The characteristic and separation effects in a cylindrical cyclone dust collector

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Abstract. A comparison of the level of circular velocities and velocities of turbulent transfer in a coaxial channel and a countercurrent cylindrical cyclone is performed. Comparison of dust separation efficiency in these apparatuses is made.

1 Introduction

Cylindrical cyclone chambers are used as technological devices for burning, melting, drying, high-temperature reactions [1-7], they are used as dust concentrators in gas cleaning systems [8, 9], in installations of dust removal of air of systems of aspirations [10, 11]. Technical characteristics on devices are efficiency of dust removal of gases, coefficient of hydraulic resistance of the device which causes the capacity of the purified gas. Efficiency is defined as the ratio of the amount of dust entering the cyclone to the amount of dust trapped by the cyclone over a fixed period of time.

There is a wide variety of devices with built-in elements forming coaxial channels with constant or variable cross-sections for separating particles from a swirling gas stream: cyclones of LIOP (Leningrad Institute of Labor Protection), Institute of Siindmashcoalenrichment [9], cyclone with intermediate dust extraction [12]. In the elements of battery cyclones, there is a stabilization section of the swirling flow, which is a coaxial channel, in which the particles are “pressed” to the periphery [13]. Calculations of the effects of dust separation in a coaxial channel along particle trajectories have shown that efficiency decreases with decreasing distance between cylinders. The existing results of the operation of cyclones are inconsistent when assessing their effectiveness in cleaning gases and, therefore, it is required to clarify the effect of hydrodynamic factors on the separation of particles. In [14], the turbulent motion of an aerosol in a coaxial channel is considered (Fig. 1).

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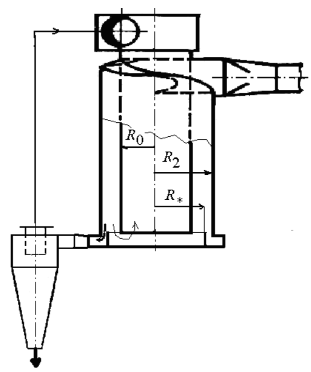

Fig. 1. Coaxial channel–1. Separation scheme with concentrator.

In the cylindrical part of the cyclone with an extended dip tube, the gas makes several revolutions in the coaxial channel, the variation in the flow parameters in the circumferential direction is insignificant and, on the whole, it is believed that the aerosol motion is axisymmetric. In [8], there are data on the optimum penetrations of the central branch pipe, from the point of view of separation efficiency, however, no physical justification is presented. The aim of the study is to distribute the circumferential velocities and to determine the separation efficiency for cylindrical cyclones with different coaxial channel lengths.

2 Experimental part

Measurement of speed and pressure in vortex chambers, associated with a significant disturbance of the flow of measuring equipment. The introduction of particles into the rotating flow leads to the deceleration of the tangential velocities, and the particle speed differs from the flow speed.

To investigate the causes of the disturbance and to determine their magnitude, studies were made of the errors of a radially injected pneumatic probe [14] in a chamber with an end-to-end injection. When the probe is inserted, the pressure on the chamber covers changes, which makes it possible to observe the influence of the probe on the vortex flow in the chamber.

The tangential speed in the vortex chamber is determined by the pressure gradient:

$$W_{\varphi}^{2} = \frac{R}{\rho}\frac{dp}{dR}\cdot \tag{1}$$

Methods based on the sounding of speed fields are laborious and require the introduction of corrective coefficients to eliminate the effect of the probe on the velocity field of the flow. In order for the influence to be negligible, it is necessary to have a probe surface less than 2 percent of the cross-sectional area of the chamber and no more than 10 percent of the cross-section of the gas outlet.

For example, in the experiments of Smulsky I.I. [14] a capillary with an outer diameter of 1.4 mm was installed, installed in the diametrical direction of the chamber. For a chamber having a diameter of 160 mm and a diameter of the air outlet opening 29 mm in diameter, the ratio of the surface of the capillary to the exit area is $100\cdot1.4\cdot160/(29^2/4) =$ 106%.

Other methods based on use of thermo anemometers don't allow defining fields of pressure. Besides, the existing methods aren't suitable for sounding of the stream containing the weighed particles.

In the curvilinear channel distribution of district speeds in the radial direction differs from uniform at internal and external surfaces [15]. In this regard, quality standards of value of district speeds in the coaxial channel on measurement of pressure difference on the internal and external cylindrical surfaces of the coaxial channel have been carried out.

In Fig. 2 shows the measurement scheme

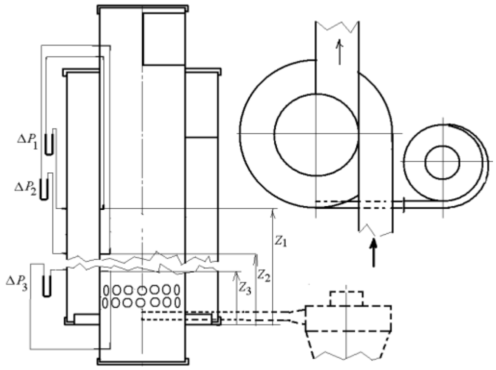

Fig. 2. Scheme of measurement of pressure differences.

The case of the cyclonic concentrator had a joint, allowing carrying out turn of section with an entrance branch pipe concerning unions of selection of pressure (fig. 3).

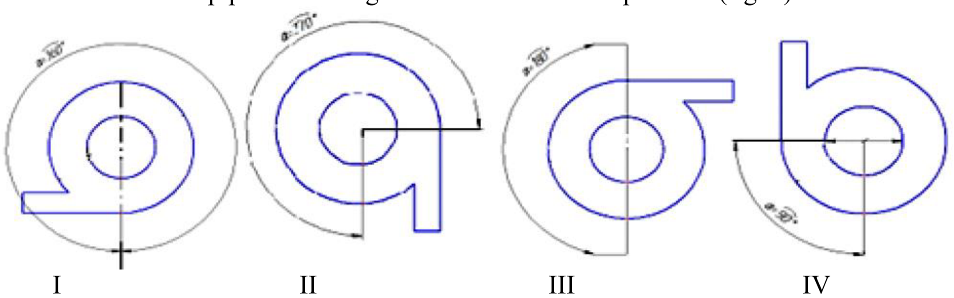

Fig. 3. Orientation of an entrance branch pipe concerning unions of selection of pressure (a vertical axis).

Water manometers were in inclined situation with a corner β to the horizon with coefficient $K=\sin\beta\approx0.1$. $\Delta P=(\Delta L\cdot K)\rho_f g\approx1.18\Delta L$ Pa, where ΔL − a difference of counting of position of meniscuses on scales of manometers in mm.

In fig. 4 the scheme of connection of devices is provided to an exhaust collector.

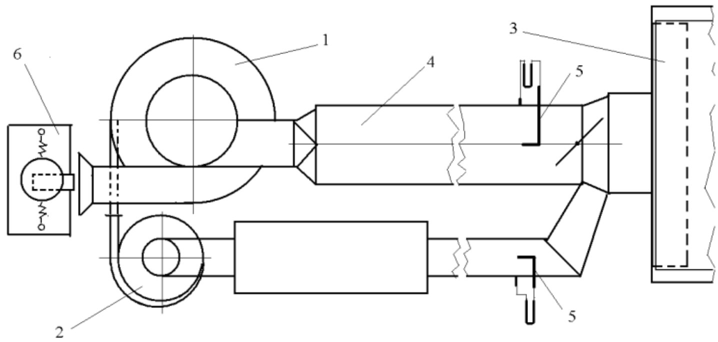

Fig. 4. The variant of the layout stand: 1 - investigated cyclone concentrator, 2 - remote dust collector, 3 - exhaust manifold with filter, 4 - connecting pipeline, 5 - flow meters, 6 - dust collector.

The air consumption through the cyclone-concentrator is calculated on a formula:

$$Q = 0.95F_Q\sqrt{\frac{\Delta P_Q}{\rho}} \approx 1.0F_Q\sqrt{\Delta L}\ (\mathrm{m^3/s}), \tag{2}$$

where F_Q - the area of the branch pipe, where the flow is measured Q, ρ - air density (ρ=1.2 kg/m^3). The input speed was calculated from the relation $W_{in}=1.22Q/F_{in.}$

The flow through the cyclone dust collector is 22% of the Q.

From formula (1), assuming that in the radial direction the circumferential component has a constant value, we obtain $W_\phi = \sqrt{\frac{\Delta P_i}{\rho \ln \frac{R_2}{R_0}}} \approx 1.09\sqrt{\Delta L}$, where ΔP_i (Pa) - The pressure difference between the outer and inner cylinders in the *i* section in Fig. 2. The effect of the solid phase was investigated by introducing a well-flowing, classified, alumina M100 powder (96% of 100 μm particles). The concentration of particles in the input stream was calculated using the formula $C=G_{in}/1{,}22Q$. Separation tests were carried out on brand 400 cement with a median size of particles δ_m =23 micron and the variance of the distribution lg σ= lg3.0=0.477. In such dust particles less than 7 μm contains 17%, particles less than 3 μm contain 4%.

The efficiency of separation of particles in the concentrator was determined by the formula $\eta_1 = \frac{G_{sed}}{G_{in}\eta_2}$, where G_{sed}, G_{in} - the amount of dust entering the cyclone concentrator and trapped in the cyclone dust collector 2. In this case, in Fig. 1 R_0= 50 mm, R_2=100 mm. Attitude R_0/R_2=0.5. Data of measurements and calculations are provided in table 1. Results of measurement of speeds of air when using of the classified large M100 alumina are given in the left columns. In the right column of table 1 are given efficiency in polydisperse cement dust.

In [16], a method is given for studying a counterflow concentrator with a small penetration of the inner tube, a spiral inlet, a bottom cylinder. In this case, experimental efficiency is also given for cement dust of grade 400. Calculations carried out using the technique with allowance for turbulent particle transport [17] showed their correlation with the experimental results. The efficiency of air dedusting proved to be more than 95%. From Table 1 it follows that the swirling flow is asymmetric, which manifests itself in the differences in speed when the inlet is turned relative to the measuring nipples. However, the efficiency of air dedusting depends little on the rotation of the inlet relative to the nozzles. And the efficiency calculated on trajectories of particles, has appeared much above, than measured. In [18], a hydrodynamic calculation of annular channels with continuous and local spiral swirls is presented. An estimate is made of the turbulent effective viscosity, which is orders of magnitude greater than the molecular viscosity. The effective viscosity is calculated from the ratio $\mu_{r\phi}^{ef} = \rho V^*(r) l(r)$ where ρ - density of gas, $V^*(r)$ - local dynamic speed, $l(r)$ - scale length of the transfer of turbulent moles, depending on the radial coordinate. At idealization of a real current on condition of prevalence of forces of inertia over viscosity forces in [18] the uniform screw stream for which solutions of distribution of speeds of gas are known is considered. The solutions include a parameter $K = \frac{2W_\phi R_2}{RW_z}$.

Table 1.

No scheme	No experience	C g/m^3	Win m/s	W1 m/s	W2 m/s	W3 m/s	Efficiency
I	1	0	17.8	9.0	9.9	14.0	Cement, C=0.6 g/m^3
	2	15	13.7	6.05	4.9	8.1	W_{in}=18 m/s, η_2=93%
	3	90	17.4	11.1	9.0	14.0	η_1=88%
II	1	0	18.1	19.3	14.9	8.1	Cement, C=0.6 g/m^3
	2	15	13.2	11.4	6. 7	5.5	W_{in}=18 m/s, η_2=93%
	3	90	14.6	13.1	6.6	5.6	η_1=89%
III	1	0	17.3	15.9	11.064	8.5	Cement, C=0.6 g/m^3
	2	15	13.0	9.0	6.02	5.41	W_{in}=18 m/s, η_2=93%
	3	90	16.3	8.05	6.05	5.3	η_1=84%
IV	1	0	16.6	14.8	11.064	13.0	Cement, C=0.6 g/m^3
	2	15	13.4	8.1	12.6	4.9	W_{in}=18 m/s, η_2=93%
	3	90	13.4	4.4	11.6	5.6	η_1=90%

In [16] the technique of a research of the counterflow concentrator with small deepening of an internal pipe, spiral input, the ground cylinder is given. At the same time experimental efficiency is also given for cement dust of brand 400. Calculations carried out using the technique with allowance for turbulent particle transport [17] showed their correlation with the experimental results. The efficiency of air dedusting proved to be more than 95%. Which determines the nature of the distribution of gas flow rates depending on the ratio R_0/R_2. When R_0/R_2=0.5 and K>6.4 gas flow in the axial direction on internal and external area of a stream are opposite. In [18] detailed distributions of components of speeds of gas for different values are given R_0/R_2 and K. Thus, in a coaxial channel turbulent mixing of gas moles in the radial direction and convective mixing in the axial direction occur.

When the flows in the lower part of the channel are divided into a flow into the central tube and the flow into the remote cyclone dust collector, the generation of turbulent vortices increases, which leads to an increase in the turbulent transfer speed. According to [19], the value of the turbulent transfer rate $V^* = \sqrt{W_{\phi 0} W_{r0}}$, где $W_{\varphi 0}$, W_{r0} - circumferential and radial speed of gas at a radius R_0. Estimates of the speed distribution over the channel height and in the lower part show that V^* is in the range 5–20 m/s, While in devices with a small depth of the central tube in the range 2–5 m/s. In [20] calculations of the efficiency are given for turbulent transport of particles.

3 Conclusion

In separators with tangential input and an elongated coaxial channel, the swirling flow is asymmetric, the tangential velocities are less important than the input speed and are not symmetrical, the separation of particles is effected by centrifugal forces and turbulent transfer, which plays a decisive role. A stabilizing role in the swirling flow of the cyclone is played by the spiral inlet and the device of the flow divider in the bottom part, in the area of concentrating the concentrate into a remote dust collector.

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