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Numerical analysis of natural convection and radiation heat transfer from various shaped thin fin-arrays placed on a horizontal plate-a conjugate analysis

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ABSTRACT

Steady state natural convection and radiation heat transfer from various shaped thin fin-arrays on a horizontal base plate has been numerically investigated. A conjugate analysis has been carried out in which the conservation equations of mass, momentum and energy for the fluid in the two fin enclosure are solved together with the heat conduction equation in the fin and the base plate. Heat transfer by radiation is also considered in analysis. The heat transfer coefficient has been determined for each of the fin array considered in the present study at the same base and the same total area. The results of the analysis show that there are some important geometrical factors affecting the design of fin arrays. Taking into consideration these factors, an optimum fin shape that yields the highest average heat transfer coefficient has been determined.

1. Introduction

Finned surfaces are applied in a wide range of engineering applications like heat exchangers, cooling of electronic equipment and similar industrial applications. These surfaces have been used to augment heat transfer by adding additional surface area and encouraging mixing. When an array of fins is used to enhance heat transfer under natural convection conditions, the optimum geometry of fins (corresponding to a maximum rate of heat transfer) should be used, provided this is compatible with available space and financial limitations. Compared to a base plate, a finned surface increases the heat transfer area. However, with the fins the flow rate is reduced. Hence, if not properly designed, it is possible that no improvement is achieved in terms of overall heat transfer. Therefore, it is important to perform a study on the geometry of fin array to have a design with considerable heat transfer enhancement. The heat transfer to the external ambient atmosphere by the heat dissipating apparatus can be obtained mainly by using the mechanisms of the heat transfer by forced convection, natural convection and by radiative heat transfer. This paper deals with those issue related to the heat transfer obtained by natural convection and radiation.

Rectangular fins are used extensively to increase the rates of natural convection heat transfer from systems, because such fins are simple and cheap, to manufacture. Other fin shapes have received limited attention. When looking to improve the performance of heat exchangers, one particular area of interest lies in using different fin shapes that are able to give higher heat transfer rates. Today, the developments in manufacturing methods have made easier the production of other shaped fins placed on a heat transfer surface. Therefore, it is important to perform a study on various shaped fin arrays to have a design with considerable heat transfer enhancement.

An extensive review and discussion of work done on the convective heat transfer in electronic cooling was presented by Incropera [1], summarizing various convection cooling options. A great number of experimental and analytical work has been carried out on this problem since Elenbaas [2], first introduced the problem of natural convection between parallel plates. Starner and McManus [3], who measured the average heat transfer coefficient not only in horizontal but also in 45° and vertical base positions, have performed the first work on horizontal rectangular fin arrays. They showed that incorrect application of fins to a surface actually might reduce the total heat transfer to a value below that of the base alone. Welling and Wooldridge [4] conducted a similar experimental study on rectangular vertical fins. They reported optimum values of the ratio of fin height to spacing. Harahap and McManus [5] observed the flow patterns in two series of horizontal rectangular fin arrays. From the observations, they conclude that the single

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Nomenclature

A	total heat transfer area, m^2
E	emissive power of surface, W/m^2
F	view factor
g	acceleration due to gravity, m/s^2
h_{av}	average heat transfer coefficient, W/m^2 K
h_i	local heat transfer coefficient, W/m^2 K
J	radiosity, W/m^2
H_f	fin height, m
K	thermal conductivity, W/mK
L	fin length, m
$\dot{m}$	mass flow rate, kg/s
P	pressure, Pa
Pr	Prandtl number
q_i''	local heat flux, W/m^2
q_0	heat flux applied to the bottom surface, W/m^2
q_{in}	energy flux incident on the surface, W/m^2
q_{out}	energy flux leaving the surface, W/m^2
S	fin spacing, m
T	temperature, K
T_w	base plate temperature, K
$T\infty$	ambient temperature, K
u, v, w	x, y, z components of the velocity, m/s
$x \cdot y \cdot z$	Cartesian coordinates

Greek symbols

ρ	density, kg/m^3
ρ_∞	density of ambient air, kg/m^3
α	thermal diffusivity, m^2/s
ε	surface emissivity
μ	dynamic viscosity, Ns/m^3
υ	kinematic viscosity, m^2/s
σ	Stefan–Boltzmann constant

Subscripts

air	air
f	fin
w	wall

chimney flow pattern yields higher rates of heat transfer. Jones and Smith [6] investigated the effects of fin height, and fin spacing on heat transfer coefficient. They concluded that fin spacing is the main geometrical parameter, and it should be chosen as characteristic length. Mannan [7] investigated the effect of all the geometrical parameters and temperature difference on heat transfer coefficient. He also found that the most important geometrical parameter is the fin spacing, whereas fin length and fin height are probably the next important geometrical parameters. Sobhan et al. [8,9] measured the local variation of temperature and heat flux during transient heating using a differential interferometer technique. They also investigated the effect of thermal conductivity of fin materials on the average heat transfer coefficient. Sane and Sukhatme [10] employed a quasi-3D numerical method to analyze the problem of natural convection heat transfer from a horizontal rectangular fin array. Yüncü and Anbar [11] carried out an experimental investigation on natural convection heat transfer from rectangular fin arrays on a horizontal base. They investigated the effects of fin spacing, fin height and temperature difference between fin base and surroundings on the natural convection heat transfer. They found that for a given base-to-ambient temperature difference the convection heat transfer rate from arrays reaches a maximum at a particular fin spacing and fin height. Vollaro et al. [12] investigated on the optimal configuration of rectangular, vertical fins mounted on a plate. Baskaya et al. [13] solved the three-dimensional elliptic governing equations for horizontal rectangular fin arrays by finite volume based CFD code. They investigated the effects of fin spacing, fin height, length and temperature on performance of rectangular fin arrays. Güvenç and Yüncü [14] carried out an experimental investigation on performance of fin array and found that higher heat transfer enhancement is obtained with vertically oriented base than with horizontally oriented base for fin arrays of same geometry. Mobedi and Yüncü [15] investigated numerically the steady-state natural convection heat transfer in a longitudinally short rectangular fin array on a horizontal base. They reported that two types of flow patterns occur depending upon values of fin height-to-length ratio and fin spacing. Dayan et al. [16] carried out an experimental and analytical study for a downward-facing hot fin array. They found that the array length, fin spacing, and surface temperature affect the heat transfer coefficient mostly compared to the fin length.

Radiation plays an important role in the heat transfer from fin arrays. Some studies exist in literature, which take into account the effects of radiation on convective heat transfer from fin arrays [17]. Yong et al. [18] concluded that the practice of neglecting the radiation view factor in the thermal analysis of fin arrays should be prohibited based on the fact the errors generated are noticeably larger than those of solely neglecting thermal radiation. Rammohan Rao and Venkateshan [19] made an interferometric study of free convection and radiation heat transfer from a horizontal fin array. The authors stressed the importance of the mutual interaction between free convection and radiation. Dharma Rao et al. [20] carried out a conjugate analysis in which the heat transfer from a horizontal fin array by natural convection and radiation is determined numerically. The problem was theoretically tackled by treating the adjacent internal fins as two-fin enclosure. Numerical results were obtained to study the effectiveness for different values of fin heights, emissivities, number of fins on a fin base, fin base temperature, and fin spacing. Sparrow and Vemuri [21] carried out an experimental study on the combined mode natural convection–radiation heat transfer from highly populated pin fin arrays. The effect of various parameters on the heat transfer was investigated. They concluded that the heat transfer performance increases with fin length. The contribution of radiation was determined to be substantial and was the greatest for more populous arrays, for longer fins, and at small base plate to ambient temperature differences. Sparrow and Vemuri [22] later extended their study to different orientations. A theoretical and experimental study was carried out on the thermal performance of a pin–fin heat sink by Kobus and Oshio [23]. They developed a theoretical model that has the capability of predicting the influence of various geometrical, thermal, and flow parameters on the effective thermal resistance of the heat sink. Then, based on the exact analytical correlations, the simplified approximate correlations for calculating the gray body view factor from a diffuse and gray plate fin heat sink were presented by Kobus and Oshio [24].

From the above literature review, one can see that the additional area provided by extended surfaces increases heat transfer, and the natural convection heat transfer from fin arrays on a base surface depends greatly on the geometrical parameters such as fin spacing, fin length and fin height. Although the heat transfer from fins on a horizontal surface has been the subject to numerous