COMPARATIVE STUDY OF HEAT TRANSFER THROUGH PLATE FIN

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ABSTRACT:
The main purpose of extended surfaces called fins enhances the heat transfer rate. Fins offer an economical solution in several situations demanding natural convection heat transfer. The choice of a selected fin configuration in any heat transfer application depends on the, weight, space, manufacturing technique and cost concern additionally because the thermal characteristics it exhibits. In the present study, a detailed work has been done to develop a finite element methodology (FEM) to compare the effect of inlet velocity of air on Nusselt number, thermal resistance and pressure drop for plate fin heat sink (PFHS) and Different profiles like Plate Fin Heat Sink (PFHS), Elliptical plate Fin Heat Sink (EPFHS), Hexagonal Plate Fin Heat Sink (HPFHS) have been taken for simulation. The effect of changing shape of pin fin keeping same hydraulic diameter and Effect of inlet velocity on Thermal Resistance and Pressure Drop, Nusselt number has been studied elaborately. KEYWORDS: Heat Exchanger, CFD, Mass Flux, Heat Transfer, Turbulence Modeling etc. Also the effect of increasing number of pin fins on thermal resistance, pressure drop, Nusselt number has been observed. Finite element method (FEM) was used to compute Thermal resistance and Nusselt number. An extensive study was carried out using ANSYS WORKBENCH 14.5, a powerful platform for finite element analysis. Results obtained from a series of thermal resistance and pressure drop, Nusselt number variation curves for different profiles like Plate Fin Heat Sink (PFHS), Elliptical plate Fin Heat Sink (EPFHS), Hexagonal Plate Fin Heat Sink (HPFHS) for different no. of pin fin. It has been founded the Nusselt number is highest for Hexagonal Plate Fin Heat Sink (HPFHS) having 5 fins, thermal resistance is also minimum although pressure drop increases as we increases inlet velocity.

KEYWORDS: Finite Element Method, Plate Fin Heat Sink (PFHS), Elliptical plate Fin Heat Sink (EPFHS), Hexagonal Plate Fin Heat Sink (HPFHS), Ansys, Thermal Resistance And Pressure Drop, Nusselt Number
INTRODUCTION

Heat transfer is the exchange of thermal energy between physical systems. Rate of heat transfer depends on the temperatures of the systems properties of the intervening medium through the heat is transferred. There are three basic modes of heat transfer conduction, convection and radiation. Heat transfer, the flow of energy in the form of heat, a method by that a system's internal energy is exchanged, therefore is of important use in applications of the First Law of thermodynamics. Conduction is similar as diffusion, to not be confused with diffusion associated with the blending of constituents of a fluid.

Convection heat transfer
The flow of fluid is also forced by external processes, or typically (in attraction fields) by buoyancy forces caused once thermal energy expands the fluid (for example during a fireplace plume), so influencing its own transfer. The latter method is usually referred to as "natural convection". All convective processes conjointly move heat partly by diffusion, as well. Another type of convection is forced convection. Convective heat transfer, or convection, is that the transfer of heat from one place to different by the movement of fluids, a method that’s primarily the transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer in several physical things, like (for example) between a solid surface and therefore the fluid.

Convection is typically the dominant form of heat transfer in liquids and gases. Though typically mentioned as a third methodology of heat transfer, convection is generally used to describe the combined effects of heat conductivity inside the fluid (diffusion) and heat transference by bulk fluid flow streaming.

Importance of Heat Sinks in Electronic Circuits
A heat sink is a passive device, and it's designed to possess increased area involved with the encircling (cooling) medium like air. The elements or electronic components or devices that are insufficient to moderate their temperature, need heat sinks for cooling. Heat generated by each component or element of electronic circuit should be dissipated for rising its reliableness and preventing the premature failure of the element. It maintains thermal stability in limits for each electrical and electronic element of
any circuit or electronics components of any system.

The thermal conductivity of metal is proportional to the heat transfer in sink. Thus, if the thermal conductivity of the metal increases, then the heat transferring capacity of the heat sink also will increase.

**LITERATURE**

Heat transfer is defined because the energy transformation from one place to a different owing to temperature distinction and flow from hot temperature region to low temperature region with none applied external force. The modes of heat transfer are conduction, convection and radiation. A steady state could be a condition wherever the temperature at every point of a body remains constant during a amount of time. The fundamental condition of steady state heat conduction is given by \( \frac{d}{t} \neq 0 \neq \frac{d}{x} \) whenever \( T \) is temperature, \( t \) is time and \( x \) is the distance along the length of the material. The conduction heat transfer happens by following the final equation of conduction as

**Yakut et al.[01]** compared the results of the heights and widths of the polygonal shape fins, stream wise and span wise distances between fins, and flow rate on the heat and pressure-drop characteristics were investigated using the Taguchi methods.
experimental-design technique. Nusselt number and friction factor were thought-about as performance statistics. An L18(21*37) orthogonal array was selected as the experimental set up for the five parameters mentioned above. whereas the optimum parameters were determined, the trade-off among goals was considered. initial of all, each goal was optimized, separately. the pressure terms of momentum equations are solved by the SIMPLEC algorithm. The plate-circular pin-fin heat sink is composed of a plate fin heat sink and some circular pins between plate fins. The purpose of this study is to examine the effects of the configurations of the pin-fins design. The results show that the plate-circular pin-fin heat sink has better synthetically performance than the plate fin heat sink.

Reddy et al.[02] examined design of machine elements plays a significant role within the field of Engineering where it includes the shape of part, size, applied loads, position and materials used. because of the applied loads specifically static, thermal and combined loads etc., the part undergoes stresses and deformations that effects the lifetime of element and conjointly the system. The Finite element method (F.E.M) may be a numerical tool used for determination problems of engineering and mathematical problems in the fields of structural analysis, heat transfer, fluid flow, mass transport etc.,. For problems involving difficult geometries, loadings and material properties, it's usually impractical to get analytical solutions. These solutions typically need the standard or partial differential equations.

Qasem et al.[03] conducted an experimental study to investigate the dissipation heat transfer by natural convection in a rectangular fin plate with circular perforations as heat sinks. In this study it's found that, the heat transfer rate and also the coefficient of heat transfer magnified with an enhanced number of perforations A three-dimensional numerical study is made for turbulent fluid flow and convective heat transfer around an array of rectangular solid and new design of perforated fins with completely different numbers and two varied sizes of perforations. in this study, the fin efficiency of perforated fins is determined and compared with the equivalent solid fin. Results show that new perforated fins have higher total heat transfer and
appreciable weight reduction as compared with solid fins. Dewan A et al.[04]. Numerical investigation is performed in the that study for three-dimensional fluid flow and turbulent forced convective heat transfer from an array of circular solid pin fins and perforated circular fins that are mounted on a flat plate in staggered fashion along the flow direction. Incompressible air as the working fluid is modeled using the Reynolds- Averaged Navier–Stokes equations. RNG k-ε turbulence model is employed to account for the impact of turbulence. Temperature field within the fins is obtained by solving Fourier’s conduction equation. The conjugate differential equations for both solid and gas phases are resolved at the same time by the finite volume technique using the easy algorithmic rules. V. Kumar et.al.[05] carries out numerical physical insight into the flow and heat transfer characteristics. The governing equations are solved by adopting a control volume-based finite-difference method with a power-law scheme on an orthogonal non-uniform staggered grid. The coupling of the velocity and the pressure terms of momentum equations are solved by the computational fluid dynamics. The Elliptical Pin Fin Heat Sink is composed of a plate fin heat sink and some circular pins between plate fins. The purpose of this study is to examine the effects of the configurations of the pin-fins design.

PROPOSED METHODOLOGY

In the literature survey it has been found that so much work had been done to enhance the convective heat transfer with pin fins. But there is no work has been done to optimize the heat transfer rate with Hexagonal plate fin heat sink(HPFHS). It has been found to optimize the given three profile, Plate Fin Heat Sink (PFHS), Elliptical plate Fin Heat Sink (EPFHS), Hexagonal Plate Fin Heat Sink (HPFHS) profile keeping in mind that it should produce maximum heat transfer with minimum pressure drop and increase in Nusselt number as it gives better heat transfer performance. Also the increase in number of pin fin gives an additional increment in heat transfer.

PROBLEM SPECIFICATION

It has been observed that from the above mentioned literature the heat transfer by
Plate fin is basically used when requirement of space is limited and high performance heat transfer device is required. For simplification in numerical analysis considered profiles but in practical problems it may be large number of profiles can be used depending on the requirements. In this study, for analysis fin dimension and boundary conditions are kept same as that of by vivek et al. The plate fin heat sink has nine plate fins each of having thickness 1.5 mm and length 51 mm. the spacing between two plate fins are kept constant and is 5 mm. Height of fin is taken as 10 mm. As the Number of fins increases the heat transfer is also increases but the design point of view the number of pin fin should be used as much as optimized. In this case study up to 5 number of pin fin is considered and also the height fins is also same in all cases.

Elliptical Plate fin Heat Sink (EPFHS) having three elliptical pin fin with major axis 5 mm and minor axis 2 mm is taken as were taken by vivek et.al. further for the same hydraulic diameter as elliptical pin fin, hexagonal pin fin are to be analyzed for pressure drop and thermal resistance. The all fins are made of ALUMINIUM.

The other property is assumed to be constant for analysis.

### Table 3.1 Geometric parameters of Plate fin heat sink

<table>
<thead>
<tr>
<th>Fin Length, L (mm)</th>
<th>Fin Height, H (mm)</th>
<th>Fin Number, N</th>
<th>Fin thickness, t (mm)</th>
<th>Fin-to-Fin distance, d</th>
</tr>
</thead>
<tbody>
<tr>
<td>51</td>
<td>10</td>
<td>9</td>
<td>1.5</td>
<td>5</td>
</tr>
</tbody>
</table>

### Properties of Air

<table>
<thead>
<tr>
<th>Fluid Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>$\mu = 1.7894 \times 10^{-5} \text{ kg/m/s}$</td>
</tr>
<tr>
<td>Specific heat of air</td>
<td>$c_p = 1006.43 \text{ J/kg K}$</td>
</tr>
<tr>
<td>Thermal conductivity of air</td>
<td>$K = 0.0242 \text{ W/m K}$</td>
</tr>
<tr>
<td>Density of air</td>
<td>$\rho = 1.225 \text{ kg/m}^3$</td>
</tr>
</tbody>
</table>
GOVERNING EQUATIONS

The schematic diagram of the heat sink configuration is shown in Fig. The turbulent three-dimensional Navier–Stokes and energy equations are solved numerically (using a finite-difference scheme) combined with the continuity equation to simulate the thermal and turbulent flow fields. An eddy viscosity model is used to account for the effect of turbulence. The flow is assumed to be steady, incompressible, and three-dimensional. The buoyancy and radiation heat transfer effects are neglected. In addition, the thermo physical properties of the fluid are assumed to be constant. The three-dimensional governing equations of mass, momentum, turbulent kinetic energy, turbulent energy dissipation rate, and energy in the steady turbulent main flow using the standard k-ε models are as follows:

(1) Continuity equation
\[ \frac{\partial \rho \vec{u}_i}{\partial x_i} = 0 \]

(2) Momentum equation
\[ \rho \frac{\partial \vec{u}_i}{\partial t} + \frac{\partial \rho \vec{u}_i \vec{u}_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \vec{u}_i}{\partial x_j} + \frac{\partial \vec{u}_j}{\partial x_i} \right) \right] \]

(3) Energy equation
\[ \rho C_p \frac{\partial T}{\partial t} + \rho \vec{u}_i \frac{\partial T}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \lambda \left( \frac{\partial T}{\partial x_j} \right) \right] \]

(4) Transport equation for k
\[ \rho \frac{\partial k}{\partial t} + \rho \vec{u}_i \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial k}{\partial x_j} \right) \right] + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \vec{u}_i}{\partial x_j} + \frac{\partial \vec{u}_j}{\partial x_i} \right) \right] \frac{\partial \vec{u}_i}{\partial x_j} - 2 \rho \varepsilon \]

(5) Transport equation for ε
\[ \rho \frac{\partial \varepsilon}{\partial t} + \rho \vec{u}_i \frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \varepsilon}{\partial x_j} \right) \right] + \rho \frac{\partial T}{\partial x_i} \frac{\partial T}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \vec{u}_i}{\partial x_j} + \frac{\partial \vec{u}_j}{\partial x_i} \right) \right] \frac{\partial \vec{u}_i}{\partial x_j} - \frac{C_1}{C_2} \frac{\partial k}{\partial x_i} \frac{\partial \varepsilon}{\partial x_i} \]

The empirical constants appear in the above equations are given by the following values:

\[ C_1 = 1.44, \quad C_2 = 1.92, \quad C_\mu = 0.09, \quad = 1.0, \quad \sigma_\varepsilon = 1.3, \quad \text{and} \quad \sigma_k = 0.7 \]

(6) The governing equation for the solid can be written as
\[ \frac{\partial}{\partial x_i} \left( k_s \frac{\partial T}{\partial x_i} \right) = 0 \]

(7) The thermal resistance of the heat sink is calculated by
\[ R_{th} = \frac{\Delta T}{Q} \]

where ΔT is the temperature difference between the highest temperature on the fin base and the ambient air temperature, and
Q is heat dissipation power applied on the fin base.

\[ h = \frac{Q}{A_h(T_{base} - T_{in})} \] (8) The average convection heat transfer coefficient \( h \) is calculated by

\[ Nu = \frac{hd}{k_a} \] (9) The average Nusselt number \( Nu \) based on the hydraulic diameter \( d \) is calculated by

From problem formulation it is very clear that for analysis the fin model prepared and defines the assumption. From the above literature review has been found that the geometry of fin is made in respective software. For this analysis the simulation software is also required. Geometry creation and analysis has been done in the next chapter.

**RESEARCH METHODOLOGY**

The purpose of those technical demonstration issues is to encourage taking advantage of the particularly broad simulation capabilities of ANSYS Mechanical APDL. The real world problems depict the features and effectiveness of Mechanical (APDL) by presenting a series of analyses from a spread of engineering disciplines. The problems have been more substantive and sophisticated than examples found within the standard documentation set. The documentation totally examines the physics involved every downside and therefore the issue and the necessary for translating issue into numerical models. Approximation problems, accuracy considerations, and main practices are discussed.

The problem description has been given via Mechanical APDL commands, element varieties, procedures, and material models. It’s entirely possible, however, to use another ANSYS, Inc. product like ANSYS Mechanical to accomplish similar simulation goals however with a distinct process. Domestically put in product installation contains the input files for every issue given during this guide. All the ansys software contain three basic elements

1. Pre processor
2. Main Solver
3. Post processor
To plot the variation of temperature drop with Reynolds number, hence showing the effect of variation of cooling effect with Reynolds’s number.

Meshing Type: Quadcore
No Of Nodes: 70240
No Of Elements: 56928

Type of Solver: Choose the solver for the problem from Pressure Based and density based solver. Here we select Pressure based solver as were selected by reference paper.

Physical model: Choose the required physical model for the problem i.e. laminar, turbulent, energy, multiphase, etc. in our analysis flow is considered to be turbulent.

Material Property: Choose the Material property of flowing fluid. Air at ambient temperature and atmospheric pressure is selected as flowing fluid. and its properties are predefined in software. For fin material Al has been selected and its properties also predefined in software.

Boundary Condition: Define the desired boundary condition for the problem i.e. velocity, temperature, heat flux etc. in given analysis the analysis has been performed for three different velocities of air at inlet and are 6.5, 9.5, 12.5 m/sec temperature of base plate is kept uniform at which fin are mounted. Due to periodic structure of heat sink only one flow passage has been investigated. The Plate
fins were subjected to convective boundary conditions on the surface and the displacement boundary condition. Thus the top and bottom surface of the horizontal section of the Plate has been taken as insulated. The fluid (Air) inlet temperature (Ti) was taken fixed at 294 K and constant heat flux of 10W is supplying at base plate. The inlet velocities are taken 6.5, 9.5, and 12.5 m/s). The flow is considered to be incompressible, steady, turbulent. Properties of air are considered to be constant as the heating is low. Effect of radiation is also neglected during analysis. (Vivek et. al., 2013).

4.2.2 Main Solver:
Solution Method: Choose the Solution method to solve the problem i.e. First order, second order
Pressure- velocity coupling Scheme : SIMPLE
Pressure – Standard
Momentum – Second order
Turbulent Kinetic Energy (k) – First order
Turbulent Dissipation Rate (e) - First order
Solution Initialization: Initialized the solution to get the initial solution for the problem. Run Solution: Run the solution by giving 500 no of iteration for solution to converge.

As the solution is converged the next phase to collect the observations also called as post processing.

RESULTS AND DISCUSSION
The purpose of this study is to examine the effects of the configurations of the pin-fins design like Elliptical Pin Fin, Hexagonal Pin Fin for the same hydraulic diameter under different wind velocity Like (6.5,9.5,12.5 m/sec). A three-dimensional model is developed to analyze flow and conjugate heat transfer within the sink for electronic applications. The periodic structure of the heat sinks, only one flow passage is investigated. The computational domain employed is shown in fig. . The
dimensions of different pin fin used are given in table. The material of the heat sink is aluminum. The bottom of the computational domain is heated at a constant heat transfer rate of 10W. The flow is assumed to be three-dimensional, incompressible, steady, turbulent, and since the heating is low, constant air properties. Radiation effect is ignored. A series of numerical calculations are conducted by FLUENT and also the results are conferred in order to indicate the consequences of temperature distribution, overall heat transfer coefficient, Thermal Resistance, Surface Nusselt number in the heat sinks. Both simulation results and Yue-Tzu yang experiment results for thermal resistances and pressure drops of the PFHS are plotted in Fig. A number of finite elements analysis have been conducted on Aluminium material Plate Pin Heat Sink system to compare the influence on Nusselt Number, Thermal resistance, and Pressure drop. Dimensions of the plate fin sink (PFHS) and plate pin-fin heat sink (PPFHS) with completely different types and arrangements of the pins during this study are represented. The results of the wind velocity and therefore the varieties of PPFHS on the thermal performance and therefore the pressure drop are investigated. The parameters employed in this study embody Uin (Uin = 6.5, 8.0, 10.0, and 12.2 m/s), the kinds of pins (Hexagonal, Elliptical) and therefore the number of pins (in-line ). In the PPFHS, the center distance of two neighbor pins is more 10D in flow direction, and also the nearest distance between the pin center and fin wall is about as 1D. The heating area is heated with heating power 10 W.

VALIDATION AND VERIFICATION

The geometric parameters of the PFHS taken are identical as the one of studies of vivek et al. and Yu et al. to verify this numerical models, the thermal resistance and also the pressure drop underneath the conditions Uin = 6.5–12.5 m/s and Q = 10W are compared with the available experimental results of literatures and designs of EPFHS and HPFHS are extended from PFHS. To the authors’ information, there aren't any offered information within the printed literature could be verified Figs. and show the thermal resistance and also the pressure drop of the PFHS. Moreover, a total range
of node and element are 70240 and 56928 respectively. The deviation between simulation results and literature’s knowledge are under 10%. Reasonable discrepancies between numerical calculations and therefore the offered experimental results of literatures could also be caused by the isotropic assumption, numerical error and experimental uncertainties.

From the analysis of the results, following conclusions can be drawn.
1. The Nusselt Number is found to be maximum at velocity 12.5 m/s for all the type of pin fin for all the three profiles. The Nusselt Number is maximum in the case of HPFHS 5 Pin profile and minimum for PFHS profile, while that of EPFHS profile lies in between the HPFHS 5 and PFHS.
2. The magnitude of the Pressure drop is maximum in the case of heat sink with hexagonal profile of pin fin(HPFHS) and the least for PFHS profile. Continuously increase in pressure drop depicts the higher pumping power required for maintaining air flow.
3. The magnitude of Thermal Resistance is maximum in the case of PFHS profile and the least for HPFHS 5 pin profile.
4. As per above discussion, for HPFHS, Pressure drop is increasing with increase in velocity and from the figure it can be observed that the Thermal resistance is decreasing as velocity is increasing. Increment in Pressure drop increases the pumping work while drop in thermal resistance increases heat transfer. So a common point should be find out to get optimized results by plotting graph

**CONCLUSIONS**

The current analysis has represented the thermal characteristics of the Plate fin heat sinks with pin fins of different profiles. CFD analysis has been carried out on Aluminium material Plate fin heat sink system. The effect of Elliptical and Hexagonal profiles of the Pin fin with constant hydraulic diameter on the Nusselt Number and Thermal Resistance and Pressure drop of the plate fin was studied.
velocity on common axis and Pressure drop on primary axis and thermal resistance on secondary axis. From graph that point is obtained at wind velocity 10.5 m/sec where the thermal resistance is found to be 0.49 K/w and pressure drop is founded 970 Pa.

The convective heat transfer characteristics of the HPFHS 5 Pin is best in comparison to other profiles with equal hydraulic diameter the operating parameter. HPFHS profile is economical as the profile and the construction cost is compared with elliptical profiles. Hence HPFHS 5 Pin profile is effective because for equivalent heat transfer it has been required much less thermal resistance than other profile.

Heat transfer through heat exchanger depends on the mass flow rate and temperature of fluid flowing inside the heat exchanger. In current flow rate of Reynold’s number 4000, 7000 and 10000 for cold fluid have been considered. To analyze the cumulative effect of Reynold’s number on the heat exchanger rate, the CFD model of heat exchanger has been developed.

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