An experimental study of the influence of a thermosyphon filling ratio on a temperature distribution in characteristic points along the vapor channel height

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Abstract. Results of experimental studies of heat transfer in a thermosyphon illustrating the influence of the filling ratio and the heat load on the temperature distribution in the vapor channel, evaporation and condensation zones are presented. The thermosyphon was made of copper and was 161 mm high with side walls 1.5 mm thick, bottom cover 2 mm thick, an internal dimmer of the evaporation part of 54 mm and an internal diameter of the vapor channel of 39.2 mm. Based on the results of experimental studies, temperature dependences were established in the characteristic cross sections of the thermosyphon on the heat flux value supplied to the bottom cover. In addition, a well-appearing thermosyphon self-regulation property has been found – the growth of the heat load in the evaporation zone in the range from 1940 to 7685 W/m^2 does not lead to a decrease in the heat removal intensity from the heat-release region.

Introduction

Closed diphasic thermosyphons (CDTs) are considered by many authors [1, 2] as sufficiently promising, reliable heat transfer heat exchangers due to their autonomy, structural flexibility, ease of manufacture, lack of moving parts, the need for electricity, pumps, etc. In this connection, it is crucial to study the possibility of using thermosyphons as the main element of the cooling systems of devices, apparatus and equipment [3, 4]. In many studies the CDT generally is divided into three zones: an evaporator, an adiabatic region, and a condenser. But such division is rather conditional, because the transport of liquid and vapor, as well as phase transformations occur in all zones [4–7]. It should be noted that the results of studying the heat transfer processes in the CDTs and their heat transfer capacity are usually conclusions about the advantages (or disadvantages) of specific thermosyphons, coolants, structural layout schemes, technical or technological solutions [8, 9]. For the physical analysis of the processes taking place in the CDT, data on the temperature fields of the characteristic zones of the thermosyphon is necessary. However due to the objective difficulties of such measurements, in most cases experimental studies [10, 11] are focused on the analysis of temperature changes only on certain sections

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of the external surface of the heat exchanger. Due to the intense heat transfer across the case of the CDT both along the transverse and longitudinal coordinates, the measurements of the temperatures of the external surfaces are insufficient to analyze the processes taking place in the evaporation, condensation zones and vapor channel. For an objective analysis of the of heat transfer mechanisms, it is necessary to obtain the data on the temperature distributions (T) or at least the gradients of T in individual sections corresponding to the evaporation, vapor transport, and condensation zones. Carrying out the analysis of the current state of the problem under consideration, active investigations in recent years of hydromechanics and heat transfer processes taking place in thermosyphons within the framework of rather complex mathematical models should be noted [12-14]. But the results of mathematical modeling obtained even in recent years using widespread ANSIS FLUENT packages [15, 16] in many cases are not confirmed by the results of an experimental study of the main characteristics of thermo physical processes, primarily temperature fields. In this connection, an experimental study of the temperature fields of the working zone of thermosyphons is a crucial problem.

The aim of the work is an experimental study of the behaviors of temperature changes in the characteristic sections of the thermosyphon working zone under conditions of its cooling along the outer contour.

Method of experimental research

To carry out studies of the thermosyphon operating modes under various heat supply conditions, an experimental set-up was developed (Fig. 1) [17].

Heat transfer studies were carried out in a thermosyphon with a constant cross-sectional area made of copper (height is 161 mm, thickness of side walls and bottom cover are 1.5 mm and 2 mm, respectively, internal diameter of evaporation part is 54 mm, internal diameter of vapor channel is 39.2 mm). The top cover of the heat exchanger is made at an angle of $\gamma = 3°$ to the plane of the base to ensure the condensate movement along one wall. A valve is installed on the thermosyphon cover designed to regulate the pressure in the vapor channel. The heat was supplied with a heating element with a voltage (up to 100 V) and alternating current (from 0.08 to 0.2 A) from a single-phase autotransformer. The measuring circuit of the set-up (Fig. 1) made it possible to simultaneously record the temperatures: the liquid layer at the center of symmetry (thermocouple No 1), the lower (thermocouple No 2) and the upper (thermocouple No 3) boundaries of the vapor channel, in the lower and upper parts of the lateral vertical wall (Thermocouple No 4, 5). The input power and pressure in the internal cavity of the thermosyphon were also recorded. According to the results of preliminary experiments, it is established that external factors (air movement, operation of ventilation systems, room temperature, etc.) significantly influence the thermosyphon operation. For this reason, to reduce such effects on the results of the studies the device was placed in a glass box (Fig. 1).

Measurements (controlling and recording) of the temperature of the liquid, vapor, and the vertical walls of the CDT were conducted using Omega HYP0 thermocouples (temperature ranges 0-673 K, maximum permissible error ± 0.015). The thermocouple readings were recorded using analog-to-digital converter NI 9214. The pressure measurement was recorded using NI USB-6001 analog-to-digital converter and specially developed NI LabView SignalExpress software.

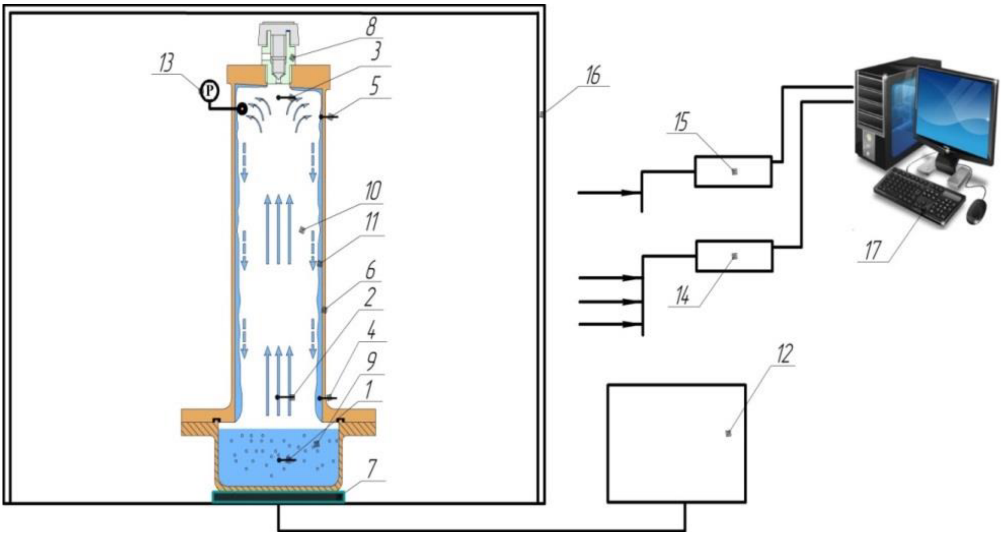

Fig. 1. Scheme of the experimental set-up: 1, 2, 3, 4, 5 – thermocouples; 6 – thermosyphon case; 7 – heating element; 8 – regulation valve; 9 – working liquid; 10 – vapor channel; 11 – condensate film; 12 – power source; 13 – pressure sensor; 14 – analog-to-digital converter NI 9214; 15 – analog-to-digital converter NI USB-6001; 16 – glass box; 17 – personal computer.

Filling ratio of thermosyphon was defined as:

$$\varepsilon = \frac{V_L}{V_E + V_C}$$

where V_L is the volume of coolant, m^3;
V_E is the volume of evaporation section, m^3;
V_C is the volume of condensation section, m^3;

Table 1. Values of filling ratios for different volumes of coolant.

V_L, cm^3	ε, %
40	19
50	24

The classical methodology of conducting experimental studies was applied for conducting research. According to this methodology the influence of each parameter was evaluated. Despite time-consuming, this approach was the most justified in the study of heat exchange inside the thermosyphon.

Results and discussion

The most important characteristics of the CDT functioning are specific heat fluxes and characteristic temperatures [1-5] for different filling ratios (ε,%).

Fig. 2 shows typical thermograms obtained during experiments in the heat loads range from 1940 to 7685 W/m2 at filling volumes of the evaporating section of ε = 19-24%.

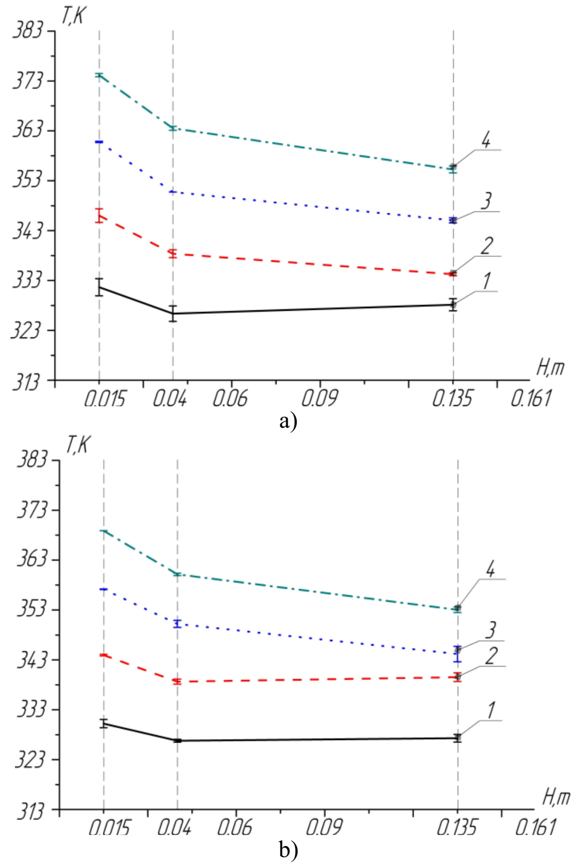

Fig. 2. Temperature distributions along the height (H) of thermosyphon at filling ratios: a) 19 %; b) 24 % and supplied heat fluxes: 1 – 1940 W/m^2; 2 – 3293 W/m^2; 3 – 5332 W/m^2; 4 – 7685 W/m^2.

The temperature distributions in Fig. 2 show that the increase in the heat flux supplied to the bottom cover of the thermosyphon nearly by four times leads to the increase in the temperature in the vapor channel by 35 K. The heat transfer in the thermosyphon is carried out as follows. Due to supplying energy the lower cover and liquid warm up. An increase in temperature leads to an intensive increase in the kinetic energy of the individual molecules of the liquid, which is necessary to overcome the attractive forces of the rest molecules, and thus to carry away these molecules (pairs) from the coolant surface. Steam moves upward due to the pressure difference in the channel and condenses on the top cover and on the side walls of the CDT releasing the phase-transition heat. A liquid film forms.

The condensate flows down the side wall of the thermosyphon under the gravitational forces into the evaporation zone. At a height of H=0.135 m with the filling ratios of 19% and 24% and the heat load of 1920-3293 W/m^2 (Fig. 2 a) a slight increase in temperature was registered which is due to the release of latent heat of condensation at the upper boundary of the vapor channel. But this temperature deviation from monotonic dependence does not exceed 1 K. The same effect is noticeable in Fig. 2 b on curves 1 and 2 (the temperature deviations do not exceed 0.5 K and 0.9 K).

Conclusions

Experimental data on temperatures of liquid and vapor phases obtained under conditions of reliable metrological support are the basis for the development of heat transfer models in thermosyphons describing a complex of interrelated processes in the evaporation, vapor transport and condensation zones with intensive heat removal not only from the surface of the top cover of the thermosyphon but also from its lateral surface.

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