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DETERMINATION OF THE PATTERN OF DUST AND AIR FLOW MOVEMENT IN VORTEX MECHANISM

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Abstract. At present, the problem of air pollution is a serious environmental problem that negatively affects the living conditions and health of people. The composition of atmospheric air in large industrial and urban agglomerations depends on the type of production and the level of its technology. A promising method of improving dust collectors is the creation of dust collectors, where the principles of operation of several devices are implemented.

Keywords: deduster, process of separation, hydraulic resistance, deduster efficiency.

1. Introduction

Nowadays, the problem of air pollution by technological and ventilation emissions affecting climate change is of great importance. According to the Law of Ukraine "On Atmospheric Air Protection", Article 10 specifies uninterrupted efficient operation and maintenance of structures, equipment and facilities for atmospheric discharge purification and reduction of the negative impacts of physical and biological factors. In order to comply with these requirements by enterprises, a number of benefits are provided in case of the introduction of low-waste, resource-saving technologies that reduce harmful effects on climate.

Moreover, the first place in terms of air pollution in most cities is firmly held by automobile transport – up to 80 % of the total emissions. Therefore, the purification of polluted air and the level of anthropogenic pressure on the air of large industrial regions is an urgent and important problem (Caryk et al., 2011).

The development of civilization resulted in the deterioration of biosphere ecosystems, ruthless depletion of soil and mineral resources and was accelerated by scientific and technological progress, having a significant increase in production, depletion of natural potential, significant pollution of summer, hydro and atmospheric emissions. This condition causes a significant deterioration of the dynamic balance between society and the natural environment. At the same time, the anthropogenic impact of human activities on nature doubles every fifteen years.

It should be noted that human society and the natural environment (biosphere) are two interconnected systems, each of which develops according to its laws.

Atmospheric air is the main environment of human life, and therefore the growing pollution of the air basin of our planet, which has an anthropogenic nature, is one of the most important problems among the most serious environmental ones. The rate of accumulation of industrial, domestic and transport emissions in many cases exceeds the natural possibilities for their disposal.

Negative environmental situations are the inevitable result of human contact with the environment. They are the result of errors in technical and economic policy caused by insufficient

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consideration of environmental changes of its economic damages from anthropogenic factors, as well as an insufficient level of technical development (Caryk et al., 2011).

Therefore, the investigation of the state and quality of the air in terms of technogenesis, presentation of its overall dynamics in time and space is an important task of modern science, the solution of which will help to preserve the environment favourable for human life and activities and prevent irreversible climate change.

The efficiency of dust collection, the main factor in the operation of dust collection equipment, significantly affects the quality of atmospheric air.

Emissions capture at the region enterprises is performed only on solids, i.e. that all types of dust and such emissions as liquid and gas mixtures are released into the air without cleaning. The vast majority of existing dust-collection equipment at the region enterprises is obsolete, and its service life exceeds 20 years or more, while the efficiency of air pollutants collection is lower than this index for modern equipment.

The important problem of environmental quality control is the organization of the control system of pollution sources and aggressive substances impact on human health and the biosphere. Such a control system at the current stage is the system for monitoring anthropogenic changes in the environment.

The process of capturing solid particles from dusty air stream is based on the direct withdrawal from it (for example, the particles fallout under the action of gravity in dust chambers) or deposition on various surfaces and bodies (fibres in fabric filters, electrodes, electrodes, electrical filters, drops in wet dust collectors, etc.) and separation from the gas stream.

Depending on the type of dust collector and the method of its operation, dust collection takes place under the action of one factor or a set of factors. Dust particles are separated by various methods: under the action of gravity, centrifugal force, inertial impact (collision), direct deposition (thermophoresis), electrostatic and magnetic deposition.

The dust-collection technology uses a large number of devices that differ from each other both in design and in the principle of suspended particles separation. Inertial dust collectors of dry and wet cleaning are widely used in modern dust collection systems. The priority is given to dry methods since they are not related to the process of water consumption and wastewater treatment (Hurets et al., 2017, Batluk et al., 2012).

In the process of improving dust collectors, the qualitatively new types of devices – vortex dust collectors, which, like cyclones, are devices of centrifugal action, are being developed. These devices make it possible to clean the airflow up to 98–99 % of the product with a significant content of the fine fraction less than 3-5 microns, which is difficult to catch even by the most efficient cyclones.

2. Experimental part

For devices with counter moving swirling flows (hereinafter CSF), the theoretical productivity of dust separation is higher than that of cyclones, and the particle size threshold at which the efficiency is zero is $\sqrt{2}$ times smaller. It is considered that the particle size threshold for CSF dust collectors is 0.4 μm.

The analysis of four dust collectors with different experimental dust is presented in Table 1.

Table 1

Efficiency of catching some products of the chemical industry with different coefficient of hydraulic resistance

Experimental dust	d_M, μm	CSF-1000	CDC-11	CDC-15	CDC-34
Limestone	5	96.0	48	45	92.0
PVC	6	97.0	50	45	93.0
Epoxy resin	22	98.0	88	82	98.0
Aluminum hydroxide	39	99.8	92	90	99.8
Suspension PVC	100	99.9	90	98	99.9

Indicators achieved by vortex dust collectors, in comparison with cyclones, are much higher in terms of both efficiency and energy consumption spent on fine dust separation.

The investigation and operation of dust collectors with counter moving swirling flows show that they have the following advantages:

– high degree of the capture of dust particles with a diameter of 1 μm and less;

– insignificant sensitivity of separation efficiency at the change of productivity on gas (50–120 % from the minimum) and dust concentration in gas (1–500 g/m^3);

– less, in comparison with cyclones, abrasive wear and adhesion of solid particles on the inner surface of devices;

– the possibility of effective purification of hot gases;

– the ability to regulate the process of dust collection by changing the ratio of gas consumption in channels;

– smaller dimensions in the plan than in cyclones with the same performance;

– effective work in group installations.

These advantages make it possible to conclude that CSF devices as dust collectors can be used in a wide range of temperatures and pressures for almost any production, any industry of polluted gas cleaning from the dust.

2.1. Investigation of dust collection efficiency

CSF devices are used in the process of drying the dispersed materials with simultaneous dust in the production of mineral fertilizers, polymeric materials, acetyl cellulose, salts (sodium sulfate), semi-finished products and dyes.

These devices can be used for other processes of chemical technology (sublimation, separation of liquid inhomogeneous systems, heat treatment, thermal-oxidative degradation, heterogeneous catalysis).

While investigating the process of air mass purification in vortex dust collectors, the authors identify the factors that significantly affect the reduction of suspended particles in the air and study the degree of influence of these factors on the cleaning efficiency. The main theories of vortex dust collectors operation are highlighted in numerous works (Savchenko-Pererva et al., 2015, Gumnytskyi et al., 2015).

In terms of energy, the advantage of vortex dust collectors over cyclones is clearly manifested when dusty gas enters both channels, and a separate fan is not used for secondary gas feed. With the same total performance of the compared devices with different housing sizes, the gas velocity in the inlet cross-sections of CSF is approximately twice as low, as the flow is distributed. And hence, at the same coefficients of hydraulic resistance of the input devices, the loss of pressure in the CSF dust collector is less.

Mathematical models describing the dynamics of counter moving swirling flows and dust collection processes in CSF devices, the authors (Kaspruk et al., 2015) conditionally divided into two classes: simplified models and models derived from the general equations of hydrodynamics.

While considering the simplified model, the flow geometry is given, and a number of assumptions regarding the motion of dust flow are made. Such models use relatively simple formulas to calculate the efficiency of dust capture by the installation and the time of presence of dispersed material in it.

In other models (Cilibert et al., 2016) a rigid boundary of the primary and secondary flows distribution on the surface of the cylinder with $r = r_0$ radius is specified. On such a surface, the field of axial velocities of the airflow is $V_z = 0$. In models (Savchenko-Pererva et al., 2015), the secondary flow is not mixed with the primary flow but passes from the top to the bottom to the baffle washer level where it mixes with the primary flow. In models (Rybdylovaa et al., 2016) the secondary flow evenly passes to the primary one over the entire apparatus height, and the secondary flow losses change from Q_2 to zero.

In the first case, the field of axial velocities of the airflow is as follows:

$$V_z = \left\{ \begin{array}{l} \dfrac{(Q_1 + Q_2)}{S_1};\ r < r_* \\ \dfrac{-Q_2}{S_2};\ r_* < r < r_0 \end{array} \right\}, \quad (1)$$

where r_0 is a radius of the device; r is a radial coordinate;

$$S_1 = \pi r_*^2 \ , \quad (2)$$

$$S_2 = \pi \left(r_0^2 - r_*^2 \right). \quad (3)$$

In the second case it is:

$$V_z = \left\{ \begin{array}{l} \dfrac{\frac{1}{S_1}\left[Q_1 + Q_2 \left(\frac{Z}{H} \right) \right]}{S_1};\ r < r_* \\ \left(\dfrac{-Q_2}{S_2} \right) \left(\dfrac{Z}{H} \right);\ r_* < r < r_0 \end{array} \right\}, \quad (4)$$

where Z is an axial coordinate;

H is the height of the working area of the device.

The comparison of the experimental field of axial velocities presented in paper (Kouzov et al., 2011) with the fields of axial velocities calculated by formulas (1), (4) shows that equation (1) for the first case is closer to the experimental values. When the ratio of the height of the device working area to its diameter is small, the secondary flow at the inlet has a sufficient kinetic energy store and is mixed with the primary flow close to the baffle washer, and solid particles have the axial velocity equal to the gas axial velocity of the. These two models are simple and reflect the process roughly.

The separation process in this vortex dust collector with a louvred air removal is considered as a process of double cleaning: centrifugal – under the action of centrifugal force during the dust air mixture rotation, and inertial – when airflows with dust particles are directly near the louvre grille and the flow passes through it.

The peculiarities of this design of the dust collector include the possibility of the louvre grille to rotate under the action of the forced drive. Effective operation of this dust collector requires a constant angular velocity of the dust air mixture in the apparatus, and a constant speed of airflow through the louvre grille along its entire height. This significantly affects the aerodynamic situation in the device and eliminates the creation of unwanted vortices, especially in the upper part of the device.

The magnitude of the centrifugal force acting on the dust particle in the cross-section of the device case depends on the operating frequency of the louvre grille rotation. During the experiment, dependencies that make it possible to determine these parameters and their relationship are defined.

Mathematically, the following relationship between the parameters of dust particle motion and the forces acting on it is described by Newton's second law:

$$\vec{F} = m \cdot \vec{a}, \tag{5}$$

where $\vec{F}$ is the total product of all forces acting on the body; m is body mass; $\vec{a}$ is body acceleration;

At uniform particle rotation in a circle its acceleration is defined as

$$a = \frac{v^2}{R}, \tag{6}$$

where v is linear velocity, m/s; R is circle radius, m.

Then in order to calculate the centrifugal force acting on the particle in the device case, let us use the following equation

$$F_{в} = \frac{mv^2}{R}, \tag{7}$$

where m is particle mass, R is apparatus radius, m.
where m is the mass of the particle, R is the radius of the apparatus, m

The linear velocity of the particle is determined by the angular velocity

$$v = \omega \cdot R, \tag{8}$$

where ω is the angular velocity, c^{-1};

Then the angular velocity depends on the speed of the gas flow n (c^{-1}):

$$\omega = 2 \cdot \pi \cdot n. \tag{9}$$

Let us calculate the centrifugal force by substituting the above given equations in equation (7), we get

$$F_{в} = 2 \cdot \pi^2 \cdot m \cdot n^2 \cdot D. \tag{10}$$

From the last equation, it follows that the centrifugal force acting on the particle depends on the frequency of the airflow rotation and the location of the dust particle in the apparatus plane at a constant louvre grille rotation. Since the centrifugal force is the main factor acting on the particle in terms of the apparatus, the particle reaches its wall faster and is transported to the hopper.

3. Results and Discussion

Determination of the investigated dust collector efficiency was carried out according to the main value characterizing its work – the dust collection coefficient. In order to determine the effect of the input velocity magnitude on the dust collection efficiency in this device, the experiment was carried out on the test bench at the airflow rate from 0.025 m^3/s to 0.09 m^3/s. The value of fictitious speed varied from 1.25 m/s to 4.5 m/s. In order to carry out comparative tests of the developed vortex dust collector with a louvre grille, the experimental stand was designed, the main requirements for which were defined.

The method of comparative tests involves the definition of the following basic, common to all types of dust collectors, technical indicators: the total degree of purification η (%) and hydraulic resistance Δp (Pa). As a result of these investigations, the graphs presented in Fig. 1–3 are constructed.

In order to compare the results of testing dust collectors different in design and purpose, the basic requirements for their tests include the requirements for experimental dust used in the apparatus. Thus, for artificial pollination of air, fed to different types of the investigated dust collectors, three grades of quartz dust with different degrees of dispersion are used. This material is obtained by grinding the same source material.

During the experiments, the data show that the separation efficiency in the device with a rotating louvre grille increases. Therefore, in the stationary position of the louvre, the transition of dust particles from the separation area into the pipe of the purified air outlet is possible. They make it possible to set the range of velocities at which the highest efficiency is achieved in terms of the device.

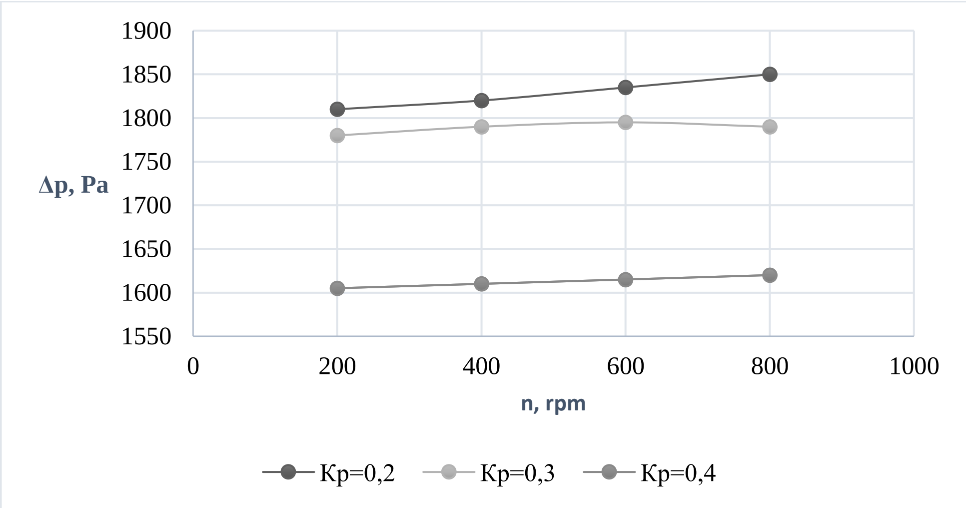

Fig. 1. The influence of rotation speed of a louvre grille on hydraulic at various coefficients of live section

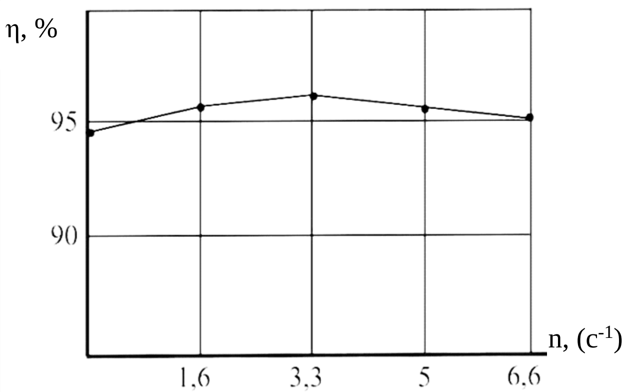

Fig. 2. The dependence of efficiency on the frequency of rotation of a louvre grille with factor Kp=0.4

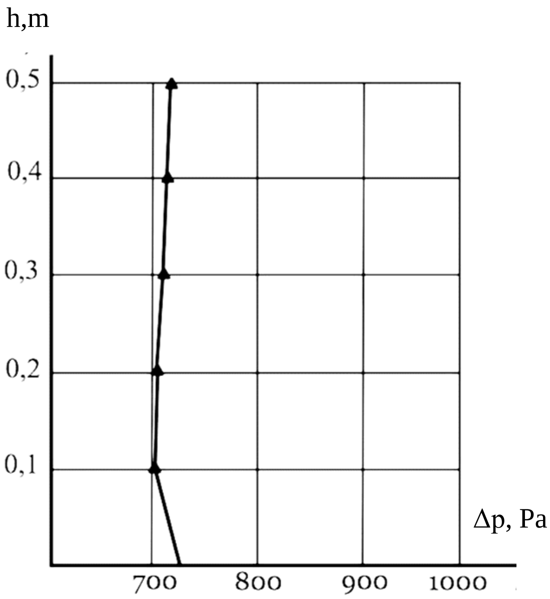

Fig. 3. The pressure drop across the height of the louvre grille with Kp=0.4

The results of the experimental investigations indicate that the centrifugal force is a major factor in the process of the dust-air mixture separation and the supply of additional centrifugal force by the rotating jalousie blades increases the resolving ability of the given dust collector with movable jalousie and affects the dust collection efficiency. The initial dust concentration in the dust-air stream entering the dust collector is Z_n= 3 r/m^3± 20%.

The results show that while rotating, the jalousie resolving ability increases. And the effect of the jalousie speed on the device hydraulic resistance remains constant within the range from 1700 Pa to 1800 Pa, at the number of revolutions from 200 rpm to 800 rpm. Therefore, the use of this type of device with movable jalousie results in the increased efficiency of dust collection.

4. Conclusions

Atmospheric environment pollution is one of the main problems at the present stage of human development. One of the most common air pollutants is industrial emissions of enterprises, such as coal dust from thermal power plants, metallurgical furnaces, and dust from cement ovens. The results of experimental investigations make it possible to evaluate and predict the possible consequences of environmental pollution. In the course of experimental investigations, the results showed that the rotation of the louvre grille significantly affects the resolution of the entire process of the dust flow separation within the installation. Especially good indices were obtained for the particle size distribution d = 8 μm, d = 20 μm., at optimal speeds of grille rotation. Therefore, it is reasonable to use this dust collector for fine dust fractions to reduce the number of pollutants in the environment.

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