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Heat transfer characteristics of a parallel miniature heat pipe system☆

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ABSTRACT

In this present study, the heat transfer characteristics of a parallel miniature heat pipes system (mHPs) intended for desktop computer processor cooling was experimentally investigated. The experimental system consisted of six single copper tube mHPs slotted into two copper blocks at the evaporator section and fifteen parallel copper sheets at the condenser section. The copper blocks were placed above the heat source (on the top of the computer processor) and the condenser section was provided with external fins perpendicular to the mHPs. Four working fluids, namely acetone, ethanol, methanol, and propanol-2 were used independently to probe the working fluids' effect on the thermal performance of the system. Heat transfer characteristics of the mHPs were determined based on the principle of phase change of the working fluids at different temperatures to evaluate the thermal performance. The thermal conductance and thermal resistance of the system were determined as the parameters of thermal performance. The results indicated that the thermal characteristics of the heat pipe varied significantly for different temperatures of the heat source at the evaporator and different working fluids. It was obtained that the methanol is the best working fluid to be used in a mHPs in comparison with other working fluids (acetone, ethanol, and propanol 2). Furthermore, the lowest evaporator surface temperature was achieved with the methanol based system.

1. Introduction

In modern days, heat removing from electronic equipment is becoming a very important issue as the internal structures are getting more compact and more complex. Conventional fan cooling in electronic devices is accepted widely for a long time despite the huge noise generation and power consumption associated with it. The development of high-end and compact computers has resulted in a considerable rise in the heat dissipation by the microprocessors. That leads to the advent of heat pipes in computer cooling [1–3]. The central processing unit (CPU) of a desktop, server computer, and notebook computer releases 80 to 130 W, and 25 to 50 W of heat energy, respectively [1,4–6]. It became more challenging because the chip surface temperature should not be allowed to go beyond 100 °C [7,8]. The inability of the conventional cooling fan system to meet these demands of the new generation of computers leads to the advent of heat pipes in computer cooling [4,9]. Furthermore, although scientists opted to apply liquid submersion cooling, active and passive heat sink cooling, thermoelectric cooling etc. in computer cooling but nowadays these became nearly obsolete for integration, reliability and cost issues [10,11]. With recent development of concept and technology in the two-phase as well as porous media heat transfer systems, heat pipes have come up as one of the best candidates to meet these challenging needs.

In the development process, as the electronic devices became more mobile in use and in size compactness, scientists started to concentrate more on micro and miniature heat pipes. Micro and/or miniature heat pipes are channels with a hydraulic diameter in the range of 0.5–5 mm, and length of several centimetres (10–100 mm) [12]. xZhang and Wong [13] studied heat transfer and fluid flow in an idealized micro heat pipe with the support of NASA and LaSPACE. They analyzed four different length to width ratios, i.e., 20, 50, 100, and 200 of an idealized micro heat pipe. Sobhan et al. [14] reported a comprehensive review on the mHPs considering various geometrical designs and asked for further research to optimize the thermal performance of mHPs. Wu and Peterson [15] developed a transient numerical model capable of predicting the thermal behavior of micro heat pipes and compared their results with the steady state results obtained by Babin et al. [16].

Notebook computers involved the first high volume use of heat pipes when Intel introduced the Pentium® TCP packages [17]. The

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Nomenclature

A	areas of mHPs inside the evaporator section [m^2]
A_{cond}	total cross-sectional area of the mHPs [m^2]
AC	alternating current [ampere]
I	current [ampere]
ID	inner diameter [m]
OD	outer diameter [m]
k	thermal conductance [W/(m K)]
L	distance between evaporator and condenser mid-sections [m]
$mHPs$	miniature heat pipe systems [dimensionless]
Q	heat supplied [W]
R	thermal resistance [K/kW]
T_c	average condenser temperature [K]
T_e	average evaporator temperature [K]
V	voltage [volt]
φ	heat flux [W/m^2]

main reason for the use of heat pipes is the Pentium® power dissipation level and the limitation and constraints of space and weight in notebooks. Compared to metal plates or heat sinks, heat pipes offer excellent thermal performance with much less weight and can spread the heat away from the CPU to other areas where the heat can be rejected. Today, Pentium® based notebooks and sub-notebooks are estimated to use several millions of heat pipes annually based on the PC based notebook volume.

The performance of natural convection heat sinks is directly dependent on the effective surface area: more effective surface area results in better performance. To enhance the heat transfer, an additional cooling fan is used with the aluminum heat sink. The increase of the microprocessor speed and number of transistors cramped into the processor core silicon die has continuously driven up its power dissipation. Heat sink sizes have been increasing in personal computers, from the 2″ × 2″ aluminum extrusion heat sinks for i486 to the 3″ × 3″ heat sinks for Pentium® and even large heat sinks for the latest Pentium® II microprocessors. Heat pipes as higher level thermal solutions are naturally being investigated as the potential thermal solutions for these systems [17,18].

Another severe problem of today's processor cooling fan is the generation of noise. Much effort has been made in recent years to minimize noise generated by CPU cooling fans, a fact that has been demonstrated by the popularity of variable and low speed fans coupled with efficient CPU heat sink designs [18]. Even with the adjustable fans generating lower noise at lower speeds, the main noise sources in a computer system are fans and hard drive. Therefore, the best way to eliminate the noise is to remove these sources. As it is impractical to get rid of the hard drives, it seems like a good idea to cool the CPU without a fan.

The heat pipe can, even in its simplest form, provide a unique medium for the study of several aspects of fluid dynamics and heat transfer and it is growing in significance as a tool for use by the practicing engineer or physicist in applications ranging from heat recovery to precise control of electronic equipments [8,19]. For electronic equipments, heat pipes of diameter 3 to 6 mm and length less than 400 mm are preferred [10]. Most preferable length is 150 mm [11]. Studies on the application of heat pipes having the diameter of 3 or 4 mm for cooling notebook PC CPU have been conducted by recent investigations [20,21]. Uddin and Feroz [4] conducted experimental investigation on parallel mHPs for cooling desktop processor. They used mHPs of 1.8 mm ID. They reported that replacement of the cooling fan and aluminum heat sink with mHPs reduced the processor surface to a value which is much lower than in the case of 5.78 mm ID. However, heat generation in the processor was not considered in their investigation. To investigate the thermal performance of parallel mHPs in cooling of desktop processor, heat generation in the processor is required. The main aim of the present investigation is to experimentally evaluate the heat transfer characteristics as well as thermal performance of the mHPs in cooling desktop computer processor with respect to the four different working fluids such as acetone, ethanol, methanol, and propanol-2.

2. Mathematical formulations

The experimental data were used to calculate the heat flux, thermal conductance and thermal resistance of the mHPs at different heat inputs.

Heat flux was obtained from,

$$\varphi = \frac{Q}{A} \tag{1}$$

where Q is the heat supplied and A is the total outer surface area of six mHPs at the evaporator section.

Thermal conductance of the heat pipe system was calculated by using the following equation,

$$k = \frac{Q\,L}{A_{cond}\,(T_e - T_c)} \tag{2}$$

where A_{cond} *is the* total cross-sectional area of the mHPs and T_e and T_c are the temperatures of the evaporator and condenser sections, respectively.

Thermal resistance of the heat pipe system was calculated according to the following way,

$$R = \frac{(T_e - T_c)}{Q} \tag{3}$$

3. Experimental setup and methodology

3.1. Experimental setup

The experimental setup mainly consists of four parts: parallel mHPs, a desktop computer, temperature measurement system and cooling system. The experimental facility consists of six parallel mHPs along with heating and cooling sections, a variac, 5 selector switches, 30 thermocouples and a temperature indicator as shown in Fig. 1 (a) and (b). Six mHPs are placed parallel to each other for cooling purposes. Every mHPs has an inner diameter of 1.8 mm and outer diameter of 2.8 mm having a length of 150 mm. There are three sections in every mHPs: evaporator, adiabatic and condenser section as shown in Fig. 2(a). The condenser section of mHPs is made of fifteen copper sheets of 67 mm × 50 mm (thickness 0.5 mm) placed parallel as extended fins at a constant interval of 5 mm as shown in Fig. 2(b). Plates are joined with the mHPs with araldite for better heat transfer. The mHPs are bent at 90° in adiabatic section due to having the space constrain in field of its application inside the CPU. The different sections of a parallel mHPs are shown in Fig. 2(a). The evaporator sections of mHPs are inserted into the grooves of copper blocks as shown in Fig. 3(a), which are placed on the top of the processor to remove the generated heat. Two copper blocks of 67 mm × 50 mm × 8 mm are made very precisely to mate with the mHPs. Grooves are cut inside the blocks. The blocks are precise in dimension and surfaces are finished highly to reduce the contact resistance as well as to increase the heat transfer rate. The evaporator section is electrically insulated using dielectric tape. Subsequently, the Nichrome wires are used to wound around this section uniformly. Finally, the thermal insulation is done using asbestos.

Heat is generated in the processor which is conducted through the copper blocks to the evaporator sections of mHPs where working fluid