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Numerical analyses of the effect of a biphasic thermosyphon vapor channel sizes on the heat transfer intensity when heat removing from a power transformer of combined heat and power station

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Abstract. Numerical analyses of the effect of a biphasic thermosyphon vapor channel sizes on the heat transfer intensity was conducted when heat removing from an oil tank of a power transformer of combined heat and power station (CHP). The power transformer cooling system by the closed biphasic thermosyphon was proposed. The mathematical modeling of heat transfer and phase transitions of coolant in the thermosyphon was performed. The problem of heat transfer is formulated in dimensionless variables "velocity vorticity vector – current function – temperature" and solved by finite difference method. As a result of numerical simulation it is found that an increase in the vapor channel length from 0.15m to 1m leads to increasing the temperature difference by 3.5 K.

1 Introduction

One of the most important units of CHP is power transformer. The stability of the power generation depends on the reliability of power transformer operation [1-3]. Failure of the power transformer leads to huge accidents and further economic repair costs. The temperature of winding is one of the main factors determining the reliability of power transformer operation [4,5]. Currently, there are some cooling systems using in energy engineering: systems with natural oil cooling of winding, oil cooling with blasting and natural circulation of oil, oil cooling with blasting and forced circulation of oil through the air coolers, oil-water cooling with blasting and natural circulation of oil. The economic effect of this heat removing systems is based on saving the insulation resource of the active part of the transformer. Deterioration of the insulation is determined by the evaluation of the changes of the transformer winding temperature. To reduce the temperature of the windings, the forced cooling of oil is used through the application of additional equipment (circulation pumps and external fans). Failure of such additional equipment leads to emergency mode of power transformer. For this reason, perspective direction is the use of autonomous heat transfer devices for heat removing from the transformers. The closed

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biphasic thermosyphons [6, 7] have proven themselves as reliable heat exchangers due to ease of manufacture and design, lack of need for electricity, pumps, etc. Therefore it is necessary to perform the analyses of the possibility of using thermosyphons for cooling power transformers of CHP.

Technical condition diagnostics of the power transformers are often held by thermal imaging method [8]. This approach allows to record the temperature changes inside the power transformers caused by small defects in insulation without the use of additional equipment in order to detect areas of temperature increase. Maximum temperature areas were identified near the top cover of the oil tank of the transformer [8]. For this reason, in this paper we consider the mounting of the closed biphasic thermosyphon to the top cover of the oil tank of the transformer. The principle of operation of such system is as follows. Heat generates under the electric current in the windings. As a result the temperature increases. The heat is transferred from the winding by conduction and natural convection to the coolant (oil). The heated oil moves up due to the natural convection, then it cools due to heat removal to the "top cover of the transformer – closed biphasic thermosyphon" system and falls down.

The purpose of this study is the numerical analyses of the effect of a biphasic thermosyphon vapor channel sizes on the heat transfer intensity when heat removing from a power transformer of CHP.

2 Setting of the problem

There are solutions of similar heat transfer problems in heat pipes [9] in the framework of a boundary layer model. However the use of such heat transfer devices is limited due to the lack of a general theory of heat and mass transfer processes in the cooling system of power transformers of CHP. The basic laws of the complex interrelated physical processes [10–12] occurring in thermosyphon systems are not enough developed

The heat transfer problem in the thermosyphon of rectangular cross section was solved (Fig. 1). The heat supply from the power transformer was carried out through the bottom surface of the thermosyphon ($y=0,\ 0<x<(l_1+l_2+L+l_3+l_4)$). Due to intensive evaporation vapor moves in the direction of y-axis (due to the pressure gradient) and is condensed on the top cover of the heat exchanger. Under the influence of gravity the condensate flows down over the side walls of the thermosyphon and spreads over the bottom cover. The outer walls were considered as insulated; heat exchange with the environment was taken into account at the upper boundary. The condition of temperatures and heat fluxes equality was accepted at the "wall/liquid" and "liquid/vapor" boundaries. The following assumptions were accepted: laminar flow regime; heat transfer in the coolant layer occurs in the conduction mode because the effect of convection in a liquid layer is negligible; vapors forming due to evaporation of coolant are considered as incompressible viscous heat-conducting medium satisfying the Boussinesq approximation [14]; thermal properties of material of casing, coolant and vapor do not depend on the temperature; condensate film thickness on a vertical wall does not change over time. Made assumptions allow to simplify the solution and they does not contribute the significant limitations to the problem formulation.

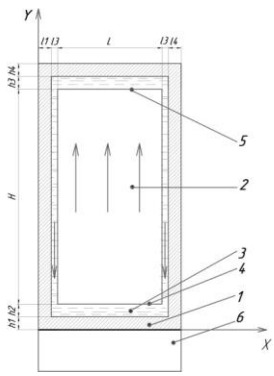

Fig. 1. Solution region: 1 – metal casing; 2 – vapor channel; 3 – liquid film; 4 – evaporation surface; 5 – condensation surface; 6 – top cover of the transformer tank. The vertical arrows indicate the direction of movement of the vapor and liquid.

Study of the heat transfer and fluid mechanics within the stated physical model is described by the two-dimensional Navier-Stokes and energy equations in dimensionless variables as in [13]. The formulated system of equations with nonlinear boundary conditions was solved by finite difference method as in [14,15], with the use of locally one-dimensional scheme of A.A. Samararsky [16]. We used an iterative algorithm [17] developed for solving the problem of conjugate heat transfer in a multiply-connected regions with intensive local absorption and release of heat.

The used algorithm and method of solution was verified on the model problems of free and forced convection [18,19]. Also a comparison of the numerical results with experimental data was conducted [20,21].

3 Results and discussion

Computational study of fluid mechanics and heat transfer were carried out for the closed biphasic thermosyphon of rectangular cross-section.

For clarity, the main results are presented in the form of dimensional fields of temperature and velocities of vapor motion for different geometrical parameters. A heat flow and heat transfer coefficient from the top cover of the thermosyphon was chosen based on typical operating conditions of the power transformers of CHP. The coordinate axes are set in meters, temperature – in degrees Kelvin.

According to the analysis of the results it can be concluded that the change in the thermosyphon height has little influence on the mode of vapor flow. An increase of the vapor channel length is found to effect slightly to the form of isotherms. Isotherms stretch uniformly in the direction of y-axis at a constant speed of vapor outflow and the heat transfer coefficient from the upper cover of the thermosyphon.

Analysis of the obtained distributions showed that the increase in the thermosyphon vertical size from 0.15m to 1m leads to the increase in the temperature difference by 3.5 K in the vapor channel. The temperature of the thermosyphon bottom cover is also reduced slightly (by 2.2°K). Based on these results, we can conclude that the closed biphasic thermosyphon with 1 meter in height can be used for cooling the power transformers of CHP. In this case, it is advisable to carry the upper part of the thermosyphon in the lower temperatures (outside the operating room of the shop), as the ambient temperature is often lower than in the room, which in turn intensifies the heat transfer. This intensification in winter, spring and autumn periods of time can be significant.

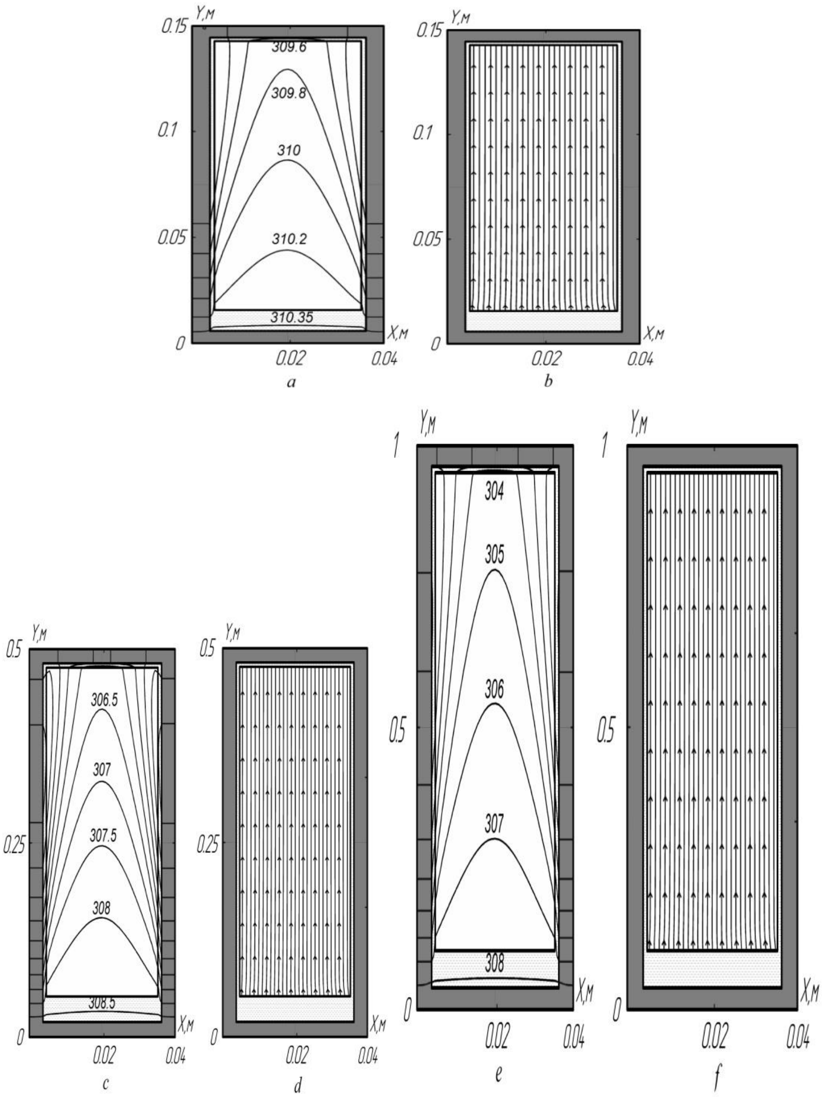

Fig. 2. Isotherms (a, c, e) and velocity fields of vapor motion (b, d, f) at q=1500W/m^2, α=18W/(m^2·K), (a, b) – H=0.15m; (c, d) – H=0.5m; (e, f) – H=1m. q is the heat flow supplied to the lower boundary of the upper wall of the transformer tank.

4 Conclusions

A new approach to modeling of thermal modes of thermosyphon systems linking the main hydrodynamic and thermal processes (forced convection, heat conduction, evaporation, condensation, etc.) occurring during operation of the heat transfer devices was proposed. We presented the temperature distribution and isolines of vapor motion velocities reflecting the impact of changes in the thermosyphon vapor channel height on the heat transfer modes in terms of cooling power transformers of thermal power plants.

The further development of the presented approach will contribute to the creation of a theoretical framework for the efficient design of heat removal systems of power transformers of CHP.

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