PETER HRABOVSKÝ[1]
PATRIK NEMEC[2]
MILAN MALCHO[3]
JOZEF JANDAČKA[4]
University of Žilina, Slovakia
[1]peter.hrabovsky@fstroj.uniza.sk
[2]patrik.nemec@fstroj.uniza.sk
[3]milan.malcho@fstroj.uniza.sk
[4]jozef.jandacka@fstroj.uniza.sk

EXPERIMENTAL DETERMINATION OF THE WORKING FLUID VOLUME FOR OPTIMAL FUNCTION OF THE LOOP HEAT PIPE

Abstract

This experiment is concentrated on the working fluid of the heat pipe. The working fluid is an important part for the function of the heat pipe regarding the transfer of the heat. The measurements point out the appropriate quantity of the working fluid regarding the correct function of the loop heat pipe in the cooling of electronic components.

Keywords: loop heat pipe, heat transfer, cooling, working fluid

1. Introduction

Pass-heat device used in this experiment is called a loop heat pipe (LHP). It is a specific type of heat pipe in which the evaporator and condenser are separated and between them is transferred the operating liquid through the pipe. After the successful demonstration of the ability and reliability of heat transfer in space applications, the loop heat pipes experienced the attention of the world in 1990 [1]. Loop heat pipes are used in the space industry for cooling of electrical equipment on spaceships now [2]. Loop heat pipes are capable of passive cooling of equipment at normal operating conditions [3]. This phenomenon is often made use of in the design of solar water heaters, particularly of small capacities, too [4]. The first published analysis of thermosyphon solar water heater circuit was by Close [5]. There have been many other publications on the analysis of these systems but they are all based on the original formulation. For verifying the theoretical results, he tested two thermosyphon systems with different characteristics and the results conformed well to those predicted. Gupta et al. [6] modified the model of Close to take into account the heat exchange efficiency of the collector absorber plate, and thermal capacitance. Ong [7] extended the work of Close and Gupta et al. by using a finite difference solution procedure. The theoretical prediction of flow rate has been compared with the measured flow rate using dye trace inject. Zerrouki et al. [8] considered natural circulation of a compact thermosyphon solar water heating system produced and commercialized in Algeria. Their calculations and measurements were performed on mass flow rate, temperature rise and fluid and absorber temperatures inside the thermosyphon of parallel tube design. An increasing volume of data obtained by testing loop heat pipes in applications developed on Earth, scientists can work around the world in the development of loop heat pipes.

2. Designee of loop thermosyphon

The aim of the experiment is to compare the cooling effect, depending on the volume of filling. At the experiment loop thermosyphon was used, which is shown on Figure 1. The loop thermosyphon is composed of evaporator, condenser and transport pipeline. Evaporator is located in the lower part of the device. It composes of alumina of dimensions 115 x 80 x 30 mm (HxWxD), inside there is a system of four vertical holes of diameter 5 mm, hole pitch 15 mm. On the sides of the evaporator are holes of diameter 10 mm, for the inlet and outlet of the working substance. On the evaporator semiconductor device is mounted and connected to a laboratory power supply voltage and current, whose actions generate heat. To increase the heat transfer between semiconductor devices and evaporator heat conductive paste is used. Between the evaporator and semiconductor device the thermometer is located for temperature control of semiconductor devices as the prevention of heat failure. The condenser section is located at the top of the device. For this application heat exchanger was used, which composes of copper pipe with the ribs from sheet of steel. Dimensions of the heat exchanger: length 740 mm, width 140 mm, height 30 mm, 3 mm rib pitch. Pipe has a length of 1.5 m, diameter 10 mm and wall thickness of the pipe is 1 mm. The volume of the pipe is calculated as 301.6 ml. Transport pipe is composed from copper pipes, copper and brass fittings and thoroughfares, which are connected to evaporator and condenser with the soft solders and soldering technology. Diameter of a copper pipe is 10 mm, wall thickness 1 mm. The total length of the transfer pipe, including fittings and thoroughfares is 1 m. Pipeline volume is 50.3 ml

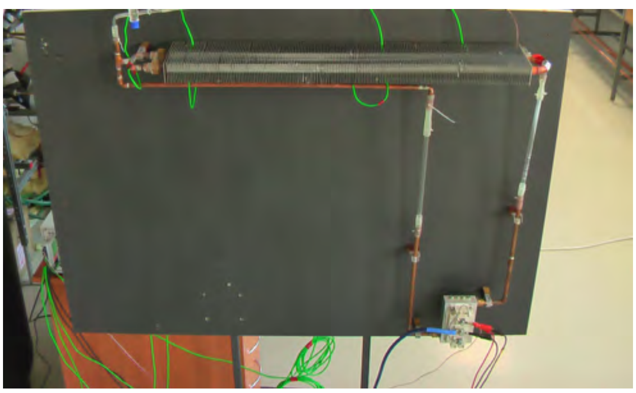

Fig. 1. Loop heat pipe

3. Characteristics of working substance

Working substance used in loop heat pipe is controlled by the range of operation temperature. Depending on operate temperature, the loop heat pipe are sorted in four classes: cryogenic (4 – 200 K), low (200 – 550 K), medium (550 – 750 K), high (750 K and more) operate temperature. Most of applications from loop heat pipe are ranked in low range of operate temperature [9]. Next important point at choosing type of working substance is the compatibility between the working fluid and the material of loop heat pipe. Whichever chemical reaction between the working fluid and the material loop heat pipe creates a non-condensable gas in the system. The existence of non-condensable gas in the system markedly reduces the performance of loop heat pipe. For more information about the compatibility between metal and working substance can be found in the literature [9]. Volume of working fluid filled in system may have critical impact on the performance of loop heat pipe. Directive exists that after there you have to make headway. Let us assume the loop heat pipe at the lowest temperatures is out of order, when transportation pipelines and condenser are fully filed with fluid. At that time there has to remain enough of operate fluid in evaporator. This pour minimal volume filling of operates fluid into loop heat pipe. Another aspect is that when the loop heat pipe is at the highest temperature out of order, volume of liquid has to be smaller than the sum of pipe's volume and evaporator. After analysis, if the minimum value of the working fluid is greater than the maximum value, then the physical size of the components must to be re-designed. This condition is usually achieved by increasing the size of the components [10, 11]. Working fluid used in this experiment is called fluorinert FC-72. Theory of the working fluid is grounded on dielectrics, which ensures the prevention of short circuits and damage to electrical equipment parts.

4. Experiment and results

To realize the experiment it is necessary to achieve equilibrium, which occurs after evaporation of the working fluid to the desired percentage amount. At steady state, the heat pipe was allowed to cool to room temperature (approx. 20°C). After cooling, the temperature data logging was turned on using the monitoring software on the computer, turned on the power source and the output power was set to an initial value of 80 W. Using the computer temperature data on the evaporator are recorded as well as on the inlet to the condenser, the condenser on the ribs, at the outlet of the condenser and the ambient air. After stabilization of the temperature at the evaporator, where there is a thermal oscillation applied, the current value and increase of the output power by 20 watts, on 100 W. Procedure described in this paragraph shall be repeated until output power is 300 W, or is not achieved at evaporation temperature of 100°C, the upper limit of the temperature of the evaporator. In experimental determination of optimal working fluid volume for loop thermosyphon, it was used quantity of working fluid in the range 30–70% of loop thermosyphon volume. The temperature values of the evaporator wall by varying quantity of the working fluid are shown in Table 1. Figure 2 shows a comparison of the cooling effect, depending on the quantity of working fluid filling.

Table 1. Measured values on the wall of the evaporator at various filling quantities

Heat load [W]	Volume of the working fluid [%]				
	30%	40%	50%	60%	70%
81	41	42	43	46	46
100	44	46	45	51	50
121	49	51	49	54	54
140	52	52	53	57	56
161	58	56	56	61	59
181	65	59	60	63	62
200	76	63	62	65	65
221	84	66	65	68	68
241	92	69	67	70	69
260	100	73	70	72	71
280		79	71	75	73
298		82	75	76	77

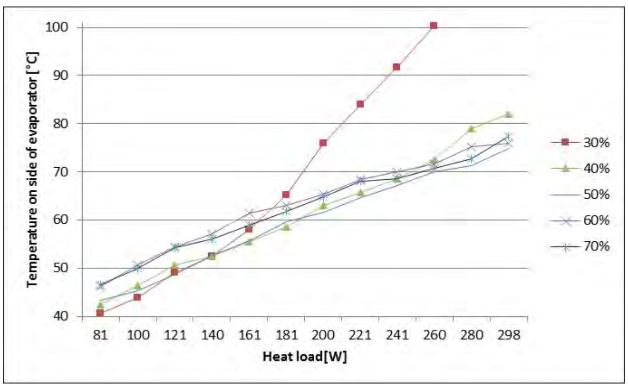

Fig. 2. Comparison of the cooling effect on the quantity of filling

In the figure it is seen the worst condition – response curve with points in the shape "X" at the quantity 30% of filling, when it is not possible to achieve a higher value of forward power 260 W. The loop thermosyphon reaches best cooling effect with working fluid volume 50%, as shown in graph by blue curve without the symbols. Although in some places this curve intersects with another curves, but then these curves show worst results. According to the graph created by measured data, we recommend50% amount of working fluid for optimal function of loop thermosyphon.

5. Conclusions

This experiment dealt with the influence of the amount of working fluid filling on the cooling effect of the loop heat pipe. The experimental measurements and calculations show the worst results for 30% of working fluid filling when it is not possible to reach a value of forward power greater than 260 W. The best results are achieved with 50% volume of working fluid. This experiment has shown the suitability of 50% filling with working fluid of loop heat pipe for the effective removal of heat from electrical components. For precise analysis of an appropriate amount of working fluid filling, we suggest to examine the scope of working fluid volume in the range of 40–60%.

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