Effect of arc element row arrangement on separator efficiency

Nguyen Vu Linh 1, Dinara Khamitova2*, Maxim Kuznetsov3, and Nailya Dubkova4

1Hanoi University of Industry, Cau Dien street, Bac Tu Liem District 298, Hanoi, Vietnam
2Kazan State Power Engineering University, 420066, Krasnoselskaya street 51, Kazan, Russia
3Kazan State Agrarian University, 420015, Karl Marx street 65, Kazan, Russia
4Kazan National Research Technological University, 420015, Karl Marx street 68, Kazan, Russia

Abstract. Dust emission gas cleaning is a crucial factor for many industries. The paper proposes a separator with the arc-shaped elements to clean dusty gas from solid particles. The study aims to examine how the distance between rows of arc-shaped elements affects separator efficiency and pressure drop, using numerical methods. In simulations, the inlet velocity of the gas flow varied from 0.5 to 5 m/s and the particle size was 10 to 170 μm. It was found that the change in the distance between the rows of the arc elements in the device leads to the formation of different streams. The results show that increasing the distance between the rows of the arc results in a decrease in the separator efficiency, since the particles during separation from the dusty gas due to centrifugal forces fly into the space between the elements, where they are inversed by the flow again. In this case, the pressure drop decreases. The maximum efficiency of particle separation by the developed device (95.4%) is achieved at a distance between rows of arc elements of 0.75. Pressure loss in the separator ranges from 16 to 1862 Pa at an inlet gas velocity of 0.5 to 5 m/s.

1 Introduction

Dust emissions from industrial enterprises have been a pressing problem for many decades. To reduce air pollution, technological processes are being improved, process equipment is sealed, pneumatic transport is applied, and various cleaning equipment is used [1–3]. However, the most effective way to prevent emissions remains the development and implementation of effective gas-solid cleaning systems. Currently, there are a huge number of devices for cleaning gas from dust, differing in design and separation mechanism [4–7]. The most common separators are the dry-type centrifugal devices. The centrifugal force has been found to dominate for particles larger than 1.1 μm [8] or when the particles are larger than the cut size [9].

There are two main performance characteristics of the gas-solid separators: separation efficiency and pressure drop, which are determined by many factors (design, size particle, particle material, regime parameters, etc.). For a newly developed separator, it is extremely important to estimate the performance characteristics taking into account these factors for

* Corresponding author: orhidey-din@mail.ru
determining the best geometric and regime parameters that provide maximum efficiency [10–12]. These tasks can be well-characterized using CFD simulations [13–15].

Cyclones are the most widely used gas-solid separators due to advantages such as no moving parts, reliability, low manufacturing cost, and low maintenance. The authors [16] proposed a new slit-cone cyclone. Using test study and CFD simulation, the influence of different slit locations on separation efficiency was evaluated. They concluded that overall separation efficiency increased on 6.2% for a developed cyclone in comparison with a conventional cyclone design. In the work [17], multi-objective optimization of a slotted vortex finder was proposed to find the best cyclone separator efficiency. The CFD results with the Response Surface Model revealed an optimal geometry shape of the novel vortex finder. Recently, the shape of the effect of the vortex finder (square or cylinder) on the efficiency of a square cyclone separator was studied numerically [18]. The results showed that the use of a cylindrical vortex finder increased the pressure drop and separation efficiency.

A new gas-solid dry-type separator with arc elements is proposed (Figure 1) [19]. Its design is based on a separation grid, consisting of longitudinal and transverse V-shaped plates. The arc elements are inserted to a certain depth into these V-shaped plates. The staggered arrangement of the arc elements allows creating a wave flow pattern of the dusty gas. The separation grid is designed to create channels for particle discharge through the hopper. In addition, they destroy the downflows of the gas, which are subsequently transformed into upflow returning the separated particles back to the main gas stream. In particular, between the transverse V-plates in the lower particles of the grid, there are continuous slots along its entire width. The linear size of slots is up to 5–10 mm. As can be seen, each slot on its right and left sides is formed by the inclined plates (which are components of the V-plates). Thus, the particles entering the space between the V-plates by inertia fall into the hopper. This design minimizes the formation of dead zones and complicates the gas flow trajectory. As a rule, the gas flows along the path of least resistance, so the wave flow pattern is saved. For the same reason, small plates are welded at the beginning and at the end of the grid. As a result, the same slots up to 5–10 mm in size are formed between them and the shell of the separator. However, their disadvantage is the creation of dead zones between the straight plates and the V-plates.

**Fig. 1.** 3D model of separator with arc elements: (1) inlet; (2) separation arc elements; (3) separator shell; (4) separation grid; (5) longitudinal V-plates; (6) transverse V-plates; (7) hopper; (8) outlet (view with local section).
The separation mechanism of particles from the gas flow is as follows. In the case of wave gas flow, centrifugal forces occur, under the action of which particles in the flow fly away towards the arc elements. The relatively small dimensions of the arc elements provide a small radius of gas rotation near them. Thus, at low gas inlet velocities, sufficiently large centrifugal forces are formed in the separator to influence the direction of trajectories of both large and small particles [20–22]. Due to the geometric shape of the arc elements and their staggered arrangement, dead zones appear in the separator during gas movement, which are located inside and directly behind the elements. Thus, particles escaping from the wave pattern of the gas strike the walls of the arc elements. Then they fly away depending on their initial impulse. There are two options here: if the initial impulse of the particles is above the limit value, they bounce off the walls of the arc elements again into the flow, otherwise, they fall into dead zone, which subsequently fall down and pass through the slots of the grid and discharged to the hopper. As there is plurality of gas rotations in the separator, the particles that have been returned to the main stream will likely be captured at a subsequent separation series of arc elements. The purified particulate gas flow exits the separator through the outlet (Figure 1).

The wave pattern of the gas flow is mainly influenced by the distance between the separation arc elements \( l \) (m), which can be calculated as

\[
l = \sqrt{0.75d},
\]

where \( d \) is the diameter of the line that passes through the middle of the wall of the arc elements, m.

The use of Equation (1) makes it possible to neglect the thickness of the arc elements.

The purpose of this work is to perform a numerical study of the effect of the distance between rows of the arc elements on the separator efficiency.

## 2 Methodology

Simulations were performed using Ansys Fluent in 3D formulation. A 3D model of the developed separator with arc elements is shown in Figure 1. The main geometric dimensions of the 3D model: the diameter is 35 mm, the thickness and height of separation arc elements are 2 and 250 mm, respectively, the linear size of the slot between the V-plates and their thickness was 10 and 2 mm, respectively, the number of rows of arc elements is 10 pcs. Three models with different distances and heights of the grid were studied to study the effect of the distance between rows of arc elements on the separator efficiency. The distance between the arc elements was taken as 75, 100, and 125\% of \( l \), which was calculated using Equation (1). When decreasing or increasing the distance between rows of arc elements, it was necessary to lengthen the height of the grid to maintain the linear size of the slot or vice versa – to change the size of the slot and save the height of the grid. In this study, the linear size of the gap remained constant. Thus, with a distance of 0.75\( l \), 1, and 1.25\( l \) between the rows of the arc elements, the height of the grid was 270, 160, and 135 mm, respectively.

In simulations, the inlet velocity of the gas flow varied from 0.5 to 5.0 m/s. The size of the particles dispersed in the gas flow changed from 10 to 170 μm. At the outlet of the separator, the pressure was set equal to atmospheric. The particle density was 7000 kg/m\(^3\). The number of elements in the mesh was 498,623 pieces with an orthogonal quality of 0.15.

The efficiency of the separator with the arc elements is calculated according to the following equation:

\[
E = 1 - \frac{n}{n_0},
\]

where \( n \) is the number of particles trapped by the separator, pcs.; \( n_0 \) is the total number of particles supplied to the separator, pcs.
The pressure loss in the separator can be found using the formula:

$$\Delta p = p_1 - p_2,$$

where $p_1$ is the pressure at the inlet to the separator, Pa; $p_2$ is the pressure at the separator outlet (atmospheric pressure), Pa.

3 Results and discussion

The simulation results showed that the change in the distance between the rows of the arc elements in the devices leads to the formation of different streams, affecting the efficiency of the separator and its pressure drop. Figure 2 shows a distribution of gas flow velocities inside the separator. It can be seen that with a different distance between the rows, the wavy structure is generally retained. However, at each predetermined distance, the location of the emerging vortices and their number vary, resulting in a partial displacement of the wave pattern of the gas stream. So, at a distance of 0.75l, vortices occur mainly in front of the arc elements. Due to the narrow space between the arc elements of the adjacent rows, part of the flow is forced to unfold, forming this swirling. When the distance is equal to l, the main points of vortex formations are located directly behind the arc elements and inside them. When the distance is increased to 1.25l, the location of the vortex points remains the same as in the previous case. In some places, the vortices are more elongated. This is mostly caused by the increased distance between adjacent rows of the arc elements. In all three cases considered, dead zones located in the wall region of the arc elements both inside and directly behind them are saved.

![Fig. 2. Gas velocity field inside the separator (top view): (a) 0.75l; (b) l; (c) 1.25l.](image)

The separator efficiency averaged 95.4, 88.3, and 87.4% with a distance between the rows of the arc elements equal to 0.75l, l, and 1.25l, respectively, with a particle density of 7000 kg/m$^3$ and a particle size of 10–170 μm (Figures 3–5). The decrease in the efficiency of particle separation by the device with an increase in the distance between the rows of the arc elements is due to the fact that some particles, when knocked out of the stream, instead of...
moving to the walls of the elements, are directed into the space between the rows of the elements, where they are inversed by the gas flow again, which also increases with growth of \( l \). In this regard, the probability of over-travel of the particle increases with the growth of \( l \), leading to a decrease in the efficiency. On the other hand, pressure losses in the separator are 18–1862, 16–1591, and 16–1563 Pa under a distance of 0.75\( l \), 1, and 1.25\( l \), respectively, at a gas inlet velocity of 0.5–5 m/s (Figure 6). As can be seen, as the distance \( l \) decreases, the pressure drop of the separator increases. Obviously, this is due to the narrowing of the gas flow passage space. Thus, it is necessary to select the optimal distance between the rows of the arc elements. It has also been found that increasing the inlet velocity of the gas flow results in a slight increase in efficiency and a significant increase in pressure loss in the separator. The most optimal gas inlet velocity for the proposed separator varies from 0.5 to 1 m/s. From Figures 3-5, it can be seen that with a particle size of more than 100 \( \mu m \), the efficiency of the separator efficiency decreases at certain input gas velocities. This is because as the particle size increases, the impulse of the particles increases, which affects the force of their bounce from the walls of the arc elements, leading to the return of the particles to the main gas stream.

With the distance between the rows of separation arc elements equal to 0.75\( l \), the efficiency of the device averaged 92.2, 92.8, 98.1 and 98.5% at an inlet gas velocity of 0.5, 1, 3, and 5 m/s, respectively. At higher velocities, the separation efficiency for fine particles increases. Therefore, with a particle size of up to 20 \( \mu m \), the efficiency at a distance between 0.75\( l \) arc elements of 0.75\( l \) is 59.8, 58.4, 93.6, and 93.6% at a gas velocity of 0.5, 1, 3, and 5 m/s, respectively (Figure 3). When the distance between the rows of separation arc elements is \( l \), the separator efficiency averages 86.9, 87.7, 89.3, and 89.5% at an inlet gas velocity of 0.5, 1, 3, and 5 m/s, respectively. With a particle size of up to 20 \( \mu m \), the efficiency at a distance between rows of arc elements equal to \( l \) is 50.4, 50.1, 62.1, and 62.4% at a gas velocity of 0.5, 1, 3, and 5 m/s, respectively. As previously noted, for larger particles, the separation efficiency of the particles is reduced. Therefore, with an increase in particle size from 100 to 170 \( \mu m \), the efficiency of the device at the distance considered equal to \( l \) decreases in the range of 91.8 to 83.1%, from 97.4 to 89.9%, from 97.7 to 94.9%, and from 97.4 to 95.9% at a gas velocity of 0.5, 1, 3, and 5 m/s, respectively (Figure 4).

![Fig. 3. Separator efficiency versus particle size at different gas inlet velocity \( W \), m/s: (1) 0.5; (2) 1; (3) 3; (4) 5. The distance between the rows of the arc elements is 0.75\( l \).](image1)

![Fig. 4. Separator efficiency versus particle size at different gas inlet velocity \( W \), m/s: (1) 0.5; (2) 1; (3) 3; (4) 5. The distance between the rows of the arc elements is \( l \).](image2)

When the distance between the rows of separation arc elements is equal to 1.25\( l \), the efficiency averaged 84.2, 83.7, 90.5, and 91.3% at an inlet gas velocity of 0.5, 1, 3, and 5 m/s, respectively. As the distance between the rows of arc elements increased, the decrease in
separator efficiency when capturing particles larger than 100 μm occur. Thus, with a particle size ranged from 100 to 170 μm, the efficiency decreased from 95.8 to 74.3%, from 96.1 to 75.3%, from 97.2 to 87.1%, and from 95.4 to 87.8% at a gas velocity of 0.5, 1, 3, and 5 m/s, respectively (Figure 5).

The pressure losses in the separator with the arc elements are 18 Pa at $W = 0.5$ m/s, 72 Pa at $W = 1$ m/s, 647 Pa at $W = 3$ m/s, and 1816 Pa at $W = 5$ m/s with a row arrangement of 0.75l, 16 Pa at $W = 0.5$ m/s, 63 Pa at $W = 1$ m/s, 572 Pa at $W = 3$ m/s, and 1591 Pa at $W = 5$ m/s with a distance between rows equal to l, and 16 Pa at $W = 0.5$ m/s, 62 Pa at $W = 1$ m/s, 564 Pa at $W = 3$ m/s, and 1563 Pa at $W = 5$ m/s with the distance between rows of 1.25l (Figure 6).

![Fig. 5. Separator efficiency versus particle size at different inlet gas velocity $W$, m/s: (1) 0.5; (2) 1; (3) 3; (4) 5. The distance between the rows of the arc elements 1.25l.](image1)

![Fig. 6. Pressure loss in the separator versus inlet gas velocity at different distances between the rows of the arc elements: (1) 0.75l; (2) l; (3) 1.25l.](image2)

Thus, a change in the distance between the rows of the arc elements affects the structure of the wave flow in the developed separator, however, in general, it remains. In turn, a small change in the flow pattern leads, on the one hand, to an increase in separation efficiency, on the other, to an increase in the pressure drop or vice versa. The high efficiency of the separator at low inlet velocities allows it to be used in various industries.

### 4 Conclusion

The simulation results can be summarized as follows:

- Increasing the distance between the rows of arc elements leads to a decrease in the efficiency of the developed device, since the particles during separation from the dusty gas due to centrifugal forces fly into the space between the elements, where they are inversed by the flow again.
- Reduction of distance between rows of arc elements results in an increase of pressure loss.
- Maximum particle separation efficiency of 95.4% is achieved at a distance between rows of arc elements of 0.75l for a particle density of 7000 kg/m$^3$.
- Pressure losses in the separator range from 16 to 1862 Pa at an inlet gas velocity of 0.5 to 5 m/s.
References

5. V. Zinurov, V. Kharkov, E. Pankratov, and A. Dmitriev, International Journal of Engineering and Technology Innovation 12, 336 (2022)
7. V. E. Zinurov, V. V. Kharkov, and I. N. Madyshev, Mining Informational and Analytical Bulletin 173 (2022)
18. H. Abd Chaghakaboodi and M. Saidi, Chemical Engineering Research and Design 194, 621 (2023)