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METHOD OF DEFINING DISPERSED COMPOSITION OF POWDER MATERIAL BY UNIFLOW CYCLONE STAGE

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At powdered burning of fine-dispersed solid fuel the behaviour of particles of different size in dust- and ash extraction devices are not the same. To make a justified choice and correct estimation of gas purification systems operation the data about dispersed composition of the extracted product are necessary. The technique allowing operative calculation of fractional composition has been developed. The obtained results and the data of dispersed analysis obtained by the other method are compared. Stable solution showing the possibility of using the method in defining dust dispersity from 10 to 50 mkm is obtained.

On-line test of dispersed material breakup containing in gases is required at torch burning of milled solid fuel in heat-generating devices of different type industrial enterprises on stages of preparation, powdered fuel pneumatic transport, and also on the areas of furnace gases ash-treatment at diagnostics and adjustment of technological and dust-collecting equipment. There are different methods of defining powder materials dispersed composition [1, 2], however, all these methods require carrying out preliminary preparation of powder samples. On the basis of experimental research of dust collection efficiency by uniflow cyclone stage and analysis of these devices operation the new method of powder materials dispersed analysis has been developed using serially set uniflow cyclones and deciphering of dust collection results by solving inverse coefficient problem at spontaneous selection of powder-gas mixture from technological equipment.

The method of serially set countreflow cyclones is developed by S.S. Yankovskiy and N.A. Fuks [2]. It does not require preliminary deposition of studied dust and allow carrying out powder dispersed analysis immediately at particles trapping from powder – gas flow. Nomograms of dust carryovers and parameters at which graduation of counterflow cyclones was carried out are presented in [2]. When collecting dust at different gas rates in cyclones or at different dust density an additional graduation of the device and recalculation of experiment results for real density of powder material are required, that, in its turn, results in inaccuracy of defining dust dispersed composition and requires additional time for obtaining results. In the given paper the method of defining dust dispersed composition by means of three serially set uniflow cyclones is developed which allows carrying out powder dispersed analysis at whatever its density and without program construction [3]. The matter of the method is as follows. Powder-gas flow of the researched powder is passed through the stage of three serially set cyclones and a filter and mass of collected powder by each cyclone and filter is determined according to the difference of bins and filters weights before and after the experiment. Density of researched powder is preliminary determined.

Summary dust breakthrough in the stage $K_{\Sigma_{123}}$ is defined as ratio of dust mass trapped by filter ΔG_{mf}, equals to the difference of filter weights after the experiment G_{f2} and before the experiment G_{f1} and mass of powder material passed through the cyclone during the experiment, which may be taken as sum of powder weights, trapped by each cyclone ΔG_{m1}, ΔG_{m2}, ΔG_{m3} and filter ΔG_{mf}. So

$$K_{\Sigma_{123}} = \frac{\Delta G_{m\phi}}{\Delta G_{m_1} + \Delta G_{m_2} + \Delta G_{m_3} + \Delta G_{m_\phi}}.$$

Total coefficient of breakthrough of the first, second and third cyclones set in the stage is defined according to the formulas

$$K_{\Sigma_1} = \frac{\Delta G_{m_2} + \Delta G_{m_3} + \Delta G_{m_\phi}}{\Delta G_{m_1} + \Delta G_{m_2} + \Delta G_{m_3} + \Delta G_{m_\phi}},$$

$$K_{\Sigma_2} = \frac{\Delta G_{m_3} + \Delta G_{m_\phi}}{\Delta G_{m_2} + \Delta G_{m_3} + \Delta G_{m_\phi}}, \quad K_{\Sigma_3} = \frac{\Delta G_{m_\phi}}{\Delta G_{m_3} + \Delta G_{m_\phi}}.$$

Total efficiency of dust collecting of *j* cyclone in the stage is defined from the ratio

$$\eta_{\Sigma_j} = 1 - K_{\Sigma_j}.$$

The data of used rate of powder-gas flow, powder material density, dynamic gas viscosity, diameter of uniflow cyclones and total effectiveness of dust collecting by uniflow cyclones are stored into computer.

Determination of powder breakup, passed through the stage of two cyclones [4], is in application of *J* functional minimum by simplex method, being a sum of squares of dust collection efficiency difference.

$$J = \sum_{i=1}^{q} \sum_{j=1}^{3} (\eta_{p_j} - \eta_{\Sigma_j})^2 \to 0, \tag{1}$$

where q is the number of rates in the experiment; η_{p_j} is the estimated values of dust collection efficiency by *j* cyclones in the stage, calculated according to the formula

$$\eta_{p_j} = 1 - \int_0^{\infty} g_0(\delta) \prod_{j=1}^{3} K_{\delta_j} d\delta, \tag{2}$$

where $g_0(\delta)$ is the weighing differential function of particles size distribution, to describe which the lognormal law is used [5], valid for many industrial dusts

$$g_0(\delta) = \frac{1}{\delta\sqrt{2\pi}\ln\sigma} \cdot e^{-\frac{(\ln\delta - \ln\delta_{50})^2}{2\ln^2\sigma}}, \tag{3}$$

δ is the current size of the particles, mkm; σ is the dispersity; δ_{50} is the mass-median size of the particle, mkm; K_{δ_j} is fractional coefficient of dust breakthrough of j uniflow cyclone in the stage, which is defined by the dependence [6]

$$K_\delta = e^{-A_{\text{us}}\text{Stk}^N}, \qquad (4)$$

where A_{uc} is the experimental coefficient, which should be determined. This coefficient should be selected according to equality condition of estimated and experimental values of breakthrough integral coefficient with following obtained results smoothing at all experimental points; Stk$=\tau V_0/d_0$ is the accelerative Stokes number; $\tau=\rho_m\delta/18\mu$ is the time of dynamic relaxation of δ size particles; ρ_m is particle density; μ is dynamic viscosity of purified gas; V_0, d_0 is the gas flow rate and cyclone diameter respectively.

Stokes N number exponent was specified by the ratio [6]:

$$N = \frac{n+1}{2(2-n)}. \qquad (5)$$

where n is the constant in the particles resistance law

$$\xi = \frac{A}{\text{Re}_\delta^n}, \qquad (6)$$

where Re_δ is Reynolds number of particle streamline in rotating gas flow in [6] was defined by the dependence

$$\text{Re}_\delta = \left(\frac{48}{A}\sqrt{18\frac{\rho}{\rho_m}\text{Re}\cdot\text{Stk}^3}\right)^{\frac{1}{2-n}}, \qquad (7)$$

where A is the constant in the particles resistance law (5); ρ is gas density; Re$=V_0d_0/\nu$ is Reynolds number; ν is the coefficient of kinematic gas viscosity.

The analysis of experimental data showed that particles more than 20 mkm are trapped by the cyclone virtually completely and selection of resistance law is not important for them, and for particles from 5 to 20 mkm the (7) eqn. solution gives the range of Reynolds numbers of particle Re_δ streamline form 1 to 10, for which the coefficient of particles resistance in the flow (6) may be calculated at constants A=26,3 and n=0,8. Therefore, for these conditions, according to ratio (5), we obtain

$$N = \frac{0{,}8+1}{2(2-0{,}8)} = 0{,}75.$$

Thus, by experimental integral values K_Σ dependence for fractional coefficient of breakthrough was recovered

$$\eta_\Sigma = 1 - \int_0^\infty K_\delta g_0(\delta)d\delta,$$

where fractional breakthrough K_δ is defined by the formula (4). So, only one constant A_{dc} for each direct flow cyclone in the stage should be defined. The influence of raised particles concentration in a gas flow on dust collection efficiency, occurring at experiments carrying out, was taken into account at recalculation according to the dependence [5]

$$K_\Sigma = \frac{K_{\Sigma_э}}{1+1{,}2\cdot10^{-3}Z_{\text{in}}\lg(0{,}1Z_{\text{in}})},$$

where $K_{\Sigma_э}$ is the experimental value of breakthrough coefficient at raised total concentration of dust particles at the device input Z_{in}, g/m^3.

Individual cyclone operation may be descried by exponential dependence of breakthrough fractional coefficient on accelerative Stokes number [7, 8] (4). At known experimental constants in this formula, cyclones stage may be used as a device for dust breakup defining.

The operation of the stage of uniflow cyclones may be presented as follows (fig. 1). Dust with known particles size distribution $g_0(\delta)$ enters the first stage device, for example, for the lognormal distribution law (3), δ_{50} and σ should be known values.

Mass-median size for normalize function of particles size distribution per unit $g_0(\delta)$ is introduced by [5]

$$\int_0^{\delta_{50}} g_0(\delta)d\delta = \frac{1}{2} \text{ or } \int_{\delta_{50}}^\infty g_0(\delta)d\delta = \frac{1}{2}.$$

The dispersity for the lognormal law of size particles distribution may be defined from the ratios

$$\sigma = \frac{\delta_{50}}{\delta_{16}} \text{ or } \sigma = \frac{\delta_{84}}{\delta_{50}},$$

where δ_{16} and δ_{84} are defined by [5]

$$\int_0^{\delta_{16}} g_0(\delta)d\delta = 0{,}16 \text{ and } \int_0^{\delta_{84}} g_0(\delta)d\delta = 0{,}84.$$

The first cyclone in the stage traps dust with the efficiency

$$\eta_{\Sigma_1} = 1 - \int_0^\infty K_{\delta_1} g_0(\delta)d\delta,$$

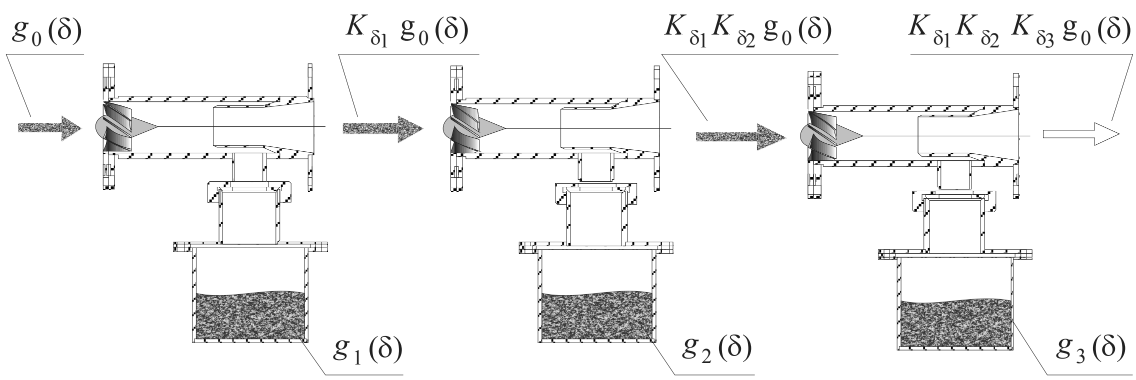

Fig. 1. *The scheme of uniflow cyclone stage operation*

where K_{δ_1} is calculated by the formula (5), in this case, in the bin of the first cyclone trapped dust should have distribution $g_1(\delta)$, and omitting by the cyclone – $K_{\delta_1}g_0(\delta)$.

At known K_{δ_1} and $g_0(\delta)$ it is possible to define

$$g_1(\delta)=(1-K_{\delta_1})g_0(\delta).$$

Thus, dust with distribution equals to $K_{\delta_1}g_0(\delta)$ enters the second cyclone and in its bin there is dust with distribution

$$g_2(\delta)=(1-K_{\delta_2})K_{\delta_1}g(\delta).$$

Knowing particles size distribution in initial dust $g_0(\delta)$ and function form of breakthrough fractional coefficient K_{δ_1} and integral efficiencies of dust collecting by individual cyclones in the stage (4), obtained experimentally, constants A_{dc} for fractional coefficient of breakthrough of every cyclone in the stage may be selected.

According to the stated method, the program «Dispersion» is made, which has been tested by artificially generated parameters of dust. The error of search was not more than 0,1 %. Reproduced fractional coefficients of individual uniflow cyclones breakthrough, serially set in the stage and breakup of dust, entered and trapped by individual cyclones, are showed in fig. 2 and 3.

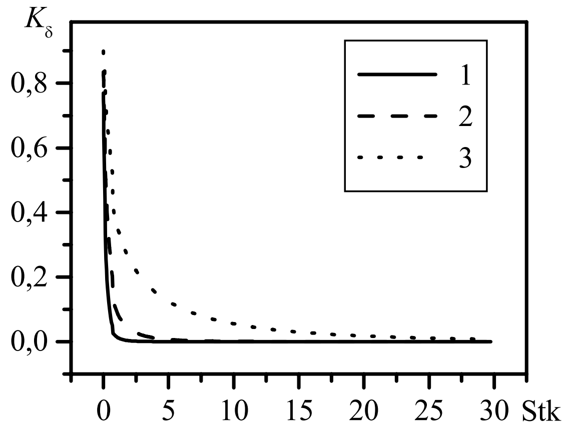

Fig. 2. *Fractional coefficients of cyclones breakthrough in the stage: 1) K_{δ_1}; 2) K_{δ_2}; 3) K_{δ_3}*

To describe the investigated powder by the dependence (3) two constants should be known: δ_{50} and σ. These magnitudes value should be selected by the formula (2) turning the functional (1) to zero. To solve this problem, i.e. to define two constants in lognormal law of size distribution of researched material particles, use of two uniflow cyclones is enough. Using the third dust collector in the stage increases accuracy of obtained result. Automatic search may be carried out, for example, by Nelder-Mied simplex method [7].

The concept of the method is in comparison of function value in (z+1) vertices of simplex and simplex displacement in the line of optimal point with the help of iterative procedure. In the simplex method, originally proposed, regular simplex was used at every stage. Nelder and Mied suggested several modifications of this method. As a result, very safe method of direct search, being one of the most effective, if $z\leq 6$, was obtained. Simplex is displaced by means of three main procedures: reflection, tension and contraction. Coefficients of reflection, tension and contraction are recommended to be taken as α=1, β=0,5 and γ=2 correspondingly. Recommendations are based on the results of the experiments with different combinations of values. These values of the parameters allow the method to be effective and work safely in various difficult situations.

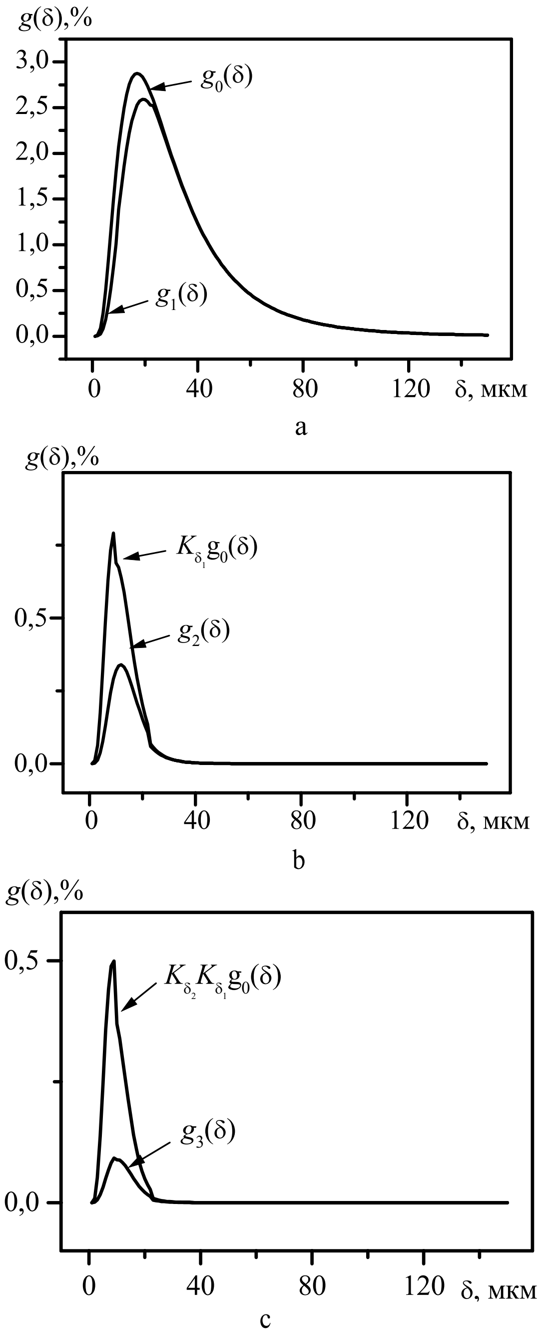

Fig. 3. *Fractional composition of entered and trapped dust. Cyclones: a) first; b) second; c) third*

The developed program «Dispersion» was used for defining lognormal law of particles distribution according to the size of modeling quartz with the parameters δ_{50}=26,16 mkm, σ=1,93, ρ_m=2650 kg/m^3. The parameters were obtained by the method of three serially set

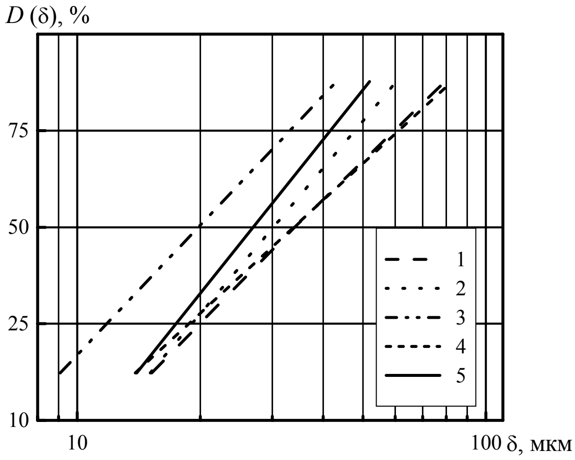

Fig. 4. *Particles distribution according to modeling dust size at V_0, m/s: 1) 6,0; 2) 7,0; 3) 8,0; 4) 10,0; 5) the parameters are defined by the method of liquid sedimentation*

uniflow cyclones with the diameter d_0=0,046 m with 8-blading impeller with blade slope angle 45° to the cyclone axis. Time of quartz sand milling was chosen from the conditions of dispersity support of obtained powder close to ash carryover dispersity at burning mineral carbon in powdered state in swirling-type furnaces of thermal stations. The results of numerical searches are presented in fig. 4, where $D(\delta)$ is the integral function of lognormal law of δ size distribution of particles.

The spread of modeling dust decoded parameters is explained by low stability of cyclones operation in the laboratory stage. The inverse problem, realized in the program «Dispersion», refers to the type of false ones, for which the condition of stability may not be fulfilled, i.e. errors in initial data may result in disproportionate growth of mistake. In the range of gas velocity in the cyclones from 6,0 to 11,0 m/s at deciphering of powder breakup the stable solution has been obtained, fig. 4. The given method may be used when dusts dispersed composition defining for on-line control of mode of operation of heat-and-power engineering equipment.

The stage of three uniflow cyclones is used for defining dispersed composition of solid powder materials at Tomsk plant DSP OOO «Tomlesderev», for controlling dusty emissions at OOO «Sibpromventilyaziya» (Tomsk) and for defining dusty emissions breakup in drying units of ZAO «Tomsk plant of ceramic materials and goods».

REFERENCES

1. Kouzov P.A. Basis of analysis of industrial dusts and milled materials dispersed composition. – Leningrad: Chemistry, 1974. – 280 p.
2. Kouzov P.A., Skryabina L.Ya. Methods of defining industrial dusts physicochemical properties. – Leningrad: Chemistry, 1983. – 143 p.
3. Pat. 2273019 RF. IPC^7 G01N 15/02. Method of defining dispersed composition of powder materials / M.I. Shilyaev, A.M. Shilyaev, V.S. Rekunov et al. Reported 05.10.00; Published 27.03.06. Bul. № 9 (II p) – 11 p.: il.
4. Shilyaev A.M., Rekunov V.S., Naumkin A.B. To the method of serielsy installed small-sized cyclones of defining powders breakup // Architecture and construction. Science, education, technologies, market: Theses of the report of International scientific and technical conference 11—12 Sept. 2002: Breakup group «Production of high grade constructional materials and goods, development of alternative, environmentally safe technologies in building industry». – Tomsk, TSACU Press, 2002. – P. 87—88.
5. Reference book on dust- and ash collecting / Edited by A.A. Rusanov. – Moscow: Energy, 1975. – 296 p.
6. Shilyaev A.M., Rekunov V.S. Application of diffusion-convection equation for calculation of the process of dust particles extraction from turbulent gas flow in direct-flow cyclone // XIV School-seminar of young scientists and specialists under the direction of academician A.I. Leontiev of RAS. – Rybinsk, 2003. – P. 335–338.
7. Shilyaev M.I., Dorohov A.R. Methods of calculation and principles of positioning of dust collecting equipment. – Tomsk: TSACU Press, 1999. – 209 p.
8. Shilyaev M.I. et al. Energy principle of dust collecting equipment resistance and positioning. Purification and neutralization of furnace gases from installations, burning waste and rubbish // Collection of scientific and technical paper. – Novosibirsk: Thermal Physics Institute SD RAS, 1999. – P. 167–169.
9. Bandi B. Optimization techniques. Introduction course. – Moscow: Radio and communication, 1988. – 128 p.

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