ANALYSIS OF EFFECT VARIOUS TYPES OF WORKING FLUIDS ON PERFORMANCE OF PULSATING HEAT PIPE

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Abstract

Modern electrical components are increasingly constrained by many requirements. They are particularly the miniaturization, long-term reliability, low cost and cooling of components. All the components are sensitive to temperature. Above the temperature range leads to their failure and damage. Therefore, it is necessary to deal with cooling. Intensification cooling electrical components is to use heat transfer through phase changes. It is necessary to create a cooling system, which did not contain moving parts. It is also necessary to create a system that is able to drain the heat loss in each operation mode devices. The use of pulsating heat pipes is one of the possible solutions to this problem. This paper presents an experiment that was used closed loop pulsating heat pipe. Three different kinds of working fluids were used. Thermal performance for different types of working fluids and the value of their volume were examined. In the next phase, the findings from this experiment used in the design of closed loop pulsating heat pipe for cooling electrical components.

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

1. Introduction

Different types of cooling are used, if we want to operate electronic components in a wide range of performances. The released heat can be carried away from the workspace in several ways, either alone or in combination. Pulsating heat pipes are new types in this area. The basic principle of the work described Akachi and Polasek.Pulsating heat pipe usually consists of copper capillary meandering shape. Heat pipe is filled with the working fluid after creation into the desired shape and dimensions.Effects of surface tension cause the formation of liquid slugs and the vapor bubble. Heating of the evaporation section leads to evaporation of the working fluid.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 and vapor phase is condensed. This process between evaporation and condensation section is continuous and it occurs when 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 (Fasula, 2009).

Movement of the individual phases to the cooler causes movement phases to high temperatures. This is manifested as a restoring force. This is possible thanks to the arrangement of tubes. It is assumed that the frequency and the amplitude of pulsations depends on the heat flux and mass fraction of the fluid in the tube (Ochterbeck, 2003).

Pulsating heat pipes can be divided into four groups (Fig. 1):

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

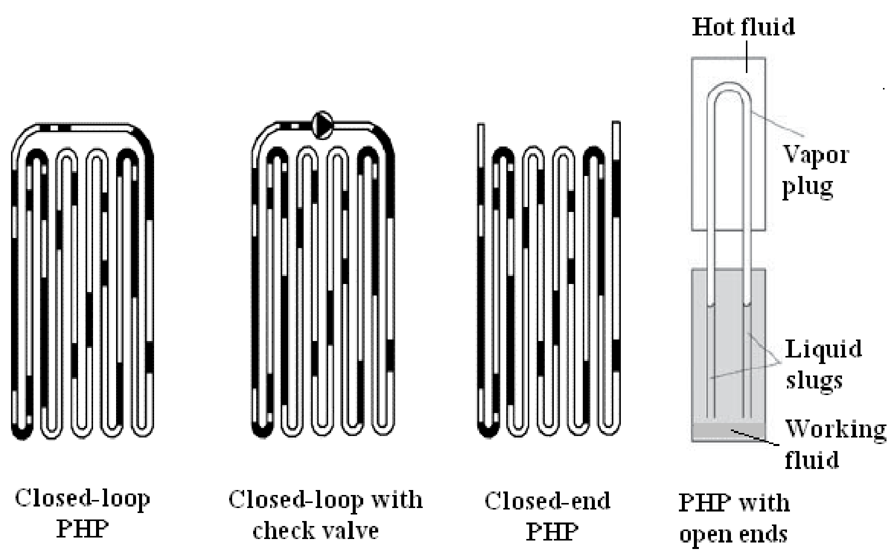

Fig.1 Types of pulsating heat pipes

The parameters that affect the performance of the closed pulsating heat pipe, summed Groll. They are working fluid, internal diameter of the tube, total length of the tube, length of the condensing and evaporating section, angle loops and thermo-physical properties.

Essential condition for the proper functioning of pulsating heat pipe is the value of the internal diameter of the capillary tube, which must be small enough so that the liquid slugs and vapor bubbles can coexist.A lot of parameters influence the formation of different phases in the evaporating section, such asthe Bond number, defined by equation 1 must be less than ~2.

$$Bo = \frac{D_i}{\sqrt{\frac{\sigma}{g}.(\rho_{liq} - \rho_{vap})}} . \tag{1}$$

Where σ – surface tension[N.m^{-1}], g – acceleration due to gravity [m.s^{-2}], ρ_{liq} – density of liquid [kg.m^{-3}], ρ_{vap} – density of vapor [kg.m^{-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:
m

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

Calculation of heat output is based on the similarity of three numbers: Karman (3), Prandtl (5) and Jacob (6), respectively, the combination of angle (measured in radians) and the number of turns N.

$$Ka_{liq} = f.\mathrm{Re}_{liq}^2 = \frac{2.\Delta p.D^3}{L_{eff}.\rho_{liq}.\nu} . \tag{3}$$

$$L_{eff} = 0{,}5.(L_e + L_c) + L_a . \tag{4}$$

Where f – friction factor, Re_{liq} – Reynolds number liquid[-], Δp – difference of pressure [N.m^{-2}], D – diameter [m], L_{eff} – effective length [m], ρ_{liq} – density of liquid [kg.m^{-3}], ν – kinematic viscosity [m^2.s], L_e – length of evaporator section [m], L_c – length of condenser section [m], L_a – length of adiabatic section [m].

$$\mathrm{Pr}_{liq} = \left(\frac{c_{p,liq}.\mu_{liq}}{k_{liq}}\right) . \tag{5}$$

$$Ja = \frac{h_{fg}}{c_{p,liq}.(\Delta T)} . \tag{6}$$

Where $c_{p,liq}$ – specific heat of liquid at constant pressure [J.kg^{-1}.K^{-1}], μ_{liq} – dynamic viscosity [Pa.s],k_{liq} – thermal conductivity [W.m^{-1}.K^{-1}], h_{fg} – latent heat of vaporization [J.kg^{-1}], ΔT - difference of temperature of the working fluid passing through the evaporator to the condenser [K].

Heat flux heat (7) can be expressed as:

$$\dot{q} = \left(\frac{\dot{Q}}{\pi.D_i.N.2.L_e}\right) = 0{,}54(\exp(\beta))^{0,48}.Ka^{0,47}.\mathrm{Pr}_{liq}^{0,27}.Ja^{1,43}.N^{-0,27} . \tag{7}$$

Where q – heat flux[W.m^{-2}], Q – heat throughput rate [W], N – number of turns [-],β – inclination angle from horizontal axis [deg/rad].

2. Production and filling of closed loop pulsating heat pipe

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 (Fig.2). The total length of the tube was 4.635 m. Then it was necessary to fill the tube. To evacuate the air from the heat pipe and to filling were attached to the condensation of 2 T - pieces with an internal diameter of 1.5 mm.

On the upper parts were attached two capillaries. Tight joint was secured by the soldering. In heat pipe was pushed into the water until they form a steady stream. In this way is made a check tightness and patency of the tube. In the heat pipe was also blown the air by the compressor. This method was also used for emptying the heat pipes. Heat pipes have been implemented as in Fig. 3. Filling burette was attached on the filling capillary. Precise amount of working fluid was dosed. On the other capillary was placed special tip to pump air to which was attached silicone tubing. The other end of the silicone hose was connected to a rotary oil pump. Between silicon hoses and other parts was applied silicone paste to ensure the tightness of joints. Between the filling capillary burette and a special end piece has been given rubber washers. Vacuum has been reached. After reaching the lowest value vacuum was pushed capillary by the special pliers. On the dosing burette was opened valve. Required amount of working fluid was applied to the heat pipe. Subsequently was pushed filling capillary. Tightness was still secured by soldering. Filling capillary was pushed. Tightness was still secured by soldering.

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. Volume of the working substance ranged from 0 - 80%.

Fig.2Closedlooppulsatingheatpipe

Fig. 3Pumping air through a pump and filling pulsating heat pipes

3. Experimentsetup

The length of the evaporating, condensing and adiabatic section was intended. The condensing section of the heat pipe has been placed in the heat exchanger. Exchanger was constructed of plexiglass and coolant was water. Circulation of coolant ensured Julabo Model SE. Temperature sensors NiCr-Ni were placed on the inlet and outlet of the heat exchanger. These sensors scanned coolant temperature. Coolant flow was measured by ultrasonic flow KAMSTRUP. Evaporating section of the heat pipe was heated water from the heater thermostat. 12 temperature sensors NiCr-Ni were placed on the adiabatic section of the heat pipe (Fig. 4). They panned temperature changes in working action of the heat pipe. All devices were connected to the input to the control panel AHLBORN. The control panel transmits information using special software to personal computer in the form of a Microsoft Excel spreadsheet (Fig. 5). Orientation of the heat pipe was vertical. The beginning of the measurement was set temperature of evaporating at 50°C, 60°C and 70°C and cooling water at 15°C.

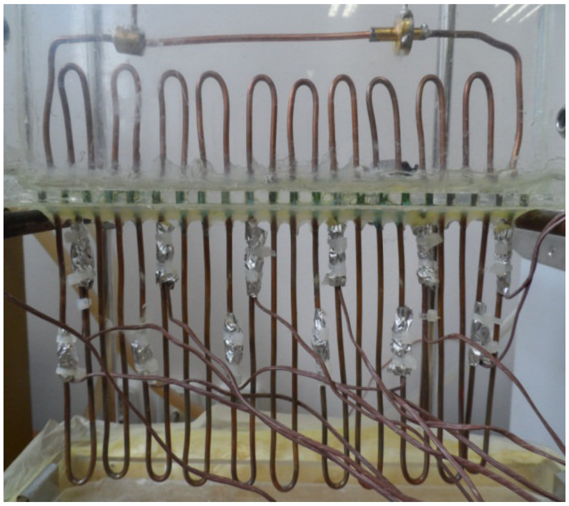

Fig. 4 Temperature sensors

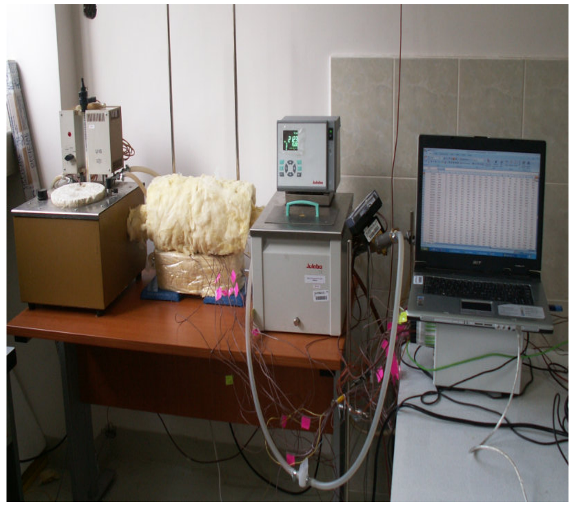

Fig. 5 Experimental measuring device

4. 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:

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

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

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

Where $\overline{Q}$ - the middle power value in fixed state [W], $\dot{m}$ - mass flow rate of cooling water [$kg.s^{-1}$], c_p - the specific heat capacity on constant pressure [$J.kg^{-1}.K^{-1}$], $\Delta\overline{t_i}$ - the difference of middle cooling water temperatures in fixed state [°C] [3].

5. Achievedresults

According to equation 4 were calculated thermal performance of pulsating heat pipes. In figures 6, 7 and 8 shows the thermal performances at all filling ratios and different temperatures of evaporation. There may see increasing thermal performance with increasing evaporation temperature of the pulsating heat pipe. Best values of thermal performances are achieved when the working fluid was distilled water (Fig. 6). 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 7).

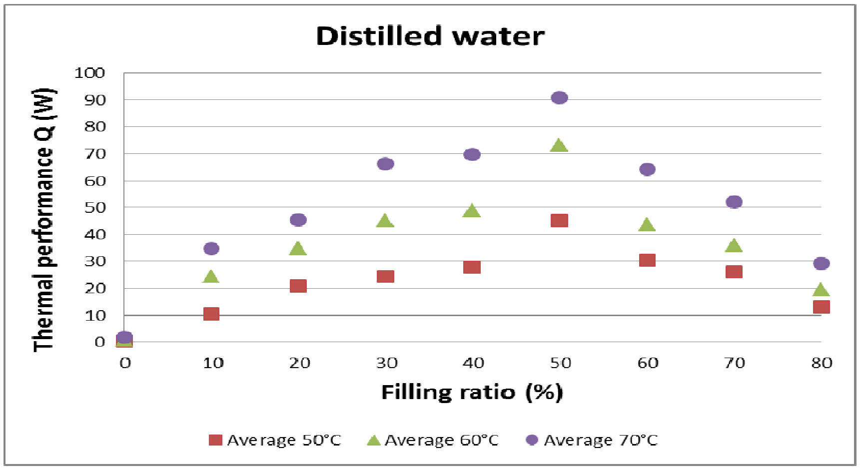

Fig. 6Effect of filling ratio on thermal performance of CLPHP, working fluid is distilled water.

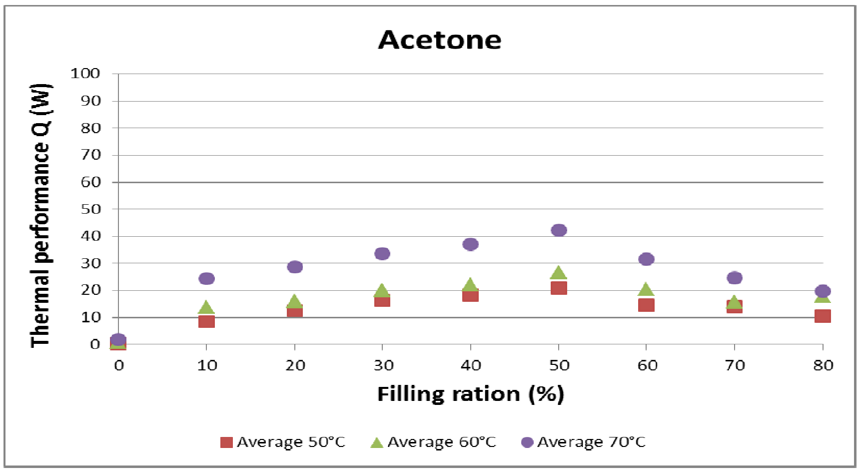

Fig. 7Effect of filling ratio on thermal performance of CLPHP, working fluid is acetone.

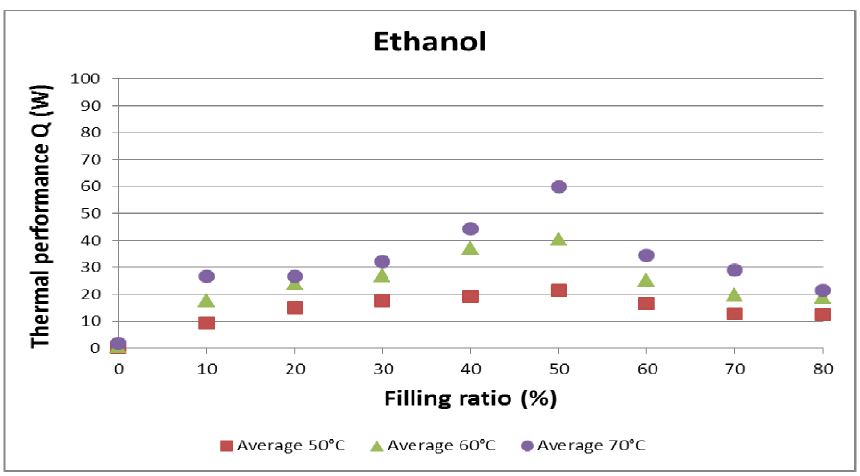

Fig. 8Effect of filling ratio on thermal performance of CLPHP, working fluid is ethanol.

Adiabatic temperature of the experiment were scanned. Fluctuation of temperature in this section is shown in Fig. 9 This phenomenon shows pulsating activity in closed loop pulsating heat pipes. Movement of the vapor is caused by cooling of the tube wall.

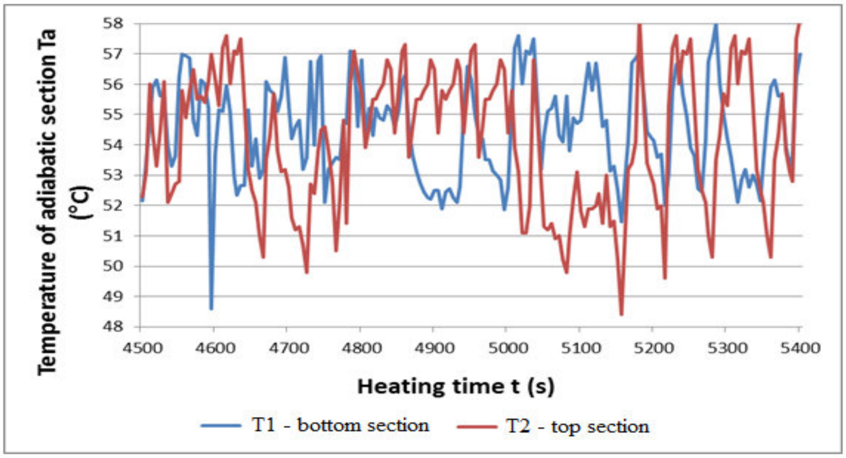

Fig. 9 Temperature fluctuations in the adiabatic section of the heat pipe, the working fluid is water

6. Conclusion

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. Experiment shows that the filling ratio of 30 to 70% achieves excellent thermal performance.Low thermal performance is in the event if filling ratio is below 30 % and above 70 %.Important informationweredeveloped about work activities, filling ratio, thermal performance. The main benefits include the creation of the filling of closed loop pulsating heat pipes. This experiment has created important environment for further research and creating a functioning cooling system.

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