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ZUZANA KOLKOVÁ[1]
MILAN MALCHO[2]
University of Žilina, Slovakia
[1]zuzana.kolkova@rc.uniza.sk
[2]milan.malcho@fstroj.uniza.sk

EFFECT OF FILLING RATIO ON THERMAL PERFORMANCE AND THERMAL PARAMETERS OF CLOSED LOOP PULSATING HEAT PIPES

Abstract
Improving the performance of electrical components needs higher heat removal from these systems. One of the solutions available is to use a sealed heat pipe with a throbbing filling, where development meets the current requirements for intensification of heat removal and elimination of moving parts cooling systems. Heat pipes operate using phase change working fluid, and it is evaporation and condensation. They have a meandering shape and are characterized by high intensity of heat transfer, high durability and reliability. Advantage of these tubes is that it is not necessary to create the internal capillary structure for transporting liquid and they need no pump to the working fluid circulation. They have a simple structure, low cost, high performance, and they can be used for various structural applications. The choice of working fluid volume and performance affects thermal performance. Distilled water, ethanol and acetone were used in the performance ranges of 0–80%.

Keywords: closed loop pulsating heat pipe, thermal performance, evaporation, condensation, filling ratio, thermal resistance, temperature.

1. Introduction

Pulsating heat pipes are one of the latest trends in heat pipe technology. In contrast to conventional types of heat pipes in which the working fluid circulation inside the tube is continuously done with capillary forces between the heat source and the heat sink in the form of counter flow, in the pulsating heat pipe working materials move in the axial direction. The basic mechanism of heat transfer is pulsatile fluid motion associated with phase change (evaporation and condensation) [1]. Akachi and Polasek describe the basic operation of these tubes. Pulsating heat pipes usually consists of copper capillary meandering shape. Pulsating heat pipes are filled with an optimum amount of fluid. Effect of surface tension creates columns of liquid phase, which are intermittent of vapor bubbles. The working fluid is evaporated in the evaporation section, where the heat input is. The effect of evaporation increases the vapor pressure inside the tube. Vapor bubbles in the evaporation section are growing and are pushing the liquid phase in the condensation section. Since the condensation part is cooled, the pressure is reduced, vapor phase is condensed and the vapor phase bubbles. This process between evaporation and condensation section is continuous and it occurs when there is the pulsating motion inside the tube. Heat is transferred through the latent heat in the vapor phase and sensible heat transported through the liquid phase [2]. Pulsating heat pipes can be divided into four groups (Fig. 1) [7]:

- closed pulsating loop heat pipe,
- closed pulsating loop heat pipe with check valve to ensure the movement of fluid in a particular direction,
- closed ends pulsating heat pipe, which is closed at both ends,
- pulsating heat pipe with open ends.

The parameters that affect the performance of the closed pulsating heat pipe, summed Groll. They are working fluids and their termo-physical properties, internal diameter of the pipe, total length of the pipe, length of condensation and evaporation section and inclination angle [3].

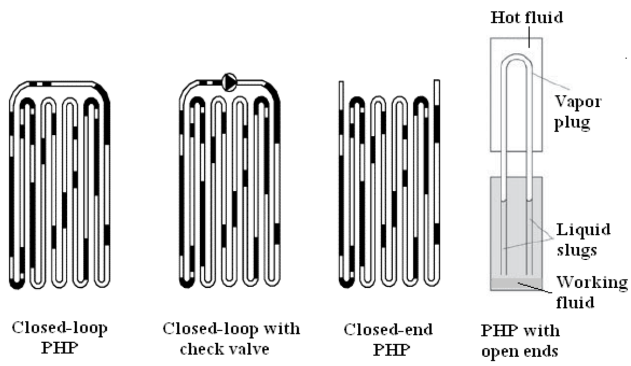

Fig. 1. Types of pulsating heat pipes [7]

A lot of parameters influence the formation of different phases in the evaporating section, such as the Bond number, defined by equation (1) must be less than ~2.

$$Bo = \frac{D_i}{\sqrt{\frac{\sigma}{g} \cdot \left(\rho_{liq} - \rho_{vap}\right)}} \qquad (1)$$

where σ – surface tension [Nm^{-1}], g – acceleration due to gravity [ms^{-2}], ρ_{liq} – density of liquid [kgm^{-3}], ρ_{vap} – density of vapor [kgm^{-3}].

The inner diameter of the tube is a parameter that affects the correct functioning of pulsating heat pipes. They work optimally only in a certain range of diameters. The value of the critical diameter can be determined from the equation (2) of Bond (Eötvös) number as [5]:

$$D_{crit} \approx 2\sqrt{\frac{\sigma}{g \cdot \left(\rho_{liq} - \rho_{vap}\right)}} \qquad (2)$$

It is also worth noting that heat pipes can be produced with an internal structure on the inner surface. It is called a wick and can be made of different microstructures. Such metal coatings have been investigated in the pool boiling mode e.g. in [8, 9].

2. Proposal of a method for measuring the thermal performance of closed loop pulsating heat pipes

Closed loop pulsating heat pipe was constructed for investigating the performance parameters, which had 21 river meanders and the inner diameter was 1.8 mm. Distilled water, acetone and ethanol were used as the working fluid. The critical diameter for water is 5.34 mm, for acetone is 3.47 mm and for ethanol is 3.39 mm. The condition affected the proper operation of internal diameter has been satisfied. Orientation of the heat pipe was vertical. At the top of the heat pipe there were over T-pieces connected two capillaries. One was used to evacuate the air from the heat pipe and the other to carry the heat pipe (Fig. 2). Volume of the working substance ranged from 0–80%. Heat pipe dimensions 235 mm x 200 mm. The beginning of the measurement was set temperature of evaporating at 50°C, 60°C and 70°C and cooling water at 15°C. It also was determined length of evaporating, condensing and adiabatic section. Condensation section was placed in a heat exchanger. Exchanger was constructed of plexiglas and the coolant water was inside. Circulation of cooling water ensured Julabo Model SE.

Fig. 2. Pumping air through a pump and filling pulsating heat pipes

In the inlet and outlet of the heat exchanger temperature sensors NiCr-Ni were placed, which panned coolant temperature. Coolant flow was measured by an ultrasonic flowmeter KAMSTRUP. Evaporation section of pulsating heat pipe was heated with the water in heater thermostat. All thermometers and ultrasonic flow meter are connected to the input of measuring units AHLBORN ALMEMO (Fig. 3).

Fig. 3. Experimental measuring device

The control panel transmits information using special software to personal computer in the form of a Microsoft Excel spreadsheet.

3. Evaluation of the measured variables

The survey was carried on pulsating heat pipes in a vertical position. Calculation of the temperature difference of cooling water in evaporator scanned on entry and exit calculated according to equation (3) in the form:

$$\Delta \overline{t_i} = \overline{t_0} - \overline{t_p} \qquad (3)$$

where $\Delta \overline{t_i}$ – the difference of middle temperatures of the cooling water in fixed state [°C], $\overline{t_0}$ – the middle value of output temperature of the cooling water [°C], $\overline{t_p}$ – the middle value of input temperature of the cooling water [°C]. The calculation of middle heat pipe power value from measuring values is determined (4):

$$\overline{Q} = \dot{m} c_p \Delta \overline{t_i} \qquad (4)$$

where: $\overline{Q}$ – the middle power value in fixed state [W], $\dot{m}$ – mass flow rate of cooling water [kgs^{-1}], c_p – the specific heat capacity at constant pressure [$Jkg^{-1}K^{-1}$], $\Delta \overline{t_i}$ – the difference of middle cooling water temperatures in fixed state [°C] [3].

4. Achievements

According to equation 4 thermal performance of pulsating heat pipes was calculated. Figures 4, 5 and 6 shows the thermal performances at all filling ratios and different temperatures of evaporation. There increasing thermal performance with increasing evaporation temperature of the pulsating heat pipe may be seen. Best values of thermal performances are achieved when the working fluid was distilled water (Fig. 4). It is influenced by the thermo-physical properties of water, a high value of latent heat of evaporation and also the value of the internal diameter of 1.8 mm. Pulsating heat pipes filled with acetone achieve the lowest thermal performance (Fig. 5).

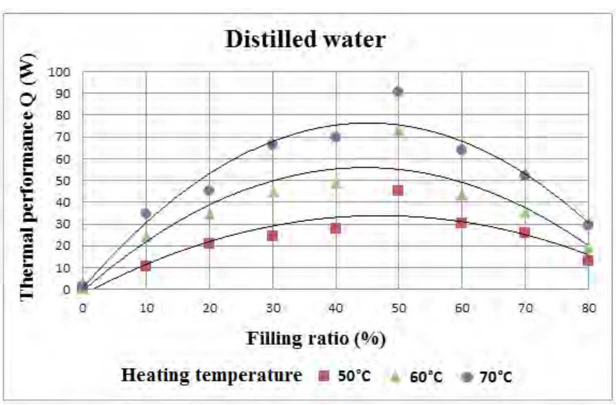

Fig. 4. Effect of filling ratio on thermal performance of CLPHP, working fluid: distilled water

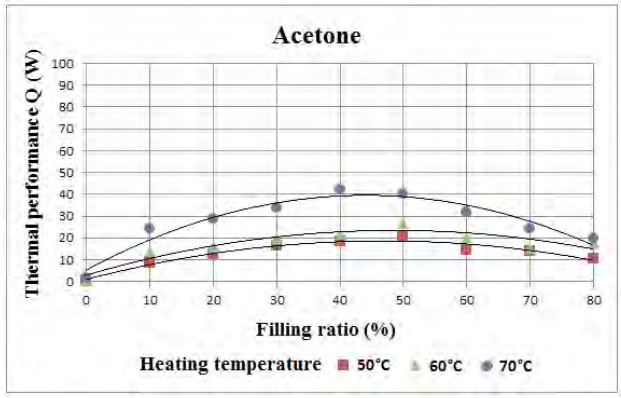

Fig. 5. Effect of filling ratio on thermal performance of CLPHP, working fluid: acetone

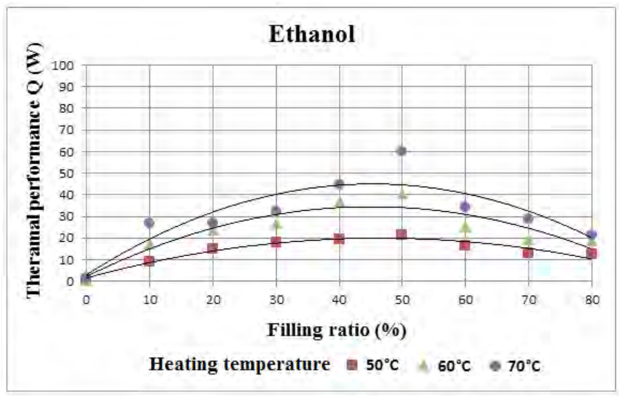

Fig. 6. Effect of filling ratio on thermal performance of CLPHP, working fluid: ethanol

Thermal resistance was also studied in experiment (Figs. 7, 8, and 9). Thermal resistance was evaluated as the mean value at each temperature of evaporation section. These values were kept constant for some time.

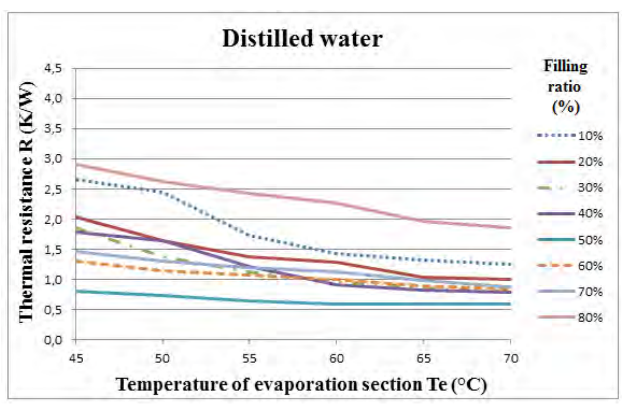

Fig. 7. Thermal resistance depending on the temperature of the evaporation section, working fluid: distilled water

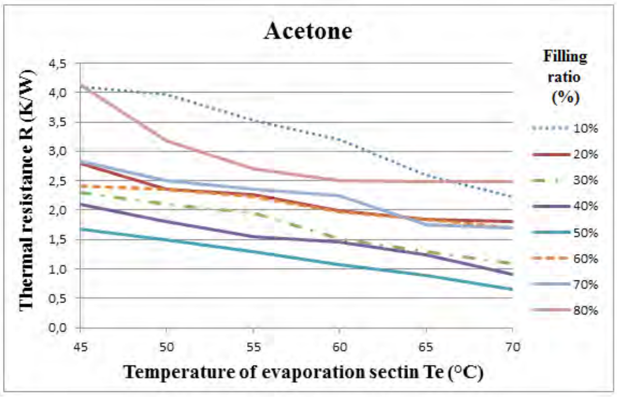

Fig. 8. Thermal resistance depending on the temperature of the evaporation section, working fluid: acetone

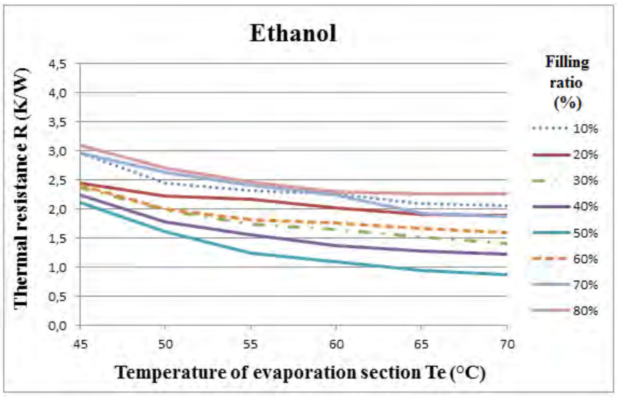

Fig. 9. Thermal resistance depending on the temperature of the evaporation section, working fluid: ethanol

5. Conclusions

The measurement results show that the thermal performance is dependent on the input heat flux. Higher temperatures of evaporation section could not be achieved due to the experimental device and evaporator design. Low temperatures of evaporation section were not able to generate enough vapor bubbles and their pumping activity was limited. This phenomena has led to a reduction in heat output and increased thermal resistance. Increasing the temperature of evaporation section reduced thermal resistance. Closed loop pulsating pipe filled with distilled water give the best performance, because thermo-kinetic water properties as thermal conductivity, latent heat of evaporation, constant pressure specific heat are better than the acetone and ethanol. The experiment shows that the lower volume filling of 30% or above 70% of the thermal performance is greatly reduced.

Acknowledgment

The research is supported by European regional development fund and Slovak state budget by the projekt Research centre of Univerzity of Žilina, ITMS 26220220183.

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