Improving the efficiency of the dust collector

V P Beloglazov¹,² and L V Mostovenko²
¹Nizhnevartovsk State University, Nizhnevartovsk, Lenin St. 56, Russian Federation
²Omsk State Technical University, 11, Mira Ave., Omsk, 644050, Russian Federation

Abstract. The object of the study is an inertial-vacuum dust collector. It is an upgraded version of the inertial-type dust collecting device. This one has the principle of anticyclone. Few articles and books are devoted to the investigation of this type of dust collectors. The purpose of this article is to explain the dependence of changes in the flow part geometry on the degree of ash particles trapping in new type of collector. This question is actual, because equipment becomes obsolete at power plants and it is necessary to find a worthy replacement, or to create a new, qualitatively best ash collecting apparatus. New dust collector allows to catch ash with efficiency of 99%. Inertial-vacuum dust collector (IVDC) was developed jointly with "All-Russia Thermal engineering institute".

1. Introduction

On the territory of Russia there are more than 24 thousand enterprises emitting harmful substances into the atmosphere and reservoirs. 29% of them are on energy facilities, 8% - coal industry facilities, 33% of emissions are provided by metallurgy enterprises. Every year in Russia only 76% of the total number of harmful substances is trapped and rendered harmless [1]. One of the reasons for such a low level of neutralization is the technological backwardness of production, low rates of introduction of resource-saving and other technically advanced and safe technologies; equipment wear, which in some cases reaches a pre-emergency condition; lack of a legal framework for insurance of man-made risks.

Of the stations operating in Omsk, such as HES (Heat electropower station)-2, 3, 4, 5; HES-4, 5 operates on coal, respectively, listed last, the station emits solid waste into the environment. Gas cleaning equipment installed at the HES-4 station can include inertial dust collectors and electrostatic precipitators; at HES-5 - bag filters. At HES-4 all ash handling facilities are obsolete; electrofilters are expensive in their repair, so it is important to find a worthy alternative to long-established installations. At the cogeneration plant-5, bag filters were recently installed, which in themselves give a degree of capture of about 99% [2]. However, Omsk HES plants operate on Ekibastuz coal, which is a sufficiently abrasive solid fuel, moreover, its ash content is 36.9%, it is not possible to use a bag filter for a long time without repairs. This fact further indicates the importance of developing new ash handling equipment.

One of the possible methods for developing fundamentally new equipment is the use of software modules such as ANSYS CFX and ANSYS FLUENT [3], [4], [5] to visualize the dispersed flow dynamics in the dust collector.
2. Formulation of the problem

The purpose of this article is to perform a computational and experimental simulation of an inertia-vacuum dust collector (IVDC) geometric characteristics effect on the degree of catching ash from Ekibastuz coal. For this, the following tasks will be performed: the mathematical formulation of the problem (1),(2),(3),(4),(5),(6),(7),(8),(9) [6]; the closure of the selected turbulence model by means of specifying the boundary conditions of the dusty flow data using modern CAD-based programs; constructing the configuration of design models using the CAD system - the SolidWorks program, conducting a series of numerical experiments to display the geometric parameters various dependencies on the efficiency of plant capture.

For the solution we used the ANSYS CFX program [7], solves this problem by the method of control volumes.

A mathematical model describing the flow of a flow:

Equation of continuity:

\[ \frac{\partial}{\partial t} \left( \rho \right) + \frac{\partial}{\partial x} \left( \rho u \right) + \frac{\partial}{\partial y} \left( \rho v \right) + \frac{\partial}{\partial z} \left( \rho w \right) = 0, \]

Equations of motion:

\[ \rho \left( \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial u}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial u}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial u}{\partial z} \right) \right) - \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial u}{\partial x} \right) \right) - \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial u}{\partial y} \right) \right) - \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial u}{\partial z} \right) \right) \]

\[ \rho \left( \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial v}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial v}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial v}{\partial z} \right) \right) - \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial v}{\partial x} \right) \right) - \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial v}{\partial y} \right) \right) - \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial v}{\partial z} \right) \right) \]

\[ \rho \left( \frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} \right) = \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial w}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial w}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial w}{\partial z} \right) \right) - \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial w}{\partial x} \right) \right) - \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial w}{\partial y} \right) \right) - \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial w}{\partial z} \right) \right) \]

Equations of the k-\( \varepsilon \) model:

\[ \rho \frac{\partial k}{\partial t} + \rho u \frac{\partial k}{\partial x} + \rho v \frac{\partial k}{\partial y} + \rho w \frac{\partial k}{\partial z} = \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial k}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial k}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial k}{\partial z} \right) \right) + \mu_{D,D} - \rho \varepsilon, \]

\[ \rho \frac{\partial \varepsilon}{\partial t} + \rho u \frac{\partial \varepsilon}{\partial x} + \rho v \frac{\partial \varepsilon}{\partial y} + \rho w \frac{\partial \varepsilon}{\partial z} = \frac{\partial}{\partial x} \left( \mu \left( \frac{\partial \varepsilon}{\partial x} \right) \right) + \frac{\partial}{\partial y} \left( \mu \left( \frac{\partial \varepsilon}{\partial y} \right) \right) + \frac{\partial}{\partial z} \left( \mu \left( \frac{\partial \varepsilon}{\partial z} \right) \right) + C_{1} \mu_{D,D} \rho_{D,D} - C_{1} \rho \varepsilon \]

Equation for effective and total viscosity:

\[ \mu_{t} = \mu + \mu_{D} - C_{1} \rho \frac{\varepsilon}{\tau} \]

Equations for describing the motion of dust particles:

\[ m_{p} \frac{d \mathbf{v}_{p}}{dt} = \mathbf{F}_{a} \]

where \( m_{p} \) is the particle’s mass, and \( \mathbf{F}_{a} \) is taken as the sum of all the forces that affect the particle.

In this case, it is necessary to determine the acting forces.

\[ \mathbf{F}_{a} = F_{D} + F_{R} + F_{B} + F_{p} + F_{BA}. \]

3. Theory

In Fig. 1 shows an inertial-vacuum dust collector.
Starting from Fig. 1, the inertial-vacuum dust collector contains a vertically arranged two-stage bulk 1, the lower stage of which is a collecting chamber (DCC) 6, and the upper one is intended for ash removal and is made in the form of two coaxially arranged cylindrical shells 2,3. Of these, the inner shell 2 serves as channel 4 (the inlet branch pipe) for the supply of flue gases to be cleaned, and the annular space between the two shells is outlet 5 for the removal of the flue gases. The dust separator also includes a rotary camera (RC) 8 in the lower part of the ash separating stage which communicates the inlet from the channel 4 into the channel 5 (outlet). The RC 8 is provided with rings 12 on the crosspiece 13, above which a cone-shaped divider 9 is positioned above the bulk 1. The latter together with the lower part of the inner shell 2 forms a confusable exit nozzle 10 of the channel 4. The inlet portion 11 of the annular channel 5 is made diffusive. The height of the divider 9 is 0.5 ... 0.8 of the height H of the inner shell 2, and the angle α of the narrowing of the convergent nozzle 10 is equal to the angle of increase in the efficiency β of the expansion of the diffuser section 11 of the cleaned gas channel 5 and is \( \alpha = \beta = (15 \ldots 20^\circ) \). Improved aerodynamics of flow of cleaned flue gases in the ash-separating part of the stepper body of the dust separator is improved by increasing the degree of ash removal efficiency to 99%.

4. Experimental results

The boundary conditions under which numerical experiments were carried out in the ANSYS CFX [8]: the inlet pressure of the installation \( \sim 100000 \) Pa, the pressure at the installation output is 99340 Pa; dust content of the gas flow \( -70 \) g / m\(^3\); ash particles distribution 5-40 microns; speed at wall sections \(-0 \) m / s.

In the course of a number of experiments carried out on the selection of the correct geometry of the flow part installation, the results can be reduced in the form of graphs and tables. The parameters that were varied are: the height of the confluent section (Fig. 2), the variation of the height of the divider (Figure 3), the effect of the axisymmetry of the divider with the rings on the capture process (Fig. 4).

The confusional site, the changes of which are present in Fig. 2, is directly related to the change in flow velocity, which affects the qualitative capture of particles.
The divider, whose different heights are shown in Fig. 3 - high important element of the IVDC. Due to it a flow is relaxed. If the height of the divider is not long enough, providing that Reynolds criterion across all sections to its middle along the installation cannot be the same. Due to this, the possible pulsations of the flow are smoothed. Also, the height is important for the uniform collection of particle velocity, and their subsequent inertial separation from the carrier phase.

In Table 1 shows the results of numerical experiments related to the change in the height of the narrator.

| Change of cutter height (mm) | Efficiency of capture (%) |
|-----------------------------|---------------------------|
| 3066 (a)                    | 99.95                     |
| 2800 (b)                    | 90                        |
| 2205 (c)                    | 85                        |
| 1800 (d)                    | 79                        |
| 1500 (e)                    | 75                        |
In Fig. 4 shows the variation of the position of the divider with the cross in regard to the center; not axisymmetry. In Fig. 5 is a graph of the change in the distance of the installation axis from the axis of the cross in regard to the efficiency of particle trapping.

**Figure 4.** Shift of the divider from the central axis to the distance b

**Figure 5.** Graph of the dependence of the shift index on the degree of capture efficiency

In Fig. 6 it can be seen that almost all the particles remained in the bunker, and only a small part left untrapped. This occurred with a shear of almost 2 mm. However, this shift gives rise to a deterioration in the capture rates. For best performance, it is necessary to rigidly fix the combination of the crosspiece with all the elements present on it to eliminate such variations in shear.

**Figure 6.** Efficiency of catching at a shift of a divider in 1.95 mm
In Fig. 7 and 8 show the movement of the flow at a maximum shear of 36.36 mm. Figure 8 [9] scales the section of the turn of the flow and the separation of particles. From the color gradation, it can be noted that the velocity distribution is uneven, where the cross section is already there, the velocities are greater there and the gas cleaning is better. And in the other section, in the meantime, the velocities reduced and the kinetic energy of the particles is not enough to detach from the gases, because of pressure and low speed, and under the pressure of the smoke exhauster they move to the outlet by far.

5. Discussion of results

From the experiments carried out (Fig. 2), it can be concluded that the confusable section must be carried out at a certain height (0.5 m). With a height of 0.7 m, the flow rate is 52 m/s, which is close to a speed of 67 m/s, at which qualitative capture occurs. However, the speed of 52 m/s flow develops after the turn, and the feature of the separation is to reach a speed of 67 m/s (for these dimensions) in a narrow area before turning to the outlet branch pipe.

According to the result (Table I), it can be concluded that the height of the divider is an important element, the height is subject of the installation efficiency as a whole. It is subject of the height of the divider, the flow arriving from the entrance will have the necessary speed (67 m/s) and divide into two separate streams: ash and gas.

Based on the results (Fig. 5), it can be concluded that the dependence of the influence is ambiguous, there is no stable improvement in indicators or deterioration as the shear increases. Either change in the cross-section at the outlet from the input pipe gives rise to the fact that the velocity distribution along the flow path becomes unequal on both sides of the divider.

6. Conclusions

On the basis of numerous experiments, the dependence of the degree of ash trapping on the geometrical dimensions of the apparatus and on its elements has been established, and the design
solutions of the installation have been calculated. This allowed to achieve maximum efficiency of particle capture without additional technical equipment, namely: a) a large contribution to the efficiency of the device was made by a divider, which increased it by 80%; b) 11% were achieved in terms of the rotary chambers and the modernization of the divider; c) The overall efficiency in terms of account the other factors, made it possible to achieve ash recovery efficiency of up to 99.7%

Deviations in the work make non-axisymmetry. For the best work of the device it is necessary to make a rigid fixation of such an element as divider in order to eliminate such variations in shear. With a shear of 36.36 mm from the color gradation, it can be noted that the velocity distribution is uneven, where the cross section is already there, the velocities are greater and the gas cleaning is better.

It is important to confirm such theoretical conclusions in the field experiment and in the future to modernize the installation.

7. References

[1] Semenova I 2009 *Industrial ecology* (Moscow: Academy) p 528
[2] Birger M 1983 *Catalog of dust and ash collecting* (Moscow: Energoatomizdat) p 312
[3] Dolinin K and Dolinin D 2003 *Application of the ANSYS FLUENT software package to simulate the motion of a dust gas stream* pp 15-18
[4] Shirokov S and Ermakov A 2005 Modern approach to the design of gas purification plants *Industrial ecology* 1 pp 37-39
[5] Chistyakov Ya 2013 Development of new generation dust collectors *Izvestiya Tula State University* 1 pp 21-31
[6] Djasim A 2012 *Mathematical modeling and aerodynamic study of the turbulent flow of a dusty stream in dust collectors* (Barnaul) 142 p
[7] Beloglazova L 2017 *Analysis of the mathematical model while solving the problems with the protected flow* (Nizhnevartovsk State University) pp 98-100
[8] Wilcox D 2006 *Turbulence modeling for CFD* (California: DCW Industries) 536 p
[9] Beloglazova L, Beloglazov V, Roschin N and I. Chavrikov 2015 Influence of the "sombrero" axisymmetry on the degree of efficiency of crossing the inertial vacuum dust collector *Omsk Scientific Bulletin* vol 3(143) pp 230-232

Acknowledgments

The researches are carried out within the framework of SRW (Science researching work) № 18052B in OmSTU.