Evaluation of the efficiency of rectangular separators to collect the particles from the gas flows

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Abstract. Analysis of the separation devices’ operation and improvement of efficient gas mixture purification processes is relevant issue and is a great interest for the specialists of different industrial branches. Modernization of internal devices in the cases of existing separators is the main goal in the field of increasing the efficiency of fine dispersed particles’ collection process. Design of a rectangular separator with a number of I-beams has been developed. Operation principle of the device is described. When the multiphase flow moves between the device elements, the centrifugal force appears, that ensures the coagulation of finely dispersed liquid drops, facilitating their uniform settling on the entire surface of I-beams. The advantage of these separators is noted. High values of centrifugal force are achieved at relatively low gas flow rates that allows to carry out the separation processes at low energy costs. Numerical study of the gas mixture flow through the rectangular separator is shown at different values of the flow rate and different diameter of particles. The results of separation efficiency are shown for different designs of I-beams. Increase in the rate leads to efficiency increase. Ranges of efficient operation of the separator have been determined. Studies showed the advisability of using the rectangular separators to purify the gases from finely dispersed particles.

1. Introduction
The main share of electricity in the Russian Federation is generated by thermal power plants. Combustion of a large amount of fossil fuels leads to pollution of atmosphere with toxic substances. The amount of emissions of harmful substances is usually determined by the type of the fuel used and the combustion process efficiency [1–5].

Devices for purification of gases from solid and liquid impurities play an important role when equipping the power, chemical, petrochemical plants with process devices. Nowadays, liquid impurities are collected by means of different devices at the enterprises, equipped with gas treatment facilities. As a result, the gas purification process becomes complicated and cost intensive, while over 60% of the costs is accounted for desulphurization. In recent years, a number of countries (Japan, USA, Germany, Russia, Poland, etc.) are developing the new methods and devices, designed for simultaneous purification of flue gases from several pollutions. New technologies are more compact and less cost intensive [6–11]. A number of scientific papers have been published regarding gas purification [12–19], as well as some experience in solving the complex issues to increase the energy & resource process...
efficiency has been accumulated. At the same time, the issue of designing the new gas purification devices and improving their efficiency is still relevant.

2. Methods of studies
Purpose of this paper is to study the process of purification of flue gases from liquid impurities by means of the developed separator [20]. Since there is a significant release of combustion products into the environment as a result of intensive operation process of power plants, it can be said that the current measures are not so effective, but cost-intensive. We propose to emit the flue gases evenly through the separation columns, for complex purification of them. In order to calculate the rate of flow and collecting the particles in rectangular separators, the finite-element method in ANSYS Fluent software program was applied.

![Analytical model of device.](image)

The separator consists of several rows of I-beams, arranged in a rectangular case (Figure 1). In order to ensure a minimum deflection, the beams are connected with each other by means of two transverse plates, which are height wise fixed to the case of device. The operation principle of device is the following: when a multiphase flow moves between the device elements, the centrifugal force appears, which provides coagulation of particles, contributing to their uniform settling on the entire surface of I-beams. Availability of several rows of I-beams increases the efficiency of collecting the fine dispersed particles due to a more structured gas flow. In order to ensure the flow in the device, and hence the minimum hydraulic resistance, the subsequent row of I-beams shall be located from the previous one at a distance equal to 52–60% of the length of I-beam [21].

In order to carry out the numerical studies, 3D model of device with a width of 60 mm, a length of 70 mm and a height of 20 mm was created. Width of elements was b = 10 mm, height of elements – 4 mm, width of gaps – 3 mm (Figure 1). The boundary conditions were the following: rate at the inlet of device, Win and pressure at the outlet of device, the medium was – air at a temperature of 20°C. Diameter of drops varied in the range of d = 1–10 µm, the initial rate of the drops was 0 m/s. Drops were located at the inlet of device. Since the diameter of drops was small enough, in order to simplify the calculations and reduce the time for carrying out of them, it was decided to ignore the gravity. When the drop came into contact with any device surface, it was considered as settled.

Operation efficiency of device was determined by the following formula:

\[ E = 1 - \frac{n_1}{n_0}, \]

where \( n_0 \) – number of particles at the inlet of device, \( n_1 \) – number of particles at the outlet of device.

3. Results of studies and discussion of them
As a result of studies, it was found that an increase in the flow rate leads to an increase in purification efficiency. This is due to the growth of centrifugal force. Slight impact of the gas flow rate on the particles with a size of 1 µm is probably explained by low inertia of them (Figure 2).
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Figure 2. Dependency of efficiency of E on diameter of particles d (a) Wm, m/s: 1 – 1, 2 – 5, 3 – 10, 4 – 15 and average gas flow rate Wm (b) d, µm: 1 – 1, 2 – 3, 3 – 5, 4 – 10, b = 10 mm.

Width of elements has insignificant impact on efficiency of device. As the width is increased, the efficiency slightly decreases. For example, when particles with a diameter of 3 µm settle on the elements with a width of 10 mm, the efficiency varies in the range of 0.88 to 1; as well as on elements with a width of 20 mm – range of 0.97 to 0.99; on elements with a width of 40 mm – range of 0.85 to 0.96 (Figure 3).

Figure 3. Dependency of efficiency of E on average gas flow rate $W_m$, b = 20 mm, d, µm: 1 – 1, 2 – 3, 3 – 5, 4 – 10.

It was found that particles with a diameter of 1 µm settle with an efficiency of about 42%. Rate has quite insignificant impact. Particles with a diameter of 9 µm begin to settle on the surface of elements with an efficiency close to 100% at rate of 2–3 m/s (Figure 4).

Figure 4. Dependency of efficiency of E of one row of device on diameter of particles d. Settled particles – polyurethane, b = 10 mm, $W_m$, m/s: 1 – 0.1, 2 – 1, 3 – 5, 4 – 10.

4. Conclusion

Thus, the advantages of the developed device are simple manufacturing design, low metal consumption, while providing the required stiffness of the load-bearing elements. High values of centrifugal forces near I-beams in the proposed device for the fine dust/gas purification lead to an increase in the overall efficiency of collecting the solid dispersed particles.
Higher values of centrifugal forces at relatively low rates of heterophase medium are created in a rectangular separator. This is due to the fact that at the same width of separators, the average radius of curvature of the circulating currents of I-beams, having concavity on both sides, is less almost by 2 times, that leads to a significant change in the gas flow structure and an increase in the centrifugal force. This means that settling efficiency of medium- and fine dispersed particles by the separators, designed in the form of I-beams, is higher when other operation conditions are equal.

As a result of studies, the following conclusion can be drawn: the devices are operating with sufficient efficiency and can be used for pre-collecting the fine dispersed particles prior to the fine purification filters.

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