Variable boundary conditions for solving the problem of dispersed flow moving

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Abstract. The paper presents comparing the results of numerical and full-scale experiments which conducted on an inertial-vacuum dust collector (IVDC). In September 2018, a full-scale experiment was held at the Omsk heat power station №4, it was allowed to verify the calculated data in ANSYS CFX. The boundary conditions were corrected after the initial calculations on IVDC of second generation. The results of numerical experiments, that conducted earlier, were corrected. In article it is spoken in detail about comparison of the dependences of the individual elements heights and their influence on the installation collection efficiency

Keywords: laden flow, ivdc, inertial dust collector, ansys cfx, relaminirization.

1. Introduction
There are many ways to capture the ash. Despite this, the question of ash collector creating with a highly collection efficient, a long service life without going into repair remains unresolved. The development of a new method of ash collection is an extremely time-consuming work, complicated by the creation of cumbersome expensive experimental facilities, carrying out field experiments on existing steam generators. The most appropriate creation variant are preliminary studies of newly created devices based on numerical calculations using programs such as ANSYS, which allows for a full-scale numerical experiment.

The inertial vacuum dust collector (IVDC) [1] is an ash collecting device designed for improving collection efficiency from thermal power plants. According to Figure 1, the inertial-vacuum dust collector contains a vertically positioned two-stage body 1, the lower stage of which is an ash-collecting chamber (ACC) 6, and the upper one is intended for ash separation and it is made in the form of two coaxially arranged cylindrical shells 2,3. The inner cylindrical shell 2 serves as an inlet pipe 4 for supplying the flue gases, and the annular space between the two shells is a channel 5 for exhausting the cleaned flue gases. The ash separator also contains a turning camera (TC) 8 in the lower part of the separating stage informing the output from the channel 4 to the channel of the outlet nozzle 5. TC 8 is made with rings 12 on the crosspiece 13, above which a cone-shaped divider 9 is installed along the axis of the housing 1. The lateral surface of the latter, together with the lower part of the inner shell 2, forms a confused output nozzle 10 of channel 4. The inlet section 11 of the annular channel 5 is made diffuser. The height h of the divider 9 is 0.5 ... 0.8 of
height $H$ of the inner shell 2, and the angle $\alpha$ of narrowing confused nozzle 10 is equal to the angle of increase efficiency degree $\beta$ of expansion of the diffuser section 11 of the channel 5 of exhaust gases and is $\alpha = \beta = (15 \ldots 20)^\circ$.

![Inertial vacuum ash collector of the second generation](image)

**Figure 1.** Inertial vacuum ash collector of the second generation. 1 - two-stage case, 2, 3 - cylindrical shells, 4 - inlet, 5 - channel for purified flue gases, 6 - ash-collecting chamber (ACC), 7 - outlet, 8 - turning camera TC, 9 - divider, 10 - confused output nozzle, 11 - inlet diffuser section, 12 - rings, 13 - retaining rings, cross, 14 - axis.

The operation principle [12] of the IVDC: gas with ash particles through the inlet 4 in the guide arrow enters the ash collector, then moves along the air channel and exits the accelerating nozzle 10. The particles acquire kinetic energy along the divider 9, by inertia move into the rotating chamber 8 and due to force gravities are deposited in the bunker 6. Particles with only the smallest diameters are not deposited. In the TC 8 an aerodynamic trap [11] is formed - particles have the opportunity to get into it, but they cannot exit. In consequence, they are completely deposited in the bunker. Thus, particles can enter the channel, and cannot exit.

2. **Methods**
In September 2018, in the Omsk region in the JSC "TGC-11" the joint venture "CHP-4" a full-scale experiment was conducted with the IVDC on the boiler BKZ-320-140. In the course of the experiment the measurements were made indicated in Figure 2. The main measurements allow to verify the turbulence mathematical model of using the IVDC: the dust concentration in flow before and after the IVDC; volumetric gas flow before and after IVDC; temperatures on inlet and outlet; pressure drop.
Figure 2. Scheme of ash collector with IVDC. IVDC – inertial vacuum dust collector, C 1,2 – cyclones, SV 1,3,4 – stop valves

The research methodology used in this article was carried out according to Regulatory guide 153-34.1-27.301-2001 «Test method of ash collecting plants of thermal power and boilers plants». This technique can be used for testing various types of dust collectors, provided that the temperature, pressure and polluting components concentration of the cleaned gases are similar to those of flue gases of boilers or atmospheric air. The measuring section in the gas duct is selected in accordance with the requirement of GOST 17.2.4.06, GOST 17.2.4.07, GOST R 50820. Measured sections should be located on straight, preferably vertical, sections of constant-flow ducts before and after ash collectors. In these areas there should be no ash deposits. When zero-type pneumometric tubes are used and dust sampling probes are used for measurement, the length of a straight section of constant cross section must be at least four hydraulic diameters of the flue. Measurements are carried out in a section dividing the plot in a 3:1 ratio in the direction of gas flow. Sections of circular cross section are preferable to square, and square should be rectangular. The IVDC has a non-standard design, and its installation had a limited space on which the cyclone was previously installed. It was impossible to comply with one of the conditions during the test - to arrange dimensional sections, at a distance of not less than four hydraulic diameters of the flue. In fact, this distance is about two hydraulic diameters. Such a deviation is due to the fact that IVDC has the opposite position of the inlet and outlet, rather than the cyclone.

The ash mass that enters the ash collecting plant with gas, as well as contained in the gas emitted into the atmosphere after cleaning. It can be determined by sampling dusty gas using dust collectors of various types, respectively, before and after the ash collecting plant.

A representative sample of the ash mass of a dusty gas can be taken under the condition that the gas velocities are equal in the sampling channel of the probe (the gas duct at the sampling point). To do this, the sampling sites must be correctly selected according to the “Methodology” and GOST 50820, and the work with the probe is properly organized.
The cross section of the flue is divided into equal elementary. Samples are taken at all scheduled points located in the center of these sites. The gas suction time from each point must be the same (at least 0.5 min).

The total gas sampling time from all the planned points of the cross section of the flue is chosen so that the ash mass collected by the dust extraction probe is at least 0.1 of the mass of the clean filter. Selection is considered complete when samples of dusty gas are taken at all scheduled points.

Such ash sampling was complicated by the fact that the velocity at the exit section of the IVDC was unevenly distributed. It is in the range of 5–20 m/s, which affects the partial sedimentation of particles in the outlet section of the ash collector. The last factor affects the efficiency of the ash collector.

3. Results and Discussion

The data of the field experiment were obtained by conducting experiments [4] with the position of the divider at elevations, as shown in Figure 3. The divider was lifted, the installation resistance was greater [5], the exhaust gas flow rate was smaller, the velocity of the gases in the narrow bore was greater and ash collection efficiency is higher.

![Figure 3. Four marks for a full-scale experiment.](image)

According to the results of the obtained data, the numerical experiments were recalculated, on the basis of which the design of the ash collecting apparatus was carried out. Previously, the boundary conditions were the differential pressure, speed, concentration of ash at the entrance. With the new numerical calculations, the inlet boundary conditions became the mass flow rate of gases 150000 m$^3$/h, the ash concentration - 70 g / m$^3$; and the outlet pressure is 0 Pa. The program was calculated the speed of the dusty flow through the flow part. The calculations were performed in the ANSYS CFX software module [6-10] using the control volume method.

The recalculation was made according to the values obtained after changing the height of the ACC (Fig. 4) and the divider height (Fig. 5).
From the graph in Figure 4 it can be seen that a change in the height of the ACC indicates the an extremum presence in the graph after which it is not advisable to increase the height of the camera. Thus, the increase in height is unjustified and carries only the useless consumption of metal.

The good collection efficiency in the case of: it (c) can be explained by the fact that the kinetic energy gained by the passage of the particle along the divider profile, it enough to pass the TC, lose energy in the TC and collapse due to gravity into the ash bunker.

When the results (a) and (e) were unsatisfactory. The lack of TC is resulted in particles moving at a speed of 60.8 m / s directly to the wall of the bunker, in connection with which increased abrasive surface wear could occur, or most of the particles moved towards the exit. TC element is needed to improve the quality of the IVDC, because its presence improves the installation collection efficiency by 30% from option (d).

The divider [3], the different heights of which are depicted in Figure 5, is a very important element of the IVDC. The flow relaminization is achieved because of it [2]. If its height is small, large velocity gradients aren’t appeared, ripple smoothing doesn’t occurs. Increasing the height of the divider leads to smoothing of possible flow pulsations. The same height is important for an uniform set of speed of the particles, and their subsequent inertial separation from the carrier phase.
Figure 5. Five marks for changing the height of the divider and its influence on collection efficiency.

It depends on the divider height whether the stream coming from the entrance will gain the necessary speed of about 60 m/s and two independent streams: ash and gas will be divided.

Figures 4 and 5 show 2 dependences: in red and blue colors. Red color dependence is data of a numerical experiment on primary boundary conditions, blue color dependence is data of a numerical experiment with verified secondary boundary conditions. According to the new results, the efficiency in both cases becomes lower due to the influence maximum speed in narrow bore.

4. Conclusions
The results of the numerical experiment were verified with respect to the full-scale experiment. Changes have been made to them. Previously obtained capture efficiency values are recalculated based on these data. They became reduced by 1-3%. Maximum installation efficiency 95%. The drop in efficiency is justified by changing the speeds along the flow along the divider, the pressure drop been recalculated.

The data presented in this article are given taking into account the errors arising during the tests.
Research on the ash collector development can be continued further. You can use the additional effect that was obtained on the inertial-vacuum dust collector of the first generation. This ash collector was tested in Omsk in 2008 and was showed efficiency in the range of 83-90%. To date, it has been
possible to improve the design of the apparatus flow-through part, so that the efficiency has become 93% without the possible discharge effect.

Additional studies of the movement of the guide vane in the vertical plane can show qualitative and quantitative changes in the flow rate and ash particles collection, allow to establish the real range for the occurrence of relaminization.

It is possible to make holes in the divider to create an additional effect of discharge.

It is also necessary to analyze the possible abrasive wear of the internal surfaces of the installation, their influence on the efficiency of the ash collecting device and to assess the durability of the installation.

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