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ScienceDirect
Energy Conversion and Management 48 (2007) 2671–2679
ENERGY CONVERSION & MANAGEMENT
www.elsevier.com/locate/enconman

Investigation on heat transfer characteristics of tapered cylinder pin fin heat sinks

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Received 8 September 2006; accepted 29 April 2007
Available online 2 July 2007

Abstract

In the present study, experimental and numerical results of the heat transfer characteristics of the in line and staggered taper pin fin heat sink under constant heat flux conditions are presented. An experimental apparatus is set up to analyze the problem. The tapered pin fin heat sink is fabricated from square aluminium with length, base and tip diameters of 67, 13 and 7.24 mm, respectively. Experiments are performed at various air Reynolds numbers in the range of 1000–9000 and heat fluxes in the range of 0.91–3.64 kW/m^2. The number of pin fins for the in line and staggered configurations are 16 and 17, respectively. The k–ε standard turbulence model is employed to simulate the turbulent heat transfer characteristics. A finite volume method with an unstructured non-uniform grid system is employed for solving the model. The predicted results are validated by comparing with measured data. The predicted results are in reasonable agreement with the experiments.

Keywords: Heat transfer characteristics; Heat sinks; Tapered pin fin

1. Introduction

In order to maintain a satisfactory temperature level of electronic components with high heat flux level, heat sinks have been extensively employed for cooling enhancement of electronics components. Numerous researchers have studied the heat transfer characteristics of various heat sinks configurations. Haq et al. [1] experimentally investigated the steady state forced convective cooling of a horizontally based pin fin assembly. Das and Razelos [2] analyzed the heat dissipation and performance of trapezoidal pin fins. Yeh [3] analytically investigated the heat transfer coefficients and heat transfer from the fin tip, the optimum dimensions of rectangular fins and cylindrical pin fins. Li et al. [4] investigated the heat transfer and flow resistance characteristics in rectangular ducts with staggered arrays of short elliptic pin fins. Hwang and Lui [5,6] studied the heat transfer and pressure drop characteristics between pin fin trapezoidal ducts with straight and lateral outlet flows. The effect of pin arrangement for the ducts of different direction outlet flows was also examined. Maveety and Jung [7] studied the heat transfer of the pin heat sink with air impingement cooling. Tahat et al. [8] experimentally and numerically simulated turbulent air impingement flow on a square pin fin heat sink. Experiments were conducted using an aluminum heat sink under uniform heat flux. The numerical method incorporates the k–z turbulence model. Sara et al. [9] investigated steady state heat transfers from pin fin arrays for staggered and in line arrangements of the pin fins. Chen et al. [10] presented the heat transfer and friction characteristics and the second law analysis of convective heat transfer through a rectangular channel with square cross section pin fins. Various clearance ratios and inter-fin distance ratios were considered. Willett and Bergies [11] applied the conjugate gradient method to estimate the heat flux of a pin fin. The accuracy of the inverse analysis was examined by using

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0196-8904/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.enconman.2007.04.020

Nomenclature

A	surface area, m^2
$C_{\varepsilon 1}$	turbulent model constant
$C_{\varepsilon 2}$	turbulent model constant
C_{μ}	turbulent model constant
C_p	specific heat, kJ/kg °C
d_h	hydraulic diameter, m
h	heat transfer coefficient, kW/m^2 °C
I	turbulent intensity
k	turbulent kinetic energy, m^2/s^2
L	turbulent characteristics length, m
m	mass flow rate, kg/s
Nu	Nesselt number
P	pressure, kPa
Pr	Prandtl number
Q	heat transfer rate (kW)
Re	Reynolds number
r	radius, m
T	temperature, °C
t	time, s
$\mathbf{U}$	velocity vector
u,v,w	velocities, m/s

Greek symbols

ε	dissipation kinetic energy, m^2/s^3
μ_τ	dynamic turbulent viscosity
ρ	density, kg/m^3
μ	viscosity, kg/ms
Φ	viscosity energy dissipation function
σ_k	diffusion Prandtl number for k
σ_ε	diffusion Prandtl number for ε
Γ	thermal conductivity, kW/m °C

Subscripts

A	air
ave	average
b	bulk
c	cross section
h	hydraulic
in	inlet
l	laminar
max	maximum
χ	parameter
out	out
s	surface
t	turbulent
wall	wall
w	water

simulated exact and inexact measurements of temperature. Chu and Chang [12] used a hybrid numerical technique to investigate the heat transfer of the cylindrical pin fin. The governing equation and boundary conditions were discretized by a central finite difference. Guglielmini et al. [13] experimentally studied pool boiling heat transfer from finned copper immersed in a saturated dielectric fluid. Twelve extended surfaces with different geometrical configurations were tested. Yu and Joshi [14] investigated the computational modeling, temperature measurements and flow visualizations under combined natural convection, conduction and radiation heat transfer for pin fin heat sinks. Sara [15] presented the heat transfer and friction characteristics and performance analysis of convective heat transfer through a rectangular channel with square cross section pin fins with staggered configuration. Saha and Acharya [16] numerically studied unsteady three-dimensional flow and heat transfer in a parallel plate channel heat exchanger with in line arrays of periodically mounted rectangular cylinder pin fins. The Navier–Stokes and energy equations were solved by using higher order temporal and spatial discretizations. Wei and Honda [17] investigated the effects of height and thickness of square micro-pin fins on boiling heat transfer from silicon. Six kinds of micro-pin fins were fabricated on the surface of a square of silicon. Won et al. [18] presented the spatially-resolved Nusselt numbers and flow characteristics of staggered array pin fins. Lee et al. [19] solved the two-dimensional inverse problem of estimating the heat flux at a pin fin base by the conjugate gradient method. Montelpare and Ricci [20] evaluated the convective heat transfer coefficient of liquid cooled short pin fins by means of infrared thermography. An experimental apparatus was set up to analyze single, in line and staggered array configurations of short pin fins. Yu et al. [21] experimentally and numerically studied the thermal performances of two types of heat sinks. Kobus and Oshio [22] theoretically and experimentally studied the thermal performance of a pin fin heat sink for pure natural convection and for combined forced and natural convection. The influence of various geometrical and flow parameters on the effective thermal resistance of the heat sink were considered. In their second paper, Kobus and Oshio [23] considered the effect of radiation on the thermal performance of a pin fin array heat sink. Yang et al. [24] numerically studied the transient analysis of a two-dimensional pin fin. The Laplace transformation and finite differences were applied to analyze the problem. Jeng and Tzeng [25] presented a novel semi-empirical model for estimating the permeability and inertial coefficient of pin fin heat sinks. Peles et al. [26] investigated the heat transfer and pressure drop phenomena over a bank of micro-pin fins. The effects of geometrical and thermo-hydraulic parameters on the total thermal resistance were discussed. Dogruoz et al. [27] experimentally and numerically studied