Pressure Drop and Particle Collection Efficiency of Multivortex Separator

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Abstract. The purification of gas emissions from dispersed particles is presently one of the mandatory measures to protect the air basin for most industrial enterprises. The authors developed a device for gas cleaning with separation elements in the form of a profile with rectangular vertical slots. Such a design creates numerous small vortices, which leads to an increase in collection efficiency. The paper aims to numerically determine the effect of the design and operating conditions on the particle deposition efficiency and the pressure drop of the multivortex separator. The height of the rectangular slots varied from 55 to 94 mm. In addition, the size of the dispersed particles changed from 1 to 15 μm in diameter. The results show that a decrease of resistance coefficient is observed with an increase in the height of the rectangular slot in the separation element. The results indicate that separation elements should be designed with a small height of rectangular slots and located in the lower part to collect fine particles in the multivortex separator efficiently.

1. Introduction

Environmental protection from industrial gas emissions is currently one of the crucial issues all over the world. The increasing volume of gas emissions from different industrial enterprises coupled with new climate rhetoric leads to stricter requirements for the efficiency of gas cleaning from particles smaller than ten microns, which negatively affects human health [1–4]. Furthermore, the small size of particles excludes or limits traditional separation methods – gravitational, inertial, and electrostatic [5,6]. Therefore, developing high-efficiency devices for cleaning gas emissions from particulate matter is an urgent task [7–10].

Centrifugal separators [11–14] are advanced types of gas cleaning equipment in the industry. However, these separators are complex in design, have high pressure losses, and have low separation efficiency for fine particles (less than ten microns). To address this problem, the authors have developed a multivortex separator [15]. The design of the multivortex separator provides the formation of numerous small vortices, which leads to an increase in the collection efficiency.
Multivortex separator includes a rectangular case 1, a mounting base 2, and a removable cover 3 (Figure 1). The base has an even number, but not less than four square holes of L side for contaminated gas input, arranged in rows and equidistant from each other and the case by a distance equal to L/4. There are separation elements 4 rigidly fixed along the perimeter of each square hole. Each separation element represents a profile with perforation as rectangular vertical slots 5. In addition, two opposite walls of the profile have two rectangular slots of L/4 width located at a distance of L/8 from each corner; and the other two walls have one slot with a width of L/4 located in the middle and two slots of L/8 width in each corner (Figure 2). The height of slots 5 is determined by the condition that the total area of all slots should be equal to the total area of the square holes in the base, which leads to a decrease in the pressure drop of the device. The separation elements are arranged on the base to rotate each element 90 degrees relative to the adjacent one. Circular holes 6 for removing purified gas are uniformly arranged in the cover above spaces formed between the separation elements 4 and between the case 1 and the separation elements 4.

![Figure 1. Multivortex separator for gas cleaning: 1 – case; 2 – mounting base; 3 – removable cover; 4 – separation elements; 5 – rectangular slot; 6 – holes.](image_url)

The multivortex separator to clean the contaminated gas operates as follows. First, the contaminated gas enters the inner space of the separation elements through the square holes of the base 2. After reaching the cover 3, it changes the straight flow direction. Then gas flows through the rectangular vertical slots 5 into the spaces formed between the separation elements 4 and between case 1 and the separation elements 4. The gas flow, passing through the slots of L/4 width, breaks down into two equal parts, which are converted into vortices with a diameter of L/4. The direction of rotation for vortices is opposite to each other (Figure 2). The gas flow, passing through slots of L/8 width, converts into a single vortex with a diameter of L/4 and the direction of rotation opposite the adjacent vortices. Thus, a regular pattern of oppositely directed vortices of equal diameter is formed around each separation element. The regular vortex structure between the separation elements is maintained since the size and rotating direction of the vortices formed by the slots on the opposite walls completely coincide. With such a gas flow pattern, dispersed particles are centrifugally displaced from the center to the periphery of the vortex structures. Particles are collected on the inner surface of case 1 and the outer walls of the separation elements 4. Purified gas flows mainly in the axial zone of vortex structures from base 2 to cover 3 and discharges through outlet holes 6. When a dense layer of separated dispersed particles accumulates on the inner surface of case 1 and the outer walls of the separation elements 4, cover 3 is removed, and the separator is cleaned mechanically.

Studies of the dynamics of particle motion in the swirled gas flow are necessary to evaluate the pressure drop and the collection efficiency of the multivortex separator. It is also essential to
determine the effect of the design and operating conditions on the particle deposition efficiency and the pressure drop of the developed separator. The work aims to numerically find the resistance coefficient and the collection efficiency of dispersed particles from gas in the multivortex separator.

**Figure 2.** Vortex flow formation in the multivortex separator (cross-sectional view): $L$ is the width of the separation elements; "plus" sign is clockwise rotating vortex; "minus" sign is counterclockwise rotating vortex.

### 2. Study objects and methods

This paper studied the multivortex separator 140 mm in height with four 80x80 mm square separation elements. The width of the slot in the middle of the separation elements was taken as 20 mm, whereas the slots' width in the corners was 10 mm. Thus, the height of the rectangular slots varied from 55 to 94 mm. The average gas velocity at the inlet of the separation elements was set to 5, 7, and 10 m/s.

Simulation of the deposition process of dispersed particles with a density of 1000 kg/m$^3$ in the air at 20°C was performed using the ANSYS Fluent software complex. Based on previous studies [16,17], the SST k-ω turbulence model was used, showing satisfactory convergence with experimental data. In addition, it was assumed that dispersed particles, contacting the walls of the separation elements and the separator case, immediately adhere to them. For example, there are similar operating conditions in separators when droplets, small particles, and other aerosols are deposited on the wetted surfaces of their elements [18,19].

The modified Darcy-Weisbach equation [20] was used to determine the resistance coefficient of the multivortex separator based on the pressure loss measurement:

$$\Delta p = \zeta \frac{H \rho_G W_0^2}{b} \frac{2}{2}$$

where $\Delta p$ is the pressure drop between the inlet and the outlet of multivortex separator, Pa; $\zeta$ is the resistance coefficient; $H$ is the height of the separator, m; $\rho_G$ is the gas density, kg/m$^3$; $W_0$ is the actual gas velocity, m/s. $b$ is the width of the separation element, m;

According to the equal flow condition for the separator, the actual gas velocity in the slots of the separation elements is equal to the average gas velocity at the inlet to the device. Then, the resistance coefficient of the multivortex separator can be expressed as:

$$\zeta = 2 \frac{\Delta p}{\rho_G W_{bs}^2} \frac{b}{H}$$
The collection efficiency can be estimated by the deposition efficiency of dispersed particles of various sizes on the wall surfaces of all separation elements and the case of the multivortex separator from the following formula:

\[
E = 1 - \frac{n}{N}
\]  

(3)

where \( n \) is the number of particles at the outlet of the multivortex separator; \( N \) is the number of particles at the inlet of the separator.

In research, the size of the dispersed particles, specifically spherical droplets, changed from 1 to 15 \( \mu \)m in diameter. The average gas velocity at the inlet to the separation elements was assumed to be 5 m/s. The number of particles was 1000, uniformly distributed along the inlet section of the separation element.

3. Results and discussion

Figure 3 shows the dependence of the pressure drop of the multi-vortex separator on the average gas velocity at the inlet of the device under changes of the rectangular slot height in the separation element. It can be seen that a decrease of resistance is observed with an increase in the slot height. For example, changing the height of rectangular slots from 0.055 to 0.075 m results in a decrease in pressure loss by 11.9–12.4%.

![Figure 3. Pressure drop vs. average gas velocity for different height of rectangular slots \( h_{sl} \), m: 1 – 0.055; 2 – 0.075; 3 – 0.094.](image)

Figure 4 indicates that the height of the rectangular slots in the separation element and the overall height of the separator, respectively, should be increased to reduce the resistance coefficient. At the same time, when the ratio of the width of the separation element to the height of the separator \( b/H \) equals 0.57, the resistance coefficient can be reduced by 17.4%, increasing the height of the rectangular slots from 0.055 to 0.094 m. It is worth noting that the values of resistance coefficient at \( b/H = 0.5 \) and 0.65 were obtained under the assumption of an insignificant change in the dynamics of the vortex flow in the separator with the height from 0.123 to 0.160 m.
As seen from Figure 5, the maximum efficiency of deposition for dispersed particles in the developed multivortex separator is observed at the lowest height of rectangular slots equal to 0.055 m. That's mainly because of the higher values of tangential velocity and the presence of an additional area for the deposition of dispersed particles. Therefore, it is preferable to make slots mainly in the lower part of separation elements to increase efficiency, making it possible to leave a significant separation zone in the upper part of the device to separate dispersed particles from the carrier gas flow. Thus, this design increases the collection efficiency of dispersed particles of 7 μm diameter by 19.4%.
4. Conclusion
The research results have shown that the collection efficiency of the multivortex separator for cleaning gas from dispersed particles depends significantly on the design of the separation elements and the particle size. The main conclusions obtained in this study may be summarized as follows:

- the height of rectangular slots in the separation element and the full height of the multivortex separator should be increased to reduce the resistance coefficient. For example, it can be reduced by 17.4% by increasing the height of rectangular slots from 0.055 m to 0.094 m.
- cutting slots mainly in the lower part of separation elements is preferable to increase the deposition efficiency. In particular, for dispersed particles with a size of 7 μm with the height of rectangular slots of 0.055 mm, the efficiency surged by 19.4%.

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