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Visual and instrumental investigations of a copper–water loop heat pipe

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ABSTRACT

Visual and instrumental investigations of the processes of condensation and redistribution of a working fluid in a loop heat pipe have been carried out. This paper presents the results of an experimental investigation of the heat transfer and hydrodynamics during the condensation of water vapor in a flat gap condenser measuring 80 × 40 × 1 mm. Investigations have been conducted at a condenser cooling temperature of 20, 40 and 60 °C. During all operating modes a stratified two-phase flow and film condensation have been observed. The temperature field in the condenser has been measured, and the heat-transfer coefficients and the thermal resistances have been determined.

1. Introduction

Heat transfer and hydrodynamics processes in loop heat pipes (LHPs) accompanying the phase changes of a working fluid have a complex character [1]. The traditional approach used to study these processes employing temperature measurement at different points of the device does not allow obtaining a comprehensive physical picture. In turn, this lack of physical information impedes the formulation of an adequate physical model, which serves as the basis for calculations of LHP operating characteristics at different modes and conditions of its operation. Visual investigations make it possible to obtain additional information and better disclose the "secrets" of the operation of these devices.

The processes in LHP condensers as well as the processes of redistribution of a working fluid between the compensation chamber (CC) and the condenser, which strongly depend on the cooling conditions of the condenser, are of some interest for visual investigations. But these investigations are not numerous considering that they require significant efforts for their preparation. Besides, they are seldom compared with results of temperature measurement. In the paper [2] the use was made of the fiber-optic equipment which made it possible to observe visually the processes proceeding in the central channel of the wick from the side of the CC. The paper [3] described a method of neutron radiography which made it possible to observe the process of partial drying of the wick as well as the phase boundary in the condenser. In the paper [4] the temperature distribution in the LHP at different heat loads was investigated by means of an infrared camera with an accuracy of ±2°C.

The purpose of this study is to perform visual investigations of the processes in the LHP and their comparison with the results of temperature measurements at characteristic points at different heat loads and cooling conditions of the condenser. A copper–water LHP with a flat evaporator and a flat gap condenser was chosen as the object of the study.

2. Description of the experimental device

Fig. 1 presents the scheme of the experimental device.

The LHP had a flat evaporator 7 mm thick supplied with a thermal interface measuring 30 × 35 mm. The length of the liquid line was 550 mm and the length of the vapor line was 250 mm. The inner diameter of lines was equal to 3 mm and 4 mm, respectively. The active section of the condenser was the multilayer object shown in Fig. 2.

There was a rubber seal between the lower copper and the upper glass plate. The inner space of the gap condenser measured 80 × 40 mm. The thickness of the gap was determined by the degree of compression of the seal and was set to 1 mm. This condenser allowed making visual observations as well as photography and video recording of the process of condensation. The lower side of the copper plate contacted a cold plate cooled by running thermostatted water. To intensify heat transfer in the condenser between the incoming vapor and the smooth cooled surface two types of intensifying inserts were used: guide inserts made of rubber and spiral inserts made of copper wire 0.4 mm in diameter.

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Nomenclature

Q	heat load,
R_{tot}	total thermal resistance of the condenser,
R_{int}	thermal resistance, connected with internal heat-exchange processes in the condenser,
$R_{w\text{-}c}$	thermal resistance, determined by the thickness and the material of the condenser wall, as well as the intensity of condenser cooling,
S^*	relative area of condensation,
$\overline{S}_{cond_i}$	average area of the condensation surface for an i-heat load,
S_{tot}	total area of the active condenser surface,
T_{cool}	condenser cooling temperature,
$\overline{T}_{cond}$	average temperature of the total area of the condenser surface.
T_v	vapor temperature at the condenser inlet.

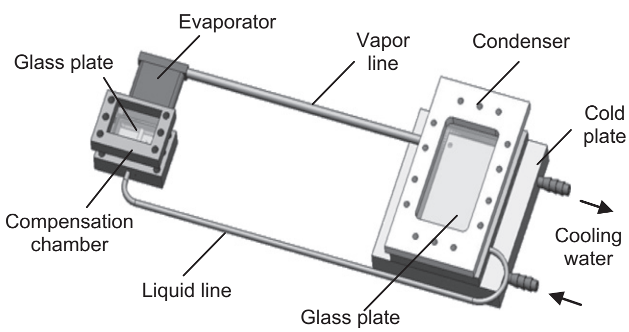

Fig. 1. Experimental LHP.

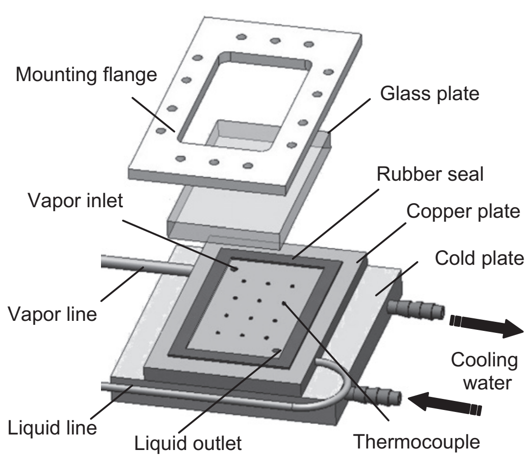

Fig. 2. Scheme of the LHP condenser.

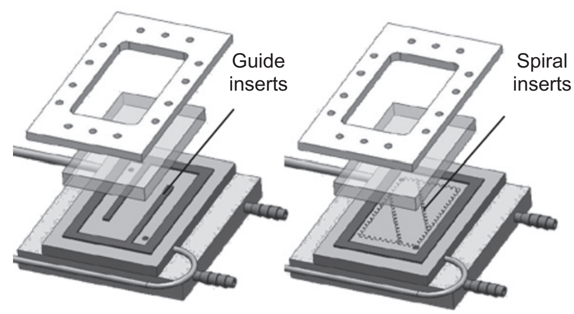

Fig. 3. Scheme of the LHP condenser with guide and spiral inserts.

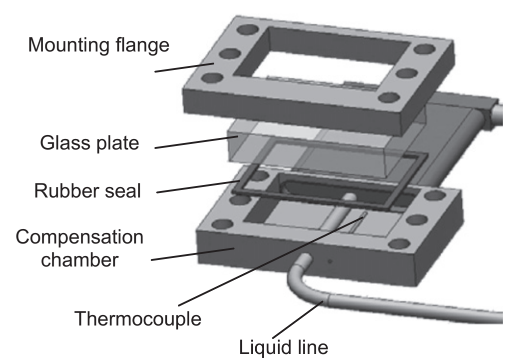

Fig. 4. Scheme of the compensation chamber.

The general view and the location of these inserts are presented in Fig. 3.

The inserts provided vapor flow turbulization at the inlet of the condenser as well as suction of the liquid film from the condensation surface. The compensation chamber shown in Fig. 4 had an analogous design.

3. Testing procedure

The experiment began with preparation of the working fluid and the loop heat pipe to avoid the effect of non-condensable gases, air and contamination on the LHP operation. This stage included cleaning and degassing of the working fluid as well as vacuum pumping and charging of the LHP. Then the cooling system of the condenser and evaporator heat source were turned on. An aluminum block, in which two heating cartridges with a power of 250 W each were installed, was as used as a heat source. The heater had a heating surface measuring 30 × 35 mm. The heat load changed stepwise with the help of a laboratory autotransformer from 20 to 500 W. The condenser was cooled by running thermostatted water with temperatures of 20, 40 and 60 °C. The ambient temperature was about 25 °C. Temperature measurements were carried out with the help of copper-constantan thermocouples OMEGA TT-T-30. The temperature on the copper plate surface, where condensation of the working fluid took place, was measured in 12 points which are shown in Fig. 2. In addition, the temperature inside the CC was also measured. Data collection and processing was performed with the help of an Agilent 34970A data acquisition unit. The readings of the thermocouples were recorded after transient processes were complete and equilibrium was established. The optical instruments placed above the condenser and the CC registered the visual images of the processes of condensation and redistribution of the working fluid between the condenser and