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Natural convection from an array of horizontal rectangular thick fins with short length

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Abstract

In this article numerical study is made to predict natural convection from an array of aluminum horizontal rectangular thick fins of 3 mm < t < 7 mm with short lengths ($L \leqslant 50$ mm) attached on a horizontal base plate. The three-dimensional elliptic governing equations of laminar flow and heat transfer were solved using finite volume scheme. For 128 fin geometries, typical results have been compared with available experimental data from the literature and good accuracy were observed. Based on the verified model, fluid flow and thermal structure around various fins were illustrated and two types of flow patterns in the channel of the fin arrays were observed. Effect of various fin geometries and temperature differences on the convection heat transfer from the array was determined for Rayleigh numbers based on fin spacing of 192–6784 and applied correlations are developed to predict Nusselt numbers with corresponding non-dimensional parameters.
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Keywords: Heat transfer; Laminar flow; Numerical simulation; Free convection; Heat transfer enhancement

1. Introduction

Natural convection heat transfer from finned surfaces has been the subject of a large number of experimental and theoretical investigations. Finned surfaces were being extensively used in a variety of engineering applications such as cooling of electronic and thermoelectric devices, solar energy applications, cooling of nuclear reactor fuel elements, improving heat transfer in radiators for air conditioning and in air cooled heat exchangers.

Compared to a bare plate, a finned surface increases heat transfer area. However, with fins, pressure drop along the surface increases and for certain plate-fin geometries the flow rate may also reduces.

Design information of natural convection for vertically oriented fins can be find from experimental data of [1–4] and the theoretical works of [5]. Starner and McManus [6] presented one of the earliest experimental investigation for heat transfer coefficients from four differently dimensioned fin arrays oriented vertically, 45° and horizontally. They have shown that incorrect application of fins to a surface actually might reduce total heat transfer below that of the base alone. Welling and Woolbridge [7] conducted a similar experimental study on rectangular vertical fins with constant length over a vertical base. They suggested that for each value of fins spacing, there is an optimal fin height corresponding to a maximum rate of natural convection. Average heat transfer coefficient and flow field from vertical rectangular fins on a horizontal base plate for two different fin lengths, were presented by Harahap and McManus [8]. They also reported a correlation that represents the results of all their experimental data by making use of non-dimensional parameters and all the relevant dimensions of fins. From the observation of flow pattern, using shadowgraph technique, they concluded that a single chimney flow pattern yields higher rate of heat transfer than the sliding chimney strip flows, so it was suggested that the sliding chimney flow should be avoided. Jones and Smith [9] studied variation of heat transfer coefficient for isothermal vertical fin arrays on a horizontal base with

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Nomenclature

A	total heat transfer area (m^2)
g	acceleration due to gravity (m/s^2)
C_p	specific heat (KJ/Kg K)
Gr	Grashof number
h	average heat transfer coefficient (W/m^2 K)
H	fin height
k	thermal conductivity (W/m K)
L	fin length
$\overline{Nu}$	average Nusselt number
P	pressure (pa)
Pr	Prandtle number
Q	total heat transfer rate (W)
Ra	Rayleigh number
S	fin spacing
T	temperature
t	fin thickness
u	x component of velocity (m/s)
v	y component of velocity (m/s)
w	z component of velocity (m/s)
x, y, z	Cartesian coordinates

Greek symbols

μ	coefficient of viscosity (Ns/m^2)
ρ	density (kg/m^3)
β	coefficient of volumetric expansion (K^{-1})
ΔT	T_b–T_a

Subscripts

a	ambient
b	fin base
f	fin material
opt	optimum value
s	fin spacing

constant length and constant fin thickness over a wide range of fin spacing. Simplified correlations using fins spacing as a characteristic dimension were suggested to evaluate average free convection heat transfer coefficient from fins. Cha and Cha [10] investigated laminar steady gravity-driven flow around a single isothermal cube in an infinite medium by employing a control volume finite difference technique. Heat transfer results were presented in terms of average Nusselt number and the face average Nusselt numbers at the top, bottom and sidewalls of the cube. They showed that maximum heat transfer occurred at the bottom at low Rayleigh numbers. However by increasing Rayleigh number, maximum heat transfer shifted to the sidewalls. Cha and Cha [11] also presented a numerical and an experimental investigation of three-dimensional natural convection flows. Rammohan and Venkateshan [12] have made an interferometric experimental investigation of interaction between free convection and radiation from a horizontal fin arrays. Yuncu and Anbar [13] and Guvenc and Yuncu [14] have reported experimental studies on natural convection heat transfer of rectangular fins attached to horizontal or vertical surfaces. The separate roles of fin height, fin spacing and fin base to ambient temperature difference have been investigated. Leung and Probert [15] studied more than 300 sets of experimental data; from several different arrays of vertical rectangular highly polished duralumin fins protruding orthogonal either from vertical or horizontal bases. They concluded that the effects of different fin geometric parameters, will dictate which orientation of fin arrays will lead to highest heat transfer rate. They also reported non-dimensional correlations for heat transfer for the two types of fin arrays configuration. Baskaya et al. [16] carried a systematic theoretical investigation of the effects of fin spacing, fin height, fin length and temperature difference between fin and surroundings on the free convection heat transfer from horizontal thin fin arrays. More recently, Arquis and Rady [17] studied natural convection heat transfer in a horizontal fluid layer with finned bottom surface and observed steady state Rayleigh–Benard convection process. Effects of fin height and fin spacing have been investigated for a sufficiently wide range of Rayleigh numbers.

Although fins are generally very thin, but in certain conditions heating elements such as single rectangle or an array of rectangles or cubes may be attached to a plate to promote heat transfer from the base plate or they may act as heat sources to the nearby ambient air.

The above literature shows that no computational studies have been found for three-dimensional fluid flow and heat transfer for rectangular horizontal thick fin arrays especially for fins with short lengths ($L \leqslant 50$ mm).

The present work simulate natural convection heat transfer from an array of aluminum horizontal rectangular thick fins attached on a horizontal base plate for various fin geometries at low temperature differences. Solution of the conjugate governing equations is made by a discretized code and attempt is made to compare the results for special condition with the experimental observations of Harahap and McManus [8] to check the validity of numerical solution. The accuracy of the proposed correlations is also compared with these experimental measurements [8] and available relations [15].

2. Computational modeling

The horizontal fin arrays under investigation with the coordinate system, relevant dimensions and computational domain is shown in Fig. 1a. The computational domain, is reduced to one quarter of one fin channel with an extension towards the open end and top of the fin, Fig. 1b. Consider-

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