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Intensification of heat dissipation from electrical elements to closed loop heat pipe

Richard Lenhard[1,*], *Katarína* Kaduchová[1], *Peter* Ďurčanský[1], *Milan* Malcho[1], and *Andrej* Kapjor[1]

[1]University of Zilina, Faculty of Mechanical Engineering, Department of Power Engineering, Univerzitna 8215/1, 010 26 Zilina, Slovak republic

Abstract. Article deals with the problem of heat transfer by condenser and evaporator for a closed loop heat pipe for cooling a hermetically sealed electrotechnical box. In an article can by find the design of the heat exchanger for condenser and evaporator for optimal cooling solution, construction and description of experimental state for measuring their performance. Air and heat exchanger temperatures, system pressure, and cooling air flow data were recorded. The measured values are then evaluated and the cooling capacity of the heat exchangers is expressed by means of a sample calculation. The performances are then compared by means of relevant graphs and verified at the end.

1 Cooling of electronic components

Electronic components produce heat as a by-product of their normal operation. When an electric current passes through a semiconductor or passive device, some of the energy is dissipated into the environment in the form of thermal energy.

It is important to keep the room temperature below the maximum allowable operating temperature specified by each electronic component manufacturer. If the maximum operating temperature is exceeded during operation, the service life, performance and reliability of the individual components decreases (Fig. 1).

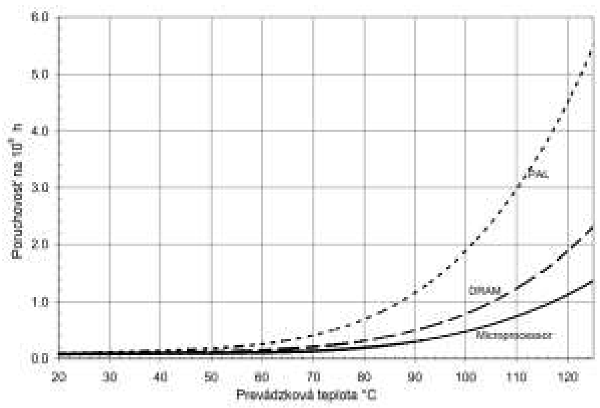

Fig. 1. Failure depending on operating temperature for PAL (Programmable Logic Array), DRAM (Dynamic RAM), and Microprocessors, [1].

Increased heat fluxes from electronic components due to increased power and reduced space requirements require more efficient and reliable cooling to ensure optimum conditions. For most electronic components it is necessary to keep the ambient temperature below 85 °C.

Due to increasing heat fluxes from electronic components, conventional types of cooling have reached their limit values. Conventional air circulation due to cooling capacity, heat transfer rate and dustiness (albeit minimal) gets into the background. The development of cooling systems focuses on cooling with liquid convection without phase change (water coolers), but also with phase change (heat pipe cooling) (Fig. 2) [2].

Fig. 2. Types of cooling: air circulation, water cooling, heat pipe cooling.

2 Closed loop heat pipe

The closed-loop heat pipe is used to transfer heat over relatively long distances without additional mechanical devices. The difference between the heat pipe and the closed loop heat pipe is that the fluid flow and the steam flow are conducted in separate conduits. Thus, the elimination of the interaction limit of the heat pipe was achieved.

In our experiment two-phase closed loop heat pipe is used – the working substance is brought to boiling and condensation. The construction also includes an

* Corresponding author: richard.lenhard@fstroj.uniza.sk

expansion tank to eliminate pressure build-up in the tube (Fig. 3).

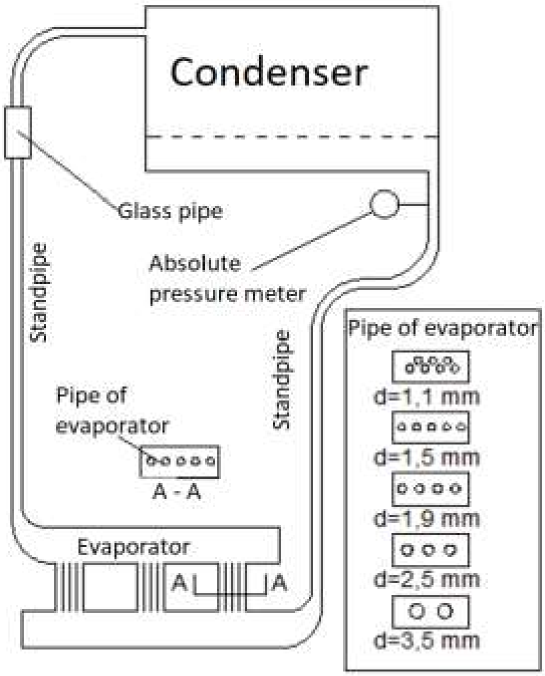

Fig. 3. Two-phase closed loop heat pipe [3].

Closed loop of heat pipe partially filled with working substance – working substance is brought to boiling and condensation. The design does not include an expansion tank to eliminate pressure build-up in the tube [4, 5].

3 Design of condenser and evaporator for closed loop heat pipe

The design of condenser and evaporator is to reduce the material and financial costs of production and achieve a cooling capacity of 1 000 W.

The condenser design consists of registers of copper coils connected to a common manifold (steam) and collector (condensate) (Fig. 4).

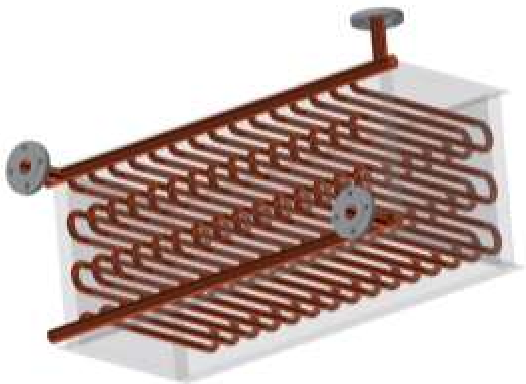

Fig. 4. Construction of copper coil registers for condenser.

The condenser heat exchanger consists of ninety-five 5/8" x 0.4 copper pipes on which fifty-five aluminium lamellas with dimensions 750 x 300 mm, thickness 0.25 mm and rib spacing 5.5 mm are placed (Fig. 4).

The design of the evaporator was based on the requirement for the service life of the designed equipment, the correct design and the limited space inside the electrotechnical box. The design must be able to extract the heat dissipated to maintain the components in the electrical enclosure at the optimum operating temperature. Increasing the coefficient can be achieved by changing the parameters, either on the air side or on the boiling side of the liquid. The figure (Fig. 5) show the final design for a loop thermosiphon.

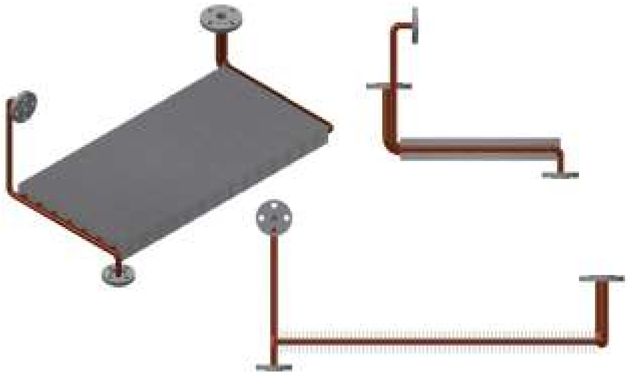

Fig. 5. The structural design of the evaporator.

4 Measurement of cooling capacity

To verify the correctness of the design, measurements were performed on an experimental state with a thermal load of 500 W, 1 000 W and 1 500 W. To achieve the maximum heat loss of 1 500 W in the interior of the electrotechnical box was used 6 resistive bodies (Fig. 6).

The following types were used as working substances: water, Novec, alcohol, acetone with a fill volume of 20 %, 40 %, 60 %, 80 %, and 100 % – the total volume after filling was 1.29 litters.

Fig. 6. Simulation heat source – resistive body.

For better heat transfer inside the electrotechnical box from the heat source to the evaporator, six computer fans 120 x 120 mm were installed with an air flow rate of 2 $m.s^{-1}$ for forced convection. The fans were connected in parallel to a separate laboratory power supply. The air flow rate was set by limiting the output current at the source. The air flow rate was measured using an anemometer. Pt100 temperature sensors were installed to record the measured temperatures in the experimental equipment. The entire experimental equipment in laboratory is shown in (Fig. 7 part with condensator a Fig. 8 part with evaporator).

Fig. 7. Experimental equipment in laboratory – part with condensator: P1 – measurement of the pressure in the heat pipe, V1 - V2 – measurement of cooling air flow rate during natural convection, T1 - T4 – measurement of the cooling air temperature after the condensator, T5 - T13 – temperature measurement on condensator, T14 - T16 – measurement of the cooling air temperature in front of the condensator, T17 – temperature measurement on steam pipe, T18 – temperature measurement on condensation piping.

Fig. 8. Experimental equipment in laboratory – part with evaporator: Tv1 – temperature measurement at the top of the box, TT2-4 –temperature measurement on evaporator tubes, Tv2 –temperature measurement in the central part of the cabinet, TT5 – vapor pipe temperature measurement, Tv3 – temperature measurement at the bottom of the cabinet, S1-6 – resistance spirals.

Cooling capacity was calculated using a calorimetric equation based on air velocity measurement and temperature measurement at inlet T11 and outlet T12.

Calorimetric equation:

$$Q = m.\ c_p.\ (T_{11} - T_{12}) \quad (1)$$

$$Q = V.\ \rho.\ c_p.\ (T_{11} - T_{12}) \quad (2)$$

$$Q = \upsilon.\ S.\ \rho.\ c_p.\ (T_{11} - T_{12}) \quad (3)$$

5 Results of cooling capacity

Measurement of the cooling capacity of the condenser in combination with the evaporator, the measured cooling capacities were shown in the graphs according to the percentage of filling and heat load (Fig. 9, Fig. 10, Fig. 11, Fig. 12).

The heat exchanger functionality is obvious from the measured results. At 80 – 100 % loading, the power was sufficient to maintain the maximum temperature requirement of 80 °C, except for acetone at a volume of 100 %. The maximum average velocity in the air flow through the condensator was 0.47 m.s^{-1}.

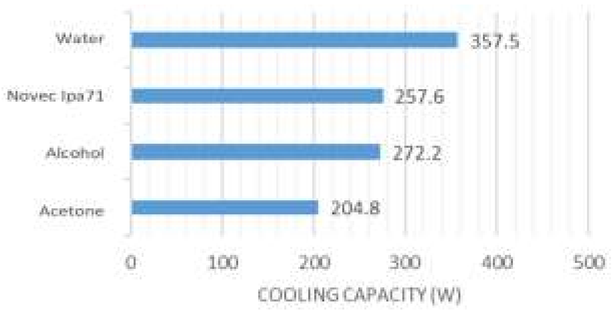

Fig. 9. Comparison of cooling capacity, load 500 W, volume 80 %.

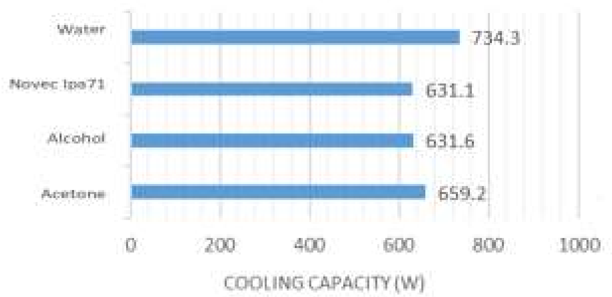

Fig. 10. Comparison of cooling capacity, load 1 000 W, volume 80 %.

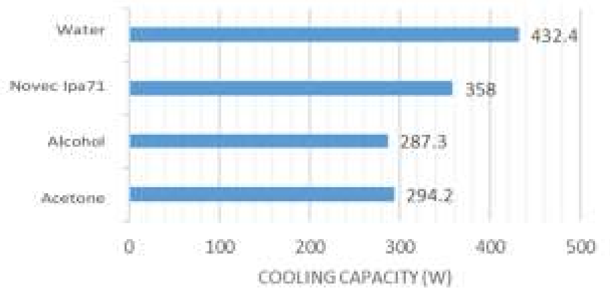

Fig. 11. Comparison of cooling capacity, load 500 W, volume 100 %.

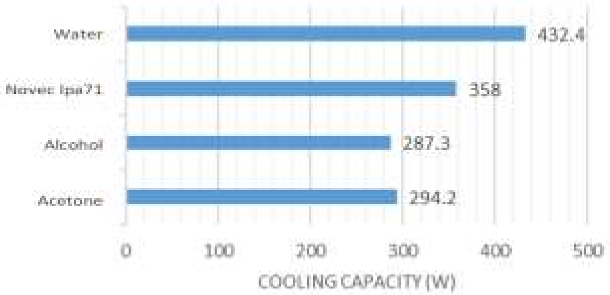

Fig. 12. Comparison of cooling capacity, load 1 000 W, volume 100 %.

5.1 Results of the temperatures in the electrotechnical box

The evaluation of the measured quantities was considered at the inlet of the heat exchanger with a homogeneous temperature field, with the same air velocity in cross-section. However, such conditions cannot be achieved in the measured device. This is also evidenced by the measured temperatures at the exchanger outlet. In Fig. 13 is an exemplary graph of temperature stabilization inside the electrical enclosure for a second evaporator using a natural convection and distilled water condenser as a working medium with a 60 % load and a 500 W load.

The total mean values of the temperatures in the box space after the measurement of individual amounts of fillings are stabilized are given in the tables (Table 1, Table 2).

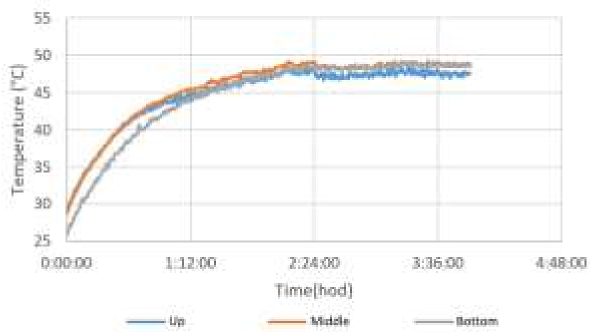

Fig. 13. Electrotechnical box temperature stabilization.

Table 1. Temperature in the electrotechnical box, load 500 W.

	20 %	40 %	60%	80 %	100 %
Acetone	-	-	59 °C	58 °C	63 °C
Alcohol	-	-	48 °C	44 °C	41 °C
Novec IPA71	80 °C	80 °C	64 °C	57 °C	-
Water	75 °C	58 °C	56 °C	45 °C	48 °C

Table 2. Temperature in the electrotechnical box, load 1000 W.

	20 %	40 %	60 %	80 %	100 %
Acetone	-	-	81 °C	76 °C	-
Alcohol	-	-	70 °C	66 °C	61 °C
Novec IPA71	-	-	-	79 °C	79 °C
Water	-	-	69 °C	61 °C	64 °C

6 Conclusion

Cooling of power converters by convection and conduction methods is affected by airborne dust. Gradual dusting of the drive components results in an increase in the internal temperature of the entire system due to insufficient heat flux, causing damage to the power converter. The heat generated by the system is an undesirable factor that shortens the life of individual components.

Experimental measurements have confirmed that the proposed evaporator solution for electrical cabinet cooling and the use of a loop thermosiphon for component cooling is a suitable solution. The Novec IPA71 working medium is recommended for direct cooling, or a different pressure in the loop thermosiphon system should be selected.

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