Efficiency of different separation elements for removal of fine particles from gas

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Abstract. A paper deals with the urgent problem of studying the separation process of gas flow from fine-dispersed particles. A device developed to intensify gas flow separation from fine-dispersed particles. The principle of operation of the device is given. The effect of the shape of separation elements, gas flow velocity, as well as size and density of particles on device efficiency, has been investigated. As a result of the study, the maximum efficiency of gas flow separation (on average 85%) is achieved at a gas velocity of 8 m/s. Moreover, the separation increases when the density and diameter of the particles begin to grow. The double-T shape of separation elements was demonstrated as the most effective type of geometry.

1. Introduction
An essential problem of most industrial enterprises that use various devices for purification of technological gases of mechanical impurities is an increase in the effectiveness of processes of separation of fine particles of gas streams [1–3].

The relevance of this task increases eventually: requirements for environmental protection become tougher that an increase in threshold limit values of harmful substances in the air, which violation attracts with sanctions and penalties for the enterprise. To the most widespread devices, the gases applied to clean of mechanical impurities dry inertial devices are. Among them, cyclones, dust chambers, and louver separators are most widespread [4].

The cyclone presents itself the closed capacity in the cone form with a top, which is turned down. The upper of capacity connects to an exit of a transporting air duct, and the bottom has the unloading hatch or the bunker batcher. At the moment time, there is a wide variety of types of cyclones. Among them, the counterflow and direct-flow cyclones are most widespread. The effectiveness of the purification of technological gases in cyclones depends on the dispersed structure of particles of dust.

As a rule, the more particle size, the cleaning is more effective. An increase in the diameter of a cyclone decreases the effectiveness of the cleaning of gas streams of dust particles. Therefore, in need of cleaning of large volumes of gas and high requirements to the extent of cleaning use battery cyclones, which represent the dust removal device, made of a large number in parallel of the established cyclonic elements. The principle of action of a classical cyclone consists of the following: the dusty gas stream enters into the device through the inlet elbow tangentially in an upper. Then in the device, the rotating gas current, which is directed down to a conic part of the device, is created. Owing to centrifugal forces, dust-like particles are taken out from a stream and settle on device walls,
then are taken a secondary stream and get to the bottom, via the outlet in the bunker for collecting dust. The gas stream cleaned from dust moves from below up and is brought out of a cyclone through a coaxial exhaust pipe. One of the main advantages of cyclones is the simplicity of design and high performance of purification of gases of particles more than 20 μm in size. Refer rather high-pressure losses and low effectiveness of purification of gases of particles less than 10 μm in size to shortcomings [5–8].

The following most widespread device on the purification of gases of mechanical impurities is the dust chamber in which fluidized dust is besieged by gravity. The dust chamber represents the cylindrical vertical device with the hopper bottom supplied with the folding hatch. As a rule, the diameter of the camera is about 4 m, height about 5 m. Dust chambers fall into to the simplest devices for cleaning of production gas streams of mechanical impurities. Sedimentation of particles happens at the expense of gravitation forces. Achievement of the required effectiveness of the cleaning of gas streams of dust-like particles requires providing most of the uninterrupted time of stay of particles of dust in the camera. Therefore, these devices are intended for the purification of gases of particles more than 50 μm in size. Ensuring high performance requires the achievement of rather low speeds of gas streams. As a rule, they should not exceed 3 m/s. Thus, the advantages of dust chambers are the simplicity of the device and longevity. Treat low effectiveness when catching dust-like particles less than 50 μm in size shortcomings, bulkiness, and rather low speeds of a gas stream.

The louver separator has various geometry, but practically in all devices, there are louver lattices that consist of several rows of plates or rings. The process of cleaning can be described as follows: the dusty gas stream passes through a louver lattice owing to what makes a set of sharp turns. Dust-like particles owing to inertia seek to keep the initial direction that leads to the office of large particles from a gas stream. As additional effect serves blows about inclined cavities of a lattice from which particles of dust are reflected and jump aside from cracks between lattice blades. This process leads to a division of a stream into two. Dust generally contains in a stream that is sucked away and send to a cyclone where it is cleaned from dust and again merge with the central part of the stream, which passed through a lattice. Indifference from dust chambers in the louver separator’s purification of gases of mechanical impurities is carried out at rather high speeds of gas streams, which reaches 15 m/s. Rather high speeds of a gas stream favorably influence inertial purification of gases of mechanical impurities. The louver of dust collectors refers rather low-pressure losses, which make 150–500 Pa to advantages. Refer to low effectiveness at the purification of gases of particles less than 20 μm in size to shortcomings of these devices and short life of plates at a high concentration of dust. Thus, one of the essential shortcomings of devices of inertial type of action is a low extent of cleaning of gas streams of dust-like particles less than 10 μm in size [9, 10].

Thereof, most industrial enterprises create the technological line of cleaning of gas streams, which consists of several steps of cleaning [11]. As a rule, the first stage of cleaning is devices of rough cleaning – inertial dust collectors, the second stage of cleaning are devices of thin cleaning – electrostatic filters and hose devices [12–15]. It should be noted that most enterprises have no opportunity to install devices of thin cleaning, owing to their high cost. Therefore, the increase in the effectiveness of processes of separation of fine particles of gas streams remains a relevant task [16–18].

2. Description of the device for separation

The authors of this work have developed a device [19–22], which allows separating fine-dispersed particles of size less than 10 μm from gas with an efficiency of over 50%. Moreover, the separation efficiency of particles above 10 μm in size from gas exceeds 99%. The device comprises several rows of separation elements, which are installed in a rectangular body (figure 1). It should be mentioned that the geometric shape of the body can be changed to another (round, square, oval, etc.) depending on the shape of the air duct while maintaining the efficiency of gas separation. The operation principle of the device depends on the centrifugal forces acting on the dusty gas when it flows around the separation elements arranged in staggered order. The flow swirls when moving between the elements,
which leads to the formation of centrifugal forces that beat out dust particles from the flow. So, the large particles fall to the bottom of the device, and small particles adhere to the surfaces of the separation elements (electrostatic forces mainly induce adhesion). When dust lodges on the device, it is appropriately disassembled and restored.

![Figure 1. Simplified two-dimensional models of the device for separation of fine-dispersed particles from gas flows with different forms of separation elements (top view): a – double-T-shaped; b – Π-shaped; c – arc-shaped.](image)

In order to intensify the separation processes of fine-dispersed particles from gas, it is proposed to use this device as the second stage of gas cleaning, for example, in series with a cyclone. So, the technology of gas cleaning from mechanical impurities in the enterprises will be as follows. Dry-type inertial devices are used to separate dust particles 10 μm in size from gas at the first stage. Then, using the developed device in the second stage, the particles are separated by size of fewer than 10 μm.

Earlier research indicated that the separation elements need to be arranged relative to one other, with the distance between their adjacent rows should be 1.65 times the element length. The fulfillment of the condition will allow achieving maximum efficiency of the separation of fine-dispersed particles from a gas due to the peak value of centrifugal force under gas flowing around the separation elements. Other various ways to increase the device efficiency of the separation process of fine-dispersed particles from gas are also of interest. One of them is the use the separation elements with excellent performance.

3. Purpose and subject of research

The objective of this work is to study the influence of separation elements shape on the device efficiency. We are engaged in research on the following shapes of separation elements: double-T-, Π- and arc-shaped elements (figure 1).

The study was performed by numerical simulation using the ANSYS Fluent software package. It should be noted that this package is intended for the model operation of the problematic currents of liquids and gases with a wide range of changes of thermal properties through ensuring various parameters of model operation and use of multigrid methods with an improving convergence. In the program, the finite element method representing a net method is used. Depending on the fitted model of turbulence, differential equations in partial derivatives which are complemented with regional conditions are set. It should be noted that at the model operation of driving of solids in a gas current in the program ANSYS Fluent complex, two basic methods – Lagrange and Euler are used. The method of Lagrange allows describing authentically driving of single particles on condition of their bumping collision from wall settlement area that is fair only for powder material of coarse fraction, which particle size makes more than 100 μm. When using a method of Euler, the difference of concentration of a dispersive phase between two points defines a diffusion stream. This method is used for dust-like particles less than 100 μm in size. Because of CFD calculations require high computational resources, we simplify the task by replacing the three-dimensional model of the device with a two-dimensional one. This assumption can be justified by the fact that the shape of the separation elements does not change in height. Additional assumptions have also been taken into account. The thicknesses of arc-
shaped elements and body walls were given as infinitesimal. The gas flow is stationary. The dust concentration excludes the mutual interaction between particles. The influence of particles on the motion of the carrier medium is neglected.

During the study, the gas flow velocity varied from 5 to 8 m/s. The chosen velocity range is determined by the relatively low inlet velocities existed in dry-type inertial devices as the first stage of cleaning gases from mechanical impurities. The ambient pressure was set equal to 101325 Pa at the outlet of the device. The following parameters were constant: the number of rows – 4, the number of particles \( n \) in the gas – 1000. The next parameters changed as follows: particle diameter \( a \) from 1 to 10 \( \mu \)m, particle density \( \rho_a \) from 1000 to 7000 kg/m\(^3\), and gas inlet velocity \( W \) from 5 to 8 m/s. The length of the separation elements fixed at 14 mm.

The efficiency of the device was calculated by the following equation:

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E = 1 - \frac{n_k}{n},
\]

where \( n_k \) is the number of fine-dispersed particles in the gas after the separation process at the second cleaning stage.

4. Research results

Figures 2–4 presents plots resulting from the study. The efficiency of separating dust particles from gas for all shapes of separation elements increases with the rise in the following parameters: the inlet velocity of the gas, particle diameter, and particle density of the fine-dispersed particles. The more complicated shape of separation elements no means always the case of an increase in the separation efficiency of fine-dispersed particles from gas. However, increasing of elements, complexity promotes the growth in the hydraulic resistance of the device due to the large number of the local resistances.

In the course of the study, it has been found that the most effective types of separation elements are double-T-shaped, then arc-shaped, and the least effective is \( \Pi \)-shaped. The minimum pressure drops in the device occur in case of the arc-shaped elements, and the maximum pressure drops in the \( \Pi \)-shaped elements.

The efficiency of the separation process of the fine-dispersed particles 1–10 \( \mu \)m in size (\( \rho_a = 1000 \) kg/m\(^3\)) from gas is around 82, 80 and 77% for double-T-, \( \Pi \)- and arc-shaped elements, respectively, at a gas flow velocity \( W = 5 \) m/s. As for the dust particles with a size of 1–5 \( \mu \)m from the separation efficiency is on average 65, 55, 50% for double-T-, \( \Pi \)- and arc-shaped elements, respectively. When separating fine-dispersed particles larger than 5 \( \mu \)m from the gas flow, the efficiency is at least 99% for any shape of the separation elements (figure 2). The most efficiency of gas separation in case of double-T-shaped elements compared with the arc-shaped and \( \Pi \)-shaped elements are achieved by initiating numerous small vortices in the inner area of the double tee, which enhances the separation process by beating out fine-dispersed particles from the flow and throwing them onto surfaces of the elements, where the particles adhere to the walls under electrostatic and intermolecular forces.

It is worth noting that the \( \Pi \)-shaped elements have a deep inner area in comparison with double-T-shaped elements, causing the formation of fewer and larger vortices, which, in addition to intensifying the separation process, results in a decrease in efficiency, as the flow structure induced by centrifugal forces is disrupted. Arc-shaped elements have simpler shapes in relation to the double-T- and \( \Pi \)-shaped elements to gas flow motion. Moreover, the geometry of the inner area of arc-shaped elements free from dead-end zones, where chaotic vortex formation occurs, which leads to disruption of flow structure as a whole, but also there is no significant increase in separation efficiency due to the absence of additional vortex formation.

The separation efficiency of the fine-dispersed particles with the size of 1–10 \( \mu \)m and density \( \rho_a = 1000 \) kg/m\(^3\) from gas is on average 84, 80 and 78 \% for double-T-, \( \Pi \)- and arc-shaped elements, respectively, at a gas flow velocity \( W = 8 \) m/s. With increasing gas flow velocity from 5 to 8 m/s, the efficiency of separating fine-dispersed particles 1–5 \( \mu \)m in size from gas grows by 3.0, 1.0, and 0.5 \% for double-T-, \( \Pi \)- and arc-shaped elements, respectively (figure 3).
Of special interest is the influence of particle density on the efficiency of their separation from gas. The fact is that there are practically no uniform particles in the gas flow since their density is different. The results showed that gas separation efficiency increases as the density of fine particles grow. On average, the separation efficiency is 82, 78, and 75% for elements with double-T, arc- and Π-shaped, respectively, at particle densities up to 3000 kg/m$^3$. When separating fine-dispersed particles with density above 3000 kg/m$^3$, efficiency for all shapes of separation elements is not less than 99% (figure 4).

Pressure drops in the device with double-T-, Π- and arc-shaped elements at a gas flow velocity of 5 m/s were 963, 928, and 1065 Pa, respectively. It should be noted that the difference of pressure drop in the device with double-T- and arc-shaped elements does not surpass 5%.
5. Conclusion

Studies have shown that various shapes of separation elements affect the flow structure in different ways, in particular on the vortex formation in the inner area of the elements capable of both increasing and decreasing the separation efficiency of fine-dispersed particles from gas. The most perspective type of elements is double-T-shaped because its inner area is divided into two symmetrical parts with small vortices, which intensify the separation process of fine-dispersed particles from gas. The relatively deep inner area of the II-shaped elements leads to efficiency reduction since they produce large vortices that fact adversely affects the flow structure, whereby the separation efficiency is decreased. Therefore, it is necessary to develop the element shape forming small vortices, which are responsible for increasing the efficiency of gas separation. However, numerous vortices also increase the pressure drop in the device, so it is necessary to develop a compromise shape of the separation elements as a contributory factor for high efficiency and low hydraulic resistance.

Based on the obtained results, it can be concluded that double-T-shaped elements are most effective, whereas elements in the shape of an arc are energy-saving. The difference between the efficiency and pressure drop in the device with double-T- and arc-shaped elements is less than 5%. Therefore, both types of separation elements have good practicality depending on industrial requirements. Furthermore, higher inlet velocities increase gas flow separation efficiency. The separation efficiency of fine-dispersed particles from gas by double-T- and arc-shaped elements at the inlet velocity of 8 m/s is at least 80%. Benefits of the device: simple design, easy to use, minimum capital, and operating costs.

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7. References

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