

PAPER • OPEN ACCESS

Intensification of gas flow purification from finely dispersed particles by means of rectangular separator

To cite this article: A V Dmitriev *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **451** 012211

View the [article online](#) for updates and enhancements.



IOP | ebooksTM

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Intensification of gas flow purification from finely dispersed particles by means of rectangular separator

A V Dmitriev¹, V E Zinurov¹, O S Dmitrieva²

¹Department of Theoretical Bases of Heat Engineering, Kazan State Power Engineering University, 51, Krasnoselskaya Str., Kazan, 420066, Russia

²Department of Food Production Equipment, Kazan National Research Technological University, 68, Karl Marx Str., Kazan 420015, Russia

E-mail: ieremiada@gmail.com

Abstract. The article considers the issues of gas flow purification from solid particles of small diameters 1-10 μm . The comparison of the efficiency of collecting the finely dispersed particles by rectangular separator and cyclonic separator CN-11 was conducted. The design of a rectangular separator and results of the finely dispersed particles settling on the I-beams of device were introduced. It was shown that different arrangement of I-shaped elements in the device and ratios between them have a significant impact on efficiency of collecting the finely dispersed particles of small diameters. The study of collecting the finely dispersed particles was conducted by means of the software package ANSYS Fluent. The numerical simulation was conducted by solving differential equations of motion and continuity. The turbulence model – SST was used in order to close the system of equations. Here we can find the results of computer simulation and impact analysis of dimensions of the I-shaped elements' projections on the separator's efficiency. The maximum efficiency of separator is achieved when the ratio of the I-beam projection towards its length is equal to 0.2428. The use of a rectangular separator provides an increase in the specific surface area of the contact of phases with a simultaneous decrease in hydraulic resistance against the gas flow.

1. Introduction

Industrial growth leads to the toughening of requirements and rules, applicable to the gas purification after technological processes at the enterprises from the contained components, such as combustion products, ash, slag etc., which have harmful impact on the airshed of enterprise and nearby settlements. Increasingly at risk are the employees of enterprises, at which the technological processes are directly conducted, entailing air pollution. In order to solve this problem, different purifying devices, allowing to solve these problems effectively enough, are used in petrochemical, energy etc. industries. The most popular and reliable purifying devices are inertial dust collectors [1,2]. Among them the most widely used are cyclonic separators, characterized by a relatively high purification degree, simplicity of design and maintainability, reliable operation at high temperatures of up to 500°C. The main disadvantages of cyclonic separators are low efficiency of collecting the finely dispersed particles of up to 10-20 μm , depending on the design of cyclonic separator and high hydraulic resistance reaching 1250-1500 Pa [3-6].

Sometimes, in order to improve the operation quality of cyclonic separators, the battery cyclonic separators are used, consisting of several parallel-connected cyclonic elements in a single case.



However, such design of cyclonic separators increases the overall dimensions, specific consumption of metal and cost of these devices [7-9].

Therefore, this work, aiming at development of new purifying devices with low hydraulic resistance and high efficiency of gas flows purification from finely dispersed particles of small diameters in different industrial processes, is a relevant objective [10,11].

This work includes the results of numerical study of the gas purification processes from finely dispersed particles by rectangular separator.

2. Statement of a problem

Study of the gas flow purification processes from finely dispersed particles is associated with numerous difficulties. Very often it is impossible to determine the geometric dependencies between the elements of device in order to improve its efficiency and reduce hydraulic resistance. In some cases, we have contradicting results, showing the hydraulic resistance decrease, but they also lead to the efficiency decrease of device or vice versa [12,13].

In order to obtain the dependencies, allowing to calculate the proposed rectangular separator, to identify the optimal design ratios and to compare with the efficiency of cyclonic separator, the calculated analysis of the gas flow separation from finely dispersed particles of less than 10 μm, with a cross flow of I-beams in rectangular separator, was conducted (figure 1) [14].

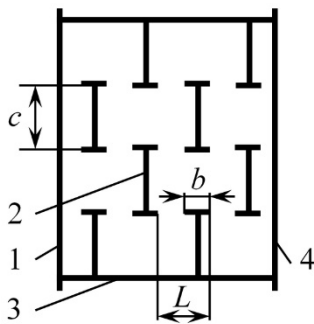


Figure 1. Rectangular separator (top view): 1 – inlet nipple, connecting the piping with rectangular separator; 2 – I-shaped element in rectangular separator; 3 – case of rectangular separator; 4 – outlet nipple from rectangular separator.

The studied device has a rectangular shape with height of 192 mm, width of 104 mm and length of 90 mm. Inside of the device there are 5 rows of I-beams and each of them has a length of $c = 13$ mm, thickness of $\delta = 0.5$ mm. In order to ensure minimum deflection, the I-beams are interconnected by 2 transverse plates, which are fixed height wise and are connected to the case of device. There are additional projections of b , mm long at the ends of I-beams. Distance between the rows of I-beams was taken of L , mm. The main goal of this work is to determine the optimal values between the parameters c , b and L in order to reduce the hydraulic resistance and improve the efficiency of the rectangular separator (figure 1).

The initial temperature of the environment under study was taken of 20°C, ambient pressure of 10^5 Pa, the volumetric gas flow rate was ranged from 0.05-0.444 m³/sec.

During the studies, an air, containing $n = 1000$ of particles with density of $\rho = 1075$ kg/m³ was taken as the working body, while the diameter of particles was ranged from $a = 1-10$ μm.

An operation principle of the device lies in the fact that the centrifugal force appears when the multiphase flow moving between the device elements and throws the dust particles to the beams, causing them to fall out of the flow. Different length of the I-shaped elements c and the length of their projections b have significant impact on this process. In order to find the optimal ratio between the lengths of I-beams and their projections, the dimensionless coefficient k was introduced, determined by the formula:

$$k = b/c \tag{1}$$

where b – length of the I-shaped elements, m; c – width of the I-shaped elements, m.

Availability of several rows of I-beams increases the efficiency of the gas flow purification from polydispersed particles due to more structural gas flow due to the centrifugal force occurrence between I-beams. In order to ensure the maximum value of centrifugal force, the following condition shall be met: a circle, drawn from the center of the I-beam shall pass through the extreme points of projections of I-shaped elements of adjacent rows. In other words, the distance between adjacent rows of I-shaped elements L , which depends on the dimensionless coefficient k , can be determined by the formula:

$$L = c(k + 1)/2 \tag{2}$$

3. The study of collecting the finely dispersed particles by rectangular separator

Development of a new technical solution, namely the purifying rectangular separator, was performed using the software module Ansys Fluent. The finite-element method was used for this task [15,16].

When studying the process of collecting the finely dispersed particles of up to 10 μm by rectangular separator, some dependencies were obtained (figure 2-4), showing that the efficiency of rectangular separator is by several times greater than that of a cyclonic separator for the gas purification from particles of small diameters. Cyclonic separator's data was taken from the previously performed studies also in the software Ansys Fluent. There was considered the model of cyclonic separator CN-11. In order to compare the rectangular separator and the cyclonic separator, the same volumetric rates Q , m^3/sec at the inlet into the devices were taken, as well as width and height of the input nipples into the rectangular and cyclonic separators and the same parameters of gas and solid particles in it [17-22].

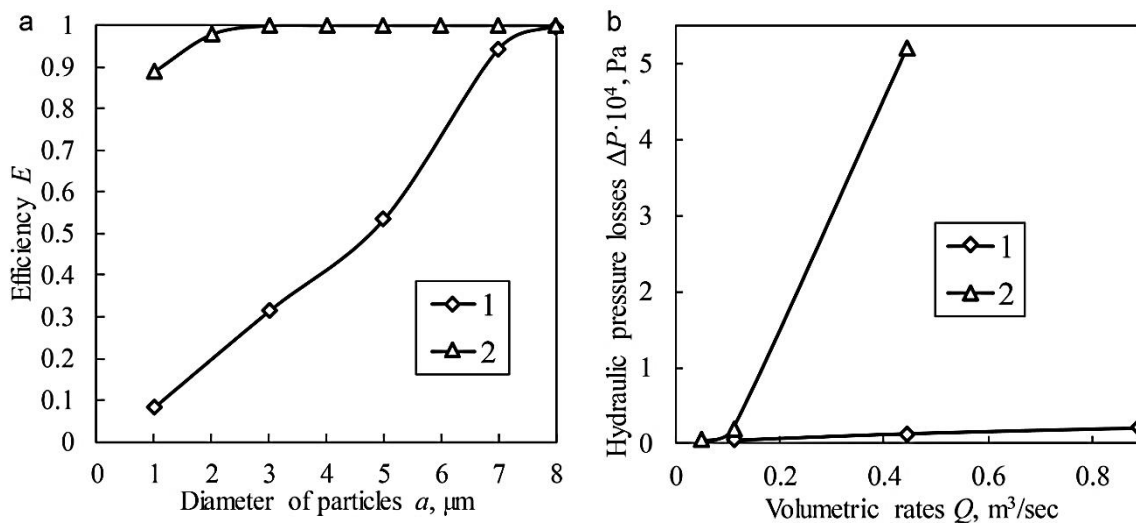


Figure 2. (a) Nature of the change of efficiency of collecting the finely dispersed particles according to an increase in their diameters for different devices; (b) Nature of the change of hydraulic pressure losses depending on volumetric gas rate at the inlet of purifying devices; 1 – cyclonic separator, 2 – rectangular separator.

Rectangular separator with design parameters $k = 0.25$, $L = 8.125$ mm, collects the finely dispersed particles of up to 6 μm at the average by 52% more than cyclonic separator CN-11 at the input volumetric gas flow rate $Q = 0.444$ m^3/sec , and at the diameter of particles of more than 9 μm , the efficiency of both devices is almost the same 99.7-100% (figure 2a). However, a significant disadvantage of a rectangular separator is a kind of large values of pressure losses (figure 2b). At $Q = 0.444$ m^3/sec , the pressure losses of the separator are by 41.81 times greater than that of the cyclonic separator, which is totally unacceptable, but with the decrease in volumetric rate at the inlet of the separator, the pressure loss values become equal to the values of cyclonic separator and at small flow

rate $Q = 0.05 \text{ m}^3/\text{sec}$, become lower than that of cyclonic separator. At small values of the volumetric rate Q , the hydraulic resistance of the cyclonic separator is also reduced, but this leads to a significant decrease in the efficiency of collecting the particles of any diameter, thus in practice the battery cyclonic separators are used, which, in its turn, leads to an increase in dimensions, weight of devices and their economic costs.

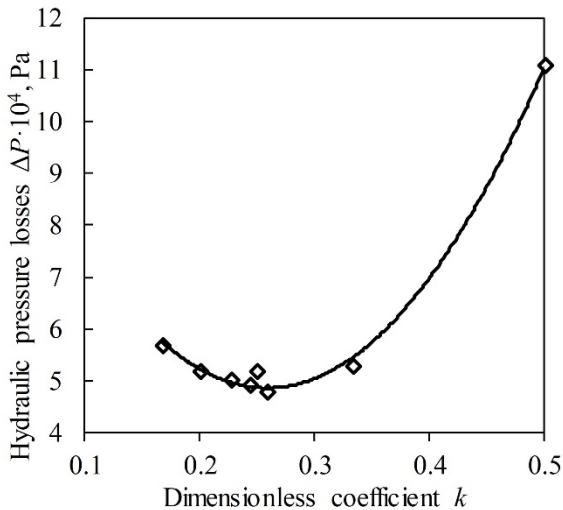


Figure 3. Dependency of the hydraulic pressure losses in a rectangular separator at different values of dimensionless coefficient k .

In order to reduce the hydraulic pressure losses in rectangular separator, the authors of this article propose to install several separators within 1 case and to use this design by the example of battery cyclonic separators. Then for the replacement of 1 cyclonic separator CN-11 at $Q = 0.444 \text{ m}^3/\text{sec}$ we need 9 rectangular separators, which should be used at $Q = 0.05 \text{ m}^3/\text{sec}$.

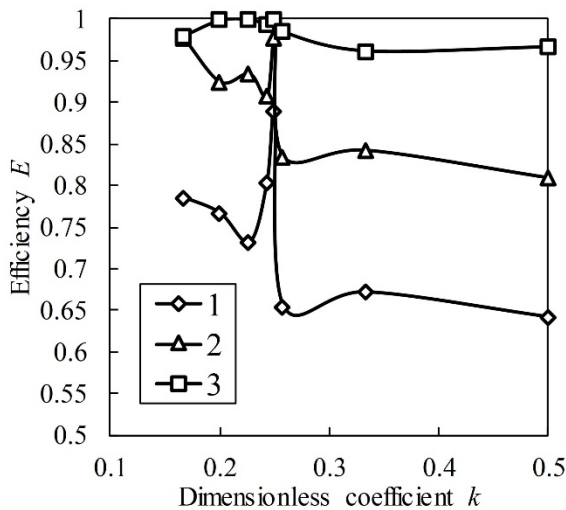


Figure 4. Dependency of the gas flow separation efficiency by rectangular separator at different values of dimensionless coefficient k for different diameters of the particles, μm : 1 – 1, 2 – 2, 3 – 3.

This design of a rectangular separator will allow achieving the hydraulic resistance by 52 Pa lower than the cyclonic separator CN-11 has and increasing the efficiency of collecting the finely dispersed particles by 2-3 times. Change of the rectangular separator's efficiency at different values of the volumetric rate Q was considered in the previous studies. These studies showed that the decrease in volumetric rate Q from 0.444 to $0.05 \text{ m}^3/\text{sec}$ reduces the efficiency of the separator at the average by 4%. Efficiency of the rectangular separator at $Q = 0.05 \text{ m}^3/\text{sec}$, depending on the dimensionless coefficient k for different diameters of particles, is shown in figure 4. As previously stated and as we can see in figure 1, different numeric values of geometric elements of a rectangular separator have a

significant impact on hydraulic pressure losses in the device ΔP and on its efficiency E . Minimum pressure loss values are achieved at $k = 0.2428$ (figure 3). This k value is the same for any of the volumetric rate Q . Maximum efficiency of collecting the finely dispersed particles by rectangular separator is also achieved at $k = 0.2428$ (figure 4). For the particles with a diameter greater than $4 \mu\text{m}$, efficiency of the separator at any k values in the limit of $0 < k < 1$ at the average is equal to 99.9%, but pressure loss values are substantially increased (figure 3,4).

After determination of an optimal value of the dimensionless coefficient k by equations (1,2), we can identify an optimal arrangement of I-shaped elements and dimensions of their projections in rectangular separator.

The calculations showed that the use of rectangular separators with correct arrangement of I-shaped elements inside of the device allows collecting the finely dispersed particles of up to $10 \mu\text{m}$ more efficiently than cyclonic separator by 2-9 times.

4. Conclusion

The use of several rectangular separators in a single case at $k = 0.2428$ allows replacing the cyclonic separator for the gas flow purification from finely dispersed particles and obtaining the hydraulic resistance inside of the device lower than that of the cyclonic separator.

Considering the simplicity of design and its maintainability, we can make a conclusion about its applicability for conducting the processes of gas flows purification from finely dispersed particles of up to $10 \mu\text{m}$.

References

- [1] Bogomolov A, Sergina N and Kondratenko T 2016 On inertial systems, dust cleaning and dust removal equipment, and work areas in the production of aerated concrete from the hopper suction apparatus *CSF Procedia Eng.* **150** 2036–41
- [2] Ontko J S 2016 Similitude in cyclone separators *Powder Technol.* **289** 159–62
- [3] Wasilewski M 2017 Analysis of the effect of counter-cone location on cyclone separator efficiency *Sep. Purif. Technol.* **179** 236–47
- [4] Rafiee S E and Sadeghiazad M M 2017 Efficiency evaluation of vortex tube cyclone separator *Appl. Therm. Eng.* **114** 300–27
- [5] Wen C, Cao X W, Yan B and Zhang J 2011 Optimization design of diffusers for supersonic separators *Appl. Mech. Mater.* **44-47** 1913–17
- [6] Song J and Hu X 2017 A mathematical model to calculate the separation efficiency of streamlined plate gas-liquid separator *Sep. Purif. Technol.* **178** 242–52
- [7] Walton W H 2014 *Dust Control and Air Cleaning. Cyclone dust separators*, 7rd edn. (Amsterdam: Elsevier) p 236–79
- [8] Cortés C and Gil A 2007 Modeling the gas and particle flow inside cyclone separators *Prog. Energy Combust. Sci.* **33** 409–52
- [9] Khafizov F Sh, Afanasenko V G, Khafizov I F, Khaibrakhmanov A Sh and Boev E V 2008 Use of vortex apparatuses in gas cleaning process *Chem. Pet. Eng.* **44** 425–28
- [10] Ziganshin M G, Ziganshin A M and Dmitriev A V 2009 Equipment and working conditions for comprehensive treatment of discharges containing halogen-bearing pollutants *Chem. Pet. Eng.* **45** 230–35
- [11] Madyshev I N, Dmitrieva O S, Dmitriev A V and Nikolaev A N 2016 Study of fluid dynamics of mass-transfer apparatuses having stream-bubble contact devices *Chem. Pet. Eng.* **52** 299–304
- [12] Makusheva O S, Dmitriev A V and Nikolaev N A 2010 Vortical chamber for cleaning gases emitted by industrial establishments *Chem. Pet. Eng.* **46** 330–33
- [13] Ovchinnikov A A, Shadrin A A, Alekseev D V and Nikolaev N A 2006 Separation of liquid-liquid and liquid-solid heterogeneous systems in single-flow vortex separators *Theor. Found. Chem. Eng.* **40** 411–15

- [14] Dmitrieva O S, Madyshev I N and Dmitriev A V 2017 Determination of the heat and mass transfer efficiency at the contact stage of a jet-film facility *J. Eng. Phys. Thermophys.* **90** 651–56
- [15] Vasilevskiy M, Zyatikov P, Roslyak A and Shishmina L 2014 Parameters of flow in cyclonic elements of separator battery *EPJ Web. Conf.* **76** 01035
- [16] Mu L and Ye X 2018 A simple finite element method for linear hyperbolic problems *J. Comp. Appl. Math.* **330** 330–39
- [17] Chu K W, Wang B, Xu D L, Chen Y X and Yu A B 2011 CFD–DEM simulation of the gas–solid flow in a cyclone separator *Chem. Eng. Sci.* **66** 834–47
- [18] Ruppel V A, Tretyakova Yu S, Lavrinenko S V, Matveeva A A and Martyshev V N 2015 Study of reduced-enrichment uranium fuel possibility for research reactors *MATEC Web. Conf.* **37** 01059
- [19] Chu K W and Yu A B 2008 Numerical simulation of complex particle-fluid flows *Powder Technol.* **179** 104–14
- [20] Kreith F, Boehm R F et al 1999 *Heat and Mass Transfer* (CRC Press LLC: Boca Raton) p 288
- [21] Juengcharoensukying J, Poochinda K and Chalermnsinsuwan B 2017 Effects of cyclone vortex finder and inlet angle on solid separation using CFD simulation *Energy Procedia* **138** 1116–21
- [22] Shukla S K, Shukla P and Ghosh P 2013 The effect of modelling of velocity fluctuations on prediction of collection efficiency of cyclone separators *Appl. Math. Model.* **37** 5774–89

Acknowledgments

The work was performed with funding from the grant of the President of the Russian Federation no.MK-4522.2018.8.