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Review

A review of the effect of flow directions and behaviors on the thermal performance of conventional heat sinks

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ABSTRACT

A heat sink is a kind of heat exchanger used as a cooling system for electronic components due to simplicity, low cost, and a reliable manufacturing process. The heat sink can be divided by plate and pin fin shapes. In the past decade, several published articles have focused on studying the effects of fin shapes and arrays of heat sinks on flow characteristics and thermal performance with forced convection. However, only a few publications have focused on the flow directions (parallel and impingement flows) and flow behaviors (bypass and non-bypass flows) through the heat sink, which are necessary for fin and overall cooling system design. The purpose of this article is to summarize the publications with respect to experimental research on the fluid flow directions and behaviors through heat sinks as well as offering guidelines for future research.

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1. Introduction

Heat sink is a type of heat exchanger used as a cooling system in electronic component. In recent years, electronic devices such as personal computers (PCs) have become more powerful and compact. Hence, the heat sink is used to increase the heat transfer area in electronic components, which is typically attached to the top of the electronic devices. The advantages of the heat sink are low initial cost, simple installation, and a reliable manufacturing process. Generally, a heat sink is made from aluminum and copper. The heat sink includes a base plate and fin, and there are two types

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Nomenclature

A	cross section area (m^2)
C	clearance between the fin tip and the shroud (m)
d	diameter (m)
D_h	hydraulic diameter (m)
f	friction factor
f_h	friction factor based on hydraulic diameter
H	height (m)
k	thermal conductivity (W/m · K)
L	length (m)
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number
S	fin spacing (m)
S_L	center-to-center longitudinal distance between the adjacent fins (m)
S_T	center-to-center transverse distance between the adjacent fins (m)
t	thickness (m)
$\dot{V}$	volume flow rate (m^3/s)
v	velocity (m/s)
W	width (m)
X_L	relative longitudinal pitch; $X_L = S_L/d$
X_T	relative transverse pitch; $X_T = S_T/d$
y_s	distance from the windward side of fin to the shield (m)
Y	distance between the nozzle and the tip of the fins (m)

Greek letters

ε	surface emissivity
μ	viscosity (kg/m s)
ρ	density (kg/m^3)

Subscripts

0	values for fin array without shield
a	air
avg	average value
b	base of heat sink
B	bypass
D	duct
f	fin
fp	fin passage
fr	frontal
m	mean value
max	maximum
s	shield

of fin shapes: plate fin and pin fin. In practical applications, the various sizes and shapes of heat sinks depend on the shape of electronic device and available space for installation. Besides heat sinks, an important part of electronic cooling systems is the movement of fluid, where heat is transferred by air or water. The different flow directions of working fluids are impingement and parallel flows due to the limitations of installation space. Likewise, the characteristics of working fluids flowing through heat sinks can be classified into bypass and non-bypass flow. Bypass flow means that the fluid flows through the passage at the top of heat sinks, while a non-bypass flow means that the fluid is forced to flow through channels between the fins.

In the past decade, most experimental research has explored improving the thermal performance of the finned heat sink in terms of the fin's physical configurations. In addition, some researchers have studied the effect of flow characteristics (bypass and non-bypass) and flow directions (parallel and impingement flows) of working fluid on thermal performance. The aim of this paper is to describe the details of the experimental study of fluid flow characteristics and flow directions through the heat sinks of previous publications and to suggest guidelines for future research.

2. Flow directions

2.1. Parallel flow

Most experimental research for parallel flow has studied heat transfer enhancement by focusing on improving the shape of plate and pin fins. For the plate fin heat sink, most researchers [1–4] have examined the effects of size (height and thickness) and the number of plate fins in the way they affect thermal performance. In addition, the shape of the fin has been extended to increase turbulence flow on the plate fin for improving thermal performance [2,3]. In recent years, there are some research studies about how a vortex generator can increase turbulence flow before flowing into the heat sink [4]. In the case of the pin–fin heat sink, and the same as the plate fin heat sink, most researchers [5–8] have primarily studied the effects of shape and position of the pin fin on lowering pressure and thermal performance. Shapes of the pin–fin that have been studied include hexagonal, circular, elliptic, square, and tapered cylinder designs.

Li and Chao [1] varied the fin height, fin width, and the Reynolds number to study the performance of plate-fin heat sinks. From experimental results, the best thermal performance of the heat sink with a constant fin width is obtained by the tallest fins. For constant fin height, the fin width that provides the best thermal performance increases with the Reynolds number. In 2009, Kim and Kim [2] presented an experimental investigation of cross-cut effects (position, length, and number of cross-cuts) on the thermal performance of heat sinks. It is observed that cross-cut length has the most significant effect on the thermal performance of heat sinks. In addition, they proposed correlations to predict the thermal performance of cross-cut heat sinks. Yang et al. [3] carried out an experiment to study the airside performances of eight heat sinks with different fin patterns. The tested fin patterns are plain fin, delta vortex generators (delta VG) fin, delta VG and plain fin, semi-circular VG fin, triangular VG fin, triangular attack VG (varied attack angle), dimple VG fin, and two-group dimple VG fin. The airside performances are considered in term of pressure drop and heat transfer coefficient. At a frontal velocity around 3–5 m · s^{-1}, experimental results illustrated that the vortex generators are more beneficial than the plain fin geometry. They then suggested that the optimum enhancement design is the triangular attack VG, which can reduce surface area about 12–15%, as is shown in Fig. 1.

Li et al. [4] experimentally and theoretically investigated heat transfer and flow characteristics of a plain fin heat sink with a pair of triangular vortex generators installed in front of the test section, as shown in Fig. 2. The effects of the geometries, attack angle (β), the distance between both trailing edges (B), distance between the vertex generators and the heat sink (L_g), and Reynolds number on thermal performance are discussed. The results show that the position of the vortex generators for the best performance is when the distance between the trailing edges of vortex generator equals the width of the heat sink and the distance between the trailing edge of vortex generators and the heat sink is zero. For the attack angle, the optimized thermal resistance and pressure drop are achieved at 30°. At Reynolds numbers (Re = 10,000), the thermal

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