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Effect of aluminum-foam heat sink on inclined hot surface temperature in the case of free convection heat transfer

M. Paknezhad[a], A.M. Rashidi[a], T. Yousefi[a,b,*], Z. Saghir[b]

[a] Department of Mechanical, Engineering, Razi University, Kermanshah, Iran
[b] Department of Industrial and Mechanical Engineering, Ryerson University, Toronto, Canada

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ABSTRACT

The need to more powerful electronic chips cause more heat generation as a consequence. So it leads to apply metal foam heat sink as a powerful cooling methods. The objective of this paper is to experimentally investigate the effect of inclination angle on the temperature of a heated surface with and without metal foam in the case of free convection heat transfer conditions. Experimental modeling has been conducted using an electrical resistor on an aluminum plate with and without aluminum metal foam in different angles with respect to the horizontal direction. The results show that the temperature variations have a linear dependency to the sine of inclination angle up to 45° and 60° for plate with and without metal foam, respectively. The slope of the lines are positive in low power input and negative in high power input. The effect of applying metal foam depends on the input power and inclination angle. In the presence of foam, the surface temperature has a decrease of 16 °C with respect to a flat plate. The maximum cooling efficiency using foam is about %17 at 90° inclination angle.

1. Introduction

Temperature control of electronic components, in spite of scientific progress, is one of the major industry challenges such as chip industry. Nowadays, in order to produce more powerful or smaller computer systems, the chips have been made with higher processing power and smaller dimensions. Therefore, it has a smaller surface per unit volume to dissipate heat from the component, consequently the chip's temperature may be increases during its working [1,2]. It should be noted that the dissipated power of transistor may be cause the temperature reaches to the unauthorized limit and leads to a serious damage or even disability of the system. Although, the generated heat in any transistor of integrated circuits is low, but high density of transistors on the chip causes the accumulation of excessive heat and consequently increasing of temperature. As it is shown in Fig. 1, the failure rate of electronic devices rapidly increases with increasing of operating temperature. The operation of the electronic devices is more reliable with cooling systems. Therefore, to increase the useful life of equipments and to prevent the thermal failure using of cooling systems are necessary [3].

Conventional cooling methods based on forced convection are as follows [4]: 1- Create sequential rib on the surface, which disrupt the flow in the boundary layer, 2- Add baffled to the system which causes mixing of the fluid, 3- The impact of the cooling fluid directly to the surface by a high-speed jet, 4- Using of heat sink, which increases the contact surface area with the surroundings. Heat sink is a heat exchanger that installed on the surface of the electronic equipment as a cooling system [5]. Although, the passive natural convection heat sink are used by some systems, but also a small fan must be installed on the processor chips. The fan creates

* Corresponding author at: Department of Mechanical, Engineering, Razi University, Kermanshah, Iran.
E-mail address: tooraj.yousefi@ryerson.ca (T. Yousefi).

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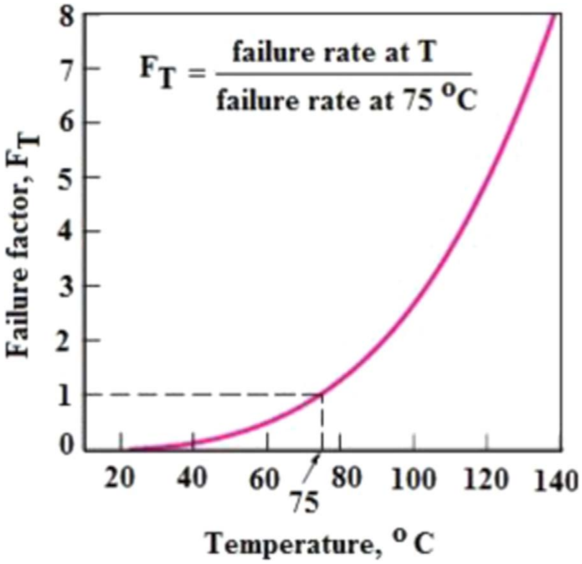

Fig. 1. Variation of failure factor versus temperature.

forced convection air to better cooling of the chips [6]. In this case, the heat transfer can be improved by increase of the air flow or contact surface with increase of the number of fins and baffles [7–9]. Both these methods have their disadvantages, first the noise increases with increase of the air speed and also it needs a powerful fane. Second the workspace, weight and pressure drop are increased by increase of the number of fins [7,8]. One solution to minimize these defects is the use of open cell aluminum foam heat sink. Open cell metal foam is a class of porous material contains numerous open paths with irregular shapes. More than 85% of the foam is consist of open cell pore. It is usually made of aluminum or copper foam that they have high thermal conductivity. For the same volume, aluminum foam is much lighter than conventional heat sink, and the contact surfaces of the air flow are higher in the metal foam. Air flow is fully stirred through the pores of a metal foam, and also the flow is turbulent in low speed, resulting the higher convective heat transfer coefficient in the aluminum foam heat sink [10,11]. Because of these characteristics, several studies have been done on the use of aluminum metal foam as a heat sink [1,2,7–17]. Effect of many parameters on the thermal behavior of aluminum metal foam heat sink have been investigated by some researchers; such as density holes [2,7,9,10,12] forced or free convection [7,12,13], using water instead of air [14], using water pulse flow instead of continues steady flow of air [15], air flow velocity [2,7,10,16,17], foam finned and the number of fins [7,8] and the angle between the longitudinal direction of the fin and air flow [18]. The angle between normal vector to the plate that heat sink installed on it (the heat transfer direction) and the Earth's gravitational vector (g) is one of the factors affecting thermal behavior of heat exchanger in the free convection heat transfer. Therefore, it should be considered in the design and positioning of each heat exchanger. A little information about the effects of heat transfer surface slope by the metal foam have been published. Bhattacharya. et al. [13] as well as Billiet et al. [19] investigated experimentally only two positions of horizontally and vertically. According to the first research, horizontal or vertical positions have a little effect, but according to the results of the latter, thermal efficiency in horizontal position is 18% higher than vertical. According to the numerical investigation of Piller and Stalio [20], inclined parallel-plate channels containing metal foam have a little effect on the Nusselt number. On the other hand, according to empirical studies done on the copper foam by Qu et al.s [21], Nusselt number depends on the value of angle with the vertical direction, and the optimum angle correspond to the maximum Nusselt number, with considering of pores density, foam density and heat flux, changes from 60° to 75°. Due to the contradictory results that have been reported, the effect of angle on free convection heat transfer of metal foam heat sink still needs more experimental and numerical evaluations. The aim of this study is to investigate the effect of angle on cooling of a heated plate by an aluminum foam heat sink for different heat fluxes. The main deference between present work and Qu et al. [21] study is in the type of metal foam and the obtained results.

2. Experimental setup and procedures

In order to achieve a hot plate uniform temperature a truncated solid aluminum cone has been used. The height of cone is 180 mm. Small diameter of cone (40 mm) was selected based on the dimensions of a typical CPU used in the PC. Then Comsol software has been used to find out the other dimensions of cone especially a plane at a distance from the bottom of the cone that perfectly is in uniform temperatures. An electrical resistance cartridge with nominal power of 120 W was inserted at the end of this cone (Fig. 2). Bottom and side surfaces of the cone were completely insulated. For the measuring of top surface temperature, five small hole with a diameter of one millimeter and a distance of one millimeter from the top surface have been created at various intervals. Five K-type thermocouples with an accuracy of 0.1 °C have been used to measuring of surface temperature.

In order to study of the effect of heat flux and inclined angle the mean value of surface temperature was measured using the