Effect of arc element diameter on fine particle collection efficiency of the separator

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Abstract. Clean gas without suspended particles is an essential factor for many industries. The paper is concerned with the design of a separation device with rows of the arc elements, in which a wave-like flow pattern is observed. The separation of solid particles from the gas occurs due to inertial and centrifugal forces. A three-dimensional model of the device and its operating principles are presented. The aim of the work is to numerically study the effect of the size of the arc elements of the separation device on the efficiency of particle collection. In the course of the simulation, the diameter of the arc elements varied from 25 to 50 mm. The exit to the stationary solution was estimated by the pressure drop of the separation device. It was found that about 870 iterations were needed. Results have shown that the diameter of the arc elements, at which the maximum efficiency of collecting particles from gas-solid flow occurs, is 40 mm. The separation efficiency of the device with a diameter of the arc elements of 25, 40, and 50 mm averages 81.1, 90.1, and 86.5%, respectively, at an inlet gas velocity of 0.5 to 5.0 m/s. The pressure loss in the separation device ranged from 12.6 to 1924.1 Pa at a gas velocity of 0.5 to 5.0 m/s. It is concluded that it is important to use a separation device to collect fine particles at a dusty gas velocity of less than 3 m/s because its pressure drop is significantly lower compared with other air separators.

1 Introduction

In many processes, industrial gases contain fine solid or liquid particles that need to be cleaned. In a number of industries, these particles are the final product; for example, in the production of some non-ferrous metals, soot, cement, and the capture of catalysts in oil refining. In other cases, it is essential to clean the gas from suspended particles, as, for example, in the air preparation in the production of sulfuric acid [1] or to achieve absolutely pure air in the special microelectronics production rooms (Clean Rooms [2]). The first step of particle separation from gas flow is usually performed using the air devices of inertial [3] or centrifugal types [4–6]. There are many experimental and theoretical studies on the study

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of air separators, but various separation mechanisms and many factors affecting the separation efficiency determine the relevance of the study.

In order to develop an efficient separator for collecting fine particles, it is necessary to select the best design characteristics and operating regime in order to ensure a high separation efficiency at the maximum flow velocity and minimum pressure loss. To solve this problem, it is proposed to use the developed separation device with the arc elements [7–9]. The aim of this work is to numerically study the influence of the element size on the efficiency of particle collection.

2 Methodology

The design of this device is shown in Figure 1. It has a number of rows of the arc-shaped elements 6, enclosed in a trapezoidal housing 5. A V-shaped separation screen 5 is located in the lower part of the device.

![3D section view of the separation device with the arc elements](image)

**Fig. 1.** 3D section view of the separation device with the arc elements: 1 – inlet pipe; 2 – V-separation screen; 3 – bunker; 4 – discharge pipe; 5 – trapezoidal housing; 6 – arc elements.

The separation device works as follows: dusty gas is supplied into the device via an inlet pipe 1 and flows around the arc elements 6, which are arranged in a staggered order inside the separation device. In this case, a wave-like pattern of gas flow is observed (Figure 2). The diameter of the arc elements is relatively small, so the turning radius of the gas is also small. This results in high centrifugal forces that act on solid particles in the flow during moving dusty flow [10–13]. In addition, the particles are affected by gravity. As a result, when the gas flow lines are deformed, the particles go off the flow and fly to the arc elements [14–16]. Contacting the surface of the elements, the particles are reflected and fall into the stagnant zones with low gas flow velocities. As a result, the particles gradually descend into the device. Eventually, the particles settle in the separator bunker, and the cleaned gas is discharged from the pipe.
However, a part of the particles after contact with the arc elements are reflected back to the main gas flow, which reduces the probability of their separation in the device. The disadvantage of the developed device is an upward gas flow, which is formed during a flow around the separation screen and is capable of picking up particles and returning them to a wave gas flow. A V-shaped separation screen has been proposed to destroy the upstream parasite drag. The screen consists of longitudinal and transverse V-shaped plates. The longitudinal plates act as stiffening ribs. The arc elements are inserted into plates at a certain depth to prevent them from slacking during the operation of the separator. The V-shaped plates form small slots about 5 mm in size in the lower part, through which separated particles are fed into the hopper. On the other hand, they are necessary to destroy the upward gas flow. A similar function of avoiding the formation of downward and upward gas flows is performed by horizontal plates welded to the first and last V-shaped plates and oriented towards the inner wall of the separator housing. It should be mentioned that between the housing and the horizontal plate welded to the V-shaped plate, there is a 5 mm gap normal to the direction of the gas flow to avoid the formation of stagnant zones where particles can collect.

The study is based on a numerical simulation using Ansys Fluent. Three different three-dimensional models of the separation device were developed with different linear sizes of the diameter of the arc elements: 25, 40, and 50 mm. The symmetry condition was applied to numerical calculations [17,18]. During the simulation, the following parameters are given: particle density $\rho = 3400 \text{ kg/m}^3$, the outlet pressure of the device is 1 atm, mass flow rate $G$ for each particle varies from 3.3 to 39.3 g/s, gas flow velocity at the inlet of the separation device changes from 0.5 to 5.0 m/s, and particle size $a$ ranges from 10 to 170 μm.

The separation efficiency of particles from the gas-solid flow $E$ can be found as [19]:

$$E = 1 - \frac{n}{n_0},$$

where $n$ is the number of particles in the discharged gas flow and $n_0$ is the initial number of particles in the gas flow at the device inlet.

3 Results and Discussion

In numerical simulations, the exit to the stationary solution was estimated by the pressure drop ($\Delta p$) of the separation device. Figure 3 shows that this point occurs after 870 iterations.
Studies have shown that the efficiency of particle separation from the gas-solid flow in the proposed device is affected by the diameter of arc elements and the inlet gas velocity. As a rule, with an increase in the gas velocity at the inlet to the separator, the efficiency for particles up to 25 μm is increased. This is due to the fact that the centrifugal field is higher at lower inlet gas velocities. However, for larger particles, the efficiency of the device is reduced. As noted above, some particles, after contact with the walls of the shaped elements, return to the wave-like flow. Accordingly, with the increase in centrifugal force, the medium and large particles are coming out of the structured flow with a greater force, which is sufficient for their return to the flow after impact with the arc elements.

The diameter of the arc elements determines the trajectory of the movement of particles in the separation device. It affects the size of the stagnant zones in the form of vortices inside and behind the arc elements, in which the particles are likely to settle into the bunker. It is obvious that with the increase in the size of the arc elements, the space in which vortex formation occurs also increases. On the one hand, this design should have a positive effect on the efficiency of the separation device. After impact with the arc elements, the particles may not have enough force to pass through a wider area with vortices. On the other hand, increasing the diameter of the arc elements leads to an enhanced distance between the rows of elements; accordingly, the turning radius of gas flowing around elements increases and the force of the centrifugal field decreases. Therefore, finding the most effective diameter of the arc elements is an important task. The study found that with an element diameter of 40 mm, the most efficient stagnation zone was created, allowing the maximum particle removal from the dusty gas. The separation efficiency of the device with the diameters of the arc elements 25, 40, and 50 mm is on average 81.1, 90.1, and 86.5%, respectively, at a gas velocity of 0.5 to 5.0 m/s (Figures 4–6). Pressure drops in the separation device ranged from 12.6 to 1924.1 Pa at a gas velocity of 0.5 to 5 m/s.

During the separation of particles with a diameter from 10 to 170 μm at an inlet gas velocity of 0.5 m/s, the efficiency of the separation device is on average 80.7, 92.9, and 82.8% with an arc diameter of 25, 40, and 50 mm, respectively. It can be seen that the diameter of the arc elements has an effect on the critical size of particles (a_{cr}), which determines 100% efficiency. So, for the diameter of elements 25, 40, and 50 mm, the critical particle size is 40, 25, and 50 μm. In addition, the collection efficiency for particles with a size smaller than the critical particle size averages 32.5, 50.9, and 51.9% for arc diameters of 25 mm (a_{cr} < 40 μm), 40 mm (a_{cr} < 25 μm), and 50 mm (a_{cr} < 50 μm), respectively (Figure 4). The pressure losses in the separation device were 20.6, 16.3, and 12.6 Pa with the diameters of the elements of 25, 40, and 50 mm, respectively, at an inlet gas velocity of 0.5 m/s.
Fig. 4. The efficiency of the separation device versus the particle size at different diameters of the arc elements, mm: 1 – 25; 2 – 40; 3 – 50. Inlet gas velocity $W = 0.5$ m/s.

The efficiency of the separation device with an inlet gas velocity of 3 m/s and a particle diameter of 10 to 170 μm is on average 80.1, 89.1, and 88.6% with a diameter of 25, 40, and 50 mm, respectively. The critical particle size increases with changing gas velocity at the device inlet from 0.5 to 3 m/s. For example, for elements of 25, 40, and 50 mm in diameter, $a_{cr}$ is 90, 40, and 60 μm, respectively. The efficiency of the separation device is on average 69.1, 61.6, and 73.4% with the diameters of the arc elements of 25 mm ($a_{cr} < 90$ μm), 40 mm ($a_{cr} < 40$ μm), and 50 mm ($a_{cr} < 60$ μm), respectively (Figure 5). The pressure losses in the separation device are 693.1, 612.1, and 413.3 Pa with the sizes of the elements of 25, 40, and 50 mm, respectively, at $W = 3$ m/s.

Fig. 5. The efficiency of the separation device versus the particle size at different diameters of the arc elements, mm: 1 – 25; 2 – 40; 3 – 50. Inlet gas velocity $W = 3$ m/s.
At an inlet gas velocity of 5 m/s and a particle size range of 10 to 170 μm, the separation efficiency averages 82.6, 90.6, and 88.1% with arc diameters 25, 40, and 50 mm, respectively. The critical particle sizes are 130, 90, and 100 μm with the element diameters of 25, 40 and 50 mm, respectively. The efficiency of the separation device averages 77.8, 85.4, and 83.3% for arc diameters 25 mm \( (a_{\text{cr}} < 130 \mu m) \), 40 mm \( (a_{\text{cr}} < 90 \mu m) \), and 50 mm \( (a_{\text{cr}} < 100 \mu m) \), respectively (Figure 6). The pressure drop values of the separation device are 1924.1, 1695.2, and 1360.3 Pa with the diameters of the elements 25, 40, and 50 mm, respectively, at \( W = 5 \) m/s.

![Fig. 6. The efficiency of the separation device versus the particle size at different diameters of the arc elements, mm: 1 – 25; 2 – 40; 3 – 50. Inlet gas velocity \( W = 5 \) m/s.](image)

The analysis of the obtained results shows that the separation device is relevant for the collection of fine particles from gas with a velocity of less than 3 m/s, because its pressure drop is significantly lower than the analogues; for example, cyclones have a pressure loss of more than 1500 Pa. In this case, it is established that the change in the diameter of the arc elements significantly affects the efficiency of particle collection because it allows forming stagnant zones of different sizes characterized by near-zero gas velocities in them, where the particles are settled into the bunker.

**4 Conclusion**

The following conclusions can be drawn from this work:

- 40 mm diameter of the arc elements provides the maximum gas-solid separation efficiency.
- The efficiency of the separation device with the diameters of the arc elements 25, 40, and 50 mm is on average 81.1, 90.1, and 86.5%, respectively, at the inlet gas velocity of 0.5 to 5.0 m/s.
- The pressure loss in the separation device is up to 693.1 Pa when the gas velocity at the inlet to the separator is less than 3 m/s.
- The main advantages of the proposed separation device are ease of manufacture and installation, durability, low cost, and high efficiency.

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