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INFLUENCE OF LIQUID TEMPERATURE AT THE TUBE INPUT ON THE HEAT CHARACTERISTICS OF SUPERCRITICAL WATER

Summary. *The article is devoted to the study of heat transfer of ascending flows in bare vertical tubes cooled with water at supercritical pressure. The results of studies on establishing the dependence of the heat characteristics of supercritical water on the liquid temperature at the inlet to the tube are presented.*

Key words: *vertical tubes, ascending flows, supercritical pressure, CFD simulation*

Introduction. An analysis of research and publications in the field of CFD simulation of flow and heat transfer at supercritical pressures is presented in a number of works [1-18]. They consider a wide range of issues concerning the features of thermophysical processes under these conditions.

The present study aims to determine temperature fields in bare tubes cooled with supercritical water using numerical simulation. It was conducted in order to establish the patterns of influence of the liquid temperature at the inlet of the tube on the heat characteristics of supercritical water.

Research results. This research is based on CFD simulation with FLUENT code, which is designed to predict heat transfer for ascending flows in vertical tubes with a heated length of 4 m and an internal diameter of 10 mm. In this case, the mass flux was G = 500 kg/m^{2}s, the density of the supplied heat flow was q = 200 kW/m^2, and the pressure at the channel inlet was P = 24.0 MPa. The temperature of the cooling liquid at the inlet t_{in} varied in the range of 320 – 360 °C.

The article considers the problem of mixed convection with an upward flow of supercritical water in vertical bare tubes. The task was solved in a two-dimensional axisymmetric formulation. To generate a developed turbulent velocity profile at the entrance to the heated section of the tube, the computational domain was increased upstream due to the initial heated section with a length of 1.2 m.

It was assumed that in the inlet section of the tube the values of velocity and temperature are constant, and the value of the turbulence intensity Tu is equal to 3%. "Soft" boundary conditions were set at the outlet section of the tube. Adhesion conditions were set on the surface of the tube flowing around by water. Adiabatic conditions were adopted as heat conditions on the unheated section of the tube. The conditions of constant heat flow were applied to the heated section. The calculation area was covered with a non-uniform grid with significant thickening towards the tube walls and contained 120×520 cells. The wall step was set equal to $1.5 \cdot 10^{-6}$ m, which ensured the value of $y^+ <1,0$. The NIST REFPROP program integrated into the FLUENT code was used to determine the physical properties of supercritical water. The task was solved with double accuracy. The k-ω SST turbulence model was used in the solution. The turbulence model was verified in [4].

Typical results of numerical studies are presented in Figures 1–3. The figures illustrate the distributions along the length of the heated section of the tube of the temperature of the inner surface of the tube wall t_w, the average temperature of the liquid t_l^* and the heat transfer coefficient α for different values of t_{in}.

As follows from the data provided, a change in the coolant temperature t_{in} can significantly affects the values of the indicated flow characteristics.

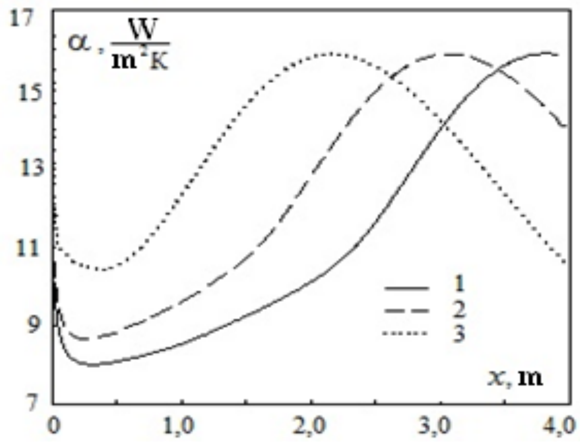

Fig. 1 Change in heat transfer coefficient α along the length of the heated section of the tube at different temperature values t_{in} at the inlet to the channel: 1 – t_{in} = 320°C; 2 – 340°C; 3 – 360°C

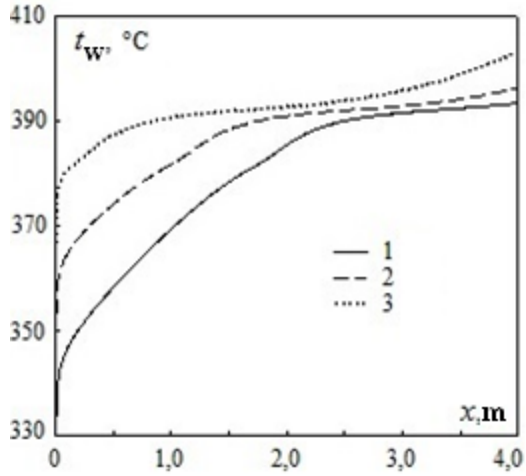

Fig. 2. Distribution of the temperature of the inner surface of the tube wall t_w along the length of the heated section at different values of temperature t_{in} at the inlet to the channel: 1 – t_{in} = 320° C; 2 – 340°C; 3 – 360°C

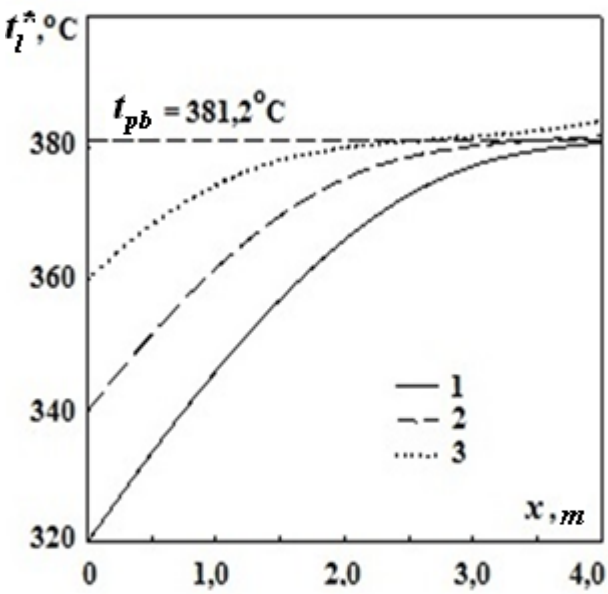

Fig. 3. Distribution of the average liquid temperature along the length of the heated section of the tube at different temperature values t_{in} at the channel inlet: 1 – t_{in} = 320°C; 2 – 340°C; 3 – 360°C

As for temperatures t_l^*, the differences in their values, corresponding to different t_{in}, tend to decrease along the length of the tube. Thus, near the entrance to the tube (x = 0,5 m), these differences at t_{in} = 360 °C and 320 °C are 35 °C, and in the outlet section of the tube – only 3 °C.

According to the obtained data, the temperature t_l^* reaches the temperature of pseudo-phase transition t_{pb} at a distance of 3.0 m and 3.9 m at t_{in} equal to 360 °C and 340 °C, respectively. For t_{in} = 320 °C, the temperature is below t_{pb} along the entire length of the tube.

The differences in temperatures t_w, corresponding to different values of t_{in}, change along the length of the tube as follows. They decrease noticeably with distance from the tube entrance, reach a certain minimum value and then increase somewhat.

The results of computer simulation also indicate that the nature of the distribution of the heat transfer coefficient α along the length of the tube depends significantly on the value of t_{in}. As can be seen from Fig. 1, outside the small inlet section of the tube at t_{in} = 320 °C, the heat transfer coefficient α increases along the length of the tube. At t_{in} = 340 °C and 360 °C, its change has an extreme character. Moreover, the higher t_{in}, the more the maximum heat transfer coefficient is shifted towards the tube entrance. It is also noteworthy that the maximum values of the heat transfer coefficient are practically the same for all considered values of t_{in}.

Conclusion. Based on the conducted studies, the patterns of influence on the heat transfer characteristics in tubes cooled by supercritical water, the value of its temperature t_{in} at the entrance to the channel in the range from 320 °C to 360 °C, were established. It was established that a change in temperature t_{in} can significantly affect the values of the tube wall temperature t_w and the heat transfer coefficient α.

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