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Fill ratio effects on vapor chamber thermal resistance with different configuration structures

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ABSTRACT

The objective of this research is to present an investigation the thermal resistance of ten vapor chambers with different configuration structures with different working fluid fill ratios. The coolant flows entering the cooling section of the vapor chamber with constant mass flow rate of 0.05 kg/s. The de-ionize water is charged into the vapor space under vacuum condition with the ranging of 20–45% by volume. A 125 kW/m^2 constant heat flux is applied at the 40 × 40 mm^2 heat source area. It can be seen from experiments that the optimized fill ratio to obtain the minimum thermal resistance of the vapor chamber depends on the operating power, geometries and material types of heat sinks, configuration structures inside the vapor chamber. The results obtained from this study are expected to lead to guidelines that will allow designing vapor chamber with the optimized fill ratio to obtain minimum thermal resistance.

1. Introduction

A phase change heat transfer method was selected as a passive cooling device for many heats dissipated from source of an electronic components. It is distributing high heat transfer rate from a small source and spread to larger area through vaporization and condensation of working fluid inside. The working fluids is distributing latent heat and then released it when touch a cooler wall and return into evaporator through a wick structure. The vapor chamber is a high-performance cooling technique which used in many applications. The work reported on the velocity, pressure and temperature distributions inside the vapor chamber with wick sheet and wick columns [1]. Hsieh et al. [2] studied the thermal performance of a water charged, gravity assisted flat vapor chamber to be used as heat spreader for electronic cooling. There was some work presented effect of heat source of a plate-fin heat sink embedded with a vapor chamber has an important influence to the performance of the vapor chamber [3]. Some study showed the improvement of thermal performance of the vapor chamber with pin fin heat sink [4,7]. Wong et al. [5,10] considered thermal resistant of the vapor chamber which used parallel grooves of the top plate replaced the conventional porous wick, however, there were papers reported on the electronic cooling components and LED cooling with flat heat pipe and vapor chamber for long thermal cycle duration [6,8,29]. The nanostructured and nanoparticles powders can be improved the thermal performance of vapor chamber [9,17,18,19,22,23]. Ji et al. [11,12] considered effects of different working fluid types (water, acetone, ethanol) inside the vapor chamber on the thermal performance. Most of the previous studies had been carried out by Naphon et al. [13–14,21,33–37]. They applied the vapor chamber with water, R-141b as working fluid for cooling HDD, CPU of personal computers. In addition, they also experimentally and numerically investigated effect of sintering columns, vapor chamber with micro-channel, vapor chamber using liquid as coolant, effect of heat source area and cooling techniques for electronic components. The works reported on the thermal performance and flow resistant of the ultrathin vapor chamber with metallic heat sink had been carried out by Ranjan et al. [15]; Reyes et al. [16]. Ju et al. [20] studied on the hybrid wicks combine distributed high-permeability liquid supply structures with thin (monolayer) evaporation layers. Some studies reporting the thermal resistant of the vapor chamber with various wick structures had been investigated by Liu et al. [24]; Mizuta et al. [25]; Huang et al. [26]. In addition, Patankar et al., [27] analyzed the thermal resistance of ultra-thin vapor chamber with various operating conditions, geometry parameters. Shaeria et al., [28,31] optimized thermal performance of vapor chamber combining hydrophobic and hydrophilic wettability in the evaporator to optimize thermal performance. Effect of copper spreader size on the thermal performance of vapor chamber and temperature distribution had been performed by Velardo et al. [30], while Zeng et al. [32] considered

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Nomenclature

A	heat transfer surface area, [m^2]
I	current, [A]
Q	total power input, [W]
q	heat flow, [W m^{-2}]
R	thermal resistance, [°C W^{-1}]
T	temperature, [°C]
t	time, [s]
V	voltage, [V]

Subscripts

base	vapor chamber base
contact	contact surface
e	electricity
heat-source	heat source
inlet	inlet
tot	total

a thin aluminum vapor chamber using micro-grooved wick with reentrant cavity array a fast temperature response and low start-up heat load. The heat transfer characteristics in the vapor chamber is the phase change heat transfer phenomena which have been comprehensively researched. The vapor chamber embedded with heat sinks with different fin configurations are becoming more and more attractive in thermal management of electronics devices in recent years especially with phase change heat transfer characteristics. They can absorb and release large amount of heat during their melting and solidification process thus keeping the system at constant temperature nearly minimizing the occurrence of overheating or other damages. Some studies reporting the phase change heat transfer characteristics of water, ethylene glycol, refrigerant and nanofluids on the pin fin tube with different structure configurations have been investigated by Ali et al. [38–50].

As literature reviews, a vapor chamber is utilized permanently in many heats dissipated applications which the most papers are presented the thermal performance. However, some papers are not concentrated on amount of working fill charge ratio in the vapor chamber with different configurations structures. Selecting an optimized vapor chamber embedded with heat sink with different configuration structures are a current major area of research for the better thermal management of electronic devices. Therefore, the objective of this paper is to investigate the optimized fill ratio to obtain minimum thermal resistance of the vapor chambers with various configuration structures.

2. Vapor chamber mechanism and fabrication

The vapor chamber is the phase change cooling technique which used as cooling device to transfer heat from source. In the past decades, a cooling technique for many applications is a heat sink embedded with fins to transfer those heat dissipated to keep an optimal temperature of the devices. The vapor chambers/heat pipes are heat spreading devices with large effective thermal conductivity due to phase change phenomena and can be more efficiently with sintering porous media. In this research, a small copper powder of an irregular shape of 100–300 μm is sintered and applied as a wick structures and wick columns. The main parts of the vapor chamber consist of three functional sections: evaporator, vapor space and condenser sections. When heat applied at heat source surface, working fluid inside the vapor chamber absorbs heat by conduction via solid wall until working fluid is saturated liquid and then evaporated under vacuum condition in the wick zone. The vapor flows from the higher-pressure region in the evaporator to the condenser section and released heat to the external cooling. At this state, the liquid releases its latent heat through convection and then condenses into liquid and flows back to the evaporator region through wick structure via capillary pumping.

The chamber is a solid material consists of two sections; vapor chamber section, heat sink section. The vapor chamber section is a bottom container which fabricated from high thermal conductivity materials. A lower part of the vapor chamber is attached directly to a heat source for absorbing heat via conduction. A wick sheet layer and wick column are embedded on a planar bottom wall over heat source area. A layer of the wick sheet and the wick column thickness are 0.5 mm and 2 mm, respectively. A circular shape wick column with 2,6 mm diameters are laid on bottom wall while the tip of wick columns are touched the upper part (condenser). The pin fins heat sink unit is embedded on the upper surface to transfer heat from vapor inside a chamber through external fluid flow via convection. Meanwhile, liquid coolant flows in and flows out through the heat sink unit.

3. Experimental apparatus and test procedure

3.1. Experimental apparatus

As shown in Fig. 1, the test loop of vapor chamber using liquid as coolant consists of two units: test section unit and liquid cooling unit. The test section is consisted of the vapor chamber and other mechanical parts including, cylinder system, heater unit, flow sensor, differential pressure transducer, thermocouples, and couplings. The vapor chamber is placed among acrylic plates as an insulator material except bottom wall. The liquid flows entering the test section at the top while the heat is generated at bottom wall of the vapor chamber. A cylinder is constructed at bottom of the test section to apply constant axial load force to push the heater plate contacting the bottom wall of the vapor chamber. The liquid flow rate is measured by flow sensor and adjusted by ball valve. Two pressure transducer head are set at inlet and outlet ports of the test section to measure different pressure across the test section. The pressure across the test section is measured by differential pressure transducer with an accuracy of 0.02% of full scale and uncertainty of ±0.2. The photograph of the experimental apparatus and cooling system are shown in Fig. 2.

3.2. Test section

The photograph of the test section of the vapor chamber using liquid as coolant is shown in Fig. 3. The cartridges heater are added into the small holes of the copper heater plate that put over cylinder to generate heat rate as heat spreader instead of heat from electronic source. The variac controlled AC power supply, a current shunt and two precision multimeters are provided for the current and voltage measurement. Four and two thermocouples are used to measure the inlet and outlet temperatures of coolant while the heat source temperature distributions are measured with six thermocouples. Before recorded all data, the system must be reached the steady state about 10 min. Type T copper-constantan thermocouples with an accuracy of 0.1% of full scale are employed to measure the temperatures which all thermocouples are