УДК 621.928.37+621.928.93

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DEDUSTING OF THE GASES OUTGOING FROM THE GLASS MANUFACTURING FURNACE

The article presents a new design of the direct-flow cyclonic dust collector for dry mechanical cleaning of the gases leaving the glass-worked furnace. Results of numerical modeling of aerodynamics, pressure drop and separation efficiency of the developed cyclone are given which application will provide catching of a sticking together dust with efficiency not less than 70% for particles with a diameter of 10 mm and more at the pressure drop not exceeding 1,400 Pa.

Introduction. The most important reserve of economy and rational use of fuel and energy resources and also improving ecological condition of the environment is utilization of warmth of end gaseous streams of various fuel and power using equipment.

Questions of gas cleaning after glass manufacturing furnaces are very relevant as in this case it is provided not only environment protection against harmful emissions, but also the cleaned gases are used as a secondary energy resource that allows to gain considerable economic effect due to gas utilization.

Main part. This problem is of current importance for the Belarusian enterprises such as public corporation “Polotsk – Glass fiber” and public corporation “Grodno glass plant”. At existing gas outlet systems of glass manufacturing furnace dusty gases pass through the gas flue with vertical and horizontal sites into boiler-utilizer and further on cleaning.

When gas is passing through a horizontal site of the gas flue and in the boiler-utilizer under the influence of gravity and inertia, and also adhesion there is deposition and accumulation of dust particles in these places that leads to their overgrowing with need of a periodic stop and cleaning. The task of the present article is development of the dust collector for cleaning of gases after the glass manufacturing furnace before the boiler-utilizer for the purpose of prevention or minimization of the specified negative phenomenon and increase in period of operation of the boiler-utilizer between stops. It is necessary to arrange dust collector directly under a vertical site of the gas flue for an exception of additional bends and horizontal sites of the gas flue where there could be deposition and dust accumulation before entering the dust collector.

Lack of the proper apparatus corresponding to all set conditions demanded carrying out additional research and development of the appropriate design of the dust collector.

An inertial (centrifugal) way of dedusting was chosen for developed system of gas cleaning after glass manufacturing furnace on the basis of the review and the analysis of existing ways of separation of dusty gas flows.

The centrifugal dust collectors of cyclonic type are the most widespread in the modern industry.

The direct-flow type of a cyclone with a vertical body and axisymmetric input of a flow on directing vanes was chosen on the basis of the analysis of existing designs of cyclonic dust collectors and requirements to the designed apparatus among which one of main is the exception of danger of dust deposition.

The direct-flow cyclone CBTI was assumed as a basis: these cyclones were recommended by CBTI (Central Boiler-and-Turbine Institute) as the first step of cleaning for a number separation systems of leaving hot gases.

The use of axisymmetric input of a flow on directing vanes instead of a tangential inlet branch pipe at the same time with vertical body will allow to attach the dust collector directly to a vertical site of the gas flue and to enter dusty gas into the apparatus without additional turns where there could be deposition of dust particles (under the influence of gravity and inertia). Besides, direct-flow cyclones in comparison with the counter-flow have smaller dimensions in the horizontal plane due to higher mean gas velocity (i.e. the gas velocity related to full section of the apparatus).

More precise definition and optimization of separated design data and the sizes of the designed dust collector requires carrying out additional research, proceeding from requirements imposed to dust collector.

Selection technique of a cyclone with the corresponding calculation of pressure drop and separation efficiency now is based mainly on experimentally determined parameters (pressure drop factor, fractional separation efficiency, the parameters characterizing overall collection efficiency, – diameter of the particles caught with efficiency of 50%, and a standard deviation as distribution of fractional efficiency) [1–3]. Determination of such parameters when developing new and modernizations, improvement of existing designs is interfaced to the known difficulties caused by need of production of skilled models of new designs, the errors connected with techniques of carrying out experiments and used devices of measurement, transfer of the results received on skilled model on a real industrial design. Differences of pressure drop factors and the parameters characterizing separation efficiency of the same cyclones according to different sources [4–7] can be an example of that. In this regard in the USSR it was recommended to send to all organizations-developers of new dry inertial dust collectors their samples to Semibratovky branch of NIIOGas for rig tests [4].

Development of computer facilities and technology of numerical modeling of various processes gave alternative opportunity of carrying out virtual (numerical) experiment. It allows to exclude or minimize the material, labor and time expenditure connected with production of skilled models of new designs, to conduct research of various options of designs in identical conditions, gives the chance of studying the processes which real modeling is difficult or impossible, for example, owing to its high temperatures as it takes place in the case under consideration cleaning of the hot gases leaving the glass manufacturing furnace.

The numerical modeling based on application of computational fluid dynamics packages was applied to research of designed cleaning system.

The pressure drop factor of the developed cyclonic dust collector was decided by a formula [8, 9]

$$\zeta = \frac{2\Delta p}{\rho w^2},$$

where Δp – pressure drop, determined by a difference of full pressure on an entrance to a cyclone and at the exit from it, Pa; ρ – gas density, kg/m^3; w – mean gas velocity in the cyclone, counted on the formula

$$w = \frac{4Q}{\pi D^2},$$

where Q – volumetric gas discharge, m^3/s; D – inner diameter of a cyclone body, m.

Efficiency of catching of dust (separation efficiency) η, %, was determined by equation [5, 6]

$$\eta = 100\,(1 - c_{\text{out}} / c_{\text{in}}),$$

where c_{out}, c_{in} – volume concentration of a dust at the exit from the dust collector and at the entrance, g/m^3.

Modeling of trajectories of movement of particles in a problem horizontal site of the gas flue before a boiler-utilizer confirmed the fact of concentration of the largest size particles near the bottom internal surface of a pipe that testifies to danger of dust deposition here.

Initially a possibility of installation of the elementary inertially gravitational dust collector in the form of the cylindrical bunker in the place of transition of a vertical site of the gas flue in the horizontal was studied.

Modeling of separation process in such dust collector showed its low efficiency. The most part of particles even such large size as 50 μm isn't caught in the apparatus, being taken by leaving flow.

As it was mentioned earlier, the direct-flow cyclone with a vertical arrangement of the body and axisymmetric input of a flow on directing vanes was chosen for a basis for a developed design of the dust collector which will allow to attach the dust collector directly to a vertical site of the gas flue and to enter dusty gas into the apparatus without additional turns where there could be deposition and accumulation of dust particles.

A number of options of the direct-flow cyclonic dust collector designs was developed and simulated and trajectories of movement of dust particles, distribution of pressure and gas flow velocities, separation efficiency and pressure drop were analysed for the following cases:

– with various designs of twisting devices (swirlers);

– with various design data of a swirler: number and tilt angle of the bottom edge of vanes, diameter and height of the core, set fairings;

– with various form of the lower part of the dust collector body – conic and cylindrical;

– with a gas outlet via the cyclone body and various heights of a separation zone of the dust collector;

– with various diameter of an exhaust pipe and with the diffuser on it;

– with a gas outlet via the bunker;

– with a fender ring set on an exhaust pipe and various ratios of core diameter, the exhaust pipe and height of the bottom fairing.

Two main types of twisting devices (swirlers) “socket” (Fig. 1, *a*) and “screw” (Fig. 1, *b–d*) are applied at axisymmetric input of a flow.

Originally for installation in a projected design the "socket" type twisting device was chosen as it has small height, though it is less steady against sticking [2, 3]. However the executed drawing and 3D model the cyclone with such 8-vane swirler (Fig. 1, *a*) showed that slot-hole gaps for gas pass between his vanes are quite narrow therefore sticking and dust accumulation to them can lead to partial or full overlapping of intervane gaps and, respectively, violation of operation of the dust collector. For prevention of such effects, it was decided to reduce number of vanes for an exception of overlappings between them, and also to investigate possibility of increase in tilt angle of vanes to the horizontal plane.

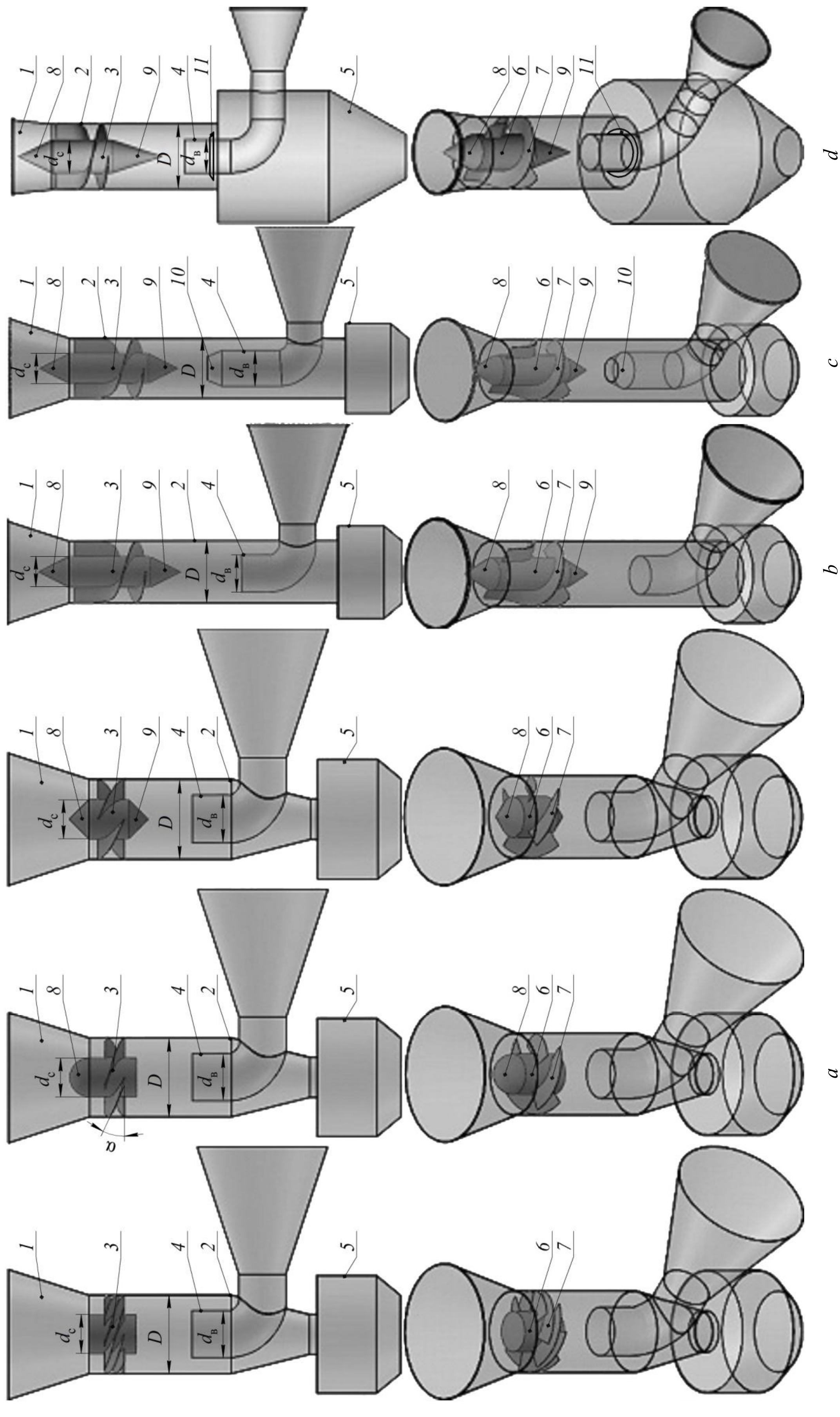


Fig. 1. Designs of the investigated cyclones:
a – with a "socket" type swirlerand various fairings; *b* – with a "screw" type swirler and cylindrical body of the apparatus; *c* – with a diffuser attached to the exhaust pipe;
d – with leading gases via the bunker and a fender ring;
1 – inlet branch pipe; *2* – body; *3* – swirler; *4* – outlet gas branch pipe (exhaust pipe); *5* – bunker; *6* – cylindrical part (core) of the swirler;
7 – vanes of the swirler; *8* – upper fairing; *9* – lower fairing; *10* – diffuser; *11* – fender ring;
D, d_{out}, d_c – diameter of a cyclone, an exhaust pipe and core accordingly; а – tilt angle of the bottom edge of vanes

A fairing was set on the twisting device for the purpose of prevention of dust accumulation on the top face surface of its core and smoother entrance of a gas flow into it. Research of two options of the fairing – hemispherical and conic were conducted. Besides, the conic fairing was also placed on the bottom face surface of the core of the twisting device for a smooth gas outlet in a separation zone.

Modeling of work of these designs showed that reduction of number of vanes negatively affects intensity of a twisting of gas flow, and as the consequence, considerably worsens efficiency of dust catching in a cyclone. The increase in a tilt angle of vanes from standard value 30° to 45° with the aim to reduce of danger of sticking and accumulation of dust particles on the top surface of vanes also led to sharp reduction of intensity of gas twisting and collection efficiency. Installation of a fairing on the bottom and top parties of the core of the twisting device reduced flow turbulization in these parts that positively affects separation efficiency. At the same time it wasn't noted advantages of a hemispherical fairing before conic therefore further it was decided to use simpler, conic fairing.

Due to the received results the decision to use the “screw” type swirler was made, which has much wider intervaned channels and smooth bend of vanes and considered preferable and more reliable when catching sticking together dust [3], that is one of the main requirements to the developed dust collector.

The form of the lower part of the cyclone body adjoining the bunker was changed from the point of view of work reliability in the conditions of catching of sticking together dust. In the cyclone CBTI assumed as a basis the conic lower part is used, however the gap for dust pass with part of gas into the bunker is considerably narrowed, especially taking into account partial overlapping of a cone by the outlet branch pipe of the cleaned gas (the exhaust pipe). On the one hand, it reduces the volume of gas passing into the bunker, and, respectively, its possibilities of transportation there caught dust particles, on the other hand it creates danger of overgrowing of the gap when particles are sticking to internal surface of the cone and the outlet branch pipe of the cleaned gas leaving here.

Research of influence of a form of the bottom part of the body showed that along with increased reliability and design simplification application of the cylindrical lower part of the body (Fig. 1, *b*) increases separation efficiency that, apparently, is explained by the large volumes of gas getting to the bunker, and intensity of transportation there dust particles, and also smaller negative influence of the outlet branch pipe of the cleaned gas on intensity of flow rotation.

Research of the “screw” type swirler with various tilt angle of the bottom edge of vanes (in the range of 10–30°) and number of vanes (from 2 to 4) showed that the most preferable is the two-vaneswirler with a tilt angle of the bottom edge of vanes 25–30°. At tilt angle reduction the tangential gas velocity and, as a result, pressure drop of the dust collector excessively increases. Besides, chocking-up of particles with formation of a dust ring rotating in one plane was observed at the exit from the twisting device.

Lengthening of cylindrical part of the core of a swirler had no essential impact on cyclone work, without having prevented and formation of a ring dust layer under the swirler.

Studying of influence of height of the main separation space (distances between the bottom edges of swirler vanes and the entrance to the outlet branch pipe of the cleaned gas) taking into account these references [10] allowed to define its most rational value which approximately equal to diameter of the cyclone body.

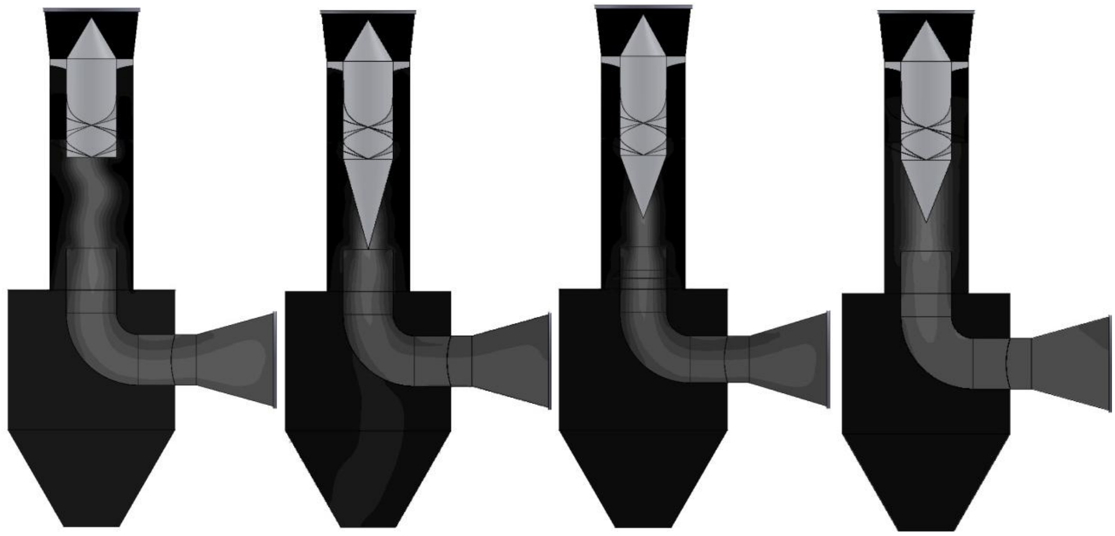
Research of operation of the dust collector with various outlet branch pipe diameter of the cleaned gas, being accepted in the range from 0.4 to 0.6 cyclone diameter, showed that reduction of diameter leads to some increase in separation efficiency and to the essential growth of pressure drop of the apparatus. Besides, as well as in a case with the reduced tilt angle of the bottom edge of vanes of the twisting device,chocking-up of particles with formation of a dust rotating ring under a swirler was observed. The effect of formation of the ring wasn't observed with the branch pipe diameter equal 0.6 cyclone body diameter therefore this size was accepted as final one.

Diffuser installation on an exhaust pipe (Fig. 1, *c*) had the same impact on operation of the dust collector, as well as usual reduction of pipe diameter.

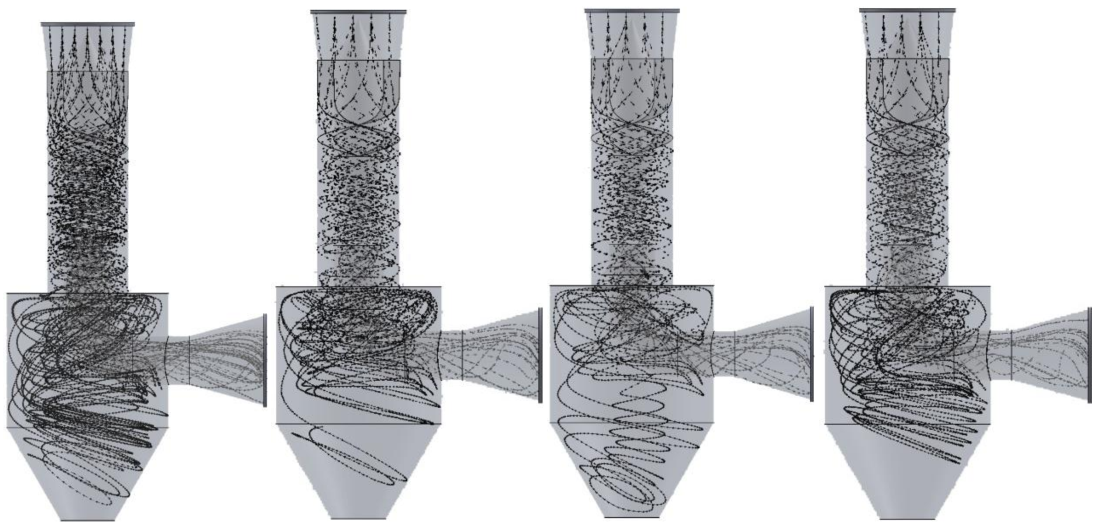
It was decided to lower the branch pipe of the cleaned gas below and carry out its outlet from the apparatus through a bunker wall (Fig. 1, *d*) that allowed to reduce height of cylindrical part of the body and minimize negative influence of horizontal part of a branch pipe on intensity of gas rotation at the entrance in the lower part of the dust collector. Besides, the outlet of the branch pipe via the bunker will allow to eliminate moisture condensation in it at cleaning of hot gases and to reduce, and even completely to eliminate chocking-up of the caught dust at its unloading (in case of dust unloading at the working dust collector or soon after switching off).

Installation a fender ring or a dust-fender washer (Fig. 1, *d*) on an external surface in the top part of an exhaust pipe is used to increaseoverall efficiency of vortex and direct-flow dust collectors.

The results of numerical modeling of distribution of pressure, trajectories of movement of gas and dust particles in various designs of the direct-flow cyclone are presented in Fig. 2.



a



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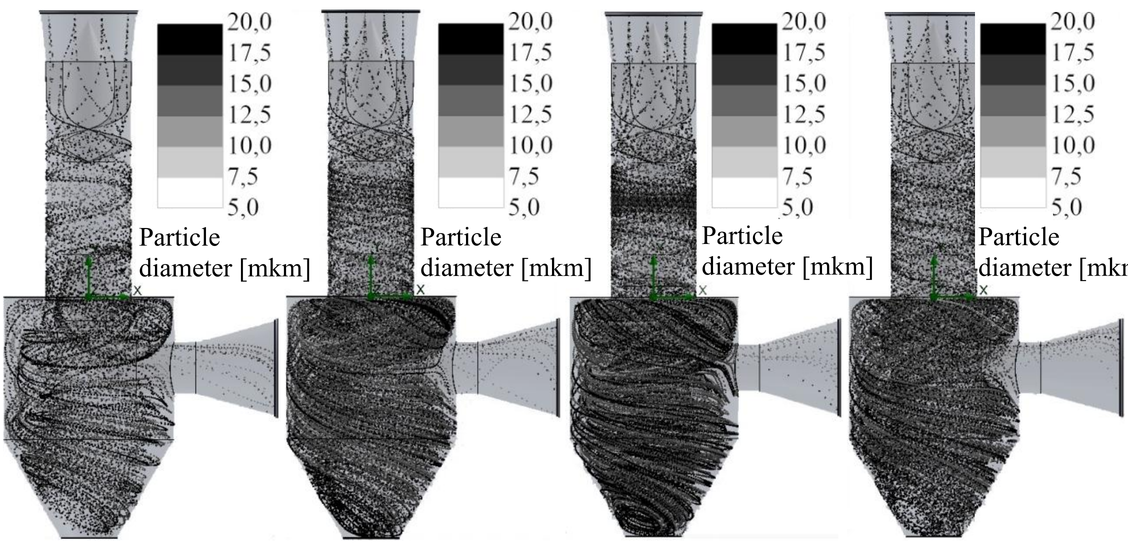

c

Fig. 2. Research results of the designs of cyclones fitted with a fender ring established on an exhaust pipe and various ratios of core diameters, the exhaust pipe and height of the bottom fairing:
a – distribution of a total pressure (lighter areas correspond to lower pressure);
b– trajectories of movement of gas particles; *c* – trajectories of movement of solid particles

The research of cyclone fitted with a fender ring confirmed the increase in separation efficiency when using such ring. However the volume of gases going to the bunker with corresponding reduction of intensity of transportation by him into the bunker of caught particles thus decreased. Considering simultaneous narrowing the gap by the fender ring of for gas pass with a dust between the exhaust pipe and the body wall and danger of sticking and dust lag on the ring, it was decided to refuse from it and use a usual exhaust pipe.

On the basis of modeling of work of the cyclone with various height of the bottom conic fairing of the twisting device (varied in the range from zero to 2.5 core diameter) its height was chosen equal 1.25 core diameter.

At certain ratios of the core diameters of a swirler and an exhaust pipe the effect of formation of a dust ring rotating under the swirler was observed, in this connection the diameter of cylindrical part of the core was chosen equal 0,6 diameters of the cyclone body.

The recommended mean gas velocity for direct-flow cyclones is in the range of 5–8 m/s [10]. For determination of optimum velocity modeling and the analysis of process of cleaning was carried out in the specified range of velocities with an interval to 1 m/s.

The researches showed that the greatest separation efficiency of the developed apparatus is reached in the range of velocity of 7–8 m/s. The increase in gas velocity to the upper bound of the recommended range also allows to reduce diameter and other related sizes of the dust collector, so and its material capacity, weight and cost.

On the basis of the conducted research the new design of a direct-flow cyclone is developed for cleaning of the hot gases, which is presented in Fig. 3.

The developed direct-flow cyclone consist of vertical cylindrical body *1* with axisymmetric inlet of flow through the inlet branch pipe *1* and swirling device *3*, outlet branch pipe *4* taking cleaned gases off through the main bunker *5*. Taking into account high temperature of the gases outgoing from the glass manufacturing furnace (about 600–700°C), the apparatus is to be made from suitable steel (for example, steel 12X18H10T) for providing its continuous work and is to be supplied with an additional bunker *6*, situated under the main bunker *5*, and two gate valves *7*. It allows to accomplish unloading of the caught hot dust from the main bunker *5* into the additional bunker *6* where the dust will be cooled up to the temperature demanded for safe unloading.

Conclusion. The developed direct-flow cyclone dust collector for cleaning the gases outgoing from the glass manufacturing furnace provides catching of a sticking together dust with efficiency not less than 70% for particles with a diameter of 10 mm and more at the pressure drop not exceeding 1,400 Pa.

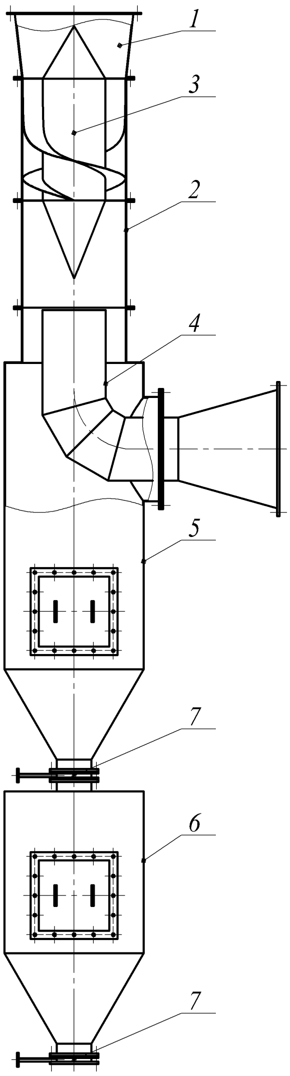

Fig. 3.The developed design of direct-flow direct-flow cyclonic dust collector for cleaning the gases outgoing from the glass manufacturing furnace:
1 – inlet branch pipe; *2* – body; *3* – swirling device (swirler);*4* – outlet branch pipe; *5* – main bunker; *6* – additional bunker; *7* – gate valve

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Received 20.02.2013