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HYDRODYNAMICS OF A SWIRLING FLOW IN THE CYCLONE-VORTEX APPARATUS

Abstract. Despite the wide spreading of apparatuses, using the centrifugal force,the process of heterogeneous systems' separation, occurring in them, is not sufficiently studied because of the difficulty in taking into accounting allparameters, influencing on it.

In view of the fact that the dusty gas stream enters the cyclone through the branch pipe located tangentially to the cylindrical dust collection chamber, passes circumferentially around the exhaust pipe and moves spirally down the wall of the cone and then up, the resulting centrifugal force isinfluencing on solid particles, causing them to cling to the inner wall of the housing and then, under the influence of gravity, to slide to the outletbranch pipe.

To calculate the cyclones,there was offered a large number of models describing the processes of flow motion and gas-solid separation system. Many researchers accept as a separating boundary the imaginary vertical cylindrical surface, corresponding to the radius of the inner tube for gas outflowfrom the apparatus.Others, to calculate the hydraulic resistance, usethe medium cylindrical surface with a radius of $\sqrt{r_1 r_2}$and height h, assuming that there occurs an abrupt flow ratechange on it. On both sides of this surface the potential flowis prevailing. As a result, there have beenderived the equations for calculation of local resistance coefficientsfor input and output in the cyclone and those of total resistance.

Some researchers propose to calculate the hydraulic resistance of the cyclone via the inlet gas velocity. To calculate thecyclone hydraulic resistance, we havesuggested the equation, takinginto account the resistance of the inlet zone, vortex zone and output zone.The results of calculation according to the proposed equation correlate well with the data of other researchers.

Keywords: cyclone, tangential branch pipe, centrifugal force, solid particles, gas velocity, resistance coefficient, hydraulic resistance.

Introduction. It is known that the application of a centrifugal force can increasegreatly the limits of separation of heterogeneous dust-gas systems [1,2-5]. However, despite the wide spreading of apparatuses, using the centrifugal force [6-13], theprocess of heterogeneous systems' separation, occurring in them, is not sufficiently studied because of the difficulty intaking into accounting all parameters,influencing on it.

In the basis of the centrifugal separation process thefollowing physical model is studied [1]. The dust-laden gas stream enters the cyclone through the branch pipe, located tangentially to the cylindrical dust collection chamber, passes circumferentially around the exhaust pipe and moves spirally down the wall of the cone and then up into the exhaust pipe.The diameter of the flow, ascending in a spiral, is almost equal to the diameter of the exhaust pipe. The gas flow at the entrance to the cyclone is moving with acceleration in the annular space between the walls of the housing of the cyclone and the exhaust pipe. The kinetic energy of the annular flow is dissipated as a result of exchange between momentumsand return flows,occurring at the boundaries of stagnant zones.

The hydraulic resistance of the apparatus, as well as the energy consumption for separation of the preset volume flow rate of the dust-gas mixture,are closely related to the geometrical dimensions of the cyclone.

To establish the correlation between the optimal geometric dimensions of the cyclone, its performance, power consumption and separation capacity is possible only approximately, with using empirical data. To calculate the cyclones, there was offered a large number of models [14], describing the processes of flow motion and gas-solid system separation. The distribution of flows in the cyclone (especially in its conical part) is still not studied sufficiently.

Methods of studies. To carry out the studies, there were used the method of direct measurement of hydraulic resistance by a well-type manometer and a micro manometer, and also the computer-aided numericalmethods.

Results of studies. It was established experimentally that the path of the gas stream inside the cyclone conforms to the Archimedean spiral's form. This is especially important to know for proper placement of the outlet branch pipe for dust[1,15,16].

The hydraulic resistance changes inside the apparatus depending on the velocity distribution and therefore can be approximatelycalculated in assuming a certain form of the gas (liquid) – solid system separating boundary. Many researchers assume as a separating boundary the imaginary vertical cylindrical surface with a radius of r_1 (equal to the radius of the inner tube for gas outflow from the apparatus). Recently [1] for calculation of hydraulic resistance there is used the average cylindrical surface with a radius of $\sqrt{r_1 r_2}$and height h, assuming that there occurs an abrupt flow ratechange on it.On both sides of this surface the potential flow is prevailing.

The pressure change at the entrance to the cyclone can be expressed by the moment of momentum M_a on the outer side (r_2) of the separation space (the correction should be allowed for the fact that the momentum in the cross-section of the inlet branch pipe $M_{вх}$ will be slightly different from M_a). The momentumon a cylindrical surface with a radius $r_1$is expressed by the difference

$$M_{вх}=M_a - M_{ср} \tag{1}$$

with

$$M_{ср}=\lambda \cdot 2\pi r_1 r_2 h \frac{\rho_c}{2} w_i w_a \tag{2}$$

As a friction coefficient λ in the first approximation there can be assumed the value $\lambda_{ст}$,defined in the conditions of existence of a turbulent boundary layer on the outer wall of the cyclone at a constant pressure[17]:

$$\lambda_{ст} = 0{,}074 Re_{ст}^{-0,2} \tag{3}$$

where

$$Re = \omega_a \cdot 2\pi r_2 / v_c, \text{ with} 5 \cdot 10^5 < Re_{ст} < 10^7$$

With taking into account these dependencies, there can be obtained the equations for calculation of coefficients of local resistances for input and output in the cyclone. For the input pipe[1]:

$$\xi_{вх} = \frac{\Delta p_{вх}}{p_c v^2/2} = \frac{r_1}{r_2}\left(\frac{w_i}{v_i}\right)^2 \left[\frac{1}{\left(1 - \frac{w_i}{v_i} \cdot \frac{h}{r_1}\lambda\right)^2} - 1\right] \tag{4}$$

For the output pipe:

$$\xi_{вых} = \frac{\Delta p_{вых}}{p v^2/2} = K\left(\frac{w_i}{v_i}\right)^{4/3} + \left(\frac{w_i}{v_i}\right)^2 \tag{5}$$

Under the experimental data [1],the constant K=4,4. The ratio of velocities at the entrance to the apparatus and the exit of it can be calculated according to the ratio of the cross-section areas of the inlet branch pipe and the outlet pipe:

$$\frac{w_i}{v_i} = \frac{1}{\frac{F_{вх}}{F_{вых}} \cdot \frac{r_1}{r_{вх}} \alpha + \frac{h}{r_1}\lambda} \tag{6}$$

whereα – the correction factor, taking into account the ratio of moments of momentums$M_{вх}/M_a$:

$$\alpha = \frac{M_{\text{вх}}}{M_{\text{а}}} = \frac{v_{\text{вх}} r_{\text{вх}}}{w_{\text{а}} r_2} \tag{7}$$

The total hydraulic resistance of the cyclone is calculatedtotally as[1]:

$$\Delta P_{\text{ц}} = \Delta P_{\text{вх}} + \Delta P_{\text{вых}} \tag{8}$$

or

$$\Delta P_{\text{ц}} = \xi \frac{\rho_c w_{\text{г}}^2}{2}, \tag{9}$$

$$\text{where} \xi = \xi_{\text{вх}} + \xi_{\text{вых}}$$

ByLIOTprocedure[18], the hydraulic resistance of cyclones of various types is calculated by the conventional (fictitious) gas flow rate in the horizontal cross section of the cylindrical part of the empty apparatus as

$$\Delta P_{\text{ц}} = \xi_0 \frac{\rho w_0^2}{2} \tag{10}$$

orby the velocity in theinput branch pipe as

$$\Delta P_{\text{ц}} = \xi_{\text{вх}} \frac{\rho w_{\text{вх}}}{2} \tag{11}$$

To reduce the hydraulic resistance of NIIOGAZ cyclones, on the exhaust pipe thereareinstalledthevolute or the annulardiffuser, reducing$\Delta P_{\text{ц}}$in average by 10 %[1].

The hydraulic resistance coefficients $\xi_{\text{вх}}$and$\xi_0$are given in [1] (CN-11$\xi_{\text{вх}} = 6{,}1, \xi_0 = 150$; CN-15 $\xi_{\text{вх}} = 7{,}6, \xi_0 = 160$; CN-24 $\xi_{\text{вх}} = 10{,}9, \xi_0 = 80$).

It should be taken into account that the hydraulic resistance of the cyclone largely depends on the dust content of gas, and the coefficients of hydraulic resistance ξ in the dusty gas flow are changing in average from 2 to 20% depending on the dust concentration [1]. According to experimental data, the presence of dust in gas in amounts exceeding 1 g/m3, causes the heterogeneity of the gas-solid systemseparation process, the formation of secondary circulation flows, the boundary layer separation and deceleration of the circumferential gas velocity. At concentrations > 10 g/m3 the influence of dust content on the hydraulic resistance cannot be neglected.

According to [19], during the sedimentation of particles under the conditions corresponding to the Stokes law, the theoretical settling velocity in m/s is calculated by the formula:

$$w_o = \frac{d^2\,(\rho_1 - \rho_2) w_{\text{г}}^2}{9\, v_2 \rho_2 D} \tag{12}$$

here$w_{\text{г}}$ – the circumferential gas velocity in the cyclone, assumed to be equal to 12 – 14 m/s; D –the cyclone diameter in m.

The diameter of the cyclone should be first preset, and then checkedby the subsequent calculation. To pre-select the diameter of the centrifugal dust precipitator, one can be guided by the data [19, 20], in which there are given the approximateratios of the main dimensions of centrifugal dust precipitatorsand the inletbranch pipewidth b or the cyclone diameter D.

The cross-sectional area of the inlet branch pipe in m2

$$f = bh = \frac{V_{\text{сек}}}{w_{\text{вх}}}, \tag{13}$$

where$V_{\text{сек}}$ – the actual second volume of gas coming into the cyclone at a preset temperature, in m^3/s; $w_{\text{вх}} \approx$ 20 m/s – the gas velocity in the inlet branch pipe of the cyclone.

The correct application of the formula (12) is checked by the equation

$$Re = \frac{w_o}{v_2} \leq 0{,}2. \quad (14)$$

AtRe>0,2the theoretical settling velocity is calculated asfollows.

After defining the criterion of Archimedes by the equation

$$Ar = \frac{g \cdot d^3}{v_2^2} \cdot \frac{\rho_1 - \rho_2}{\rho_2} \quad (15)$$

the separation factor is found:

$$\Phi_\text{р} = \frac{w_\text{г}^2}{gR} = \frac{2w_\text{г}^2}{gD} \quad (16)$$

The criterion of Reynolds should be calculated according to the formulas:
at $Ar\Phi_\text{р}<84000$

$$Re = \left(\frac{Ar\Phi_\text{р}}{13{,}9}\right)^{1/1{,}4}; \quad (17)$$

at$Ar\Phi_\text{р}>84000$

$$Re = 1{,}71\sqrt{Ar\Phi_\text{р}} \quad (18)$$

By the found values of the criterion Re the theoretical precipitationrateis determined.

Based on the pre-determined performance of the cyclone,the internal diameter of the exhaust pipe is determinedaccording to the equation

$$d_\text{т} = 1{,}13\sqrt{\frac{V_\text{сек}}{w_\text{т}}}, \quad (19)$$

where$w_\text{т}$ – thegasvelocityintheexhaust pipe inm/s (in practical calculations) $w_\text{т}$is assumed to be equal to 4-8 m/s).

The outer diameter of the exhaust pipe

$$D_1 = d_\text{т} + 2\delta; \quad (20)$$

hereδ – the wall thickness of the exhaust pipe.

The correctness of the chosen value of the cyclone diameter is verified by the formula

$$D = \frac{D_1}{1 - 10\frac{v_\text{ос}}{w_\text{г}}}. \quad (21)$$

The height of the cylindrical part of the centrifugal dust precipitator

$$h_1 = \frac{2V_\text{сек}}{(D - D_1)w_\text{г}}. \quad (22)$$

Theheight$h_2$of the conical part of the cyclone can be determined by the data, given in [19, 20]. The reliable withdrawal of entrained particles from thecyclone is provided with the value of the angle at the top of the cone of 30-40°.The hydraulic resistance of the cyclone is calculated by the formula:

$$\Delta P_\text{ц} = \xi_\text{ц}\frac{w_\text{вх}^2 \rho_2}{2}, \quad (23)$$

where$\xi_ц$ – the resistance coefficient, depending on the design of the cyclone (for CKKB design cyclones $\xi_ц = 2{,}5$, for VTI cyclones $\xi_ц \approx 6$, for NIIOGAZ cyclones$\xi_ц \approx 7[5]$).

As can be seen from the formula (12), the settling rate of particles in centrifugal dust precipitators can be increased by increasing the gas flow rate $w_г$ or decreasing the radius of rotation R. the First way is inefficient, as it causes a sharp increase in the hydraulic resistance of the apparatus, with increasing the turbulence of the gas flow and, finally, the reduced efficiency factor. The second way has resulted in the creation of multiclonestructures.

In paper [20] to calculate the pressure drop in a cyclone there is proposed the equation:

$$\Delta p = \xi \frac{pw^2}{2}. \tag{24}$$

According to the preset efficiency, the actual gas velocity in the cyclone iscalculated, and the gas velocity in the cyclone should not deviate from the optimal one by more than by 15%.

According to the tables, given in the paper, there isassumedthe hydraulic resistancecoefficient, corresponding to the predetermined type of a cyclone. For NIIOGazcyclones (single ones or group ones) the specifyingcorrections are made bythe formula

$$\xi = К_1 К_2 \xi_{ц\,500}^{с.п} + К_3, \tag{25}$$

where $\xi_{ц\,500}^{с.п}$ - the hydraulic resistancecoefficientof a single cyclone with adiameter of 500 mm. Index «с» meansthat the cyclone operates in a hydraulic network, while«п» - without the network, i.e. directly with exhausting intothe atmosphere; $К_1$ – the correction factor for the cyclone diameter; $К_2$– the correction factor for gas dust content; $К_3$ – the coefficient, taking into account the additional pressure losses, caused by the arrangement of cyclones in a group.

To calculate the hydraulic resistance of a cyclone,we have proposed the equation:

$$\Delta P_ц = \Delta P_{вх} + \Delta P_{в.з} + \Delta P_{вых}, \tag{26}$$

where $\Delta P_{вх}$ – thehydraulicresistanceof the entrance area, Pa; $\Delta P_{в.з}$ – thehydraulicresistanceof the vortex area, Pa; $\Delta P_{в.з}$ - the hydraulic resistance of the exit area, Pa.

Thehydraulicresistanceof the entrance area:

$$\Delta P_{вх} = \xi_{вх} \frac{w_{вх}^2 \rho_г}{2}, \tag{27}$$

where $\xi_{вх} = 3{,}32$ – the resistance coefficient at the entrance to the apparatus.

Thehydraulicresistanceof the vortex area:

$$\Delta P_{в.з} = \xi_{в.з} \frac{w_{в.з}^2 \rho_г}{2}, \tag{28}$$

where $\xi_{в.з} = 4{,}1$ – theresistancecoefficientof the vortex area; $w_{в.з}$ – gas velocity in the vortex area, m/s.

The hydraulic resistance of the exit area:

$$\Delta P_{вых} = \xi_{вх} \frac{w_{вых}^2 \rho_г}{2}, \tag{29}$$

where $\xi_{вых} = 5{,}7$ – theresistancecoefficient at the exit of the apparatus.

Figure 1 gives the results of the cyclone hydraulic resistance calculations according to the equations, presented by various authors.

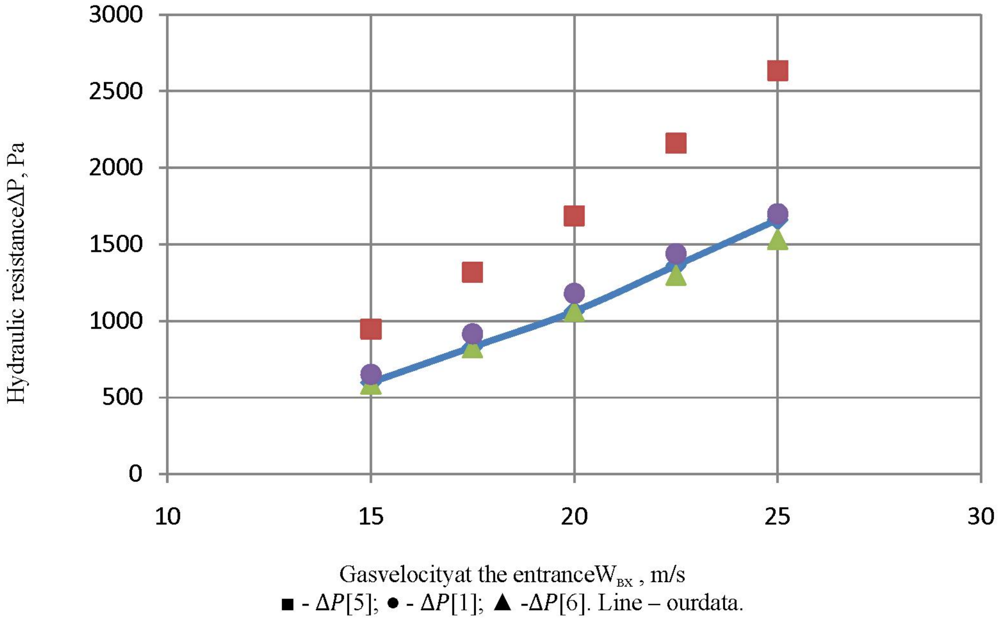

Figure 1 – the cyclone hydraulic resistance ΔPdepending on the gasflow velocityat the entrance$w_{вх}$.

As it can be seen from the figure, the cyclone hydraulic resistance, depending on the gas flow rate at the entrancetothe apparatus increases. It is obvious, because with increasing speed there are growingthe expenditures on overcoming the local resistances and creation of a swirling flow. Calculations on the equations,proposed in papers [1, 20], and our data have close values, whereas the data in paper [19] areslightly overvalued.

Conclusions. There has been considered the model of centrifugal separation of a dust-laden gas stream.

There has been given the analysis of different approaches to determination of the cyclone hydraulic resistance.

Proceeding from the analysis done, there has been proposed the equation that takes into consideration the resistance of the entrance area, vortex area and exitarea, well correlated with the data of other researchers.

REFERENCES

[1] Romankov P.G., Kurochkina M.I. Gidromekhanicheskie protcessy khimicheskoi tekhnologii. L.: Khimiia, **1974**. 288 p.(In Russian).

[2] Tekhnika pyleulavlivaniia i ochistki promyshlennykh gazov: Sprav. izd. /Aliev G.M.-A. M.: Metallurgiia, **1986**. 544p.(In Russian).

[3] Ochistka promyshlennykh gazovotpyli / V.N.Uzhov, A.Iu.Valdberg, B.I.Miagkov, I.K.Reshidov. M.: Khimiia, **1981**. 390 p. (In Russian).

[4] Lukin V.D., Kurochkina M.I. Ochistka ventiliatcionnykh vybrosov v khimicheskoi promyshlennosti. L.: Khimiia, **1980**. 232 p.(In Russian).

[5] Karpov S.V., Saburov E.N. Vliianie osnovnykh geometricheskikh parametrov na aerodinamicheskui ueffektivnostt ciklonnykh apparatov // Teor. osn. khim. tekhnol. **1990**. t.24. № 5. P.651–660 (In Russian).

[6] Kouzov P.A., Mylnikov S.I. Raschet effektivnosti pyleulavlivaniia v tciklonakh s vodianoiplenkoi // Tr. in-tov okhranytruda. **1972**. vyp. 77. P. 6–12.(In Russian).

[7] Prechistenskii S.A. Tcentrifugirovanie aerozolei v TcRP. M.: Atomizdat, **1960**. 190 p.(In Russian)

[8] Ochistka gazov v khimicheskoi promyshlennosti. Protcessy i apparaty / O.S.Balabekov, L.Sh.Baltabaev. M.: Khimiia, **1991**. 256 p. (In Russian).

[9] Volnenko A.A. Konstruirovanie dvukh stupenchatykh vikhrevykh apparatov dlia provedeniia protcessov pyleulavlivaniia. // Nauka i obrazovanie Iuzhnogo Kazakhstana. **1997**. № 7. P.200. 202.(In Russian).

[10] Volnenko A.A. Ochistkagazov v dvukhstupenchatykh apparata khvikhrevogotipa // Problemy razvitiia predpriiatii osnovnoi i gornoikhimii: Sb. nauch. TrudovAO ”KazNIIkhimproekt”.-Shymkent, **1996**. P.228-230.(In Russian)

[11] ValdbergA.Iu., KovalevskiiIu.V., Lebediuk G.K. Mokrye pyleuloviteli udarno-inertcionnogo, tcentrobezhnogo i forsunochnogo deistviia. M.: TcINTIKhimneftemash, **1981**. 38 p.(In Russian).

[12] Potapov O.P., Kropp L.D. Batareinye tciklony. M.: Energiia, **1977**. 152 p.(In Russian).

[13] Kropp L.D., BronshteinA.Sh. Ekspluatatciia batareinykh tciklonov. M.: Energiia, **1964**. 152 p.(In Russian).

[14] Gordon G.M., Peisakhov I.L. Pyleulavlivanie i ochistka gazov. M.-L.: Metallurgiia, **1968**. 499 p.(In Russian).

[15] Kouzov P.A. Sravnitelnaia otcenka tciklonov razlichnykh tipov. V kn.: Obespylivanie v metallurgii. M.: Metallurgiia, **1971**. P.185-196.(In Russian).

[16] Gazoochistnoe oborudovanie. Tciklony. M.: Tcintikhimneftemash, **1977**. 24 p.(In Russian).

[17] Shlikhting G. Teoriia pogranichnogo sloia. Per. s angl. M.: Nauka, **1969**. 741 p.(In Russian).

[18] Kouzov P.A., Iofinov G.A. Ispytanie obespylivaiushchikh ventiliatcionnykh ustanovok. L.: VNIIOT, **1971**. 165 p.(In Russian).

[19] Mashiny i apparaty khimicheskikh proizvodstv. Pod red. I.I. Chernobylskogo. M.: Mashinostroenie, **1975**. 454 p.(In Russian).

[20] Birger M.I., Valdberg A.Iu., Miagkov B.I. Spravochnikpopyle i zoloulavlivaniiu // Pod obshch.red. A.A. Rusanova. M.: Energoatomizdat, **1983**. 312 p.(In Russian).

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ГИДРОДИНАМИКА ЗАКРУЧЕННОГО ПОТОКА В АППАРАТЕ ЦИКЛОННО-ВИХРЕВОГО ДЕЙСТВИЯ

Аннотация.Ортадан тепкіш күшті қолданатын аппараттардың кең таралғанына қарамастан, оларда өтетін біркелік емес жүйелерді бөлу процесі оларға әсер ететін барлық параметрлерді ескерудің күрделілігіне байланысты жеткіліксіз зерттелген.

Шаңдалған газ ағыны циклонға цилиндрлі шаңтұндырғыш камерасына тангенциалды орналасқан келте құбыр арқылы кіретіндіктен газ шығаратын түтікше айналасында шеңбер бойымен өтіп конус қабырғасы бойымен спиральды түрде төмен қарай қозғалады да және содан соң жоғары қарай қозғалады, бұл ретте пайда болатын ортадан тепкіш күш қатты бөлшектерді қаңқаның ішкі қабырғасына жабысуына мәжбүрлей отырып әсер етеді, олар кейін ауырлық күші әсерімен шығарушы келте құбырға сырғып түседі.

Циклондарды есептеу үшін газ-қатты заттар жүйесін бөлу мен ағындар қозғалысы процесстерін сипаттайтын көптеген модельдер ұсынылды. Көптеген зерттеушілер бөлу шекарасы ретінде аппараттан газды шығаруға арналған ішкі құбыр радиусына сәйкес келетін елестетілген тік цилиндрлі бетті қабылдайды. Өзгелер гидравликалық кедергіні есептеу үшін h биіктігімен және радиусы $\sqrt{r_1 r_2}$ орташа цилиндрлі бетті, онда ағын жылдамдығының секірмелі өзгерісі болады деп ойлап, пайдаланады. Бұл беттің екі жағы да потенциалды ағысқа ие болады. Нәтижесінде жалпы кедергі мен циклонға кіру және шығуға арналған жергілікті кедергілер коэффициенттерін есептеуге арналған теңдеу алынды.

Зерттеушілердің бір бөлігі шығу жақтағы газ жылдамдығы бойынша циклонның гидравликалық кедергісін есептеуді ұсынады. Біз циклонның гидравликалық кедергісін есептеу үшін кіріс аймағының, құйынды аймағының және шығыс аймағының кедергілерін ескеретін теңдеу ұсынып отырмыз. Ұсынылып отырған теңдеу бойынша есептеу нәтижелері өзге зерттеушілердің мәндерімен жақсы үйлеседі.

Түйін сөздер: циклон, тангенциалдыкелте құбыр, ортадан тепкіш күш, қатты бөлшектер, газ жылдамдығы, кедергі коэффициенті, гидравликалық кедергі.

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ГИДРОДИНАМИКА ЗАКРУЧЕННОГО ПОТОКА В АППАРАТЕ ЦИКЛОННО-ВИХРЕВОГО ДЕЙСТВИЯ

Аннотация.Несмотря на широкое распространение аппаратов, использующих центробежную силу, протекающий в них процесс разделения неоднородных систем недостаточно изучен из-за сложности учета всех действующих на него параметров.

В виду того, что запыленный газовый поток входит в циклон через патрубок, расположенный тангенциально к цилиндрической пылеосадительной камере, проходит по окружности вокруг выхлопной трубы и движется спирально вниз по стенке конуса и затем вверх, возникающая при этом центробежная сила воздействует на твердые частицы, заставляя их прижиматься к внутренней стенки корпуса, которые затем, под действием силы тяжести, сползают к выпускному патрубку.

Для расчета циклонов предложено большое число моделей, описывающих процессы движения потока и разделения системы газ-твердое вещество. Многие исследователи принимают в качестве границы разделения воображаемую вертикальную цилиндрическую поверхность соответствующую радиусу внутренней трубы для выхода газа из аппарата. Другие для расчета гидравлического сопротивления использует среднюю цилиндрическую поверхность радиусом $\sqrt{r_1 r_2}$и высотой h, предполагая, что на ней происходит скачкообразное изменение скорости потока. По обе стороны этой поверхности преобладает потенциальное течение. В результате получены уравнения для расчета коэффициентов местных сопротивлений для входа и выхода в циклоне и общего сопротивления.

Часть исследователей предлагает рассчитывать гидравлическое сопротивление циклона по скорости газа на входе. Нами для расчета гидравлического сопротивления циклона предложено уравнение, учитывающее сопротивление зоны входа, вихревой зоны и зоны выхода.Результаты расчета по предложенному уравнению хорошо коррелируются с данными других исследователей.

Ключевые слова: циклон, тангенциальный патрубок, центробежная сила, твердые частицы, скорость газа, коэффициент сопротивления, гидравлическое сопротивление

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