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INVESTIGATION OF THE HYDRAULIC RESISTANCE OF A COMBINED DUST COLLECTOR

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A new structure of a combined dust collector, in the unified energy field of which suspended particles are separated in interacting swirling flows, with subsequent aftercleaning of the gas by filtration has been developed. The hydraulic resistance of the combined dust collector has been investigated. The change in the pressure loss as a function of the total rate of flow of the gas in the apparatus and the flow-rate ratio has been determined. The dependence for calculation of the hydraulic resistance of this dust collector has been obtained.

Inertial gas collectors, mechanical and electric filters, and apparatuses whose action is based on the use of thermal, magnetic, diffusional, acoustic, and other mechanisms of deposition and their different combinations are used in aspiration and pneumatic-transport systems at enterprises of the food industry and other industries of the national economy [1, 2]. The most widespread are inertial apparatuses for dry and wet cleaning of the gas from dust; preference is given to dry dust collectors.

Among the existing principles of inertial dust collecting, the most efficient and perfect is that of separation of dust in the centrifugal field. Cyclones in which this technique is realized are representative of the most widespread dust-collecting equipment at present. They are easy to manufacture, operate, and maintain.

The required efficiency of cleaning of gases in collection of a coarse fraction (30–40 μm) is ensured in cyclones. In separation of a fine dust, particularly when its concentration is high, they act as the apparatus of precleaning of the gas and are used as the first stage of a gas-cleaning unit.

The technique of separation of suspended particles in swirling counterflows enables one to overcome the energy level of centrifugal cleaning of gases in a traditional cyclone. Numerous vortex dust collectors different in structure and having a number of advantages over cyclones have been created based on it [3–8]. However, in collection of particles less than 8 μm, the efficiency of cleaning of the gas in vortex gas collectors is reduced.

Combined dust collectors — filter cyclones — and dust-collecting systems consisting of two or more apparatuses placed in series are used at enterprises of the food industry to isolate a fine dust from a gas flow. Inertial dust collectors of differential structures are used as the first stage of cleaning. At the final stage, filters are placed for fine cleaning of the gas. Such systems ensure the required efficiency but are characterized by a large specific quantity of metal and a high energy consumption, most of which is accounted for by the filters. This is attributed to their structural complexity, the limited service life of the filter material, and the necessity of regenerating it [9, 10].

Filter cyclones are less metal-intensive. However, the dust load on the filter cloth in the cyclone remains fairly large at the first stage because of the comparatively low efficiency of collecting of dust.

We have developed a fundamentally new structure of a combined dust collector in which centrifugal separation of suspended particles is carried out in a system of two interacting flows swirling in one direction and moving in opposition with subsequent aftercleaning of the gas by filtration (Fig. 1) [7, 11, 12].

Clearly, the use of the separation chamber of vortex dust collecting as the element of the first stage of cleaning ensures a high efficiency of separation of dust for a comparatively low hydraulic resistance. The dust load on the filter cloth is reduced, which makes it possible to increase the rate of filtration.

To more completely use the energy of the flow swirl in redistribution of the gas after the separation stage we have installed hoses made of filter cloth around the vortex-dust-collecting chamber.

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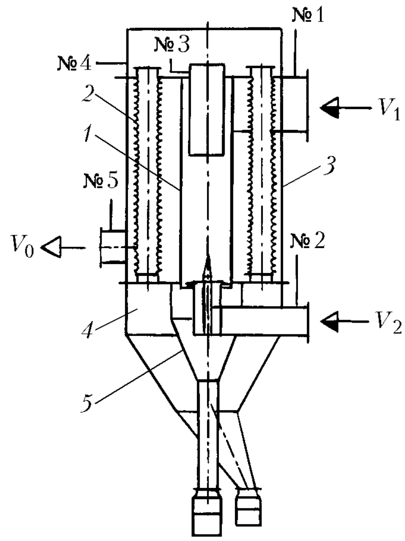

Fig. 1. Schematic diagram of a combined dust collector: 1) separation chamber of vortex dust collecting; 2) filter element manufactured in the form of hoses; 3) frame of the combined dust collector; 4) bunker of a fine fraction; 5) bunker of a coarse fraction.

For the gas flows supplied to a combined dust collector, we write the energy-balance equation [4, 12, 13]

$$\Delta P V_0 = [(P_1 + \rho w_1^2/2) - (P_3 + \rho w_3^2/2)]\, V_1 + [(P_2 + \rho w_2^2/2) -$$

$$- (P_3 + \rho w_3^2/2)]\, V_2 + [(P_3 + \rho w_3^2/2) - (P_5 + \rho w_5^2/2)]\, V_0 \, . \quad (1)$$

The indices correspond to the cross sections (marked in Fig. 1 (Nos. 1–5)) of the combined dust collector.

Representing the differences of the total pressures in (1) as ΔP_1, ΔP_2, and ΔP_3 respectively and dividing the expression by the total flow rate of the gas V_0, we obtain the dependence for calculation of the pressure loss of the combined dust collector in general form:

$$\Delta P = \Delta P_1 V_1 / V_0 + \Delta P_2 V_2 / V_0 + \Delta P_3 \, . \quad (2)$$

Applying the relations $V_0 = V_1 + V_2$ and $k = V_1 / V_0$ to (2), we obtain

$$\Delta P = k \Delta P_1 + (1 - k)\, \Delta P_2 + \Delta P_3 \, . \quad (3)$$

When the dust-laden gas is supplied only to the peripheral (primary) branch pipe ($V_0 = V_1$), Eq. (2) yields

$$\Delta P = \frac{1}{k} \left[k \Delta P_1 + (1 - k)\, \Delta P_2 \right] + \Delta P_3 \, . \quad (4)$$

In the case where the dust-laden gas is supplied only to the central (secondary) branch pipe ($V_0 = V_2$), dependence (2) takes the form

$$\Delta P = \frac{1}{1 - k} \left[k \Delta P_1 + (1 - k)\, \Delta P_2 \right] + \Delta P_3 \, . \quad (5)$$

It has been established that the hydraulic resistance of the filtration stage is determined from the dependence [10, 14, 15]

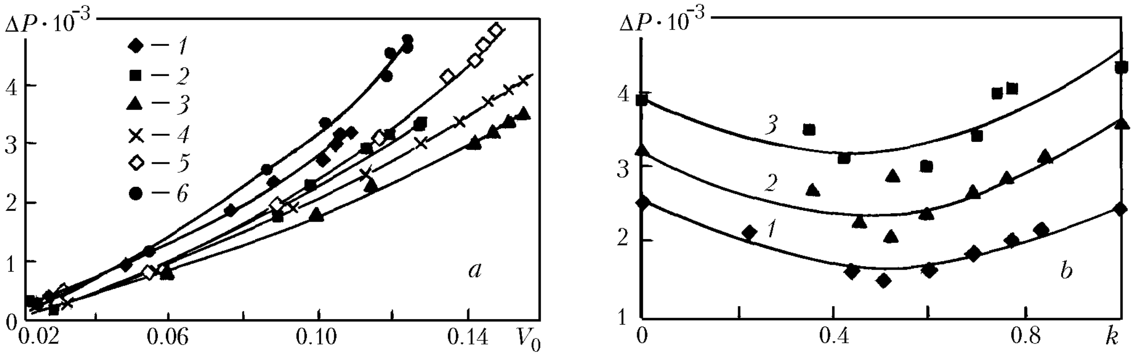

Fig. 2. Pressure loss ΔP of the combined dust collector vs. total flow rate of the gas V_0 (a) [1) $k = 0.22$, 2) 0.39, 3) 0.53, 4) 0.60, 5) 0.69, and 6) 0.83] and flow-rate ratio k (b) [1) $V_0 = 0.083$, 2) 0.111, and 3) 0.138 m^3/sec]. ΔP, Pa.

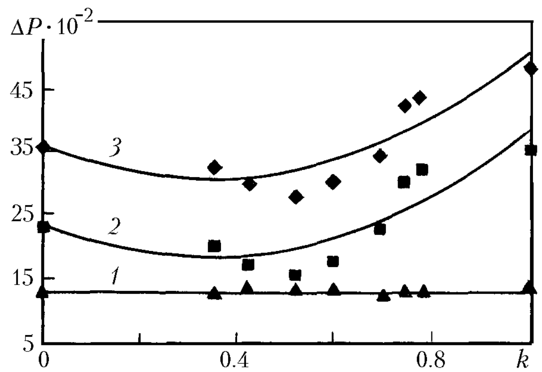

Fig. 3. Pressure loss ΔP vs. flow-rate ratio k for the total flow rate of the gas $V_0 = 0.138$ m^3/sec: 1) filtration stage; 2) separation stage; 3) combined dust collector. ΔP, Pa.

$$\Delta P_3 = \Delta P_{\text{loc}} + \Delta P_{\text{f}} + \Delta P_{\text{d.layer}} \,. \tag{6}$$

The investigations have shown that the value of the local resistances at the filtration stage is insignificant as compared to the resistance of the filter baffle [15]. Consequently, we have

$$\Delta P_3 = \mu \, (K w_{\text{f}} + K_{\text{d.layer}} \tau z_{\text{in}} w_{\text{f}}^2) \,. \tag{7}$$

Substituting (7) into (3), we obtain the calculated dependence of the pressure loss of the combined dust collector:

$$\Delta P = k \Delta P_1 + (1 - k) \, \Delta P_2 + \mu \, (K w_{\text{f}} + K_{\text{d.layer}} \tau z_{\text{in}} w_{\text{f}}^2) \,. \tag{8}$$

We have manufactured a prototype of a KP-150-1.36 combined dust collector and have created a laboratory setup. The diameter of the frame of the apparatus is 0.45 m, whereas its height is 1.4 m. Twelve hoses of total filtration area 1.36 m^2 are installed around a centrifugal-cleaning chamber of diameter 0.15 m and height 0.6 m [12, 13].

Investigations were carried out according to the procedure of the Scientific-Research Institute of Gas Cleaning with the combined dust collector brought to the operating regime after multiple regeneration of the hoses made of IFPZ-1 needl-epunched filter cloth (specifications 17-14-45-77) [9, 13]. We have determined the values of the dynamic pressure in the range of total flow rate of the gas $V_0 = 0.083$–0.155 m^3/sec. The results of the experiment have been processed and systematized.

In collecting fine formula-feed products, such as phosphates, we have experimentally determined for IFPZ-1 the coefficient characterizing the resistance of the filter baffle with the dust layer left on it $K = (4.4$–$4.8) \cdot 10^8$ m^{-1} and

TABLE 1. Values of the Basic Specifications of Dust Collectors of Different Types

Specifications	Cyclones		Vortex dust collectors		Hose filters		KP-150-1.36 combined dust collector
	SKTsN-34	UTs-38	VSKP-200	VZP-200	FRKN5VU-01	FROS-13.5-500	
V_0, m^3/sec	0.138	0.138	0.138	0.138	0.140	0.138	0.138
D_{ch}, m	0.32	0.43	0.2	0.2	—	—	0.15
S_f, m^2	—	—	—	—	5	13.5	1.36
w_{pl}, m/sec	1.72	0.95	4.5	4.5	—	—	7.8
w_f, m/min	—	—	—	—	1.7	0.61	6.15
ζ	1150	957	126	45	—	—	86
ΔP, Pa	2041	518	1530	547	1800	2500	3250
η, %	—	—	99.33	99.2	—	—	99.96
k	—	—	0.65	0.65	—	—	0.65
M, kg	28	32	20	25	435	1100	85

the coefficient of resistance of the dust layer $K_{d.layer} = (0.8–1.6)\cdot10^9$ m/kg [15]. The pressure losses in the combined dust collector as functions of the total flow rate of the gas have been plotted for different flow-rate ratios k. It has been noted that the dependences have a square-law form, and the pressure loss in the combined dust collector increases less intensely with flow rate for $k = 0.53$ (Fig. 2a).

The dependences of the pressure loss on the flow-rate ratio for constant flow rates of the gas (Fig. 2b) have a parabolic form, and their minimum values fall within the range $k = 0.4–0.65$. The pressure loss increases with total rate of flow of the gas in the apparatus.

We investigated the pressure loss at the stages of separation and filtration and its relation in the total hydraulic resistance of the combined dust collector (Fig. 3). It has been established that the pressure loss at the filtration stage in the steady-state operating regime of the apparatus developed is independent of the flow-rate ratio. The reason is that, as k changes, the gas flow rate in filtration remains constant, and consequently the filtration rate is invariant.

The experiments on determination of the efficiency of collecting phosphates in the combined dust collector have shown that the efficiency of separation of suspended particles amounts to 99.90–99.96% in the range $k = 0.5–0.8$ for this material.

A joint analysis of the optimum ranges of the flow-rate ratio for the pressure loss and the collecting efficiency enables us to infer that for $k = 0.5–0.65$ the apparatus ensures a high degree of separation of suspended particles with a low hydraulic resistance. What this means is that the KP-150-1.36 dust collector developed is an apparatus with a controlled hydrodynamics and the possibility of controlling its operating regime depending on the physical and chemical properties of the product collected [15–17].

Table 1 compares the specifications of dust-collecting equipment of different types with a gas flow rate of 0.138 m^3/sec [3, 10, 14, 17, 18].

The advantage of a combined dust collector over hose filters is an increase of more than 3.5 times in the filtration rate due to the reduction in the concentration of dust in the gas flow arriving at the filter material at the separation stage. The specific quantity of metal of the apparatus significantly decreases.

CONCLUSIONS

1. Based on the equation of energy balance of the gas flows supplied to the combined dust collector developed, we have obtained the dependence for calculation of the pressure loss.

2. A series of experimental investigations on study of the hydrodynamics of the apparatus has been carried out. The range of optimum values of the flow-rate ratio $k = 0.5–0.65$ has been established.

3. The KP-150-1.36 dust collector may be recommended for use at enterprises of the food industry and in other industries where it is necessary to ensure high-efficiency collection of fine particles from air.

NOTATION

D_{ch}, diameter of the separation chamber of vortex dust collecting, m; K, coefficient characterizing the resistance of the filter baffle with the dust layer left on it, m^{-1}; $K_{d.layer}$, coefficient of resistance of the dust layer, m/kg; k, flow-rate ratio; M, mass of the apparatus, kg; ΔP, total pressure loss, Pa; P_i (i = 1, 2, 3, and 5), static pressure at the inlets of the peripheral and central flows, of the gas cleaned at the first stage, and at the outlet from the apparatus, Pa; ΔP_i (i = 1, 2, and 3), pressure loss of the peripheral and central flows, at the filtration stage, Pa; ΔP_{loc}, pressure loss by local resistances, Pa; ΔP_f, resistance produced by the filtration surface and the dust layer left on it after regeneration, Pa; $\Delta P_{d.layer}$, resistance of the layer of dust accumulated in the process of filtration in the period between regeneration of the hoses, Pa; S_f, filtration surface, m^2; V_i (i = 1, 2, and 0), volumetric rate of flow of the gas in the peripheral and central branch pipes and total rate of flow of the gas in the apparatus, m^2/sec; w_{pl}, planned air velocity referred to the cross section of the vortex-dust-collecting chamber, m/sec; w_i (i = 1, 2, 3, and 5), average velocity of the gas of the peripheral and central flows, in the exhaust pipe of the separation chamber of vortex dust collecting, and at the outlet from the apparatus, m/sec; w_f, filtration rate, m/sec; z_{in}, concentration of the dust as it enters the filtration stage, kg/m^3; ζ, coefficient of hydraulic resistance of the dust collector; η, collecting efficiency of the apparatus, %; μ, dynamic viscosity of air, Pa·sec; ρ, density, kg/m^3; τ, duration of the filtration cycle, sec. Subscripts: in, inlet, entry; ch, chamber; loc, local; pl, planned; d.layer, dust layer; f, filtration.

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