International Journal of Heat and Mass Transfer 118 (2018) 129–153

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Review

Optimization of thermal design of heat sinks: A review

Hamdi E. Ahmed [a,*], B.H. Salman [b,c], A.Sh. Kherbeet [d], M.I. Ahmed [e]

[a] Department of Mechanical Engineering, University of Anbar, Ramadi 31001, Iraq
[b] DNV GL, Engineering Department, Las Vegas, NV 89146, USA
[c] Department of Mechanical Engineering, University of Nevada, Las Vegas, NV 89154, USA
[d] Department of Mechanical Engineering, KBU International College, 47800 Petaling Jaya, Selangor, Malaysia
[e] Department of Mechanical Engineering, Faculty of Engineering, Islamic University in Medinah, Prince Naif Ibn Abdulaziz, Al Jamiah, Medinah 42351, Saudi Arabia

A R T I C L E I N F O

Article history:
Received 24 July 2017
Received in revised form 20 October 2017
Accepted 23 October 2017

Keywords:
Optimization
Hydrothermal design
Heat sink
Active and passive technical enhancement methods

A B S T R A C T

Heat sinks are a kind of heat exchangers used for cooling the electronic devices due to the simplicity of fabrication, low cost, and reliability of heat dissipation. The extended surfaces from the heat sinks are either flat-plate fins or pins fins shapes. In the last decades, intensive attentions were spent on miniaturizing the electronic devices because of the high sophisticated micro- and nano-technology development. But the heat dissipation is still the major problem of enhancing the thermal performance the heat sink. In this article, a comprehensive review is carried out on the methods used for optimizing the hydrothermal design of heat sinks. Therefore, available investigations regarding the passive and active techniques utilized for enhancing the heat removal from heat sinks by modifying either the solid domain or fluid domain are covered. The purpose of this study is to summarize the investigational efforts spent for developing the thermal performance of the heat sinks, limitations, and unsolved proposed solutions.

Contents

* Corresponding author.
E-mail addresses: hamdi.ahmed@uoanbar.edu.iq (H.E. Ahmed), eng.bassam2007@yahoo.com (B.H. Salman).

https://doi.org/10.1016/j.ijheatmasstransfer.2017.10.099
0017-9310/

Abbreviations

AR	aspect ratio
DLMCHS	double-layer microchannel heat sink
FPF	flat-plate fin
HS	heat sink
MC	micro-channel
MiCHS	mini-channel heat sink
MT	micro-tube
NF	Nanofluid
Nu	Nusselt number
PF	pin-fin
Pr	Prandtl number
Ra	Rayleigh number
Re	Reynolds number
R_{th}	thermal resistance
SLMCHS	single-layer microchannel heat sink

1. Introduction

With the continuous development of electronic devices towards high performance and miniaturization size, heat dissipation problem has become a major obstacle to their development. Besides, the traditional air cooling method has been unable to meet the high-density heat dissipation requirement. Computer users prefer computers that having high-speed processors. The thermal design optimization of the heat sinks leads to minimize the size and weight of the heat sink, and then improve the heat removal in consequently increasing the speed of electronic devices. Electronic devices are increasingly miniaturized and the operating power of CPU increases. Besides, a larger amount of data processed by the CPU at a time causes greater heat generation. This development in the computer manufacturing makes the transfer of generated heat to the ambient becomes more difficult [1]. Generally, the heat generated by the processors is typically transferred to a heat sink (HS) by heat conduction, and then to the ambient by natural, mixed or forced convection. Low efficiency of heat removal of the heat sink possibly causing damage to the electronic component as the temperature rises [2]. This problem has motivated the computer manufacturers to employ sophisticated technology to improve the speed of electronic elements with increasing the heat removal. In contrary, the smallest size of the computers increases the overall flow resistance for the system and eventually suppresses the fluid flow between fins of the heat sink. This significantly influences the fan performance and affects its heat removal capability. Therefore, the heat sink must be designed properly to promote heat transfer and to avoid overheating of the electronic element. The effective thermal management of heat sinks is of priority concern of researchers. It is necessary to be mentioned that the common popular coolant of electronic systems is air due to the ease of obtaining the coolant and the simplicity, high reliability and low cost of the required equipment [3].

With rapid developments in microelectronic techniques, the electronic devices are going to be more miniaturized having high power, high performance, and higher temperature. The traditional heat transfer method of forced air convection is reached to its thermal limit. Therefore, the challenge is how to develop effective methods for cooling high flux devices. Generally, the working limit temperature of electronic devices is ranged from 85 to 100 °C. The literature has shown that the reliability of chip reduces 5% and the life span significantly reduces when the temperature raises every 1 °C above the limit temperature. Therefore, a huge threatens to chip reliability and service lifetime if the high heat generated by the electronic element cannot be removed in time. Thus, it is necessary to investigate and develop an effective cooling technology to meet the demand of high heat generated by electronic components [4]. Due to the development of the micro-technology, highly integrated electronic circuits led to increased heat generation rates in electronic chips. In other words, the speed of chips is increasing, the heat generated by the chip is going up, and the temperature of the chip is rising while the volume of the chip is miniaturized. The average heat flux of the chip was about 50 W/cm^2 in 2010 and rose to be around 250 W/cm^2 in 2012. Porous metal has been demonstrated that it can enhance the forced convection heat transfer strongly [5,6]. Heat sink with a porous medium can increase both the surface contact area between the fins and coolant and the local mixing velocity of the coolant, which ensures better heat removal. The thermal performance of a porous heat sink can be enhanced if porosity conditions and the geometric parameters of the channel are properly designed. High-pressure drop is carrying out between the inlet and outlet of a porous microchannel heat sink (MCHS) having low porosity and permeability which needs more pumping power. Therefore, the high-pressure drop associated with using porous medium plays a vital role in the design of a porous MCHS [7,8].

The advantages of micro-channel compact heat exchangers have gotten plenty of attention of investigators since the last two decades. The ratio between the contact surface area with the refrigerant and the heat exchanger volume increases with decreasing the channel hydraulic diameter. This characteristic permits minimizing the heat exchanger size, low amount of material used in the heat exchanger manufacture, and reducing the refrigerant amount. These aspects not only impact the fabrication cost but also environmental aspects. Flow boiling in mini- and microchannels can be used for cooling many high power density devices such as Micro Electro Mechanical Systems (MEMS), microprocessors, laser diode arrays and Light Emitting Diodes (LEDs) [9]. Flow boiling in microchannels is very effective in the thermal management of high-flux modern electronics. To avoid electric hazards of electronic equipment or integrated circuit component, the dielectric fluids such as fluorocarbon fluids featuring excellent electrical and chemical properties, are the leading candidates for such applications [10].

The past two decades have witnessed intense interest among researchers in the use of MCHS, which has been spurred by such unique attributes as compactness, high power dissipation to volume ratio, and small coolant inventory. Due to their high area-to-volume ratios, the use of MCHS has been introduced, first by Tuckerman and Pease in 1981, as an alternative solution for removing high heat fluxes from small areas. The mode of flow in microchannels mostly remains under laminar flow regime due to the small hydraulic diameter of the microchannel and eventually the pumping power at the micro-scale is still a limiting factor. One of the most common means for cooling electronic modules