EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER IN INTERFIN CHANNELS OF PUNCHED SPIRAL TUBE FINNING

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Abstract: To reduce the metal consumption of boilers of steam-turbine power units and waste-heat boilers of gas-steam turbine units, the spiral-tape finning of low-temperature convection heating surfaces is applied. However, the heat transfer in the bundles of such tubes has not been studied sufficiently, the influence of the geometric dimensions of the cut portion of the fins has not been experimentally investigated. In most heat exchange calculation methods, based on the generalization of the results of experimental studies, this influence is also not taken into account. It is proposed to take into account the influence of the finning geometry on heat transfer by introducing correction coefficients in the generalizing equations, determined from the results of a numerical research.

To evaluate the validity of the introduction of the results of numerical research into generalizing equations, an experimental investigation of heat exchange in the interfin channels of the punched spiral finning of the tubes is carried out. A research method is developed based on the results of measurements of the surface temperatures of the fins and air in different zones of the interfin channel along its height, as well as the air temperature in front of the bundle and the air flow through the bundle. The study is carried out by placing the calorimeter tubes in the transverse rows of the chess and corridor bundles of tubes at different Reynolds numbers.

The results of the investigation of one of the bundle. The calorimeter is installed in the fifth row of a six-row tube bundle with fin interval of S_f=6 mm and tube steps in the bundle S_1=85 mm, S_2'=85 mm.

At the Reynolds number, Re_d=10042: the heat flux in the interfin channels Q=711.0 W, the same according to electrical measurements – 731.0 W; discrepancy – 2.73 %; the heat transfer coefficient in the blade zone is α_{ifcb}=162.0 W/m^2°C; discrepancy – 2.88 %. The average surface heat transfer coefficient in the interfin channel is $\overline{\alpha}_{ifc}=132.35$ W/m^2°C; by numerical calculation – 122.6; discrepancy is 7.31 %. The average surface heat transfer coefficient of a single transverse row of tubes, taking into account the flow of a part of the air through the intertubular channels, is $\overline{\alpha}_c=83.05$ W/m^2°C; the discrepancy is 5.12 %.

In the remaining experiments, the difference in the values of the heat transfer coefficients is 3.19...15.7 %. The results of the investigation confirm the validity of the use of the results of numerical investigation in generalizing equations for calculating the heat transfer of bundles of tubes with a spiral finning.

Keywords: punched spiral finning, interfin channels, heat exchange intensification, heat transfer coefficient, experimental study.

1. Introduction

One of the topical tasks of modern boiler construction, along with increasing profitability, is the reduction of metal consumption and the cost of boiler units. The main reserve in this respect is a reduction in the metal consumption of low-temperature convective heating surfaces for boilers of traditional steam-turbine power units and for all heating surfaces of waste-heat recovery boilers of gas-turbine power units. This problem is currently being solved, mainly, by using tubes with fins on the side of the gaseous coolant. The tube finning allow increasing the specific heat exchange surface several times, but at the same time it weakens the heat exchange. Therefore, it is very important to intensify heat transfer in finned heating surfaces, in particular, by deformation of the fins. Certain definite prospects for wide application have a spiral-tape finning of tubes (other names are “segmented”, “cut”, “gear”), the fragments of which are shown in **Fig. 1**.

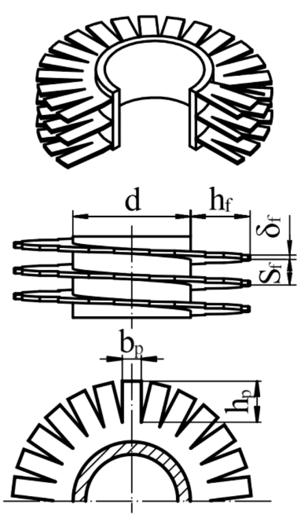


Fig. 1. Fragments of a tubes with punched fins

At present, there are the results of experimental studies of heat transfer in bundles of tubes with punched spiral fins, in particular [1–5]. In all the studies an increase in heat transfer is obtained in comparison with the traditional continuous helical ribbon finning. Analysis and comparison of the results of the studies [2–5] reveal a noticeable effect on the heat exchange of the height of the cut portion of the fins (blades), but this influence has not been explicitly investigated.

There are also results of numerical studies of the heat exchange of tubes with a punched spiral finning [6–9]. In [6, 7], the effect on the heat exchange of the blade width, the height and thickness of the fin is studied. The influence of the blade height on the heat exchange is not separately investigated.

In the study [8, 9], the influence on the heat exchange of all the geometric dimensions of the punched finning is studied.

Based on the analysis and generalization of the results of experimental studies, methods for calculating the heat transfer of chess and corridor bundles of tubes with punched fins are proposed [1–5, 10, 11]. The geometric dimensions of the blades are not taken into account. In the generalizations [4, 5], correction factors are proposed to take into account the height and width of the blade and the thickness of the edge, determined from the results of a numerical study [9].

The aim of research is establishment of the correspondence of numerical calculation results to the results of the experimental determination of the parameters of heat exchange in the interfin channels. To achieve this aim, the following tasks are set:

– carrying out an experimental study in interfin channels with a separate determination of the heat transfer coefficients in the punched and not-perforated portions of the fins; to compare them with the results of numerical calculations for similar conditions;

– taking into account the ratio of air flow through interfin channels and unheated intertubular channels, determine the average surface heat transfer coefficients of one transverse row and compare them with the data from the heat transfer study in the deep rows of the bundle.

2. Methods of research

The study used tubes with a diameter of 28x3 mm, a length of 240 mm with punched finning. The fin height – h_f=14.5 mm, the blade height – h_b=9.5 mm, the number of blades in one turn – m_b=26, the blade width – b_b=4,0 mm, the fin thickness – δ=1,0 mm, the fin interval – S_f=5; 6 and 8 mm. All the tubes in the bundle, including the calorimeter tubes, are heated by electric current (calorimeter tubes – through the voltage regulator) and cooled by air. The calorimeter tubes in each experiment are rotated about a longitudinal axis from 0° to 180° in 30° increments. The study of heat exchange in the interfin channels (IFC) is carried out in parallel with the study of the medium-surface heat transfer of the bundle as a whole [4, 5].

The temperature of the fin surface and air is measured by thermocouples of standard graduation XA at the base of the fin and at a height of 3.0 mm, 7.0 mm and 13.0 mm. Measuring methods and errors of measuring instruments are given in [5].

The study of heat exchange in the interfin channels is based on measuring the temperatures of the heat-dissipating surface and air in different zones of the interfin channel, as well as the air temperature in front of the bundle and the total air flow through the bundle.

Based on the results of measurements of the temperatures of the outer surface of the tube and fins, as well as air in the interfin gap, dependency curves are plotted

$T_w=f(h_i;\ \beta)$, h_i=const, $t_w=f\ (h_i;\ \beta)$, β=const,

$t_a=f(h_i;\ \beta)$, h_i=const, $t_a=f\ (h_i;\ \beta)$, β=const,

where h_i – the installation height of the i-th thermocouple; β – the angle of installation of the rotary calorimeter relative to the direction of the oncoming flow.

According to these graphs, the dependences of $\overline{t}_w$ and $\overline{t}_a$ on the fin height are plotted, averaged over the angle of attack β, over which the following are determined: air temperatures at the inlet and outlet of the IFCB (interfin channels in the blade zone) and their difference $\Delta t_{a.ifcb}$, inlet and outlet air temperatures of IFCN (interfin channels in the non-perforated part of the tubes) and their difference $\Delta t_{w.ifcn}$, the average wall temperature in the IFCB zone, the average wall temperature in the IFCN zone.

The average air temperatures in the IFCB and IFCN zones, the difference between the mean wall and air temperatures in the IFCB and IFCN zones, the heat sinks in the IFCB and IFCN zones, and the overall heat dissipation in the interfin channels are calculated.

Using the obtained values of heat sinks, heat exchange surfaces and temperature head, heat transfer coefficients in the IFCB and IFCN zones are calculated, as well as the average surface heat transfer coefficient in the interfin channels.

The average air temperatures in the IFCB and IFCN zones after mixing are determined and plotted on the graph. According to the graph, the average wall and air temperatures and their difference in the IFCB and IFCN zones after mixing of air flows are determined. The heat transfer coefficients in the IFCB and IFCN zones, referred to the total air flow and the mean surface heat transfer coefficient of the deep row of the bundle, are calculated.

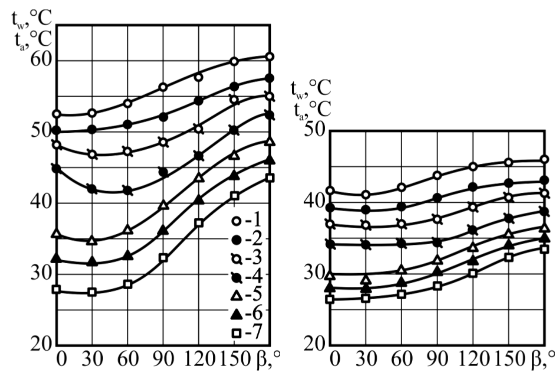
3. Results

The heat transfer in the interfin channels of the punched spiral-tape finning at various intervals of the fins and tubes in bundles, various Reynolds numbers, a chess and corridor arrangement of bundles is studied. A small part of the results of the study is presented in the form of data on individual bundles.

1. Six-row bundle of tubes with S_f=6 mm; the tube intervals in the bundle: S_1=85 mm, S_2=85 mm; tube-calorimeter is installed in the fifth row. The experiments are carried out at Re_d=10042 and 28647. For Re_d=10042, the dependences $\overline{t}_w$= =f (β; h_f, i); $h_{f,i}$=const and $\overline{t}_a$=f (β; h_f, i); $h_{f,i}$=const is shown in **Fig. 2, *a***; for Re_d=28647 – in **Fig. 2, *b*.**

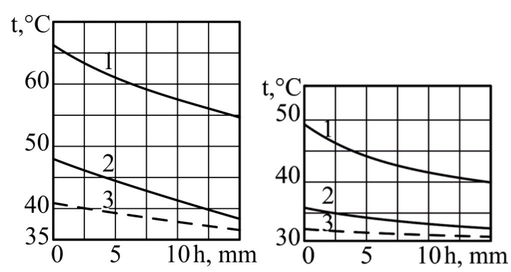
According to **Fig. 2**, the values of $\overline{t}_a$ and $\overline{t}_w$ averaged over the angle of attack β are determined for different values of $h_{f,\ i}$ shown in **Fig. 3.**

According to **Fig. 3**, the temperature of the fin wall and air at the boundaries of the blade and the non-perforated part of the fin is determined, the average temperatures in these IFC zones and subsequent calculations are performed according to the accepted technique. The following are only the final results of processing the experimental data.



a *b*

Fig. 2. Dependence of the temperature of the fin wall and air in the interfin channel on the angle of attack β and the height of the location of thermocouples on the fin:
a – Re_d=10042; *b* – Re_d=28,647; 1 – $h_{f,i}$=0,0 mm;
2 – $h_{f,i}$=3.0 mm; 3 – $h_{f,i}$=7,0 mm; 4 – $h_{f,i}$=13,0 mm;
5 – $h_{f,i}$=3,0 mm; 6 – $h_{f,i}$=7,0 mm; 7 – $h_{f,i}$=13,0 mm



a *b*

Fig. 3. Change of the fin and air temperatures averaged over the angle of attack β in the interfin channel along its height in the fifth row of the six-row bundle:
a – Re_d d=10042; *b* – Re_d=28,647; 1 – fin temperature;
2 – air temperature; 3 – air temperature after mixing the flows from the interfin and intertubular channels

According to **Fig. 3**, the temperature of the fin wall and air at the boundaries of the blade and the non-perforated part of the fin, the mean temperatures in these IFC zones, and the subsequent calculations according to the adopted procedure are determined. The following are only the final results of processing the experimental data.

Re_d=10042.

The heat flux, diverted to the IFC from one row of the bundle tubes, calculated by the method of experimental study of heat transfer in the IFC – Q_f=711 W; the same, calculated from the results of measurements of electrical parameters, $Q_{f.el}$= =731 W; discrepancy is 2.73 %. The coefficient of heat transfer in the IFC in the zone of the blades is α_{ifcb}=157.46 W/m$^2\cdot$°C; according to the results of a numerical study, α_{ifcb}=162,0 W/m$^2\cdot$°C; discrepancy – 2.88 %. The average surface heat transfer coefficient in the IFC is $\overline{\alpha}_{ifc} = 132.35$ W/m$^2\cdot$°C; according to the numerical calculation 122.6, the discrepancy is 7.31 %. When recalculating to the whole air flow through a number of tubes, the average surface heat transfer coefficient is 87.3 W/m$^2\cdot$°C; for the bundle as a whole, α_c=83.05 W/m$^2\cdot$°C; the discrepancy is 5.12 %.

Re_d=28647.

Heat sink from the deep row of tubes in the interfin channels Q=696.6 W; the same from measurements of electrical parameters Q_e=715.88 W; the discrepancy is δQ=2.69 %. The heat transfer coefficient in the IFC in the blade zone is $\overline{\alpha}_{ifcb} = 263{,}1$ W/m$^2\cdot$°C; the same according to the results of a numerical calculation $\overline{\alpha}_{ifcb} = 247{,}47$ W/m$^2\cdot$°C; the discrepancy is $\delta\ \overline{\alpha}_{ifcb} = 5.94$ %. The average surface heat transfer coefficient of the deep row is $\overline{\alpha}_c = 211.25$ W/m$^2\cdot$°C; the same from the numerical calculation of $\overline{\alpha}_c = 189.4$ W/m$^2\cdot$°C; divergence $\delta\ \overline{\alpha}_c = 10.3$ %.

In terms of the total air flow through the interfin and intertubular channels: the coefficient of heat transfer in the blade zone $\overline{\alpha}_{ifcb} = 201.9$ W/m$^2\cdot$°C; the heat transfer coefficient in the zone of the continuous part of the fins is $\overline{\alpha}_{ifcn} = 85.31$ W/m$^2\cdot$°C; average surface heat transfer coefficient of the deep row $\overline{\alpha}_c = 159.6$ W/m$^2\cdot$°C; the same results from the bundle experiment as a whole $\overline{\alpha}_c = 164.4$ W/m$^2\cdot$°C; the discrepancy is $\delta\ \overline{\alpha}_c = 2.91$ %.

2. A six-row chess bundle of tubes with S_f=8.0 mm; tube interval in the bundle: S_1=85, S_2=85; tube-calorimeter is installed in the fifth row.

The main results of the experiment characterizing heat transfer.

Re_d=9666.

Heat sink of one row of tubes Q_{ifc}=726.17 W; by measurements of electrical parameters Q_e=731.04 W; discrepancy δQ=0.67 %.

The heat transfer coefficient in the IFC in the blade zone is $\overline{\alpha}_{ifcb} = 149{,}91$ W/m$^2\cdot$°C; according to a numerical study – $\overline{\alpha}_{ifcb} = 162{,}0$ W/m$^2\cdot$°C; divergence – $\delta\ \overline{\alpha}_{ifcb} = 8{,}06$ %.

The heat transfer coefficient averaged over the surface in the IFC is $\overline{\alpha}_{ifc} = 117.75$ W/m$^2\cdot$°C; the same according to the results of numerical calculations – $\overline{\alpha}_{ifc} = 119.95$ W/m$^2\cdot$°C; discrepancy – $\delta\ \overline{\alpha}_{ifcb} = 1.87$ %.

After mixing the air flows from the IFCB and IFCN for the deep row of the bundle: $\overline{\alpha}_b = 91{,}65$ W/m$^2\cdot$°C; the same experimentally for the bundle as a whole $\overline{\alpha}_b = 83.25$ W/m$^2\cdot$°C; discrepancy $\delta\ \overline{\alpha}_b = 10.1$ %.

Re_d=27838.

Heat sink of one row of tubes Q_{ifc}=705 W; by measurements of electrical parameters Q_e=715.77 W; divergence δQ=1.43 %. The heat transfer coefficient averaged over the surface in the IFC is $\overline{\alpha}_{ifc} = 232.6$ W/m$^2\cdot$°C, the same is for a numerical study of α_{ifc}=211.7 W/m$^2\cdot$°C; the discrepancy is 8.99 %.

After the mixing of air flows from the IFCB and IFCN: $\overline{\alpha}_b = 172.6$ W/m$^2\cdot$°C; according to the experiment for the deep-seated series of the bundle $\overline{\alpha}_b = 170.66$ W/m$^2\cdot$°C; discrepancy $\delta\ \overline{\alpha}_b = 1.14$ %.

In the remaining experiments, the difference in the values of the heat transfer coefficients is 3.19...15.7 %.

4. Discussion of results

The presented results of the experimental study of heat exchange in the interfin channels show a close coincidence of the values of the heat transfer coefficients in the IFC in the zone of the punched fins and in the overall IFC obtained experimentally and numerically. The values of the heat transfer coefficients of one row of the bundle are also quite close, taking into account the passage of part of the air through the intertubular channels obtained in the experimental study of heat exchange in interfin channels and in bundles as a whole. The values of the heat sinks for one row of the bundle, obtained in the study of heat transfer in IFC and from electrical measurements, are also quite close. This confirms the validity of the use of the results of numerical investigation in the formation of generalizing equations for the calculation of medium-surface heat transfer in bundles of tubes with punced spiral finning. Unfortunately, in this study it is not possible to more accurately determine the air flow ratio, through the interfin and intertubular channels, to estimate separately the heat transfer of the solid part of the fin and the heating surface of the tube in the IFCN zone.

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