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IMPROVEMENT OF THE CALCULATION METHOD OF CYCLONE DUST COLLECTORS

Об'єктом дослідження є метод розрахунку ефективності циклонів з використанням величини швидкості поперечних пульсацій турбулентного газового потоку у вхідному патрубку циклона. Одним з найбільш проблемних питань при створенні нової циклонічної техніки очищення газів від пилу є необхідність виконання досить великого обсягу робіт – моделювання циклонів в лабораторних умовах на модельних циклонах, облік масштабного переходу та ін. Тому розробка найбільш точнішого аналітичного методу розрахунку ефективності циклонів є важливою проблемою, оскільки з'явиться можливість швидко і точно визначити всі необхідні параметри циклону для конкретних умов виробництва.

В ході дослідження використовувалися закономірності осадження частинок пилу в наближенні «дифузійного прикордонного шару», що дозволило з високою точністю розраховувати ефективність очищення від промислового пилу в різних за конструкцією циклонах. При цьому, також значно зменшуються витрати часу та об'єм експериментальних робіт при розробці нових видів циклонів чи по їх модернізації чи підбору.

Отримано найбільш точні залежності для оцінки найважливіших параметрів ефективності очистки пилу в різних циклонах. Це пов'язано з тим, що запропонований у роботі метод розрахунку циклонів має ряд особливостей, зокрема розробки нових залежностей для розрахунку величини діаметра відсікання «$d_{\eta=50}$», коефіцієнта інерційного захоплення частинок пилу «E» та ін. Запропоновано також використання середньої по поперечному перерізу вхідного патрубка циклона швидкості поперечних пульсацій турбулентного газового потоку та нової інтерполяційної залежності коефіцієнта інерційного захоплення частинок пилу «E» при потенційному режимі обтікання у вхідному патрубку циклонних апаратів. Завдяки цьому забезпечується можливість отримання найточніших значень показників ефективності очистки в різних за конструктивними параметрами циклонах. У порівнянні з аналогічними відомими методами розрахунків, це забезпечує такі переваги, як точність розрахунків, швидкість виконання та достовірність результатів.

Ключові слова: *циклонічна техніка очищення газів від пилу, діаметр «відсікання», динамічна швидкість, коефіцієнт очистки.*

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1. Introduction

Cyclone dust collectors are among the most common types of inertial dust collection equipment, due to the relatively high degree of purification from dust fractions with a diameter of more than 10 microns, simplicity of design, and high gas flow rate. Existing methods for calculating the effectiveness of dust removal in cyclones are not always accurate enough. Basically, experimental test methods are used for this, associated with a significant investment of time and money [1]. Therefore, the development of the most accurate and improved analytical method for calculating the parameters of the fractional degree of purification of cyclone apparatus still remains an extremely important and urgent task [2].

2. The object of research and its technological audit

The object of research is a method for calculating the efficiency of cyclones using the magnitude of the velocity of transverse pulsations of a turbulent gas flow in the inlet of the cyclone. The complexity of the existing methods for calculating the efficiency of cyclones is that it is necessary to take into account a large number of factors affecting the final result. Of these factors, the gas velocity in the inlet of the cyclone, the diameter of the cyclone, the diameter of the exhaust pipe of the cyclone, the distribution of dust particles in size, the density of gas, dust, etc. are influential.

That is, the problem is multifactorial and therefore rather difficult to solve, and the available methods for calculating the efficiency cyclones, in some cases, are not sufficiently inaccurate.

One of the most problematic issues when creating a new cyclonic technique for gas dust cleaning is the need to carry out a fairly large amount of work – modeling cyclones in laboratory conditions on model cyclones [3], taking into account the large-scale transition, etc. Therefore, the development of the most accurate analytical method for calculating cyclone efficiency is an important problem, since it makes it possible to quickly and accurately determine all the necessary cyclone parameters for specific production conditions [4, 5].

3. The aim and objectives of research

The aim of research is creation of the most accurate analytical method for calculating the efficiency of cyclones at various design and technological parameters.

To achieve this aim, it is necessary to complete the following objectives:

1. To analyze the effect of the mean cross-sectional average velocity of the transverse pulsations of the turbulent gas flow in the inlet of the cyclone on the «cut-off» diameter «$d_{\eta=50}$».
2. To justify the advantages of the proposed improved method for calculating the total degree of tin in various cyclones and various parameters of dust and gases.

4. Research of existing solutions of the problem

Among the main directions of solving the problem of developing analytical methods for calculating the efficiency of cyclones identified in the resources of scientific periodicals, [6, 7] can be distinguished, but they do not consider comparisons of various analytical methods for calculating the most important for calculating the efficiency of cyclones of diameter «$d_{\eta=50}$».

But the work [4] is devoted to the calculation of cyclone efficiency using the dependence of the diameter value «$d_{\eta=50}$» on the value of the hydraulic resistance coefficient of cyclones. However, there is an unresolved issue of the effect on the effective cleaning of the pulsating dynamic flow rate.

The author of [5] shows the influence of dust tows and their characteristics on the efficiency of cleaning cyclones. But the question remains of the effect on the cleaning efficiency of the pulsation parameters of the turbulent gas flow.

An alternative solution to the problem described in [8, 9] provides for the use of dust particle deposition conditions in the approximation of the «diffusion boundary layer», which is much closer to creating the most accurate analytical calculation method. However, it does not take into account the mean cross-sectional velocity of the transverse pulsations of the turbulent gas flow in front of the «diffuse boundary layer» over the cross section of the inlet of the cyclone. It also gives a much more complex scheme for calculating the «cut-off» diameter.

According to the authors of [10], the calculation of the «cut-off» diameter «$d_{\eta=50}$» should be performed by the final velocity of gas pulsations after they pass through the «diffuse boundary layer». This leads to some inaccuracies in the calculations.

Thus, the results of literature analysis allow to conclude that the existing analytical methods for calculating cyclones do not take into account the influence of the most important turbulent flow [11, 12]. Namely, the values of the transverse pulsation velocity of the turbulent gas flow average of the cross section of the inlet of the cyclone [13, 14].

5. Methods of research

To consider the problem of developing the most accurate method for calculating the cleaning efficiency in cyclones, let's introduce the following notation:

– a – the width of the inlet of the cyclone (in fractions of the diameter of the cyclone);
– b – the height of the inlet of the cyclone (in fractions of the diameter of the cyclone);
– D_c – cyclone diameter;
– D_e – diameter of the exhaust pipe of the cyclone (in fractions of the diameter of the cyclone);
– d_{eq} – equivalent diameter of the inlet of the cyclone;
– d_{50} – median diameter of the ash;
– $d_{\eta=50}$ – «cut-off» diameter or the diameter of the particles of ash, captured in a cyclone with an efficiency of 50 %;
– t – temperature, parameter of the fractional degree of purification;
– V – speed;
– E – particle capture coefficient by an obstacle (cyclone surface; dust bundle);
– h – cleaning efficiency;
– μ – dynamic viscosity coefficient;
– u_* – dynamic velocity of the gas flow in the inlet of the cyclone;
– $u_{c.s.}$ – average cross-sectional velocity of the transverse pulsations of the turbulent gas flow over the cross section of the inlet of the cyclone;
– ν – kinematic viscosity coefficient;
– ρ – density;
– σ_d – standard deviation of dust particle size distribution;
– σ_η – standard deviation of the distribution of the fractional degree of purification.

Indices:
– c – calculation;
– e – experiment;
– *in* – at the inlet to the cyclone;
– g – gas; d – dust; *fr* – fractional.

Abbreviations:
– *eq.* – equivalent;
– S_{tk} – Stokes test;
– *com.* – common.

6. Research results

The most common for analytical calculations of dust cyclone efficiency was obtained by the probabilistic calculation method based on the use of the log-normal law as a function of the size distribution of dust particles. In addition, the dependence of the dust collection efficiency in the cyclone on the «cut-off» diameter ($d_{\eta=50}$), that is, dust particles that are captured by the cyclone by 50 %, is also used [1].

When using this calculation method, it is necessary to have data on two parameters characterizing the dispersion of dust, it is captured (d_{50}, σ_d) – known or which are set, and data in two parameters characterizing the cyclone efficiency – «$d_{\eta=50}$» and «$\lg\sigma_\eta$».

The value of «$\lg\sigma_\eta$» for various cyclones can be assumed constant and equal to 0.35. The parameter «$d_{\eta=50}$» is the only quantity that can be determined experimentally or calculated for some cyclones, after the corresponding experimental studies presented in the special reference literature [1].

These four parameters determine the value of the calculated parameter «t» [1]:

$$t = \frac{\lg d_{50} - \lg d_{\eta 50}}{\sqrt{\lg^2 \sigma_d + \lg^2 \sigma_\eta}}. \qquad (1)$$

The total degree of purification of the gas stream from dust in the cyclone is finally calculated according to the dependence [1]:

$$h_{tot} = \Phi(t) = \frac{1}{2}\pi(\exp)^{-t/2} dt, \tag{2}$$

where $\Phi(t)$ – the Gaussian integral, which is determined from special probability tables [1].

When developing the theory of cyclonic cleaning and improving their designs, the significant influence on the cleaning efficiency of the hydrodynamic situation in the jet section of the cyclone (in the zone of gas flow in the cyclone body) was not taken into account. Therefore, the improvement of cyclones was mainly aimed at studying the influence of two other sections of the cyclone (cyclone body and exhaust pipe). Although, as was noted in [3], the underestimation of the effect of the jet section of the cyclone, for example, on heat transfer, leads to significant calculation errors (up to 40 %).

Since the processes of transfer of substance (concentration, heat, speed) are described by Fick's law of convective diffusion, it is possible to indirectly judge the determining effect of the initial section on the intensity of the dust collection process. So, for example, when considering the laws of heat transfer according to [4], where it is noted that at a distance of 0.25 m from the inlet pipe along the gas, the heat flux density and heat transfer coefficient decreased by 2–3 times. Moreover, in a cyclone with one inlet nozzle – 2 times and 3 times – in a cyclone with four inlet nozzles – compared with a similar value at the end of the initial section of turbulence formation.

In studies [2, 5], the contribution of cyclone (initial) section of cyclone chambers to dust cleaning efficiency was quantified, where it is noted that when the gas flow rotates 150°, the bulk of the dust settles on the cyclone wall. Approximately 70 % of the dust settles in the first quarter of the cyclone circumference when the flow is rotated by 90° and another 20 % is deposited in a further rotation of the flow by 45°.

This gives reason to conclude that it is the initial jet section of the cyclone chambers that determines the efficiency of cyclones. Therefore, when constructing various analytical methods for calculating the efficiency of dust removal in cyclones, one should take into account the patterns of dust deposition precisely on the initial jet section of cyclones.

This work is a continuation of the previously proposed method for calculating the efficiency of cyclones [8–10]. In these works, let's use the characteristics of turbulent flows and the laws of the process of deposition of dust particles on the wall of the cyclone, on the surface of the «bundle» of dust in the «diffusion boundary layer».

This work is aimed at developing a new, most accurate and improved method for calculating the efficiency of cyclones using the basic characteristics of a turbulent flow. So, let's use the velocity of transverse pulsations of the turbulent flow in the inlet of the cyclone, the dynamic velocity of the pulsations of the gas flow, etc. At the same time, the process of deposition of dust particles was carried out in the approximation of «diffusion boundary layer».

To do this, let's use the concept of free inertial flight of particles from a turbulent gas flow in the precipitation surface (cyclone wall, on the surface of the dust «bundle»), which has been widely used in studying the process of turbulent aerosol deposition [9, 13]. This concept was first expressed in [14], which boils down to the assertion that in the near-wall zone of the turbulent flow there is an inertial emission of dust particles from the turbulent vortices supporting them in the direction of the cyclone surface.

The authors came to this idea with the well-known Prandtl scheme, according to which the turbulent flow is divided into two separate areas – the turbulent flow core and the laminar layer in the wall, the remainder devoid of turbulent pulsations. According to this scheme, near the laminar layer near the cyclone wall, turbulent vortices slow down their movement to zero, and suspended dust particles, due to inertia, continue their path through the inhibited layer to the cyclone wall [13].

The authors of [10] suggested that the ejection of dust particles to the wall occurs with an initial velocity equal to the average velocity of the transverse pulsations of the turbulent flow over the pipe cross section, that is, with $u_{c.s.} = 0.9u_*$ [13].

In this work, a similar pattern of the behavior of dust particles near the precipitation surface of a cyclone is proposed. Moreover, a quantitative assessment was made of the appropriateness of using such a method for calculating the efficiency of cyclone dust collectors for the 19 most widely used cyclone dust collectors, given in [9].

The estimation of cyclones of the value «$d_{\eta=50}$» was made taking into account the laws of motion of dust particles in the «diffusion boundary layer». In this case, let's use the values of the velocity of transverse pulsations of the turbulent flow in the inlet of the cyclone, which were recently successfully developed in [8, 10], which give the most accurate analytical calculated dependences. It is also assumed that particles are delivered to the boundary of the «diffusion boundary layer» due to the mechanism of convective diffusion and the influence of turbulent pulsations of the gas flow. In the «diffusion boundary layer», the particles move toward the sedimentation surface of the cyclone at approximately a constant speed, taken equal to the average transverse pulsation velocity of the turbulent flow, in particular, over the cross section of the pipe. In addition, it is believed that the final particle velocity (when they touch the cyclone wall or the surface of the «dust bundle») is not zero [13, 14]. The basis for this was the hypothesis of the existence of a periodic invasion of large-scale vortices from the nucleus in the parietal region. Under the accepted assumption, the mean free path of the particle is:

$$l = 0.9u_*.$$

Then the value of the final particle velocity obtained by this method (when they touch the wall of the cyclone or the surface of the dust «bundle») is the determining value in assessing the probability of their deposition. In this case, the cleaning efficiency is due to the combined influence of convective diffusion mechanisms and inertial forces.

This paper proposes an improved method for calculating the efficiency of dust collection in a cyclone based on the use of turbulence characteristics of flows. The regularities of the process of deposition of dust particles along the path (cyclone wall, on the surface of the dust «bundle») in the «diffusion boundary layer» are also used.

The calculation of the dust collection efficiency in cyclone apparatuses according to the new method is proposed to be performed in the following sequence:

– equivalent diameter of the inlet of the cyclone [8, 14]:

$$d_{eq}=\frac{2ab}{(a+b)}D_c; \qquad (3)$$

– dynamic Pulsation velocity of the gas flow in the inlet of the cyclone is determined by the dependence [9]:

$$u_*=\frac{0.354u_{in}}{1.8\lg\mathrm{Re}-1.64}, \qquad (4)$$

where

$$\mathrm{Re}=\frac{u_{in}d_{eq}}{\nu_g}; \qquad (5)$$

– average cross-sectional velocity of the transverse pulsations of the turbulent gas flow over the cross section of the inlet of the cyclone [13]:

$$u_{c.s.}=0.9u_*; \qquad (6)$$

– Stokes criterion [1]:

$$S_{tk}=\frac{d_d^2u_{c.s.}p_d}{18D_{dc}v_r}\ \left(\text{at } D_{dc}=10^{-4}\text{ m }[15]\right); \qquad (7)$$

– coefficient of inertial capture of dust particles «E» – according to the most accurate interpolation dependence obtained by the author with a potential flow regime in the inlet pipe of cyclone apparatuses:

$$E=\left(\frac{S_{tk}}{S_{tk}+0.24}\right)^2. \qquad (8)$$

It should be noted that there are a number of other dependencies for evaluating calculations of the particle capture coefficient at obstacles «E» under the potential flow regime and the most famous of them are given below:

– according to [11] for estimated calculations of the coefficient of capture of large dust particles by large drops of liquid in Venturi scrubbers with a potential flow regime:

$$E=\left(\frac{S_{tk}}{S_{tk}+0.59}\right)^2; \qquad (9)$$

– according to [16] for the estimated calculations of the capture coefficient of spherical particles in a dispersed-ring flow:

$$E=\left(\frac{S_{tk}}{S_{tk}+0.125}\right)^2; \qquad (10)$$

– according to [12]:

$$E=\left(\frac{S_{tk}}{S_{tk}+0.135}\right)^2. \qquad (11)$$

An analysis of dependences (8)–(11) shows that formula (8) gives the most accurate estimate of the coefficient «E» of the inertial capture of dust particles by an obstacle during the potential flow regime in the inlet pipe of cyclone apparatuses. This applies both to the estimation of the «cut-off» diameter ($d_{\eta=50}$) and the estimation of the diameter ($d_{\eta=84}$), which determines the value of $\lg\sigma_\eta$, which is important for the calculation of cyclones. In addition, errors in estimating the value of $\lg\sigma_\eta=0.35$ (for $\sigma_\eta=2.24$), for example, for a cyclone of the «CN-15» type, are for formulas (8), (10), (11), respectively, 1.78 %; 30.6 %; 17.3 %, which also confirms the higher accuracy of the calculations of formula (8).

From the solution of equation (8) it follows that at $E=0.5$, $S_{tk}=0.59$, the value of the «cut-off» diameter ($d_{\eta=50}$) is determined from the solution of equation (7) to evaluate the criterion «S_{tk}» with the value of $E=0.5$ ($\eta=0.5$). That is, when the value $d_{\eta=50}$ should correspond to the dependence:

$$d_{\eta=50}=\sqrt{\frac{18\cdot D_{dc}\cdot v_r\cdot S_{tk\,\eta=50}}{p_d\cdot 0.9u_*}}, \qquad (12)$$

if to consider that the optimal value for $D_{dc}=100\cdot 10^{-6}$ m [15], and $E=0.5$ [11], $S_{tk\ \eta=50}=0.59$ [11], then:

$$d_{\eta=50}=\sqrt{\frac{18\cdot 100\cdot 10^{-6}\cdot v_r\cdot 0.59}{p_d\cdot 0.9u_*}}\cdot 10^{-8}\text{ m}; \qquad (13)$$

– the value $d^{z)}_{\eta=50}$, taking into account the influence of the values D_c and D_e, is calculated according to the dependence [9]:

$$d^{z)}_{\eta=50}=d_{\eta=50}\left(\frac{D_e}{0.59}\right)\left(\frac{D_c}{0.6}\right)^{1/4}; \qquad (14)$$

– according to two parameters ($d_{\eta=50}$ and σ_η), as well as two dispersion parameters of the caught dust (d_{50} and σ_d), the value of the auxiliary calculation parameter «t» is determined by dependence (1):

$$t=\frac{\lg d_{50}-\lg d_{\eta 50}}{\sqrt{\lg^2\sigma_d+\lg^2\sigma_\eta}};$$

– the total degree of purification of the gas stream from dust in the cyclone is finally calculated according to the dependence [9]:

$$\eta_{tot}=50+44t-10(t)^2\ (\text{for } t\le 2); \qquad (15)$$

$$\eta_{tot}=105.4-\frac{15}{t}\ (\text{for } t>2). \qquad (16)$$

Table 1 shows the experimental and calculated methods proposed in this paper for calculating the values $d^e_{\eta=50}$ and $d^c_{\eta=50}$. Such calculations were performed for the 19 most widely used cylindrical and conical cyclones in industry, given in [9].

The average error in estimating the estimated value $d^c_{\eta=50}$, for those given in Table 1 cyclone (19 pcs.) amounted to 6.7 %, which is lower than the average error of 7.52 % given for the same 19 cyclones in [9].

Table 1

Assessment of cleaning efficiency in cyclones of various designs

Cyclone	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
a	0.26	0.26	0.26	0.2	0.26	0.18	0.264	0.21	0.2	0.26
b	0.66	0.48	1.1	0.6	0.8	0.4	0.535	0.52	0.4	0.7
D_c, m	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	1.6	0.6
D_{eq}, m	0.224	0.202	0.25	0.18	0.236	0.149	0.212	0.18	0.427	0.228
D_e	0.59	0.59	0.59	0.59	0.5	0.22	0.33	0.34	0.203	0.5
ζ	160	250	80	210	92	2000	600	1270	4420	115
ρ, kg/m^3	1930	1930	1930	1930	2650	1930	1930	1930	2300	2200
$\nu_g \cdot 10^6$, m^2/s	25	25	25	25	15.3	25	25	25	35.53	15.3
U_{av}, m/s	3.5	3.5	3.5	3.3	5.4	3.5	3.5	3.5	1.6	4.77
U_{in}, m/s	16	22	9.6	21.6	20.4	38.2	19.5	25.16	15.7	20.57
$D^e_{\eta=50}$, μm	4.5	3.65	8.5	4.12	$2.75^{z)}$	1.13	2.31	1.95	$2.27^{z)}$	$3.0^{z)}$
$D^c_{\eta=50}$, μm $\Delta d_{\eta=50}$, %	**4.5** **0**	**1.37** **1.37**	**5.74** **32**	**3.923** **4.77**	**$2.767^{z)}$** **0.62**	**1.12** **0**	**2.318** **0**	**2.11** **8.15**	**$2.08^{z)}$** **7.96**	$2.91^{z)}$ **3.0**

Cyclone	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	No. 19
a	0.16	0.2	0.25	0.25	026	0.223	0.182	0.104	0.2
b	0.38	0.4	0.5	0.28	1.0	0.41	0.527	0.586	0.52
D_c, m	0.3	0.3	0.2	0.8	0.37	0.3	0.55	0.512	0.25
D_{eq}, m	0.067	0.08	0.07	0.211	0153	0.087	0.149	0.0906	0.0722
D_e	0.4	0.187	0.5	0.38	0.5	0.325	0.545	0.533	0.48
ζ	1300	1900	237	1640	85	985	425	130	130
ρ, kg/m^3	2600	1000	2200	2650	2650	2650	2070	3100	2650
$\nu_g \cdot 10^6$, m^2/s	15.3	15.3	15.3	15.3	15.3	15.3	34.0	15.3	15.3
U_{av}, m/s	1.6	1	2.8	1.3	3.5	2.33	3.6	3.2	3.4
U_{in}, m/s	20.66	9.81	17.0	14.6	10.57	20	29.5	9.66	25.7
$D^e_{\eta=50}$, μm	$1.39^{z)}$	$1.27^{z)}$	$2.4^{z)}$	$2.4^{z)}$	$3.37^{z)}$	$1.85^{z)}$	$3.0^{z)}$	$2.79^{z)}$	$1.64^{z)}$
$D^c_{\eta=50}$, μm $\Delta d_{\eta=50}$, %	**$1.48^{z)}$** **6.9**	**$1.51^{z)}$** **7.0**	**$2.6^{z)}$** **1.83**	**$2.22^{z)}$** **7.5**	**$3.74^{z)}$** **3.64**	**$1.73^{z)}$** **–**	**$3.38^{z)}$** **12.67**	**$3.9^{z)}$** **7.52**	**1.57** **4.09**

Note: No. 1 – CN-15 [1]; No. 2 – CN-11 [1]; No. 3 – CN-24 [1]; No. 4 – CBTI (C) [9]; No. 5 – MIOT [9]; No. 6 – MIOT [9]; No. 7 – CK-CN-34M [1]; No. 8 – CK-CN-33 [1]; No. 9 – [9]; No. 10 – [9]; No. 11– SCN-40 [9]; No. 12 – [9]; No. 13 – RISI [9]; No. 14 – UC-38; No. 15 – VCNIIOP [9]; No. 16 – [9]; No. 17 – [9]; No. 18 – [9]; No. 19 – [9]; the quantities are marked with z), which correspond to the operating conditions of the cyclone ash collector

The values «$d^c_{\eta=50}$» proposed by the State Research Institute for Industrial and Sanitary Gas Treatment (Kyiv, Ukraine) are calculated according to the dependence:

$$d^c_{\eta=50} = 64.35\zeta^{-0.51}, \qquad (17)$$

for conditions $D_c=0.6$ m; $V_g=3.5$ m/s; $\mu_g=22.2\cdot 10^{-6}$ Pa·s; $=1930$ kg/m^3.

If necessary, recounting to other conditions can be carried out according to the formula:

$$d^{z)}_{\eta 50} = d^{p}_{\eta 50}\sqrt{\frac{D^{z)}_c}{0.6}\cdot\frac{3.5}{V^{z)}_c}\cdot\frac{\mu^{z)}_g}{22.2\cdot 10^{-6}}\cdot\frac{1930}{\rho^{z)}_d}}\ \ \mu\text{m},$$

where the quantities are marked with $^{z)}$, which correspond to the operating conditions of the cyclone ash collector.

The average loss for the recorded dependency by State Research Institute for Industrial and Sanitary Gas Treatment (17), with an estimate of the value «$d_{\eta=50}$» for the index in the Table 1 of the same cyclones (19 pcs.), 21.46 % accumulated [9]. It is 3.2 times more dangerous than with the value of the rosette of $d_{\eta=50}$ in the fallow deposits (8).

It should be noted that, in addition to higher accuracy, the new method allows forecasting the value of «$d_{\eta=50}$» when there is a change in the turbulence of the gas flow at the inlet to the cyclone, which is unacceptable when there is a complete change in method.

7. SWOT analysis of research results

Strengths. A positive effect of the studies is the high accuracy of analytical calculations of the cleaning efficiency of various cyclones both at the design stage and in industrial conditions of operation of cleaning systems.

Weaknesses. A negative factor in the study is that the conclusions of the work should be extended to a larger number of cyclone designs and conditions for dust dispersion and gas flow characteristics.

Opportunities. When implementing the results of the study, in some cases it is possible to significantly reduce capital costs for the purchase of more expensive treatment equipment for electrostatic precipitators, bag filters. This will give enterprises significant cost savings. The results of the work may be interesting not only for Ukraine.

Threats. When implementing the results of the study, additional costs are practically not required.

8. Conclusions

1. The analysis of the influence of the average cross-sectional average of the inlet pipe of the cyclone of the velocity of the transverse pulsations of the turbulent gas flow in the inlet of the cyclone [2, 13] on the value of the «cut-off» diameter «$d_{\eta=50}$» [1]. It has been established that the greatest influence on the value of the «cut-off» diameter «$d_{\eta=50}$», as well as on the cleaning efficiency, is exerted by the velocity of transverse pulsations of the turbulent gas flow in the inlet of the cyclone [2, 13].

2. The proposed improved method for calculating the efficiency of dust removal of cyclones is based on the characteristics of turbulent flows and the efficiency of the process of deposition of dust particles on the path (cyclone wall, on the surface of the dust bundle) in the approximation of the «diffusion boundary layer». This allows one to calculate with high accuracy the effective cleaning of industrial dusts in cyclones, significantly reduce the time spent and the amount of experimental work when developing new types of cyclones or selecting them for solving various problems in the field of aerosol mechanics. Using the most accurate experimental data on the effectiveness of dust cleaning in various cyclones [1, 9], the advantages of this method for calculating the total degree of ash extraction in cyclones with different designs and various parameters of dust and gases are substantiated. When assessing the accuracy of the calculations of the methods, the results of calculations by the most accurate method are considered [9, 10]. It is shown that the average accuracy in estimating $d_{\eta=50}$ is 12 % higher than in [9, 10].

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