ISSN 0040-6015, Thermal Engineering, 2013, Vol. 60, No. 5, pp. 355–362. © Pleiades Publishing, Inc., 2013.
Original Russian Text © I.A. Mel'nikov, N.G. Razuvanov, V.G. Sviridov, E.V. Sviridov, A.A. Shestakov, 2013, published in Teploenergetika.

HEAT AND MASS TRANSFER AND PROPERTIES OF WORKING FLUIDS AND MATERIALS

An Investigation of Heat Exchange of Liquid Metal during Flow in a Vertical Tube with Non-Uniform Heating in the Transverse Magnetic Field

I. A. Mel'nikov[a], N. G. Razuvanov[b], V. G. Sviridov[a], E. V. Sviridov[a], and A. A. Shestakov[a]

[a] *Moscow Power Engineering Institute, ul. Krasnokazarmennaya 14, Moscow, 111250 Russia*

[b] *Joint Institute of High Temperatures, Russian Academy of Sciences, ul. Izhorskaya 13, Moscow, 125412 Russia*

Abstract—The results of experimental investigations of heat exchange during the downflow of liquid metal in a vertical tube with non-uniform heating in the transverse magnetic field are presented. The experiment was more realistic in terms of conditions of the blanket of a fusion reactor of the tokamak type. Profiles of the average temperature, distribution of local and mean heat transfer coefficients (Nusselt numbers), and the intensities and spectra of temperature pulsations have been measured. On certain combinations of operating parameters in the strong magnetic field low-frequency temperature pulsations with abnormal intensity were found.

Keywords: liquid metal, transverse magnetic field, blanket of a fusion reactor, low-frequency temperature pulsations, heat transfer coefficient (Nusselt number), secondary vortex structures, buoyance force

DOI: 10.1134/S004060151305008X

Investigations of heat exchange in a flow of mercury in the transverse magnetic field in the horizontal tube have been carried out in [1]. A pronounced effect of thermogravitational convection on the temperature fields and on distributions of heat transfer coefficients with both uniform and non-uniform heating was observed. Secondary flows caused by thermogravitational convection resulted in flow swirling and the intensification of heat exchange in the horizontal heated tube. Distribution of the wall temperature became non-uniform around the perimeter of the tube cross section. In the transverse magnetic field turbulence was suppressed, the effect of thermogravitational convection was reduced, and this also brought about the reduction in effects associated with the latter. Nusselt numbers averaged over the perimeter of the tube cross section decreased to the values of Nu_{lam}, $Ha = 7$, which correspond to the laminar flow when there is the Hartmann effect. On heating of the lower part of the tube alone, in the presence of the transverse magnetic field, the occurrence of low-frequency, nearly monochromatic temperature pulsations with abnormally high intensity were found [2]. The occurrence of this effect is correlated with the formation of periodic secondary vortex structures with axes parallel to the magnetic field.

Investigations of heat exchange in a vertical tube with the downflow of liquid metal were carried out on the magnetohydrodynamic test bench in the Moscow Power Engineering Institute (MPEI) in the longitudinal magnetic field [3]. With uniform heating of the tube under some conditions unexpected effects caused by the influence of thermogravitational convection were observed. One of them was the occurrence of low-frequency temperature pulsations and intensification of heat exchange associated with them. It should be noted that such a flow pattern is not typical for heat exchange channels of a fusion reactor.

In practical applications to the tokamak vertical arrangement of the channels in the transverse magnetic field is most likely. Investigations of heat exchange under more realistic conditions were carried out in [4]. In these experiments consideration was given to the downflow of mercury in the vertical heated tube in the transverse magnetic field with uniform distribution of the heat flow density on a wall. As an outcome of these investigations, interesting features of heat exchange under such flow conditions were discovered. The transverse magnetic field suppresses turbulence and brings about flattening of a velocity profile along lines of magnetic induction (the Hartmann effect) [5]. Because of turbulence suppression, Nusselt numbers averaged over the perimeter of the tube cross section decrease from turbulence values to laminar ones. The occurrence of the Hartmann effect produces significant non-uniformity of distribution of the wall temperature around the perimeter of the tube, with the presence of maxima and minima. It should be noted that such non-uniformity of the wall temperature is an adverse factor which causes thermal stresses in the wall, and they, under certain conditions