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A novel heat sink design with interrupted, staggered and capped fins

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ABSTRACT

In present study, radiation and natural convection heat transfer from vertical finned heat sink is investigated numerically. Present 3D simulation is verified with available experimental data in the literature for continuous finned heat sink. The studied cases consist of 10 various configurations of interrupted, staggered and capped finned heat sink to find the optimum configuration. Heat dissipation from heat sink by the natural convection and the radiation heat transfer mechanisms are separately estimated for each case. Average temperature and mean Nusselt number on heat sink are calculated at given heat fluxes. Results show that decreasing the fin space less than 3 mm in the staggered-fins configuration does not improve cooling procedure. Also, it was observed that although Capped fins enhance the heat transfer rate, they have higher weight than regular continuous fins. Moreover, it was concluded that L-shape cut-capped fins have the lowest temperature without increasing the weight which implies the fact that they are of better performance in comparison to the other designs.

Nomenclature

A	Area, m^2	*Greek symbols*	
F	Surface view factor	ε	surface emissivity coefficient
g	Gravitational acceleration, m/s^2	σ	Stefan-Boltzmann constant
H	Heat sink length, m	β	Thermal expansion coefficient, $1/K$
k	Thermal conductivity, W/mK	μ	Dynamic viscosity, $kg/m{\cdot}s$
L	Fin length, m	ν	kinematic viscosity, m^2/s
Nu	Nusselt number	ρ	Density
P	Pressure, pa	*Subscripts*	
S	Fin space, m	m	mean
T	Temperature, K	rad	radiation
u,v,w	Velocity, m/s	t	total
W	heat sink width, m	w	wall
h	Convective heat transfer coefficient, W/m^2K		

1. Introduction

Nowadays, electronic devices are essential components of industrial systems and human's life. They produce a large amount of heat that must be dissipated to the medium that is air in most applications. So, they must be equipped with an effective removal of heat dissipation system for a reliable operation and safe temperature. It becomes as critical issue by increasing the required heat flux due to need of higher speed, multifunctioning and higher power dissipation in recent years.

Natural convection and radiation can dissipate the heat without consuming additional energy against forced convection. Heat sinks with extended surfaces especially at upward horizontal or vertical orientation have been vastly used for this purpose [1–4].

There is a large number of papers in the literature that deal with the effect of fins on enhancement of forced, mixed and natural convection heat transfer at various geometries and applications [5–10]. Bocu and Altac [11] performed a 3D numerical study on natural convection within enclosure with different configurations of cylindrical pin fins. The enclosure was heated from one lateral wall while it was cooled from opposite lateral wall. Their result showed that heat transfer from heated wall increases by increasing the number of fins, fins length and also Rayleigh number. Moreover, they found that staggered configuration of fins found out to be the best configuration. Cordoba et al. [12] carried out an experimental and numerical study of natural convection inside cubic cavity. They considered the left and right vertical

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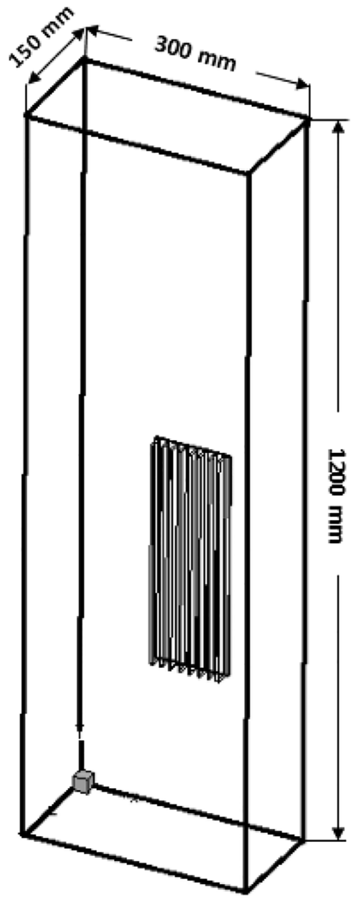

Fig. 1. Schematic of computational domain.

walls as hot and cold walls and other walls as adiabatic surfaces. They found that the convective flow has stable pattern at Rayleigh numbers from $Ra = 1.7 \times 10^8$ to $Ra = 6.3 \times 10^8$.

Rabienataj et al. [13] performed a 3D numerical study on enhancement of mixed convection inside a cubic square by adding fins and nanoparticles. After having performed a 2D numerical study, they came to this conclusion that the secondary flow above the hot wall at high Richardson numbers, which corresponds to the dominance of natural convection, could not be predicted. Also their results indicated that adding fins augments the heat transfer at high Richardson numbers. Charles and Wang [14] performed an experimental study on natural heat transfer from heat sink with rectangular, trapezoidal and inverted trapezoidal fins. They found that the heat transfer coefficient of inverted trapezoidal fins is 25% and 10% higher than the trapezoidal and rectangular ones, respectively.

The effect of fin geometry and fin array were vastly investigated experimentally and numerically by researchers on the enhancement of natural heat transfer from the vertical fins [15–19]. Goshayeshi and Ampofo [20] numerically studied the natural convection heat transfer from horizontal and vertical heated surface with rectangular fins. Their results indicated that the vertical plate with vertical fins has the best heat transfer rate among the investigated cases. They found that the maximum heat transfer rate occurs at special fin space which varies by $1/Ra^{1/5}$. Goshayeshi et al. [21] stated that there is an optimum fin spacing for maximum heat transfer from vertical heat sink. Similar results were reported by Fahiminia et al. [22].

Ahmadi et al. [23] carried out an experimental and 2D numerical study on heat transfer from continuous and interrupted fins. They investigated the effect of fin interruption and fin spacing on the heat transfer. Their results indicated that thermal efficiency of heat sink increases by interrupting the fins and there is an optimum interruption length. Naserian et al. [24] conducted an experimental and numerical study on natural convection heat transfer from different arrays of V-type fin. They achieved an optimum configuration by investigating the effects of the fin shape and the fin gap on the heat transfer coefficient. In an experimental and numerical investigation, Mehrtash and Tari [25] studied the natural convection heat transfer from heat sink with rectangular fin at different inclination angles. They concluded that the optimum inclination angle is vertical arrangement and the fin height affects the heat sink performance especially where the fin spacing is higher than the optimum value. They [26] later presented a correlation for heat transfer as function of fin length and tilt angle at different Rayleigh numbers ranging from 0 to 2×10^8.

There are a few works on the vertical heat sink by implementing interrupted fins with various configurations. The main objective of this study is related to finding the optimum fin configuration by interrupting, staggering, capping and cutting fin. Continuity, Momentum and energy equations are solved to simulate the three dimensional flow and heat transfer for 10 cases of various fin configurations. A comparison is performed between present study and experimental data available in the literature [23] for heat sink with continuous fins which reveals an acceptable agreement. Results are depicted in form of velocity and temperature contours, average temperature of heat sink, mean Nusselt number and the radiation to total heat dissipation (Q_{rad}/Q_t) ratio plots versus different heat fluxes. Also, the weight of each heat sink is considered as an important factor.

2. Governing equations

The treated problem is a three dimensional vertical finned heat sink with length of 305 mm and width of 101 mm. The computational domain with length, width and height of 1200, 300 and 150 mm is shown in Fig. 1. Heat sinks with 10 different configurations of fins are located at the center of domain. Fig. 2 shows those heat sinks as follows: 1- continuous fins (CF) 2- interrupted fins (IF) 3- staggered interrupted fins with s = 8 mm (S8IF) 4- staggered interrupted fins with s = 5 (S5IF) 5- staggered interrupted fins with s = 3 (S3IF) 6-staggered interrupted fins with s = 2 (S2IF) 7-capped fins (CPF) 8- cut capped fins with s = 3 mm (CCF) 9- cut capped fins with longer space at top (CCF2) 10- L-shaped cut capped fins (LCCF).

The height and thickness of fins are 18 mm and 3 mm, respectively. Table 1 gives the properties of considered heat sink and air.

The continuity, momentum, and thermal energy equations for a 3-D laminar flow can be expressed as follows:

Continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{1}$$

Momentum equations:

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z}\right) = -\frac{\partial p}{\partial x} + \mu\nabla^2 u \tag{2}$$