# Catching fine-dispersed particles in rectangular separator depending on different process parameters

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**Abstract.** We have considered the pressing issue of increasing the efficiency of catching fine solid particles from process gas flows in industrial enterprises. A developed rectangular separator allows collecting fine-dispersed particles of 1–10 μm in diameter from gas flows. It was found that the efficiency of the separator is not less than 99% at the gas flow rate of more than 10 m/s at particle density of 1000 kg/m$^3$. We have investigated the effect of the gas flow velocity and the fine particle size on the collection efficiency and pressure drop in the device. Using the separator as a second cleaning stage, placed in series with the coarse cleaning apparatus, can prevent re-entrainment of valuable material into the atmosphere.

## 1. Introduction

At present, hardening the requirements of sanitary standards for air purity near electric power stations, boiler-house plant and other enterprises leads to the need for modernization of existing gas cleaning systems. The relevance of this problem increases from year to year since the growth of industrial enterprises using solid fuel involves an increase in the share of low-grade coal, produced by the most economical way (open-cut mining). In this way, the combustion of low-grade fuel increases the total amount of ash and coal dust to be cleaned, which presents a considerable challenge to solve environmental problems. Moreover, the cleaning process of gas emissions from solid particles has a significant complication in the decrease of the dispersion degree of ash and coal particles [1–5].

The most common devices used for catching dust particles from process gases are cyclones and ash traps of different types [6–11]. These devices allow collecting solid particles of size 10–50 μm from gases with high efficiency (> 99%), depending on the device modification. The crucial trouble with the devices mentioned above is the low efficiency of catching fine-dispersed particles less than 10 μm in size from the process flows. Various types of electric and bag filters are used to improve the collection efficiency of dry materials, which are capable of catching dust particles with a size of less than 1 μm. However, replacing obsolete ash collectors with new types of electric or bag filters is not always practically possible and economically feasible. Thus, for industrial enterprises, the urgent problem is to intensify the catching process of fine-dispersed particles from gas. It is worth noting that an increase in the cleaning degree of gases from coal dust is required not only to satisfy sanitary standards of gas emissions. This fact increases the operating economy of boiler plants due to the reuse of collected material. Moreover, engineering solution for intensification of catching particles from gas requires the following factors: compact size, ease of fabrication and maintenance, catching of dry ash and dust, and low capital and operating costs [12].

The solution to the problem is a rectangular separator developed by the authors (figure 1). The device has a compact rectangular body with several rows of elements connected by transverse plates. The sizes of the rectangular separator are selected depending on the configuration of the duct, wherein the dust flow moves. Earlier studies have shown that the collection efficiency of fine particles with a size of 1–10 μm from dust flow using the rectangular separator is above 50%, as for particles with 10 μm in size efficiency is more than 99% [13–16].

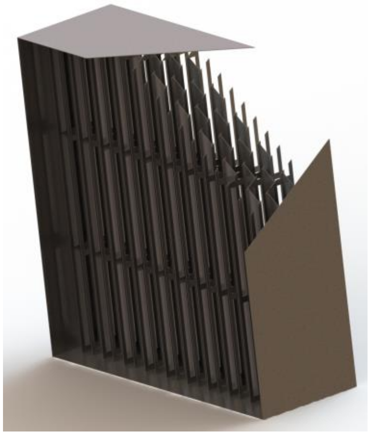

**Figure 1.** A three-dimensional model of the rectangular separator with double-T-shaped elements.

It is proposed to integrate the developed rectangular separator into the process cleaning system of gas flows immediately after the cyclone, ash collector, or other coarse-cleaning apparatus. Thence, the technology of gas cleaning includes two successive stages. Firstly, coarse-cleaning devices (cyclones, ash collectors, and others) are used to separate dispersed particles of large- and moderate sizes from gases. At the second stage utilizing the rectangular separator, the smallest particles from gases are captured.

Catching of dust particles in the rectangular separator is mainly associated with centrifugal forces effect. During the flow of dust-laden gas between the separator elements arise a plurality of centrifugal force points affecting the flow pattern. As a consequence, solid particles are beaten out of the structured flow and adhere to the element surfaces, which mostly caused by electrostatic and intermolecular forces.

In time the rectangular separator device is filled with dust, so it requires proper disassembly and restoration at specified intervals determined by the process parameters, for example, productivity.

## 2. Study objects and methods

An essential task in the design of most devices is to determine the best efficient process parameters. Therefore, the work objective is to investigate the effect of various process parameters on the efficiency of the rectangular separator.

Three types of elements of 14 mm length were given in the work: double-T-, arc- and П-shaped. In order to increase the separation efficiency of fine-dispersed particles in a gas, rows of elements relative to one other are arranged so that the peak value of centrifugal force occurs. For this purpose, the following condition must be fulfilled: the circle with the center of the web for the double-T-shaped element must pass through the webs of adjacent rows of the elements. The gas flow velocity $W$ at the inlet of the device ranged from 3 to 25 m/s. Atmospheric pressure is equal to $10^5$ Pa. A certain number of particles $n$ = 1000 was specified at the inlet of the device to evaluate the efficiency of catching fine particles from gas. After each calculation, the number of particles $n_k$ remaining in gas after the cleaning was constant at the device outlet. Therefore, the efficiency of the rectangular separator was calculated in terms of the number of particles in gas before and after the cleaning processes by the following equation:

$$E = 1 - \frac{n_k}{n}, \qquad (1)$$

In the course of the calculations, the following parameters were variables: the diameter of particles $a$ changed in the range of 1–4 μm and the particle density $\rho_a$ – in the range from 1000 to 2000 kg/m$^3$.

The hydraulic resistance factor of the rectangular separator was expressed as:

$$\xi = \frac{2\Delta p}{\rho W_h^2}, \tag{2}$$

where $\Delta p$ is a pressure drop in the rectangular separator, Pa; $\rho$ is gas flow density, kg/m$^3$; $W_h$ is the velocity in the contraction between the separator elements, m/s.

The velocity of the gas flow in the contraction between the separator elements obtained from the inseparability equation is given by

$$W_h = \frac{FW}{F_h n_h}, \tag{3}$$

where $F$ is the inlet cross-sectional area of the rectangular separator, m$^2$; $F_h$ is the cross-sectional area of the contraction between the separator elements, m$^2$; $n_h$ is a number of contractions in one row of the elements.

The study was performed by numerical simulation using the ANSYS Fluent software package. We simplify the task by replacing the three-dimensional model of the device with a two-dimensional one. This assumption of transition from the 3D to the 2D model can be justified by the fact that the shape of the separation elements does not change in height. It should be noted that transverse plates serving as construction strengthening installed at the top and bottom parts of the rectangular separator were not taken into account in the calculations of 2D models. The reason is that they do not affect the operation principle of the device, and their influence on the hydraulic resistance of the device is small [16–18].

## 3. Results and discussion

The results of the numerical experiments are presented graphically in figures 2–4. The separator was demonstrated to have several operating regimes, which significantly affect the hydraulic resistance of the device and the efficiency of catching fine particles. Different regimes are determined by gas flow structure, changed with the increasing number of vortex points, and the vortices size, which is associated with the rise in the gas flow velocity at the inlet. It should be noted that, in some cases, the collection efficiency of fine-dispersed particles in gas does not depend on the operating conditions of the rectangular separator. For example, with a relatively low particle density $\rho_a = 1000$ kg/m$^3$, the change in the regime does not reduce the separation efficiency of these particles from gases (figure 3). However, at a particle density of 2000 kg/m$^3$, a change in the operating regime of the separator leads to a decrease in the efficiency of catching fine particles (figure 4). It has also been found that the use of arc-shaped elements in the rectangular separator is energy-saving (figure 2), whereas the double-T-shaped elements are the most effective measure for catching fine particles (figures 1–4).

An analysis of the obtained data revealed three distinct operation regimes of the rectangular separator. The first regime corresponds to the gas flow velocity up to 10 m/s, the second “transient” regime – from 10 to 15 m/s, and the third regime – more than 15 m/s. The hydraulic resistance of the rectangular separator also depends on the shape of elements (double-T-, arc- or П-). In the first operation regime of the device at a gas velocity of less than 10 m/s, the hydraulic resistance of the device is on average 14.1, 15.3, and 16.7 when using arc-, double-T- and П-shaped elements, respectively. When the gas flow velocity exceeds 15 m/s (third operation regime), the hydraulic resistance of the device is, on average, 22.9, 23.8, and 25.1 for arc-, double-T- and П-shaped elements, respectively. The difference between the first and third operating regimes averages about 36%. Thus, the least energy-consuming type of elements is arc-shaped with gas velocity no more than 10 m/s at the inlet (figure 2).

The efficiency of catching fine-dispersed particles with a density $\rho_a = 1000$ kg/m$^3$ increases as the inlet gas velocity becomes large. At a gas flow rate of up to 15 m/s, the average separator efficiency is 75.1, 73.3, and 70.5% obtained for-double-T-, arc- and П-shaped elements, respectively. As regards gas with the flow velocity over 15 m/s, the separation efficiency of fine-dispersed particles in the rectangular separator is more than 99% when using any shape of the elements discussed above (figure 3).

Further, the density of fine particles is increased to 2000 kg/m$^3$. In this case, the efficiency of the rectangular separator rises to 19.7, 19.6 and 20.2% at a gas flow rate of up to 15 m/s for double-T-, arc- and П-shaped elements, respectively, in comparison with catching particles with the density $\rho_a$ = 1000 kg/m$^3$. The increase in separation efficiency is due to doubling the density of fine-dispersed particles, which is associated with a fall in the probability of particles re-entrainment when they are beaten centrifugally out of the structured flow. Separation efficiency for fine-dispersed particles in the gas with velocity up to 10 m/s is 94.8, 92.9, and 90.7 using double-T-, arc- and П-shaped elements, respectively. With the gas flow velocity of more than 15 m/s, device efficiency is 63.1, 60.3, and 58.1% for double-T-, arc- and П-shaped elements, respectively (figure 4).

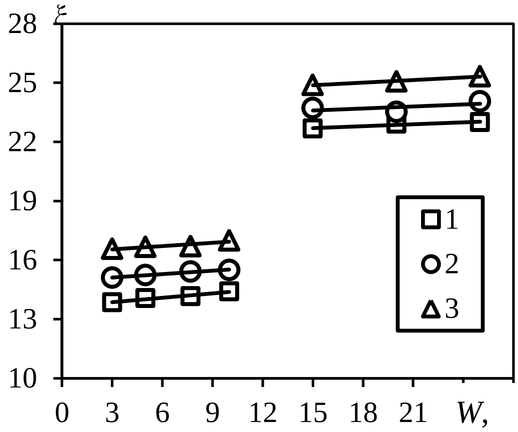


**Figure 2.** Relationship between hydraulic resistance coefficient and inlet gas flow velocity at different types of elements: 1 – arc-shaped; 2 – double-T-shaped; 3 – П-shaped.

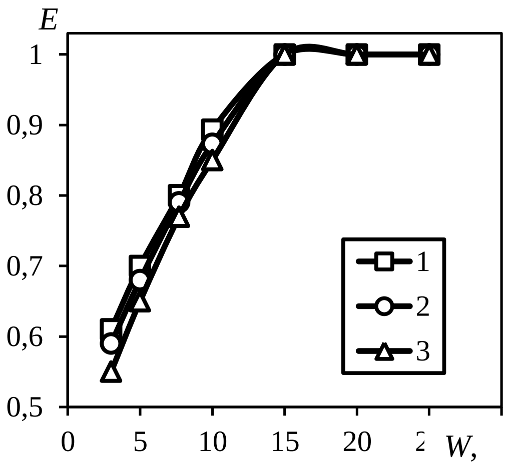


**Figure 3.** Catching efficiency of fine-dispersed particles from gas at different types of elements: 1 – double-T-shaped; 2 – arc-shaped; 3 – П-shaped. The density of fine particles $\rho_a$ = 1000 kg/m$^3$.

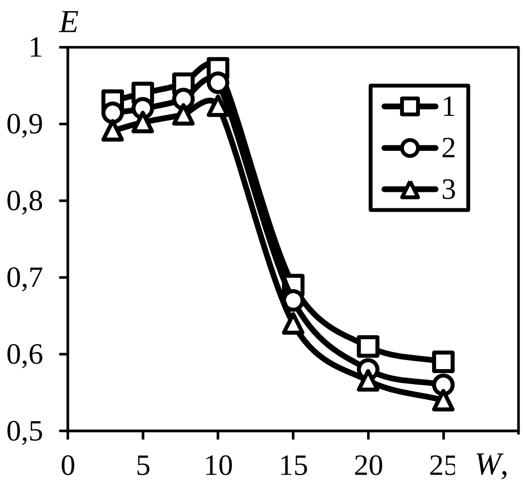


**Figure 4.** Catching efficiency of fine-dispersed particles from gas at different types of elements: 1 – double-T-shaped; 2 – arc-shaped; 3 – П-shaped. The density of fine particles $\rho_a$ = 2000 kg/m$^3$.

The increase in the density of particles in the gas to 2000 kg/m$^3$ results in a steady-state effect on the efficiency of the rectangular separator. As the density of the fine-dispersed particles and the gas flow velocity increase, their momentum raising too, eventually, a skip of particles between rows of separator elements occurs.

In the course of the study, it has been found that detailed information on the material (particle density $\rho_a$, particle diameter $a$) required for increasing the efficiency of the rectangular separator. Three operation regimes of the separator depending on the gas flow velocity, which affects the efficiency of catching fine-dispersed particles in accordance with their density. In was found that the most effective velocities of the gas flow for catching fine particles are less than 10 m/s since these values correspond to the first operation regime of the separator, and hence its hydraulic resistance is minimal. In the case of catching particles with a relatively low density, for example, $\rho_a$ = 1000 kg/m$^3$, it is recommended adding several rows of elements to the separator, which increases the device efficiency at gas flow velocities up to 10 m/s. As at velocities above 15 m/s, the hydraulic resistance of the separator increases by 36% on average, which is a much larger value compared to the additional one or two rows of elements.

The advantages of the developed design of the rectangular separator are high efficiency of catching fine-dispersed particles from gas, easy to use, maintainability, and low cost.

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