

Classification of bulk material from the gas flow in a device with coaxially arranged pipes

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Abstract. The paper deals with the problem of classification of bulk material, based on silica gel, larger than 30 μm , from dusty gas flow. In order to solve this problem, the design of a classifier with coaxially arranged pipes is proposed. According to the conducted studies, it is more efficient to use a classifier with an inner conical pipe to solve the problems of separating the particles from the gas flows of various sizes, since a greater value is achieved for the centrifugal, inertial, gravitational and other forces acting on the dusty flow, that contribute to knocking the particles out of its structure, than in a classifier with a cylindrical inner pipe. On average, the efficiency of a classifier with a conical inner pipe is by 35.3% higher than that of a classifier with a cylindrical inner pipe. Classification of particles of bulk material, based on silica gel, larger than 30 μm from the dusty gas flows is solved most effectively by using a classifier with a conical inner pipe and h_d parameter of 50 mm and a classifier with a cylindrical inner pipe and h_d parameter of -10 mm.

1 The first section in your paper

At industrial enterprises, the mills are used for crushing out the bulk material, resulting in the formation of particles with a large size range. However, in most cases, a specific size range is required, which depends on the specific technological process. This causes the installation of special devices for the selection of a required fraction of solid particles. Therefore, the dust collecting systems, consisting of the classic cleaning devices, mentioned above, are supplemented with the dust collectors-classifiers. In some cases, they can replace coarse and fine cleaning devices. As noted earlier, the main task for the dust collectors-classifiers is to separate the dust into fractions. For this purpose, several working zones are structurally implemented in these devices, and the process of collecting a certain fraction of particles takes place in each zone. As a rule, coarse particles are collected by the first zone, while the second and third zones are intended for medium and finely dispersed particles, respectively. One of the main disadvantages of classifiers-dust collectors is that they are not universal for the most processes of classifying the collected dust. This is mainly due to the features of the technological production line. Each line has its own requirements for the material dispersion. Therefore, new models of devices are developed for each separate

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technological line on the basis of classic ones or existing devices are structurally supplemented [1–6].

The cyclones are mainly used for separating the dust particles larger than 10-20 μm from the gas flows. When they operate, smaller particles are collected, so they are not suitable as a classifier. The aim of this research paper is to develop a classifier for fractionation of bulk material, based on silica gel, larger than 30 μm , from the gas flow in the technological production line at the Salavatsky catalyst plant. In this case, the volume fraction of the collected material smaller than 30 μm shall not exceed 2% of the total fraction of the collected material. It should be noted that most of classic coarse cleaning devices (cyclones, louver dust collectors, etc.) cannot be used to solve this problem. The efficiency of these devices for collecting the particles smaller than 30 μm significantly exceeds 2% of the total collected fraction [7–11].

2 Description of the developed classifier

The authors of this research paper developed a design of classifier with coaxially arranged pipes (Figure 1), which is proposed to be used for fractionation of particles from the gas flows, larger than 30 μm .

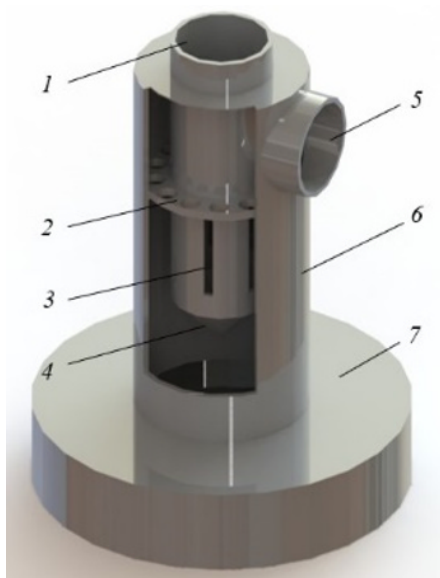


Fig. 1. Classifier with coaxially arranged pipes: 1 – inlet nozzle, 2 – grid with coaxially arranged pipes, 3 – rectangular openings, 4 – hole, 5 – outlet nozzle, 6 – casing of device, 7 – hopper.

The classifier is a cylindrical body 6, inside of which there is a cylindrical pipe with rectangular openings 3, designed to exit the gas flow from this pipe; the inner pipe is surrounded by a grid with coaxially arranged pipes 2; the lower part of the pipe has a conical shape with a hole 4, designed to pour the collected material into the hopper 7. The design also includes inlet 1 and outlet 5 nozzles.

The classifier operates as follows: the dusty gas flow enters the device through the inlet nozzle 1, then descends down the inner cylindrical pipe to the rectangular openings 3, then the trajectory of the gas flow changes abruptly perpendicular to the pipe; during the movement of the dusty gas flow along these trajectories, a part of particles falls out of the flow structure and falls into the hopper 7 through the hole 4. When the gas flow exits each rectangular opening 3, it is divided into 2 jets that move in the same proportions to the right

and left sides, reaching the inner wall of the cylindrical body 6; the gas jets turn around and move as a vortex to the upper part of the device; when vortices take place, centrifugal forces arise and throw the particles of bulk material, based on silica gel, out of the structured flow to the device surfaces; then the dislodged particles fall into the dust hopper 7. When the gas flow moves to the upper part of the device, it passes through a grid with coaxially arranged pipes, which is an additional separation element, knocking out the particles of bulk material, based on silica gel, from the flow structure, after that they also fall into the hopper 7. The gas flow, purified from the particles of bulk material, based on silica gel of up to $30\ \mu\text{m}$ goes out from the classifier with coaxially arranged pipes through the outlet nozzle 5 (Figure 1).

Thus, the particles of bulk material, based on silica gel, are mostly collected by inertial and centrifugal forces. The effect of inertial forces is stronger when the gas flow trajectory changes abruptly – when the gas passes through rectangular openings 3 and through a grid with coaxially arranged pipes 2. The effect of centrifugal forces is stronger when the gas flow is vortexed after the gas passes through a grid with coaxially arranged pipes 2 (Figure 2).

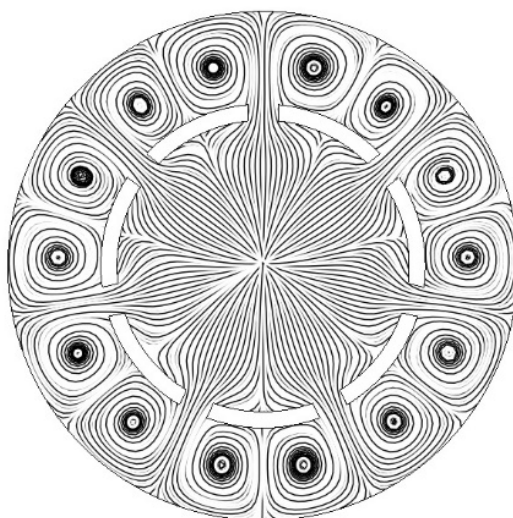


Fig. 2. Formation of vortices in a classifier with coaxially arranged pipes. The gas flow lines (top view).

The peculiarity of classifier with coaxially arranged pipes is that each vortex, during its rotation, additionally accelerates two neighboring vortices relative to itself, which increases the values of centrifugal forces and, as a result, increases the efficiency of collecting the particles from the gas flow (Figure 2).

3 Results of the study and their description

The study of classification processes of loose material particles, based on silica gel, from the gas flow by means of a separator with coaxially arranged pipes, was carried out in the ANSYS Fluent software package. First of all, a three-dimensional model of the classifier was created, having the following geometric dimensions: height of device – 290 mm, diameter of inlet nozzle – 60 mm, diameter of outlet nozzle – 60 mm, diameter of cylindrical body of separator - 100 mm, length of inner pipe – 192 mm, hole diameter 4–16 mm, width and height of rectangular openings – 6 and 60 mm respectively, diameter of

coaxially arranged pipes – 12 mm, diameter and depth of hopper – 210 and 50 mm, respectively.

In the course of studies, the following boundary conditions were set: the volume flow rate of the gas flow was set at the inlet nozzle of classifier – $0.03 \text{ m}^3/\text{s}$, and the atmospheric pressure was set at the outlet nozzle – 101325 Pa . In this case, the ambient temperature was taken as equal to 20°C , the dynamic viscosity of air $18.1 \cdot 10^{-6} \text{ Pa}\cdot\text{s}$, and the gas flow density 1.22 kg/m^3 . In order to estimate the efficiency of collecting the particles of bulk material, based on silica gel, from the gas flow, a certain number of particles n equal to 1000 was set in it. The density of particles of the silica-based bulk material was taken equal to 1075 kg/m^3 . Also, a condition of particles bouncing was set for all solid surfaces. The size of particles of bulk material, based on silica gel a , varied from 1 to $100 \mu\text{m}$. At the end of each calculation, the number of silica gel particles in the hopper was recorded, which allowed to determine the operation efficiency of the classifier with coaxially arranged pipes.

The efficiency of classifier with coaxially arranged pipes E was evaluated with the following equation [12]:

$$E = 1 - n_k/n, \quad (1)$$

where n_k – the number of dust particles in the hopper 7 (Figure 1).

When carrying out the numerical calculations, the following basic assumptions were accepted: the interaction of particles with each other during the movement of the gas flow was not taken into account, there were no phase transitions, and an ideal gas was considered.

In the course of studies, in order to obtain the final design of the classifier with coaxially arranged pipes, corresponding to the characteristics, specified above, 6 models, divided into 2 groups, were considered. The devices with a conical inner pipe were considered from the first group and one of these devices is shown in Figure 1. It should be noted that three models from the first group differed from each other in the degree of the inner cone-shaped pipe immersion into the device. The distance h_d corresponding to the distance between the hole of cone-shaped inner pipe 4 and the upper border of dust hopper 7 was chosen as a specific distinctive size between them (Figure 1). The following values of h_d parameter were considered: 20, 50 and 100 mm, which corresponded to 3 models from the first group. Three devices with a cylindrical inner pipe were considered from the second group, i.e. the pipe section remained constant along its entire length.

The following values of h_d parameter were studied: 20 and 30 mm. It should be noted that the third device from the second group was partially included into the dust hopper by 10 mm. Thus, h_d parameter corresponded to a negative value of -10 .

The results of conducted studies are shown graphically in Figures 3, 4. The different shape of the inner pipe cross-section along its length and the degree of pipe immersion into the device significantly affect the classification efficiency of particles of bulk material, based on silica gel, from the gas flow, due to the changes in the gas movement structure and the redistribution of the influence of inertial, centrifugal, gravitational and other forces on separation of particles from the dusty flow. According to the results of studies, devices, belonging to the first group, with a conical inner pipe are the most effective for the processes of particles classification from the gas flows. This is largely caused by 2 factors: 1) the movement of dusty gas flow along the inner cone-shaped pipe gradually decreases its radius that increases the value of centrifugal forces acting on the flow, 2) the smaller size of outlet nozzle of cone-shaped inner pipe relative to the cylindrical one that redistributes the amount of dusty gas flow through the rectangular openings and the outlet nozzle 4 (Figure 1); the throughput capacity of rectangular openings within a cone-shaped pipe increases relative to the cylindrical one, while the throughput capacity of the outlet nozzle 4 decreases relative to the throughput capacity of cylindrical pipe, which is the reason for

increasing the values of centrifugal forces in vortexes that are formed behind the rectangular openings.

The efficiency of collecting the silica gel particles from the dusty gas flow, larger than 30 μm by means of classifier with coaxially arranged pipes was on average equal to 70.5 and 35.2% for the devices from the first and the second groups, respectively. The efficiency of collecting the particles of 1–100 μm by the devices from the first and the second groups was on average equal to 47.4 and 25.8%, respectively. It should be noted that one of the ways to intensify the process of collecting the particles of bulk material, based on silica gel, from the gas flow in this device is to seal the lower part of the inner pipe. However, in practice this is not possible, since the inner pipe will be clogged with bulk material: when the dusty flow that moves from the inner part of the pipe to the inter-pipe space of the classifier through rectangular holes turns around, some part of the particles is knocked out of it and falls into the lower part of the pipe. The executed hole allows the particles to pour into the hopper. Thus, the outlet nozzle 4 (Figure 1) should have a minimum size, which will increase the efficiency of separating the particles of bulk material based on silica gel from the gas flows. However, it should be taken into account that the particles may stick together, resulting in a clogged hole, so the size of the exit hole of inner pipe shall also be determined depending on the physical and chemical properties of the material being collected.

The efficiency of collecting the silica gel particles of 1–100 μm from the dusty gas flow by means of separator with coaxially arranged pipes and with a conical inner pipe was on average equal to 45.8, 31.1 and 65.1% and the value of h_d parameter was equal to 20, 50 and 100 mm, respectively. It should be noted that when classifying the particles of up to 30 μm , the efficiency of classifier was on average equal to 17.3, 8.6 and 40.4% with h_d parameter value equal to 20, 50 and 100 mm, respectively. When fractionating the silica gel particles larger than 30 μm from the dusty flow, the efficiency of device was on average equal to 69.7, 56.6, and 85.8% with h_d parameter value of 20, 50, and 100 mm, respectively. Thus, the most effective design solution among 3 considered models is to manufacture the classifier with a distance between the upper border of hopper and the hole within the cone-shaped pipe equal to 100 mm, which is the largest among the considered ones. It should be noted that when h_d parameter is increased, there is a tendency of increase in the efficiency of collecting the silica gel particles from the gas flow (Figure 3).

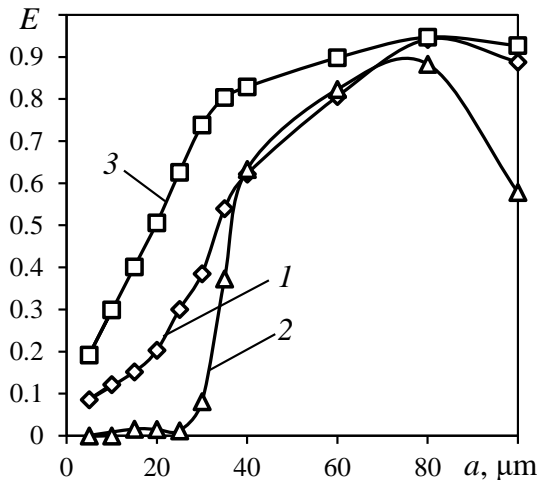


Fig. 3. Dependency of the change in fractionation efficiency of bulk material particles, based on silica gel, from the gas flow, on the size of them in the classifier with conical inner pipe at different values of h_d parameter, mm: 1 – 20, 2 – 50, 3 – 100.

The fractionation efficiency for the silica gel particles of 1–100 μm from the dusty gas flow by a classifier with coaxially arranged pipes and with a cylindrical inner pipe on average was equal to 22.1, 50.3 and 5.1% with h_d parameter value equal to 20, 30 and -10 mm, respectively, which is on average by 2 times less than when using a classifier with an inner cone-shaped pipe. At the same time, the efficiency of the particles fractionation from the gas flow by the device, smaller than 30 μm , was on average equal to 13.1, 30.1, 1.1% and h_d parameter value equal to 20, 30 and -10 mm, respectively.

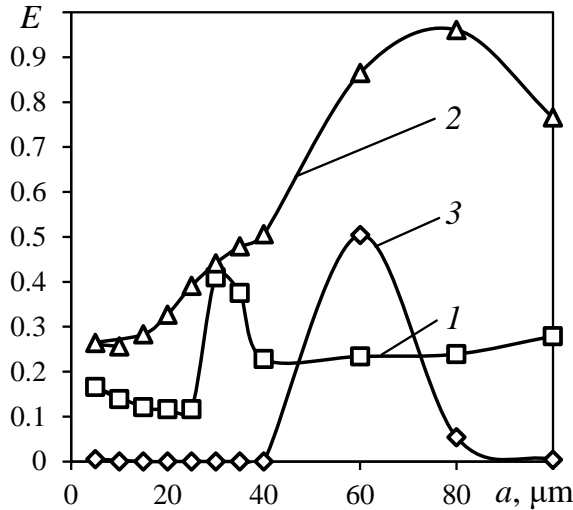


Fig. 4. Dependency of the change in fractionation efficiency of bulk material particles, based on silica gel, from the gas flow, on the size of them in the classifier with a cylindrical inner pipe at different values of h_d parameter, mm: 1 – 20, 2 – 30, 3 – -10 .

The classification of particles, from the dusty flow by means of a classifier, larger than 30 μm was performed with an average efficiency of 29.4, 66.9, 93.7% and h_d parameter value of 20, 30 and -10 mm, respectively. It should be noted that the most suitable device among 3 models under the study is a classifier with h_d parameter equal to -10 mm, since when fractionating the particles smaller than 30 μm , almost zero efficiency is achieved, and when collecting the particles larger than 30 μm , a high efficiency above 90% is achieved. However, the negative parameter of this design is that when the size of silica gel particles increases over 80 μm , the classifier efficiency tends to a value close to 0 (Figure 4).

Thus, according to the conducted studies, it is more efficient to use a classifier with an inner conical pipe to solve the problems of separating the particles from the gas flows of various sizes, since a greater value is achieved for the centrifugal, inertial, gravitational and other forces acting on the dusty flow, that contribute to knocking the particles out of its structure, than in a classifier with a cylindrical inner pipe. On average, the efficiency of a classifier with a conical inner pipe is by 35.3% higher than that of a classifier with a cylindrical inner pipe.

4 Conclusion

It was also stated that almost any design changes have a significant impact on the classifier operation efficiency. The following design changes were considered: the shape of inner pipe and the depth of inner pipe immersion into the device, indicated by h_d parameter, showed that the problem of classifying the particles of bulk material, based on silica gel, of 30 μm , from the dusty gas flows can be solved most effectively by using a classifier with a

conical inner pipe and h_d parameter equal to 50 mm and a classifier with a cylindrical inner pipe and h_d parameter equal to -10 mm.

The advantages of the developed classifier with coaxially arranged pipes are high efficiency, design simplicity, easy to assemble, low capital and operating costs.

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