Proc. Estonian Acad. Sci. Phys. Math., 1994, **43**, 4, 280–292
https://doi.org/10.3176/phys.math.1994.4.06

FLOW OF AIR AND PARTICLES MIXTURE IN A DISINTEGRATOR

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Received June 27, 1994; revised September 30, 1994; accepted November 14, 1994

Abstract. A disintegrator is a grinding apparatus for breaking particles by high velocity collision. It has two rotors revolving in opposite directions. Each rotor consists of a disk and one or more concentric treatment rings on it. The disintegrators designed in TTU operate both for direct and separative grinding. Air (gas) and particles mixture is directed into the disintegrator. During the treatment by rotors the size of particles is reduced. The flow of air and particles in case of separative grinding is directed from the grinding module through a tube into the classifier. The paper deals with the analysis of the flow in the classifier in which large and small particles are separated by the inertial method at relatively low pressure drop in the grid. On the basis of the theory a DS series of disintegrators will be designed and produced.

Key words: grinding by collision, inertial separation, air and particles mixture.

INTRODUCTION

A disintegrator is a grinding apparatus for breaking particles by a high velocity collision. It has two rotors (Fig.1) revolving in the opposite directions. Each rotor contains a disk and one or more concentric treatment rings. Each treatment ring consists of a number of blades (grinding tools) located at the same distance from the centre of the axis of the disintegrator (Figs. 1, 2). The blades fulfil the following tasks:

– They serve as targets for colliding particles. The collision takes place with the relative velocity v_{0r} (Fig. 2), which is the vectorial sum of the absolute velocity v_1 and the velocity of transportation v_{2e}.

– They are the accelerators of particles for the next collision. After collision, fragments of broken particles slide along the blade, and leave the blade with the relative velocity v_{1r}. The blade has the transportation velocity v_{1e} and the particles leave the treatment ring with the absolute velocity v_1.

– The blades of treatment rings operate as the blades of a fan. Although their aerodynamical characteristics as those of a fan are not the best, they produce certain subpressure in the inlet and overpressure in the outlet of the disintegrator.

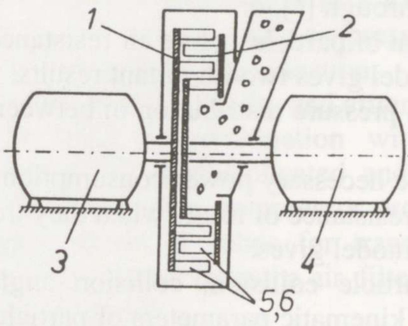

Fig. 1. A disintegrator consists of two rotors *1*, *2* and two motors *3*, *4* revolving in opposite directions. Each rotor contains one or more treatment rings *5*, they consist of a number of grinding tools *6*.

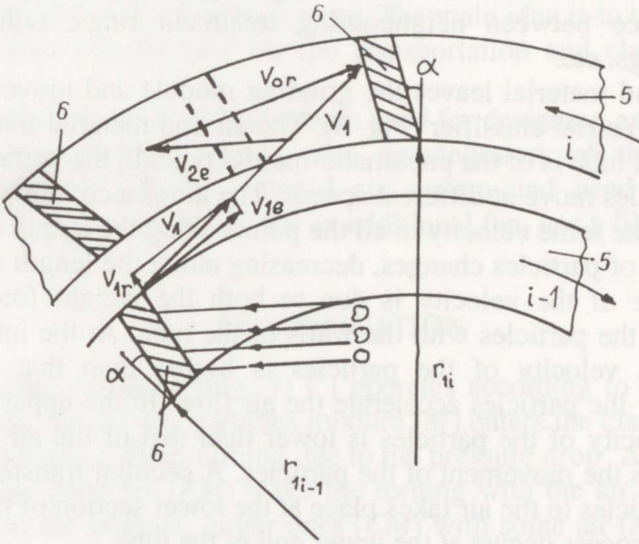

Fig. 2. Particle movement between and in the treatment rings *5*. A particle falls on the grinding tools (blade) *6*, breaks, slides along the blade and leaves it with velocity v_1. The velocity of next collision is v_{0r}.

The disintegrator takes in material and some air. In the disintegrator a mixture of material particles and air is formed. The flow of air and particles mixture proceeds between the treatment rings which are moving in the opposite direction and from there onto the following treatment rings. The fineness of the material, the number of particles and air temperature all increase as the mixture moves from the centre to the periphery of the rotors.

The aerodynamics of the mixture under such conditions is complicated and has not yet been understood up to now. The movement is described by two boundary models based on their modelling:

(i) – pure air flow as the Couette flow between two coaxial cylinders with radial air flow-through [1], or

(ii) – the movement of particles while air resistance is neglected [2].

The first basic model gives two important results:

– Air velocity and pressure distribution in between two treatment rings for the laminar flow.

– Estimation of the necessary power consumption at the idle run of the disintegrator, i.e. air resistance of rotors when they treat no material.

The second basic model gives:

– Velocity of particle collision, collision angles, direction of the movement and other kinematic parameters of particles after they have left a blade.

– Relationship between energy demand of the material to be treated and the productivity of disintegrator.

– Necessary constructional parameters for designing rational rotors: the number of blades on each treatment ring, angles of the slope of blades, radial distance between neighbouring treatment rings, radial size of treatment rings, etc.

The ground material leaves the grinding module and moves along the tube into an inertial classifier (Fig. 3). The air and material transportation in the vertical tube is of the pneumatic-inertial type. In the vertical tube the air and particles move at different speeds. The air as a continuous medium moves with the same velocity in all the points along the length of the tube. The velocity of particles changes, decreasing along the length of the tube. The decrease of the velocity is due to both the weight force and the collisions of the particles with the walls of the tube. At the intake end of the tube the velocity of the particles is higher than that of the air, consequently the particles accelerate the air flow. In the upper part of the tube the velocity of the particles is lower than that of the air and the air flow supports the movement of the particles. A peculiar transfer of energy from the particles to the air takes place at the lower section of the tube and the reverse process occurs at the upper end of the tube.

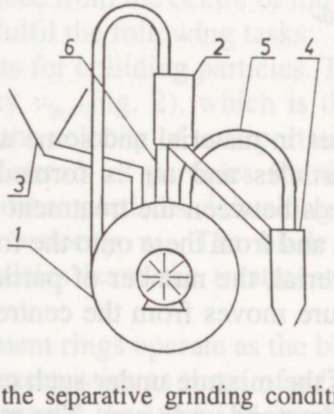

Fig. 3. Disintegrator under the separative grinding conditions. *1* – Disintegrator, *2* – Classifier, *3* – Material feeder, *4* – Separation of fine particles from air, *5* – Air circulation, *6* – Coarse material circulation.

Höffle [3] and Ushakov [4] have analyzed several classifiers, including the inertial ones. The inertial classification in a narrow slit has been a subject of several studies, such as [5]. High air pressure drop in the range from 10^1 to 10^2 MPa, is required for classification.

The estimations of classification quality and criteria are given in [6, 7].

The classifiers are used in combination with grinders. Such a combination, for example [8], is complicated and includes beside the grinder several additional devices: a compressor providing the necessary pressure for classifying, a set of tubes for transporting materials, a separator for extracting the product from the air, filters for cleaning the air and fans for generating a vacuum.

This paper considers grinding with classification on the example of coal. The classification of particles is carried out by an outfit of inclined strips and slits between the strips. The rotor of the disintegrator can be considered as an air fan producing low pressure air from 10^{-4} to 10^{-3} MPa. The rotors of the disintegrator produce a mixture of ground material and air with a certain velocity and pressure. The main idea is to use the kinetic energy of the mixture flow for the transportation and classification of materials.

The results of the studies have been used for designing and making DS (Disintegrator-Separator) series. The disintegrators of this series are simple, compact, include a closed air system and need no auxiliary devices: neither a compressor, nor an additional fan, nor a filter system.

CLASSIFICATION

Our inertial classifier (Fig. 4) [9] operates according to the following principle: the air (*A*) and particles mixture (*M*) enters the classifier; the air is forced to make a sharp turning due to the pressure drop $\Delta p = p_0 - p_1$ in the grid; tiny particles (*FM*) make the turning with the air (*AF*), and are directed into the product; larger ones (*CM*) with some air (*AC*), however, continue direct movement and proceed to the next retreatment stage.

If there (Fig. 5) is an air flow with the velocity v_0 along the grid and the pressure drop Δp in the grid, an air layer with the thickness of δ enters the slit. The air layer can be considered a jet that changes its flow direction due to the pressure drop. The dynamic pressure of the layer must be equal to the pressure drop on the surface of the jet curvature.

$$\Delta p = \frac{\rho_a v_0^2 \delta}{r}, \tag{1}$$

where ρ_a is air density.

The layer thickness δ, radius of the curvature r and angles φ_0, ψ, (see Fig. 5) are determined according to the sinus theorem in the system of equations

$$\frac{\cos(\varphi_0 - \psi)}{r - \delta} = \frac{\cos\psi}{r} = \frac{\sin\varphi_0}{l_0}. \tag{2}$$

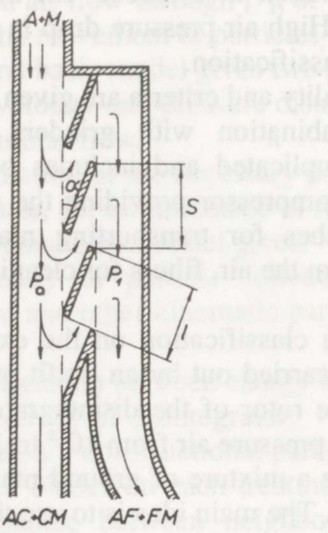

Fig. 4. Inertial classifier consists of a grid of sloped strips. α – slope, s – step of the grid, l – width of the strip, p_0, p_1 – pressure before and after the grid, $A+M$ – mixture of air and material, CM – coarse material, FM – fine material.

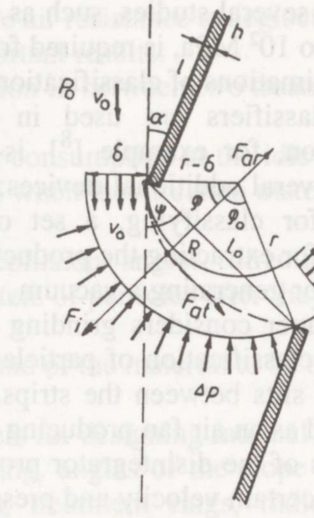

Fig. 5. Model of the movement of air layer and a particle in a slit of the grid. Δp – pressure drop, δ –thickness of the layer, r – radius of curvature, R, φ – polar coordinates of a particle.

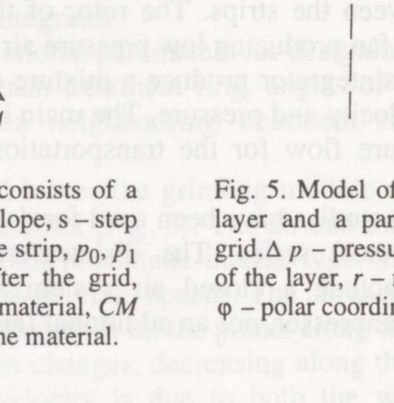

Fig. 6. Dependence of the air layer thickness δ and that of the curvature radius r, on the pressure drop in the grid.

The results of the calculation for the layer thickness δ and radius of the curvature r in dependence from the pressure drop Δp are shown in Fig. 6 for two values of mixture velocity v_0. With the increase of pressure the layer thickness δ drop and the outer radius of the curvature r increases, too; the inner radius of the curvature of the layer $r - \delta$, decreases. At a certain drop of the pressure the r and δ curves join. The outer radius of the curvature r is then equal to the thickness of the layer δ, the inner radius of the curvature limits to zero and the centre of the curvature moves to the edge of the strip. The layer flow reduces to the ordinary air flow through a grid.

The trajectory of particles is different from that of the air. The inertial force F_i and the air resistance force F_a are imposed on a particle. As the relative velocity of particles with respect to the air is low, the air resistance force is the Stokes force

$$F_a = 3\pi\mu_a d(v_p - v_a), \tag{3}$$

where μ_a is the dynamic air viscosity, v_a, v_b are the vectors of the air and particle velocities, respectively, and d is the size of a particle.

The positioning of particles is determined by the polar coordinates R and φ. The motion of a particle is described by differential equations

$$\ddot{R} = R\dot{\varphi}^2 - \frac{\dot{R}}{\tau}, \tag{4}$$

$$\ddot{\varphi} = \frac{k}{R^2\tau} - \frac{2\dot{R}\dot{\varphi}}{R} - \frac{\dot{\varphi}}{\tau}, \tag{5}$$

where $k = v_0(r - \delta/2) = \text{const.}$, $\tau = m/(3\pi\mu_a d)$ and $\dot{R} = dR/dt$.

The latter equation (5) allows to be integrated once:

$$R^2\dot{\varphi} = k + C\cdot\exp\left(-\frac{t}{\tau}\right). \tag{6}$$

After satisfying the initial conditions

$$t = 0, \quad \varphi = 0, \quad \dot{\varphi} = \frac{v}{r-\delta}, \quad R = r - \delta, \tag{7}$$

the constant C becomes of the value

$$C = -v_0 \cdot \delta/2.$$

Then the movement of boundary particles reduces to the numerical solution of the system of differential equations

$$\ddot{R} = R\dot{\varphi}^2 - \frac{\dot{R}}{\tau}, \tag{8}$$

$$\dot{\varphi} = \frac{1}{R^2}\left(k - \frac{y_0\delta}{2}\exp\left(-\frac{t}{\tau}\right)\right). \tag{9}$$

The calculated trajectories of the movement of coal particles relative to a particle size for the mixture velocity of $v_0 = 15$ m/s in the separator, are shown in Fig. 7. The size of a bound particle by the separation under these conditions is about 33 μm.

The size of a bound particle by the separation depends on the velocity in the classifier. If all other conditions, except air velocity are the same, the increase in air velocity calls forth the decrease in the size of the bound particle, which is shown in Fig. 8.

The size of a bound particle depends on the slope of strips on the grid. The slope has its optimal value at about $10^0 - 12^0$ (Fig. 9). If the slope is smaller, the probability of direct flying of rough particles will increase. If the slope exceeds the optimal one, the resistance of the grid will increase. Due to the fact that for larger particles the velocity loss on the strips is higher, the probability of their going into the fine product section will increase again.

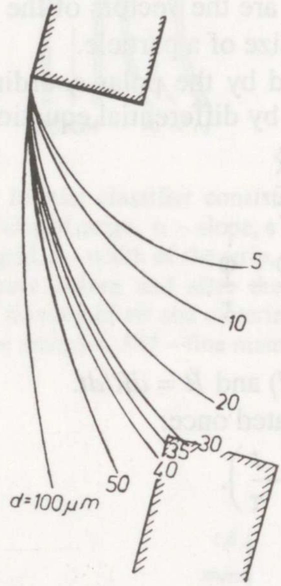

Fig. 7. Movement of coal particles of various size in a slit of the grid. In these conditions the size of bound particle is 33 µm.

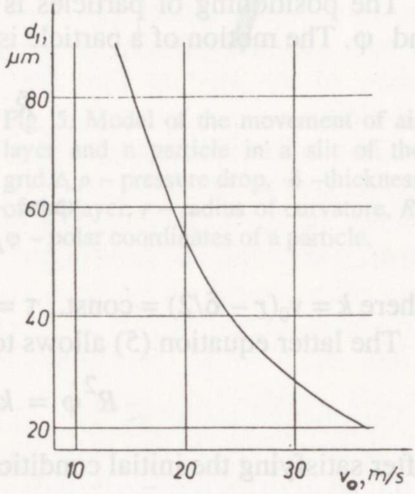

Fig. 8. Dependence of the size of bound particle d_1 of classification on the air velocity v_0 in the classifier.

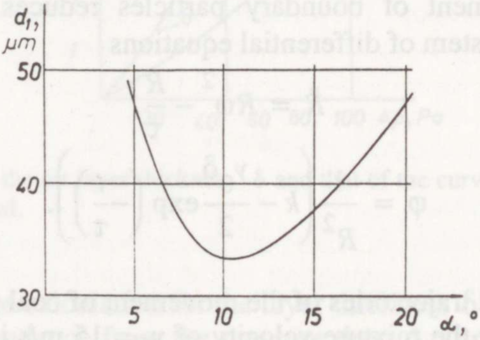

Fig. 9. Dependence of the size of bound particle on the slope of the blades of grid strips. The slope has the optimal values of 10^0–12^0.

By treating a material, the fineness of the product is mainly controlled by the velocity in the slits of the grid. The velocity in the slits determines the air productivity Q_a m²/s for a unit of the grid length $Q_a = Q_{asp}/L$. The dependence of the size of a bound particle on Qa is shown in Fig. 10, *a* and the results of the experiments for coal and the disintegrator DSL-38 are shown in Fig. 10, *b*. We can conclude that the size of a bound particle is highly sensitive on Q_{asp}.

The dependence of the size of a bound particle on the material concentration is extremely low in a wide range of concentrations, as it is shown in Fig. 11. For traditional conditions the voluminal concentration has the values of $\beta = (1–5) \cdot 10^{-4}$.

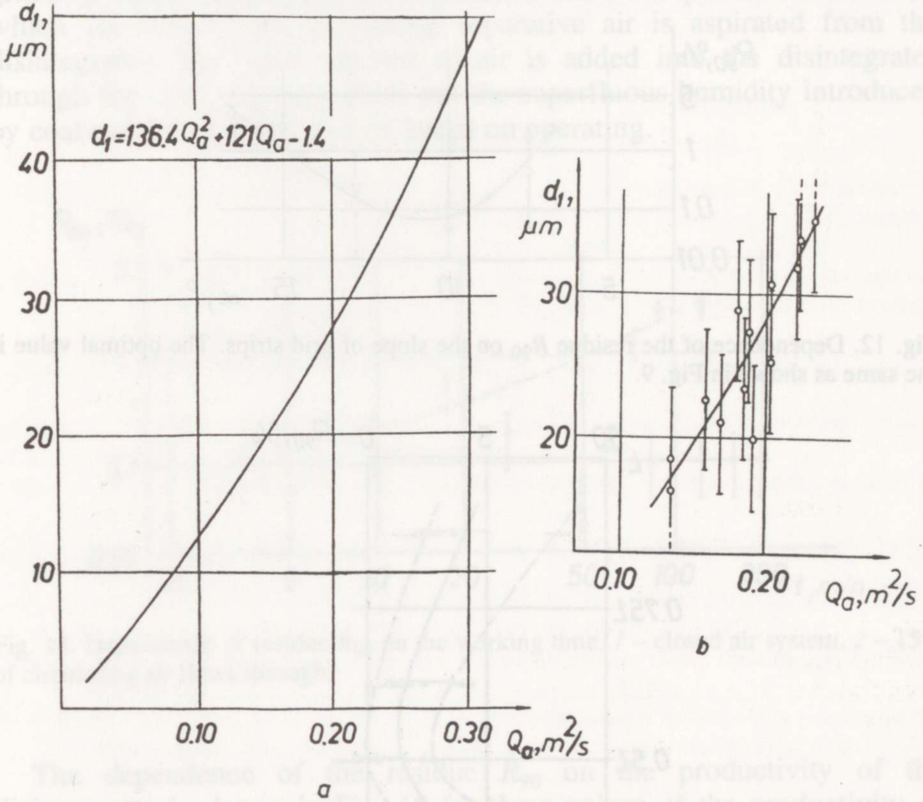

Fig. 10. Dependence of the size of bound particle on the air velocity in the grid slit for coal: *a* – theoretical dependence; *b* – experimental results with DSL-38.

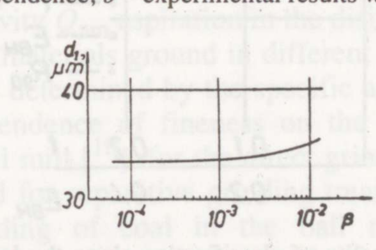

Fig. 11. Dependence of the size of bound particle on voluminal concentration of particles in the air. The ordinary concentration is less than $\beta < 10^{-3}$.

QUALITY OF THE PRODUCT

The quality of the product is determined by the parameters such as (i) the size of an average particle of the material, (ii) the upper limit of the particle size of the material. The quality of the classifier [7] is determined by such parameters as (i) the sharpness t of classification and (ii) the efficiency of separation E_{BH} (the Barski-Hankock coefficient) [7].

The upper limit of the particle size is measured by the residue R_d on the sieve with meshes of d μm. The dependence of coal residue R_{90} on the slope of strips according to the theory and our experimental results are shown in Fig. 12. The dependence of the residue on the slope of the strips is similar to the dependence of the size of a boundary particle shown in Fig. 9. The optimal values of the slope of strips are the same too.

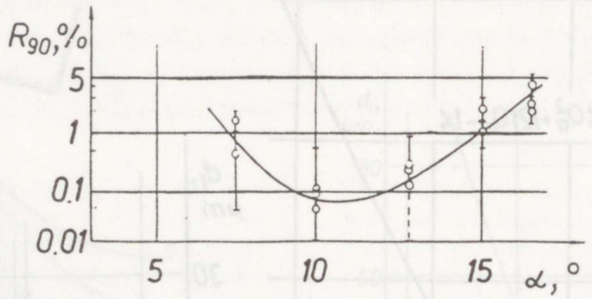

Fig. 12. Dependence of the residue R_{90} on the slope of grid strips. The optimal value is the same as shown in Fig. 9.

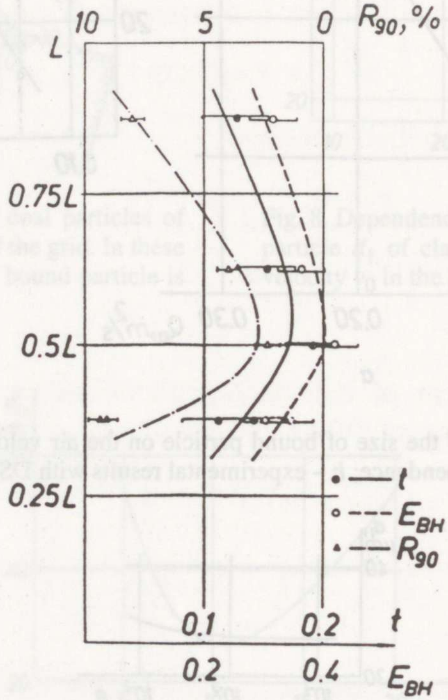

Fig. 13. Variability of the quality of classification along the longitude of the grid. t – parameter of sharpness of separation, E_{BH} – Barski-Hankock coefficient, R_{90} – residue on the sieve with the meshes of 90 μm.

The quality of classification along the longitude of the grid may change. Fig. 13 shows the dependence of the quality of the classifier on the length of the grid. The quality of classification is better in the central section of the grid and worse at the ends. Fig. 13 shows the importance of accurate aerodynamic design at the ends of the grid.

The dependence of coal residue R_{90} on the treatment time in the disintegrator DSL-38 is shown in Fig. 14. The dash line corresponds to the closed air system. The material entering for treatment brings in some moisture that remains in the air circulation system. When the humidity of the circulating air increases, the superfluous moisture condenses on the strips, the coarse particles brake on the water film, they lose their velocity and the amount of rough particles in the product increases, while the grinding quality decreases. The continuous line corresponds to the case in which 10–15% of the circulating separative air is aspirated from the disintegrator. The same amount of air is added into the disintegrator through the inlet. The air carries out the superfluous humidity introduced by coal and the grinding system keeps on operating.

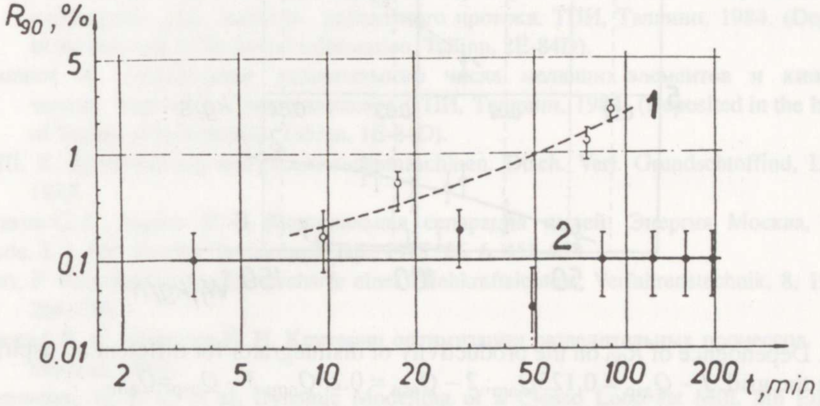

Fig. 14. Dependence of residue R_{90} on the working time. *1* – closed air system, *2* – 15% of circulating air flows through.

The dependence of the residue R_{90} on the productivity of the disintegrator is shown in Fig. 15 for three values of the productivity of separative air Q_{asp} aspirated through the grid. The productivity of separative air Q_{asp} represents here a certain fraction of the possible maximum productivity Q_{am} aspiration in the disintegrator DSL-38.

The fineness of materials ground in different units is compared in Fig. 16. The fineness is determined by the specific area S_{sp} m^2/g of coal. Fig. 16 shows the dependence of fineness on the consumption of specific energy E_0 for a ball mill [10], for the direct grinding in DSL-38 with two different rotors and for separative grinding treatments. The curves (*1*, *2*) showing the grinding of coal in the ball mill are given only for information. These can not be compared with the other curves because of the difference in the coals used. Curves *3–5* show the results of grinding the same coal in the disintegrator DSL-38 by direct and separative grinding.

In direct grinding the specific energy that is released to the unit of material by the five-row rotor is about twice greater than the specific energy released by the three-row rotor. Although the results are about the same (curves *3* and *4*).

The separative grinding with low energy consumption produces the same product as in direct grinding. The separative grinding gives a higher specific surface area (i.e. the finer product) as compared with the direct grinding with higher energy consumption.

We can conclude that the direct grinding method of coal is preferable if the needed specific area is less than 0.4 m^2/g. For receiving a higher specific area the separative grinding is preferable.

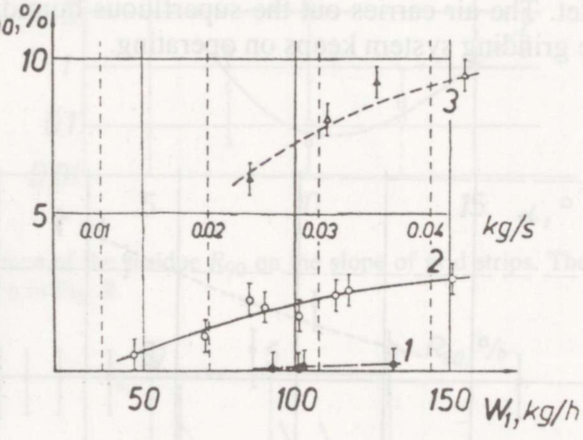

Fig. 15. Dependence of R_{90} on the productivity of disintegrator for different air aspiration through the grid: *1* – $Q_{asp} = 0.125 Q_{am}$, *2* – $Q_{asp} = 0.25 Q_{am}$, *3* – $Q_{asp} = Q_{am}$.

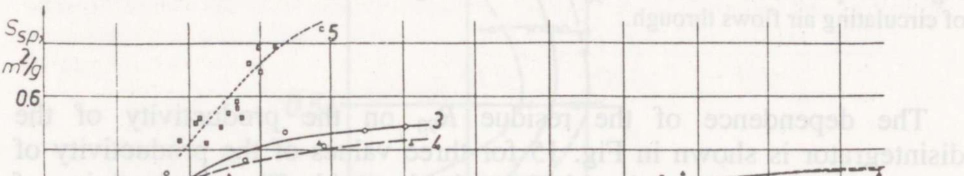

Fig. 16. Dependence of specific surface area S_{sp} on the specific energy consumption E_0: *1*, *2* – a ball mill [4], *3*, *4* – DSL-38 direct grinding with three and five row rotors, correspondingly, *5* – DSL-38 under the condition of separative grinding.

CONCLUSION

1. The present study shows some properties of the separative grinding of materials in an inertial classifier for relatively low pressure drop in the grid of classification.

2. The theory serves as a basis for designing a disintegrator series using air pressure and air and material kinetic energy from rotors for the transportation and classification of the material. The designed system operates on a low pressure drop and needs neither additional compressor, nor fans, nor filters.

3. The data obtained in this study help to design and produce a new DS series of grinding equipment that would operate under the conditions of: (i) – direct grinding, (ii) – separative grinding, (iii) – selective grinding or (iv) – selective-separative grinding.

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ÕHU JA MATERJALI SEGU LIIKUMINE DESINTEGRAATORIS

Aleksei TÜMANOK, Jaan TAMM, Andrus ROES

Desintegraator on jahvatusagregaat, mis purustab materjali osakesi põrkemeetodil. Töödeldud materjali ja õhu (inertgaasi) segu väljub desintegraatorist ja suunatakse torujuhtme kaudu klassifikaatorisse, mis töötab inertsiaalprintsiibil. Siinne artikkel vaatleb segu liikumist klassifikaatoris, milles toimub suurte ja väikeste osakeste eraldamine inertsiaalmeetodil. Väikesed osakesed koos õhuga suunatakse valmis produkti ja suured osakesed suunatakse kordustöötlusele. Käesoleva uurimistöö baasil on loodud DS-tüüpi desintegraatorite seeria.

ДВИЖЕНИЕ СМЕСИ ВОЗДУХА И ЧАСТИЦ В ДЕЗИНТЕГРАТОРЕ

Алексей ТЮМАНОК, Яан ТАММ, Андрус РОЭС

Дезинтегратор – измельчитель, который разрушает частицы материала соударением при высоких скоростях. Он состоит из двух роторов, вращающихся в противоположные стороны. Роторы содержат диски с концентрически расположенными кругами и мелющими элементами. В дезинтеграторе образуется смесь измельчаемого материала и воздуха (инертного газа), смесь движется по трубопроводу и поступает в классификатор инерциального типа. В работе проведено исследование классификации частиц по крупности в классификаторе типа жалюзи при малых перепадах давления на решетке. Разработана ДС серия дезинтеграторных установок, которые могут работать в режимах прямого, сепарационного, селективного и селективно-сепарационного измельчения.