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OPTIMIZATION OF THE OPERATING-DESIGN PARAMETERS OF A COMBINED DUST SEPARATOR

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The hydrodynamics of a combined dust separator designed by us on the basis of mathematical planning of an experiment has been investigated. Computational relations for determining the dependence of the ratio between the total pressure losses in this apparatus and their minimum value, the hydraulic-resistance coefficient in it, and the efficiency of dust suppression in the centrifugal-separation chamber at the filtration stage and in the combined dust separator on its operating-design parameters were obtained. Optimization of the indicated separator has been performed. Optimum ranges of change in the operating-design parameters of the combined dust separator at which a high efficiency of dust suppression is provided at a minimum hydraulic resistance were determined. KP-350-10 and KP-400-10 combined dust separators have been developed and introduced at the Krasnyi Mozyryanin Public Company.

Introduction. At industrial enterprises, fine-dust particles are usually separated in two-stage dust-separation systems consisting of, e.g., a cyclone (I stage) and a bag filter (II stage). However, these systems have disadvantages influencing their use in practice, such as a large specific quantity of metal, large overall dimensions, and a high expenditure of energy. Therefore, a promising direction is the application of combined dust-separation equipment, in the energy field of which several types of dust separation are combined. Filter cyclones are combined dust-separating apparatus that have enjoyed the widest application in the food industry; however, these apparatus have a significant disadvantage — in them, bag filters are installed in the zone of centrifugal separation. As a result, a gas executing a rotary-translatory motion is transferred to the filtration stage with a high concentration of dust particles, because, due to the vortices arising in the zone where bag filters are installed and the separation of dust particles, including large ones, from the near-wall region, the separated material enters the gas flow. This deteriorates the working characteristics of the filtration material of the bag filters and the apparatus as a whole.

To eliminate the indicated deficiencies, we have designed a combined dust separator, in which a centrifugal-force field formed by two counter flows is used as the first separation stage and a gas is additionally purified from fine-fraction particles in the process of its filtration through a series of bag filters installed around the centrifugal-separation chamber [1–3].

Investigation of the Hydrodynamics of a Combined Dust Separator. The combined dust separator developed by as differs radically from other analogous apparatus in that, in it, suspended particles are collected in a centrifugal-force field in the system of two interacting flows swirled in one direction and moving to meet each other and a gas is additionally purified by filtration [3–6]. We fabricated a laboratory KP-150-1.36 combined dust separator with a centrifugal-separation chamber of diameter 0.15 m and a filtration partition of area 1.36 m^2. The diameter of the body of the apparatus is equal to 0.45 m and its height is 1.4 m.

For the purpose of investigating the hydrodynamics of the apparatus developed, mathematical planning of an experiment was performed by the Box–Wilson plan 2^3 + star with two experiments at the center of the plan and a star-shoulder value of $\alpha = 1.284$ [7]. The output functions were the ratio between the total pressure losses in the apparatus and their minimum value $\Delta P_0/\Delta P_{\min}$ ($\Delta P_{\min}$ corresponding to the smallest pressure loss in the range of factors being investigated), the hydraulic resistance coefficient ζ of the apparatus, and the efficiency of dust separation η in the centrifugal-separation chamber at the stages of filtration and in the combined dust separator [8, 9].

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On the basis of these investigations, we selected the following varying factors: an operating parameter — the flow-rate ratio $k = 0.35$–0.75 — and two design parameters — the ratio between the diameter of the exhaust pipe of the centrifugal-separation chamber and the diameter of the chamber $d_{\text{e.p}}/D_{\text{c}} = 0.46$–$0.74$ and the ratio between the diameter of the bag filter and its height $d_{\text{b}}/h_{\text{b}} = 0.1$–$0.14$.

Experimental results were processed using a package of applied programs for mathematical and statistical analysis of the STATGRAPHICS Plus data. The adequacy of the regression equations was estimated by the Fisher criterion with a confidence probability of 0.95.

We were the first to obtain, after elimination of insignificant factors, the computational relations for determining the ratio between the total pressure losses in the combined dust separator and their minimum value

$$\frac{\Delta P_0}{\Delta P_{\text{min}}} = 9.15 - 4.5k - 10.17\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} - 19.3\cdot\frac{d_{\text{b}}}{h_{\text{b}}} + 6.2k^2 - 2.9k\frac{d_{\text{e.p}}}{D_{\text{c}}} + 7.25\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 , \qquad (1)$$

the hydraulic-resistance coefficient in this separator

$$\zeta_0 = 831.1 - 548.5k - 941.2\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} - 1595.8\cdot\frac{d_{\text{b}}}{h_{\text{b}}} + 538.9k^2 + 576.3\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 , \qquad (2)$$

in the centrifugal-separation chamber

$$\zeta_1 = 518.9 - 484.3k - 949.1\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} + 617.1k^2 - 253.7k\frac{d_{\text{b}}}{h_{\text{b}}} + 697.4\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 \qquad (3)$$

and at the filtration stage

$$\zeta_3 = 812.2k + 1454.4\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} + 72421.1\cdot\frac{d_{\text{b}}}{h_{\text{b}}} - 738.3k^2 - 1212\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 - 25533.8\left(\frac{d_{\text{b}}}{h_{\text{b}}}\right)^2 - 4809.5 , \qquad (4)$$

as well as the efficiency of dust separation in the combined dust separator

$$\eta_0 = 94.1 + 5.2k + 12.9\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} - 3.87k^2 - 9.8\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 \qquad (5)$$

and in the centrifugal-separation chamber

$$\eta_1 = 293.5k + 1101.2\cdot\frac{d_{\text{e.p}}}{D_{\text{c}}} - 200.6k^2 - 982.6\left(\frac{d_{\text{e.p}}}{D_{\text{c}}}\right)^2 - 319.2 . \qquad (6)$$

Graphs of the ratio between the total pressure losses in the combined separator and their minimum value, the hydraulic-resistance coefficient in the apparatus, and the efficiency of dust separation in the separator, in the centrifugal-separation chamber, and at the filtration stage versus k, $d_{\text{e.p}}/D_{\text{c}}$, and $d_{\text{b}}/h_{\text{b}}$ (Figs. 1–3) were constructed in the three-dimensional space. The least-significance factor was taken as a constant.

It was established that the dependences of $\Delta P_0/\Delta P_{\text{min}}$ (Fig. 1) and the hydraulic-resistance coefficient of the combined dust separator developed by us and of the centrifugal-separation chamber (Fig. 2a and b) on the operating and design parameters of this separator are of the same type in character. Their minimum values fall within the ranges $k = 0.35$–0.65 and $d_{\text{e.p}}/D_{\text{c}} = 0.55$–$0.74$ at $d_{\text{b}}/h_{\text{b}} = 0.14$ and comprise $\Delta P_0/\Delta P_{\text{min}} = 1.1$ (Fig. 1), $\zeta_0 = 87$ (Fig. 2a), and $\zeta_1 = 16$ (Fig. 2b). It is assumed that the factor $d_{\text{b}}/h_{\text{b}}$ takes a maximum value from the interval because, in this case, the area of the filtration surface is increased and, consequently, the hydraulic resistance is decreased. The flow-rate ratio, determined as the ratio between the volumetric rate of flow of the gas supplied through the peripheral inlet pipe and the rate of the total gas flow passing through the apparatus ($k = V_1/V_0$, $V_0 = V_1 + V_2$), and the ratio between

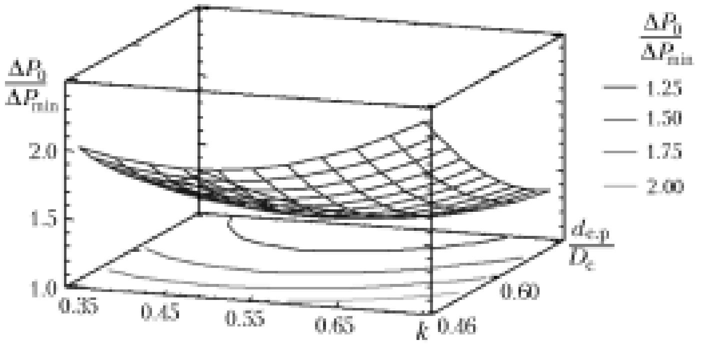

Fig. 1. Dependence of the ratio between the total pressure losses in the KP-150-1.36 combined dust separator and their minimum value on k and $d_{e.p}/D_c$ at $d_b/h_b = 0.14$.

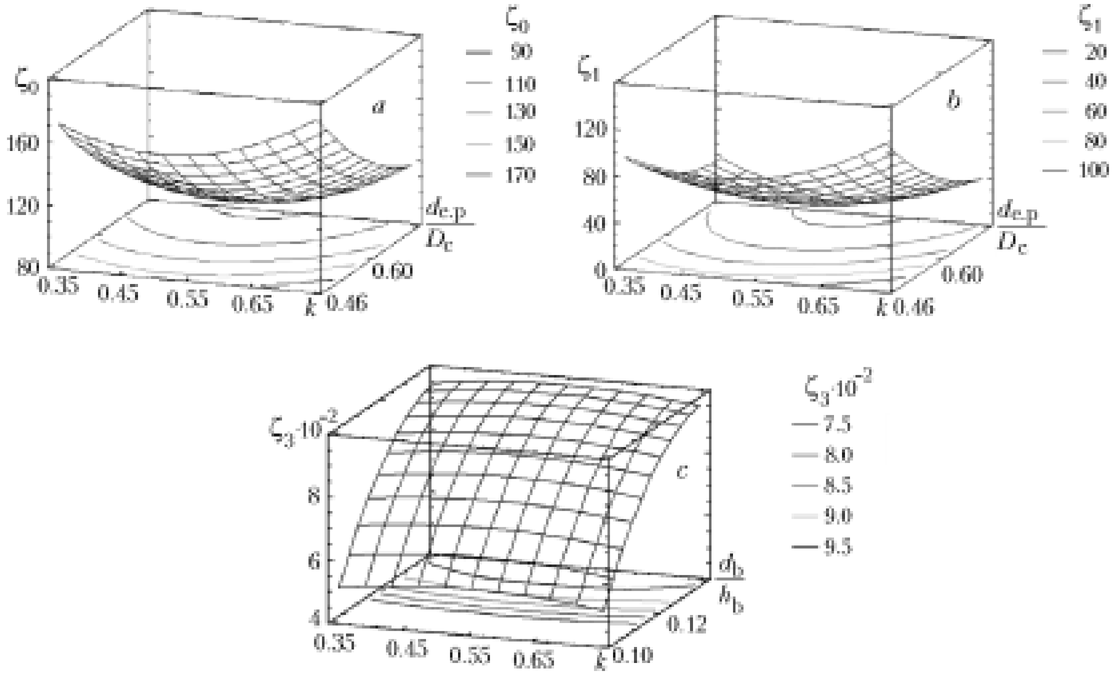

Fig. 2. Change in the hydraulic-resistance coefficient depending on the dust-separation stages in the KP-150-1.36 combined dust separator (a), in the centrifugal-separation chamber (b) at $d_b/h_b = 0.14$, and at the filtration stage (c) at $d_{e.p}/D_c = 0.6$.

the diameter of the exhaust pipe of the centrifugal-separation chamber and the diameter of the chamber do not have a pronounced effect on the hydraulic-resistance coefficient at the filtration stage ζ_3 (Fig. 2c). This is explained by the fact that the whole gas flow, independently of the value of k, is subjected to afterpurification at the filtration stage characterized by the ratio between the diameter of the bag filter and its height; $d_{e.p}/D_c$ is a design parameter of the centrifugal-separation stage.

The dependence of the efficiency of separation of fine-fraction yeast particles in the combined dust separator on its operating-regime parameters has been experimentally investigated. It was established that the total efficiency of separation of yeast particles in the apparatus reaches maximum values: $\eta_0 = 99.9\%$ (Fig. 3a), and, for the centrifugal-separation chamber, $\eta_1 = 96.6\%$ (Fig. 3b) at $k = 0.6$–0.75, $d_{e.p}/D_c = 0.55$–0.65, and $d_b/h_b = 0.14$. Analysis of the results obtained shows that, because of the high degree of purification of a gas at the centrifugal-separation

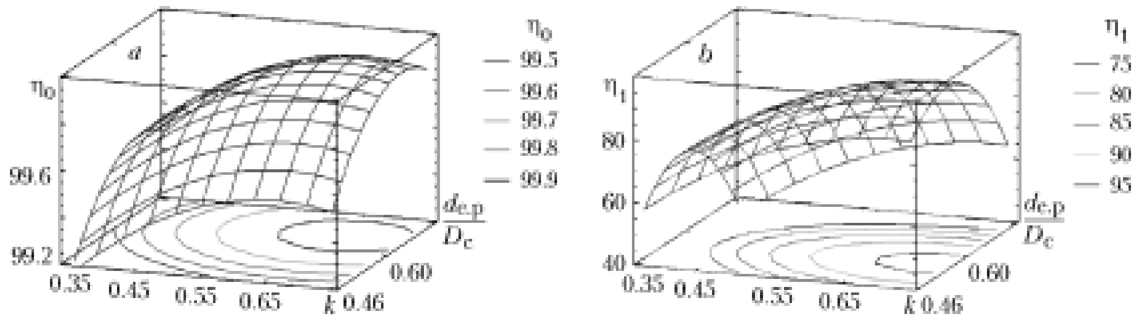

Fig. 3. Dependence of the efficiency of dust separation on k and $d_{e.p}/D_c$ at $d_b/h_b = 0.14$ in the centrifugal-separation chamber (a) and in the KP-150-1.36 combined dust separator (b). η, %.

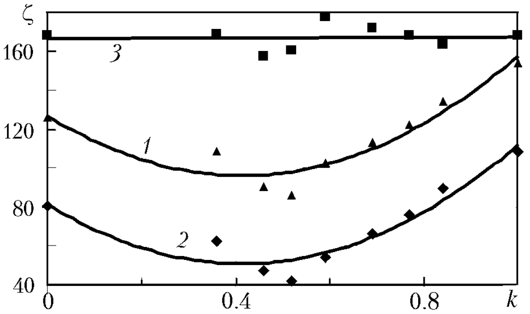

Fig. 4. Dependence of the hydraulic-resistance coefficient on the flow-rate ratio at $d_{e.p}/D_c = 0.6$ and $d_b/h_b = 0.14$ at a total-gas-flow rate $V_0 = 0.111$ m^3/sec: 1) combined dust separator; 2) centrifugal-separation chamber; 3) filtration stage.

stage, the dust load decreases at the filtration stage, which leads to an increase in the total efficiency of the combined dust separator.

Optimization of the Operating and Design Parameters of the Combined Dust Separator. Optimization of the combined dust separator being investigated, performed on the basis of simultaneous consideration of the dependences shown in Figs. 1–3 on condition that a high efficiency of dust separation is provided at a minimum hydraulic resistance, allowed us to determine optimum intervals of change in the operating and design parameters of this separator: $k = 0.6$–0.65, $d_{e.p}/D_c = 0.55$–0.65, and $d_b/h_b = 0.12$–0.14.

Based on Eqs. (1), (5), and (6), we wrote a goal function and obtained a solution with the use of the superstructure "Retrieval of solution" in the Microsoft Excel program on condition that this function tend to a maximum value in the range of change of the operating-design parameters being investigated. We obtained the values of $k = 0.62$, $d_{e.p}/D_c = 0.6$, and $d_b/h_b = 0.14$, corresponding to the optimum intervals of the varying factors; in this case, $\Delta P_0/\Delta P_{min} = 1.42$, $\eta_0 = 99.98\%$, and $\eta_1 = 92.2\%$.

Figure 4 shows the dependences of the hydraulic-resistance coefficient of the combined dust separator, the centrifugal-separation chamber, and the filtration stage on the flow-rate ratio at $d_{e.p}/D_c = 0.6$ and $d_b/h_b = 0.14$. In our experiments, the total gas flow through the combined dust separator was equal to 0.111 m^3/sec. It was established that, in the interval $k = 0.4$–0.65, the hydraulic-resistance coefficients of the dust-separation stages take minimum values. This is consistent with the results obtained earlier and confirms their reliability.

Since the working characteristics of the combined dust separator proposed depend on the gas-flow rate ratio k, it may be suggested that this dust separator is an apparatus with a controlled hydrodynamics. The results obtained in the present work were used for development of a method of engineering calculating combined-type apparatus.

Development and Introduction of Industrial Dust Separators. On the basis of theoretical and experimental investigations of the hydrodynamics of a combined dust separator and optimization of its operating-regime parameters,

Fig. 5. Combined dust separator of type KP-350-10 introduced into the aspiration system of line No. 1 for production of marshmallow at the Krasnyi Mozyryanin Public Company (Narovlya).

we have developed a KP-350-10 combined dust separator (Fig. 5) with a centrifugal-separation chamber of diameter $D_c = 0.35$ m and a filtration surface of area $S_f = 10$ m^2 (the apparatus is designed for a total flow rate of a gas of $V_0 = 2100$ m^3/ h) and a KP-400-10 combined dust separator ($D_c = 0.4$ m, $S_f = 10$ m^2, $V_0 = 3000$ m^3/ h) and introduced them into the aspiration system for separation of castor-sugar particles in line Nos. 1 and 2 for production of marshmallow at the Krasnyi Mozyryanin Public Company (Narovlya). Reports of production tests and introduction of the indicated dust separators have been obtained.

CONCLUSIONS

1. The hydrodynamics of a combined dust separator has been investigated with the use of the Box–Wilson plan 2^3 + star. The relations for calculating the ratio between the total pressure losses and their minimum value in the apparatus, the hydraulic-resistance coefficient, and the efficiency of dust separation in the combined dust separator, in the centrifugal-separation chamber, and at the filtration stage have been obtained.

2. Optimization of the combined dust separator developed has been performed on condition that a high efficiency of dust separation be provided at a minimum hydraulic resistance. The following optimum ranges of change in the operating and design parameters of the combined dust separator were obtained: $k = 0.6$–0.65, $d_{e.p}/D_c = 0.55$–0.65, and $d_b/h_b = 0.12$–0.14.

3. Combined dust separators of type KP-350-10 and KP-400-10 have been developed and introduced into the systems for aspiration of castor-sugar particles in line Nos. 1 and 2 for production of marshmallow at the Krasnyi Mozyryanin Public Company (Narovlya). Reports of production tests and introduction of the indicated separators have been obtained.

NOTATION

D_c, diameter of the centrifugal-separation chamber, m; $d_{e.p}$, diameter of the exhaust pipe of the centrifugal-separation chamber, m; d_b, diameter of the bag filter, m; h_b, height of the bag filter, m; k, flow-rate ratio; ΔP_0, total pressure losses in the apparatus, Pa; ΔP_{min}, minimum value of the total pressure losses in the apparatus in the range of factors investigated, Pa; S_f, filtration surface, m^2; V_i ($i = 1, 2, 0$), volumetric rate of gas flow through the peripheral and central branch pipes, rate of total gas flow through the apparatus, m^3/sec; α, value of the star shoulder; ζ_i ($i = 1$, 3, 0), hydraulic-resistance coefficient in the centrifugal-separation chamber, at the filtration stage, and in the combined dust separator; η_i (i = 1, 0), efficiency of the dust separation in the centrifugal-separation chamber and in the combined dust separation. %. Subscripts: e.p, exhaust pipe; c, chamber; b, bag filter; f, filtration; min, minimum.

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