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GAS CLEANING FROM DUST IN A CYCLONE ROTARY DEVICE

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The cyclone rotary dust collector got its name due to the fact that it embodies the principle of two-stage separation of inhomogeneous dust and gas systems in a centrifugal field. First, in the first stage, operating on the principle of a cyclone, and then in the second, operating on the principle of a rotary dust collector. The apparatus differs from serial cyclones in that it has a shortened central tube with a conical baffle and a rotating rotor. It provides gas circulation and returns fine dust from the upper rotation zone to the lower cyclone zone. This greatly improves the efficiency of dust collection. The device is able to create a vacuum in the suction and pressure in the discharge pipe, due to which it can work autonomously (without a fan) and treat gases that do not have an initial overpressure. Due to the large centrifugal force acting on the particle in the rotary part of the dust collector, it effectively captures particles with a diameter of less than 8 microns. With the help of the rotor, a fine dispersion of the liquid and an exceptionally uniform (circular) irrigation of the walls of the apparatus are achieved, which has a positive effect on the capture of fine and sticky dust. The installation of a shortened central pipe with a conical baffle in the dust collector made it possible to divide the apparatus into two parts and carry out a two-stage gas purification. The rotor, mounted on the top of the dust collector, also performs a number of other functions. Working like a centrifugal atomizer, it finely atomizes the liquid, facilitating more efficient (wet) particle capture. At the same time, it provides an extremely uniform, circular irrigation of the walls of the first and second stages of the apparatus, which is necessary for washing off adhering dust. This is especially important when trapping sticky particles. When cleaning gases from loose, non-sticking particles, the apparatus can operate in dry mode without irrigation. By changing the speed of rotation of the rotor within certain limits, it is possible to change the productivity and pressure of the dust collector. *Key words:* cyclone-rotary dust collector, gas cleaning from dust, fine dust.

Очищення газів від пилу в циклонно-ротаційному апараті. Кузнєцов С.І., Венгер О.О., Григор'єва Л.І., Семенченко О.О., Безпальченко В.М., Івкіна Є.С.

Циклонно-ротаційний пиловловлювач отримав свою назву завдяки тому, що в ньому втілено принцип двоступеневого поділу неоднорідних пило-газових систем у відцентровому полі. Спочатку в першому ступені, що працює за принципом циклону, а потім у другому, – працює за принципом ротаційного пиловловлювача. Апарат відрізняється від серійних циклонів тим, що в ньому встановлена укорочена центральна труба з конусною перегородкою і ротор, що обертається. Він забезпечує циркуляцію газу та повертає дрібнодисперсний пил з верхньої ротаційної зони в нижню циклонну. Завдяки цьому суттєво підвищується ефективність пиловловлення. Апарат, здатний створювати розрідження у всмоктувальному та тиск у нагнітальному патрубку, завдяки чому може працювати автономно (без вентилятора) та піддавати очищенню гази, що не мають початкового надлишкового тиску. Завдяки великій відцентровій силі, що діє на частинку в ротаційній частині пиловловлювача, він ефективно вловлює частинки діаметром менше 8 мкм. За допомогою ротора досягається тонке диспергування рідини і виключно рівномірне (кругове) зрошення стінок апарату, що позитивно позначається при вловлюванні дрібнодисперсного і пилу, що злипається. Установка в пиловловлювачі укороченої центральної труби з конусною перегородкою дозволило розділити апарат на дві частини та здійснити двоступінчасте очищення газів. Ротор, встановлений у верхній частині пиловловлювача виконує, також і ряд інших функцій. Працюючи як відцентрова форсунка тонко розпорошує рідину, сприяючи більш ефективному (у мокрому режимі) уловлюванню частинок. Одночасно він забезпечує виключно рівномірне, кругове зрошення стінок першого і другого ступеня апарату, що необхідно для змиву пилу, що налипає. Це особливо важливо при уловлюванні часток, що злипаються. При очищенні газів від сипких частинок, що не злипаються, апарат може працювати в сухому режимі без зрошення. Змінюючи в певних межах швидкість обертання ротора, можна змінювати продуктивність і напір пиловловлювача. *Ключові слова:* циклонно-ротаційний пиловловлювач, очищення газів від пилу, дрібнодисперсний пил.

Formulation of the problem. Formulation of the problem. Air pollution by technogenic dust, today, has become one of the most pressing modern problems. Solid particles can accumulate and travel long distances. They adsorb harmful substances from the air, worsening the ecological situation on a local and global scale.

Particles smaller than 10 microns do not linger in the upper respiratory tract, accumulate in the lungs and interfere with the gas exchange of the body with the external environment. In industrial emissions into the atmosphere, their countable number is huge, despite the fact that the mass fraction is negligible. According to WHO experts, ninety percent of the world's population breathes polluted air. Microscopic particles enter the respiratory and circulatory systems, damaging the tissues of the lungs, heart and brain and causing diseases such as cancer, stroke, heart and lung diseases.

On the recommendation of WHO in the EU countries in 2015, the following maximum permissible concentrations of dust were established:

– for particles with a size of 10 microns and less than 0,05 mg/m³;

– for particles 2,5 microns and less – 0,085–0,01 mg/m³ [1].

Pollutant emissions from stationary sources are also regulated by the order of the Ministry of Environment and Natural Resources of Ukraine No. 309 and should not exceed 50 mg/m³ [2].

Analysis of recent research and publications. The dust collection systems used today operate with design efficiency in a narrow range of speeds, concentrations, thermodynamic parameters of the carrier medium, and with all the advantages, in some cases, their use becomes ineffective. This applies to the capture of fine, agglomerating dust, as well as in case of insufficient pressure of the gas to be purified [3-7].

The developed design of the dust collector is devoid of these disadvantages.

Formulation of research objectives. The design and principle of operation of the two-stage cyclone-rotary dust collector provides gas circulation, in which fine dust returns from the rotation zone to the cyclone and coagulates, as a result of which the dust collection efficiency of fine particles is significantly increased.

Statement of the main material. Figure 1 shows an axonometric view of a cyclone-rotary dust collector. It has a shortened central tube with a conical baffle and a rotor [8].

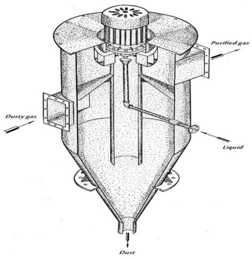

Fig 1. Cyclone-rotary dust collector

A gap is provided between the conical partition and the inner part of the cylinder, the dimensions of which are in the range from 5 mm to 9 mm, depending on the dimensions of the apparatus. The installation of a conical partition on the central pipe in the dust collector makes it possible to divide the apparatus into two parts and carry out two-stage gas purification. At the same time, in the second stage, due to the installation of a rotating rotor with variable speed in it, the centrifugal force (Pc) can be increased by 3–5 times compared to that achieved in cyclones of known designs. This allows you to increase the degree of gas purification and effectively capture dust particles with a diameter of less than 10 microns. The cyclone rotary dust collector is capable of operating both in dry and wet modes [9].

The rotor installed in the dust collector performs the following functions:

– working as a gas blower, it creates a vacuum in the inlet and excess pressure in the discharge pipe. In this regard, the dust collector can operate autonomously (without a fan) and purify gases that do not have an initial overpressure;

– working like a centrifugal nozzle – it finely atomizes the liquid, contributing to a more efficient (in wet mode) trapping of particles. At the same time, it provides a uniform, circular irrigation of the walls of the first and second stages of the dust washer. This is especially important when dealing with sticky dust. When cleaning gases from loose, non-sticking particles, the apparatus can operate in dry mode without irrigation, while the purification efficiency does not significantly decrease;

– by changing the speed of rotation of the rotor within certain limits, it is possible to change the productivity and pressure of the dust collector.

To determine the efficiency of gas purification in cyclone-rotary dust collectors, let us consider some theoretical prerequisites for the separation of inhomogeneous dust and gas systems in a centrifugal field. As is known, during the operation of a cyclone, three components act on a particle moving in the field of centrifugal forces.

The first component is the centrifugal force, which throws the particle to the periphery of the cyclone:

$$P_C = \frac{m \cdot \omega_т^2}{R}, \quad (1)$$

where m – is the particle mass, kg; ω_T – is the tangential velocity of the particle ($\omega_T = \omega_{вх}$), m/s; R – is the radius from the center to the particle, m.

The second is the force of resistance to the movement of the particle in the radial direction:

$$P_R = 3\pi \cdot \omega_R \cdot d_ч \cdot \mu, \quad (2)$$

where ω_R– particle radial velocity, m/s; $d_ч$ – particle diameter, m; μ – medium viscosity, $N \cdot s/m^2$

The third is gravity:

$$P_g = m \cdot g, \quad (3)$$

where m – is the mass of the particle, kg; g – acceleration of gravity.

The particle begins to move in the radial direction when $P_C > P_R$. Equating (1) and (2) forms and assuming that

$$m = \frac{\pi \cdot d_ч^3}{6} \cdot \rho_ч, \quad (4)$$

we get: $$\omega_R = \frac{d_ч^2 \cdot \omega_т^2 \cdot \rho_ч}{18\mu \cdot R} \quad (5)$$

The time of deposition of particles in the space of the apparatus between R_2 and R_1 will be:

$$\tau_{oc} = \frac{R_2 - R_1}{2\omega_R} = \frac{9\mu \cdot \left(R_2^2 - R_1^2\right)}{d_ч^2 \cdot \omega_т^2 \cdot \rho_ч}, \quad (6)$$

where R_2 and R_1 – radii of the central pipe and cyclone, m ($R = \frac{R_1 + R_2}{2}$); $\rho_ч$ – density, kg/m³;

we get: $$\frac{m \cdot \omega_т^2}{R} = 3\pi \cdot \omega_R \cdot d_ч \cdot \mu \quad (7)$$

Assuming that the collected dust has a spherical shape, according to formula (8), the smallest particle diameter can be found that will be completely captured by the apparatus during the time τ_{oc}.

$$d_{min} = 3\sqrt{\frac{\mu \cdot (R_2 - R_1)}{\pi \cdot n' \cdot \rho_ч \cdot \omega_т}} \quad (8)$$

From (8) it is possible to make an estimate of the degree of dust collection of the cyclone, assuming that fractions with particle sizes d_{min} and larger will be completely captured in the apparatus. For them, the degree of capture of particles in fractions of a unit will be one. The degree of particle trapping, the diameter is $d_x < d_{min}$ determined from the ratio:

$$\eta_x = \frac{R_2 - R_x}{R_2 - R_1} = \frac{d_x^2}{d_{min}^2} \quad (9)$$

Attitude $\frac{P_C}{g} = Fr_C$ called the separation factor or centrifugal Froude criterion. Substituting the value P_C and g we get:

$$Fr_C = \frac{m \cdot \omega_т^2}{R \cdot mg} = \frac{\omega_т^2}{Rg} = \frac{n^2 \cdot R}{900}, \quad (10)$$

where n – particle rotation frequency, m^{-1}.

Сопротивление циклона определяется из соотношения:

$$\Delta P_C = \xi \cdot \frac{\rho_г \cdot \omega_{entr}^2}{2}, \quad (11)$$

where ω_{entr} – gas velocity in the inlet pipe, m/s; $\rho_г$ – gas density, kg/m^3.

Instead of ω_{entr} the conditional gas velocity can be used, referred to the cross-sectional area of the cylindrical part of the cyclone – ω_{con} (ω_{con} = 3÷5 m/s). Then

$$\Delta P'_ц = \xi' \cdot \frac{\rho_г \cdot \omega_{entr}^2}{2}, \quad (12)$$

where ξ и ξ' – cyclone hydraulic resistance coefficient.

For various designs of cyclones $\xi'=$ 2–5; $\xi' = 50$–30.

From the equation (12) can be written:

$$\frac{\Delta P_ц}{\rho_г} = \frac{\xi \cdot \omega_{entr}^2}{2} \quad (13)$$

For each cyclone design, the ratio $\frac{\Delta P_C}{\rho_г}$ has the optimum value. The best cleaning conditions are provided when $\frac{\Delta P_ц}{\rho_г} = 50 \div 75m$.

Cyclone performance in m^3/h is determined from the formula:

$$Q = \omega_{con} \cdot S \cdot 3600, \quad (14)$$

where S – cyclone cross section, m^2.

Thus, using the above equations, it is possible to determine the main indicators of the process of separating dust and gas systems in a centrifugal field. Table 1 shows the comparative characteristics of the operation of the cyclone TsN-15 and the cyclone-rotary dust collector – 600, obtained by calculation under the following conditions: D = 0,6m; R_2 = 0,3m; R_1 = 0,15m; $R = \frac{R_1 + R_2}{2}$ = 0,225m; μ =1,8·10^{-5}N·s/m^2; $\rho_ч$=1500 kg/m^3.

The data given in the table show that cyclone rotary dust collector-600 compares favorably with the TsN-I5 cyclone of equal diameter. It has a centrifugal force 12,5 times greater than in the TsN-15 cyclone. The settling rate is increased by the same factor and the settling time of particles is reduced. The Froude criterion (separation factor) for cyclone rotary dust collector-600 is 30 times higher than for cyclone TsN-15. Due to these advantages, the minimum diameter of particles to be captured in cyclone rotary dust collector-600 is 6,96 microns, while in cyclone TsN-I5 it is 13,1 microns, i.e. 2 times more. Especially significant is the advantage of cyclone rotary dust collector-600 when capturing micron particles. Particles with a diameter of 10, 8, 6, 4 microns in the cyclone rotary dust collector-600 are captured by 100, 100, 74 and 33%, respectively, while in the TsN-I5 cyclone – by 58, 37, 21 and 9%. To this it should be added that the cyclone rotary dust collector-600 operates autonomously (without a fan) and is capable of developing a pressure of 680 Pa, while the TsN-15 cyclone has a hydraulic resistance of ~ 400 Pa and requires the installation of a fan.

Note: Values P_C, ω_R, τ_{oc} determined for nominal particle diameter d=10 micron.

The combination of several principles of dust cleaning in one apparatus and the creation of controlled additional forces that contribute to the capture of dust in the working volume of the apparatus makes it possible to increase the efficiency of dust collection and create conditions for additional separation of the dust and gas flow when passing through the apparatus. However, at the same time, the hydraulic resistance of the apparatus should not increase significantly.

Cyclone-rotary dust collector has a number of advantages compared to conventional cyclones:

– acting as a gas blower, it creates a vacuum in the suction and pressure in the discharge pipe, due to which it can work autonomously (without a fan) and clean gases that do not have an initial overpressure;

– due to the large centrifugal force acting on the particle in the rotary part of the dust collector, it effectively captures particles with a diameter of 8 microns;

– with the help of a rotating rotor, a fine dispersion of the liquid and uniform irrigation of the walls of the apparatus are achieved, which contributes to an increase in the efficiency of capturing fine and sticky dust.

In cyclone rotary dust collector effectively implemented:

– absorption processes for purification of ventilation emissions from harmful gases (SO_2, CO, NO_2, etc.);

– technological processes of gas and liquid interaction;

– wet collection of fine dust and aerosols;

– cooling, humidification (drying) of gas;

Table 1

Comparative characteristics of cyclone TsN-15 and cyclone rotary dust collector-600

№	Parameter	Symbol	Units	Parameter value	
				TsN-15	**Cyclone rotary dust collector-600**
1	Performance	L	m^3/h	4000	4000
2	Cyclone diameter	D	m	0,6	0,6
3	Cyclone diameter	ω_{entr}	m/s	15	15
4	Gas velocity in free section	ω_{con}	m/s	3,93	3,93
5	Centrifugal force	P_C	kg·m/s	$7,8510^{-10}$	$98,5\cdot10^{-10}$
6	Particle speed in radial direction	ω_R	m/s	0,46	5,84
7	Settling time	τ_{oc}	s	0,324	0,026
8	Minimum particle diameter	d_{min}	m	$13,1\cdot10^{-6}$	$6,96\cdot10^{-6}$
9	Separation factor	Fr_C		102	3270
10	Device resistance	$P_ц$	Pa	405	405
11	Hydraulic resistance coefficient	ξ		3	3
12	Pressure	P_n	Pa	–	680
13	Ratio $\frac{\Delta PC}{\rho_o}$		m	337,5	337,5
14	The degree of trapping of particles with a diameter:				
	d_2 = 15micron	η	%	100	100
	d_2 = 10micron	η	%	58	100
	d_2 = 8micron	η	%	37	100
	d_2 = 6micron	η	%	21	74
	d_2 = 4micron	η	%	9	33

– can be used at various enterprises as absorbers – dust collectors, effectively capturing solid particles, aerosols and gaseous impurities.

An important task was to determine the degree of dust collection depending on the speed of rotation of the rotor, which in turn determines the performance and head of the dust collector. The studies were carried out both in dry and wet modes at the maximum aerodynamic efficiency of the dust collector (0,39–0,4). The real flow rate of the liquid in the studies was 0,2–0,25 dm^3/m^3. The dust content in the gas was determined by the gravimetric method with external filtration at the inlet, after the first and after the second stage of the dust collector. In the cyclone rotary dust collector, the main characteristic is not resistance (ΔP), but pressure (P). When working, both in dry and wet modes, the degree of purification increases as the irrigation P/ρ_o increases. Moreover, this increase is initially intense, and then smooth, fading. The transition region lies at P/ρ_o = 200÷300. Operation at higher values of P/ρo would be impractical, since in this case a slight increase in the degree of purification would be accompanied by a disproportionate increase in the energy expended. But here it should be taken into account that with an increase in the ratio P/ρo, the productivity of the apparatus increases. Therefore, the optimal area of operation of the cyclone rotary dust collector lies at the maximum values of P/ρ_o. When working in dry mode,

Table 2

Characteristics cyclone rotary dust collector-600

Cylinder diameter	0,6 m
Height	1,02 m
Central tube diameter	0,3 m
Central tube height	0,84 m
Rotor diameter	0,35 m
Rotor height	0,12 m
Cone height	0,9 m
Rotor speed	2800 min^{-1}
Inlet size	0,24×0,24 m
Outlet size	0,15×0,15m
Performance	4000 m^3/h
pressure	750 Pa
Engine power	2,5 kW
Cone height	0,12 m
Cone baffle diameter	0,582 m
Permissible dust content	200 mg/m^3
Minimum effective particle size	8 micron
Cleaning degree	99,7%
Specific liquid consumption per 1000 m^3 of gas	0,1–0,3 m^3
Specific electricity consumption per 1000 m^3 of gas	0,2–0,3 kW

the degree of cleaning is not significantly reduced. When cleaning gases from sticking dust, effective cleaning is possible only in wet mode, otherwise the dust collector may become blocked.

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