vertical drum

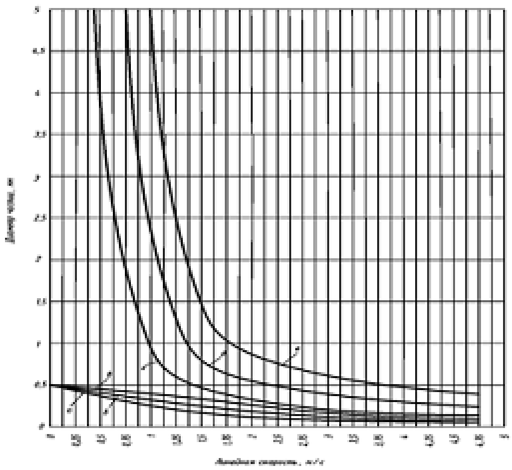


a – for a horizontal drum ϕ150 mm, b – for a horizontal drum 240 mm
c – for a horizontal drum ϕ356 mm, d – for a vertical drum 500 mm
e – for a vertical drum ϕ1000 mm, f – for a vertical drum 2000 mm

Fig. 7. Dependence of the diameter of retained particles outside the corona on the number of revolutions of a collecting electrode

sec corresponds to the linear speed of 0.75 and 1.0 m/sec of a horizontal drum of ϕ240 mm; the linear speed for a vertical drum of ϕ1 m is 1.5 and 2 m/sec.

When the linear speed is 0.75 and 1.0 m/sec, the particles (Fig. 2.16) of 0.37 and 0.23 mm, respectively, can retain on a horizontal drum of ϕ240 mm outside the corona. For vertical drums the increase in size of particles retained outside the corona will be as follows: for a collecting electrode of ϕ0.5 m – 2.1 and 1.25 mm; for a collecting electrode of ϕ1.0m – 2.3 and 1.9 mm.



a – for a horizontal drum ϕ150 mm, b – for a horizontal drum 240 mm,
c – for a horizontal drum ϕ 356 mm,
d – for a vertical drum ϕ 500 mm, e – for a vertical drum 1000 mm,
f – for a vertical drum ϕ 2000 mm

Fig. 8. Dependence of the diameter of particles retained outside the corona on the linear speed of a collecting electrode

The efficiency of a drum-type CES with a vertical collecting electrode can be determined based on the value of the efficiency of an electric separator with a horizontal electrode according to the formula (Shikhov, & Urvantsev, 2001):

$$Q_{V.S.} = \sqrt{\frac{R_V}{R_H} \cdot \frac{L_V}{L_H}} \cdot N \cdot C_V \cdot Q_{H.S.} \qquad ...(29)$$

where C_v is the coefficient of occupation of the surface of a vertical collecting electrode which is determined by the ratio of the length of an outlet slot of the feeder (*L*o.f) to the length of the generator of a collecting electrode (*L*v) in unit fractions (*C*v = *L*o.f./ *L*v); $Q_{H.S}$ is the efficiency of an electric separator with a horizontal collecting electrode calculated by the formula $Q_{SEP} = N \cdot L \cdot b \cdot \cdot q \cdot 3{,}6 \cdot 10^3$m/hour) or experimentally, t/h; R_V and R_H are the radiuses of a collecting electrode, vertical and horizontal, m; L_V and L_H are the lengths of the generator of a collecting electrode, vertical and horizontal, m; *N* is the number of individual sections of an electric separator with a vertical collecting electrode.

When the linear speed of drums at constant intensity increases, the efficiency of the electric field of separators decreases. This is due

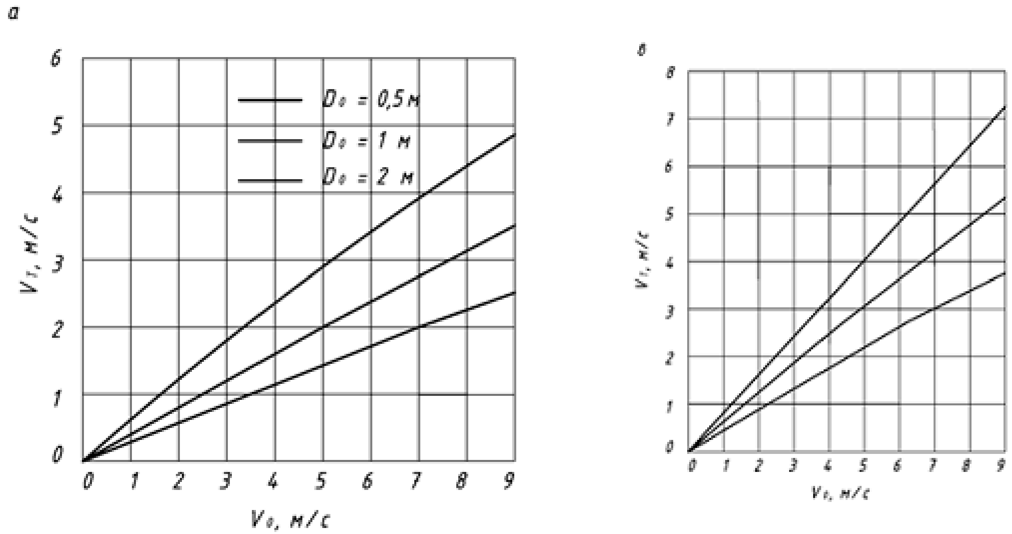


Fig. 9 . Diagrams of correspondence of linear speeds of vertical and horizontal collecting electrodes to the same centrifugal force (Karnaukhov, & Tarasova, 1963). a – at ϕ of a horizontal collecting electrode 150 mm; b – at e of a horizontal collecting electrode 240 mm; c – at ϕ of a horizontal collecting electrode 356 mm;

to the increase in the centrifugal force – the size of retained particles is decreased, the size of the layer on the drum is decreased, separator efficiency is reduced.

Fig. 10 shows the diagrams of dependence (calculated and experimental) of the size of nonconductor particles retained on the surface of a collecting electrode of "1 m on the drum rotation speed (obtained in experiments on classification of quartz raw materials in the Kyshtym Mining and Processing Plant and upgrading of titaniferous sand of the Irshansk Mining and Processing Plant) (Plaksin, & Olofinsky, 1964).

Researches on classification and upgrading were performed using an experimental facility. The diagrams in Fig. 10 show that experimental values from 26 to 60 rev/min differ from the calculated ones not more than by 10%. Experimental values from 20 to 26 rev/min of a drum differ from calculated ones a little more than by

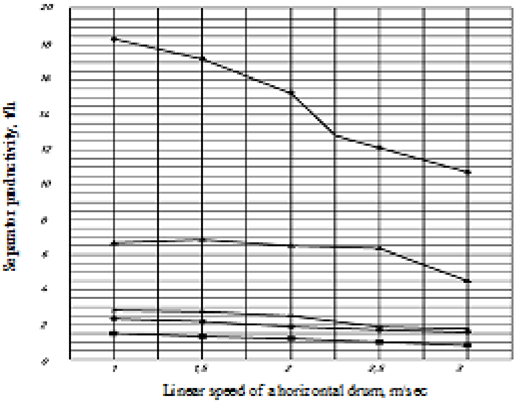


Fig. 10. Dependence of the efficiency of electric separators with a horizontal (ϕ150, 240, 356 mm) and vertical (ϕ0.5 m and 1.0 m) collecting electrode on the linear speed of a drum (Urvantsev *et al.*,1995)

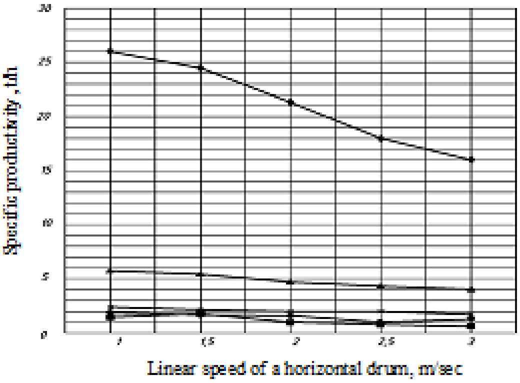


Fig. 11. Dependence of the specific productivity of electric separators with a horizontal (ϕ150, 240, 356 mm) and vertical (ϕ0.5 and 1.0 m) collecting electrode on the linear speed of a drum

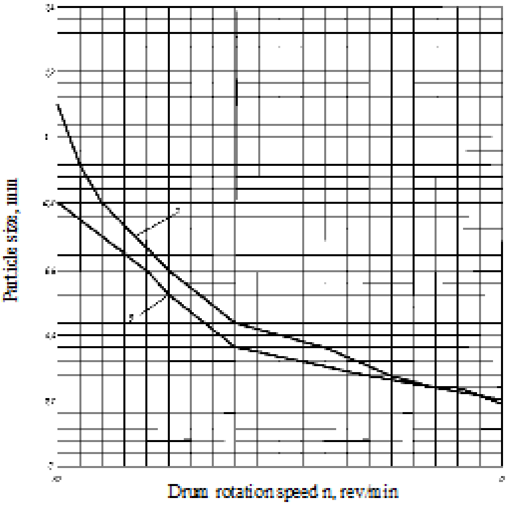


Fig. 12. Dependence of the size of particles retained on a vertical collecting electrode with the diameter of 1.0 m on the drum rotation speed. a – experimental values; b – calculated values

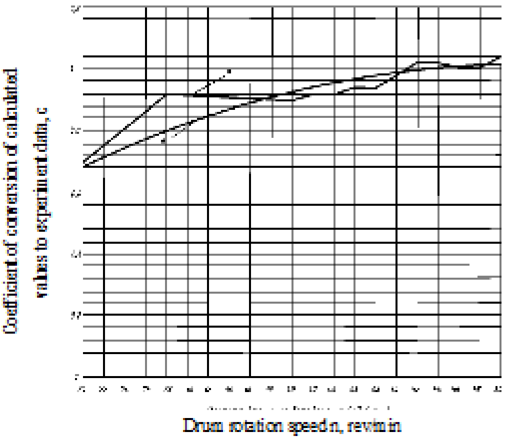
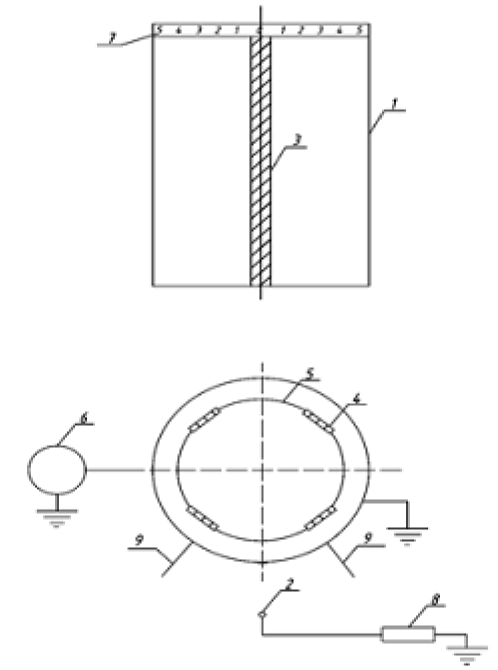


Fig. 13. Approximation of dependence of the coefficient (ñ) of conversion of calculated values of the size of particles – dielectrics to experiment size values, retained on the surface of a collecting electrode with the diameter of 1.0 m, on the drum rotation speed (Urvantsev *et al.*, 1995)



1 – collecting electrode; 2 – corona-producing electrode; 3 – sensor; 4 – dielectric stand; 5 – slip ring; 6 – microammeter or oscilloscope; 7 – measuring tape; 8 – high voltage source; 9 – glass-cloth plates

Fig. 14. Schematic diagram of a laboratory unit to measure the topography of currents of the corona discharge in a separator with a vertical drum.

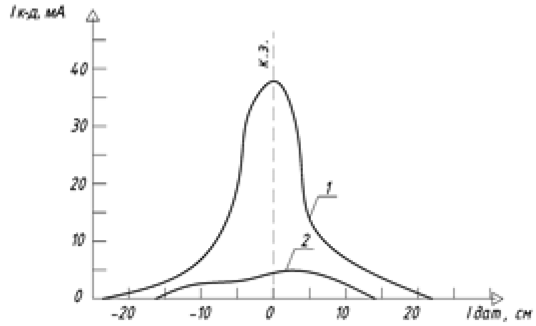
10%, which is obviously due to an actual shape of separated particles and their real physical properties of the surface. Fig. 11 shows a diagram of dependence of the coefficient of conversion of calculated values to experiment data on the rotation speed of a collecting electrode. The value of the correction coefficient is expressed in the equation (Plaksin, & Olofinsky, 1964; Cherchintsev, 1975):

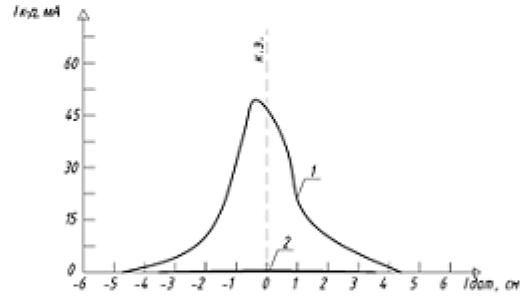
$$k = 0.7448 \cdot n^{0.102} \quad ...(30)$$

where n is the rotation speed of a collecting electrode, rev/min.

To retain a collecting electrode of dielectric particles on the surface when the linear speed of a drum is increased the charging process for a material being separated must be intensified (Shikhov, & Urvantsev, 2001). To successfully separate mineral mixtures in a CES the particles must be charged and must contact the surface of a collecting electrode. The flow of ions generated in the “corona hood”, affected by the electric field, moves to the collecting (grounded) electrode, where it charges the particles. Thus, the corona discharge current and its value are the factors affecting generation of charges on particles, which are sufficient for their separation.

Separation of minerals in drum-type corona separators is determined by the discharge current intensity. However, the current levels of the corona discharge in different points of a

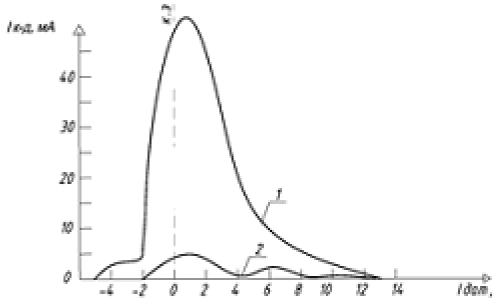




1 – voltage across a corona-producing electrode of 32 kV; 2 – voltage across a corona-producing electrode of 16 kV

Fig. 15. Level and distribution of the current of the corona discharge on the surface of a vertical collecting electrode of “1 m for the “wire-drum” open system

Fig. 16. Level and distribution of the current of the corona discharge on the surface of a vertical collecting electrode of e1 m for the “wire-drum” open system bounded by glass-cloth plates in two sides



1 – voltage across a corona-producing electrode of 32 kV;
2 – voltage across a corona-producing electrode of 16 kV

Fig. 17. Level and distribution of the current of the corona discharge on the surface of a vertical collecting electrode with the diameter of 1 m for the "wire-drum" system bounded by a glass-cloth plate in one side

collecting electrode differed and in the course of the experiment on a chamber corona separator the following trend was observed: the content of magnetite in the center of a section of the grounded electrode is usually minimal, it increases near the edges and then it decreases again (Karnaukhov, & Tarasova, 1963).

In order to find out the causes of nonuniform settlement of particles and distribution of the corona current along the grounded electrode have been studied. The curves of distribution of magnetite and discharge current are similar, which allows to associate distribution of separated components along electrode sections with distribution of the corona discharge in this direction.

Electrical resistivity of brown coal in its nature is ionic and is widely used depending on humidity. Heat-treated crushed brown coal has low electrical resistivity of 10^{-2} - 10^{-4} Ohm/m, similar to magnetite values, which allows to use the results of experiments for a comparative analysis.

DISCUSSION

Thus, the value and distribution of the current of the corona discharge on the surface of a collecting electrode affect the results of electric separation (Kovalev, 1950). Fig. 14 shows the schematic diagram of a laboratory unit. Fig. 15, 16, 17 show the examples of distribution of the current of the corona discharge on the drum surface at a voltage of 32 kV (1) and 16 kV (2) for the interelectrode distance of 80 mm. At that, it has been found that the corona current depends not only on the shape of a corona-producing electrode and the voltage applied but also on design features of the corona discharge area.

Investigation of dependences will allow to find optimal technological and design parameters of separation of materials on drum-type CES.

CONCLUSION

The upgrading of heat-treated brown coal will result in increased energy efficiency of enterprises of up to 5%. The conducted researches proved that the effective techniques for separation of semiconductor (organic component) and dielectric materials (mineral component) for upgrading of heat-treated crushed brown coal are electric separation techniques including drum-type corona-electrostatic, plate-type electrostatic, drum-type triboelectrostatic and drum-type tribo adhesive ones. The maximum level of coal particle charge was provided in a corona-electrostatic separator, a lower charge level was observed in a triboelectrostatic separator and the lowest ones were established in a plate-type electrostatic separator. Laboratory tests performed to establish the optimal size of HTCBC fed into separators and to select the most efficient upgrading technique showed the following:

Techniques using a plate-type electrostatic separator and a tribo adhesive separator work poorly for separation of heat-treated crushed brown coal.

A drum-type CES is the most efficient one.

The basic efficiency constraint for drum-type corona-electrostatic separators is the diameter of a collecting electrode and one operating area. To select the directions for increasing the productivity and efficiency in separating heat-treated crushed brown coal in drum-type corona-electrostatic separators the results of studies of changes in force vectors affecting its charged particles, nature of their motion in the electric field resulting in separated products – organic and mineral components of brown coal, taking this into consideration the factors of the heating temperature, voltage across a corona-producing electrode (drum), diameter of a corona-producing electrode and its rotation speed, have been analyzed.

a) Increase in the diameter of a corona-producing electrode results in reduction in the corona discharge current.

b) Increase in the voltage across a corona-producing electrode of up to 32 kV has the greatest influence on the yield of nonconductors.

c) The rotation speed of a drum affects the quality of fractions separated, halving of the drum rotation speed (from 60 to 30 rev/min) results in increase in the yield of a nonconductor fraction.

The increased efficiency of a drum-type CES is associated with removing a constraint from design parameters parameters – the diameter of a collecting electrode (drum). It is realized through the change of orientation of a collecting electrode from horizontal to vertical.

ACKNOWLEDGMENT

This article presents the results of work performed under the Agreement on Granting a Subsidy No. 14.579.21.0036 of June 5, 2014 (a unique identifier of applied researchers (project) RFMEF157914X0036) with financial support from the Ministry of Education and Science of the Russian Federation.

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