Separation efficiency of device with different number of arc-shaped settler rows

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Abstract. An original design of a separating device with arc-shaped settlers (SDAS) has been developed to purify air from solid particles. In this study, the separation efficiency of the device was studied numerically. The influence of the number of rows of arc-shaped settlers of the SDAS on its efficiency was evaluated. Geometric models of the separating device with three configurations were used: 5, 7, and 9 rows of arc-shaped settlers. The diameter and height of the arc-shaped settlers and the distance between the rows were the same for all models. The results obtained showed that the most effective configuration of the separating device that allows the maximum efficiency of particle removal from a dusty gas stream was observed with 5 rows of arc-shaped settlers, providing an efficiency of about 66.7% with an input gas stream rate in the range of 0.5 to 3 m/s. It was found that the separation efficiency decreases with an increasing number of rows and stream rate of the gas stream as a result of particle reflection from the device walls.

1 Introduction

Industrial enterprises are sources of emission of harmful substances into the gas environment. Efficient purification of dusty gas emissions from modern enterprises is a mandatory part of the sustainable development strategy [1,2]. Therefore, the use of an effective separation system, whose operation ensures compliance with sanitary standards for air quality control, is an urgent task.

Air separators are the most common devices for purifying the gas stream from solid particles, the operation principle of which is based on the difference in their terminal velocities. To develop an effective air separator, it is necessary to study its separation efficiency as a function of particle size, velocity field within the device, channel geometry, and operating mode. Computational fluid dynamics (CFD) is a powerful and best tool to solve this task [3,4].

The authors [5] used CFD to study the flow and pressure fields, and the particle size distribution of a separator. They concluded that at an initial air stream rate of 2.5 m/s, the impact separator efficiency is maximum. The CFD approach [6] was used for the analysis of

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the structure of the stream within a square cyclone to improve separation efficiency. Vortex effects generally promote separation efficiency, especially for fine particles [7]. A dust separator [8] with helical channels was designed and studied numerically to determine the effect of the air input stream rate on its efficiency. It was found that even at low air stream rates, the overall separation of fine particles can be effectively achieved. In [9], a validated model for CFD simulation of the particle trajectory was created in a vane-type separator to evaluate the efficiency of the particle removal process. In the paper [10], the authors studied the inner stream pattern and the energy loss of vortex separators with a different number of inputs using the CFD approach. They revealed that more than one input provides the stream symmetry.

A new conceptual model of a separating device with arc-shaped settlers (SDAS) was developed for solid particle removal from a gas stream. A feature of the separation mechanism of this device is that the stream of dusty gas, when flowing around the arc-shaped settlers, acquires a wavelike structure. Moreover, a relatively small diameter of the arc-shaped settlers provides a small gas turning radius. As a result, when the dusty stream moves in the device, the dust particles in the stream are subjected to significant centrifugal force, allowing high-efficiency indicators to be achieved.

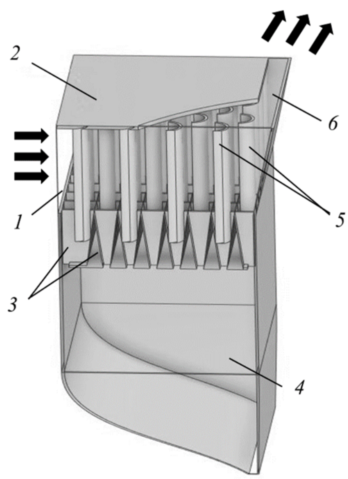

Fig. 1. Cross-sectional view of a three-dimensional model of the SDAS: (1) dusty gas stream input; (2) case; (3) V-shaped grid; (4) hopper; (5) arc-shaped settlers; (6) purified gas stream.

A gas-solid stream is fed to the SDAS through an input section. As a result of bending the gas stream lines, the particles are separated from the stream and directed toward arc-shaped settlers. When they are in contact with their surface, the solids are repelled and get into areas of reduced gas stream rate near arc-shaped settlers. Particles entering these zones begin to settle in a hopper under the action of gravity. However, some of the solids after interaction with the settlers are repelled and returned to the main stream, reducing the possibility of their removal. One of the disadvantages of the device is the formation of upward gas streams that can pick up previously separated particles and return them back to the purified gas stream. To solve this problem, a V-shaped grid is used consisting of lateral and transverse plates. The settlers are arranged into the plates to a specific height, forming 5 mm slots between the inclined plates in the lower part of the grid. The particles fall through the inclined plates and enter the hopper through the slots. The design of the grid helps reduce gas blowoff from bottom to top. A similar function is satisfied by horizontal plates, which are held together by the first and last V-plates and directed towards the SDAS internal wall.

The major benefits of the SDAS are its simple design and low cost. At the same time, it is important to determine such geometric and operating parameters of the device that provide high efficiency at the lowest stream rate, ensuring a low pressure drop. The objective of this paper is to perform a numerical study of the effect of the number of rows of arc-shaped settlers of the SDAS on the efficiency of separating solid particles from the gas stream.

2 Materials and methods

Numerical simulations were performed using the CFD software program. Three configurations of the SDAS with 5, 7, and 9 rows of arc-shaped settlers were studied. The following geometric parameters were established: four arc-shaped settlers in each row, the diameter and height of which were 20 and 110 mm, respectively. The distance between the rows of settlers was 17 mm. The device is 160 mm wide and 307 mm high. The length of the longitudinal plates was equal to the width of the device. The opening angle of the outlet section was 10º. The width of the device, as well as the outlet and input sections, was 170, 244, and 319 mm for cases with 5, 7, and 9 rows, respectively. The thickness of all the walls of the device was set to 2 mm. Given the symmetry of the SDAS design, the symmetry condition was applied for the calculations.

During the study, the following conditions were specified: dust density 7000 kg/m3, pressure at the output of the device 1 bar, gas mass stream rate of 0.0033 to 0.0393 kg/s, gas stream rate W at the input of the SDAS from 0.5 to 3 m/s, particle diameter a from 10 to 200 microns. The overall efficiency of the SDAS can be calculated using Eq. (1), where N is the number of particles separated by the device from the gas stream, N_0 is the total number of solid particles in the gas stream.

$$E = \frac{N}{N_0} \tag{1}$$

3 Results and discussion

The results obtained show that the efficiency of solid particle removal from a dusty gas stream using the SDAS is influenced by the number of settler rows and the input gas stream rate (Figure 2). The SDAS efficiency at the gas stream rate at input of 0.5 m/s averaged 91.3, 95.5, and 97.1% for 5, 7, and 9 rows of arc-shaped settlers, respectively. It can be seen from Figure 2a that the change in the number of settler rows affects the particle diameter at which the efficiency approaches 100%, defined as the critical particle size a_{cr}. When the number of rows 5, 7, and 9, acr is equal to 26, 22, and 19 microns, respectively. The average separation efficiency for particles smaller than the critical diameter is 44.2, 50.1, and 48.4% for each configuration.

With an increase in the input stream rate of dusty gas to 1 m/s, the efficiency is on average 71.3, 78.2, and 80% with the number of rows of arc-shaped settlers 5, 7, and 9, respectively (Figure 2b). Also, when the number of rows was 5, 7, and 9, the critical particle size increased to 91, 40, and 26 microns. The SDAS separation efficiency for the particles of subcritical diameter at the number of rows 5 (a_{cr} < 91 microns), 7 (a_{cr} < 40 microns), and 9 (a_{cr} < 26 microns), averages 62.4%, 54.3% and 42.2%, respectively.

The separation efficiency of the SDAS at an input stream rate of dusty gas W = 3 m/s and a particle size from 10 to 200 microns is on average 37.5, 25.6, and 14.4% with the number of settler rows of 5, 7, and 9, respectively (Figure 2c). At this stream rate, the efficiency is quite low and decreases with an increase in the number of rows of settlers from 5 to 9. This is due to the fact that at stream rates greater than 1 m/s, the momentum of the particle exceeds the critical value at which the particle bounces back into the stream.

Thus, it was revealed that as the gas stream rate decreases, the efficiency of the SDAS increases. This is caused by the fact that, at high input gas stream rates, the centrifugal field has a greater force. As noted above, a portion of the dust, upon interaction with the walls of settlers, flies back into the wave-structured gas stream. Therefore, with increasing centrifugal force, the solids are pulled out of the wave-structured stream with a higher force, which is enough to return them back to the stream after hitting the settlers. The trajectory of the particles in the SDAS is influenced by the number of settler rows. Obviously, with an increase in the number of rows of settlers, the efficiency should be higher. However, this trend continues at low gas stream rates, up to 1 m/s. Alternatively, this structural change should have a beneficial impact on the SDAS efficiency, since the particles encounter more arc-shaped settlers, which act as obstacles to the outlet.

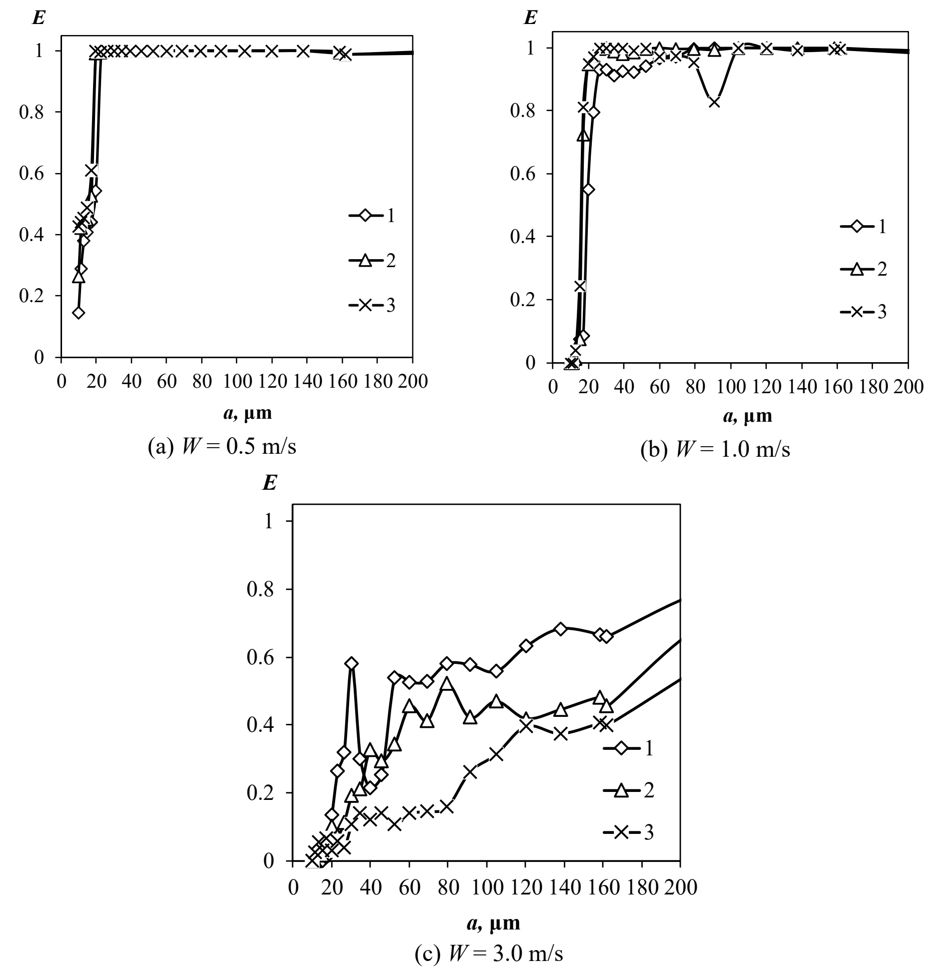

Fig. 2. Fractional efficiency of the SDAS at different gas stream velocity with different numbers of rows of arc-shaped settlers, pcs: (1) 5; (2) 7; (3) 9.

We came to the conclusion that five rows of arc-shaped settlers provide the maximum efficiency of dust removal from the gas-solid stream. The SDAS efficiency with the number of rows of settlers 5, 7, and 9 averages 66.7, 66.4, and 63.8%, respectively, at a gas stream rate ranging from 0.5 to 3 m/s. (Figure 2). Analysis of the results obtained showed that the device effectively separates fine solid particles from the solid gas stream at rates of less than 1 m/s.

4 Conclusion

Based on the numerical study, it can be concluded that the maximum efficiency of the developed SDAS is reached when five rows of arc-shaped settlers are used. The device is an alternative for gas purifying systems that require effective separation of solid particles at low stream rates of a gas stream, which can essentially reduce overall energy costs. In the future, the influence of the number of arc-shaped settlers on the pressure drop of the SDAS is planned.

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