Computational Analysis of Inverted Notched Fin Arrays Dissipating Heat by Natural Convection

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Abstract—The extended surfaces known as fins are used for the heat transfer purpose in various instruments like heating and cooling equipments. Fins offer an economical and trouble free solution in many situations demanding natural convection heat transfer. Heat sinks in the form of fin arrays on horizontal and vertical surfaces are extensively used in refrigeration and air conditioning applications as well as in electronic and thermal control equipment. Heat sinks are of considerable economic significance. The controlling variable generally available to designer is geometry of fin arrays. In a lengthwise short array, where the single chimney flow pattern is present, the central portion of fin flat becomes ineffective due to the fact that, already heated air comes in its contact. A stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. Hence it is removed in the form of inverted notch at the central bottom portion of fin to modify its geometry for enhancement of heat transfer. The comparison of experimental and computational analysis is done and results are well matching. It is found that the average heat transfer coefficient for inverted notch fin arrays is higher as compared with normal fin array.

Index Terms—Heat transfer enhancement, Natural convection, Inverted notched fins, Single chimney flow pattern, Ansys Fluent 12.

I. INTRODUCTION

The heat transfer can be increased by the three different augmentation techniques such as Passive techniques, Active techniques and Compound techniques. The active heat transfer enhancement techniques have not found commercial interest because of the capital and operating cost of the enhancement devices, also external power is required. A compound technique involves complex design. The majority of passive techniques employ special surface geometry or fluid additives for enhancement i.e. no direct application of external power. Practically useful, augmentation techniques are mostly passive ones. Passive techniques are treated, structured surfaces, rough surfaces, extended surfaces, displaced enhancement devices, swirl flow devices, additives for liquids and gases, etc. Extended surfaces are widely used passive techniques to enhance heat transfer [23]. Whenever it is difficult to increase the rate of heat transfer either by increasing heat transfer coefficient or by increasing the temperature difference between the surfaces and surrounding fluid, the fins are commonly used. Natural convection heat transfer is often augmented by provision of rectangular fins on horizontal or vertical surfaces in many electronic applications, motors and transformers. The current trend in the electronic industry is miniaturization, making the overheating problem more acute due to the reduction in surface area available for heat dissipation. Further enhancement in heat transfer can be obtained by proper selection of form of extended surface or by making some modifications in the geometry of surfaces like dent marks, grooved or different types of notches, etc. The fin which gives single chimney flow pattern that fin will good for heat transfer rate. Fins are of two types without notch fins and with notch fins. Notch fins gives more heat transfer rate than without notch fins because single chimney flow pattern is more in notch fins.

II. SINGLE CHIMNEY FLOW PATTERN

In single chimney flow pattern, there is sideway entry of the air in case of natural convection cooling of fin array. The air coming inwards gets heated as it moves towards the centre of the fin, as well as it rises due to decrease in density. So, the central portion of the fin becomes ineffective because hot air-stream passes over that part and therefore it does not bring about large heat transfer through that portion. So, if some of the material from that central portion is removed, and is added at the place where greater fresh air comes in the contact of the fin surface, it would increase overall heat transfer coefficient ‘h’. This has been confirmed experimentally by Sane et al. figure 1 shows configuration of such fin arrays [7].

Fig. 1: Single Chimney Flow Pattern

III. NEED OF INVESTIGATION

Specially designed finned surfaces called heat sink, which are commonly used in the cooling of electronic equipment and stationary engines needs optimized design with minimum material and maximum heat transfer from them. In the natural cooling of fins, the temperature drops along the fins exponentially and reaches the environment temperature at
some length. But a stagnant zone is created at the central bottom portion of fin array channel and hence it does not contribute much in heat dissipation. It results in wastage of material for small heat transfer rate. Cutting this portion of fins, results in the complete elimination of heat transfer from that region. Also the central portion of the fin flat becomes ineffective due to the fact that, already heated air comes in its contact. In this investigation, fins are modified in the form of inverted notch at the central bottom portion of fin to modify its geometry for enhancement of heat transfer.

IV. EXPERIMENTATION

Experimentation is done for four different cases of inverted notch fin arrays. For experimental setup, base plate and fins are cut from 1.2 mm thick rolled aluminum sheet and assembled together to form the required fin array. The dimensions of the fin arrays for experimental work are shown below.

Table 1: Specifications for Aluminum Fin Arrays

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>L (mm)</th>
<th>H (mm)</th>
<th>S (mm)</th>
<th>No. of fins</th>
<th>Depth of Notch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>127</td>
<td>38</td>
<td>8</td>
<td>7</td>
<td>Without notch</td>
</tr>
<tr>
<td>2</td>
<td>127</td>
<td>38</td>
<td>8</td>
<td>7</td>
<td>40%</td>
</tr>
<tr>
<td>3</td>
<td>150</td>
<td>75</td>
<td>8</td>
<td>7</td>
<td>40%</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>85</td>
<td>8</td>
<td>7</td>
<td>40%</td>
</tr>
</tbody>
</table>

Figure 1 shows the schematic representation of experimental set up. The fin array consists of number of fins fixed to the base plate by using aluminum welding operation. Heating coil placed in the base portion of the fin array. The heating coil is fixed in an insulating box. An assembled array is placed in insulating box to base portion to minimize heat loss by conduction through base and sides of the fin array. Calibrated thermocouples (k-Type) with temperature indicator are used to measure temperatures at various locations of fin array. A calibrated wattmeter is connected to measure heater input. Experiments are performed and steady state observations are recorded.

Computational fluid dynamic, results are directly analogous to the experimental results obtained. Ansys Fluent 12 software is used for Computational fluid dynamic analysis. The fin surfaces, with base are assumed as a source, held at uniform temperature. Laminar natural convection is the mechanism for heat transfer from the fin array. Radiation heat loss is not considered. The Boussinesq approximation is employed. ANSYS-workbench is used to create geometry of model. Geometry and meshing capabilities within ANSYS Workbench is done. The 3D geometric model of inverted notch fin array is created. Figure showing the 3D geometry model which is created in ANSYS fluent consisting the fin array assembly and enclosure for natural convection condition. The geometry for all four cases is created as like shown below.

3D Model consisting the fin array assembly as well as wooden block for the conditions of natural convection. After creating the geometry, the next step is to prepare the mesh, accuracy of the CFD analysis depends on the quality of mesh. Mesh generation involves the application of elements and nodes on existing geometry. We have selected the unstructured mesh to generate the mesh on geometry in which the tetrahedral volume mesh is generated. The meshing is generated till the overlapping of elements, negative element not generated. The fin surface and base are held at a constant temperature Ts. Interfacing of mesh is done in which air wall is interface with the fin wall and air-bottom wall is intermeshing with the plate-top wall. All the remaining boundaries are assigned as pressure outlet where air enters or leaves the channel at the ambient temperature T∞. Here the ambient pressure is used as stagnation boundary condition with the incoming mass having the ambient temperature. The static pressure is assumed equal to the pressure of surrounding atmosphere. Analysis and evaluation of the solution results is referred to as post processing. Post processor software contains sophisticated routines used for sorting, printing, and plotting selected results, graphics and animation. From
graphics and animation, contours of temperature at various surfaces are viewed. Generally, the post-processor allow the generation of graphs to show the variation of wide range of parameters with time and space. In this work the temperature distribution profile on the base plate, fins and temperature distribution from body to surrounding is obtained which would be helpful to calculate the heat transfer coefficient. Contours for all fin array set up is captured for various heat flux like 1755 W/m$^2$, 2192 W/m$^2$, 2632 W/m$^2$. From this, mean temperature is obtained and further calculation is done.

V. RESULT AND DISCUSSION

Results which are obtained from present experimental and computational investigation are discussed as below.

A. Effect of inverted notch fin Array

Figure 5 shows the effect of heat input on heat transfer coefficient for inverted notch fin array and normal fin array. The value of $L_c$ for without notch fins is 0.0585 m and for notch fins the value of $L_c$ 0.03234 m. The heat transfer coefficient is value of $h$ is depends upon the ratio $Nu/L_c$. The heat transfer coefficient is directly proportional to Nusselt number. The value of $Nu$ is affected as $L_c$ is increase or decrease. In notch fins the value of $L_c$ is less than without notch fins. Hence the value of $h$ is more in notch fins than without notch fins. It is observed that more temperature difference in notch fins hence ultimately increase the value of heat transfer coefficient. It is clear that as heater input increases, heat transfer coefficient is increases.

B. Temperature distribution along the fin array

In this work, the temperature distribution profile on the base plate, fins and temperature distribution from body to surrounding is obtained by CFD analysis which would be helpful to calculate the heat transfer coefficient. Analysis and evaluation of the solution results is referred in the post processing. From graphics and animation, contours of temperature at various surfaces are viewed. Generally, the post-processor allow the generation of graphs to show the variation of wide range of parameters with time and space. From this, mean temperature is obtained and further calculation is done. It is observed that 6 % variation in the results. From the CFD analysis of the fin arrays contours for all fin arrays at different heat flux are obtained which are showing the temperature distribution along the fin array as like shown below.

C. Effect of dimensions on heat transfer coefficient

The results are obtained in terms of heat transfer coefficient. Figure 7 shows the effect of heat input on heat transfer coefficient. As the heat input increases there is exist a temperature difference between surface and surrounding. Then the mean film temperature is calculated from temperature difference. From this Grashof number is calculated. The Nusselt number is a function of Grashof number. As Grashof number increases, the value of Nusselt number is also increases which increase the heat transfer coefficient. The heat transfer coefficient is directly proportional to Nusselt number. When the heat input increases the value of Grashof increases and ultimately the value of heat transfer coefficient increases. Hence it concluded that as the heat input increases the value of heat transfer coefficient increases. In this investigation, the geometric parameters of fins, i.e. length and height of fin array is different for all three cases which affect on the heat transfer rate. And remaining parameter is same for all fin arrays.
VI. CONCLUSION
In this investigation, experimental and computational analysis of fin array is done. It is concluded that the heat transfer coefficient is more in notch fin array than without notch fin array. Geometric parameters of fin affects on the performance of fins, so proper selection of geometric parameter such as length of fin, height of fin, spacing between fins, depth of notch is needed. The value of average heat transfer coefficient is more for case 2 fin array than other fin arrays. The heat transfer rate is also more for case 2 itself. The values of heat transfer coefficient are higher for inverted notch fin arrays giving better performance than normal fin arrays. The inverted notch fin array performs better as single chimney flow pattern is more in with notched fin. The performance of heat transfer fins can be analyzed effectively by commercially available CFD software, Ansys Fluent 12.

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