THEORETICAL STUDY AND FINITE ELEMENT ANALYSIS OF CONVECTIVE HEAT TRANSFER AUGMENTATION FROM HORIZONTAL RECTANGULAR FIN WITH CIRCULAR PERFORATION

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ABSTRACT

This study examines the heat transfer augmentation from horizontal rectangular fins with circular perforations under natural convection compared with solid fins. Fins with different thickness keeping length constant are also examined. The parameters considered were geometrical dimension and thermal properties of fin such as material properties, convective heat transfer coefficient. Finite element analysis has been done using ANSYS 11. Study showed that as perforations increases heat transfer rate also increases. Heat transfer enhancement of the perforated fin increases with increase in fin thickness.

KEYWORDS: Element Analysis, Heat Transfer Rate, Natural Convection, Perforated Fin

INTRODUCTION

The removal of excess heat from system components is essential to avoid damaging effects of overheating. Therefore, the enhancement of heat transfer is an important subject of thermal engineering. Heat transfer between a surface \( T_o \) and the fluid surrounding it \( T_s \) is given by \( Q = h A (T_o - T_s) \). Heat transfer rate may be increased by increasing the heat transfer coefficient between a surface and its surrounding, or by increasing the heat transfer area of the surface. In most cases, the area of heat transfer is increased by extending surfaces.

These extended surfaces are called as fins. Fins are used to enhance convective heat transfer in a wide range of engineering applications and offer a practical means for achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are commonly applied for heat management in electrical appliances such as computer power supplies or substation transformers. Other applications include engine cooling, condensers in refrigeration and air conditioning.

Fins as heat transfer enhancement devices have been quite common. The different materials like Mild steel, Stainless Steel, Aluminum, Silver, Copper etc are used for making fins. As the extended surface technology continues to grow, new design ideas have been emerged including fins made of anisotropic composites, porous media, interrupted and perforated plates. Due to the high demand for lightweight, compact, and economical fins, the optimization of fin size is of great importance. Therefore, fins must be designed to achieve maximum heat removal with minimum material expenditure taking into account the ease of the fin manufacturing. The improvement in heat transfer coefficient is attributed to the restarting of the thermal boundary layer after each interruption. Thus perforated plates and fins represent an example of surface interruption.

ANALYTICAL ANALYSIS

If Biot number is less than 0.01 then one directional heat transfer analysis can be assumed. The Transverse Biot
number in z-direction is can be calculated by \((\text{hp}. \frac{t}{2k})\) and Biot number in y direction can be calculated by \((\text{hp}. \frac{(ly +d/2)/k})\). As values of Biot number is less than 0.01 then heat transfer in y and z direction is assumed lumped and heat transfer can be taken in one direction. Analytical study has been calculated on following assumptions.

- Steady state one directional heat transfer.
- Homogeneous and isentropic fin material with constant thermal conductivity.
- Uniform base and abîment temperature.
- Uniform heat transfer coefficient over fin solid surface.

Aluminium fins with dimension 100 mm X 50 mm X 10 mm and perforations ranging from 2 to 12 is taken for study purpose. Also comparative study is done with solid fin. Heat transfer rate from a solid fin or perforated fin depends upon fin area and heat transfer coefficient. Base temperature of fin is taken as 100°C. The average value of heat transfer coefficient of fin is given by \(h = \frac{N_{u}. K}{L_{c}}\), where \(L_{c} = \frac{L. \delta}{(2.L + 2.\delta)}\).

The average value of heat transfer coefficient for perforated fins considered in study becomes 11.356 W/m²°C. The following table shows values of Heat flux of solid fin and Perforated fins with various perforations (i.e. 2,4,6,8,10,12).

### Table 1: Values of Heat Fluxes for Perforated Fins

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>No. of Perforations</th>
<th>Heat Flux (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Solid fin (0 perforation)</td>
<td>656</td>
</tr>
<tr>
<td>2</td>
<td>2 perforations</td>
<td>819</td>
</tr>
<tr>
<td>3</td>
<td>4 Perforations</td>
<td>883.4</td>
</tr>
<tr>
<td>4</td>
<td>6 Perforations</td>
<td>847.4</td>
</tr>
<tr>
<td>5</td>
<td>8 Perforations</td>
<td>911</td>
</tr>
<tr>
<td>6</td>
<td>10 Perforations</td>
<td>999</td>
</tr>
<tr>
<td>7</td>
<td>12 Perforations</td>
<td>1040.1</td>
</tr>
</tbody>
</table>

**FINITE ELEMENT ANALYSIS**

Various steps, involved in finite element analysis, are explained below.

**Creating Geometry**

Create geometry of fin, dimensions 100 mm X 50 mm X 10 mm, in CAD design software Pro-E. Circular perforations of 10 mm diameter are created at various distance on overall length.

**Defining Material Properties and Meshing**

After creating geometry define material properties of fin as aluminum, create mesh. Figure 1 shows the mesh fin and Table no. 2 shows meshing properties.

### Table 2: Meshing Properties

<table>
<thead>
<tr>
<th>Object Name</th>
<th>Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistics</td>
<td></td>
</tr>
<tr>
<td>Nodes</td>
<td>1898</td>
</tr>
<tr>
<td>Elements</td>
<td>298</td>
</tr>
</tbody>
</table>
Applying Loads and Boundary Conditions

Base of fin is attached to the heating source which is maintained at 100 °C and this temperature is kept constant for a period of time. Therefore analysis is considered as steady state thermal analysis. Applying average value of convective heat transfer coefficient over all surfaces of fin at ambient temperature of 22 °C. Figure 2 shows fin with boundary condition.

Solve for Solution

Applying loads and boundary conditions solve for results.

Figure 4 shows contours of heat flux in fin with 2 perforations. Heat fluxes contours of fins having 4 perforation, 6 perforations, 8 perforations, 10 perforations and 12 perforations are shown in Figures 5, Figure 6, Figure 7, Figure 8, Figure 9 respectively.
**Figure 4:** Heat Flux Contours of Fin with 2 Perforations

**Figure 5:** Heat Flux Contours of Fin with 4 Perforations

**Figure 6:** Heat Flux Contours of Fin with 6 Perforations

**Figure 7:** Heat Flux Contours of Fin with 8 Perforations
Theoretical Study and Finite Element Analysis of Convective Heat Transfer Augmentation from Horizontal Rectangular Fin with Circular Perforation

RESULTS DISCUSSIONS AND CONCLUSIONS

Analytical heat flux results of solid fin and perforated fin are given in Table 1. Figure 3 shows heat flux analysis of solid fin. It is then compared with fins having different perforations. In both analytical and finite element analysis, it is found that as the number of perforations increases, heat transfer rate increases. Heat transfer rate is found maximum in fin with 12 perforations. Figure 10, Figure 11 and Figure 12 show the comparison of number of perforations on fin versus heat flux in analytical, Ansys and comparison of both analytical and Ansys. Results of heat transfer rate obtained are quite satisfactory.
Figure 11: Ansys Heat Flux verses Number of Perforations

Figure 12: Comparative Chart of Analytical and Ansys Heat Fluxes

NOMENCLATURE

\( h \) = Convective heat transfer coefficient.

\( h_p \) = Convective heat transfer coefficient of perforated fin.

\( t \) = Thickness of fin.

\( K \) = Conductive heat transfer coefficient.

\( l_y \) = Length of fin in y direction.

\( L_c \) = Characteristic length of fin.

\( L \) = Length of fin.

\( \delta \) = Thickness

\( Nu \) = Nusselt number

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