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SEPARATION OF PARTICLES IN SWIRLING FLOW IN COAXIAL CHANNEL

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Abstract. Cyclones are widely used devices to separate a dispersed phase (e.g. particles or droplets) from a continuous phase. The separation of particles in coaxial channels with different length is considered in paper. In this study we show that as coaxial channels length grows, the efficiency increases. In addition we demonstrate that as a gap between cylinder components is reduced, the aerosol spray efficiency is reduced also in turbulent flow.

There are a large variety of devices with add-in component that form coaxial channels with constant or variable cross-sections to extract particles from swirling flow: cyclone collector LIET, institute Hydromashugleobogaschenie [1], direct-flow cyclone with intermediate selection of dust (DCISD) [2]. In multi cyclone separator there are stabilized zone that is the coaxial channel, in which the swirling flow particles *are pressed* against the wall [3]. Gas purification efficiency has been estimated during the operation of cyclones with contradicting results. Obviously, it would be desirable to investigate the turbulent effect to the particle distribution. In turbulent flow the moving-transfer mechanism is the same as the mass-transfer mechanism therefore coefficient of gas turbulent diffusion can be equal to coefficient of turbulent viscosity ε. In paper [4] there are estimation of coefficient of gas turbulent diffusion as a function of particle size.

In paper [5] we are considered the turbulent aerosol spray moving in coaxial channels (Fig.1).

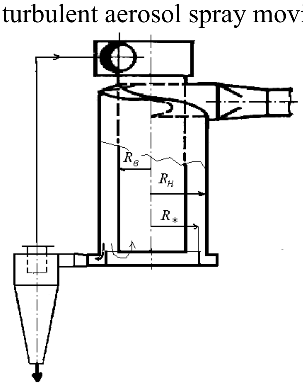

Figure 1. Scheme of the separator thickener – coaxial channels.

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In cyclone barrel with lengthened diptube the gas flow make several cycle in coaxial channel, accordingly the flow circumferential direction parameters change negligibly, and we could propose that the aerosol spray moving is axiosymmetrical.

In coaxial channel in swirling motion we can define the friction stress at the wall as total flow interreaction. The axial friction stress is determined by pressure difference. Contrariwise, the moving in tangential stress is in the form of wall jet flow with deceleration flow to this direction. The coefficient of strength (friction) flow in channel without mixing and the one with jet flow around surface are estimated by different methods. In the former case – in condition of equation of force that affect to uniformly moving gas (equilibrium friction forces and pressure drops). In the latter case– from the momentum equation [6]. The paper [7] repots about influence of external and internal cylinder bowing on friction factor to nonswirling flow. In paper [5] we showed the value of flow resistance factor to nonswirling flow of bowing surfaces in cyclone. In addition in [5] we estimated peripheral velocity distribution along the channel, and the coefficient of turbulent viscosity.

The motion equation for weak concentration of small particle that the whole crew are carried out by turbulent fluctuation, calculated as

$$\frac{W_\varphi^{\,2}}{R} = \frac{V_r}{\tau}, \quad V_z = W_z \qquad V_r = \Delta U, \tag{1}$$

where W_φ – periphery gas velocity, W_z – axial gas velocity, V_r – particle velocity in radial axis

In the case of turbulent flow the transfer equation images as

$$\frac{\partial}{\partial Z} R(\overline{CV_Z} + \overline{C'V'_Z}) + \frac{\partial}{\partial R} R(\overline{C}\overline{V_r} + \overline{C'V'_r}) = 0 \tag{2}$$

$$R\frac{\partial}{\partial Z}(W_Z C) + \frac{\partial}{\partial R} R\left(CV_r - \varepsilon\frac{\partial C}{\partial R}\right) = 0$$

In latter equation the sign smoothing is dropped опущен. Changing variablese in equations (1), (2) $R=rR_н$, $Z=tW_zR^2/\varepsilon$, $V_r=(\alpha/r)(\varepsilon/R_н)=\mathrm{Stk}W_{вх}/r$, (we can denote the nondimensional quantity $w=W_zH/\varepsilon$ – relative axial velocity), $H=R_н-R_в$; $Z=tW_zR_н^{\,2}/\varepsilon$; t– nondimensional quantity; $t=(Z/R_н)(H/R_н)/w)$; $C=cC_0$; we can calculate (2) as

$$r\frac{\partial c}{\partial t} = \frac{\partial}{\partial r} r\left(\alpha\frac{c}{r} - \frac{\partial c}{\partial r}\right) = 0 \quad \alpha=\mathrm{Stk}\cdot W_{вх}R_н/\varepsilon. \tag{3}$$

Whereas, there are no particle transferring in the boundaries (impenetratable wall), the total flow might be zero due to centrifugal effort and diffusive transfer.

The boundary and the initial conditions is calculated by following formulas

$$-\frac{\partial c(r_H,t)}{\partial r} + \alpha\frac{c(r_H,t)}{r_H} = 0 \qquad -\frac{\partial c(r_в,t)}{\partial t} + \alpha\frac{\partial c(r_в,t)}{r_в} = 0 \quad c(r,0)=c_0=1. \tag{4}$$

In equations (3), (4) the values α and t is obtained by ε that depend on Z in general. For another thing, the variation of α and W_φ must be taken, поскольку the latter specify inertial parameter $\mathrm{Stk}=W_\varphi\tau/R_н$. $\tau=(\rho_\delta/\rho)(\delta^2)/(18\nu_1)$, where ρ_δ, ρ – particle and gas density, accordantly, δ – particle diameter, ν_1– coefficient of kinematic viscosity. To solve this task we can apply the numerical calculation. In paper [5] we got analytical solution. We denote the values α and ε independent of Z for this purpose.

We define the separation process in barrel by following. We allocate the aerosol spray area ($r_в$, r_*), from which the whole particles are carry-over. The separation process is predicated upon the particles concentration in this area ($r_в$, r_*) decreases as the movement of the aerosol. The separation efficiency of the aerosol spray is determined by the formula

$$\eta = 1 - \frac{2\int_{r_{в}}^{r_{*}} \omega d r}{r_{*}^{2} - r_{в}^{2}} \tag{5}$$

Accordingly the investigation in [5] for flow without mixing $\eta_{l} = 1 - \frac{r_{*}^{2} - r_{в}^{2} - 2Stk t_{l}}{r_{*}^{2} - r_{в}^{2}}$, $t_{l} = W_{вх} Z / W_{z} R_{н}$.

For “unsteady” turbulent flow the aerosol spray efficiency is calculated numerically. For “steady” turbulent flow it is calculated by following formula

$$\eta = 1 - \frac{r_{*}^{2(\nu+1)} - r_{в}^{2(\nu+1)}}{1 - r_{в}^{2(\nu+1)}} \cdot \frac{1 - r_{*}^{2}}{r_{*}^{2} - r_{в}^{2}} \tag{6}$$

where we denote: $W_{\varphi} = W_{вх} = 20$ m/s ; $W_{z} = 4$ m/s; $\nu_{1} = 1{,}5 \cdot 10^{-5}$ m^{2}/s ; $R_{н} = 0{,}4$ m; $R_{в}/R_{н} = 0{,}6$; $\rho_{\delta}/\rho = 2800$.

Table 1 shows the concentration distribution of particle separation in coaxial channel.

In the table 2 we demonstrate the particle separation efficiency in coaxial channel depending on inner cylinder dimension at Stk=$10.5 \cdot 10^{-3}$ (R=0.4 м, Z=0.5R).

Table 1. The fractional particle separation efficiency in coaxial channel.

Particle size, mkm	1	5	10	15	20	30
turbulent flow	0.00875	0.222	0.7	0.944	0.994	0.9999
flow without mixing	0.011	0.283	1	1	1	1

Table 2. The particle separation efficiency in coaxial channel depending on inner cylinder dimension at Stk=10.5·10-3 (R=0.4 м, Z=0.5R).

$r_{1} = \bar{r}_{1} R$	0.4R	0.5R	0.7R
r_{1}, м	0.16	0.2	0.28
turbulent flow	0.245	0.229	0.193
flow without mixing	0.224	0.26	0.456

As the coaxial channels length is increased, the efficiency unintermitting grows, as distinguished from the real operation. As the gap between cylinder components is reduced, in turbulent flow the aerosol spray efficiency is reduced as well, in a radical departure from interspersion

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