[illegible] 16.07.2013 T/FM.02.02
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Content of the abstract of doctorial dissertation

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Докторлик диссертацияси мавзуси Ўзбекистон Республикаси Вазирлар Маҳкамаси ҳузуридаги Олий аттестация комиссиясида 12.05.2015/B2015.1.T463 рақам билан рўйхатга олинган.

Докторлик диссертацияси Тошкент давлат техника университети қошидаги тармоқ машинашунослик муаммолари илмий тадқиқот марказида бажарилган.

Диссертация автореферати уч тилда (ўзбек, рус, инглиз) веб-саҳифанинг www.tdtu.uz ҳамда «ZiyoNet» ахборот-таълим портали www.ziyonet.uz манзилларига жойлаштирилган.

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Диссертация автореферати 2016 йил «14» 07 куни тарқатилди.
(2016 йил «14» 07 даги 15 рақамли баённомаси).

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раиси, т.ф.д.

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[illegible] [illegible] II. «[illegible]» [illegible]

[illegible][1]. [illegible] NASA Glen research center, Boeing scientific reserch laboratories, Massachusetts institute of technology, Stanford university ([illegible]), Cambridge university ([illegible]), Hettingen laboratory ([illegible]), The Air Systems Research Center ([illegible]), China Aerodynamics Research and Development Center ([illegible]), [illegible] ([illegible]), [illegible]

[illegible] (Stanford university, Boeing scientific reserch laboratories, Massachusetts institute of technology, [illegible]); [illegible] (Cambridge university, [illegible]), [illegible] (Hettingen laboratory, [illegible]); [illegible] (The Air Systems Research Center, [illegible]); [illegible] (China Aerodynamics Research and Development Center, [illegible]), [illegible] ([illegible]).

[illegible] ; [illegible] ; [illegible] .

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[1] [illegible] http:/www.nasa.gov/centre/glenn/home/index.html; http://universal_ru_en.academic.ru/66921/; Wildes, Karl L.; Lindgren, Nilo A. (2005). A Century of Electrical Engineering and Computer Science at MIT, 2006-2009. Cambridge, Mass.: MIT Press. ISBN 9780262231190; Stuart W. Leslie: The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford. Columbia University Press, New York [u. a.] 1993, ISBN 0-231-07958-3; http://www.mod.go.jp/trdi/en/research/kenkyu_koukuu_en.hyml; University of Cambridge (ed.). "The Revived University of the Nineteenth and Twentieth Centuries" Retrieved 7 August 2014; http://www.utias.utoronto.ca; http://www.cards.cn:88; http://universal_ru_en.academic.ru/240165; [illegible] 1. 2. [illegible], 2000; [illegible], 2008. 480 [illegible] ISBN 5-02-007017-3; [illegible] 1971; [illegible], 2001, [illegible] 20; [illegible] 1987; Faizullaev D.F. Laminar motion of multiphase media in conduits.//Consultants bureau, New York, 2003 [illegible]

[illegible]

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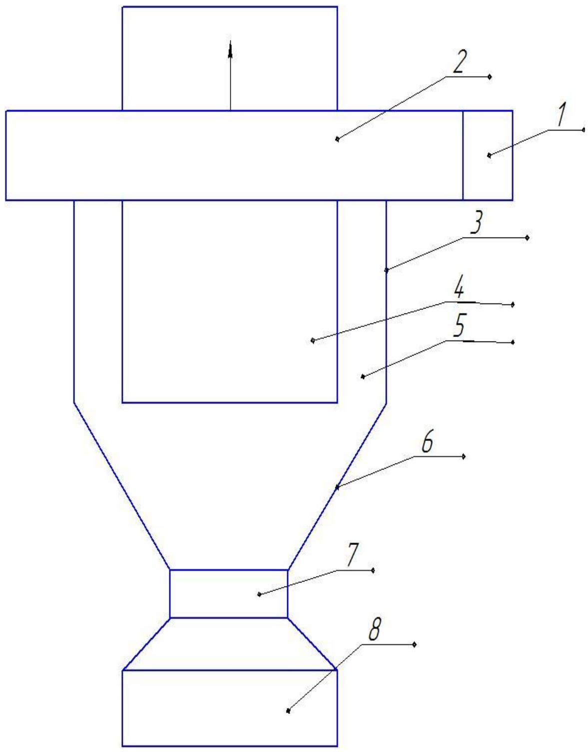
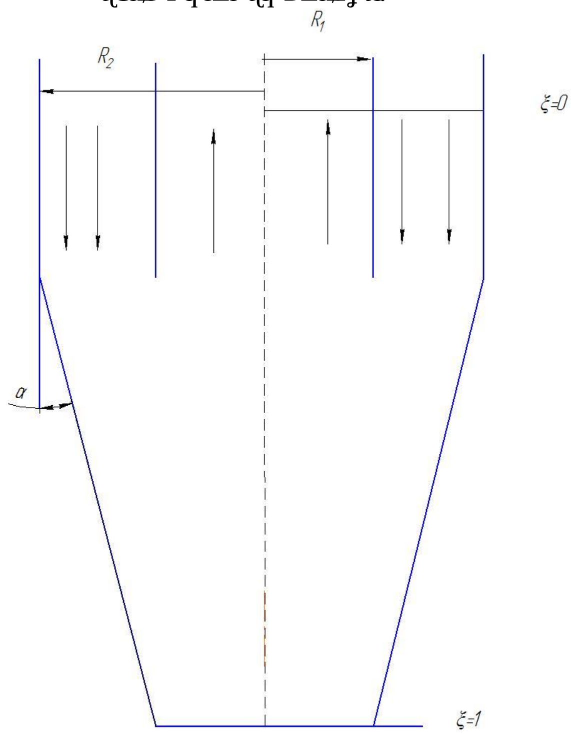


1-[illegible]:
1 – [illegible], 2 – [illegible], 3 – [illegible], 4 – [illegible], 5 – [illegible], 6 – [illegible], 7 – [illegible], 8 – [illegible]



2-[illegible]

[illegible] (z, r, φ) [illegible]

$$\begin{cases} \dfrac{\partial (r\upsilon_z)}{\partial z} + \dfrac{\partial (r\upsilon_r)}{\partial r} = 0, \\ \dfrac{\partial \upsilon_z}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_z}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_z}{\partial r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial z} = 0, \\ \dfrac{\partial \upsilon_r}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_r}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_r}{\partial r} - \dfrac{\upsilon_\varphi^2}{r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial r} = 0. \end{cases} \qquad (1)$$

[illegible] ψ, [illegible] ζ [illegible]:

$$\upsilon_r = -\frac{1}{r}\frac{\partial \psi}{\partial z}, \quad \upsilon_z = \frac{1}{r}\frac{\partial \psi}{\partial r},$$

$$\zeta = \frac{\partial \upsilon_r}{\partial z} - \frac{\partial \upsilon_z}{\partial r}, \quad \Gamma = r\upsilon_\varphi. \qquad (2)$$

[illegible]

$$\begin{cases} \dfrac{\partial \zeta}{\partial t} + \dfrac{\partial \upsilon_r \zeta}{\partial r} + \dfrac{\partial \upsilon_z \zeta}{\partial z} = \dfrac{\partial}{\partial z}\dfrac{\Gamma^2}{r^3}, \\ \dfrac{\partial \Gamma}{\partial t} + \upsilon_r \dfrac{\partial \Gamma}{\partial r} + \upsilon_z \dfrac{\partial \Gamma}{\partial z} = 0, \\ \dfrac{\partial^2 \psi}{\partial z^2} + \dfrac{\partial^2 \psi}{\partial r^2} - \dfrac{1}{r}\dfrac{\partial \psi}{\partial r} = -r\zeta. \end{cases} \qquad (3)$$

[illegible]

$$\xi = z, \qquad \eta = \frac{r}{R(z)}, \qquad R(z) = R_2 - z\,tg\alpha.$$

[illegible]

$$\frac{\partial \zeta}{\partial t} + \frac{\partial \upsilon_z \zeta}{\partial \xi} + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} + \frac{1}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} =$$

$$= \frac{\partial}{\partial \xi}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right) + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial}{\partial \eta}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right)$$

$$\frac{\partial \Gamma}{\partial t} + \upsilon_z \frac{\partial \Gamma}{\partial \xi} + \left(\upsilon_z \frac{\eta tg\alpha}{R(\xi)} + \frac{\upsilon_r}{R(\xi)}\right)\frac{\partial \Gamma}{\partial \eta} = 0, \qquad (4)$$

$$\frac{\partial^2\psi}{\partial\xi^2}+2\frac{\eta tg\alpha}{R(\xi)}\frac{\partial^2\psi}{\partial\xi\partial\eta}+\left[\frac{1}{R^2(\xi)}+\frac{\eta tg^2\alpha}{R^2(\xi)}\right]\frac{\partial^2\psi}{\partial\eta^2}+$$

$$+\left[2\frac{\eta tg^2\alpha}{R^2(\xi)}-\frac{1}{\eta}\right]\frac{\partial\psi}{\partial\eta}=-\eta R(\xi)\zeta,$$

$$\upsilon_r=\frac{-1}{\eta R(\xi)}\frac{\partial\psi}{\partial\xi}-\frac{tg\alpha}{R^2(\xi)}\frac{\partial\psi}{\partial\eta},\quad \upsilon_z=\frac{1}{\eta R^2(\xi)}\frac{\partial\psi}{\partial\eta}$$

[illegible] $\xi=0$ (2-[illegible]) [illegible].

[illegible]) $R_1/R_2\le\eta\le 1$ [illegible].

$$\psi=\frac{V(\eta^2R_2^2-R_1^2)}{2},\qquad \Omega=\omega\eta^2R_2^2,\quad \zeta=0,\quad \upsilon_z=V,\quad \upsilon_r=0. \tag{5}$$

[illegible] V, ω [illegible]. [illegible] $\omega=const$.

[illegible]) $0<\eta<R_1/R_2$ [illegible].

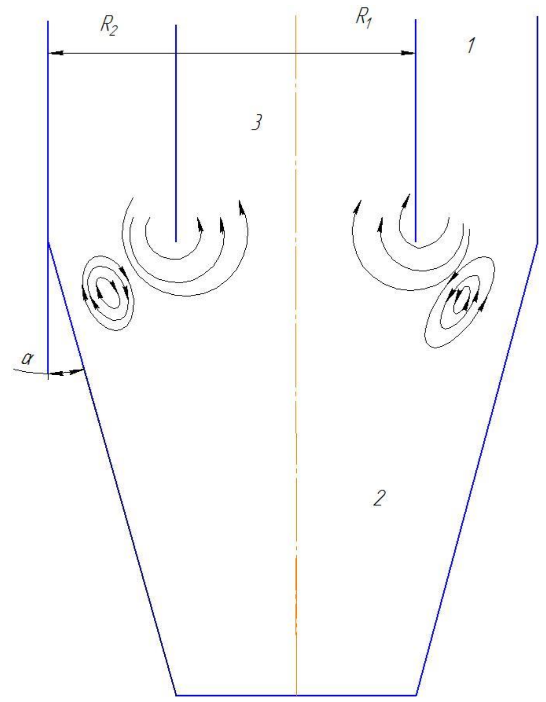
$$\frac{\partial^2\zeta}{\partial\xi^2}=0,\quad \frac{\partial^2\Omega}{\partial\xi^2}=0,\quad \frac{\partial^2\psi}{\partial\xi^2}=0 \tag{6}$$

[illegible] $\xi=1$ - [illegible].

[illegible]) $0<\eta<1$ [illegible] $\psi=\psi_2$; $\Omega=\Omega_2$; $\zeta=\zeta_2$. [illegible] 2 [illegible].

(4) [illegible] $O(\Delta t^2,\Delta\xi^2,\Delta\eta^2)$. [illegible] η [illegible] ξ [illegible].

3-[illegible] $8^0\le\alpha\le 13^0$, [illegible].


R2
R1
1
3
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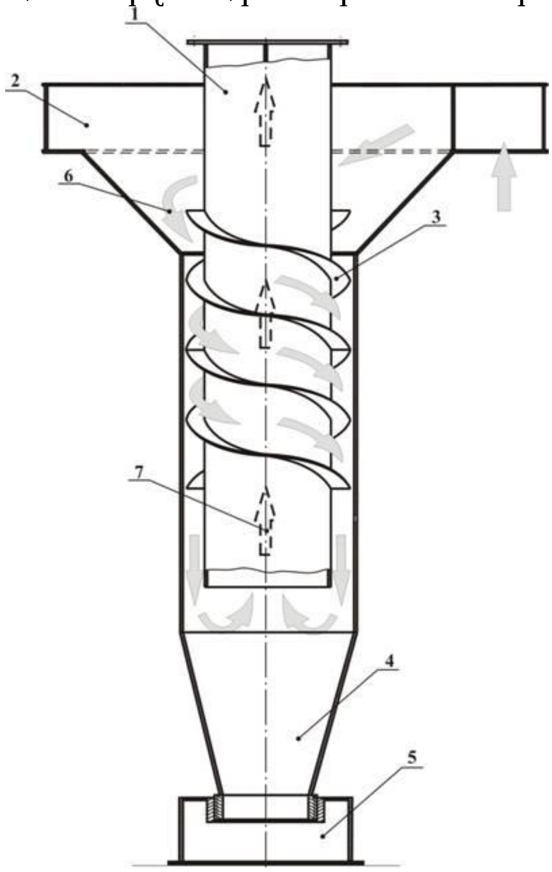
α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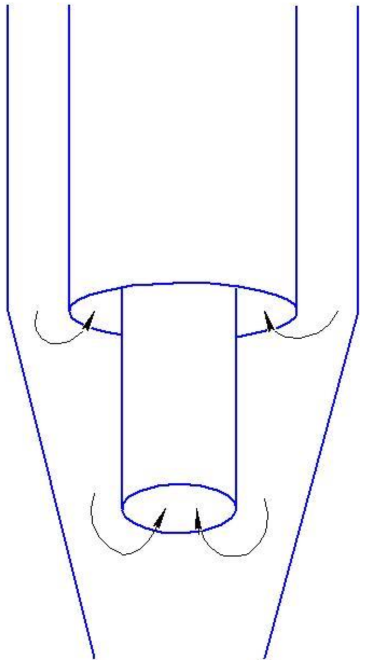
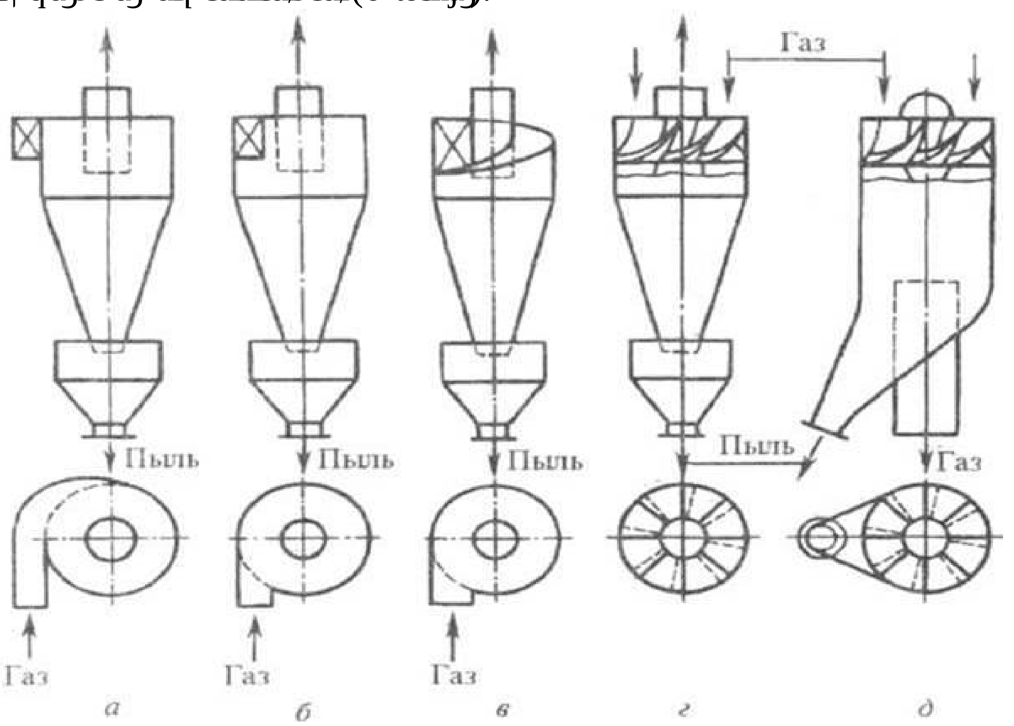


5-[illegible]

[illegible] 2.4 [illegible]: [illegible]; [illegible]; [illegible]; [illegible] (6-[illegible]).



6-[illegible]

[illegible]

$$
\begin{cases}
\dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2 V_r) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta V_\theta) = 0, \\
V_r \dfrac{\partial\rho_p}{\partial r} + \dfrac{V_\theta}{r}\dfrac{\partial\rho_p}{\partial\theta} = \dfrac{1}{r^2}\dfrac{\partial}{\partial r}\left(Dr^2\dfrac{\partial\rho_p}{\partial r}\right) + \dfrac{1}{r^2\sin\theta}\dfrac{\partial}{\partial\theta}\left(D\sin\theta\dfrac{\partial\rho_p}{\partial\theta}\right), \\
\dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2 \tau_{rr}) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta\, \tau_{r\theta}) - \dfrac{\tau_{\theta\theta}+\tau_{\varphi\varphi}}{r} = 0, \\
\dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2 \tau_{r\theta}) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta\, \tau_{\theta\theta}) + \dfrac{\tau_{r\theta}-\tau_{\varphi\varphi}\, ctg\theta}{r} = 0.
\end{cases}
\qquad (7)
$$

(7) [illegible]:

$$
\begin{cases}
\tau_{rr} = p + (\rho+\rho_p)V_r^2 - 2\nu_t(\rho+\rho_p)\dfrac{\partial V_r}{\partial r} - 2DV_r\dfrac{\partial\rho_p}{\partial r}, \\
\tau_{\theta\theta} = p + (\rho+\rho_p)V_\theta^2 - 2\nu_t(\rho+\rho_p)\left(\dfrac{1}{r}\dfrac{\partial V_\theta}{\partial\theta} + \dfrac{V_r}{r}\right) - 2D\dfrac{V_\theta}{r}\dfrac{\partial\rho_p}{\partial\theta}, \\
\tau_{\varphi\varphi} = p - 2\nu_t(\rho+\rho_p)\left(\dfrac{V_r}{r} + \dfrac{V_\theta\, ctg\theta}{r}\right), \\
\tau_{r\theta} = (\rho+\rho_p)V_r V_\theta - \nu_t(\rho+\rho_p)\left(\dfrac{1}{r}\dfrac{\partial V_r}{\partial\theta} + \dfrac{\partial V_\theta}{\partial r} - \dfrac{V_\theta}{r}\right) - D\left(\dfrac{V_r}{r}\dfrac{\partial\rho_p}{\partial\theta} + V_\theta\dfrac{\partial\rho_p}{\partial r}\right)
\end{cases}
\qquad (8)
$$

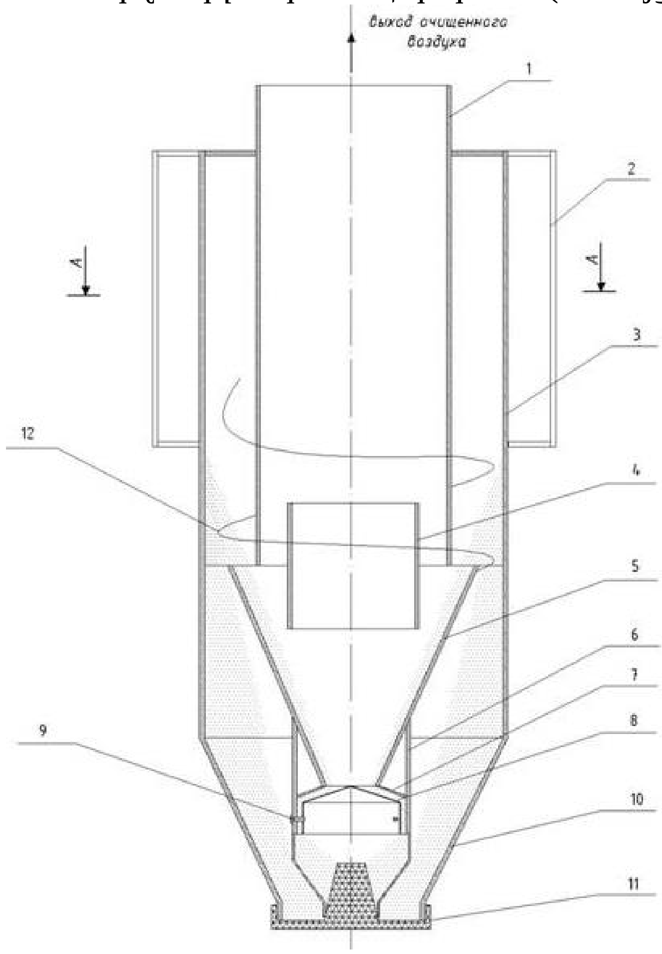
[illegible] $p, \rho, \rho_p, V_r, V_\theta, \nu_t, D$ - [illegible]. [illegible] (7) [illegible].

$$
\nu_t = \frac{\nu_0}{1 - \dfrac{2-Sc}{2}\dfrac{\rho_p}{\rho}}, \quad D = \frac{\nu_0}{Sc\left(1 - \dfrac{2Sc-1}{2Sc}\dfrac{\rho_p}{\rho}\right)} \qquad (9)
$$

[illegible] Sc [illegible], ν_0 - [illegible]. [illegible] Sc = 1. [illegible] (9) [illegible] Δ [illegible] η [illegible]

$$
\eta = 1 - e^{-u\Delta/\nu_0} \qquad (10)
$$

[illegible] $R_1 = 5$ [illegible] $R_2 = 10$ [illegible] 5 [illegible] 87 [illegible], $\Delta \approx 2$ [illegible] (7-[illegible]).



7- [illegible]

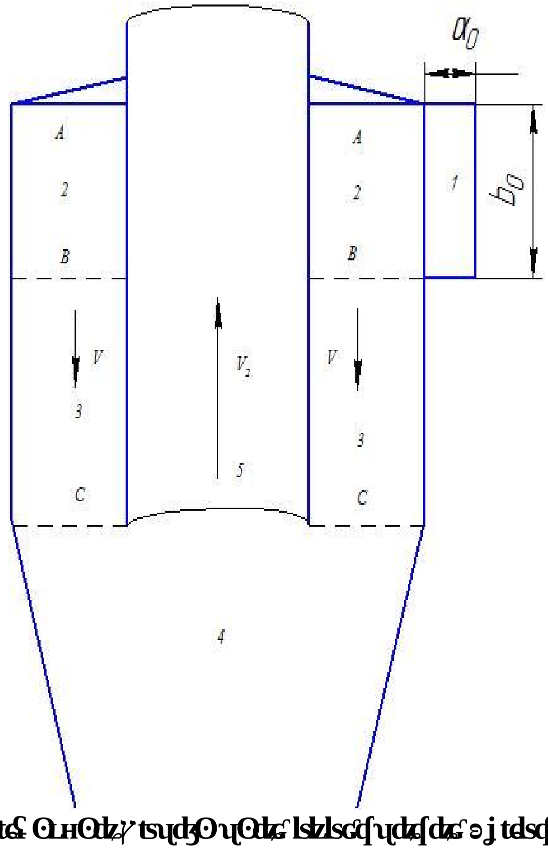
1 – [illegible], 2 – [illegible], 3 – [illegible], 4 – [illegible], 5 – [illegible], 6 – [illegible], 7 – [illegible], 8 – [illegible], 9 – [illegible], 10 – [illegible], 11 – [illegible], 12 – [illegible].

[illegible] 1 [illegible] 3 [illegible] 3, 10, 11, 6, 5 [illegible]

[illegible]

[illegible]

[illegible]



8-[illegible]

[illegible]

$$\xi = r_1 / r_2,\ D_{[illegible]} = 2a_0 b_0 / (a_0 + b_0),\ D_{[illegible]} = 2ab/(a+b). \tag{11}$$

[illegible]:

$$U_0 = \frac{G}{2a_0 b_0} \tag{12}$$

[illegible]

$$U_1 = \frac{G}{2ab} \tag{13}$$

[illegible] - $\mathrm{Re}_0 = \dfrac{U_0 D_{[illegible]}}{\nu}$.

[illegible] - $\lambda_0 = 0.11\left(\dfrac{\Delta_{[illegible]}}{D_{[illegible]}} + \dfrac{68.5}{\mathrm{Re}_0}\right)^{0.25}$. [illegible] - $\Delta_{[illegible]} = 0.15$ [illegible].

[illegible]:

$$\Delta p_1 = \lambda_0 \frac{2\rho U_0^2}{9\beta + 3\alpha} \frac{l}{D_{[illegible]}} \left(\exp\left(\frac{9\beta + 3\alpha}{4}\right) - 1 \right). \tag{14}$$

[illegible] $\alpha = \ln(D_{[illegible]} / D_{[illegible]})$, $\beta = \ln(U_1 / U_0)$.

[illegible]:

$$V = \frac{G}{\pi (r_2^2 - r_1^2)}. \tag{15}$$

[illegible]

$$\Delta p_2 = \frac{\rho U_1^2 (1 - \xi^2)}{2} + \frac{\rho V^2}{2}. \tag{16}$$

[illegible] - $\omega_0 = k \dfrac{U_1}{r_2}$.

[illegible] $D_{[illegible]} = 2(r_2 - r_1)$.

[illegible] - $\mathrm{Re} = \dfrac{D_{[illegible]} \sqrt{V^2 + 0.25\omega_0^2 (r_2 + r_1)^2}}{\nu}$.

[illegible] $\lambda_0 = 0.11\left(\dfrac{\Delta_{[illegible]}}{D_{[illegible]}} + \dfrac{68.5}{\mathrm{Re}}\right)^{0.25}$.

[illegible]: $K(\xi) = \dfrac{\lambda \omega_0 L}{2V} \dfrac{1 + \xi^4}{1 - \xi^4}$,

$$\Delta p_3 = \lambda \frac{\rho V^2}{2} \frac{L}{D_{[illegible]}} + \frac{\rho \omega_0^2 r_2^2}{4} (1 + \xi^2) \left(1 - \frac{1}{(1 + K(\xi))^2} \right). \tag{17}$$

[illegible]:

$$\Delta p_4 = \frac{\rho V^2}{2}\frac{1-\xi^2}{\xi^4} + \frac{\rho \omega_1^2 r_2^2}{2}. \qquad (18)$$

[illegible] - $\omega_1 = \dfrac{\omega_0}{1+K(\xi)}$.

[illegible] $V_1 = \dfrac{G}{\pi r_1^2}$.

[illegible]

$$\mathrm{Re}_1 = \frac{2r_1\sqrt{V_1^2 + 0.25\omega_1^2 r_1^2}}{\nu}.$$

[illegible] $\lambda_1 = 0.11\left(\dfrac{\Delta_{\prime}}{2r_1} + \dfrac{68.5}{\mathrm{Re}_1}\right)^{0.25}$.

[illegible]:

$$K_1 = \frac{\lambda_1 \omega_1 L}{2V_1},$$

$$\Delta p_5 = \lambda_1 \frac{\rho V_1^2}{4}\frac{L}{r_1} + \frac{\rho\, \omega_1^2 r_1^2}{4}\left(1 - \frac{1}{K_1^2}\right). \qquad (19)$$

[illegible]

$$\Delta p = \Delta p_1 + \Delta p_2 + \Delta p_3 + \Delta p_4 + \Delta p_5\ . \qquad (20)$$

[illegible] 4.2- [illegible] LK 07 [illegible] ([illegible]) [illegible] ([illegible]) 9- [illegible], [illegible]

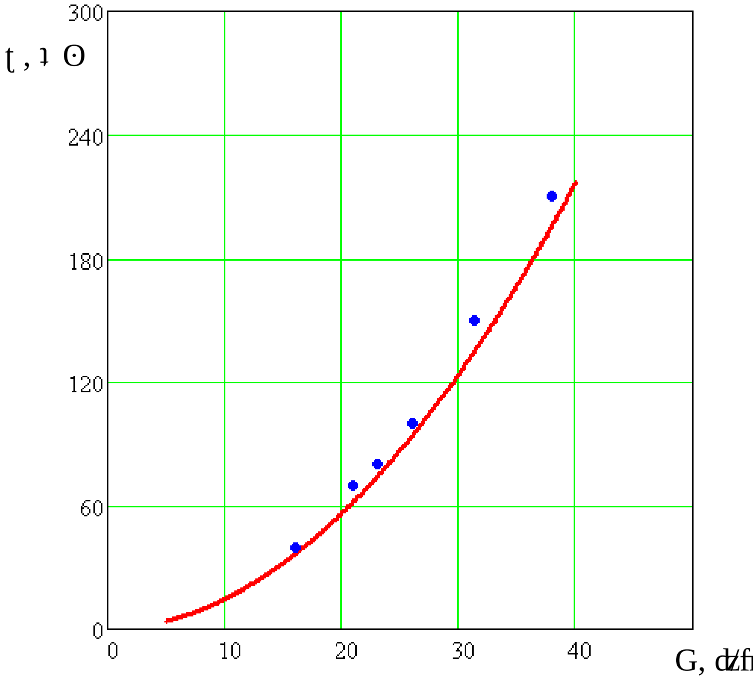
[illegible] ([illegible]) [illegible]:

$$\eta(\delta) = \frac{1}{1-\xi^2}\left[1 - \exp\left(-\frac{C_m \delta^2 \rho_{\text{ч}} \omega_0^2(\xi) L}{9V(\xi)\rho\nu(1+K(\xi))}\right)\right]. \qquad (21)$$

[illegible] ξ - [illegible], C_m - [illegible], δ - [illegible], $\rho_ч$ - [illegible], ω_0 - [illegible], [illegible], $V(\xi)$ - [illegible], ρ - [illegible], ν - [illegible], $K(\xi)$ - [illegible] δ_i [illegible] ε_i [illegible]:

$$\bar{\eta} = \sum_{i=1}^{N} \varepsilon_i \, \eta(\delta_i) \,, \tag{22}$$

[illegible] N - [illegible].



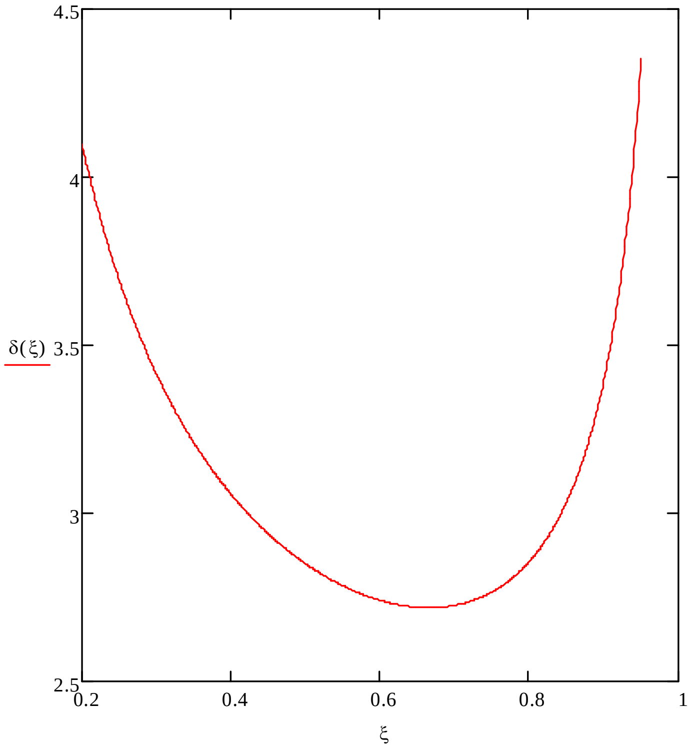
9-[illegible]

4.4-[illegible] (4) [illegible].

$$\begin{cases} m_p \dfrac{DV_{zp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_z - V_{zp}), \\ m_p \dfrac{DV_{rp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_r - V_{rp}) + \dfrac{m_p V_{\varphi p}^2}{r}, \\ m_p \dfrac{DV_{\varphi p}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_\varphi - V_{\varphi p}). \end{cases} \tag{23}$$

[illegible] V_r, V_z, V_φ – [illegible]; m_p – [illegible], V_{zp}, V_{rp}, $V_{\varphi p}$ – [illegible], δ - [illegible]; $\frac{D}{Dt}$ - [illegible], μ_m – [illegible].

[illegible] 4.5-[illegible] [illegible] 10-[illegible] $\xi \approx 0.66$ [illegible].



10-[illegible]

[illegible].

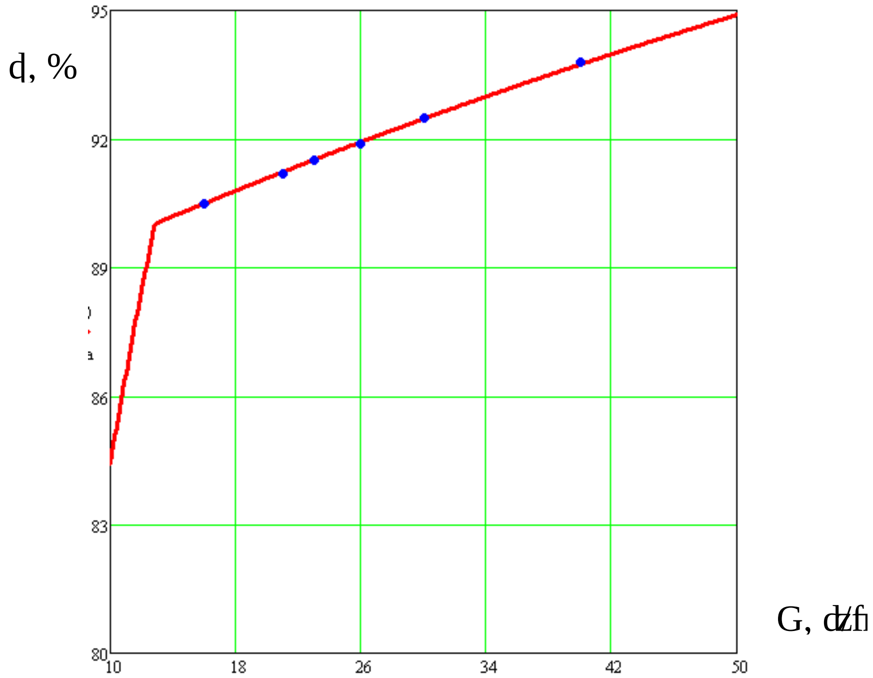
4.6-[illegible] 400 [illegible] 400 [illegible] 1-[illegible].

11-[illegible] LK 07 [illegible].

1-[illegible]

[illegible] 400 [illegible].

[illegible], [illegible]	[illegible], [illegible]	[illegible], %
0é 10	5	12,0
10é 20	15	36,2
20é 30	25	19,39
30é 40	35	17.2
40é 50	45	12.8
50é 60	55	0,3
60é 70	65	1,2
70é 80	75	0,8
80é 90	85	0,3
90é 100	95	1.2



11-[illegible]

[illegible]

[illegible]

[illegible]

1. [illegible]

2. [illegible]

3. [illegible] 20% [illegible]

4. [illegible]

5. [illegible]

6. [illegible]

[illegible] 16.07.2013 [illegible]/FM.02.02 [illegible]

[illegible]

[illegible]

[illegible]

01.02.05 [illegible]

[illegible]

[illegible] 2016

Тема докторской диссертации зарегистрирована в Высшей аттестационной комиссии при Кабинете Министров Республики Узбекистан за № 12.05.2015/B2015.1.T463

Докторская диссертация выполнена в научно-исследовательском центре по отраслевому машиноведению при Ташкентском государственном техническом университете

Автореферат диссертации на трёх языках (узбекский, русский, английский) размещён на веб-странице по адресу www.tdtu.uz и информационно-образовательном портале «ZiyoNet» по адресу (www.ziyonet.uz).

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[illegible][1]. [illegible] NASA Glenn research center, [illegible] Boeing Scientific Research Laboratories, [illegible] Massachusetts institute of technology, [illegible] Stanford university ([illegible]), [illegible] Cambridge university ([illegible]), Hettingen laboratory ([illegible]), [illegible] The Air Systems Research Center ([illegible]), [illegible] China Aerodynamics Research and Development Center ([illegible]), [illegible].

[illegible] (Stanford university, Boeing Scientific Research Laboratories, Cambridge university, Massachusetts institute of technology, [illegible]); [illegible] (Cambridge university, [illegible]); [illegible] (Hettingen laboratory, [illegible]); [illegible] (The Air Systems Research Center, [illegible]); [illegible] (China Aerodynamics Research and Development Center, [illegible]), [illegible].

[illegible]

[illegible]. [illegible] XIX [illegible] XX [illegible] 1967 [illegible]

[1] [illegible] http:/www.nasa.gov/centre/glenn/home/index.html; http://universal_ru_en.academic.ru/66921/; Wildes, Karl L.; Lindgren, Nilo A. (2005). A Century of Electrical Engineering and Computer Science at MIT, 2006-2009. Cambridge, Mass.: MIT Press. ISBN 9780262231190; Stuart W. Leslie: The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford. Columbia University Press, New York [u. a.] 1993, ISBN 0-231-07958-3; http://www.mod.go.jp/trdi/en/research/kenkyu_koukuu_en.hyml; University of Cambridge (ed.). "The Revived University of the Nineteenth and Twentieth Centuries" Retrieved 7 August 2014; http://www.utias.utoronto.ca; http://www.cards.cn:88; http://universal_ru_en.academic.ru/240165; [illegible] 1. 2. [illegible], 1955; [illegible], 2008. 480 [illegible] ISBN 5-02-007017-3; [illegible] 1971; [illegible]

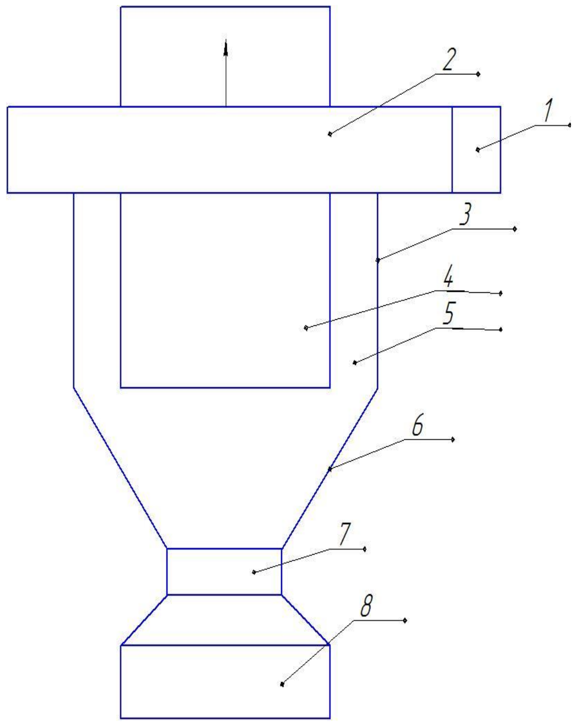
[illegible] // [illegible], 1956, [illegible] 20; [illegible] 1987; Faizullaev D.F. Laminar motion of multiphase media in conduits.//Consultants bureau, New York, 196 [illegible]

[illegible]

[illegible]

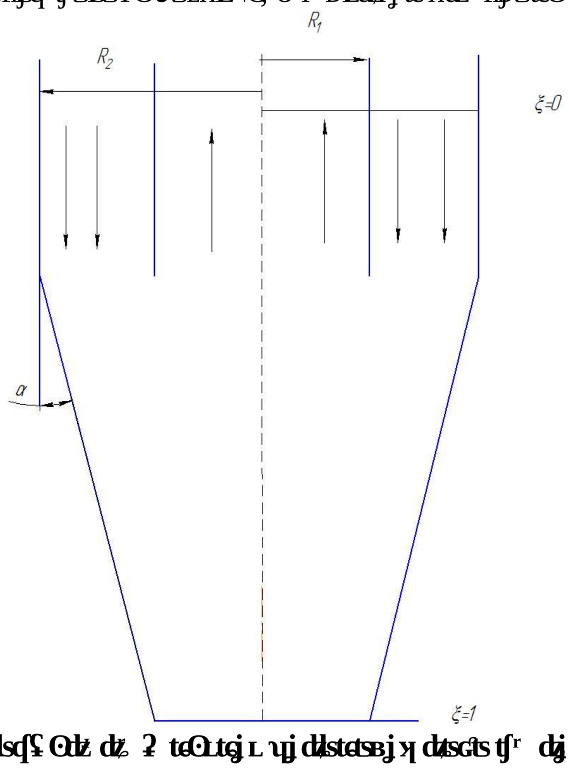
[illegible] .13-12 [illegible] » (2012-2014), [illegible] 02-1541 [illegible] » (2010-2011), [illegible] 02-2180 [illegible] » (2011-2012), [illegible] 02-2092 [illegible] » (2012-2013), [illegible] 14/2012 [illegible] » (2012-2013), [illegible] 02-1466 [illegible] (2013-2014).

[illegible]



[illegible] 1. [illegible]

1 – [illegible], 2 – [illegible], 3 – [illegible], 4 – [illegible], 5 – [illegible], 6 – [illegible], 7 – [illegible], 8 – [illegible].



[illegible] 2. [illegible]

[illegible] (z, r, φ). [illegible]:

$$
\begin{cases}
\dfrac{\partial (r\upsilon_z)}{\partial z} + \dfrac{\partial (r\upsilon_r)}{\partial r} = 0, \\[2ex]
\dfrac{\partial \upsilon_z}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_z}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_z}{\partial r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial z} = 0, \\[2ex]
\dfrac{\partial \upsilon_r}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_r}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_r}{\partial r} - \dfrac{\upsilon_\varphi^2}{r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial r} = 0.
\end{cases} \tag{1}
$$

[illegible] ψ, [illegible] ζ, [illegible] Γ. [illegible]

$$
\upsilon_r = -\frac{1}{r}\frac{\partial \psi}{\partial z}, \;\; \upsilon_z = \frac{1}{r}\frac{\partial \psi}{\partial r},
$$

$$
\zeta = \frac{\partial \upsilon_r}{\partial z} - \frac{\partial \upsilon_z}{\partial r}, \;\; \Gamma = r\upsilon_\varphi. \tag{2}
$$

[illegible]

$$
\begin{cases}
\dfrac{\partial \zeta}{\partial t} + \dfrac{\partial \upsilon_r \zeta}{\partial r} + \dfrac{\partial \upsilon_z \zeta}{\partial z} = \dfrac{\partial}{\partial z}\dfrac{\Gamma^2}{r^3}, \\[2ex]
\dfrac{\partial \Gamma}{\partial t} + \upsilon_r \dfrac{\partial \Gamma}{\partial r} + \upsilon_z \dfrac{\partial \Gamma}{\partial z} = 0, \\[2ex]
\dfrac{\partial^2 \psi}{\partial z^2} + \dfrac{\partial^2 \psi}{\partial r^2} - \dfrac{1}{r}\dfrac{\partial \psi}{\partial r} = -r\zeta.
\end{cases} \tag{3}
$$

[illegible]:

$$
\xi = z, \qquad \eta = \frac{r}{R(z)}, \qquad R(z) = R_2 - z\,tg\alpha.
$$

[illegible]:

$$
\frac{\partial \zeta}{\partial t} + \frac{\partial \upsilon_z \zeta}{\partial \xi} + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} + \frac{1}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} =
$$

$$
= \frac{\partial}{\partial \xi}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right) + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial}{\partial \eta}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right)
$$

$$\frac{\partial \omega}{\partial t}+\upsilon_z\frac{\partial \omega}{\partial \xi}+\left(\upsilon_z\frac{\eta tg\alpha}{R(\xi)}+\frac{\upsilon_r}{R(\xi)}\right)\frac{\partial \omega}{\partial \eta}=0, \qquad (4)$$

$$\frac{\partial^2\psi}{\partial\xi^2}+2\frac{\eta tg\alpha}{R(\xi)}\frac{\partial^2\psi}{\partial\xi\partial\eta}+\left[\frac{1}{R^2(\xi)}+\frac{\eta tg^2\alpha}{R^2(\xi)}\right]\frac{\partial^2\psi}{\partial\eta^2}+$$

$$+\left[2\frac{\eta tg^2\alpha}{R^2(\xi)}-\frac{1}{\eta}\right]\frac{\partial\psi}{\partial\eta}=-\eta R(\xi)\zeta,$$

$$\upsilon_r=\frac{-1}{\eta R(\xi)}\frac{\partial\psi}{\partial\xi}-\frac{tg\alpha}{R^2(\xi)}\frac{\partial\psi}{\partial\eta},\quad \upsilon_z=\frac{1}{\eta R^2(\xi)}\frac{\partial\psi}{\partial\eta}.$$

[illegible] $\xi=0$ [illegible] $\xi=1$), [illegible]

а) [illegible] $\frac{R_1}{R_2}\le\eta\le 1$ [illegible], [illegible] – [illegible]:

$$\psi=\frac{V(\eta^2R_2^2-R_1^2)}{2},\quad \omega=\omega\eta^2R_2^2,\quad \zeta=0,\quad \upsilon_z=V,\quad \upsilon_r=0. \qquad (5)$$

[illegible] $V,\ \omega$ – [illegible]. [illegible], [illegible] $\omega=const$.

в) [illegible] $0<\eta<\frac{R_1}{R_2}$ [illegible] – [illegible]

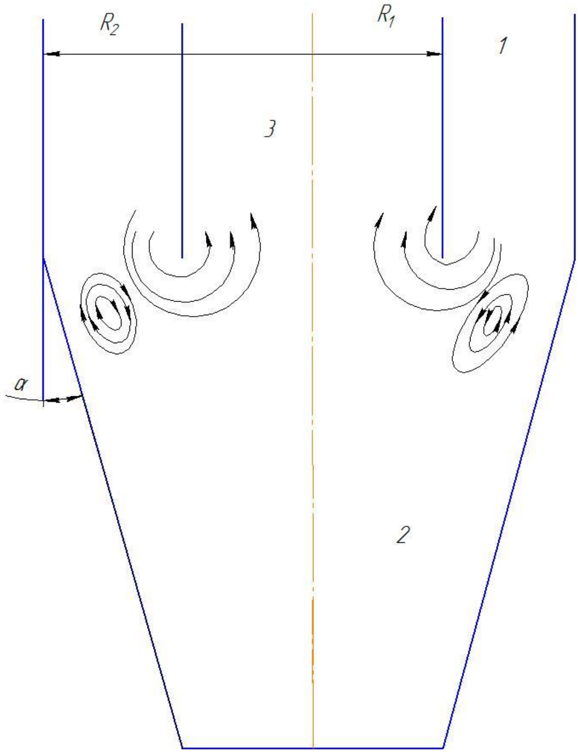
$$\frac{\partial^2\zeta}{\partial\xi^2}=0,\quad \frac{\partial^2\omega}{\partial\xi^2}=0,\quad \frac{\partial^2\psi}{\partial\xi^2}=0. \qquad (6)$$

[illegible] $\xi=1$ [illegible]:

а) [illegible] $0<\eta<1$: $\psi=\psi_2$; $\omega=\omega_2$; $\zeta=\zeta_2$. [illegible] 2 [illegible].

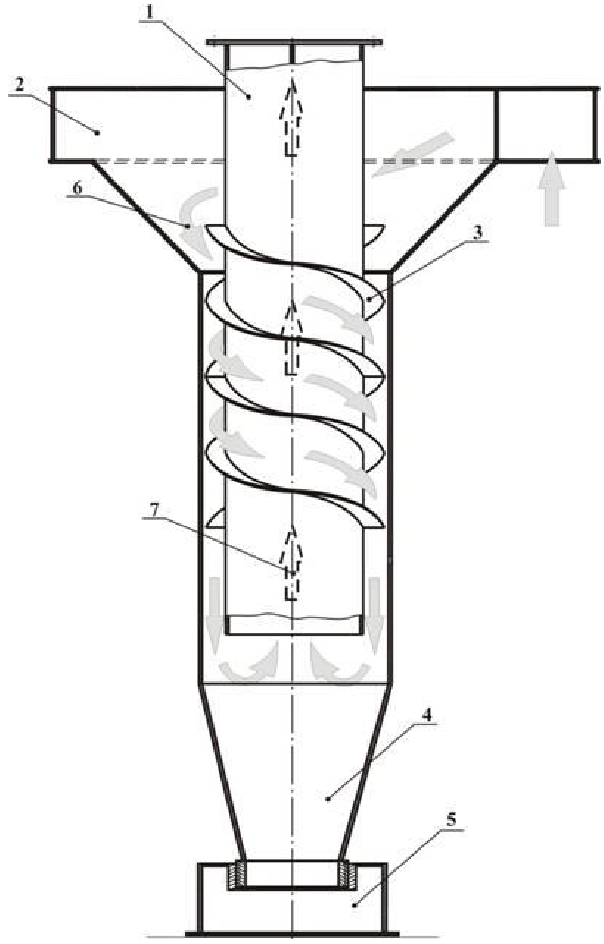
[illegible] (1) [illegible] $O(\Delta t^2,\Delta\xi^2,\Delta\eta^2)$. [illegible] η [illegible] ξ_i. [illegible].

[illegible] 3 [illegible] $8^0 \le \alpha \le 13^0$.



[illegible] 3. [illegible]

[illegible] 40% [illegible] 75%. [illegible] (4). [illegible] 2.2 [illegible] (4).

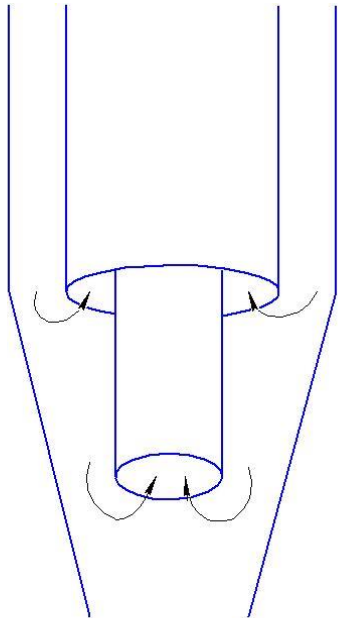


[illegible] 4. [illegible]

1 – [illegible], 2 – [illegible], 3 – [illegible], 4 – [illegible], 5 – [illegible], 6 – [illegible], 7 – [illegible]

[illegible] 0.9 [illegible] 32 [illegible] 85%. [illegible] -15 [illegible] 69%, [illegible] 3.2 [illegible]

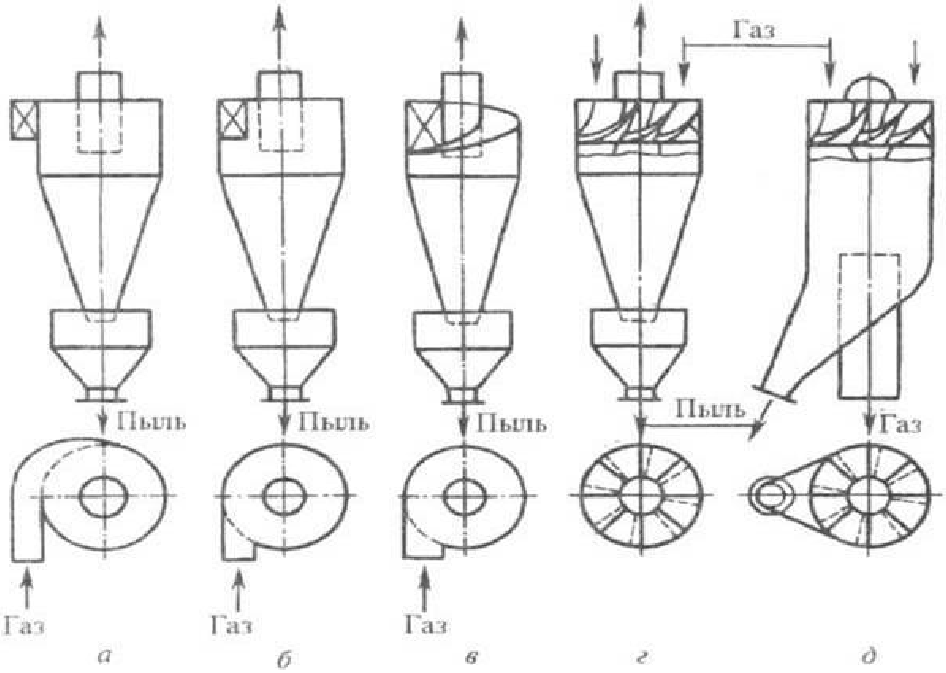
[illegible] (…5).



[illegible] 5. [illegible]

[illegible]

[illegible] 4) [illegible] 5) [illegible] (…6). [illegible] 96%. [illegible]



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[illegible] 3.4 [illegible] r, θ:

$$\begin{cases} \dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2 V_r) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta V_\theta) = 0, \\ V_r\dfrac{\partial\rho_p}{\partial r} + \dfrac{V_\theta}{r}\dfrac{\partial\rho_p}{\partial\theta} = \dfrac{1}{r^2}\dfrac{\partial}{\partial r}\left(Dr^2\dfrac{\partial\rho_p}{\partial r}\right) + \dfrac{1}{r^2\sin\theta}\dfrac{\partial}{\partial\theta}\left(D\sin\theta\dfrac{\partial\rho_p}{\partial\theta}\right), \\ \dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2\sigma_{rr}) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta\,\sigma_{r\theta}) - \dfrac{\sigma_{\theta\theta}+\sigma_{\varphi\varphi}}{r} = 0, \\ \dfrac{1}{r^2}\dfrac{\partial}{\partial r}(r^2\sigma_{r\theta}) + \dfrac{1}{r\sin\theta}\dfrac{\partial}{\partial\theta}(\sin\theta\,\sigma_{\theta\theta}) + \dfrac{\sigma_{r\theta}-\sigma_{\varphi\varphi}\,ctg\theta}{r} = 0. \end{cases} \quad (7)$$

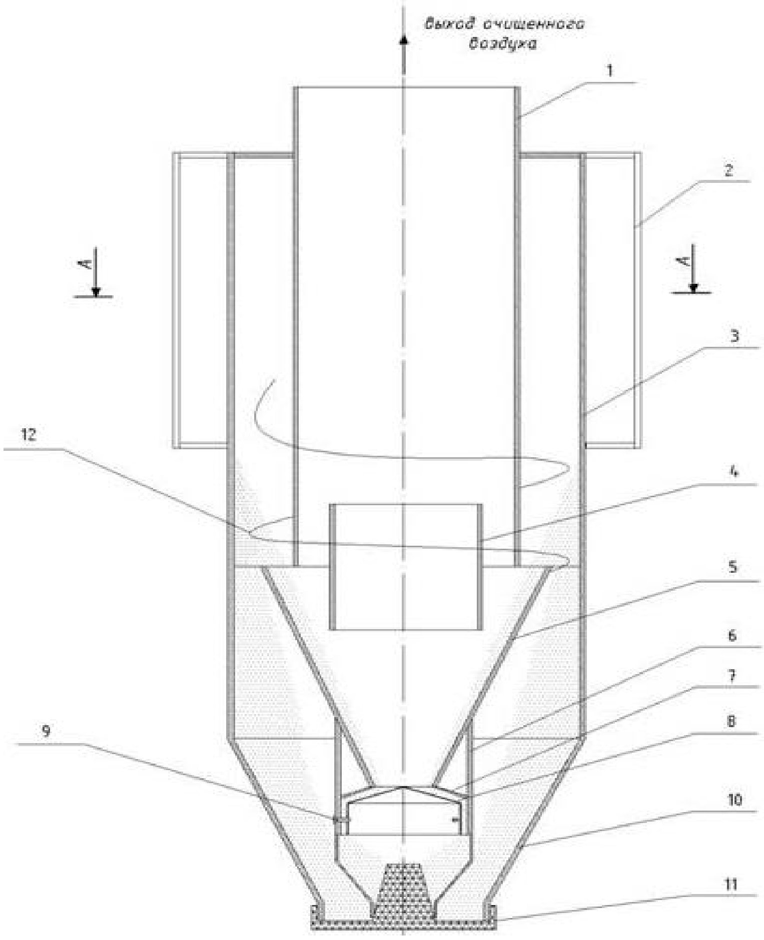
[illegible] (7) [illegible]

$$\begin{cases} \sigma_{rr} = p + (\rho+\rho_p)V_r^2 - 2\nu_t(\rho+\rho_p)\dfrac{\partial V_r}{\partial r} - 2DV_r\dfrac{\partial\rho_p}{\partial r}, \\ \sigma_{\theta\theta} = p + (\rho+\rho_p)V_\theta^2 - 2\nu_t(\rho+\rho_p)\left(\dfrac{1}{r}\dfrac{\partial V_\theta}{\partial\theta} + \dfrac{V_r}{r}\right) - 2D\dfrac{V_\theta}{r}\dfrac{\partial\rho_p}{\partial\theta}, \\ \sigma_{\varphi\varphi} = p - 2\nu_t(\rho+\rho_p)\left(\dfrac{V_r}{r} + \dfrac{V_\theta\,ctg\theta}{r}\right), \\ \sigma_{r\theta} = (\rho+\rho_p)V_rV_\theta - \nu_t(\rho+\rho_p)\left(\dfrac{1}{r}\dfrac{\partial V_r}{\partial\theta} + \dfrac{\partial V_\theta}{\partial r} - \dfrac{V_\theta}{r}\right) - D\left(\dfrac{V_r}{r}\dfrac{\partial\rho_p}{\partial\theta} + V_\theta\dfrac{\partial\rho_p}{\partial r}\right) \end{cases} \quad (8)$$

[illegible] $p, \rho, \rho_p, V_r, V_\theta, \nu_t, D$ - [illegible] (7) [illegible]:

$$\nu_t = \frac{\nu_0}{1 - \dfrac{2-Sc}{2}\dfrac{\rho_p}{\rho}}, \quad D = \frac{\nu_0}{Sc\left(1 - \dfrac{2Sc-1}{2Sc}\dfrac{\rho_p}{\rho}\right)}. \quad (9)$$

$$\eta = 1 - e^{-u\,\Delta / \nu_0} \qquad (10)$$


Выход очищенного воздуха
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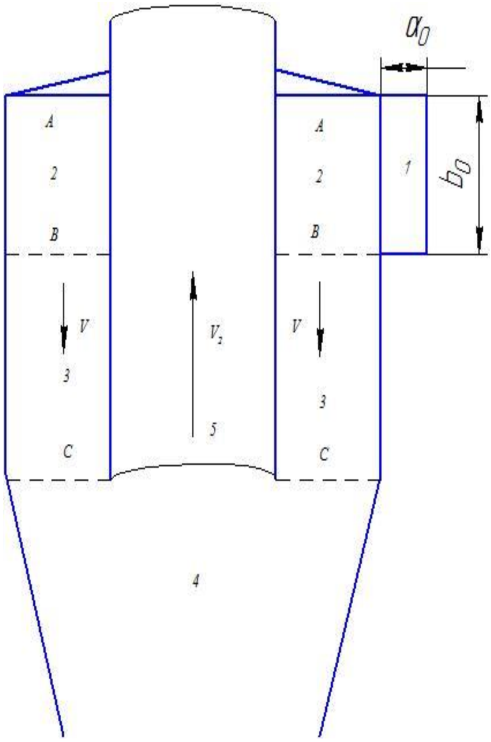


[illegible] 8. [illegible]

[illegible] G [illegible]:

$$\xi = r_1 / r_2, \qquad D_{э1} = 2a_0 b_0 / (a_0 + b_0), \qquad D_{э2} = 2ab/(a+b). \tag{11}$$

[illegible]

$$U_0 = \frac{G}{2a_0 b_0} \tag{12}$$

[illegible]

$$U_1 = \frac{G}{2ab} \tag{13}$$

[illegible] - $\mathrm{Re}_0 = \frac{U_0 D_{э1}}{\nu}$, [illegible] - $\lambda_0 = 0.11\left(\frac{\Delta}{D_{э1}} + \frac{68.5}{\mathrm{Re}_0}\right)^{0.25}$. [illegible] $\Delta = 0.15$ [illegible].

[illegible]

$$\Delta p_1 = \lambda_0 \frac{2\rho U_0^2}{9\beta + 3\alpha} \frac{l}{D_{э1}} \left[\exp\left(\frac{9\beta + 3\alpha}{4}\right) - 1 \right]. \tag{14}$$

[illegible], $\alpha = \ln(D_{[illegible]} / D_{[illegible]})$, $\beta = \ln(U_1 / U_0)$.

[illegible]

$$V = \frac{G}{\pi(r_2^2 - r_1^2)}. \tag{15}$$

[illegible]:

$$\Delta p_2 = \frac{\rho U_1^2 (1-\xi^2)}{2} + \frac{\rho V^2}{2}. \tag{16}$$

[illegible] $\omega_0 = k\dfrac{U_1}{r_2}$.

[illegible] $D_{[illegible]} = 2(r_2 - r_1)$.

[illegible] $\mathrm{Re} = \dfrac{D_{[illegible]}\sqrt{V^2 + 0.25\omega_0^2 (r_2 + r_1)^2}}{\nu}$,

[illegible] $\lambda_0 = 0.11\left(\dfrac{\Delta_{[illegible]}}{D_{[illegible]}} + \dfrac{68.5}{\mathrm{Re}}\right)^{0.25}$.

[illegible]:

$$K(\xi) = \frac{\lambda \omega_0 L}{2V}\frac{1+\xi^4}{1-\xi^4},$$

$$\Delta p_3 = \lambda \frac{\rho V^2}{2}\frac{L}{D_{[illegible]}} + \frac{\rho\, \omega_0^2 r_2^2}{4}(1+\xi^2)\left(1 - \frac{1}{(1+K(\xi))^2}\right). \tag{17}$$

[illegible]:

$$\Delta p_4 = \frac{\rho V^2}{2}\frac{1-\xi^2}{\xi^4} + \frac{\rho \omega_1^2 r_2^2}{2}. \tag{18}$$

[illegible] $\omega_1 = \dfrac{\omega_0}{1+K(\xi)}$.

[illegible] $V_1 = \dfrac{G}{\pi r_1^2}$.

[illegible] $\mathrm{Re}_1 = \dfrac{2r_1\sqrt{V_1^2 + 0.25\omega_1^2 r_1^2}}{\nu}$,

[illegible] $\lambda_1 = 0.11\left(\dfrac{\Delta_{[illegible]}}{2r_1} + \dfrac{68.5}{\mathrm{Re}_1}\right)^{0.25}$.

[illegible]:

$$K_1 = \frac{\lambda_1 \omega_1 L}{2V_1},$$

$$\Delta p_5 = \lambda_1 \frac{\rho V_1^2}{4} \frac{L}{r_1} + \frac{\rho\, \omega_1^2 r_1^2}{4} \left(1 - \frac{1}{K_1^2} \right). \qquad (19)$$

[illegible]

$$\Delta p = \Delta p_1 + \Delta p_2 + \Delta p_3 + \Delta p_4 + \Delta p_5\,. \qquad (20)$$

[illegible] 4.2 [illegible] LK 07. [illegible] 9. [illegible]

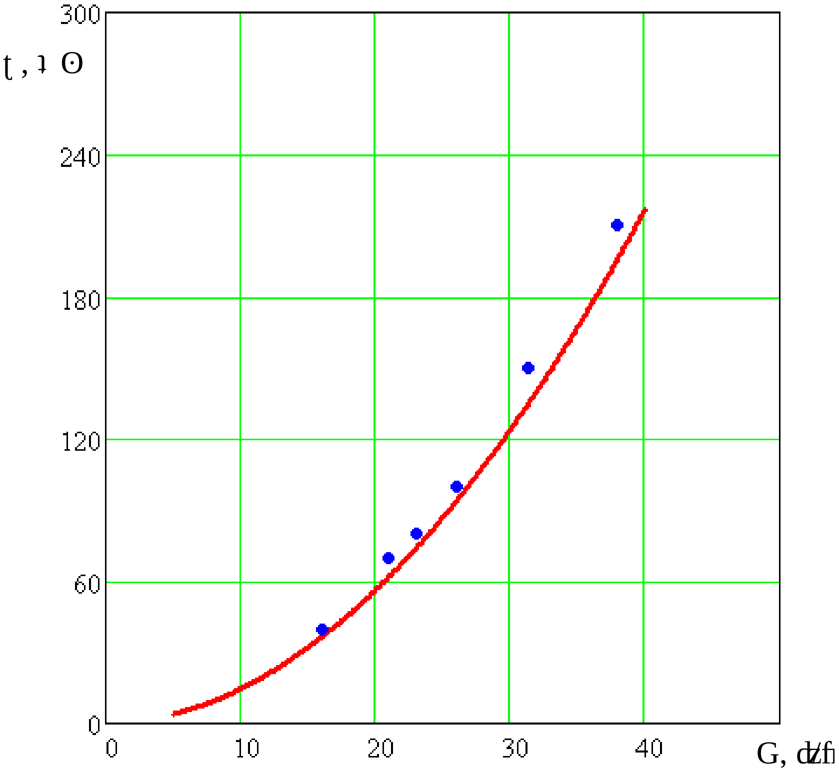
[illegible] 4.3 [illegible]

$$\eta(\delta) = \frac{1}{1-\xi^2}\left[1 - \exp\left(- \frac{C_m \delta^2 \rho_{ч} \omega_0^2(\xi) L}{9V(\xi)\rho\nu(1+K(\xi))} \right) \right]. \qquad (21)$$

[illegible] ξ - [illegible], C_m - [illegible], δ - [illegible], $\rho_{ч}$ - [illegible], ω_0 - [illegible], L – [illegible], $V(\xi)$ - [illegible], ρ - [illegible], ν - [illegible], $K(\xi)$ - [illegible] ε_i [illegible] δ_i, [illegible]

$$\bar{\eta} = \sum_{i=1}^{N} \varepsilon_i\, \eta(\delta_i)\,, \qquad (22)$$

[illegible] N - [illegible].



[illegible] 9. [illegible]

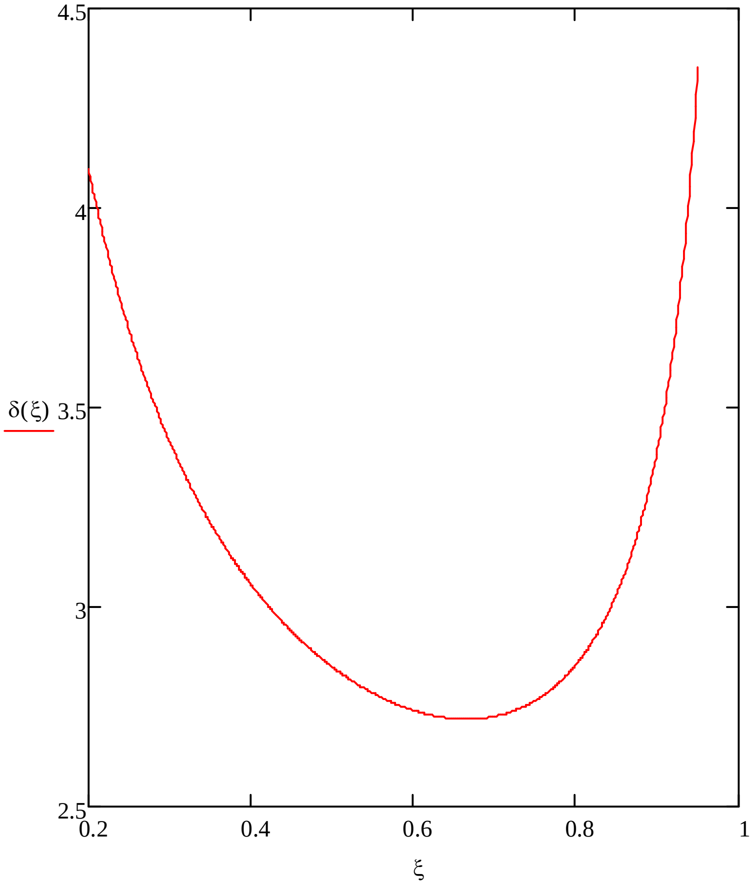
[illegible] 4.4, [illegible] (4) [illegible]:

$$\begin{cases} m_p \dfrac{DV_{zp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_z - V_{zp}), \\ m_p \dfrac{DV_{rp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_r - V_{rp}) + \dfrac{m_p V_{\varphi p}^2}{r}, \\ m_p \dfrac{DV_{\varphi p}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_\varphi - V_{\varphi p}). \end{cases} \tag{23}$$

[illegible] V_r, V_z, V_φ [illegible]; m_p - [illegible]; V_{zp}, V_{rp}, $V_{\varphi p}$ - [illegible], δ - [illegible]; $\dfrac{D}{Dt}$ - [illegible], C_m - [illegible].

[illegible] 4.5 [illegible] 10 [illegible].

[illegible] $\xi \approx 0.66$. [illegible]



[illegible] 10. [illegible]

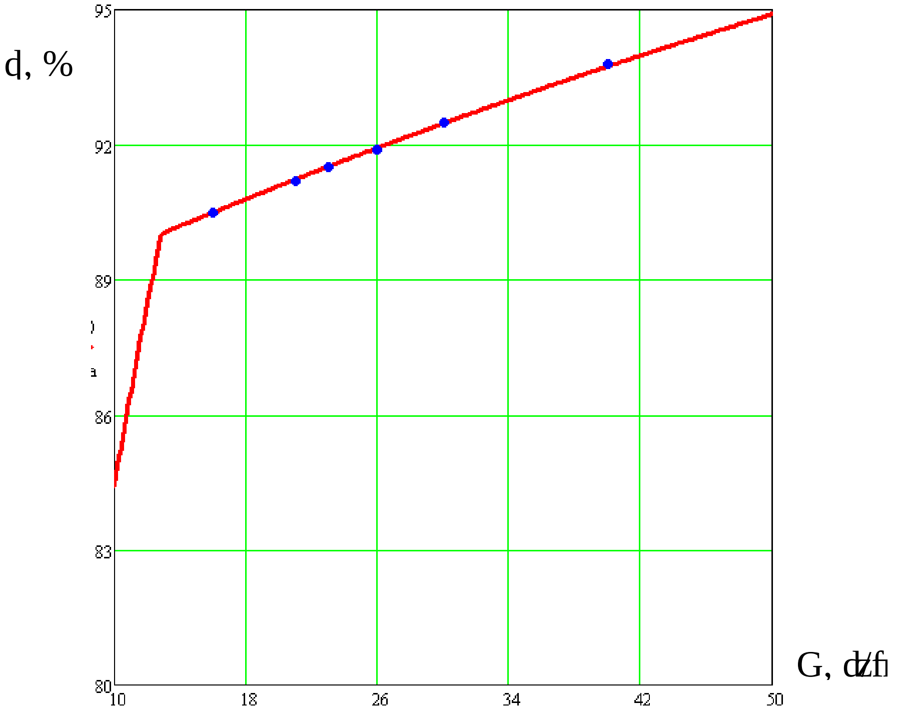
[illegible] 1

[illegible] 400.

[illegible]	[illegible]	[illegible], %
0é 10	5	12,0
10é 20	15	36,2
20é 30	25	19,39
30é 40	35	17.2
40é 50	45	12.8
50é 60	55	0,3
60é 70	65	1,2
70é 80	75	0,8
80é 90	85	0,3
90é 100	95	1.2

[illegible] 4.6 [illegible] 400. [illegible] 400 [illegible] 1.

[illegible] 11 [illegible] LK 07 [illegible].



[illegible] 11. [illegible]

[illegible]

[illegible]

ONE TIME SCIENTIFIC COUNCIL ON THE BASE OF SCIENTIFIC COUNCIL ON AWARD OF SCIENTIFIC DEGREE OF DOCTOR OF SCIENCES 16.07.2013.T/FM.02.02 AT TASHKENT STATE TECHNICAL UNIVERSITY AND NATIONAL UNIVERSITY OF UZBEKISTAN

SCIENTIFIC RESEARCH CENTRE FOR SECTORIAL MACHINES SCIENCE AT THE TASHKENT STATE TECHNICAL UNIVERSITY

MALIKOV ZAFAR MAMATKULOVICH

DEVELOPMENT OF HIGH-PERFORMANCE CENTRIFUGAL DUST CATCHERS ON THE BASIS OF AERODYNAMIC PROCESSES

01.02.05 ï Mechanics of fluid and gas (technical sciences)

ABSTRACT OF DOCTORAL DISSERTATION

TASHKENT ï 2016

The theme of doctoral dissertation is registered the Supreme Attestation Commission of the Cabinet of Ministers of the Republic of Uzbekistan in № 12.05.2015/B2015.1.T463.

The doctoral dissertation was completed at scientific research centre for sectorial machines science at the Tashkent state technical university.

The abstract of dissertation are in three languages (Uzbek, Russian, English), posted on the web page at www.tdtu.uz and in informational-educational portal of «ZiyoNet» at (www.ziyonet.uz).

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Official opponents:	**Ravshanov Normahmat** Doctor of sciences in technics
	Shokirov Anvar Odilovich Doctor of sciences in technics, professor
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O'ZBEKISTON RESPUBLIKASI OLIY VA O'RTA MAXSUS TA'LIM VAZIRLIGI ABU RAYHON BERUNIY NOMIDAGI TOSHKENT DAVLAT TEXNIKA UNIVERSITETI

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INTRODUCTION (annotation of doctorial dissertation)

The urgency and relevance of the theme of the dissertation. Rapid development of the industry in the world along with the growth of goods production has led to an increase in negative impact of production on environment. This, in its turn, sets the new tasks for researchers, including reduction of industrial wastes, reduction of amount of the toxic gases released into the atmosphere. For the last fifty years emissions of carbon compounds into the atmosphere are 9 times greater. As a result of it environment is polluted and there is a global environmental problem.

When solving these problems, preventing environmental disasters and the processes of global warming of climate, the reduction of the impact of industrial emissions into environment becomes very important. Applying in practice of dust cleansing facilities and dust catchers for purification of gas pollutions in environment is an actual task. Dust catchers are necessary not only for purification of industrial gases, but also for ensuring the operation of internal combustion engines in an optimum rhythm. All transport vehicles, used in mining, are operated in the conditions of high dust content. In such conditions, abrasive particles of dust, getting into the working camera of the engine, cause wear of its surfaces and lead to the reduction of engine capacity, and to an increase in fuel consumption and lubricants.

After achieving independence in our country a great attention was paid on localization processes in many fields of industry, including the improvement and development of dust catchers in accordance to climatic conditions of the republic. More than 80% of the dust catchers, used in the industry, are the dust catchers working on centrifugal force. Therefore, carrying out researches on improvement and development of new designs of highly effective dust catchers has a great scientific and practical value.

This dissertation research serves as an accomplishment of the problems provided in the Resolutions of Cabinet of Ministers of the Republic of Uzbekistan No. 232-1 on April 26, 1996 "On approval of the regulations of the Committee on environmental protection" and RP-142 on May 27, 2013 "On action program on environmental protection of the Republic of Uzbekistan for the years 2013-2017".

Compliance of research with priority directions for science and technology development of the country. This study was performed in the compliance with priority direction II of science and technology of the republic: "Energy, energy-saving and resource-savingò.

A review of international research on the subject of dissertation[1].The scientific researches directed to studying of aerodynamic processes of a multiphase flow in dust catchers are carried out in many leading scientific centers of the world, including NASA, Glenn research center, Boeing Scientific Research Laboratories, Massachusetts Institute of Technology, Stanford university (USA), Cambridge university (UK), Hettingen laboratory (Germany), Air Systems Research Center

(Japan), Aerodynamics Research and Development Centre (China), Moscow State University (Russia) and Tashkent State Technical University.

As a result of research all over the world on studying the processes occurring inside the dust catchers, a number of scientific results are received, including: various finite-differential methods and finite-element methods are developed for the numerical solution of the equations for multiphase flows (Stanford university, Boeing Scientific Research Laboratories, Cambridge university, Massachusetts institute of technology, USA); aerodynamic effects for multiphase flows are obtained (Cambridge university, UK); the mathematical model of dynamics of a free turbulent flow in flowing the obstacles is received (Hettingen laboratory, Germany); designs of highly effective vortex dust catchers are built (The Air Systems Research Centre, Japan) are developed; the mechanism of separation of polluted dust particles is developed (China Aerodynamics Research and Development Centre, China), the design of a cascade multistage dust catcher for purification of gases from metallurgical furnaces is developed (Moscow State University).

Researches on a number of priority directions are conducted all over the world on improvement of designs of dust catchers; they include: mathematical modelling of turbulent multiphase flows; development of effective algorithms for the numerical solution of these models; improvement of designs of dust catchers on the basis of the processes of laws of aerodynamics.

Scientific study of the issue. Pioneer works on research of aerodynamics of multiphase medium have been carried out as early as XIX century. However by the XX century, practical value of multiphase flows has medium has gained a considerable development. In 1967 A.Fortie has developed the theory of migration for a multiphase turbulent flow. This theory has gained its further development in the works of European and American scientists (Friedlander, Johnstone, Owen, Davis, Bill, Zemel and others). A serious contribution to the development in this area was made by Uzbek scientist, professor of Moscow University H.A.Rakhmatulin. He is a founder of the theory of interpenetrating motions in multiphase flows. H.A. Rakhmatulin was the first who has derived the system of equations for compressed multiphase medium; he has analyzed the fundamental laws of wave propagation, and has developed the bases of the theory of boundary layer in two-phase mixture. H.A Rakhmatulin's theory has found a wide application in hydraulic engineering, in chemical technology, in nuclear power industry.

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[1] The extent of knowledge of the problem http:/www.nasa.gov/centre/glenn/home/index.html; http://universal_ru_en.academic.ru/66921/; Wildes, Karl L.; Lindgren, Nilo A. (2005). A Century of Electrical Engineering and Computer Science at MIT, 2006-2009. Cambridge, Mass.: MIT Press. ISBN 9780262231190; Stuart W. Leslie: The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford. Columbia University Press, New York [u. a.] 1993, ISBN 0-231-07958-3; http://www.mod.go.jp/trdi/en/research/kenkyu_koukuu_en.hyml; University of Cambridge (ed.). "The Revived University of the Nineteenth and Twentieth Centuries" Retrieved 7 August 2014; http://www.utias.utoronto.ca; http://www.cards.cn:88; http://universal_ru_en.academic.ru/240165; [illegible] 1 2. [illegible] ., 1955; [illegible], 2008. 480 [illegible] ISBN 5-02-007017-3; [illegible] // [illegible] .: [illegible], 1971; [illegible] // [illegible], 1956, [illegible] 20; [illegible] //[illegible], 1987; Faizullaev D.F. Laminar motion of multiphase media in conduits.//Consultants bureau, New York, 196.

To name another scientist, who has made an essential contribution to the development of the theory of multiphase flow we should mention academician R. I. Nigmatullin. Under supervision of H.A.Rakhmatullin, R.I.Nigmatullin has considered the mathematical models of particles interaction and has completed the system of equations of multiphase mixture. An essential contribution to the development of laminar currents of multiphase continua in Uzbekistan the was made by professor Zh.F. Fayzullayev.

Despite serious achievements of researches in the field of multiphase flows, there are a lot of unresolved problems. For example, the strict mathematical equations for a turbulent flow of multiphase continua are not derived yet. The existing mathematical models have mainly an empirical character and not always adequately describe the arising phenomena in turbulent multiphase continua. It can be observed especially in twirled flows inside centrifugal dust catchers.

Connection of the dissertation theme with the plans of scientific researches. Dissertation research is executed within the plan of research works of fundamental projects of Scientific research center on sectorial machines science at Tashkent state technical university F.13-12 on the subject "Processes of Heat Transfer and Concentration of Weighed Particles in a Turbulent Jet Flow" (2012-2014), and economic contracts No. 02-1541 ƽ ʈ. "Development and trial testing of a vortex dust catcher in zinc plant JSC AMMC" (2010-2011), No. 02-2180 ƽ ʈ. "Upgrade and implementation of the inertial filter for the underground motor transport working in the conditions of high dust content" (2011-2012), No. 02-2092 ƽ ʈ. "Development of highly effective air cleaner for engines of heavy-load rock dump trucks" (2012-2013), No. 14/2012 "Implementation of the inertial air cleaner for engines of NMMC vehicles" (2012-2013), No. 02-1466 ƽ ʈ. "Industrial testing with development of a set of design documentation and implementation of the inertial air cleaner for internal combustion engines of heavy-load cars" (2013-2014).

The aim of the research is a development of industrial highly effective centrifugal dust catchers, and air cleaners for engines of vehicles and special equipment on the basis of the theory of aerodynamics of multiphase continua.

Research problems:

mathematical modelling of dynamics of flow in a centrifugal dust catcher on the basis of the equations of hydrodynamics;

development of a numerical method of calculation of the equations of hydrodynamics;

on the basis of numerical experiment, the search of optimum parameters and elements of the centrifugal dust catcher providing a continuous flow;

increasing the efficiency of the devices of gas flow swirling;

modelling of processes in aerosols flow on the basis of kinetics;

development of methods of determination of resistance and efficiency of centrifugal dust catcher;

development of an optimization method of geometrical parameters of a dust catcher;

on the basis of research results the development of modernized, highly effective centrifugal dust catcher.

The objects of the research are dust catcher devices used in the industry, and air cleaners for internal combustion engines.

The subject of the research is the design, technical and economic characteristics of industrial centrifugal dust catchers and air cleaners for internal combustion engines.

Research methods. In the dissertation the methods of numerical research of one and two-phase medium, methods of analytical analysis of derived equations are applied, laboratory testing of the received results is conducted.

Scientific novelty of the research consists in:

the new design of a screw dust catcher is developed;

the new design of the air cleaner working on a basis of centrifugal force for engines is developed;

the method of determination of aerodynamic parameters of a flow inside a dust catcher is improved;

the mathematical model of processes of mass and heat transfer in aerosol flow on the basis of the kinetic theory is improved;

the methods of determination of efficiency and aerodynamic resistance of a dust catcher are improved;

the method of determination of optimum parameters of a dust catcher is developed.

Practical results of the dissertation.

Industrial screw dust catchers and air cleaners working on a basis of centrifugal force for internal combustion engines are developed.

Reliability of obtained results is proved by correct mathematical statement of the problems of hydrodynamics, by the use in numerical solution of the equations of proved methods and known algorithms to build a design program, and by a comparison of theoretical and numerical results with experimental data.

Theoretical and practical importance of the research results.

The scientific importance of results of research is determined in their application in case of mathematical modelling of multiphase continua and the numerical solution of constructed equations.

The practical importance of work serves for the development of highly effective industrial dust catcher and air cleaners for **internal combustion engines.**

Implementation of the research results. On the basis of results of research of aerodynamic processes in industrial dust catchers and air cleaner:

screw dust catchers are implemented at "Limy plant" of Almalyk mining and metallurgical combine joint-stock company (the certificate on November 18, 2015 of Almalyk mining and metallurgical combine joint-stock company No. FM-7222). Efficiency of the implemented dust catchers was 15-16% higher, than at serial dust catchers and has allowed to catch additionally about 210-243 tons of dust per year;

air cleaners for internal combustion engines are implemented in mine machines in Angren mine administration of Almalyk mining and metallurgical combine joint-stock company, on the dump trucks BelAZ and diesel locomotives of the State Entity of the Navoiy mining and metallurgical combine (the certificate on November 18, 2015 of the AGMK joint-stock company No. FM-7222). The implemented air cleaners have allowed 2 times increase of enginesô life.

Approbation of research results. Results of research have passed an approbation at 4 international and republican scientific and technical conferences, including: "Proceedings of XVIII Scientific readings on astronautics devoted to reminiscence of outstanding scientists-pioneers of development of a space" (Moscow, 1994); "Geo-technology: innovative methods of subsurface use in the 21st century" (Moscow, 2007); "Modern equipment and technology of a mining and metallurgical industry and way of their development" (Navoi, 2008); "Energy saving, energy efficiency and renewable energy resources" (Tashkent 2015).

Publication of research results. 29 scientific works are published, including 14scientific articles (4 in foreign editions), 1 patent for the invention on the topic of dissertation.

Structure and scope of dissertation. The dissertation consists of the introduction, four chapters, conclusion, the list of references of 149 titles and an appendixes; it contains 184 pages of typewritten text, including 65 figures, 3 tables.

MAIN CONTENT OF DISSERTATION

In the introduction the urgency and relevance of the work are substantiated, the purpose and tasks, and also object, a subject and methods of research are formulated, compliance of researches to the priority directions of development of science and technologies of the Republic of Uzbekistan is given, scientific novelty and practical results of research are stated, reliability of the received results is proved, reveal the theoretical and practical importance of the received results, results of introduction of dissertation work are given to practice, data on approbations and the published works, structure and volume of the thesis.

In the first chapter of the thesis **"review of industrial dust catchers and air cleaners for internal combustion engine"** characteristics of all types of industrial dust catchers and air cleaners are given, used for air cleaning in internal combustion engine technology. Their strong points and shortcomings are considered in details. Substantiation for the development of inertial centrifugal dust catchers and air cleaners, which can be used in almost all industrial processes, is given.

Principal scheme of the centrifugal dust catcher is illustrated in Figure 1. The principle of operation of centrifugal dust catcher consists in: dusty air flow in air inlet acquires rotational velocity and enters into circular channel - between the casing and the pipe for withdrawal of clean air. Solid particles due to centrifugal force are pressed to the body of the dust catcher, further moving along the inner cone surface, then enter the bunker, and the air, cleaned from the particles, flows into outlet pipe.

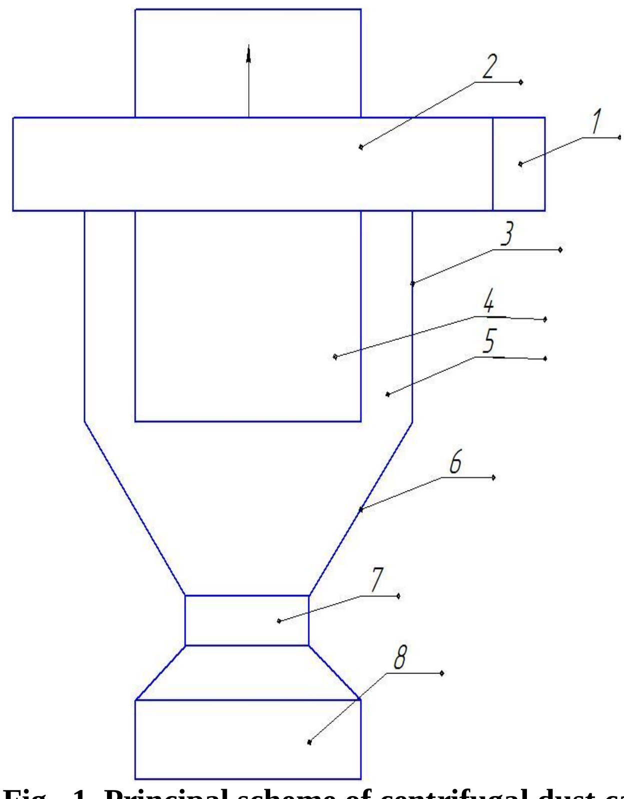

Fig. 1. Principal scheme of centrifugal dust catcher

1 - a window to feed dusty air into dust catcher, 2 - air inlet for swirling air flow, 3 - the case of the dust catcher, 4 - pipe for withdrawal of cleaned air, 5 - separated dust, 6 ï cone section of dust catcher, 7 - a pipe to damp air flow velocity, 8 - a bunker for collected dust.

Existing centrifugal dust catchers of mass production, have productivity no more than 75%. Therefore, in this chapter problems whose solutions lead to the development of high-performance centrifugal industrial dust catchers and air cleaners for different vehicles are formulated. To achieve this goal, it is necessary first to start exploring the aerodynamics of the air flow inside the centrifugal dust catcher. There for in the second chapter **"aerodynamic processes occurring inside the centrifugal dust catcher"**, based on the system of Euler equations, the characteristics of flow in different parts of centrifugal dust catcher are studied.

In Section 2.1, a numerical study of the system of Euler equations in the conical part of the dust catcher is carried out (Figure 2). For stationary solution of the system of equations, we have used the method of establishing. The essence of this method lies in the fact that non-stationary problem is solved and at high values of time its solution tends to the solution of stationary problem.

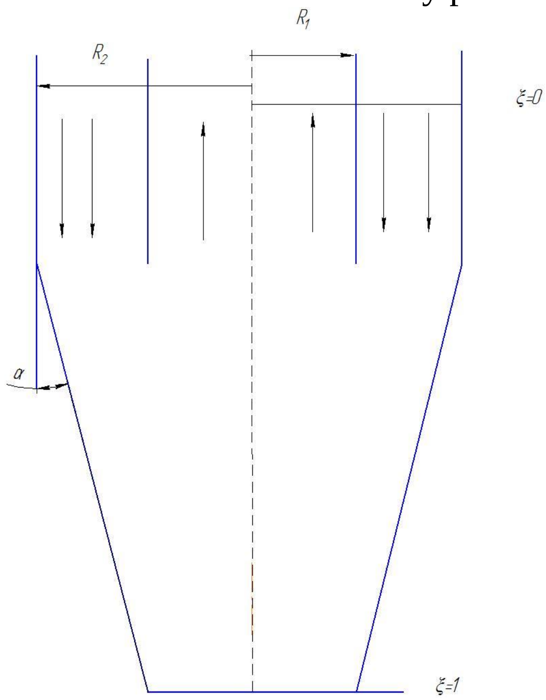

Fig 2. Vertical section of centrifugal dust catcher

Stream flow region has axial symmetry, so the system of equations is studied in cylindrical coordinates (z, r, φ).The system of the equations of aerodynamics in cylindrical coordinates has an appearance:

$$\begin{cases} \dfrac{\partial(r\upsilon_z)}{\partial z} + \dfrac{\partial(r\upsilon_r)}{\partial r} = 0, \\ \dfrac{\partial \upsilon_z}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_z}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_z}{\partial r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial z} = 0, \\ \dfrac{\partial \upsilon_r}{\partial t} + \upsilon_z \dfrac{\partial \upsilon_r}{\partial z} + \upsilon_r \dfrac{\partial \upsilon_r}{\partial r} - \dfrac{\upsilon_\varphi^2}{r} + \dfrac{1}{\rho}\dfrac{\partial p}{\partial r} = 0. \end{cases} \tag{1}$$

For numerical research of this system of the equations, introduced the parameters of flow function $-\psi$, vortex of flow $-\zeta$, flow circulation $-\Gamma$. These parameters with components of flow velocity are related as follows:

$$\upsilon_r = -\frac{1}{r}\frac{\partial \psi}{\partial z}, \quad \upsilon_z = \frac{1}{r}\frac{\partial \psi}{\partial r},$$
$$\zeta = \frac{\partial \upsilon_r}{\partial z} - \frac{\partial \upsilon_z}{\partial r}, \quad \Gamma = r\upsilon_\varphi. \qquad (2)$$

After substitution of new variables, the system of equations of aerodynamics will be

$$\begin{cases} \dfrac{\partial \zeta}{\partial t} + \dfrac{\partial \upsilon_r \zeta}{\partial r} + \dfrac{\partial \upsilon_z \zeta}{\partial z} = \dfrac{\partial}{\partial z}\dfrac{\Gamma^2}{r^3}, \\ \dfrac{\partial \Gamma}{\partial t} + \upsilon_r \dfrac{\partial \Gamma}{\partial r} + \upsilon_z \dfrac{\partial \Gamma}{\partial z} = 0, \\ \dfrac{\partial^2 \psi}{\partial z^2} + \dfrac{\partial^2 \psi}{\partial r^2} - \dfrac{1}{r}\dfrac{\partial \psi}{\partial r} = -r\zeta. \end{cases} \qquad (3)$$

Further, conversion of variables is made for convenience of setting of boundary conditions:

$$\xi = z, \qquad \eta = \frac{r}{R(z)}, \qquad R(z) = R_2 - z\,tg\alpha.$$

As a result of transformations, the system of Euler equations is reduced to:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial \upsilon_z \zeta}{\partial \xi} + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} + \frac{1}{R(\xi)}\frac{\partial \upsilon_r \zeta}{\partial \eta} =$$
$$= \frac{\partial}{\partial \xi}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right) + \frac{\eta tg\alpha}{R(\xi)}\frac{\partial}{\partial \eta}\left(\frac{\Gamma^2 R^3(\xi)}{\eta^3}\right)$$
$$\frac{\partial \Gamma}{\partial t} + \upsilon_z \frac{\partial \Gamma}{\partial \xi} + \left(\upsilon_z \frac{\eta\, tg\alpha}{R(\xi)} + \frac{\upsilon_r}{R(\xi)}\right)\frac{\partial \Gamma}{\partial \eta} = 0, \qquad (4)$$
$$\frac{\partial^2 \psi}{\partial \xi^2} + 2\frac{\eta\, tg\alpha}{R(\xi)}\frac{\partial^2 \psi}{\partial \xi \partial \eta} + \left[\frac{1}{R^2(\xi)} + \frac{\eta\, tg^2\alpha}{R^2(\xi)}\right]\frac{\partial^2 \psi}{\partial \eta^2} +$$
$$+ \left[2\frac{\eta\, tg^2\alpha}{R^2(\xi)} - \frac{1}{\eta}\right]\frac{\partial \psi}{\partial \eta} = -\eta R(\xi)\zeta,$$
$$\upsilon_r = \frac{-1}{\eta R(\xi)}\frac{\partial \psi}{\partial \xi} - \frac{tg\alpha}{R^2(\xi)}\frac{\partial \psi}{\partial \eta}, \quad \upsilon_z = \frac{1}{\eta R^2(\xi)}\frac{\partial \psi}{\partial \eta}.$$

Boundary conditions for this system are determined on the section $\xi = 0$ (Fig.1), which is positioned on some distance from the cone end.

a) The range $\frac{R_1}{R_2} \le \eta \le 1$ corresponds to co-axial channel from which swirling flow enters. The following conditions are stated for entering flow:

$$\psi = \frac{V(\eta^2 R_2^2 - R_1^2)}{2}, \quad \Gamma = \omega \eta^2 R_2^2, \quad \zeta = 0, \quad \upsilon_z = V, \quad \upsilon_r = 0 \qquad (5)$$

Here V, ω ï are longitudinal and angular flow velocities, respectively. Numerous tests have shown $\omega = const$.

b) Condition $0 < \eta < \frac{R_1}{R_2}$ corresponds to flow outlet. Extrapolation conditions are stated here :

$$\frac{\partial^2 \zeta}{\partial \xi^2} = 0, \quad \frac{\partial^2 \Gamma}{\partial \xi^2} = 0, \quad \frac{\partial^2 \psi}{\partial \xi^2} = 0. \qquad (6)$$

These conditions are standard devices in numeric realization of hydrodynamic equations in the outlet. $\xi = 1$ corresponds to the section located far from the cone end. Conditions in this section are as follows:

c) for $0 < \eta < 1$: $\psi = \psi_2$; $\Gamma = \Gamma_2$; $\zeta = \zeta_2$. Here the index 2 refers to external pipe and the cone.

For numerical solution of the equation of transfer of flow circulation of the system (1) McCormackôs finite-difference scheme is used, which, being a two step scheme, has an accuracy of second-order $O(\Delta t^2, \Delta\xi^2, \Delta\eta^2)$. For numeric solution of the equation of flow function an iterative method of upper relaxation towards η and runs along $\xi_{i.}$ are used. As an initial condition for considered non-stationary problem the solution of stationary potential flow is used.

Figure 3 shows the flow lines, obtained by numerical solution of the problem.

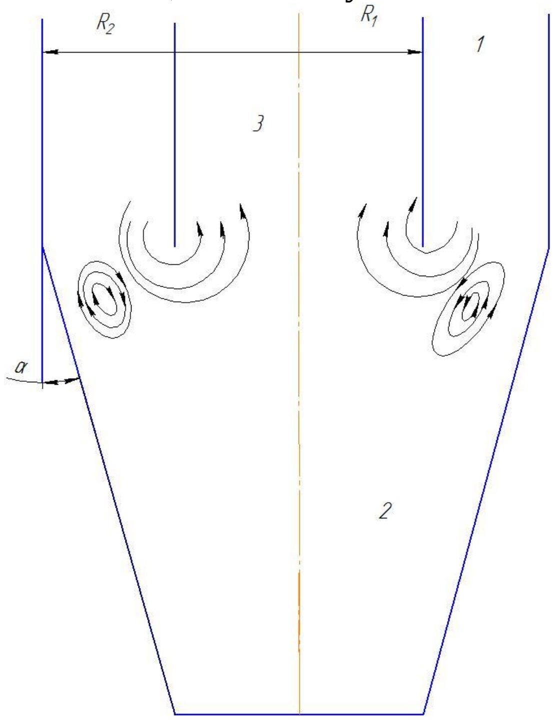

Fig.3.Flow lines inside the dust catcher

As can be seen from the figure the zone of backflow is formed. This vortex is due to flow separation. However, in numeric experiment the range of cone angle was found, at which the intensity of reverse flow is reduced considerably. Numeric experiments show that this happens when $8^0 \le \alpha \le 13^0$.

The resulting vortex negatively affects the efficiency of equipment, as dust particles pressed to the wall, are thrown back. As a result, dust particles enter into the inlet of withdrawal pipe, instead of moving along the cone wall into the bunker, which lies at the end of the cone. The experiments showed that the choice of the optimum angle of the cone can increase the efficiency of centrifugal dust catcher from 40% to 75%. The reason of reverse flow, from the point of physics, is the source of the vortex in the right side of the first equation of the system (1). In Section 2.2 it is theoretically shown that it is possible to minimize this source, if to use screw conveyor channel as a swirling element of air. As a result, a screw-conveyor dust catcher is designed (Figure 4).

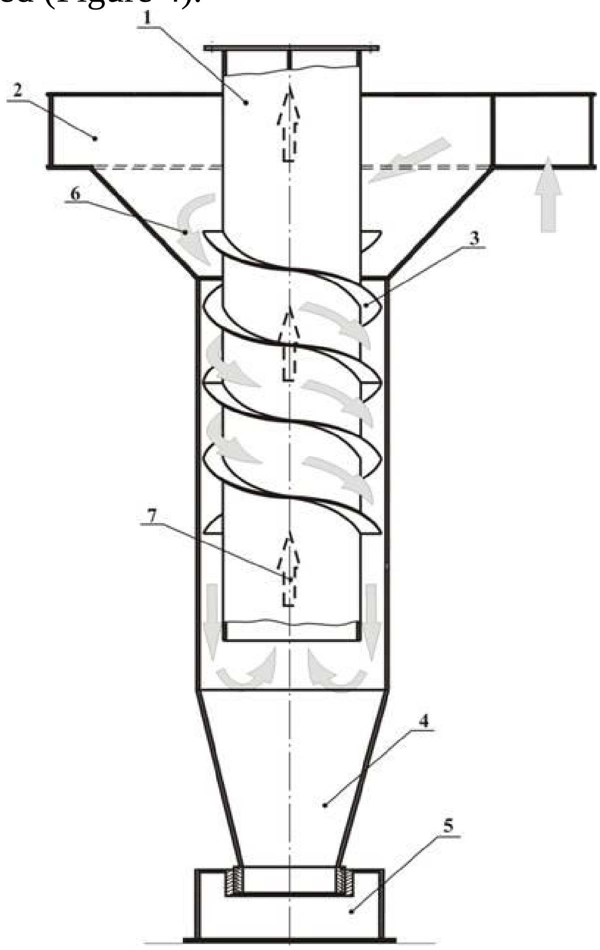

Fig. 4. Principal scheme of screw-conveyor dust catcher

1- withdrawal pipe for cleaned gas, 2 - air intake, 3 ï screw-conveyor to swirl the flow, 4 - cone of separation zone, 5 ï a bunker for collected dust, 6 - gas flow 7 ï flow direction of cleaned gas.

Designed screw-conveyor dust catchers with productivity of 0.9 m^3/s each (32 in number) are set in lime plant of AGMK and have demonstrated the efficiency of 85%. At the same time performance indicator of serial cyclones CN-15 is 69%, with similar air-dynamic resistance.

Despite the advantage of dust collecting by screw-conveyor dust catchers when compared with centrifugal inertial cyclones, they still have a number of drawbacks. The first drawback - it is complicated in manufacturing, the second ï it is still not efficient enough, and the third - it cannot be used for the dust, which has strong adhesion to the surfaces as there is a high probability of clogging of the screw conveyor channel with dust. The latter drawback of dust catcher greatly reduces its range of application. This drawback has pushed the researchers to develop a good design of a dust catcher with minimal probability of dust adhesion. In this regard, the structure of cyclone seems an attractive one. The main problem is to find a solution for the problem - to minimize the reverse vortex. In Section 3.2 another way to solve this problem is described. Simple and very effective solution proved to be a simple branch pipe that is inserted into the inlet pipe to withdraw cleaned air (Figure 5).

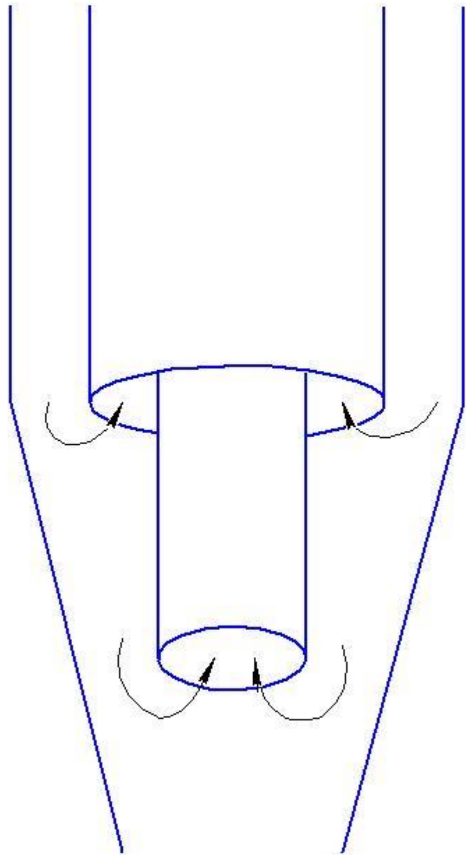

Fig.5. Centrifugal dust catcher with stabilizer

The effect of this branch pipe consists in the fact that it re-distributes the incoming air flow into withdrawal pipe. As a result, this reduces the possibility of flow separation, i.e. the flow is stabilized. Therefore, this element is called a stabilizer. In this section, a numerical study of aerodynamic flow inside the dust catcher with this element is carried out; and it is shown that the stabilizer does reduce the intensity of the reverse vortex.

Stabilization of the flow and consequently the efficiency of centrifugal dust catcher is strongly influenced by the design of air intake. It is the swirl element of dust catcher. Therefore, in the fourth paragraph of the second chapter, the analysis of all known types of air intakes is performed. To twist the incoming air flow to dust catcher a number of principles of gas feeding is used: a) spiral, b) tangential c) screw-like, 4) outlet with gas return, 5) direct-flow outlet (Figure 6).

In this section we give a mathematical proof of the advantages of spiral intake compared with others. Therefore, this type of air intake further was used to create a highly efficient dust collectors and air cleaners. As a result, the efficiency of the laboratory centrifugal dust catcher was increased up to 96%. In order to increase the efficiency of dust catcher an extensive literature and patent analysis of inertial dust catchers and air cleaners was conducted in recent years. The use of different elements and devices described, did not lead to the desired result. This shows that a further increase in efficiency due to air flow stabilization only does not seem possible. Therefore there is a need to study the transport processes of dust particles, considered in the third chapter of the thesis

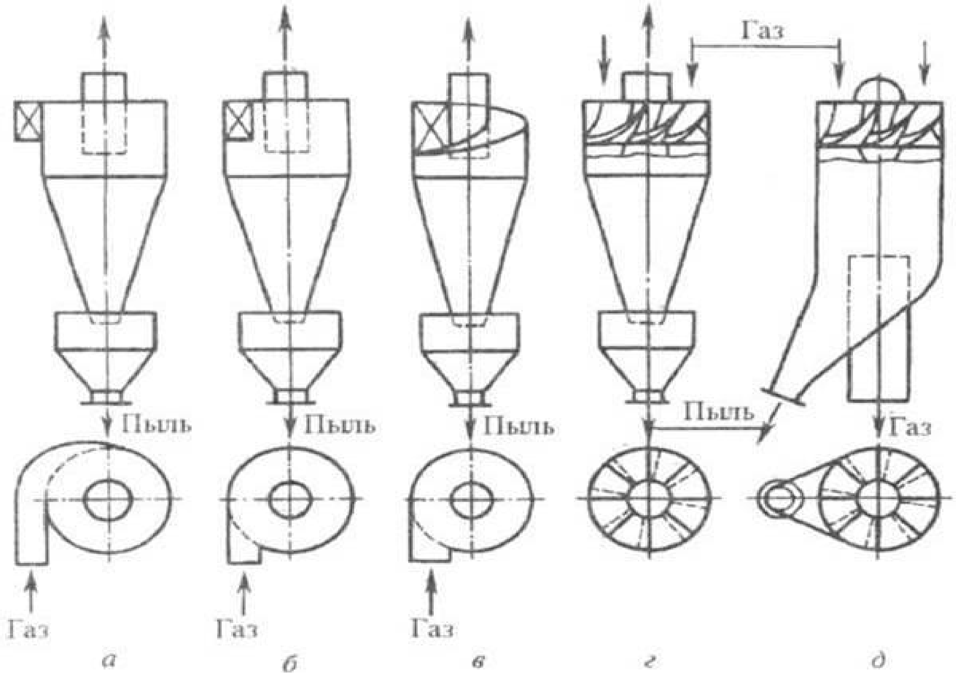

Fig. 6. Types of gas feeding into centrifugal dust catchers

In the third chapter **"dynamics of dust particles and aerosols in the centrifugal dust catcher"** the dynamics of dust particles and aerosols in the centrifugal dust catcher is considered.

Section 3.1 deals with the properties and characteristics of turbulent flow. It is shown that centrifugal flow inside the dust box is turbulent. However, this turbulence is manifested in the boundary layer, where dust particles are accumulated. Therefore, for the mathematical modeling of multiphase jet inside dust catcher it is proposed to divide the flow domain into two zones: the main one and close-to-wall one. In the main area, far from the wall, the turbulence has a small-scale character. Therefore, in this zone for the mathematical description of air flow Euler equation can be used. A motion of bearing flow and particles in close-to-wall zone is chaotic in nature; consequently diffusive transfer of substances prevails in this zone.

Section 3.2 presents an analysis of all the forces acting on the dust particles in the main zone of flow. Their assessment is conducted and it is shown that the main forces are centrifugal and hydrodynamic ones; other forces can be neglected.

It often happens that, along with solid dust particles it is necessary to collect aerosol droplets as well. Aerosols can appear due to condensation of industrial gases emitted to the atmosphere. Apart from the natural condensation of gases aerosols may appear in wet-inertial dust catcher, as in such dust catchers dusty flow is wetted with water. Therefore, in Section 3.3 the dynamics and heat mass transfer of small aerosols are examined in the approximation of free-molecular flow by gas stream. Calculation formulas which can be used for design of various dust catchers are obtained

In Section 3.4 the process of transfer of solid phase in close-to-wall zone is examined. As mentioned above, transfer process in this zone is of diffuse nature. Therefore, to determine the diffusion coefficient the problem - the dynamics of two-phase turbulent submerged jet and transfer processes - was analytically solved. To solve the problem, hydrodynamic equations for two-phase jet in spherical coordinates r, θ were considered:

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2 V_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta V_\theta) = 0,$$

$$V_r\frac{\partial\rho_p}{\partial r} + \frac{V_\theta}{r}\frac{\partial\rho_p}{\partial\theta} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(Dr^2\frac{\partial\rho_p}{\partial r}\right) + \frac{1}{r^2\sin\theta}\frac{\partial}{\partial\theta}\left(D\sin\theta\frac{\partial\rho_p}{\partial\theta}\right),$$

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\Pi_{rr}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\,\Pi_{r\theta}) - \frac{\Pi_{\theta\theta}+\Pi_{\varphi\varphi}}{r} = 0, \quad (7)$$

$$\frac{1}{r^2}\frac{\partial}{\partial r}(r^2\Pi_{r\theta}) + \frac{1}{r\sin\theta}\frac{\partial}{\partial\theta}(\sin\theta\,\Pi_{\theta\theta}) + \frac{\Pi_{r\theta}-\Pi_{\varphi\varphi}\,ctg\theta}{r} = 0.$$

In the system (7) tensors of flow impulses are:

$$\Pi_{rr} = p + (\rho+\rho_p)V_r^2 - 2\nu_t(\rho+\rho_p)\frac{\partial V_r}{\partial r} - 2DV_r\frac{\partial\rho_p}{\partial r},$$

$$\Pi_{\theta\theta} = p + (\rho+\rho_p)V_\theta^2 - 2\nu_t(\rho+\rho_p)\left(\frac{1}{r}\frac{\partial V_\theta}{\partial\theta} + \frac{V_r}{r}\right) - 2D\frac{V_\theta}{r}\frac{\partial\rho_p}{\partial\theta},$$

$$\Pi_{\varphi\varphi} = p - 2\nu_t(\rho+\rho_p)\left(\frac{V_r}{r} + \frac{V_\theta\,ctg\theta}{r}\right), \quad (8)$$

$$\Pi_{r\theta} = (\rho+\rho_p)V_rV_\theta - \nu_t(\rho+\rho_p)\left(\frac{1}{r}\frac{\partial V_r}{\partial\theta} + \frac{\partial V_\theta}{\partial r} - \frac{V_\theta}{r}\right) - D\left(\frac{V_r}{r}\frac{\partial\rho_p}{\partial\theta} + V_\theta\frac{\partial\rho_p}{\partial r}\right).$$

Here $p, \rho, \rho_p, V_r, V_\theta, \nu_t, D$ are the pressure, density of the gas medium, the density of the solid phase, the two components of the velocity, the kinematic viscosity and the diffusion coefficient of the multiphase turbulent flow, respectively.

In the thesis auto-model solutions of the first two approximations for the system of equations (7) were obtained. It was proved that the obtained solutions exist when coefficients of viscosity and diffusion of two-phase flow have the form:

$$\nu_t = \frac{\nu_0}{1 - \frac{2 - Sc}{2}\frac{\rho_p}{\rho}}, \quad D = \frac{\nu_0}{Sc\left(1 - \frac{2Sc - 1}{2Sc}\frac{\rho_p}{\rho}\right)} \qquad (9)$$

In these expressions, Sc ï is a Schmidt number, ν_0 - kinematic turbulent viscosity of the pure gas flow. The resulting solution generalizes the known solutions for pure gas by L.D. Landau and Yu.B. Rumer. For most of the dust particles it can be assumed that Sc = 1. Formula (3) is used to calculate the diffusion transfer of dust particles in close-to-wall region. As a result, the percentage of dust η is determined depending on the distance - Δ:

$$\eta = 1 - e^{-u\,\Delta/\nu_0} \qquad (10)$$

Here u - is a radial velocity which dust particles gain due to centrifugal force. It is shown that for dust catcher with a withdrawal pipe of the radius $R_1 = 5$ ***fg3*** and the body of the radius of the $R_2 = 10$ ***fg3***, about 87% of dust particles with a diameter of 5mcm will be contained in the layer of $\Delta \approx 2\,sm$ thickness. It can be seen that the dust layer takes quite a lot of space. The appearance of this layer adversely affects the efficiency of the dust catcher, because dust particle are sucked into the withdrawal pipe from the upper region of the layer. Therefore, reduction or elimination of the dust layer is another way to increase the efficiency of dust catcher device. This issue has been successfully solved in proposed dust catcher. The dust catcher is illustrated in Figure 7. The principle of this device consists in the fact that the flow of cleaning air in spiral air intake 1 acquires rotary motion, and as a result of the centrifugal force dust particles are pressed to the case 3, then, after coagulation they become larger and form a dust layer; then by momentum they fall into the space between the 3, 10, 11, 6 and 5. This space forms a bunker for particles of large and medium sizes. Mainly large and medium-sized dust particles fall into this bunker. Smaller ones go into cone part of air cleaner 5. There the stream before entering the bunker for fine particles strikes the reflector, whereby air flows into the outlet pipe, and dust particles fall into inner bunker.

High efficiency of dust collection of this unit is achieved due to the fact that in a bunker for large and medium particles about 90% of the dust is accumulated, so in cone section the thickness of dust layer is substantially reduced compared to the case with no external bunker. A decrease in the thickness of dust layer in the cone leads to a reduction of dust particles withdrawal into outlet pipe. As a result of this phenomenon, the effectiveness of laboratory air cleaner has increased from 96% up to 99%.

The fourth chapter - **"Method of calculation of aerodynamic resistance, optimal parameters and efficiency of air cleaner"** of the thesis - is devoted to the study of aerodynamic resistance, efficiency and optimization of the parameters of centrifugal dust catchers.

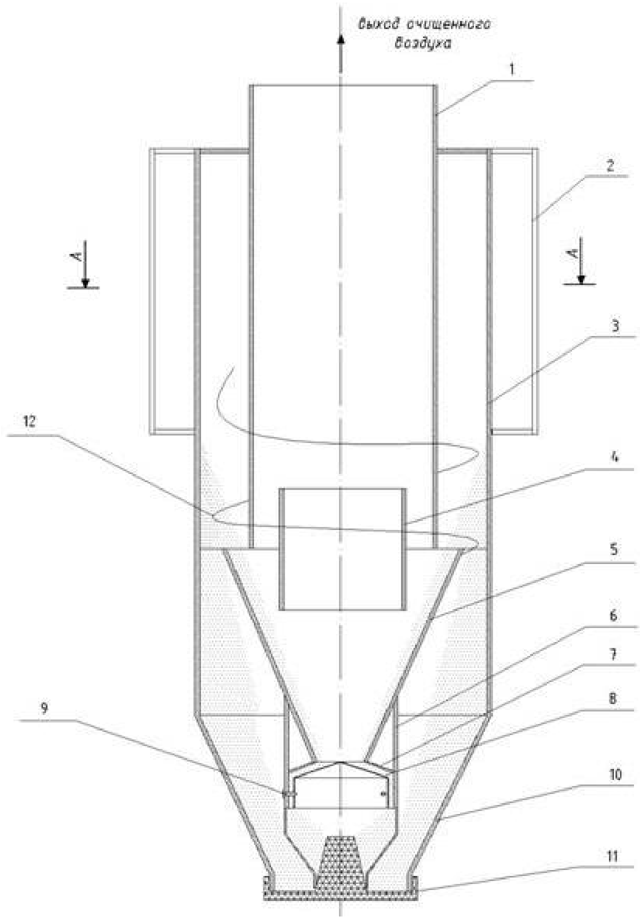

Fig. 7. Principal scheme of proposed dust catcher

1- pipe to withdraw cleaned air, 2 - spiral air intake, 3 ï body, 4 ï branch pipe to stabilize the flow of air, 5 - cone to collect fine particles, 6 - the case of the bunker for fine particles, 7 - expanding cone, 8 - reflector 9 - a fixing bolt, 10 - cone to collect large particles, 11 ï bunker cover, 12 - trajectory of the flow

In Section 4.1, to calculate the aerodynamic resistance of dust catcher, stream flow region is divided into 5 zones (Fig. 8): 1 - the zone of spiral inlet, 2 - the zone where the flow acquires rotational motion and translational velocity directed downwards, 3 ï zone of coaxial channel, 4 ï the zone where the flow is reversed and flows into outlet pipe, 5 ï the zone of stream flow in outlet pipe. Full aerodynamic resistance of air cleaner is the sum of pressure losses in these zones. To calculate the aerodynamic resistance (total pressure drop) of dust catcher for a given productivity - G (l/s) the following calculation formulas are derived:

$$\xi = r_1 / r_2, \quad D_{эп} = 2a_0 b_0 / (a_0 + b_0), \quad D_{эгп} = 2ab/(a+b) \qquad (11)$$

Flow velocity on the entrance into air inlet is

$$U_0 = \frac{G}{2a_0 b_0} \qquad (12)$$

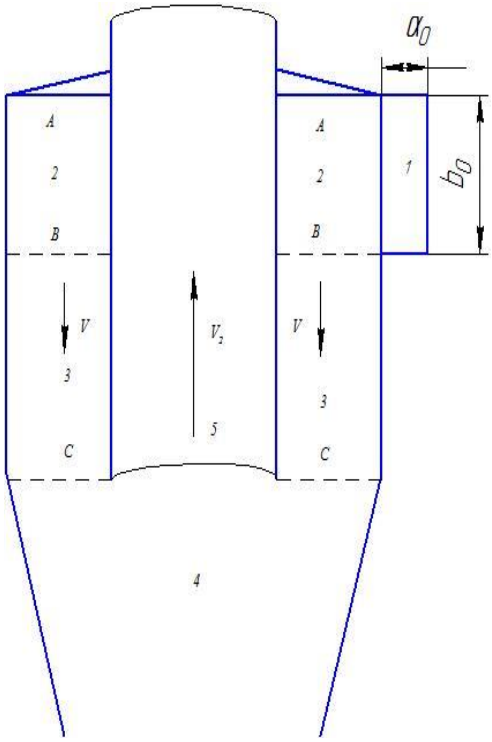

Fig. 8. Vertical section of centrifugal dust catcher

Flow velocity on withdrawal from air inlet is

$$U_1 = \frac{G}{2ab} \tag{13}$$

Reynoldsô number on the entrance into air inlet - $\mathrm{Re}_0 = \dfrac{U_0 D_{э}}{\nu}$, friction co-efficient - $\lambda_0 = 0.11\left(\dfrac{\Delta_{э}}{D_{э}} + \dfrac{68.5}{\mathrm{Re}_0}\right)^{0.25}$. Roughness of air cleaner walls for ventilation pipes is taken as equal to $\Delta = 0.15\,mm$.

Frictional resistance of air inlet is

$$\Delta p_1 = \lambda_0 \frac{2\rho U_0^2}{9\beta + 3\alpha} \frac{l}{D_{э}} \left[\exp\left(\frac{9\beta + 3\alpha}{4}\right) - 1\right]. \tag{14}$$

Here, $\alpha = \ln(D_{э} / D_{э'})$, $\beta = \ln(U_1 / U_0)$.

Longitudinal velocity in circular channel equals to

$$V = \frac{G}{\pi(r_2^2 - r_1^2)}. \tag{15}$$

Pressure drop at flow transportation from air inlet into co-axial pipe is:

$$\Delta p_2 = \frac{\rho U_1^2 (1 - \xi^2)}{2} + \frac{\rho V^2}{2}. \tag{16}$$

Initial angular velocity of flow - $\omega_0 = k \dfrac{U_1}{r_2}$.

Effective diameter of circular channel ï $D_{э} = 2(r_2 - r_1)$.

Reynoldsô number in circular channel ï $\mathrm{Re} = \dfrac{D_{\iota\text{ж}}\sqrt{V^2 + 0.25\omega_0^2 (r_2 + r_1)^2}}{\nu}$.

Friction coefficient ï $\lambda_0 = 0.11\left(\dfrac{\Delta_\iota}{D_{\iota\text{ж}}} + \dfrac{68.5}{\mathrm{Re}}\right)^{0.25}$.

Pressure drop in co-axial channel: $K(\xi) = \dfrac{\lambda\omega_0 L}{2V}\dfrac{1+\xi^4}{1-\xi^4}$,

$$\Delta p_3 = \lambda\frac{\rho V^2}{2}\frac{L}{D_\iota} + \frac{\rho\,\omega_0^2 r_2^2}{4}(1+\xi^2)\left(1 - \frac{1}{(1+K(\xi))^2}\right). \qquad (17)$$

Pressure drop at flow turn into withdrawal pipe:

$$\Delta p_4 = \frac{\rho V^2}{2}\frac{1-\xi^2}{\xi^4} + \frac{\rho\omega_1^2 r_2^2}{2}. \qquad (18)$$

Angular velocity in withdrawal pipe ï $\omega_1 = \dfrac{\omega_0}{1+K(\xi)}$.

Longitudinal velocity of the flow in withdrawal pipe ï $V_1 = \dfrac{G}{\pi r_1^2}$.

Reynoldsô number in withdrawal pipe ï $\mathrm{Re}_1 = \dfrac{2r_1\sqrt{V_1^2 + 0.25\omega_1^2 r_1^2}}{\nu}$,

Friction coefficient ï $\lambda_1 = 0.11\left(\dfrac{\Delta_\iota}{2r_1} + \dfrac{68.5}{\mathrm{Re}_1}\right)^{0.25}$.

Pressure drop in withdrawal pipe:

$$K_1 = \frac{\lambda_1\omega_1 L}{2V_1},$$

$$\Delta p_5 = \lambda_1\frac{\rho V_1^2}{4}\frac{L}{r_1} + \frac{\rho\,\omega_1^2 r_1^2}{4}\left(1 - \frac{1}{K_1^2}\right). \qquad (19)$$

Total resistance of air cleaner is the sum of pressure drop in all sections of the device

$$\Delta p = \Delta p_1 + \Delta p_2 + \Delta p_3 + \Delta p_4 + \Delta p_5\,. \qquad (20)$$

In Section 4.2 comparison of results of calculations by formulas derived with experimental data is carried out. Experiments and calculations are performed for an air cleaner that is designed and implemented to mine loader LK 07. The results of calculations (solid line) and experimental data (circles) are shown in figure 9. As seen from the figure, the agreement of theoretical curve with the experimental data is quite satisfactory.

In Section 4.3 design formula of efficiency of the first stage of cleaning is derived (dust collection efficiency of external bunker). Coefficient of dust collection is obtained for this fraction of dust particle

$$\eta(\delta)=\frac{1}{1-\xi^2}\left[1-\exp\left(-\frac{C_m\delta^2\rho_{ч}\omega_0^2(\xi)L}{9V(\xi)\rho\nu(1+K(\xi))}\right)\right]. \qquad (21)$$

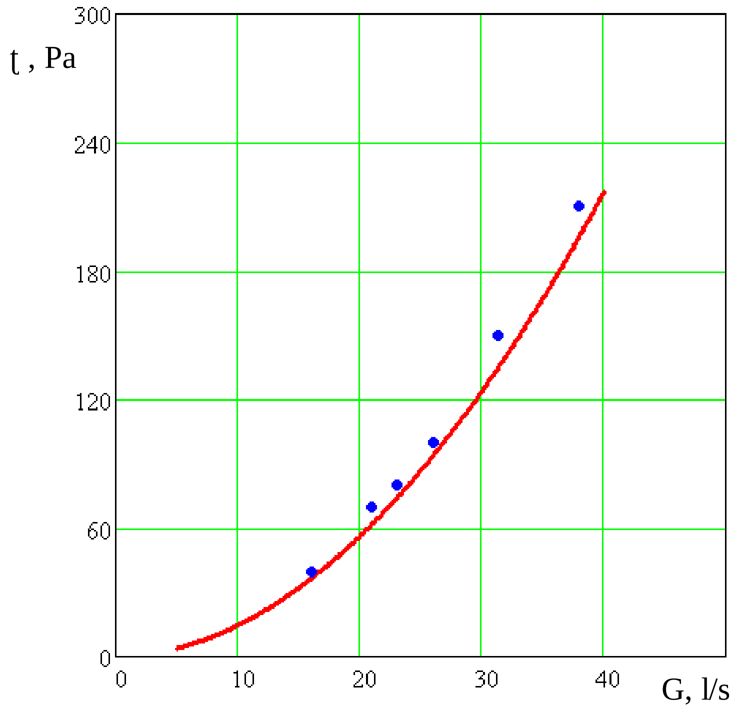

Fig.9. Comparison of design results of resistance of dust catcher with tests data

In this expression ξ - is the ratio of pipe diameters, C_m - Kenninghemôs factor, δ - the diameter of dust particle, $\rho_{ч}$ - the density of dust material, ω_0 - the angular velocity of flow at the beginning of coaxial channel, L ï the length of coaxial channel, $V(\xi)$ - longitudinal velocity of the flow in the coaxial channel, ρ - air density, ν - molecular viscosity of air, $K(\xi)$ - ratio, which is mentioned above, in calculating the resistance of coaxial channel. With known dispersed composition of dust, namely share part by weight ε_i of the particles of δ_i size, the total efficiency of the dust catcher of the first stage of cleaning is:

$$\bar{\eta}=\sum_{i=1}^{N}\varepsilon_i\,\eta(\delta_i)\,, \qquad (22)$$

here N - is a number of fractions.

In Section 4.4 the method of numerical calculation of the efficiency of the second stage of cleaning is given. The method consists in the fact that the calculated trajectories of dust particles are conducted on the basis of hydrodynamic equations (4) and calculation of collected particles is done by statistics:

$$
\begin{cases}
m_p \dfrac{DV_{zp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_z - V_{zp}), \\
m_p \dfrac{DV_{rp}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_r - V_{rp}) + \dfrac{m_p V_{\varphi p}^2}{r}, \\
m_p \dfrac{DV_{\varphi p}}{Dt} = \dfrac{3\pi\mu\delta}{C_m}(V_\varphi - V_{\varphi p}).
\end{cases} \tag{23}
$$

Here V_r, V_z, Vű - are velocities of moving flow; m_p - mass, V_{zp}, V_{rp}, $V_{\varphi p}$ - velocities, δ - particle diameter; $\frac{D}{Dt}$ - substantial derivative, ʉ m - Kenninghemȏs coefficient. In Section 4.5 an optimum correlation between pipe diameters of dust catcher is found. At optimal correlation of pipe diameters, maximum efficiency of the first stage of cleaning is reached, which leads to maximum efficiency of dust catcher as a whole.

Figure 10 shows the dependence of the minimum size of collected particles on the ratio of dust catcher pipe diameters. From this graph it is clear that the analyzed function has a precise minimum for $\xi \approx 0.66$. Therefore, the maximum efficiency of the first step of cleaning of dust catcher is achieved at this ratio of diameters. The same optimum ratio of diameters of the annular channel and the dust catcher has been found in numerous laboratory studies.

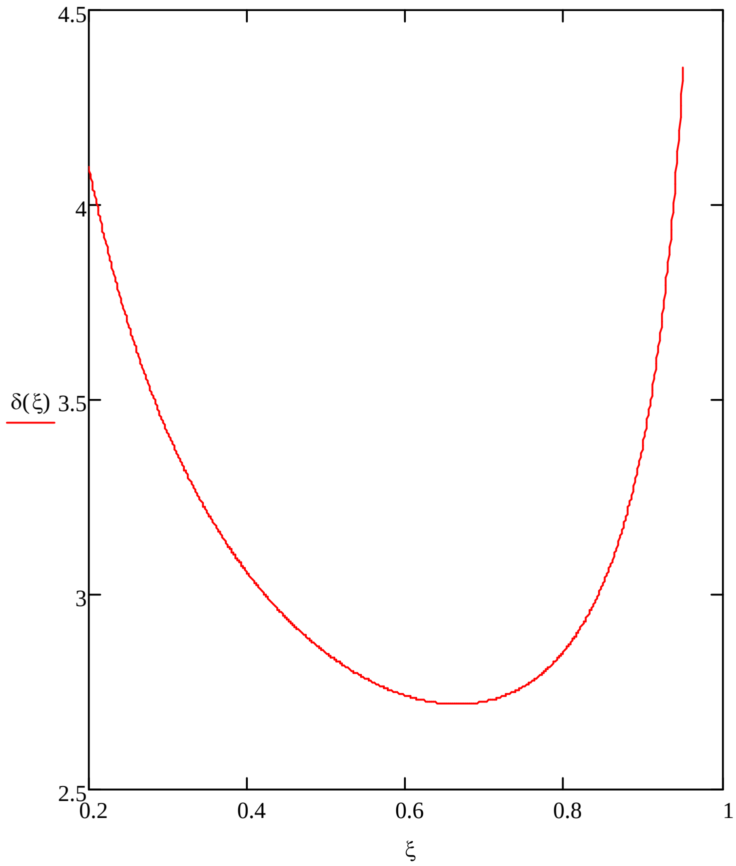

Fig.10. Minimal size of collected particle depending on diameter ratio of dust catcher pipes

In Section 4.6 the methodology of experimental measurements of effectiveness of dust catchers and air cleaners is described. In this section the comparison of obtained formulas for the efficiency of dust collector with experimental measurements for dust of Portland cement 400 was carried out. Dispersed composition of Portland cement 400 is shown in Table 1.

Table 1

Dispersed composition of Portland cement 400.

Size range, mcm	Medium size, mcm	Outlet of fraction, %
0é 10	5	12,0
10é 20	15	36,2
20é 30	25	19,39
30é 40	35	17.2
40é 50	45	12.8
50é 60	55	0,3
60é 70	65	1,2
70é 80	75	0,8
80é 90	85	0,3
90é 100	95	1.2

Fig. 11 shows the dependence of total efficiency of air cleaner for ICE LK 07 on productivity of air for cement dust. The same figure shows tests measurements plotted in circles. As can be seen, the agreement between the calculated curves and experimental data is very good. This fact testifies to the adequacy of design formula.

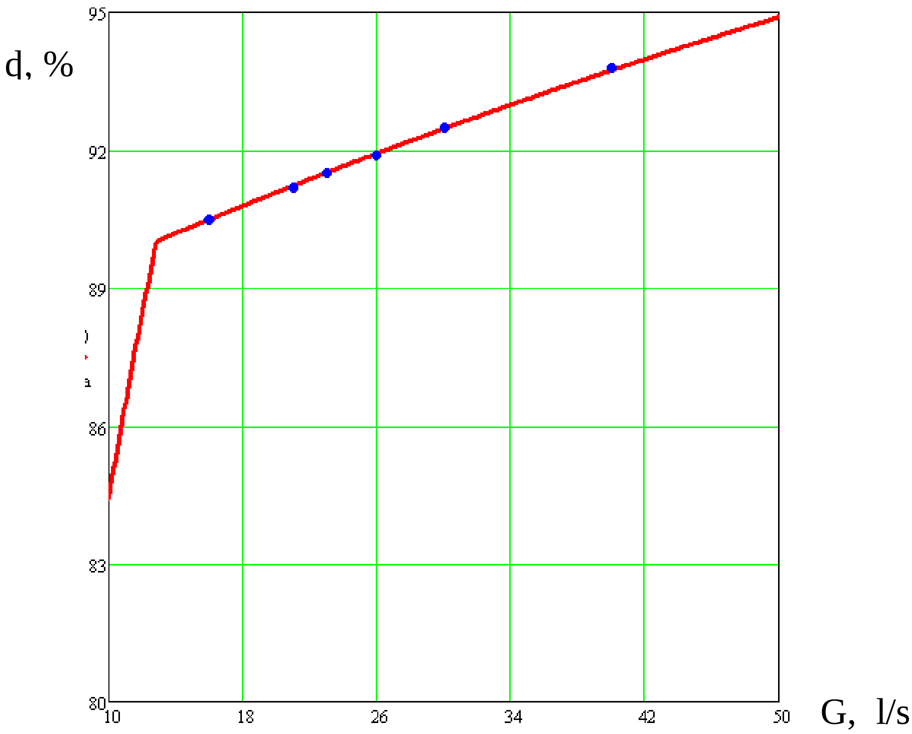

Fig. 11. Dependence of total efficiency of air-cleaner on productivity

The results obtained in the thesis allow to create high-performance centrifugal dust catchers and air cleaners. The newly created devices are not only similar to foreign analogues, but exceed them in many ways. Dust catchers and air cleaners are introduced into various enterprises and successfully operate in the Republic.

CONCLUSION

On the basis of the conducted researches on the doctoral dissertation on the subject "development of highly effective centrifugal dust arresters on a basis of aerodynamic processes" the following conclusions are provided:

1. On the basis of numerical research of dynamics of a flow in a centrifugal dust catcher it is revealed that the whirlwinds arising in the device are the main factors in decrease in efficiency of a dust catcher.

2. For the first time the analysis on the basis of the theory of stability of a flow has allowed to determine efficiency of the twisting dust arrester air devices. These researches will be useful when designing highly effective centrifugal dust arresters.

3. Researches on reduction of intensity of whirlwinds have led to creation of the stabilizer device which has allowed to increase efficiency of a dust arrester to 20%.

4. Researches of dynamics and a mass transfer of a turbulent two-phase flow have allowed to determine coefficients of viscosity and diffusion. Researches in this area are necessary for determination of the necessary sizes of elements for the first step of cleaning of a dust arrester.

5. Methods of determination of efficiency and aerodynamic resistance of a centrifugal dust arrester are developed. These methods are necessary when designing centrifugal dust arresters and air cleaners.

6. The optimization method of the sizes of details of a dust arrester is developed. The conducted researches in this area have allowed to develop the compact, highly effective and having minimum aerodynamic resistance of an industrial dust arrester and the air cleaner for the engine of vehicles.

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