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Technical Solutions to Reduce the Amount of Dust Particle Breakthrough when Cleaning Emissions from the Production of Reinforced Concrete Products Using Dust Collectors with Counter Swirling Flows

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Abstract

Introduction. The production of reinforced concrete products, being the basis of modern industrial construction, is a very significant source of dust emissions. Traditional cleaning methods are often unable to ensure the compliance with air quality requirements, and replacing them with more modern ones requires significant capital and operational costs. One of the most promising ways to solve the problem is the use of a new class of inertial dust collectors with counter swirling flows, combining constructive simplicity and low operating costs with sufficiently high work efficiency. The aim of the work was to analyze the factors influencing the magnitude of the breakthrough coefficient of fine dust particles, as well as the development of constructive solutions aimed at reducing it.

Materials and Methods. An analytical review of technical solutions aimed at reducing the breakthrough magnitude was carried out, on the basis of which the designs of the lower input of dust collectors with counter swirling flows were developed. Methods of computational experiment and field measurements were used to confirm the effectiveness of the developed structures.

Results. By means of numerical experiments, the information about the aerodynamic flow pattern in the separation chamber of the CSF dust collector was obtained, and the breakthrough magnitude of dust particles was estimated. The solutions were developed for the design of the lower coaxial input of the swirling flow of dust collectors on the counter swirling flows, taking into account the features of dust pollution generated during the operation of technological equipment of reinforced concrete production.

Discussion and Conclusion. The presence of a displacement of the axis of the secondary swirling flow from the axis of symmetry of the separation chamber was established. The consequence of this was the non-coaxiality of the primary and secondary flows, which led to a decrease in the intensity of the twist, the formation of parasitic vortices, and, as a consequence, an increase in the value of the breakthrough coefficient. This effect was especially pronounced with a large proportion of fine dust particles, characteristic of dust pollution formed during the production of reinforced concrete products. The proposed design of the coaxial input of the secondary swirling flow reduced the magnitude of this eccentricity, which made it possible to achieve a significant reduction in the breakthrough magnitude of fine particles characteristic of dust emissions of reinforced concrete industries. The results obtained can be effectively used both in the production of reinforced concrete products and in other branches of construction production, which is characterized by intensive formation of fine dust emissions.

Keywords: dust collector with counter swirling flows, dust particle breakthrough coefficient, enterprises for the production of reinforced concrete products and structures

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Научная статья

Технические решения по снижению величины проскока пылевых частиц при очистке выбросов производства железобетонных изделий пылеуловителями со встречными закрученными потоками

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Аннотация

Введение. Производство железобетонных изделий, будучи основой современного индустриального строительства, является весьма существенным источником пылевых выбросов. Традиционные методы очистки зачастую неспособны обеспечить соблюдение требований к качеству воздушной среды, а замена их более современными требует значительных капитальных и эксплуатационных затрат. Одним из наиболее перспективных путей решения проблемы является применение нового класса инерционных пылеуловителей со встречными закрученными потоками, сочетающими конструктивную простоту и низкие эксплуатационные затраты с достаточно высокой эффективностью работы. Целью работы был анализ факторов, оказывающих влияние на величину коэффициента проскока мелкодисперсных пылевых частиц, а также разработка конструктивных решений, направленных на его снижение.

Материалы и методы. Проведен аналитический обзор технических решений, направленных на снижение величины проскока, на основании которых разработаны конструкции нижнего ввода пылеуловителей со встречными закрученными потоками. Для подтверждения эффективности разработанных конструкций применялись методы вычислительного эксперимента и натурные замеры.

Результаты исследования. Посредством проведения численных экспериментов получены сведения об аэродинамической картине течения в сепарационной камере пылеуловителя ВЗП, а также произведена оценка величины проскока пылевых частиц. Разработаны решения по конструктивному оформлению нижнего коаксиального ввода закрученного потока пылеуловителей на встречных закрученных потоках, учитывающие особенности пылевых загрязнений, образующихся при работе технологического оборудования железобетонного производства.

Обсуждение и заключение. Было установлено наличие смещения оси вторичного закрученного потока от оси симметрии сепарационной камеры. Следствием этого является некоаксиальность первичного и вторичного потоков, приводящая к снижению интенсивности закрутки, образованию паразитных вихрей, и, как следствие, увеличению значения коэффициента проскока. Особенно сильно данный эффект проявляется при большой доле мелкодисперсных пылевых частиц, характерной для пылевых загрязнений, образующихся при производстве железобетонных изделий. Предложенная конструкция коаксиального ввода вторичного закрученного потока снижает величину данного эксцентриситета, что позволяет достигать существенного снижения величины проскока мелкодисперсных частиц, характерных для пылевых выбросов железобетонных производств. Полученные результаты могут быть эффективно использованы как в производстве железобетонных изделий, так и в других отраслях строительного производства, для которого характерно интенсивное образование мелкодисперсных пылевых выбросов.

Ключевые слова: пылеуловитель со встречными закрученными потоками, коэффициент проскока частиц пыли, предприятия по производству железобетонных изделий и конструкций

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Для цитирования. Месхи Б.Ч., Евтушенко А.И., Боровков Д.П. Технические решения по снижению величины проскока пылевых частиц при очистке выбросов производства железобетонных изделий пылеуловителями со встречными закрученными потоками. *Безопасность техногенных и природных систем.* 2023;7(4):7–19. https://doi.org/10.23947/2541-9129-2023-7-4-7-19

Introduction. The designs of dust-collecting devices for dust and gas cleaning are gradually becoming more complicated [1–5], which is accompanied by an increase in the costs of their production. This circumstance makes it difficult to widely use new types of dust collectors: wet washing devices, electric filters, fabric dust collectors of various types. Modern requirements in the field of air cleanliness require the expansion of the use of dust collecting devices and increasing the efficiency of their operation [6]. A promising way to resolve this contradiction is to improve inertial methods of dust collection, characterized by constructive simplicity and low cost of operation. One of the directions of development of inertial methods of dust collection is dust collectors on counter swirling flows (hereinafter referred to as CSF). Their main advantage is lower values of the dust breakthrough coefficient compared to cyclones, the stability of work and the simplicity of structures [6]. However, the spread of this type of dust collectors is constrained by insufficient information on the effectiveness of application in specific areas of industrial production. In addition, there is a wide variety of design schemes of such devices, each of which requires fine-tuning in the conditions of a specific technological process. Therefore, the development of technical solutions for the adaptation of dust collectors on counter swirling flows is an urgent task.

There are two main types of dust collectors on counter swirling flows. The first type includes devices in which compressed air is used to create a secondary swirling flow. The inlet through which compressed air is supplied is located on top and is called secondary. The second type includes devices created on the basis of cyclones [6–8]. The main difference between CSF devices and cyclones is that a lower inlet is added to the usual upper inlet. A patent was obtained by E. Schaufler and H. Zennek for the described designs in 1953 (Fig. 1) [9].

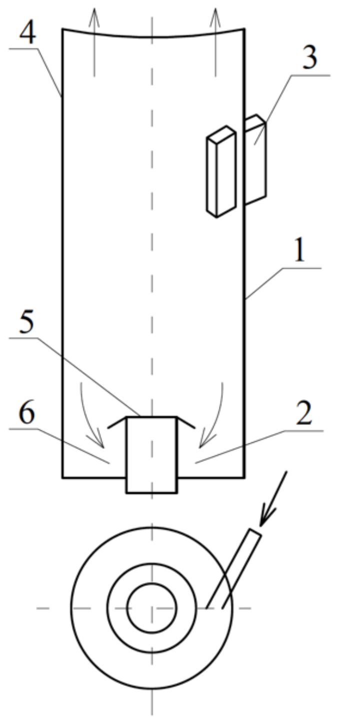


Fig. 1. Vortex chamber for separation of solid and liquid aerosol particles by means of an auxiliary swirling gas flow:
1 — separator; 2 — primary flow inlet; 3 — nozzle for secondary flow;
4 — exhaust pipe; 5 — jack washer; 6 — dust collection hopper [10]

In 1972, the designs of nozzle (Fig. 2 *a*) and vane (Fig. 2 *b*) types were proposed [6].

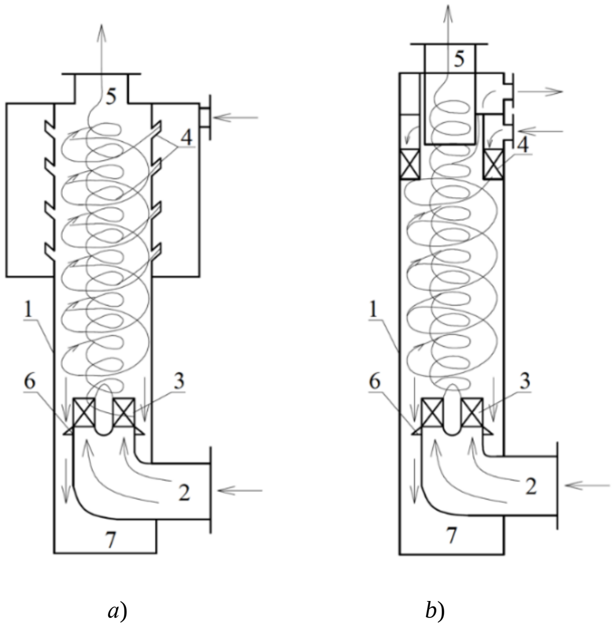


Fig. 2. Vortex dust collectors: *a* — nozzle type:
1 — chamber; 2 — inlet pipe; 3 — vane swirler of the "socket" type; 4 — nozzles; 5 — outlet pipe;
6 — retaining washer; 7 — dust hopper; *b* — vane type: 1 — chamber; 2 — inlet pipe; 3 — vane swirler of the "socket" type;
4 — annular vane swirler; 5 — outlet pipe; 6 — retaining washer; 7 — dust hopper [10]

The exclusion of inertial dust collectors from the layout schemes of cleaning systems, as well as the use of cyclones of outdated design as the first stage, negatively affects the resource, energy efficiency and operating costs. Dust collectors on counter swirling flows, due to the increased efficiency of separation of medium and small fraction particles, can significantly relieve more expensive and energy-intensive dust collecting equipment, increasing the operational characteristics of emission purification systems and reducing the cost of their operation.

Currently, the study of CSF devices and their introduction into various productions are conducted by several research teams of Russia. In the works of V.N. Azarov, S.A. Koshkarev, N.M. Sergina, D.P. Borovkov, etc. a number of design changes in the CSF devices have been proposed, and various schemes of dust cleaning systems have been developed, in which cyclones, CSF and bag filters are used [6]. For example, in order to increase the reliability of operation of CSF devices, including at the factories of the concrete industry, it is proposed in a number of designs to take the bottom inlet vortex generator outside the devices [6, 11]. In addition, a number of devices with several upper inlets have been developed, for example, dust collectors (Fig. 3) [6].

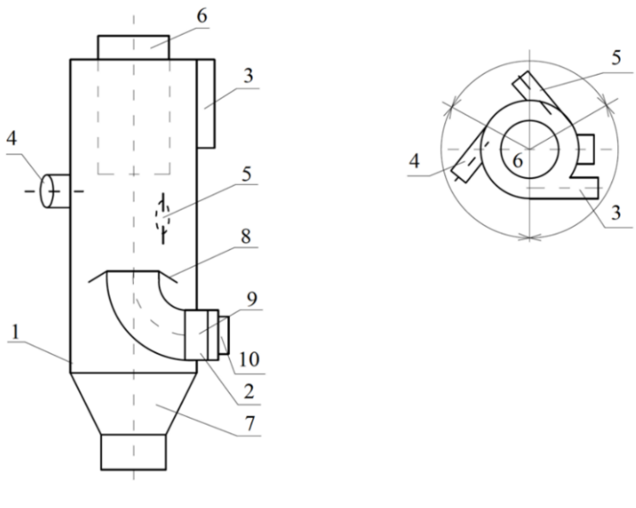


Fig. 3. Diagram of the DC-CSF dust collector:
1 — housing; 2 — inlet of the secondary dust flow; 3, 4, 5 —inlets of the primary dust flow;
6 — outlet of the purified air; 7 — dust collector;
8 — jack washer; 9 — swirler; 10 — hatch for cleaning [10]

Works by E.I. Boguslavskiy, V.N. Azarov and others are devoted to stochastic models for CSF calculation [6, 11]. In works [12–15], the calculations of fractional efficiency of CSF devices using modern software systems were carried out.

As follows from the analysis of literature sources on this topic, at present, the design schemes of CSF dust collectors differ mainly in the type of secondary flow inlet (with an external and internal vortex generators), and the main efforts of researchers are aimed at studying aerodynamic parameters and creating calculation techniques. However, it is the improvement of the design of the secondary inlet that allows reducing the value of the breakthrough coefficient. The main feature characteristic of dust particles formed during the production of reinforced concrete products is their fine dispersion [16, 17]. Particles of small fractions are more prone to slip, especially in conditions of insufficient intensity of the secondary flow twist. One of the factors influencing the intensity of the twist is the geometric configuration of the secondary inlet, which introduces serious distortions into the kinematic structure of the flow in the lower region of the separation chamber of the CSF dust collectors [17]. In addition to reducing the overall intensity of the flow twist, when it interacts with the secondary inlet pipe, undesirable idle vortices occur that can cause entrainment of already captured dust particles [18].

The aim of this study was to analyze the factors that had a decisive influence on the value of the breakthrough coefficient of fine dust particles of reinforced concrete production and to develop appropriate design solutions for the design of the lower inlet of the swirling flow of CSF dust collectors.

Materials and Methods. The study of the parameters of movement of dust-air mixture in the lower part of the separation chamber of the dust collector with counter swirling flows was carried out by means of a computational experiment. The kinematic model of the motion of gas dust collector in the separation chamber on the counter swirling flows, implemented using the numerical solution of Navier-Stokes equations and continuity, was closed using the k-ε turbulence model in the COSMOSFlowWorks application for the SolidWorks software.

To solve this problem, models of CSF dust collector of several standard sizes with standard strapping were built. The dimensions of the main elements of the vortex dust collector were accepted as typical for CSF and CIF series of vortex dust collectors. Dust collectors with separation chamber diameters of 160, 350 and 700 mm were used as prototypes in the construction of models. Figure 4 provides the scheme of a computational model (made with the use of SolidWorks numerical modeling environment). At the first stage, initial and boundary conditions were set to bind the mathematical model to a specific task and to the computational domain.

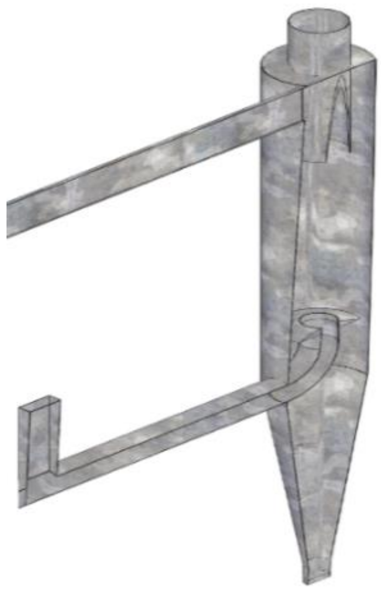


Fig. 4. Scheme of computational model of vortex dust collector

The experimental research plan included three series of experiments conducted for different values of the flow rate supplied to the inlet section of the lower vortex generator (zone B) (Fig. 5).

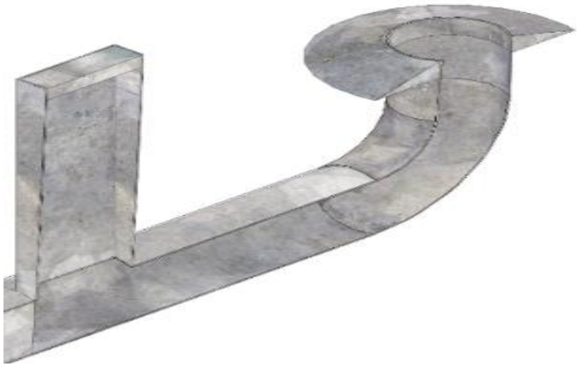


Fig. 5. Cross section of the lower inlet pipe of the secondary dust and gas flow of the CSF dust collector

The scheme for determining the design parameters of the lower inlet is shown in Figure 6 (made with the use of SolidWorks numerical modeling environment).

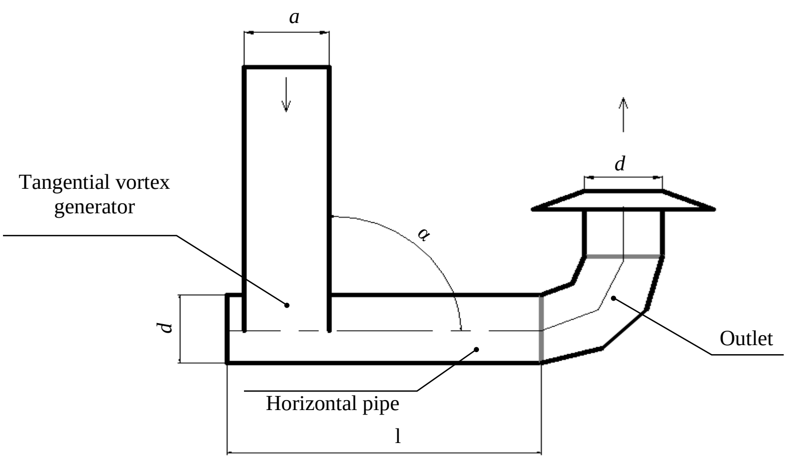
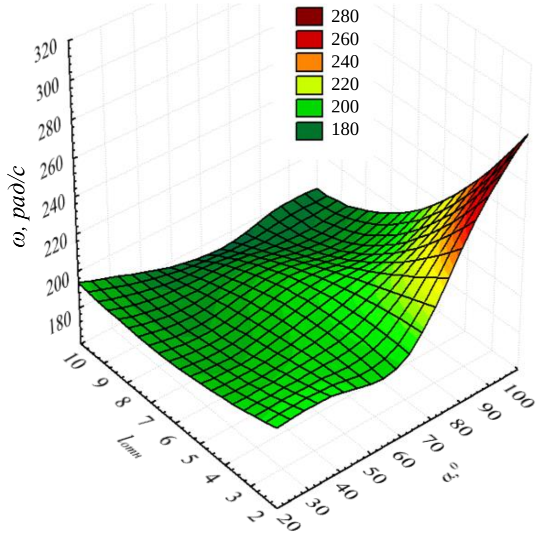


Fig. 6. Characteristic design dimensions of the secondary flow vortex generator:
l — length of the swirling flow pipe related to the diameter (*d*);
a — relative width of the tangential branch pipe related to the diameter (*d*);
α — angle of entry of the tangential pipe

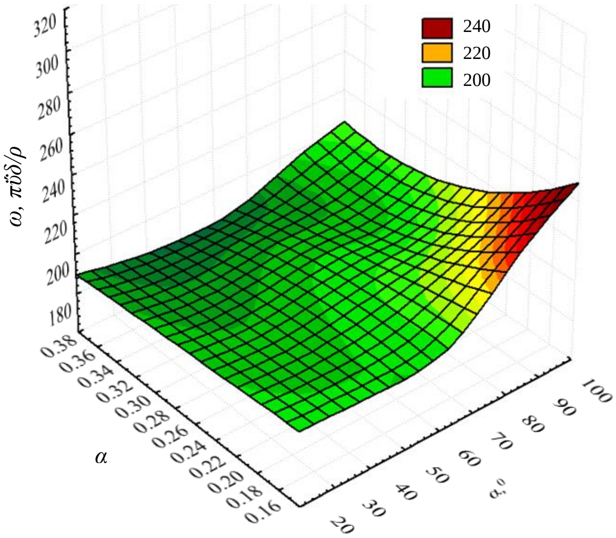
After calculating the values of gas flow velocities characterizing the flow field in the calculated sections, the trajectories of dust particles of fractions characterized by the values of equivalent diameters of dust particles $d_ч$ = *10–100 microns* were calculated. Based on the results obtained, the fraction of the number of particles entering the volume of the separation chamber of the vortex dust collector through the upper and lower inlets was calculated. Also, for the aerodynamic modes specified by the range of values of the average Reynolds numbers Re = 8 700–28 000 over the section of the separation chamber, the values of the aerodynamic drag of the dust collector and angular velocities in the wall zone of the separation chamber, which had a determining value on the magnitude of the dust particle breakthrough, were calculated.

Full-scale measurements of the breakthrough coefficient were carried out on the existing dust collectors in accordance with standard measurement methods in NIIOGAZ dispersion flows using Pitot pneumatic tubes, micromanometers MMN – 250, electric respirators, and AFA filters.

Results. Figures 7–9 (made with the use of SolidWorks numerical simulation environment) present the results of calculations of angular velocity values obtained during the variation of design characteristics of the lower inlet at Re = 8 700–28 000 in the form of response surfaces.

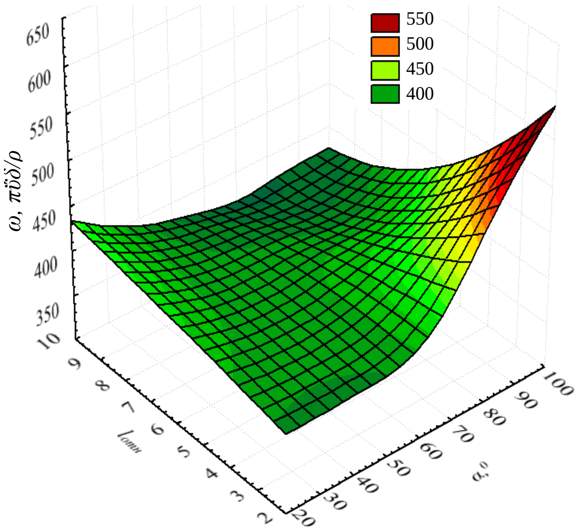


a)

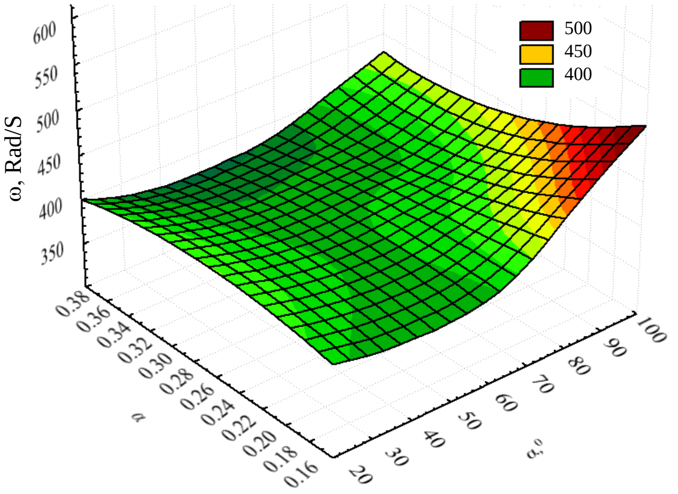


b)

Fig. 7. Results of calculations of angular velocity values ω, rad/s, at Re = 8,700:
a — dependence of angular flow velocity on the values of relative length of the branch pipe of the swirling flow of the angle of entry of the tangential branch pipe ω ($l_{отн}$;α); *b* — dependence of angular flow velocity on the values of the relative width of the tangential branch pipe of the flow and the angle of entry of the tangential pipe ω ($l_{отн}$;α).

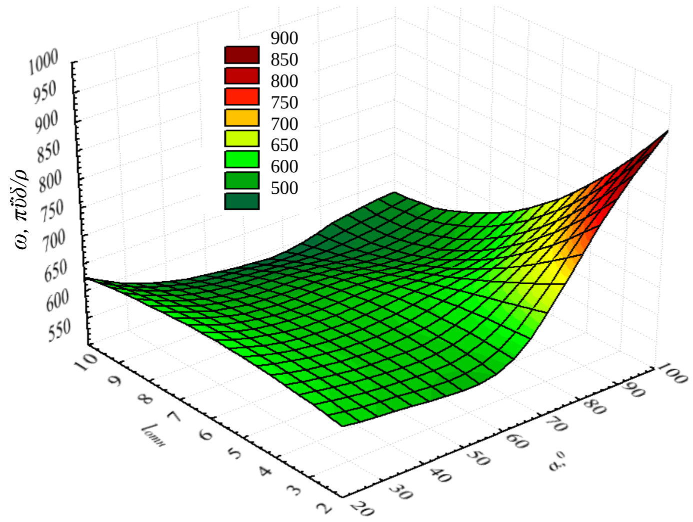


a)

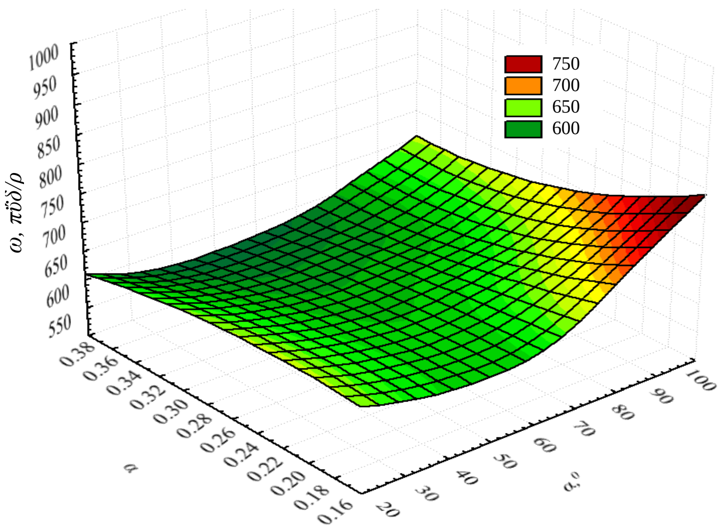


b)

Fig. 8. Results of calculations of tangential velocity values ω, rad/s, at Re = 17,900:
a — dependence of angular flow velocity on the values of the relative length of the swirling flow branch pipe and the angle of entry of the tangential branch pipe ω ($l_{отн}$;α); *b* — dependence of angular flow velocity on the values of the relative width of the tangential branch pipe and the angle of entry of the tangential branch pipe ω ($l_{отн}$;α)



a)



b)

Fig. 9. Results of calculations of angular velocity values ω, rad/s, at Re = 28,000:
a — dependence of angular flow velocity on the values of the relative length of the swirling flow branch pipe and the angle of entry of the tangential branch pipe ω ($l_{отн}$;α); *b* — dependence of angular flow velocity on the values of the relative width of the tangential branch pipe and the angle of entry of the tangential branch pipe ω ($l_{отн}$;α)

Figure 10 (made with the use of SolidWorks numerical simulation environment) shows the distribution of tangential velocities values of the gas flow along the section of the separation chamber at the cut-off level of the secondary flow outlet pipe.

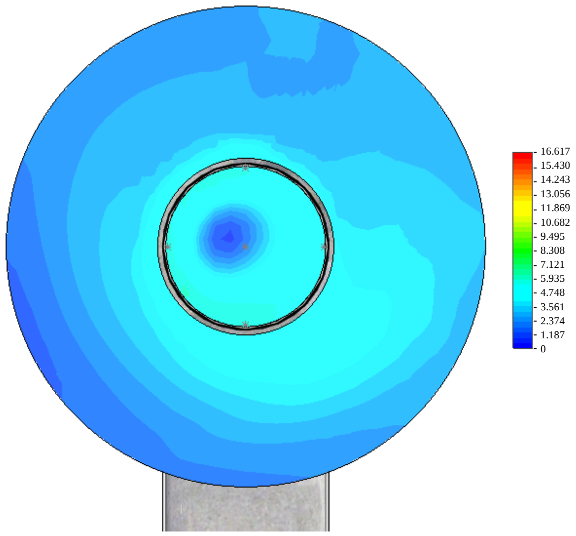


Fig. 10. Distribution of tangential velocities values of gas flow along the section of the separation chamber at the cut-off level of the secondary flow outlet pipe (m/s)

To clean the dust emissions of reinforced concrete production, a design of a CSF dust collector with an axial secondary flow supply for the use in reinforced concrete plants was proposed (Fig. 11) [19].

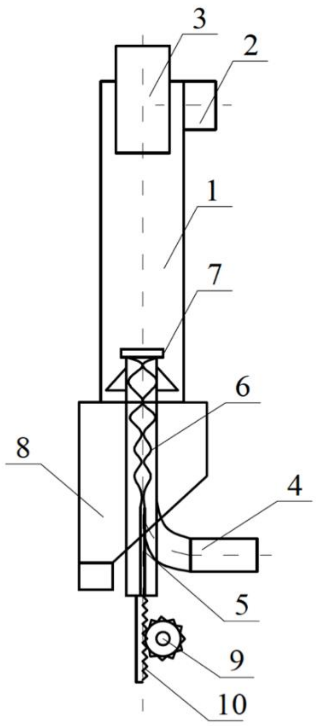


Fig. 11. Diagram of the device of a vortex dust collector with a screw-type swirler: 1 — cylindrical separation chamber; 2 — tangential inlet of the cleaned flow; 3 — coaxial exhaust pipe; 4 — axial pipe of primary inlet; 5 — screw type vortex generator; 6 — screw swirler; 7 — conical jack washer; 8 — dust collection hopper; 9 — gear wheel; 10 — gear rack [19]

At the second stage, full-scale measurements of the values of the breakthrough coefficient for fine dust of enterprises producing reinforced concrete products were carried out on standard CSF dust collectors and on the devise of the proposed design. The dependencies obtained in the course of experimental studies are shown in Figure 12. For comparison, the figure also shows the results obtained during the tests of the CSF of the classical design (curve 4).

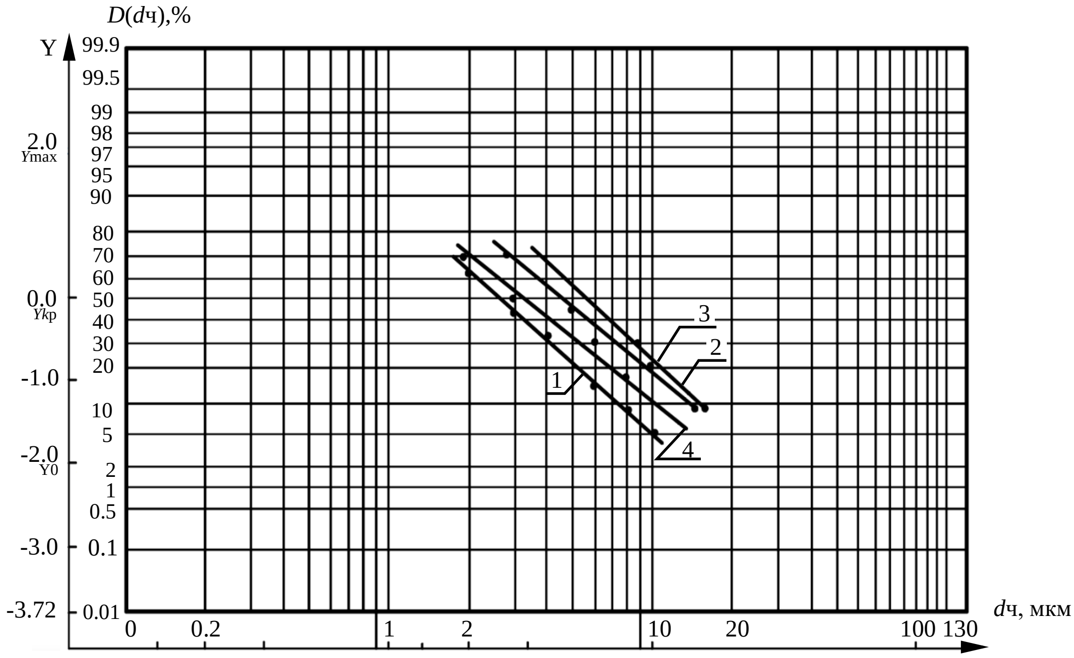


Fig. 12. Results of experimental studies of the breakthrough functions of the CSF dust collectors:
1 — CSF-200; 2 — CSF-400; 3 — CSF-600 with coaxial inlet; 4 — CSF-200 designs by V.D. Kononenko

Discussion and Conclusion. The results obtained during computational experiments strongly support the assumption that there is a negative influence of the secondary inlet pipe on the kinematic structure of the flow in the lower part of the separation chamber of dust collectors on counter swirling flows. From the data presented in Figure 10, it follows that the axis of rotation of the flow is offset from the axis of the separation chamber. This leads to a decrease in the useful effect of the vortex effect, which consists in increasing the intensity of the twist due to the interaction of unidirectionally twisted flows.

The mismatch of the axis of rotation of the swirling flow with the axis of the separation chamber, which is also the axis of rotation of the primary swirling flow formed by the upper tangential inlet, leads to a noticeable increase in the magnitude of dust particles breakthrough. This fact is explained by the formation of idle vortices at the confluence boundaries of non-coaxial swirling flows. The consequence of this is carrying-away of dust particles already caught or trapped in the wall zone. Being torn out of the wall stream, or blown up by an idle vortex, dust particles fall into the secondary stream, and, due to its opposite orientation, are carried away into the pure gas pipe.

It should be noted that this effect is most pronounced on particles of small fractions, which are characterized by a significant predominance of aerodynamic forces over mass ones. And it is this fact that makes the task of eliminating the negative influence of the secondary branch pipe, which introduces undesirable distortions during the secondary swirling flow, especially relevant in the conditions of using CSF devices in reinforced concrete production, for which dust emissions are characterized by the presence of a large proportion of fine dust particles.

To eliminate the described problem, the use of a coaxial inlet of the secondary flow is proposed (Fig. 12). The main feature of the proposed design of the vortex dust collector is the use of a coaxial inlet of the secondary swirled flow, achieved through the use of screw-type twirlers. The use of such a layout scheme makes it possible to optimize the movement of the swirling flow in the lower part of the separation chamber, as well as reduce the likelihood of suction. The absence of a radial branch pipe of the secondary flow that overlaps a part of the live section of the separation chamber of dust collectors of traditional design allows avoiding undesirable disruption of the kinematic structure of the flow. The absence of idle swirls of the flow in the lower part of the separation chamber makes it possible to significantly reduce secondary carrying-away of dust particles located in the wall zone of the flow, which, in turn, reduces the total amount of dust particle breakthrough. In addition, the use of coaxial inlets makes it possible to obtain some reduction in the aerodynamic drag of CSF dust collectors, increasing their energy efficiency.

The proposed design of the coaxial inlet of the secondary swirling flow allows us to solve the problem. This fact is confirmed by the results of pilot tests, the results of which are shown in Figure 12. Curve 3, which characterizes the function of dust particles breakthrough in the device with a coaxial inlet, is located above the others, which indicates a smaller breakthrough of particles of all fractions.

Thus, the use of dust collectors on counter swirling flows with coaxial secondary inlet at enterprises producing reinforced concrete products makes it possible to achieve a high degree of purification of dust emissions without resorting to expensive replacement of inertial dust collectors with devices of other types.

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