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THE INFLUENCE OF THE FLOW-THROUGH RAYLEIGH – BENARD CELL ON THE CONVECTIVE MASS TRANSFER OF A HEAT CARRIER

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The problem of forming laminar thermal hydraulics regimes of supercritical heat carriers (water, carbon dioxide, etc.) is considered. For this purpose, it is proposed to use a Rayleigh-Bénard flow convective cell, in which convective heat and mass transfer is combined with a Poiseuille flow. A system of equations describing heat and mass transfer in a Rayleigh-Bénard flow cell is formulated. Free boundary conditions are used as boundary conditions, where the perturbed vertical velocities at the horizontal boundaries of the layer are not zero, but are determined by the Poiseuille dependence on the radius. The solution of the original system of equations in the free and forced convection regime is considered. It is shown that the flows formed by a supercritical heat carrier are laminar, which distinguishes this method of organizing heat and mass transfer from those where transitions to a turbulent regime are possible.

Supercritical water is used in nuclear power engineering as a heat carrier in fourth-generation nuclear reactors [1, 2].

In heat carrier pipes with a vertical temperature gradient, convection may occur, which can make a significant contribution to the heat exchange process.

The study of the occurrence of convection in a liquid in a vertical cylindrical pipe with a longitudinal constant temperature gradient is directly related to the problem of the functioning of heat exchange circuits, including those in nuclear reactors.

When using supercritical water as a heat carrier, the main attention is paid to the study of the heat exchange process at supercritical pressures and temperatures. The purpose of such studies is to obtain information on managing the efficiency of heat exchange processes. For example, in [3], an analysis was made of the influence of the density of the heat flux supplied to the wall of a vertical pipe with a supercritical heat carrier on the position of the boundaries of the beginning and end of the pseudo-phase transition zone and on the associated features of the spatial change in the physical properties of the heat carrier.

The above-mentioned changes in the heat and mass transfer parameters are undesirable and therefore require a search for technological solutions to eliminate them.

In addition to using supercritical water as a heat carrier, it is also possible to use it as a solvent. To implement the dissolving properties of supercritical water, it is possible to use a Rayleigh-Benard convection cell, in which the mass transfer of the supercritical fluid ensures the most complete extraction of the target material from the source material. In [4-6], it is shown that in a horizontal layer of supercritical fluid, which is supercritical CO_2, in the presence of a vertical temperature gradient characteristic of Rayleigh-Benard convection, the initial matrix dissolves and complexes of isotopes of the target metal are released into the fluid.

The disadvantages inherent in the above-mentioned problems of heat and mass transfer and dissolution of various materials with subsequent extraction can be eliminated if the Rayleigh-Benard convection cell [7] is made flow-through. Such a device of a flow convection cell can also be useful for organizing a laminar flow of supercritical water in the heat carrier circuit by using proper solutions of the Rayleigh-Benard problem with flow boundaries. It should be noted that the schematic view of a flow convection cell proposed is qualitative. Practical implementation of the proposed scheme of a flow convection cell requires the creation of a physical model of convective mass transfer in liquid layers with free horizontal boundaries heated from below, a theoretical description of heat and mass transfer in it and its experimental confirmation.

Generalization of the obtained equations gives a system of initial equations describing the Rayleigh-Benard flow cell in the stationary case:

$$\Delta\Delta v_z' + \frac{\beta_\rho g}{\nu}\Delta_\perp T' = 0,$$
$$-(V_z(r) + v_z')A = \chi\Delta T',$$
$$div(\vec{v}\,') = 0,$$

where $V_z(r) = U_0\left(1 - \frac{r^2}{R^2}\right)$; U_0 is constant, ν is kinematic viscosity coefficient; g is acceleration of gravity; β_ρ is coefficient of thermal expansion of liquid; $T_{0z}(z) = -A\cdot z + T_2$ is externally specified linear change in the temperature of the liquid inside the cell along the z coordinate; $A = \Theta/h$; $\Theta = (T_2 - T_1)$, T_1, T_2 are temperature of the upper and lower horizontal boundaries of the cell; $T_2 > T_1$, h is thickness of the horizontal layer of liquid heated from below.

Since the cell is flowing, the liquid passing through it washes the horizontal boundaries of the layer. Therefore, in the problem under consideration, free boundary conditions are applicable, where the disturbed vertical velocities at the boundaries of the layer are not equal to zero, but are characterized by a Poiseuille dependence on the radius:

$$v|_{z=0} = v|_{z=1} = -V_z(r)\,,\ \left.\frac{\partial^2 v}{\partial z^2}\right|_{z=0} = \left.\frac{\partial^2 v}{\partial z^2}\right|_{z=1}.$$

The solution of the output system of the level in the mode of free and induced convection is examined. Lines of equal temperatures and lines of convective heat and mass transfer in a flow-through convective medium were created for upstream and downstream convective flows in the Rayleigh-Benard sell.

Also, it is considered that the vertical flow is direct from the horizontal boundary with a lower temperature to the horizontal boundary with a higher temperature. It has been shown that the flow of supercritical heat transfer is formed as laminar, that makes not possible it transitions in a turbulent regime.

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