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Research Article

Performance of convective-radiative porous fin heat sink under the influence of particle deposition and adhesion for thermal enhancement of electronic components

George Oguntala*, Raed Abd-Alhameed

School of Electrical Engineering and Computer Science, Faculty of Engineering and Informatics, University of Bradford, West Yorkshire, UK

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Abstract

This work presents an investigation on the effect of particle deposition and adhesion on the thermal behaviour of convective-radiative porous fin heat sink using Differential Transform method (DTM). The numerical solutions of the developed thermal models are also used to study the influence of thermal conductivity, porosity, convection and radiation factors on the thermal distribution and efficiency of the fin. The analysis reveals the impact of particles or thermal fouling on the surface of the fin, which causes a rise in the temperature uniformity and distribution in the fin while reducing the rate of heat transfer from the fin. Moreover, the study also establishes that the heat transfer rate decreases due to particle deposition on the fin which depends on the particle size, particle density and cooling air flow rate. The fin efficiency decreases with increasing value of the fouled Biot, Darcy and radiation numbers, and thermo-geometric parameter. Furthermore, the analysis shows that the efficiency of the fouled porous fin is always greater than the efficiency of the clean porous fin. The result of this study shows an excellent agreement with the established results of Runge-Kutta with shooting method.

Keywords: Particles deposition; Thermal fouling; Porous fin; Convective-radiative condition; Thermal enhancement; Electronic devices

1. Introduction

The ever-increasing demand for high-performance electronic systems for various applications often results in the production of excess heat within their thermal components. An ineffective removal of excess heat dissipated from those thermal components often results in adverse effects on the functionality and eventual damage to the circuitry of most electronic systems [1]. Moreover, since the inevitable miniaturisation and electronic packaging of modern electronic devices is on the increase, it often becomes unfeasible to introduce cooling liquid fluid or employ forced gas convection. Therefore, the utilization of natural convection normally with air as the cooling medium for electronic cooling comes into play as a practical electronic component cooling alternative. Moreover, different cooling approaches have been employed to dissipate heat from earlier electronic systems.

* Corresponding author.

E-mail addresses: G.A.Oguntala@bradford.ac.uk (G. Oguntala), R.A.A.Abd@bradford.ac.uk (R. Abd-Alhameed).

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However, the application of fin has proved effective in augmenting rate of heat transfer. Fin or extended surface provides a simple, passive approach to enhance heat dissipation from thermal surfaces of electronic systems following the discovery of its viability by Kiwan and Al-Nimr [2]. The utilization of porous fin heat sink has proved reliable in dissipating heat due to its relatively miniaturized size and cost. In addition, based on cost-benefit analysis porous fins have proven to better than convectional solid fins in terms of therma performance and material saving [3−5]. Virtually in all cases of heat dissipation using heat sinks, the densely packaged heat sink fin usually operates in thermally-enveloped environments under prolonged and continuous exposure to particulate matters. Consequently, during active or idle periods of operation, most electronic systems ingest particulate contaminants including dust, soil particles, cigarette smoke, combustion products, human and animal skin cells etc., which are subsequently introduced to the heat sink fins. However, the apparent inhibiting effects of these contaminant particulates on the thermal performance of heat sinks are indisputable. This is because, under prolonged exposure of cooling systems to contaminants, the deposited particles on the extended surfaces of the heat sinks creates a thermal fouling or insulating layer on the surface of the fin which subsequently creates pores blockage. The blockage increases the thermal resistance of the solid-fluid interface with the heat flow in the fin, especially in porous fin compared to geometrically-equivalent solid fin. In addition, the contaminant particulates blockage reduce the permeability of the porous medium and prevent the cooling air from passing through the pores depending on the cooling air flow rate, particle size and density, the deposited particle reduces the heat transfer between the solid and the fluid phase. Furthermore, by the rule of thumb, the thermal performance inhibiting effects of particulate contaminants causing deposition and adhesion on the heat-exchanging surface would be more adverse in porous fin than a solid fin due to the insulation or coated layer on the surface of the porous fin, which blocks the pores of the porous fin. Therefore, the interaction of local values of excess temperature, fouling resistance and surface characteristics of the deposits can be quite complex but is an interesting research area. Different authors have carried out diverse in-tense investigation on the thermal behaviour of porous fins due to its viability, efficiency and cost [6−12]. However, recent research direction has focus on the effect of thermal deposition and fouling on thermal performance on heat exchanging surfaces [13−17]. Montgomery [18] in his work used a computational software, FLOTHERM, to study the effect of particle deposition on the thermal performance of a dense solid pin fin array. Esaway et al. [19] presents a numerical investigation on the effects of deposit formation on the performance of annular finned tubes during nucleate pool boiling. Aparajith et al. [20] analyses the performance of different geometries extended surfaces subjected to fouling. The investigation of these authors [18−20] focuses on the effect of fouling on extended surfaces using solid fin under different temperature conditions. However, considering the viability of porous fins, as compared with solid fins, an accurate understanding of the thermal implication of particle deposition on the overall functionality of heat sink using porous fin is timely for the optimum design of thermally-efficient electronic cooling systems. Nonetheless, to the best of the author's knowledge, there is no study, experimentally or theoretically, on the thermal implication of particle deposition on the thermal behaviour and performance of porous fin.

Thus, in this work, the effect of particle deposition on the thermal performance of a porous fin heat sink of an electronic system in a convective-radiative environment is investigated using differential transformation method. The developed models are also used to investigate the effects of porous, convective, radiative, thermal conductivity parameters on the thermal efficiency of the porous fin. The paper is organized as follows: Section 2 formulates the porous fin problem with particle deposition. We model the particulate on the porous fin operating in a convective-radiative environment in Section 3. The developed model is solved using the DTM in Section 4, whilst fin efficiency is presented in Section 5. The developed results are discussed in Section 6. We conclude the outcome of the study in Section 7.

2. Problem formulation

To formulate the fin problem, we consider a straight porous fin of length L and thickness t exposed on both faces to a convective-radiative environment at temperature T_∞, as shown in Fig. 1a. Due to prolong and repeated exposure to contaminants, the heat sink porous fin is fully and uniformly covered with particles as shown in Fig. 1c. To analyse the problem, the following assumptions are made:

i. The porous medium is homogeneous, isotropic and saturated with a single-phase fluid.

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