Experimental and Numerical Investigation on Optimum Orientation of Fin Arrayed Heat Sinks

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy (Ph.D.)

in

Mechanical Engineering

by

PABITRA KUMAR MANDAL

(Registration No: **NITD/PhD/ME/2016/00779**)

Under the Supervision of

Dr. Subhas Chandra Rana
(Associate Professor)
Department of Mechanical Engineering
National Institute of Technology Durgapur -713209, India
&

Dr. Dipankar Bhanja
(Assistant Professor)
Department of Mechanical Engineering
National Institute of Technology Silchar – 788 010, India



DEPARTMENT OF MECHANICAL ENGINEERING
National Institute of Technology Durgapur
West Bengal – 713209
India

May, 2022

Abstract

The purpose of present study is to investigate the optimum orientation angle (β) for differently arranged (viz, staggered or inline) vertical pin fin array (solid or perforated) embedded on the base-plate of the horizontal sink by studying the heat transfer over a wide range of inflow Reynolds number (*Re*). The work is performed numerically as well as experimentally. The characteristics of air are ambient air and its temperature is considered as 27^{O} C throughout the investigation.

The first study deals with a simple but effective technique for improving the forced convective cooling of a horizontal heat sink with vertical solid pin-fin-array. The pin fins are embedded in an Inline arrangement on the base-plate of the horizontal sink. Air, while passing through the fin-array, convects the heat conducted from the solid base-plate to the fins' surface. β is varied from 0° to 45° by rotating the horizontal sink about a vertical axis passing through the centre of the sink. A detailed CFD (computational fluid dynamics) study is coordinated over a wide range of inflow Reynolds number (*Re*) to explore the possibility for obtaining an optimum orientation angle (β) for which Nusselt number (*Nu*) would be the maximum. Results indicate that optimum orientation angle, β hovers around 40° regardless of the values of *Re*.

The second study deals with staggered arrangement. Air, while passing through the fin-array, convects the heat conducted from the solid base-plate to the fins' surface. β is varied from 0° to 360° by rotating the horizontal sink about a vertical axis passing through the centre of the sink. A detailed CFD (computational fluid dynamics) study is coordinated over a wide range of inflow Reynolds number (*Re*) to explore the possibility for obtaining an optimum orientation angle (β) for which Nusselt number (*Nu*) would be the maximum. Results indicate that optimum orientation angle, β hovers around 120° regardless of the values of *Re*.

In the third study, the solid pin fins are embedded on the base plate of the heat sink in either staggered or inline patterns. A comparative study is carried out between the two optimum arrangements, viz. inline and staggered. Heat is transferred from the bottom of the base-plate by conduction and is convected by air used here as the working fluid. Present study emphasizes examining the role of orientation angle (β) on the performance of the heat sink. A systematic computational method is implemented in order to obtain an optimum orientation angle (β) for which Nusselt number (*Nu*) would be the maximum. Results indicate that

regardless of the values of inflow Reynolds number *Re*, the optimum angle occurs at $\beta = 120^{\circ}$ for the staggered arrangement and that for the inline arrangement occurs at $\beta = 40^{\circ}$. A comparison between the two optimum arrangements, viz. inline ($\beta = 40^{\circ}$) and staggered ($\beta = 120^{\circ}$), explores that the optimised staggered arrangement performs reasonably well than the optimised inline arrangement, particularly when Re is not large.

Fourthly, both the experimental and numerical studies have been performed under the same geometric configurations of the test plate and an acceptable agreement in results is obtained. To examine the influence of the orientation angle (β) on system performance, the heat sink is rotated anticlockwise in a regular interval from 0^{0} to 360^{0}about a vertical axis passing through the centre of the sink. The study is coordinated over a wide range of inflow Reynolds number (*Re* = 8500 to 38500) to explore the possibility of obtaining an optimum orientation angle (β) for which Nusselt number (*Nu*) would be the maximum. Experimental results indicate that thermal dissipation attains maximum value at $\beta = 40^{\circ}$ for the inline arrays and that for $\beta = 120^{\circ}$ in case of staggered arrays. For low Reynolds number values (*Re* = 8500), the system performance is found better at an angle 35^{0} and 120^{0} for inline and staggered arrangement respectively. However, with *Re* = 38500, the maximum system performance is achieved at an angle 10^{0} and 240^{0} for inline and staggered arrangement respectively.

Finally, a numerical comparison between solid pin fin and perforated pin has been done. Results are taken over a wide range of inflow Reynolds number (*Re* = 8500 to 38500) to explore the possibility for obtaining an optimum orientation angle (β) for which thermal performance would be the maximum. It is found that highest *Nu* is achieved at $\beta = 180^{\circ}$for perforated fin array for all the values of *Re*, however, for solid fin optimum angle hovers around $\beta = 120^{\circ}$ for all *Re*. Lowest *Nu* recorded at $\beta = 90^{\circ}$ for perforated fin array because at this arrangement perforations are in perpendicular position to the flow. So, perforations are useless at this orientation. Moreover at $\beta = 90^{\circ}$ orientation, staggered arrangement becomes inline arrangement.