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# Pressure Loss in Classifier with Coaxial Pipes with a Different Number of Axisymmetric Holes

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**Abstract.** The purpose of this paper is to study the influence of vortex flow aerodynamics in the inter-pipe space on the pressure loss in the classifier with coaxially arranged pipes. The results of studies showed that the developed design of classifier with coaxially arranged pipes allows to create a stable vortex structure in the inter-pipe space. In this case, the pressure loss in the classifier is not more than 1000 Pa while the inlet gas flow rate is within the range of 7.3–22.2 m/s. The minimum pressure loss in the classifier, not exceeding 805 Pa, was obtained for all open round holes in the inner cylindrical pipe. In the course of physical experiments, power dependences were obtained. The degree of obtained functions, characterizing the dependency of pressure loss in the classifier on the inlet rate, varies from 1.64 to 1.68. The discrepancy between the physical experiment and the numerical simulation is within the range from 2.2 to 22.5% when the inlet gas rate varies within the range from 8.94 to 22.2 m/s, which, on the one hand, requires additional study, on the other hand, shows that the numerical simulation at the specified parameters can be used for estimation calculations.

## INTRODUCTION

An important task for the production lines of finely dispersed powders at industrial enterprises is to increase the classification efficiency with a given limiting size in separation devices. The relevance of this task increases every year, as the demand for the finely dispersed powders increases by various industries. For example, the production of composite materials and alloys requires alloying materials, which are subject to strict requirements for median size and dispersion. First of all, quality of them depends on the dispersion of fractional composition of the resulting alloying material. However, when classifying this material, the formation of limited range of collected fractions of micro - and nanoscale particles is a problem. This task is relevant for petrochemical enterprises that use catalysts and adsorbents, which are bulk powder based on silica gel. In order to use this product in adsorbents during the process of simultaneous drying and topping of natural gas for transportation, the size of silica gel particles should not be more than 30–40 microns.

Currently, in order to fractionate the powders, as noted before, the separation devices are used, namely, classifiers, which are divided into centrifugal, gravity and sieve. The centrifugal classifiers allow the separation of finely dispersed powders of 40–500 microns in limiting size. The process of separating particles from the gas flow by size and density is carried out due to the impact of centrifugal forces on it. The centrifugal classifiers are divided into two categories: the first – devices that do not have rotating (movable) elements, the second – devices that additionally have the rotation of some parts of separation chamber. The use of additional rotating elements makes it possible to increase the efficiency of particle classification i.e. due to an increase in the circumferential rate in the separation zone, a more uniform field of centrifugal forces is created [1-3]. The disadvantage of availability of rotating elements in the device is the increased hydraulic resistance and relatively short life of mechanisms. As a rule, the efficiency of classifiers with rotating elements is more than 0.85–0.9. In centrifugal classifiers that do not have moving elements, the vortex structure in the separation zone is formed by means of guide vanes. This method reduces the hydraulic resistance of device in comparison with centrifugal classifiers which have rotating elements,

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but the field of centrifugal forces has lower values, resulting in lower efficiency, which is more than 0.8 when fractionating particles of 60–500 microns in limiting size [4-6].

In gravity classifiers, the separation of bulk material is carried out due to inertial forces. When the gas, with the material particles dispersed in it, turns or passes around the structural elements, the particles are knocked out of the structure and, due to gravity, are lowered into the hopper of device. As a rule, gravity classifiers are used to separate bulk material of 0.1–5 mm in limiting size. Therefore, they are not designed for fractionation of finely dispersed powder [7-8].

In sieve classifiers, sieves are used to separate the bulk material into certain fractions, which are a woven mesh with different size of cells. The disadvantage of sieve separators is the necessity for periodic cleaning and replacement of sieves. The sieve separators are used for the separation of finely dispersed bulk material of more than 60 microns in limiting size.

One of the ways to improve the efficiency of classifying finely dispersed bulk material is to improve the classic and create new separation devices with low hydraulic resistance. Many researchers are studying this problem. In scientific paper [9] you can find a hydro-vortex classifier, which was developed for the separation of finely dispersed material with grain of 0.5–5 microns in limiting size. In the course of study, it was found that the classification of finely dispersed particles depends on the median diameter, while the geometric parameters of device are determined by the energy characteristics of hydro-vortex aerator and its efficiency. This scientific paper [10] includes the study on modernization of classical centrifugal classifier with two upper pipes. The authors propose to lower the inlet nozzles along the height of device, making them in the middle of classifier. The numerical calculations showed that this approach improves the flow structure, as a result of which the entrainment of finely dispersed particles into a large fraction reduces that is a significant disadvantage with the upper inlet nozzles. According to scientific paper [11], the processes of separation of polydisperse spherical particles in a paddle mixer are studied by applying experimental computational methods.

## DESCRIPTION OF THE DEVELOPED DEVICE

The authors developed a design of classifier with coaxially arranged pipes for separating finely dispersed bulk material of 30–40 microns in limiting size. A simplified three-dimensional model of device is shown in Fig. 1. The design of classifier includes the following main elements: inlet *1* and outlet *6* nozzles, internal *3* cylindrical pipe with round holes *4*, external cylindrical pipe *4*, grid with round holes *2* and the bottom of device *5*. It should be noted that the device hopper is not available in the simplified model. This was done to simplify the calculations when conducting numerical simulations. In the real model, for strength and in order to avoid loosening of components, the inner *3* and outer 7 cylindrical pipes shall be welded to the grid with round holes *2*. Welding is also used at the contact point of classifier hopper and body (Fig. 1).

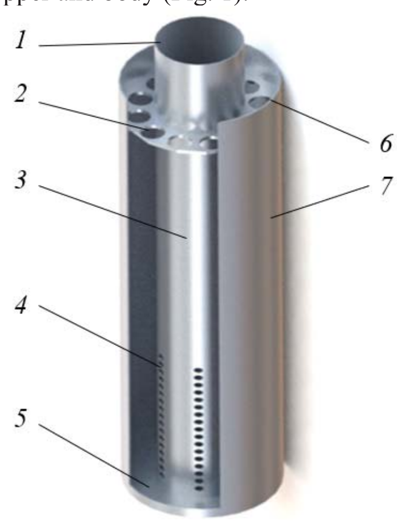


**FIGURE 1.** The simplified three-dimensional model of classifier with coaxially arranged pipes (sectional view): *1* – inlet nozzle; *2* – grid with round holes; *3* – inner cylindrical pipe; *4* – round holes within inner cylindrical pipe; *5* – bottom of apparatus; *6* – outlet nozzle; *7* – external cylindrical pipe.

The separation of finely dispersed bulk material in the classifier with coaxially arranged pipes can be described as follows: the gas flow, containing the material particles, enters the device through the inlet nozzle *1*, after that it moves along the cylindrical inner pipe *3*; when the gas reaches the level at which the round holes *4* begin to be located, most part of gas in equal proportions begins to move in an axisymmetric way in the direction of round holes *4*. When the dusty gas flow turns to the holes *4*, the largest particles are knocked out of the flow structure and fall into the hopper. When the gas with particles passes through the round holes *4*, a stable vortex zone begins to form in the inter-pipe space of classifier with coaxially arranged pipes. When the gas stream exits the round hole *4*, it is divided into two parts, which in equal proportions move in opposite directions relative to each other. Due to the design features, each gas stream forms a vortex. Thus, when the gas flow exits each series of round holes *4*, two vortices are formed along the height. An important feature is that each vortex is not overlapped with the neighbouring one, but has several points of contact, at which the rate vectors are co-directed, which allows maintaining the flow structure in the inter-pipe space. Further, the vortices go in the direction of outlet hole *6* and pass through the grid with round holes *2*. The separation of finely dispersed particles of bulk material of more than 30–40 microns in limiting size is carried out in the inter-pipe space due to the impact of centrifugal forces on the dusty gas flow. When the finely dispersed particles are knocked out of the gas flow, they fall into the classifier hopper. At the outlet from the classifier, the gas flow contains finely dispersed particles of finished product of less than 30–40 microns in limiting size. It should be noted that when separating finely dispersed bulk material, the limiting size can be shifted to a larger or smaller size range by changing the design dimensions of classifier with coaxially arranged pipes (Fig. 1).

As noted before, when developing new industrial models of devices or improving classic devices, it is necessary to create not only high-efficiency devices, but also with low hydraulic resistance [12-16]. In this regard, the purpose of this paper is to study the influence of vortex flow aerodynamics in the inter-pipe space on the pressure loss in the classifier with coaxially arranged pipes.

## DESCRIPTION OF THE EXPERIMENTAL SETUP

An experimental unit was created to conduct the study. Its scheme is shown in Fig. 2. The classifier under study with coaxially arranged pipes *1* and the forced-draft fan *2* were the main elements of experimental unit. During the experiments, the gas flow rate and pressure were measured in the gas supply line by means of measuring instruments.

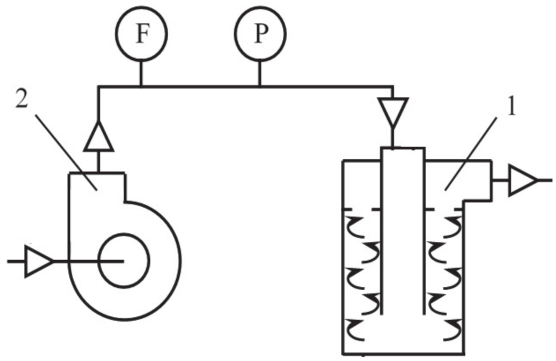


**FIGURE 2.** The scheme of experimental unit: *1* – classifier with coaxially arranged pipes; *2* – forced-draft fan.

The process of conducting physical experiments can be described as follows: the gas flow was fed into the classifier with coaxially arranged pipes *1* along the gas supply line by means of forced-draft fan *2*. When the gas flow passed through the line, the rate and pressure were measured. After the gas flow passage inside the classifier, it left the device through the outlet nozzle. At the outlet of device, the pressure was equal to atmospheric one (Fig. 2). Thus, the pressure loss in the separator with coaxially arranged pipes was determined by the formula:

$$\Delta p = p_1 - p_a, \tag{1}$$

where $p_1$ – pressure, measured by differential pressure gauge in the gas supply line of experimental unit, Pa; $p_a$ – atmospheric pressure at the outlet of classifier with coaxially arranged pipes, Pa.

The classifier with coaxially arranged pipes was made of non-plasticized polyvinyl chloride, which is a polymer of vinyl chloride. The geometrical dimensions of classifier were the following: device height – 400 mm, diameter of outer cylindrical pipe – 88 mm, diameter of inner cylindrical pipe – 50 mm, diameter of round holes within inner cylindrical pipe – 5 mm, step in height between them – 7.5 mm, distance along the inner cylindrical body between the rows of round holes – 26 mm, distance from the centers of lower and upper round holes – 120 mm, number of round holes in each row – 17, total number of round holes – 102, diameter of round holes in the grid 2 (Fig. 1) – 14, number of them – 12. During the experiments, five series of studies were conducted. In the first series, all the round holes in the inner cylindrical pipe were opened. In each subsequent series of studies, 2 round holes in each upper row were closed.

## RESEARCH RESULTS AND THEIR DISCUSSION

The results of study showed that the developed design of classifier with coaxially arranged pipes makes it possible to create a stable vortex structure in the inter-pipe space. In this case, the pressure loss in the classifier is not more than 1000 Pa, while the inlet gas flow rate is within the range of 7.3-22.2 m/s. The minimum pressure loss in the classifier, not exceeding 805 Pa, was obtained for all open round holes in the inner cylindrical pipe. As the round holes were closed, the pressure loss increased. This is due to the fact that the total area of passage sections decreased. In the course of study, the power-law dependences of pressure loss in the classifier with coaxially arranged pipes on the inlet rate of gas flow with a degree of 1.65–1.68 were obtained, depending on the number of closed round holes in the inner cylindrical pipe, which allow us to suggest that the turbulent flow is laminarized in the inter-pipe space. Due to this, low pressure losses in the classifier are achieved, not exceeding 1000 Pa at inlet gas flow rates of up to 22.2 m/s (Fig. 3). The authors also made comparison between a physical experiment with all open round holes in an inner cylindrical pipe and a numerical simulation in the ANSYS Fluent software package. The results showed that the discrepancies range from 2.2 up to 22.5%. As the inlet rate increases, the discrepancies between the physical experiment and the numerical simulation increase as well. Mostly, this is due to the fact that during the physical experiment, the rate was recorded for a certain point in the gas supply line, and during the numerical simulation, this value was taken as an average inlet rate (Fig. 4). However, the application of results, obtained by numerical simulation, as estimated data allows to reduce the time and financial costs for conducting experimental studies.

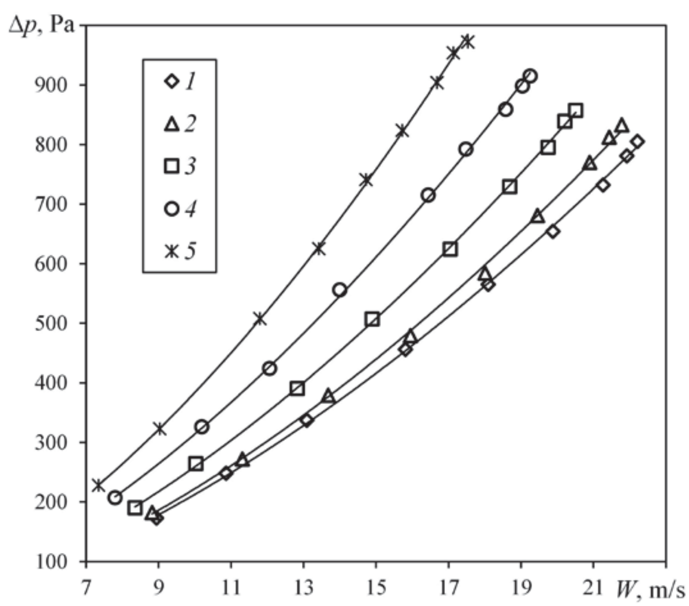


**FIGURE 3.** The dependency of pressure loss in the classifier with coaxially arranged pipes on the gas flow rate with a different number of closed round holes in each upper row of inner cylindrical pipe: *1* – 0; *2* – 2; *3* – 4; *4* – 4; *5* – 6.

The process of separating initial powder into large and small fractions relative to the limiting size in the separation zone of apparatus is mainly affected by the created stable vortex structure of dusty gas flow. In particular, the properties of turbulent vortex flow have a decisive influence on the separation of finely dispersed particles from the gas, since during the separation of finely dispersed particles from the gas, they are again picked up by chaotic vortices and return back to the general flow structure. As a result, the efficiency of classifiers decreases when fractionating finely dispersed particles. Also, excessive flow turbulence leads to an increase in the pressure loss in the device. In the developed classifier with coaxially arranged pipes, low pressure losses are achieved, in comparison, for example, with cyclone separators, due to the laminarization of turbulent flow. The obtained power-law dependences: for all open holes (2), for 2 closed round holes in each upper row (3), for 4 closed holes (4), for 6 closed holes (5) and for 8 closed holes (6), show that the degree of function is less than 2, which is typical for the turbulent flow, as a result of which the pressure loss in the classifier is less than in other air classifiers (Fig. 3). It should be noted that the reliable approximation of $R^2$ is at least 0.99.

$$\Delta p = 4.71W^{1.65}, \tag{2}$$

$$\Delta p = 4.62W^{1.68}, \tag{3}$$

$$\Delta p = 5.66W^{1.66}, \tag{4}$$

$$\Delta p = 7.16W^{1.64}, \tag{5}$$

$$\Delta p = 8.03W^{1.68}, \tag{6}$$

where $W$ – gas flow velocity, m/s.

When conducting numerical simulation in ANSYS Fluent software package, the authors used a three-dimensional model of classifier with coaxially arranged pipes, shown in Fig. 1, made according to the geometric dimensions shown above [17-20]. Transition SST model, which is an improved version of standard SST model, was used as turbulence model. The calculation grid consisted of 486995 cells. The obtained results showed that when performing numerical simulation, the pressure loss is within the range from 169 to 1038 Pa, when the inlet gas flow rate - from 8.94 to 22.2 m/s. As can be seen, at high gas flow rates, the discrepancies between the physical experiment and the numerical simulation increase, which, on the one hand, requires additional study, on the other hand, the obtained results can be used for the estimation calculations (Fig. 4).

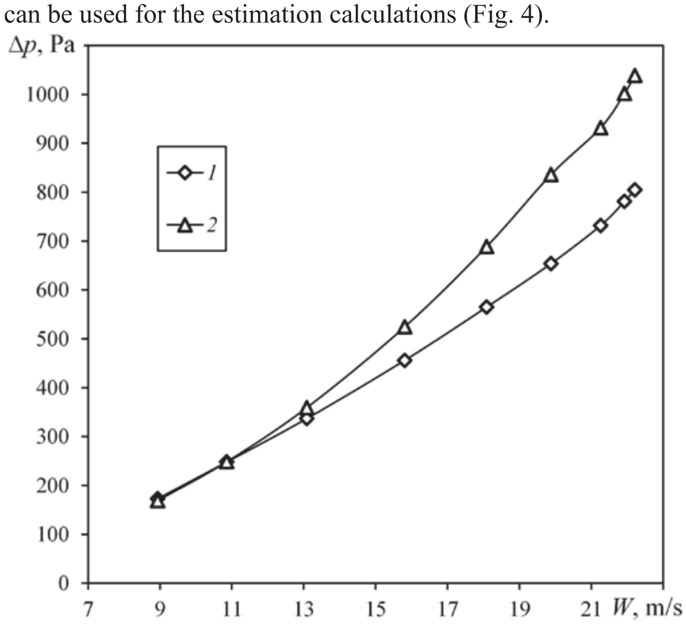


**FIGURE 4.** Comparison of physical experiment and numerical simulation in the ANSYS Fluent software package for all open round holes in internal cylindrical pipe: *1* – experiment; *2* – numerical simulation.

Thus, the conducted studies showed that the pressure loss in the classifier with coaxially arranged pipes is less than 1000 Pa at high gas flow rates of more than 15 m/s. During the processing of experimental data, it was hypothesized that low pressure losses in the classifier with coaxially arranged pipes are achieved due to the laminarization of turbulent flow in the inter-pipe space, which also requires further study to confirm this effect. Comparison of physical experiment with the numerical simulation showed that at high gas flow rates, a discrepancy of more than 20% is observed, which can be caused by both incorrectly set rates and incorrect turbulence model. However, in the course of physical experiment and numerical simulation, the visualization of formation of vortices in the inter-pipe space coincides. Therefore, the numerical simulation to carry out estimation calculations for this turbulence model is acceptable.

## CONCLUSION

Based on the conducted study, the following conclusions can be drawn:

- the classifier with coaxially arranged pipes for separating finely dispersed bulk material of 30–40 microns in size was developed;
- in the course of physical experiment the pressure loss in the classifier with coaxially arranged pipes was not more than 1000 Pa at the inlet gas flow rates within the range from 8.94 to 22.2 m/s;
- it is hypothesized that low pressure losses in a classifier with coaxially arranged pipes are achieved by laminarization of turbulent flow in the inter-pipe space;
- the degree of obtained functions, characterizing the dependency of pressure loss in the classifier on the inlet rate, is within the range from 1.64 to 1.68;
- it is shown that the overlap of round holes increases the pressure loss in the classifier, due to a decrease in the total area of passage sections;
- the discrepancy between the physical experiment and the numerical simulation is within the range from 2.2 to 22.5% when the inlet gas rate varies within the range from 8.94 to 22.2 m/s, which, on the one hand, requires additional study, on the other hand, shows that the numerical simulation at the specified parameters can be used for estimation calculations;
- the absence of moving elements in the design of classifier, ease of assembly and operation allow you to use the developed device at almost any industrial enterprise.


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