SAT-LCR-P-2-CT(R)-05

COMPARISON AND EVALUATION OF DIFFERENT THEORETICAL METHODS FOR CONSTRUCTIVELY SIZING OF CYCLONES

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Abstract: *The present work aims to make compare and evaluate the possibilities of the known theoretical methods for the constructive sizing of cyclones. Three theoretical methods for the constructive sizing of cyclones have been considered, and their application has been realized through the calculation of specific methodologies for the selection and calculation of cyclones for given initial data. The calculation procedures along the three methods were made for particular object the service of which is to separate gas from furnace for burning cement clinker with a cyclone, aiming to achieve capturing efficiency not less than 60%. A comparison between the capabilities of the three theoretical methods for constructive dimensioning of cyclones is made.*

Keywords: *Cyclone efficiency, Dimensioning of cyclones, Selection of cyclones, Methods*

INTRODUCTION

Many industrial production lines form heterogeneous gaseous systems. The separation of these systems prevents the contamination of atmosphere with hazardous pollutants, protects the environment, diminishes the losses of valuable products and increases the economic efficiency of the technological process. The centrifugal dust collectors are widely spread devices in industry and the various kinds of cyclones are their typical representatives (Hoffmann, A. C., Stein L. E., 2008; Genchev, Chr., Koleva, D., 2012). The purpose of cyclones is to collect dust from drying ovens, and from apparatuses with pseudo fluid layer of granular material, dust from aspirators, capture solid particles from flue gases, dust from the air in pneumatic transportation installations, separation of gases in chemical and metallurgic facilities, etc. (Wang, B., Xu, D. L., Chu, K. W., Yu, A. B., 2006; Ibhadode, O. O., Ogedngbe, E. O. B., Rosen, M. A., 2017). Many designs of cyclones are known and their versatility is determined by: technological factors, the type and the physicochemical properties of the separated heterogeneous gas system and the degree of separation. The advantages of cyclones are their simple construction, lack of moving parts, capability to separate aggressive chemical gases at high temperatures and high efficiency in separation of particles larger than 20 μm. These advanatges make them economically efficient and stipulate their widespread use in industrial production (Hoffmann, A. C., Stein L. E., 2008; Genchev, Chr., Koleva, D., 2012; Shkopad, D. E., Novikov, O. P., 1987; Bogatykh, S. A., 1978). Since the theoretical dimensioning of cyclones is a complex task to determine their actual technical parameters, various methodologies for calculation of their basic technological characteristics have been published in the literature (Domansky, I.V., Isakov, V.P., et al., 1982; Aleshina, V. M., Waldberg, Yu. A., Gordon, M. G., Gurvits, A. A., Levin, S. L., Mettus, A. A., 1984; Panev, P., et al, 1982; Bogatykh, S. A., 1978; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990; Wang, B., Xu, D. L., Chu, K. W., Yu, A. B., 2006; Ibhadode, O. O., Ogedngbe, E. O. B., Rosen, M. A., 2017). The aim of the preset work is to make compare and assess the abilities of the well-known theoretical models for constructive dimensioning of cyclones. The suggested methods can successfully be applied for choice and dimensioning of cyclones, as well as in the education of the stidents in specialties Chemical engineering and Chemical technology.

EXPOSITION

Practically, the dimensioning of the cyclones is carried out by the following sequence: 1) the initial data are set (flow rate of the purified gas under operational conditions); 2) properties of the gas (viscosity, density, etc.) are considered; 3) dust content (quantity, size and density of the solid particles) is taken into account; 4) required degree of purification (efficiency) is set; 5) allowable hydraulic resistance of the cyclone □p is determined; 6) the coefficients of hydraulic resistance (ζ) of the inlet orifice and the cylindric part of the cyclone are taken from reference tables. Using these data and in the well-known formulae for □p together with the debit equation, the velocity, cross-sectional area, orifice diameters and the cylindrical part of the cyclone are calculated. All the other dimensions are determined in relation to the diameter of cyclone cylindrical part, as ratios. (Domansky, I.V., Isakov, V.P., et al., 1982; Aleshina, V. M., Waldberg, Yu. A., Gordon, M. G., Gurvits, A. A., Levin, S. L., Mettus, A. A., 1984; Panev, P., et al, 1982; Bogatykh, S. A., 1978; Pavlov, K. F., Romanko,v P. G., Noskov, A. A., 1990; Wang, B., Xu, D. L., Chu, K. W., Yu, A. B., 2006; Ibhadode, O. O., Ogedngbe, E. O. B., Rosen, M. A., 2017).

To achieve the objectives of the present study, a choice and calculaitons were carried out by three different methods for cyclone type NIIOGAZ, based on the following initial data: separation of gas from cement clinker burning furnace with collection efficiency not less than 60%, initial dust concentration in the gas 60 g/m^3, gas flow rate 18 000 m^3/h, maximum allowable device resistance should be 700 Pa, dust density is $\rho_d = 2800\ kg/m^3$, gas temperature – $t_g = 400°C$, gas viscosity $\mu_g = 22{,}1.10^{-6} Pa.s$, gas density under normal conditions – $\rho_0 = 1{,}293\ kg/m^3$.

The dust particles are distributed by size as follows:

$\delta_p, \mu m$	4	4÷8	8÷15	15÷25	25÷36	36÷50	50÷70	70÷100
$R(\delta, \%)$	22	24	22	14	7	5	3	3

According to the first method of constructive dimensioning of cyclones, (Domansky, I.V., Isakov, V.P., et al., 1982) the initial step is to plot the particles mass distribution curve – R-curve (Fig.1) on which the fractional composition of the dust is found in the new boundaries $R(\delta)$ (corresponding to the size of particles of reference dust (Table 1.).

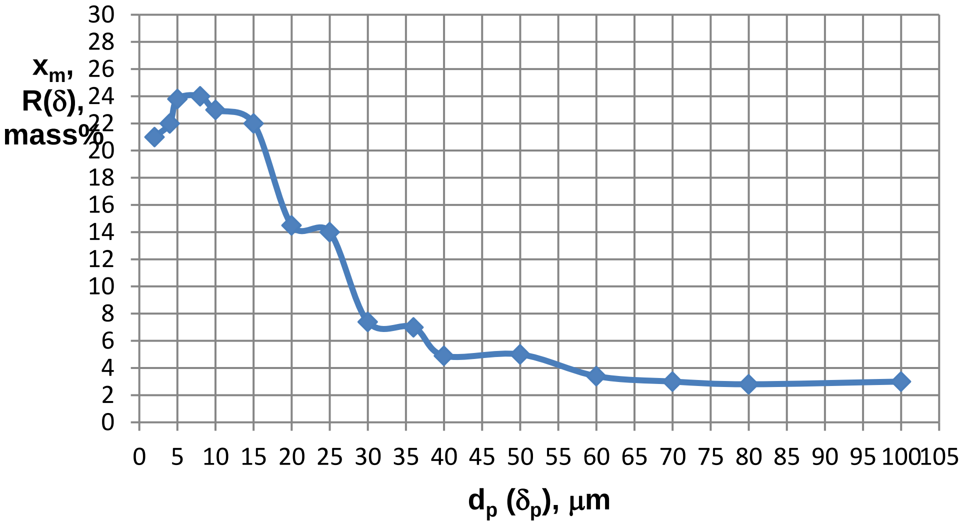

Fig. 1. Function of distribution of the particles by size.

Table 1. The fractional composition of the dust in the new boundaries R(δ) (corresponding to particles'size of reference dust).

$\delta_p, \mu m$	5	10	20	30	40	60	80	100
$x_m, \%$	23,8	23	14,5	7,4	4,9	3,4	2,8	2,5

Consequently, the full degree of purification $\eta_п$ is calculated from the fractional degrees of purification with the corresponding corrections for three values of the quantity conditional degree of purification η_{20} at $\delta_d = 20$ μm, $\eta_{20} = 0{,}50; 0{,}70$ and $0{,}95$ (equation 1).

$$\eta = \eta_{\delta_1}.f(\delta_1) + \eta_{\delta_2}.f(\delta_2) + \cdots + \eta_{\delta_n}.f(\delta_n) \quad (1)$$

$f(\delta_n) = x_m$- content of certain fraction of dust particles with size δ_n or the mass part of dust particles in certain fraction, kg/kg; $\eta_{\delta_1}, \eta_{\delta_2}; \eta_{\delta_n}$- the fraction's degree of purification or dust collection. Based on the results obtained, the printout curve is drawn where the abscissa is the full degree of purification or the full efficiency and the ordinate is the conditional degree of gas purification η_{20}. From the printout curve, the value of the conditional degree of purification corresponding to the set degree of purification conditional η = 60% is taken, in this case η_{20} = 0,85. From the graphical dependence presented by the authors Domansky, I.V., Isakov, V.P., et al., 1982, the cyclones corresponding value of η_{20} = 0,85 are considered, as well as the conditional time of residence of the gas in the cyclones τ_y. In this case, the cyclones are four CN-24, CN-15y, CN-15 and CN-11. For these cyclones, the optimal diameter and the number of cylones are determined to ensure the required degree of purification.

$$D_{опт} = 0{,}49\tau_y\sqrt[3]{K_c.K_p} \quad (2) \quad K_c = K_{c.e.}/\xi \quad (3) \quad K_p = \frac{E_p + K_d + K_{w.c.}}{0{,}016.\rho_g} \quad (4) \quad W_\Gamma = \frac{D}{\tau_y}, m/s$$
(5)

K_c- constructive coefficient of the cyclone; K_p- pertional coefficient of the cyclone; $K_{c.e.}$– coefficient of capital expenses (Domansky, I.V., Isakov, V.P., et al., 1982); ξ – coefficient of resistance of the cyclone (Domansky, I.V., Isakov, V.P., et al., 1982) E_p - standardized coefficient of payout ($E_p = 0{,}17$); K_d– coefficient of depreciation ($K_d = 0{,}1$); $K_{w.c.}$ – coefficient of workshop cost ($K_{w.c.} = 0{,}07$); D – diameter of the cyclone accepted according to the standards and close to the optimal diameter D_{opt}, m. The velocity of the gas in the cyclone is calculated by equation 5. The number of cyclones in the separation complex is determined by equation 6.

$$z = \frac{4V_g}{\pi D^2 W_g} \quad (6) \quad RC_{min} = \left[\frac{5{,}25.\rho_g.\xi.0{,}016.D^2}{\tau_y^2} + \frac{1{,}27(E_p + K_d + K_{w.c.}).K_{c.e.}.\tau_y}{D}\right].V_g \quad (7)$$

The last stage of the first method is redued to the final choice of cyclone type according to the minimum reduced costs (equation 7). The results obtained from the calculations made are shown in Table 2.

Table 2. Results obtained from the calculations according to the first method.

Parameters	Given degree of purification η = 60% and conditional degree of purification η_{20} = 85%			
	CN-24	CN-15y	CN-15	CN-11
Conditional time of residence of the gas in the cyclone τ_y, s	0,12	0,25	0,36	0,55
Constructive coefficient of the cyclone, K_c	15,2	6	7,3	4,4
Optimal diameter, D_{opt}, m	0,5	0,77	1,18	1,52
Acepted diameter, D, m	0,5	0,77	1,20	1,50
Gas velocity in the cyclone, W_g, m/s	4,17	3,08	3,33	2,73
Number of cyclones, z	6	4	2	1
Minimal reduced costs, RC_{min}	891,70	908,37	1048,50	1204,00
Hydraulic resistance of the cyclone, Δp, Pa	340	406,97	446,88	474,75
Specific costs, $\frac{\Delta p}{\rho_g}$, m^2/s^2	653,85	782,63	859,38	912,98

According to the results obtained from the first method of cyclone dimensioning and the comparison of the minimal reduced costs, under the given condition for effective dust collection with degree of purification of at least 60%, it can be concluded that it would be expedient to use 6 cyclones type CN-24 each with diameter of 500 mm.

By the second method of constructive dimensioning of cyclones, called nomographic (Aleshina, V. M., Waldberg, Yu. A., Gordon, M. G., Gurvits, A. A., Levin, S. L., Mettus, A. A., 1984; Panev, P., et al, 1982), initially the degree of purification is calculated on the basis of dust fractional composition and the fractional degrees of dust collection. The content of dust particles of given fraction with size δ_n taken from Fig.1 for the average diameter of the fraction (5, 10, 20, 30, 40, 60, 80 и 100μm), while the fractional degrees of purification are taken from a nomogram (Panev, P., et al, 1982). For the calculated general degree of purification $\eta = 69{,}33\ \%$ (equation 1), three cyclones were found in the nomogram: CN-15, CN-15y and CN-24. Once the type of cyclone is established, its diameter is determined according to equation 8, followed by determination of the number of cyclones, fictitious velocity of the gas, the hydraulic resistance of the cyclone (as per equation 9) and its specific costs (equation 10). The results obtained from the calculations made according to the second method are given in Table 3.

$$D_{opt} = \sqrt{\frac{V_г}{0{,}785.W_{opt}}}, m \quad (8) \qquad \Delta p_{(CN\text{-}15)} = \frac{\xi.W_{opt}^2.\rho_g}{2}, Pa \quad (9) \qquad E_{c(CN\text{-}15)} = \frac{\Delta p}{\rho_g}\ m^2/s^2 \quad (10)$$

The optimal velocities in the cyclones are: $W_{opt(CN\text{-}15 \text{ и } CN\text{-}15y)} = 3{,}5\ m/s$; $W_{opt(CN\text{-}24)} = 4{,}5\ m/s$ (Aleshina et al., 1984); Δp - hydraulic resistance of the cyclone.

Table 3. Results obtained from the calculations according to the second method.

Parameters	Set degree of purification η = 60% and general degree of gas purification η_{cal} = 69,33 %		
	CN-24	CN-15y	CN-15
Optimal diameter, $D_{опт}, m$	1,18	1,34	1,34
Accepted diameter, D, m	1,18	1,34	1,34
Gas velocity in the cyclone, W_g, m/s	4,5	3,5	3,5
Number of cyclones, z	1	1	1
Hudraulic resistance of the cyclone, Δp, Pa	395	526	494
Specific costs, $\frac{\Delta p}{\rho_g}$, m^2/s^2	760	1012	950

By the second method of dimensioning, following the requirement of achieving at least 60% degree of purification, the overall degree of purification obtained was 69,33%, accompanied by lower hydraulic resistance. Therefore, it would be advisable to use single cyclone type CN-24 with diameter of 1,18 m.

According to the third metod for dimensioning of cyclones (Bogatykh, S. A., 1978; Pavlov, K. F., Romankov, P. G., Noskov, A. A., 1990), cyclone type CN-24 with coefficient of resistance $\xi = 75$ is selected and the value of the ratio □p/□g is assumed to be $\frac{\Delta p}{\rho_g} = 600\ m^2/s^2$. Once the value of the ratio $\frac{\Delta p}{\rho_g}$ is accepted, the gas velocity in the cylindrical part of the cyclone is calculated, as well as the diameter to which it corresponds, the hydraulic resistance of the cyclone and the number of cyclones. The results obtained from the calculations made according to the third method are summarized in Table 4.

$$W_{g(CN\text{-}24)} = \sqrt{\frac{2.\Delta p}{\xi.\rho_g}}, m/s \quad (11) \qquad D_{(CN\text{-}24)} = \sqrt{\frac{V_g}{0{,}785.W_g}}, m \quad (12) \qquad \Delta p_{(CN\text{-}24)} = \frac{\xi.W_g^2.\rho_g}{2}, Pa \quad (13)$$

On the basis of the results obtained by the third method of dimensioning, observing the required degree of purification of at least 60%, obtained overall degree of purification 69,33% and accepted value of the ratio $\frac{\Delta p}{\rho_g} = 600\ m^2/s^2$, it can be concluded that it would be expedient to use one cyclone type CN-24 with dimeter of 1,26 m.

The results presented in Table 5 illustrate the comparison of the capabilities of the three theoretical methods used.

Table 4. Results obtained form the calculations by the third method.

Parameters	Set degree of purification η = 60% and overall degree of gas purification η_{cal} = 69,33 %
	CN-24
Optimal diameter, D_{opt}, m	1,26
Accepted diameter, D, m	1,26
Gas velocity in the cyclone, W_g, m/s	4,00
Number of cyclones, z	1
Hydraulic resistance of the cyclone, Δp, Pa	312
Coefficient of resistance of the cyclone ξ	75
Specific costs, $\frac{\Delta p}{\rho_g}$, m^2/s^2	600

Table 5. Summarized results obtained form the calculations for cyclones type CN-24 carried out according to the three methods of constructive dimensioning.

Parameters of cycone type CN-24	First method	Second method	Third method
Set degree of purification, η, %	60	60	60
Overall degree of gas purification, η_{cal}, %	85	69,33	69,33
Optimal diameter, D_{opt}, m	0,5	1,18	1,26
Accepted diameter, D, m	0,5	1,18	1,26
Gas velocity in the cyclone, W_g, m/s	4,17	4,5	4,00
Number of cyclones, z	6	1	1
Hydraulic resistance of the cyclone, Δp, Pa	340	395	312
Specific costs, $\frac{\Delta p}{\rho_r}$, m^2/s^2	653,85	760	600

Table 6. Constructive dimensions of cyclones type CN-24 with respect to the diameters of the cylindrical part calculated by the three methods used.

Geometric dimension	Cyclone type		
	CN-24 D = 0,5 m	CN-24 D = 1,18 m	CN-24 D = 1,26 m
Diameter of the outlet tube, d_t, m	0,30	0,71	0,76
Length of the outlet tube, h_t, m	1,06	2,49	2,66
Diameter of the dust orifice, d_1, m	0,20	0,47	0,50
Width of the inlet channel guide, b, m	0,10	0,24	0,25
Height of the inlet channel guide, a, m	0,56	1,31	1,40
Length of the inlet channel guide, l, m	0,30	0,71	0,76
Height of the cylindrical part, $H_{cyl.}$, m	1,06	2,49	2,66
Height of the conical part, $H_{con.}$, m	0,88	2,07	2,21
Cyclone total height, H, m	2,13	5,03	5,37
Depth of cyclone immersion, h_{im}, m	0,16	0,38	0,40

With the first method, the overall degree of purification turned out to be higher – 85%, compared to that calculated by by the second and third methods – 69,33 %. The calculations by the first method gave higher number of cyclones with smaller diameter of the cylindrical part while the second and third methods gave the smaller number of cyclones, but with higher diameter. The smallest hydraulic resistance was obtained by the third method but it requires to accept certain value of the ratio $\frac{\Delta p}{\rho_g}$. In each method, the constructive dimensions of the cyclone are obtained as fractions of the diameter of the cylindrical part. Table 6 shows the constructive dimensions of cyclone type CN-24 according to the diameters of the cylindrical part calculated by the three methods used.

CONCLUSION

Three theoretical methods for constructive dimensioning of cyclones are discussed and their application was realized using specific methodologies for choice and calculation of cyclones on the basis of provided initial data. The calculation procedures were carried out by the three methods for specific object, the task of which is to separate the dust from the gas from a furnace for burning cement clinker and achieve capturing efficiency of at least 60%. The capabilities of the three theoretical methods for constructive dimensioning of cyclones were compared. The three methods suggested the same choice of cyclone but the first and second methods are better suited for more precise dimensioning while the third can be applied for initial orientation about the type of the cyclone. The first method conforms to the main factors that influence the choice of a cyclone: achieving high degree of purification and low hydraulic resistance of the device (which affects the operational costs) and, last but not least, lowering the capital costs due to the smaller diameter of the cyclone.

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