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DETERMINATION OF OPTIMAL QUANTITIES AND SIZES OF TANGENTIAL SWIRLERS OF VORTEX DEVICES IN SOLIDWORKS FLOW SIMULATION.

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Abstract

Heat transfer processes in contact heat exchangers are largely determined by the hydrodynamic regimes of the apparatus. The aim of the research is to determine the optimal quantities and sizes of tangential swirlers of the vortex apparatus, which ensure the highest efficiency of its operation. The paper presents the data obtained when studying various designs of gas flow swirlers of a vortex apparatus and their effect on the structure of swirling flows by virtual modeling of trajectories by the SolidWorks software in the Flow Simulation application. A comparative analysis of these parameters is carried out for different values of the swirl coefficient (dimensions of the swirler slots) and the number of tangential swirlers of the gas flow. As a result, the optimal parameters of tangential swirlers were established for effective design of the swirling flow process.

Keywords: vortex apparatus; number and size of swirlers; swirl ratio; hydraulic resistance; vortex; SolidWorks Flow Simulation.

ВИЗНАЧЕННЯ ОПТИМАЛЬНИХ КІЛЬКОСТЕЙ ТА РОЗМІРІВ ТАНГЕНЦІАЛЬНИХ ЗАВИХРЮВАЧІВ ВИХРОВИХ ПРИСТРОЇВ У SOLIDWORKS FLOW SIMULATION.

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Анотація

Процеси теплообміну в контактних теплообмінниках в значній мірі визначаються гідродинамічними режимами апарату. Метою даного дослідження є визначення оптимальних кількостей та розмірів тангенціальних завихрювачів вихрового апарату, що забезпечують найбільшу ефективність його роботи. У статті представлені дані, отримані при дослідженні різних конструкцій завихрювачів газового потоку вихрового апарату і їх впливу на структуру закручених потоків шляхом віртуального моделювання траєкторій за допомогою програми SolidWorks у додатку Flow Simulation. Проведено порівняльний аналіз цих параметрів для різних значень коефіцієнта завихрення (розмірів щілин завихрювача) та кількості тангенціальних завихрювачів потоку газу. У результаті були встановлені оптимальні параметри тангенціальних завихрювачів для ефективного проектування процесу закрутки потоку.

Ключові слова: вихровий апарат; кількість і розмір завихрювачів; коефіцієнт завихрення; гідравлічний опір; вортекс; SolidWorks Flow Simulation.

ОПРЕДЕЛЕНИЕ ОПТИМАЛЬНЫХ КОЛИЧЕСТВ И РАЗМЕРОВ ТАНГЕНЦИАЛЬНЫХ ЗАВИХРИТЕЛЕЙ ВИХРЕВЫХ УСТРОЙСТВ В SOLIDWORKS FLOW SIMULATION.

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Аннотация

Процессы теплообмена в контактных теплообменниках в значительной степени определяются гидродинамическими режимами аппарата. Целью данного исследования является определение оптимальных количеств и размеров тангенциальных завихрителей вихревого аппарата, обеспечивающих наибольшую эффективность его работы. В статье представлены данные, полученные при исследовании различных конструкций завихрителей газового потока вихревого аппарата и их влияния на структуру закрученных потоков путем виртуального моделирования траекторий с помощью программы SolidWorks в приложении Flow Simulation. Проведен сравнительный анализ этих параметров для различных значений коэффициента завихрения (размеров щелей завихрителя) и количества тангенциальных завихрителей потока газа. В результате были установлены оптимальные параметры тангенциальных завихрителей для эффективного проектирования процесса закрутки потока.

Ключевые слова: вихревой аппарат; количество и размер завихрителей; коэффициент завихрения; гидравлическое сопротивление; вортекс; SolidWorks Flow Simulation.

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Introduction

Recently, highly efficient vortex devices have been developed and are successfully used in industry for intensifying heat and mass transfer processes [1–6]. The rotating flow intensifies technological processes by increasing the contact surface of the phases and, accordingly, the coefficients of heat and mass transfer, increases the specific productivity due to the high permissible speed of the media and efficiency by one order of magnitude, which makes it possible to reduce the size and metal consumption of equipment by the same amount, as well as combine several processes in one apparatus [7; 8].

Gas rotation devices used in contact devices are divided into axial and tangential. Accordingly, in devices with an axial swirler, a continuous vortex flow is formed, which retains its characteristics throughout the entire path. Such devices have high hydraulic resistance.

In apparatuses with tangential swirlers, the vortex is usually created at the inlet and the flow swirl damps along the height of the apparatus [9; 10]. Tangential swirlers are the most promising because they are more efficient and easy to manufacture [11].

The complexity of vortex flows requires the use of the most modern research methods in their study. The significant influence of flow swirling on the intensity of heat and mass transfer during their flow is well known. When swirling is useful, it makes sense to determine the optimum values for the swirl ratio, swirling gas flow rates and liquid flow rates [12; 13]. Improving the design in order to increase the efficiency of vortex devices with tangential swirlers requires the creation of a large number of experimental devices of various designs, as well as a huge number of experiments. One of the ways to reduce the time and money spent on improving the design of devices is the computer simulation of the processes occurring in them and the analysis of the obtained virtually hydrodynamic parameters [14–16].

At present, research into the hydrodynamics of vortex devices using CAD/CAE systems is becoming increasingly important, in which it is possible to analyze how the structure of the device will behave under certain operating conditions. The main feature of the work is the substantiation of the possibility to improve the design of hollow vortex apparatuses with tangential swirlers based on computer simulation of hydrodynamic processes in the SolidWorks environment in the Flow Simulation application [17; 18].

The Flow Simulation application makes it possible to simulate the hydrodynamic conditions of the process. Using the Flow Simulation program, the aerodynamic processes that occured in the swirling flow of the vortex device were simulated, and the numerical values of the main characteristics of the flow were obtained.

Experimental

To study the operation of vortex devices with different numbers of tangential swirlers of the gas flow, swirl coefficients of the flow hydrodynamic model and its parameters in the vortex device, three-dimensional modeling was carried out under normal external conditions. Air was used as a working medium. In order to study the aerodynamics of a swirling single-phase flow, simulations were preliminarily carried out without liquid supply to the vortex apparatus [15].

The swirl coefficient is determined from the ratio:

$$A = F_{ap} / F_s = w_s / w_{ap} \tag{1}$$

where F_{ap} – is the cross-sectional area of the apparatus, m^2; F_s – cross-sectional area of the slots of the tangential nozzles for gas injection, m^2; w_s – is the gas velocity in the swirler slots, m/s; w_{ap} – fictitious (arriving at the cross-sectional area of the apparatus) gas velocity, m/s.

The helix angle β was determined by the formula:

$$tg\beta = \frac{S}{2\pi R_a} = \frac{1}{A\varphi} \tag{2}$$

where S – is the step of the air stream; R_a is the average radius of the swirling air stream; φ = F_j/F_p is the flow area ratio; F_j and F_p are the cross-sectional areas of the jet and tube, respectively.

From equation (2), you can determine the pitch of the jet:

$$S = 2\pi R_a \cdot tg\beta = \frac{2\pi R_a}{A\varphi} \tag{3}$$

The attenuation of the tangential velocity was estimated by the relative increase in the pitch of the swirling jet, which was determined by the formula:

$$S_{ri} = s_i / s_e \tag{4}$$

where s_i – the step of the jet in the initial section of the working tube; s_e – jet pitch in the end zone of the vortex tube.

As an object of research, a three-dimensional model of vortex apparatuses was created using the

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SolidWorks software. While modeling and simulating the working processes of the swirlers, thermophysical, thermobaric, and chemical parameters of the process has not been taken into account in our work. However, various quantities and sizes of gas flow tangential vortices slits were designed with the following parameters:

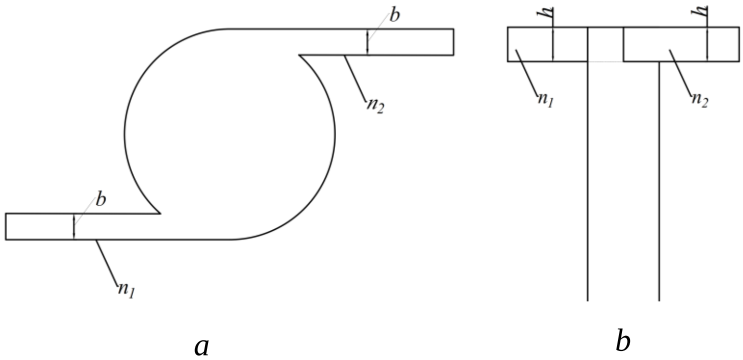


Fig. 1. The scheme of the vortex apparatus. *a* - top view; *b*-front view.

n_1, n_2-tangential gas vortices; $n = n_1 + n_2 +..+ n_x$ – the quantity of tangential swirlers; h and b - the height and width of the swirler slots;

- the coefficient of twist with the number of tangential swirlers n=2: A=2, (h=100 mm, b=19.625 mm); A=4, (h=100 mm, b=9.81 mm); A=6 (h=100 mm, b=6.54 mm); and A=8 (h=100 mm, b=4.9 mm); with the number of tangential swirlers n= 4: A=2, (h=100 mm, b=9.81); A=4, (h=100 mm, b=4.9 mm); 6 (h=100 mm, b=3.27 mm); and 8 (h=100 mm, b=2.45 mm);

- the diameter of the vortex apparatus D=100 mm, height H=1200 mm, respectively, the ratio of the height to the diameter of the vortex tube will be equal to: $H/D = 12$;

- the change in the degree (coefficient) of twist was carried out by changing the cross-sectional area of the slot F_s and the number of gas swirlers;

- the cross-sectional area of the slot F_s is changed only by the width of the slot, and the height remained equal to h=100 throughout the entire modeling process;

- in all models of the apparatus, the axial, average gas flow velocity at the inlet of the apparatus was set as the boundary conditions, which was equal to 20 m/s;

- ambient pressure 101325 Pa,

- air temperature 20 °C.

Three-dimensional models of vortex devices are shown in Fig. 2 *a* with the number of tangential swirlers n=2 and in Fig. 2 *b* with the number of swirlers n=4.

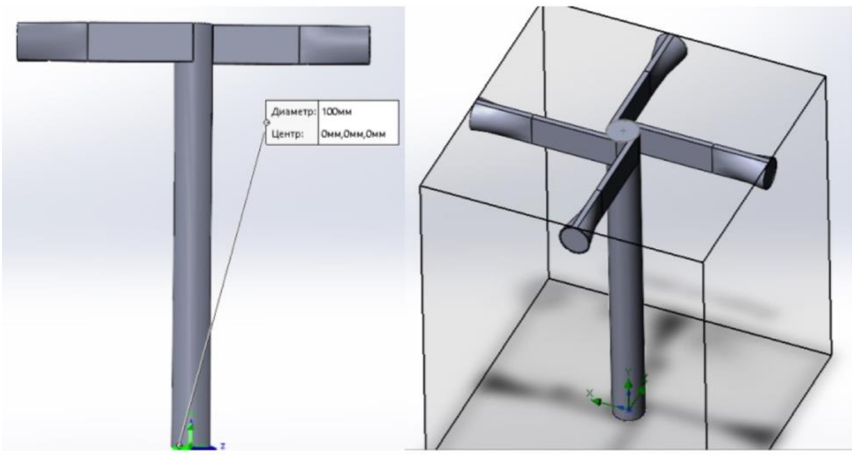
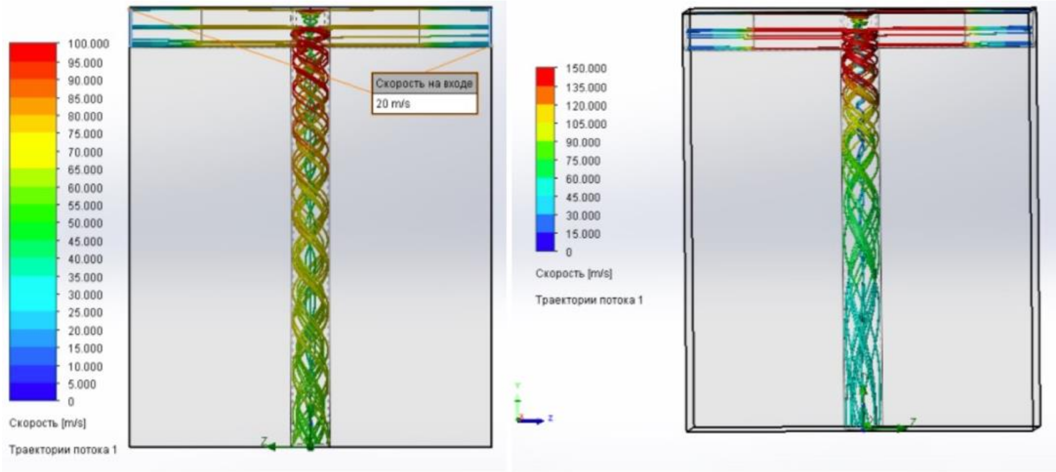


Fig. 2. Three-dimensional models of vortex devices with a number of tangential swirlers: *a* – $n = 2$; *b* – $n = 4$.

Results and Discussion

Fig. 3 shows the structures of air flows in dry vortex apparatuses with the ratio of the height of the apparatus working part to its diameter equal to H/D=12, with two tangential swirlers and the swirl coefficients A=2 (Fig. 3 *a*) and A=4 (Fig. 3 *b*).



a *b*

Fig. 3. Structures of gas flows in vortex devices with two tangential holes and swirl coefficients: *a* - *A*=2; *b* - *A*=4.

Figure 3*a* shows that in the apparatus with the coefficient of twist A=2, there is a slight attenuation of the tangential component of the velocity along the height of the apparatus. We can say that the vortex motion of the air flow in this apparatus is fairly well preserved by 85–90 % of the working part of the apparatus. Only in the lower part of the tube, which is about 10–15 % of the height of the vortex tube, there was a slight attenuation of the tangential velocity. The number of steps of swirling jets in this apparatus was equal to five. The analysis of the obtained results showed that in a vortex apparatus with the ratio H/D=12 and A=2 due to the attenuation of the tangential component of the velocity, the pitch of the swirling jet S increased from 20 cm to 39,0 cm, i.e. the relative increase in the pitch of the swirling jet was 1,95, the helix angle β increased from 33° to 57°.

In a vortex apparatus with a height-to-diameter ratio equal to H/D=12 and a twist coefficient A=4 (Fig. 3*b*), there was a noticeable increase in the swirl pitch and attenuation of the tangential velocity, starting from the second half of the working tube along its height. In this apparatus, the number of steps of swirling jets was 3. In an apparatus with H/D=12 and A=4, the attenuation of the tangential velocity led to an increase in the step S from 19 cm to 56 cm, while the relative increase in the jet step was equal to 2,947. At the same time, the helix angle β increased from 40° to 70° [5; 6].

Thus, with the same ratio of the height of the apparatus to its diameter, equal to H/D=12 and an average gas flow rate equal to 20 m/s, an increase in the twist coefficient from 2 to 4 leaded to a significant increase in the helix angle β and the pitch of the swirling jet S, i.e. to a significant attenuation of the tangential air flow velocity. In this case, the relative increase in the pitch of the swirling jet was 51 %. In devices with two tangential holes, with a twist coefficient of both A=2 and A=4, the air flow rate did not differ much.

Based on the data obtained, it was found out that more efficient swirling of the gas flow was carried out in the apparatus with the swirl coefficient A=2.

Fig. 4. shows the structures of swirling gas flows in vortex devices with four tangential holes and with the following values of the swirl coefficient: A=2 (Fig. 4 *a*), A=4 (Fig. 4 *b*).

In fig. 4*a*, it can be seen that in a device with a twist coefficient A=2, an increase in the jet pitch is observed, especially after 55–60 % of the working tube height, although the vortex motion of the air flow remains along the entire length of the tube. The total pitch of the swirling jet in this apparatus is equal to three. The results showed that in a vortex apparatus with a ratio of H/D=12 and A=2, due to the attenuation of the tangential velocity, the pitch of the swirling jet S increased from 33 cm to 60 cm, and the helical line rise angle β increased from 41° to 65°.

In a vortex apparatus with a height-to-diameter ratio equal to H/D=12 and a twist coefficient A=4 (Fig. 4 *b*), the vortex motion of the air flow is poorly preserved along the tube height. In this case, the total number of steps of the swirling jet was 2. In the apparatus with H/D=12 and A=4, the attenuation of the tangential velocity led to an increase in the step S to 90 cm, and the helical line rise angle β to 73°.

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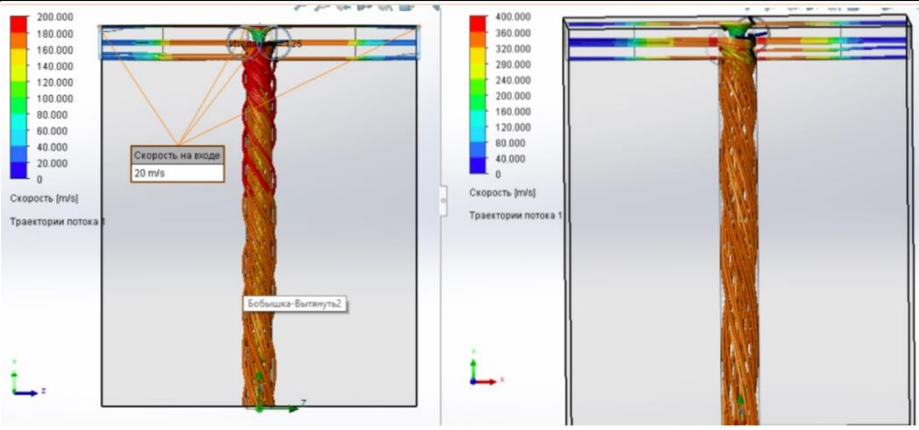
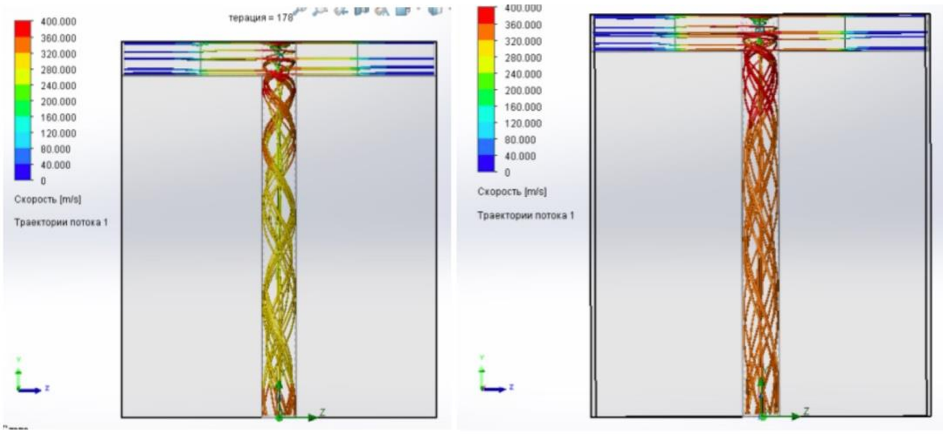


a *b*

Fig. 4. Structures of flows in vortex devices with four tangential holes and swirl coefficients: *a* – A = 2; *b* – A = 4.

Thus, in a vortex apparatus with four tangential holes at the same ratio of the height of the apparatus to its diameter equal to H/D=12 and an average gas flow rate equal to 20 m/s, an increase in the twist coefficient from 2 to 4 leads to an increase in the ascent angle of the helical line β and the pitch of the swirling jet S, i.e. to a significant attenuation of the tangential air flow velocity.

Fig. 5 shows the structure of flows in vortex devices with two tangential holes and swirl coefficients A=6 (Fig. 5 *a*) and A=8 (Fig. 5 *b*).



a *b*

Fig. 5. Structures of flows in vortex devices with two tangential holes and swirl coefficients: *a* – A = 6; *b* – A = 8.

Fig. 5*a* shows that in the apparatus with the degrees of twist A=6, the vortex motion of the air flow is maintained along the entire length of the tube. However, the pitch of the swirling jet is rather large. A noticeable damping of vortices is observed after 30 % of the working tube height. The number of steps of the swirling jet in this apparatus is equal to 2–2.5.

In a vortex apparatus with a ratio of height to diameter equal to H/D=12 and degrees of swirling A=8 (Fig. 5 *b*), the vortex motion of the air flow is poorly preserved along the entire length of the tube. In this case, the number of steps of the swirling jet was 1.5.

The analysis of the obtained results showed that in a vortex apparatus with the ratio H/D=12 and A=6, due to the attenuation of the tangential velocity, the pitch of the swirling jet S increased from 40 cm to 65 cm, the helical line rise angle β increased from 59° to 69°. In the apparatus with H/D=12 and A=4, the damping of the tangential velocity led to an increase in the step S up to 75 cm, the helix angle β from 63° to 73°.

Thus, with the same ratio of the height of the apparatus to its diameter, equal to H/D=12 and an average gas flow rate equal to 20 m/s, an increase in the twist coefficient from 4 to 6 led to an increase in the jets S [7], i.e. to a significant attenuation of the tangential air flow velocity.

Fig. 6 shows the structures of flows in vortex devices with four tangential holes and swirl coefficients A=6 (Fig. 6 *a*) and A=8 (Fig. 6 *b*).

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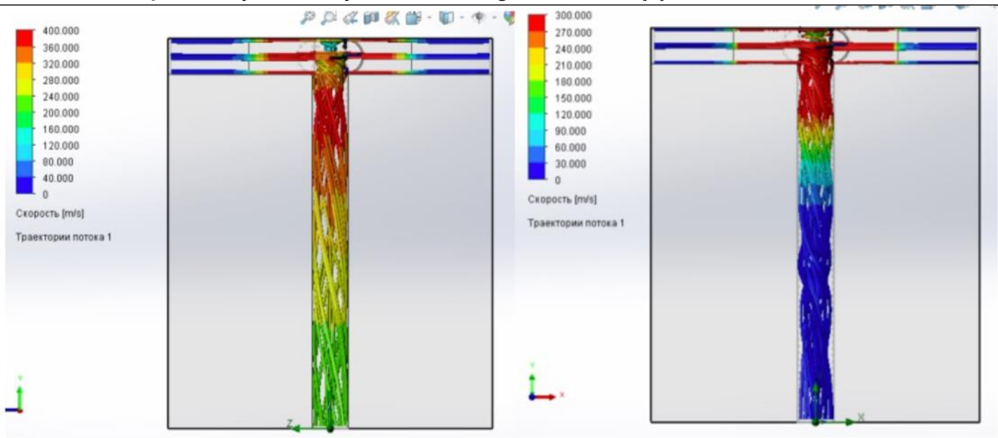

a *b*

Fig. 6. Structures of flows in vortex apparatuses with four tangential holes and swirl coefficients:
a − A = **6**; ***b*** − A = **8**.

Fig. 6*a* shows that in an apparatus with a twist coefficient A=6, the vortex motion of the air flow is poorly maintained along the height of the tube. The number of steps of the swirling jet in this apparatus is equal to one.

In a vortex apparatus with a height-to-diameter ratio equal to H/D=12 and a swirl ratio A=8 (Fig. 6 *b*), the vortex motion of the air flow is maintained almost over the entire height of the tube. But in this case, the number of steps of the swirling jet was also equal to one.

An analysis of the obtained results showed that in a vortex apparatus with a ratio of H/D=12 and A=6, due to the attenuation of the tangential velocity, the pitch of the swirling jet S increased to 100 cm, the ascent angle β of the helical line increased to 78°. In the apparatus with H/D=12 and A=4, the damping of the tangential velocity led to an increase in the step S up to 75 cm, and the helix elevation angle β from 63° to 75°.

Thus, with the same ratio of the height of the apparatus to its diameter, equal to H/D=12 and an average gas flow rate equal to 20 m/s, an increase in the twist coefficient from 6 to 8 led to an increase in the jets S, i.e. to a significant attenuation of the tangential component of the air flow velocity.

Conclusion

The results on the structure of swirling flows were obtained by virtual modeling using the SolidWorks software in the Flow Simulation application. The simulation showed that there is a direct relationship between the increase in the pitch of the swirling jet, i.e., the decrease in the number of steps and the attenuation of the tangential velocity. It is known that the smaller the jet (Eq. 3) and the greater the number of steps (Eq. 1) are, the more intense heat and mass transfer processes will take place, and the spray loss will also decrease. Simulation detects an increase in tangential velocity damping with increasing swirl ratio and the number of swirlers. It should be noted that with an increase in the degree of swirl with the same number and height of swirlers, the thickness of the jet increases.

Thus, by means of computer modeling, detailed data were obtained on the nature of the attenuation of the tangential component of the swirling flow velocity in vortex devices with various quantities and sizes of tangential gas flow swirlers and, accordingly, swirl coefficients, which made it possible to exclude unpromising swirler designs from consideration and substantiate ways to further improvement of the devices of this type.

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