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Research Paper

Double condenser pulsating heat pipe cooler

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HIGHLIGHTS

- A newly designed pulsating heat pipe cooler (PHP) based on automotive technology is investigated.
- The PHP has two condenser areas, one above and one below the evaporator.
- Measurements were performed with the refrigerant fluid R245fa in three different orientations.
- The results show that the device is orientation-free with identical performance in all tested orientations.

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ABSTRACT

A novel pulsating heat pipe cooler (PHP) based on automotive technology is presented. This technology uses numerous aluminum Multiport Extruded (MPE) tubes disposed in parallel to achieve the desired compactness. The sub-channels of the MPEs are connected in a serpentine manner by means of fluid distribution elements integrated in the two condenser manifolds. This configuration enables the oscillation of liquid slugs and elongated bubbles between the evaporator and the condenser areas. This power electronics cooling system with a double condenser area was experimentally characterized and the thermal performances measured with R245fa are presented in this paper. The influence of different parameters such as the heat load, fluid filling ratio and orientation are investigated. The results show that the device is orientation-free: the performance was identical in all orientations, vertical, horizontal and anti-vertical.

1. Introduction

Power electronics and microelectronic cooling requirements are becoming every year more demanding due to the continuous increase of power density. Pulsating heat pipes (PHP) have emerged in the last years as suitable cooling devices for dissipating the high heat loads generated by electronic devices since they allow for the extension of air cooling's applicability into areas nowadays covered by water-cooling [1]. These devices are entirely passive and they comply with long-term operation without maintenance. Furthermore, the possibility to work independently from the orientation allows higher flexibility on their mechanical integration compared to two-phase thermosyphon coolers. The overall functionality of PHPs is still not completely understood [2]. The complex interplay of local hydrodynamics, thermodynamics, and phase change phenomena make a comprehensive model extremely difficult to develop. Reviews of past research as well as unresolved issues relating to PHPs can be found in works by Zhang and Faghri [3] and Khandekar et al. [4]. Research efforts continue to move toward a more comprehensive understanding of this technology.

Experimental investigations test the performance limits of PHPs with different design parameters [5,3,7]. Among these, Lin et al. [6] tested experimentally a water-cooled open-loop PHP with two symmetrical condensers using fluorocarbons as the working fluids. The experimental configuration consisted of a copper tube with an inner diameter of 1.75 mm which was bent in 40 turns. The PHP dissipated a maximum heat load of 2.04 kW, representing a heat flux of 6.4 W/cm^2 and a thermal resistance of 48 K/kW. Experiments reported similar thermal conductivities for horizontal and vertical orientations, showing that the heat pipe was orientation independent.

Numerical models have also been developed in an attempt to predict the thermal and hydrodynamic behavior of these devices [8–11]. Nikolayev [12] has produced a recent work that numerically and theoretically predicts oscillation development and start-up criterion for a single branch PHP.

All current models include essential simplifications in order to keep the problem tractable. Future work must continue to capture effects that have thus far been neglected such as boiling, contact

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Nomenclature

Cond	condenser
$C_{p,air}$	air specific heat capacity (J/kg K)
FR	filling ratio (%)
$\dot{m}_{air}$	air mass flow rate (kg/s)
dp	differential pressure (bar)
P_{max}	maximum operative pressure
Q	input power (W)
Q_{air}	power extracted by air stream (W)
R_{th}	thermal resistance (K/W)
$T_{b,max}$	maximum base plate temperature (°C)
T_{ai}	inlet air temperature (°C)
T_{ao}	outlet air temperature (°C)
u	uncertainty
V_{air}	volumetric air flow rate (m^3/h)
ΔT	temperature difference (K)

angle, etc. Continued experimental work is important to provide reference and verification for the models.

2. Experiments

Fig. 1 reports a schematic of the novel pulsating heat pipe heat exchanger [13].

The cooler is made of 11 parallel aluminum multi-port extruded (MPE) tubes having capillary dimensions and connected by fluid distribution elements in the two condenser manifolds. Each MPE tube has 7 sub-channels with rectangular cross section and 1.54 mm hydraulic diameter. The heat load is transferred to the internal channels by an aluminum baseplate (evaporator) in which several grooves are machined and the MPEs are embedded. The heat is then transferred to the two opposite ends where the MPEs are thermally connected using louvered fins (condenser) and finally transferred to the external air by forced air convection. The pulsating heat pipe configuration is achieved by connecting in series the sub-channels of the MPEs at the manifolds [14] enabling the pulsation as shown in Fig. 2. The manifold design used results in a total of 27 turns and an open loop configuration.

The newly designed cooler has two condensing areas, one at the top and one at the bottom of the evaporator baseplate, where the heat source device is mounted. In such a way, the fluid has the possibility to pulsate/oscillate in both directions symmetrically. Furthermore, this adds the benefit of having the fluid turns in the manifolds with the fluid being most likely in the liquid state thus reducing the local pressure losses.

The PHP has a width of 155 mm and a height of 134 mm for both condensing areas and 125 mm for the evaporator baseplate, respectively.

A schematic of the test facility is reported in Fig. 3. Tests have been performed by using one centrifugal fan and a T-conduit to split the air flow between the two condensers. To ensure equal mass flow rates, the pressure drop across each condenser was measured (dp_1 and dp_2) and kept equal by opening and closing the respective valves (V_1 and V_2). The overall mass flow of air was controlled by adjusting the fan speed and monitored using a flow meter (FM). Furthermore the air inlet temperature was regulated by the heater (H_2) and set by a PID controller. The heat load was supplied to the system by means of six ceramic heaters (H_1) each having a size of 50 × 50 mm and monitored using a Hameg (HM8115-2) power meter.

All signals have been acquired through a National Instruments SCXI box connected to a laptop running Labview. Thermocouples have been calibrated using an Omega DP97 precision thermometer with platinum probes to measure the reference temperature and a Lauda R207 chiller to control the temperature.

3. Data reduction

From the experimental campaign, it is possible to determine the thermal resistances of the cooling device.

The thermal resistance is calculated as follows:

$$R_{th} = \frac{T_{b,\max} - T_{ai}}{Q} \tag{1}$$

where T_{ai} is the inlet air temperature, Q is the heat load to be dissipated by the cooler and $T_{b,max}$ is the maximum base plate temperature measured with the 9 temperature measurements T_b. The thermocouples are placed inside 1.2 mm diameter holes drilled from the backside of the baseplate and with a depth reaching 1 mm to the top surface. The thermocouple tip was fixed to the baseplate holes by means of a highly thermally conductive epoxy (supplier omega, type 101), thermal conductivity 1.04 W/m K.

Several thermocouples have been installed to monitor the air temperature conditions: one at each condenser inlet cone and three on each outlet. From the measured air volumetric flow rate, the heat exchanged on the air side can be calculated with a thermal balance (assuming uniform air flow rate):

$$Q_{air} = \dot{m}_{air} \cdot c_{p,air} \cdot (T_{ao} - T_{ai}) \tag{2}$$

The above equation can be evaluated for each condenser: the term T_{ao} represents the mean outlet temperature of the six measured val-

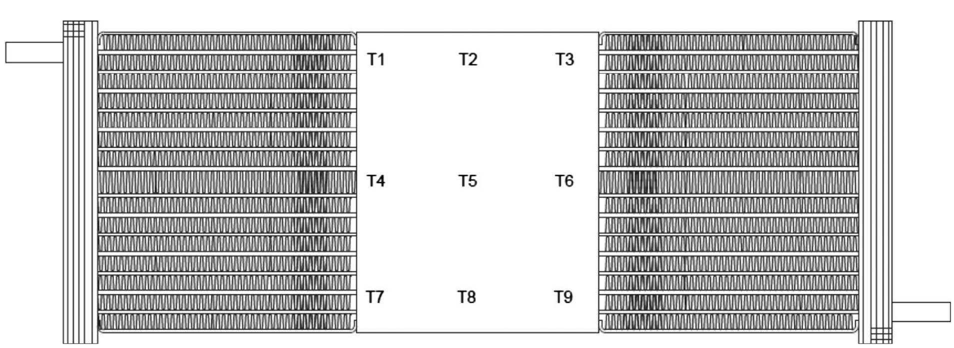

Fig. 1. Schematic of test section and thermocouple positioning.