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Hydrodynamics of Rotary Apparatus of The Wet Method of Dust Cleaning

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Abstract
The article presents the device and principle of operation of the improved design of the contact element of the rotary apparatus for wet dust and gas cleaning. As a result of theoretical studies, formulas were derived for calculating local and hydraulic resistances and the total lost pressure created in the direction of movement of the dusty gas supplied to the apparatus. As a result, depending on the total pressure loss in the device, it is possible to determine the efficiency of gas and dust cleaning and determine the optimal hydrodynamic parameters of the device.

Keywords: dust gas, rotor, support grid, fibrous material, nozzle, diffuser, confuser, drop catcher.

Introduction

The importance of atmospheric gas for mankind and other living organisms is invaluable. The biggest global environmental problems of our time are related to anthropogenic pollution of the atmosphere. Atmospheric gas has a special place among other components of the biosphere. It must have a certain purity, and any deviation from the norm is dangerous for the health of mankind and living organisms and the environment [2,3,4,5].

Industrial enterprises are in the leading positions in atmospheric gas pollution. About 20% of all devices used in dust gas cleaning in industrial enterprises are wet devices. Regardless of the size and concentration of industrial dust, the efficiency of wet cleaning is higher than other methods, so there is a tendency to increase the use of this method. A lot of research is being done to use this type of equipment.

Wet gas cleaning devices have the following advantages: ohhas the ability to retain dust with particles smaller than 1 micron in size. Therefore, these devices can be used in the process of cleaning dusty gases from light and electric filters operating in a dry method. It is also possible to return the captured dust to the production process. These devices have small dimensions and low cost, require little energy [2,3,4,5].

Currently, many scientific research works are being carried out on the creation of new constructions of dust gas cleaning devices. The main requirements for the devices being created should be low energy consumption, high efficiency of capturing fine dispersed dust, and low hydraulic resistance in the device [3,4,5,8].

Research Object

Based on the above requirements, we have developed a new structure of the rotor apparatus that cleans dusty gases in a wet way. Below is the structural structure and principle of operation of this apparatus (Fig. 1).

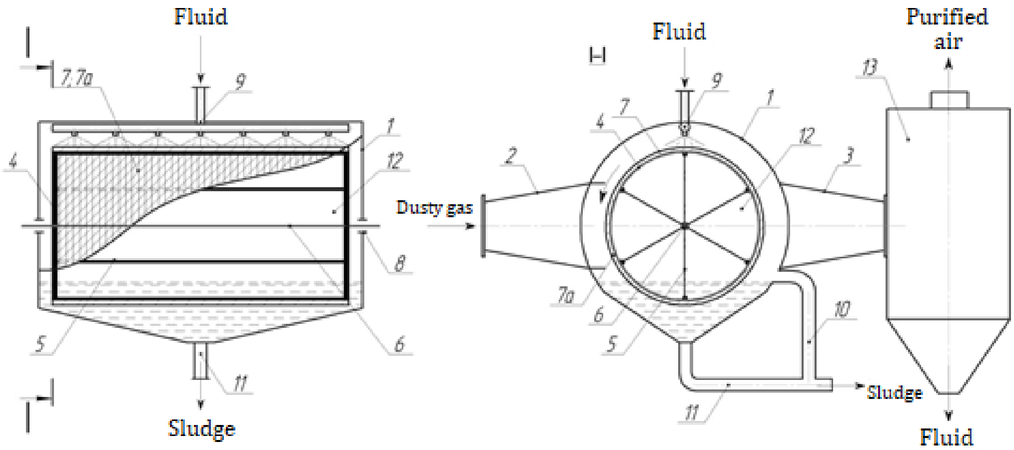

Figure 1. Overview of the device.

The structure of the device is as follows:
The apparatus consists of a cylindrical body 1, which is equipped with dust gas inlet 2 and purified gas outlet 3, as well as a device 13 for catching liquid drops. The rotating rotor 12 of the device is equipped with support disks 4 and steering wheels 5 on both sides. Disks 4 allow dust gas to pass only through the working rotor surfaces, and the rotor shaft 6 is mounted on these disks through bearings 8. As a support for the rotor 12 formed on the basis of the struts, a two-layer steel grid 7 is laid between the fibre material 7a and installed along the circumference of its diameter. Nozzles 9 serve to sprinkle the liquid in the form of small drops on the contact surface of the rotor filter 12. In order to ensure that the rotor filter 12 is partially immersed in the liquid in the apparatus, a level regulating tube 10serves. The formed slurry is removed from the apparatus through pipe 11.
The device works as follows:
Through the device 2, which introduces a flow of dusty gas into the apparatus, it is transferred to the counter-rotating rotor filter 12. The contact surface of the rotor 12 formed from the base mesh 7 and the fibrous material 7a laid between them is sprayed in the form of a drop of liquid through nozzles 9. In this process, the liquid droplets hit the steel mesh wires and fiber material and are further crushed, and the contact surfaces are increased, passing through the mesh and fiber material slits to the inside of the rotor filter. During this passage, a liquid film is also formed on the surface of the perforated steel mesh 7 and the fibrous material 7a. Dusty gas impinges on the outer working surface A of the rotor filter in a perpendicular position. As a result, mutual contact of the dusty gas with the liquid film on the surfaces of the sprayed liquid droplets and mesh filter wires and fibrous material is formed, and the dust cleaning process

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begins. On the working surface A of the apparatus, the primary purified gas reduces its speed depending on the resistance coefficient of the working surface, spreads on the volume in the inner part of the rotor filter, comes into contact with liquid droplets and the liquid film formed on the surface of the mesh wires and fibrous material when it passes through the working surface B, and the gas is cleaned of dust again. Purified gas continues its path and passes through the droplet catcher 13, and the liquid droplets that come out together with the purified gas are captured.

Dispersed dust caught on the A and B contact surfaces of the rotor filter is continuously washed and moistened in the liquid bath due to the rotation of the rotor filter. Dispersed dust caught in the filter settles under the influence of gravitational and inertial forces when it passes into the liquid environment of the bath.

Pipe 10 ensures that the liquid in the bath is at the same level. The cleaned droplet is discharged into the atmosphere through the catcher device 13.

Depending on the amount of dust trapped in the liquid in the bath, the sludge is removed through the pipe 11.

The type of supporting steel meshes installed on the rotor and the type of fibrous material laid between them is selected by the condition of achieving high cleaning efficiency, depending on the physical and chemical properties of the dusty gas to be cleaned, temperature regimes, and the coefficients of hydraulic resistance of the steel meshes and the laid fibrous material and the pressure losses calculated through them.

The amount of liquid required to form drops in the inner chamber of the rotor and the liquid film formed when the drops of liquid sprinkled on the rotor filter 12 hit the base mesh and fibre material is determined depending on the number of sprinkling nozzles and the diameter of the sprinkling hole of the nozzle and the coefficient of resistance. It takes into account high cleaning efficiency with low liquid consumption.

The number of rotations of the rotor is selected by the condition that the liquid film formed on the fibrous material laid between the steel meshes does not disperse from the filter under the influence of centrifugal force.

Results

The cleaning efficiency of the device depends on the hydraulic resistance in the working bodies, and theoretical studies were conducted to determine the coefficients of hydraulic resistance in the working bodies of the device and the pressure loss [1,9].

Below are the results of theoretical research. Using the calculation scheme of the apparatus, it is possible to write the total hydraulic resistance of the apparatus according to sections II and II-II as follows, Pa;

$$\Delta P_{com} = P_1 + P_2 + P_3 + P_4 \quad (1)$$

where P_1 $P_{диф}$ - is the pressure lost due to internal friction during the transfer of dusty gas to the device through the pipe, and is determined by the Darcy-Weissbach formula as follows, Pa[1,9];

$$P_1 = \lambda_1 \cdot \frac{l_1}{d_{dif}} \cdot \rho_{mix} \cdot \frac{\omega_{dif}^{2}}{2} \quad (2)$$

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where λ_1-is the coefficient of friction with the diffuser wall that transmits dusty gas to the device; l_1 is the length of the diffuser through which dusty gas moves, m; d_{dif}-average size of diffuser, m; ρ_{mix}-density of dust and gas mixture, kg/m^3; ω_{dif}- is the velocity of the dusty gas mixture moving in the diffuser, m/s.

The average size of the diffuser is determined as follows according to figure 2.

$$d_{dif} = \frac{(a+A)+(в+B)}{2} \tag{3}$$

The density of the mixture is determined as follows.

$$\rho_{mix} = \rho_g + (\rho_{dust} \cdot \gamma) \tag{4}$$

where ρ_g-gas density, kg/m^3; ρ_{dust} -dust density, kg/m^3; The percentage of dust in g-gas, %.

The coefficient of friction λ depends on the modes of flow of dusty gas in the pipe, and for the laminar mode, when Re ≤ 2320, it is determined as follows [1,9];

$$\lambda = \frac{64}{\mathrm{Re}} \tag{5}$$

The flow mode is defined as follows when 2320<Re<4000.

$$\lambda = 0.0025 R_e^{0.333} \qquad \lambda = 0,0025\,\mathrm{Re}^{0,333} \tag{6}$$

For smooth pipes, when 4000<Re<10000, it is defined as follows.

$$\lambda = \frac{0,3164}{R^{0,25}} \tag{7}$$

P_2 - is the pressure lost during the passage of dusty gas to the rotor through the contact device formed by the fibrous material laid through the supporting mats, and is determined as follows, Pa;

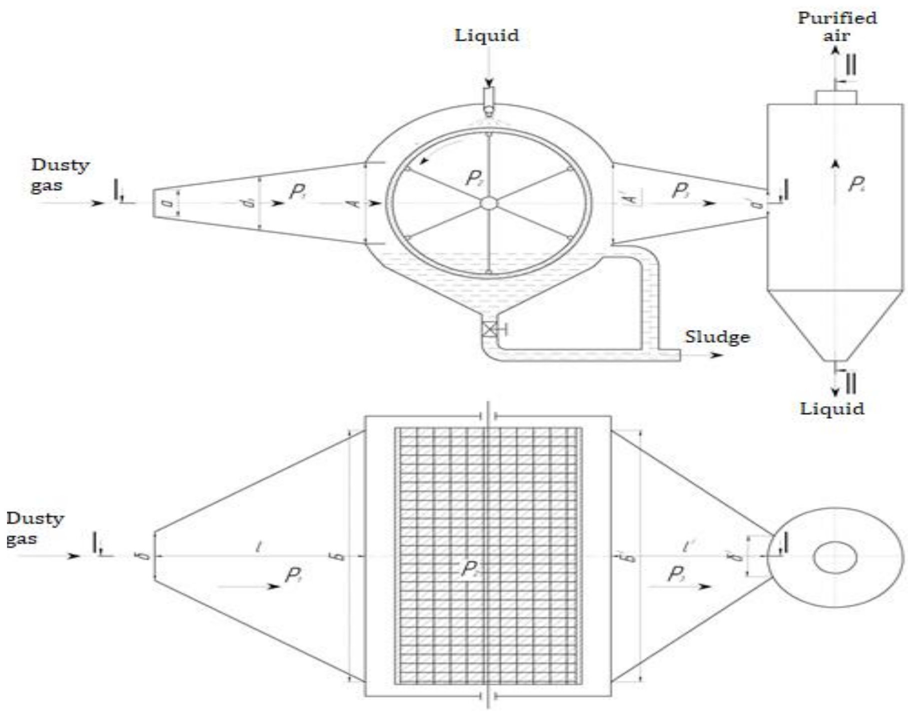

Fig. 2. Device calculation scheme

$$P_2 = \left(\xi_{nw} + \xi_{ws} + \xi_w\right)\frac{\rho_{mix} \cdot \omega_{wd}^2}{2} \quad (8)$$

where ω_{wd} -is the movement speed of the dusty gas mixture over the surface of the rotor contact device, m/s; ξ_{nw}-is the general resistance coefficient of the base grid in the state of non-sprinkled water, depending on the surface of the dusty gas passing through the grid, it is determined as follows [8];

$$\xi_{wd} = \Delta\Pi \frac{\sum S_c \cdot \delta}{\sum S_c \cdot a} \quad (9)$$

where ΔΠ -is the correction coefficient, determined by experiments, $\sum S_c$-is the total surface of the base mesh, m^2; δ-grid wire thickness, m; a-square hole dimensions of a mesh, m. Optimum values of the sizes of mesh holes to be laid on the rotor are determined by experiments.

ξ_{ws} - is the coefficient of resistance of the fibrous material laid between the base mats in the state where water is not sprinkled, and is determined as follows [6,7];

$$\xi_{ws} = \frac{S_f}{\Delta K S_r} \quad (10)$$

where ΔK-is a correction factor determined by experiments; S_f - relative contact surface of fibrous material, m^2; S_r-rotor cylinder surface area, m^2.

ξ_w - is the coefficient of resistance of water sprinkled on the contact element of the device, determined through experiments.

The relative contact surface of the fibrous material is reduced as follows. The density equation was used to calculate the contact surface of the fibrous material, kg/m3 [6,7];

$$\rho = \frac{m}{V} \quad (11)$$

where m - is the mass of glass fiber, kg; V is the volume of glass fiber and is determined as follows. m^3;

$$V = \pi \cdot R^2 \cdot l \quad (12)$$

where R - is the glass fiber radius, m; l – glass fiber length, m.

If we put equation (12) into equation (11) and find the length of the glass fiber, the equation will look like this.

$$l_{ум} = \frac{m}{\pi \cdot R^2 \cdot \rho} \quad (13)$$

To find the relative contact surface of glass fibers, the length of the circumference is found depending on its diameter, m;

$$l_a = 2\pi \cdot R \quad (14)$$

The total contact area can be found by multiplying the total length of the fiberglass by the length of the circumference. That is

$$S = l_{com} \cdot l_a \quad (15)$$

If the values of equations (13) and (14) are put into equation (15), the equation for determining the relative contact surface of glass fiber is derived m^2[6,7];

$$S_f = \frac{m}{\pi R^2 \cdot \rho} \cdot 2\pi \cdot R = \frac{2m}{R \cdot \rho} \quad (16)$$

where m -is the mass of fibrous material, kg; R – fiber material radius; m; Density of r-fiber material, kg/m^3

P$_3$ $P_{диф}$– is the pressure lost in the device contact element when the purified gas is released from the deviceIt is determined by the Darcy-Weissbach formula as follows, Pa [1,3,8];

$$P_3 = \lambda_2 \cdot \frac{l_2}{d_{konf}} \cdot \rho \cdot \frac{\omega_{konf}^2}{2} \quad (17)$$

where l$_2$ is the coefficient of friction with the wall of the mixer that releases the purified gas from the apparatus, l$_2$ is the length of the mixer in which the purified gas is moving, m; d$_{konf}$- the average size of confuser, m; ρ-refined gas density, kg/m^3; ω_{konf} -speed of purified gas moving in the confuser, m/s.

According to Figure 2, the average size of the confusor is determined as follows.

$$d_{dif} = \frac{(a' + A') + (в' + B')}{2}$$

P$_4$-Pressure loss in the droplet arrester that mixes with the purge air. Pa. It is defined as follows[1,3,8];

$$P_4 = \lambda_3 \cdot \frac{l_3}{d_t} \cdot \rho \cdot \frac{\omega_ч^{\;2}}{2} \quad (18)$$

where l$_3$ - is the coefficient of friction with the wall of the gas purified from drops leaving the device, l$_3$ is the length of the droplet catching device in which the gas is moving, m; d$_t$ - diameter of the droplet catching device, m; ρ-refined gas density, kg/m^3; ω_{ch} - velocity of the purified gas moving in the triple device, m/s.

As a result of theoretical studies, we derived the formulas for calculating the lost pressure in the working bodies of the apparatus using Bernoulli's equation. Now, in order to determine the total pressure in the device, if we replace the values of P$_1$, P$_2$, P$_3$, P$_4$ in formula 1 with the values in formulas 2, 8, 9, 10, 17, 18, the formula will look like this:

$$\Delta P_{com} = \lambda_1 \cdot \frac{l_1}{d_{dif}} \cdot \rho_{mix} \cdot \frac{\omega_{dif}^{\;2}}{2} + \left(\Delta П \frac{\sum S_c \cdot \delta}{\sum S_c \cdot a} + \frac{S_f}{\Delta K S_r} + \xi_w \right) \times \\ \times \frac{\rho_{mix} \cdot \omega_{wd}^2}{2} + \lambda_2 \cdot \frac{l_2}{d_{konf}} \cdot \rho \cdot \frac{\omega_{konf}^2}{2} + \lambda_3 \cdot \frac{l_3}{d_t} \cdot \rho \cdot \frac{\omega_ч^{\;2}}{2} \quad (19)$$

With the help of this derived formula 18, we will be able to calculate the total pressure loss in the apparatus.

Conclusion

In the article, the structure and principle of operation of the improved design of the contact element of the rotor device with high cleaning efficiency of the dusty gas cleaning method in the wet method was presented. As a result of theoretical studies, the formulas for calculating the local and hydraulic resistances and the total lost pressure created in the direction of movement of the dust gas supplied to the apparatus were derived. As a result, depending on the

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total pressure loss in the apparatus, it was possible to determine the efficiency of dust gas cleaning and determine the optimal hydrodynamic parameters of the apparatus.

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