To Study Heat Transfer Characteristics of Plate Finned Tube Heat Exchanger

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ABSTRACT

The paper presents analysis of calculation of heat transfer coefficient, fin efficiency on the fin inside one-tube plate finned-tube heat exchangers for various air inlet speeds and temperature difference between the ambient temperature and tube surface temperature, for different materials like steel and Al. Based on the mathematical model, a computer simulation program in the MATLAB for plate finned-tube heat exchanger is developed. The temperature data is proposed to predict the average heat transfer coefficient and fin efficiency on the fin inside one tube plate finned tube heat exchangers. The validation is done using the available data from the research papers. The prediction agrees with the data very well.

Keywords : Heat Exchanger, Fin Tube, MATLAB

I. INTRODUCTION

The heat exchange at different temperature between two fluids that are separated by a solid wall covers the wide area of engineering applications. The device simply used to exchange the heat is known a heat exchanger, and the major area of heat exchanger comprise space heating, and air-conditioning, power production, waste heat recovery, and chemical processing.

From the last two and half decades, heat exchanger playing a crucial role in energy conversion and recovery and leading the way to search new energy resources. The introduction of heat exchanger in environmental engineering create unbeaten opportunities to deal with different types of pollution such as thermal pollution, air pollution, water pollution, and waste disposal.

In the indirect contact heat exchanger, one fluid is a gas (more commonly, air) and the other secondary fluid is a liquid (more commonly, water) and are readily separable after the energy exchange. A water cooling tower with forced- or natural-draft airflow is the most common application. Other applications are the air-conditioning spray chamber, spray drier, spray tower, and spray pond. The heat transfer coefficient h for gases is generally one or two orders of magnitude lower than that for water, oil, and other liquids.

To increase the heat transfer area, appendages may be intimately connected to the primary surface to provide an extended surface. These extended surface elements are referred to as fins. Thus, heat is conducted through the fin and convected from the fin to the surrounding fluid.

Now a days, fin–tube heat exchangers have very important application in power stations, chemical plants, refrigerating industries, aircrafts, automobiles, etc. So far, many researchers have studied to enhance the efficiency of the fin–tube heat exchanger.

In the present work, an attempt is made analysis the heat transfer rate and heat transfer coefficient, fin efficiency, fin effectiveness for different material of fin, using mat lab programming for one plate finned tube heat exchanger.

of a louver fin radiator in an automotive power system’. Herchang et al. 2002 has studied the ‘Local heat transfer measurements of plate finned-tube heat exchangers by infrared thermography’ using the infrared thermovision. Jiong et al. 2005 studied ‘A study on the thermal contact conductance in fin–tube heat exchangers with 7 mm tube’, have been investigated through the experimental–numerical method.

II. METHODS AND MATERIAL

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>area of the whole plate fin,</td>
<td>m²</td>
</tr>
<tr>
<td>Aj</td>
<td>area of the jth sub-fin region,</td>
<td>m²</td>
</tr>
<tr>
<td>[A]</td>
<td>global conduction matrix</td>
<td></td>
</tr>
<tr>
<td>do</td>
<td>outer diameter of the a tube,</td>
<td>m</td>
</tr>
<tr>
<td>h</td>
<td>local heat transfer coefficient,</td>
<td>W/m²K</td>
</tr>
<tr>
<td>$\bar{h}$</td>
<td>average heat transfer coefficient on the whole plate fin</td>
<td>W/m²K</td>
</tr>
<tr>
<td>$\bar{h}_j$</td>
<td>average heat transfer coefficient on the jth sub-fin region</td>
<td>W/m²K</td>
</tr>
<tr>
<td>k</td>
<td>thermal conductivity of the fin,</td>
<td>W/mK</td>
</tr>
<tr>
<td>L</td>
<td>length of plate fin,</td>
<td>m</td>
</tr>
<tr>
<td>l</td>
<td>distance between two neighboring nodes in the x and y directions.</td>
<td>m</td>
</tr>
<tr>
<td>m</td>
<td>dimensionless parameter</td>
<td></td>
</tr>
<tr>
<td>$\bar{m}_j$</td>
<td>dimensionless parameter on the jth sub-fin region.</td>
<td></td>
</tr>
<tr>
<td>Nx</td>
<td>number of nodes in x-direction</td>
<td></td>
</tr>
<tr>
<td>Ny</td>
<td>number of nodes in y-direction</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>total heat flux dissipated from the whole plate fin</td>
<td>W</td>
</tr>
<tr>
<td>$q_j$</td>
<td>heat flux dissipated from the jth sub-fin region.</td>
<td>W</td>
</tr>
<tr>
<td>Red</td>
<td>Reynolds number</td>
<td></td>
</tr>
<tr>
<td>ro</td>
<td>outer diameter of the circular tube</td>
<td>m</td>
</tr>
<tr>
<td>T</td>
<td>temperature</td>
<td></td>
</tr>
<tr>
<td>$T_j$</td>
<td>temperature measurements on the jth sub-fin region</td>
<td></td>
</tr>
<tr>
<td>To</td>
<td>outer surface temperature of the circular tube</td>
<td></td>
</tr>
<tr>
<td>Tamb</td>
<td>ambient temperature</td>
<td></td>
</tr>
<tr>
<td>$\Delta T$</td>
<td>temperature difference, To-Tamb</td>
<td></td>
</tr>
<tr>
<td>Vair</td>
<td>velocity of air,</td>
<td>m/sec</td>
</tr>
<tr>
<td>X,Y</td>
<td>spatial coordinates</td>
<td>m</td>
</tr>
<tr>
<td>x,y</td>
<td>dimensionless spatial coordinates</td>
<td></td>
</tr>
<tr>
<td>$\delta$</td>
<td>fin thickness</td>
<td>m</td>
</tr>
<tr>
<td>$\Pi f$</td>
<td>fin efficiency</td>
<td></td>
</tr>
</tbody>
</table>

Greek Symbols

$\nu$ kinematic viscosity of the air, m²/sec

DESIGN SPECIFICATIONS

<table>
<thead>
<tr>
<th>Type of heat exchanger</th>
<th>One plate fin tube heat exchanger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube diameter</td>
<td>40 mm</td>
</tr>
<tr>
<td>Tube thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td>Plate fin thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td>Fin length</td>
<td>100 mm</td>
</tr>
<tr>
<td>Fin width</td>
<td>100 mm</td>
</tr>
<tr>
<td>Fin materials</td>
<td>stainless Steel, aluminium</td>
</tr>
<tr>
<td>Fin thermal conductivity</td>
<td>14.9, 200, W/mK</td>
</tr>
</tbody>
</table>

ASSUMPTION

The basic assumptions are as follow-
- The heat flow in the fin and its temperatures remain constant with time.
- The fin material is homogeneous, its thermal conductivity is the same in all directions and it remains constant.
- Negligible tube thermal resistance.
- The temperature of the medium surrounding the fin is uniform.
- The temperature at the base of the fin is uniform.
- There are no heat sources within the fin itself.
- The heat transferred through the tip of the fin is negligible compared with the heat leaving its lateral surface.
- Radiation heat transfer from and to the fin is neglected.
- Fin is considered to be insulated at the tip.

ANALYSIS

The analysis of work indicates that most of the researchers has studied plate finned tube heat exchanger, and the effect of tube arrangement. The present work mostly focuses on the study of heat transfer coefficient, fin efficiency and fin effectiveness using matlab for the one plate finned tube heat exchanger, for the different material of the fin.

- To develop a programs in mat lab.
- Validation.
To analyse heat transfer coefficient, heat transfer rate, fin efficiency for steel and aluminium.

Comparative study

MATHEMATICAL FORMULATION

The schematic diagram of the one-tube plate fin heat exchanger is shown in Fig1 and Fig2 which shows the physical model of the two-dimensional thin plate fin inside a one-tube plate fin heat exchanger, where \( r_0, L \) and \( d \) denote the outer radius of the circular tube, the side length of the square plane fin and the fin thickness, respectively.

The circular tube is located at \((L/2, L/2)\). \( T_0 \) and \( T_{∞} \) respectively denote the surface temperature of the circular tube and the ambient temperature.

Fin heat transfer area is divided into six regions. The region 2 and 5 are the wake fin area and upstream fin area respectively. The region 4 and 6 are leading edge area of the fin. The Reynolds number is defined as \( Re = \frac{Vd_0}{\nu} \), where \( V \) is frontal air speed, \( do \) is the outside diameter of the circular tube and \( \nu \) is the kinematic viscosity of the air. The \( Re \) number values ranges from 2500 to 13000. It is clear that in the present work, if the airflow is greater than 5m/sec, it become turbulent.

The “insulated tip” assumption can be an adequate approximation provided that the actual heat flux dissipated through the tip is much smaller than the total heat flux drawn from the base wall. The heat transfer coefficient on the fin inside a plate finned-tube heat exchanger can be estimated provided that the fin temperatures at various locations can be taken.

The circular tube is located at \((L/2, L/2)\). \( T_0 \) and \( T_{∞} \) respectively denote the surface temperature of the circular tube and the ambient temperature.

Fin heat transfer area is divided into six regions. The region 2 and 5 are the wake fin area and upstream fin area respectively. The region 4 and 6 are leading edge area of the fin. The Reynolds number is defined as \( Re = \frac{Vd_0}{\nu} \), where \( V \) is frontal air speed, \( do \) is the outside diameter of the circular tube and \( \nu \) is the kinematic viscosity of the air. The \( Re \) number values ranges from 2500 to 13000. It is clear that in the present work, if the airflow is greater than 5m/sec, it become turbulent.

Under the assumptions of the steady state and the constant thermal properties, the two-dimensional heat conduction equation for the continuous thin fin inside a plate finned-tube heat exchanger can be expressed as-

\[
\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2} = \frac{2h(X, Y)(T - T_{∞})}{k}\delta
\]  

Its corresponding boundary conditions are-

\[
\frac{\partial T}{\partial X} = 0, \text{ at } X=0 \text{ and } X=L \\
\frac{\partial T}{\partial Y} = 0, \text{ at } Y=0 \text{ and } Y=L \\
T = T_0 \text{ (X, Y) on S1}
\]

Where \( T \) is the fin temperature. \( X \) and \( Y \) are Cartesian coordinates.

DESIGN METHODOLOGY

S1 denotes the boundary of the circular tube with radius \( r_0 \). \( k \) is the thermal conductivity of the fin.

For convenience of the inverse analysis, the following dimensionless parameters are introduced as-

\[
x = X/L, \ y = Y/L, \ \text{and} \ m(x, y) = 2L^2h(x, y)/k \delta
\]
Substitution of Eq. (5) into Eqn (1)–(4) gives the following equations
\[
\partial^2 \theta/\partial x^2 + \partial^2 \theta/\partial y^2 = m(x, y)\theta \tag{6}
\]
\[
\partial \theta/\partial x=0, \text{ at } x=0 \text{ and } x=1 \tag{7}
\]
\[
\partial \theta/\partial y=0, \text{ at } y=0 \text{ and } y=1 \tag{8}
\]
And
\[
\theta=0 \text{ (x, y) on } S1 \tag{9}
\]
Where \( \theta = T-T_\infty \)

Rearrangement of eqn in conduction with difference equations in the neighbouring of the circular tube can yield the following matrix equation.

\[
[A][\theta] = [F] \tag{10}
\]

Where \([A]\) is global conduction matrix. \([\theta]\) is a matrix representing the nodal temperature. \([F]\) is a force matrix. With this a set of N algebraic equations are obtained, and by solving equations, heat transfer coefficient, and heat transfer are obtained for sub-fin region.

The step wise design methodology are used in this dissertation are presented below-1-The average heat transfer coefficient on the whole plate fin \( \overline{h} \) can be written as-

\[
\overline{h} = \Sigma h_j A_j / Af
\]

Where \( N \) is the total number of sub-fin regions. \( Af \) is the area of whole plate fin.

2-Heat flux dissipated from the sub-fin region \( q_j \) are given by-

\[
q_j = \overline{h} J \int (T-T_\infty) dA \text{ for } j=1,2,\ldots,N
\]

3- The efficiency of the continuous plate fin \( \Pi_f \) is defined as the ratio of the actual heat transfer from the continuous plate fin to the dissipated heat from the fin, maintained at the tube temperature \( T_0 \). Thus the fin efficiency \( \Pi_f \) can be expressed as-

\[
\Pi_f = \Sigma q_j / Af(T_0-T_\infty)\overline{h}
\]

4-The total heat flux dissipated from the whole plate fin to the ambient \( Q \) can be expressed as-

\[
Q = \Sigma q_j = \Pi_f Af
\]

\[
Q = \sqrt{(hPkA) \theta \tanh mL}
\]

In order to estimate the unknown heat transfer coefficient on the \( j \)th sub-fin region \( h_j \), and heat transfer rate the additional information of the steady-state temperature measurements is required at \( N \) interior measurement locations. The more a number of the sub-fin regions are, the more accurate the estimation of the unknown average heat transfer coefficient on the whole plate fin is. Relatively, a more computational time can be required. The temperature measurement taken from the \( j \)th thermocouple at the measurement location \( x_j \) is denoted by \( T_j(j=1\ldots N) \), as shown below in Tables 1 and table 2.

Table 1 shows the list of various temperatures on sub-fin region at frontal air velocity 1-5 m/sec at the tube surface temperature 59.6\(^\circ\)C and 25.6\(^\circ\)C ambient temperature.

Table 2 shows the list of various temperatures on sub-fin region at frontal air velocity 1-5 m/sec at the tube surface temperature 69.6\(^\circ\)C and 26.5\(^\circ\)C ambient temperature.

### III. RESULTS AND DISCUSSION

In the present work, attempt has been made to study the heat transfer characteristics; heat transfer coefficient, heat transfer rate, fin efficiency of plate finned tube heat exchanger.

Materials for the manufacture of fins are limited by the operating temperature of certain applications. For low to moderate temperature application, fins can be made...
from aluminium, copper and thus maintain high fin efficiency. For the high temperature application stainless steel and heat resistance alloys may be used with the possibly a reduction in fin efficiency.

Here we are calculating average heat transfer coefficient, fin efficiency on the entire fin surface. For this we consider three fin materials-

1- stainless steel
2- aluminium

1-when steel is used as fin material at \( \Delta T=33^\circ C \)

Table 3. When the temperature is \( T_0=59.6^\circ C \) and \( T_\infty=25.6^\circ C \)

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity</th>
<th>Density(kg/m³)</th>
<th>( \rho/\kappa )</th>
<th>( \rho/\kappa / (\rho/\kappa)a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>200</td>
<td>2723</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>Steel</td>
<td>15</td>
<td>7850</td>
<td>52</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 4. When the temperature is \( T_0=69.5^\circ C \) and \( T_\infty=26.5^\circ C \)

2- when steel is used as fin material at \( \Delta T=43^\circ C \)

3-When aluminium used as fin material at \( \Delta T=33^\circ C \)

Table 5. When the temperature is \( T_0=59.6^\circ C \) and \( T_\infty=25.6^\circ C \)

4-When aluminium used as fin material at \( \Delta T=43^\circ C \)

Table 6. When the temperature is \( T_0=69.5^\circ C \) and \( T_\infty=26.5^\circ C \)

IMPROVED EFFICIENCY

Thus, from the above result we can see, the fin efficiency is reduced from 0.71 to 0.61, about 14% reduction, by changing material from aluminium to steel. This in turn will reduce fin heat transfer by about 14%.

LOW WEIGHT

The mass of the fin is proportional to \( \rho/\kappa \). It may be seen that by using aluminium, instead of steel, a weight saving can be achieved. Steel have weight 40 times of aluminium, as shown below in table-

Table 7. Comparison of different fin material

It is seen that aluminium is preferred for fin material of a heat exchanger, because it has low cost, low weight, and ability to resistance corrosion.

The various graph plotted for \( \eta \) with velocity for various conditions of temperature for steel and aluminium. This shows the effect of frontal air speed on the heat transfer coefficient, heat transfer rate, fin efficiency. It is clear that wavy flow behind the tube has become turbulent and random in motion. Due to the blockage of tube, the heat transfer coefficient and heat transfer is maximum at upstream fin region. This implies that region 2 is contributing most of heat transfer. Heat transfer coefficient is low at the back surface(downstream region of fin) and contribute little heat transfer. It is also clear from the tables’ result that, at the same speed the
average heat transfer coefficient increases with the $\Delta T$ value and fin efficiency decreases with increasing $\Delta T$ value. The value of average heat transfer coefficient is also increasing with the increase in air velocity. The fin efficiency in the range of 1-5 m/sec decreases with increasing air velocity.

The fin temperature decreases more rapidly away from the circular centre when the frontal air speed increases, which is different from the ideal isothermal temperature distribution. Within a plate finned tube heat exchanger, there exists a complex flow pattern due to flow separation. The flow accelerates around the tube and forms a low-velocity wake region behind the tube. The fin temperatures on the downstream fin region are markedly higher than those on the upstream regions for various air speed. It can be observed from the figure shown below, that there is a temperature drop between the tube wall and edge of the plate fin.

**FIN TEMPERATURE DISTRIBUTION**

The fin temperature distribution is shown in figure below-

**Figure 1.** Variation of $h$ under various $\Delta T$ conditions for steel

**Figure 2.** Variation of $\eta$ under various $\Delta T$ conditions for steel

**Figure 3.** Variation of $\eta$ under various $\Delta T$ conditions for aluminium

**Figure 4.** Variation of fin temperature over fin surface for 1m/sec velocity for $\Delta T=33^\circ C$

**Figure 5.** Variation of fin temperature over fin surface for 1m/sec velocity for $\Delta T=43^\circ C$
IV. CONCLUSION

A study of correlation to predict heat transfer characteristics of plate finned tube heat exchanger with the matlab program is carried out at the six sub-fin region. The heat transfer coefficient, fin efficiency and fin effectiveness has been estimated, and it has found-1. Fin efficiency increases from 61 to 71% by changing material steel to aluminium; it means there is 14% increment in heat transfer.

2-Fin efficiency decreases from 61 to 31% for steel at \( \Delta T=33 \) with the increase in air velocity from 1m/sec to 5m/sec for the same fin material.

4-Heat transfer coefficient increases from 12 to 41W/m²K with air velocity from 1m/sec to 5m/sec.

V. REFERENCES


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