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Intensification of convective heat exchange processes in boilers of local heat supply systems by improving the design of surface turbilizers

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ABSTRACT: The article discusses improving the efficiency of boilers in the local heat supply system of social facilities. Based on the conducted research, the use of structures in the form of spherical depressions and bulges is recommended to increase the efficiency of convective heat transfer processes. The results of a numerical study conducted in the SolidWorks software environment have been obtained, which show a significant increase in the efficiency of such boilers. Calculation formulas for determining geometric non-standard shapes of depressions are presented.

I. INTRODUCTION

Currently, in remote regions of the republic, heat supply systems with a low-power coal-fired boiler are used for heating and hot water supply of social facilities. The advantages are relatively low capital and operating costs, as well as lower resistance along the gas and air path. The disadvantages of such boilers are the relative metal consumption, the increased value of the heat exchange surface area and the high temperature of the exhaust flue gases in the range of 230-250 ^{0}C. The main elements of the boiler are a furnace device and a convective part with a flat metal surface. Modern designs of heat exchange surfaces with highly efficient corrugations have 8-10 times the heat transfer area relative to flat smooth convective surfaces. The geometric shape of the corrugations determines the efficiency of heat exchange processes in the boiler unit. In most cases, corrugated metal sheets with a thickness of 0.55-1.2 mm are used. [1; 2; 3; 4].

II. METHODS AND MATERIALS

Currently, various improved designs of metal sheet corrugations are used to increase heat transfer with reducing hydrodynamic resistance. A long-term analysis of the efficiency of low-power boilers shows that one of the main reserves for increasing efficiency is the intensification of heat exchange processes through the use of efficient heat exchange surface designs [5; 6; 7].
Thus, the research is aimed at improving the efficiency of small heating boilers by intensifying the processes of hydrodynamics and heat exchange in its convective part, leading to energy and resource conservation, and the task is relevant. [5; 6; 8; 9].
The intensification of heat exchange in heat exchange units is currently carried out by a variety of methods [2; 3; 4; 5; 6]. In heat exchange installations with single-phase heat carriers, surface turbulators, surfaces with artificial roughness, finned surfaces, surfaces with vortices, vibration of the heat exchange surface, pulsations of the heat carrier flow, etc. are most often used.

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Currently, with the intensification of heat exchange processes, there is an increased interest in depressions and bulges. This is due to specific hydrodynamic properties, such as low hydraulic losses, the best thermal and hydraulic characteristics, unsteady fluctuations inside the depressions and the formation of numerous vortices behind them [2; 6; 9].
To increase the heat exchange characteristics while reducing the hydrodynamic resistance, it is proposed to manufacture turbulators in the form of spherical bulges and depressions located on both sides of the channel wall. Depending on the objectives of the study the location of the bulge or recess on the heat exchange surface is carried out in different ways, [2; 6; 9; 10; 11; 12].

III. RESULTS

Studies of the effect of intensifiers on the aerodynamic resistance of the channel were carried out on an experimental installation simulating the convective part of the boiler (Fig. 1).

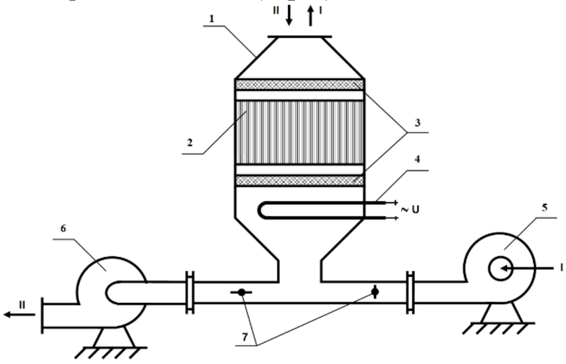

Fig. 1. Scheme of an experimental installation for studying the efficiency of heat exchange surfaces:

1- the body of the working chamber; 2- turbulator with spherical heat exchange surfaces; 3-air flow stabilizers; 4-electric heater for air heating; 5- fan; 6- exhaust fan; 7- dampers for switching the direction of air flow into the working chamber.

The installation is located vertically. The air supply is carried out in the lower part of the duct. The front panel of the channel is made of transparent organic glass. It is possible to visually study the shape of the turbulators on the nature of the movement of the gas stream. The channel dimensions are as follows: width 70 mm, height 6 mm, length 500 mm. Modules made of polymer material in the form of a hemisphere with various geometric characteristics were used as spherical surfaces [5; 7].
A differential pressure gauge MMH-240 with pulse tubes (d = 3 mm) was used to measure the resistance. The air velocity and flow rate were measured with an AV-2 anemometer. Channels with three bands of intensifiers arranged in a checkerboard pattern for three geometric types of intensifiers were studied. The intensifiers were arranged in a checkerboard pattern.

a) b)

Fig. 2. Constructions with recesses: a) with a sharp edge; b) with a smooth edge; D is the diameter of the recess; h is the height of the recess; r is the radius of the base of the recess.

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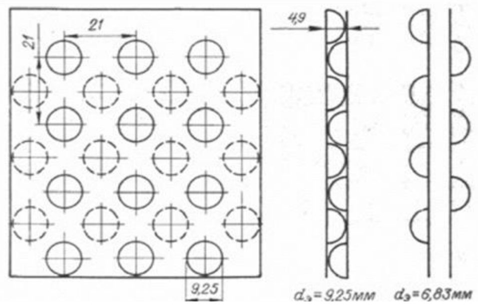

Fig. 3. Chessboard arrangement of depressions on one side and bulges on the other side of the wall of the heat exchanger.

The surface area of the depressions is calculated using the following formula:

$$S = S + S = \pi(2RH + r^2) \tag{1}$$

The total area of all the depressions is determined by the following formula:

$$S = n\ m\ S\ = \pi\ n\ m\ (2\ R\ H + r^2) \tag{2}$$

The radius of spherical depressions is determined by the following formula:

$$R=\frac{1}{2H}\sqrt{[\ (r+r_0)^2+H^2]\ \ [(r-r_0)^2+\ \ H^2]} \tag{3}$$

According to the stated purpose and objectives of the work, a numerical study of the turbulence of gas-liquid heat carrier fluxes in the SolidWorks software environment was performed. In the channels of the local hot water boiler, heat exchange surfaces are installed in the form of hemispherical depressions on one side and in the form of hemispherical projections on the other side.

Figures 4; 5; 6; 7; 8 show the results of a numerical study. Fig. 4 and Fig. 5 show changes in the temperature of flue gases in the convective part of the boiler. As can be seen, the flue gases cool significantly as they pass through the convective heat exchange surfaces. This process occurs due to the turbulence of the flue gas flow. Intensive turbulence of flue gas flows is formed due to the improved design of heat exchange surfaces.

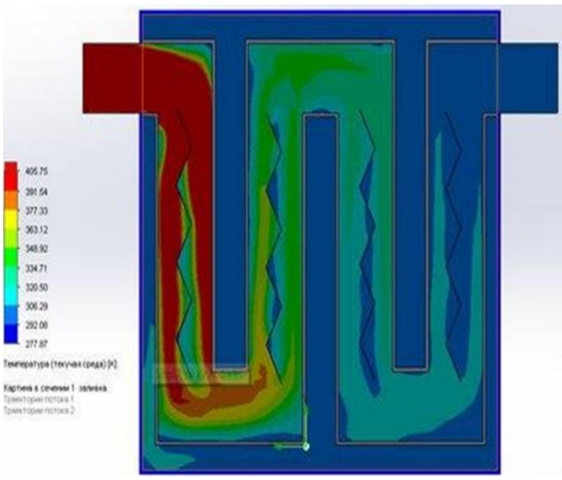

Fig. 4. Temperature change of flue gases in the channel of the local hot water boiler.

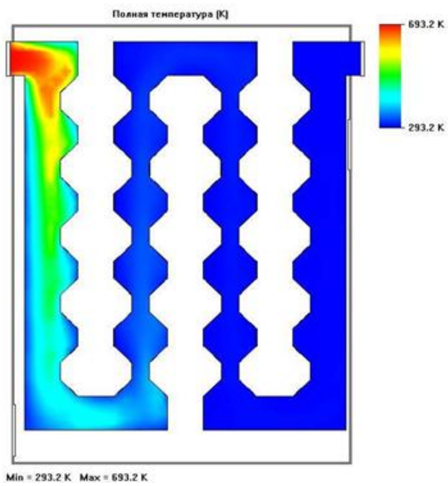

Fig. 5. Change in the temperature field of flue gases in the channel of a local hot water boiler.

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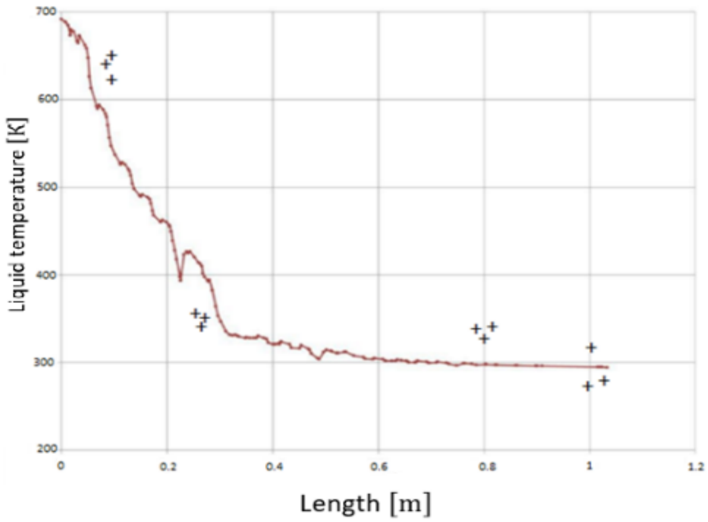

Fig. 6. Temperature change of flue gases in the channel of a hot water boiler unit: — calculation; + experiment

Figure 6 shows the changes in flue gas temperature as a graph. As it passes through the convective surfaces, the temperature of the flue gases decreases significantly in the initial part of the convective channel. This phenomenon is of interest for reducing the channel length. This can lead to a reduction in the overall metal consumption of the boiler unit.

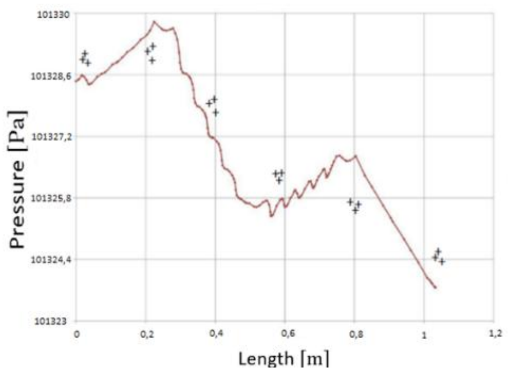

Fig. 7. Change in flue gas pressure in the duct of a hot water boiler unit: — calculation; + experiment.

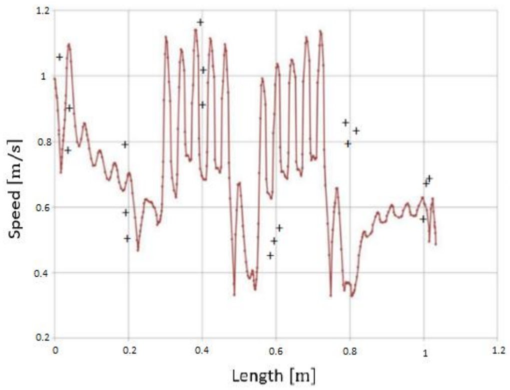

Fig. 8. Change in flue gas velocity in the channel of a hot water boiler unit: — calculation; + experiment.

The change in flue gas pressure in the duct of a hot water boiler is shown in Fig. 7. From there it can be seen that the nature of the numerical study curve is highly oscillatory. Pressure surges are obtained at the sites of changes in the direction of flue gas movement. The points on the graph represent experimental data that agree with the calculated data within the acceptable margins of engineering calculation errors.

Figure 8 shows the curve of the flue gas velocity along the length and the experimental points. A highly oscillatory curve is also observed when analyzing the velocity of flue gases. This phenomenon is explained in the same way as in Figure 6. However, the experimental points are relatively scattered from each other, which is explained by the presence of relatively high values of the Reynolds criterion for flue gas flow.

Thus, knowing the values of the Reynolds criterion, it is possible to calculate the Nusselt number and the heat transfer coefficient from the flue gases to the wall.

The classical heat transfer equation for stationary and non-stationary process modes is used for calculation:

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$$Q = K \cdot F \cdot \Delta t \tag{4}$$

$$К = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_{\text{СТ}}}{\lambda_{\text{СТ}}} + \frac{1}{\alpha_2}} \tag{5}$$

where: Q - is the amount of heat transferred during heat transfer, W (J); K - is the coefficient of heat transfer through the wall, W/(m^2·K); F - is the heat exchange surface, m2 ; Δt - is the temperature pressure ($\Delta t = t_1 - t_2$), ^{0}C; τ - time, s; $\delta_{ст}$ – wall thickness, m; $\lambda_{ст}$ – wall thermal conductivity coefficient, W/(m·K); a1 and a2 - heat transfer coefficients, W/(m^2·K); The Reynolds criterion:

$$Re = \vartheta \cdot d/\gamma \tag{6}$$

ϑ - is the average flow velocity along the pipeline section, m/sec; γ - is the kinematic viscosity of the measured medium in m^2/sec; d - is the diameter of the pipeline, m;

The Nusselt Criterion:

$$Nu = \alpha \cdot d/\lambda \tag{7}$$

α - is the heat transfer coefficient, W/(m^2· K); d - is the characteristic size, m; λ - is the thermal conductivity coefficient of the medium W/(m · K).

IV. CONCLUSION

The implementation of heat exchange surfaces in the form of spherical depressions and bulges has shown the possibility of increasing the values of the Reynolds and Nusselt numbers. Especially in places where the direction of movement of flue gases changes, spikes in the curves of graphs and dots are determined in the direction of increasing the values of flue gas pressure and velocity. As the curves of the graphs approach the end of the channel, a relatively slow decrease in the temperature of the hot heat carrier is observed. This makes it possible to shorten the length of the boiler channel with increased productivity and a reduction in its metal consumption. Calculation formulas for determining non-standard geometric shapes of depressions and bulges are presented.

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