Comparative Heat Transfer Analysis of Vertical Heated Plate Using Fin Array

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Abstract: In this paper, the investigation is being done on heat transfer rate on vertical heated plate using different fin array by experimental study, the numerical analysis of this technique is done by using Ansys 15.0 Workbench. Natural convection heat transfer from vertical surfaces with a large surface element is encountered in several technological applications like electronic circuits which present an inherently reliable cooling process. This heat transfer enhancing technique is investigated for natural convection adjacent to a vertical heated plate with a multiple v-type and s-type partition plates (fins) in ambient air surrounding. This V-type partition plate is compact and hence highly economical. As compared to conventional vertical fins, this v-type partition plate works not only as extended surface but also as a flow turbulator. The experimental studies have been carried out on three geometric orientations. It was observed that among the three different fin array configurations on vertical heated plate, V-type fin with short length design performs better than vertical S fin array and V-fin with bottom spacing design. In this research work the numerical analysis is done by using Ansys 15.0 Workbench for validating the result.

Keywords: S fin and V type fins, V-type partition plate, ansys 15.0 workbench analysis, numerical analysis.

I. Introduction

Natural convection cooling with the help of finned surfaces often offers an economical and trouble free solution in many situations. For effective dissipation of heat, plain horizontal surfaces facing upward are preferred since they provide relatively higher surface heat transfer coefficients than other orientations. The active heat transfer enhancement techniques have not found commercial interest because of the capital and operating cost of the enhancement devices. The majority of passive techniques employ special surface geometry or fluid additives for enhancement i.e. no direct application of external power. 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. The tall vertical fin array restricts the heat transfer enhancement from tall vertical base plate. This is because of the boundary layer thickening and subsequent interference developed over the height. To obtain an appreciable improvement of the heat transfer in case of the horizontal fin array and Vertical fin array the fin height may be increased. The modes of heat transfer are conduction, convection and radiation. Fin performance can be measured by using the effectiveness of fin, thermal resistance and efficiency. Fins are also extensively used in cooling of generators, motors, transformers, refrigerators, cooling of computer processors and other electronic devices etc. Enhancement of heat transfer is of vital importance in many industrial applications. One of the methods of enhancing heat transfer is the use of extended surfaces or fins. The current trend in the electronic industry is miniaturization, making the overheating problem more acute due to the reductions in surface area available for heat dissipation. Thus heat transfer from fin arrays has been studied extensively, both computationally and experimentally.

A. Description and working of fins

Engine life and effectiveness can be improved with effective cooling. The cooling mechanism of the air cooled engine is mostly dependent on the fin size. The heat is conducted through the engine parts and convected to air through the surfaces of the fins. Insufficient removal of heat from engine will lead to high thermal stresses and lower engine efficiency. As air-cooled engine builds heat, the cooling fins allow the wind and air to move the heat away from the engine. On the basis of above advantages of fins they are termed as Extended Surfaces.

Temperatures $T_s$ and $T_0$ are fixed by design considerations, as is often the case, there are two ways to increase heat transfer rates:

1. To increase convection heat transfer coefficient [h] &
2. To increase the surface area [As].
The alternative is to increase the surface area by attaching to the extended surfaces called fins made of highly conductive materials. The main purpose of extended surfaces is to increase the heat transfer rate. 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.

B. Materials used for fins
Generally there are two types of materials used for fins aluminium and copper. The thermal conductivity of aluminium is 225 W/m K and that of copper is 385 W/m K. The melting and boiling point of copper are 1084˚ and 2595˚ and that of aluminium are 658˚ and 2057˚. In experimental work the material used for fins is aluminium.

II. Problem Definition
Numbers of researchers have worked on V-fin. One of them used single V-fin with water ambience; other used single V-fin with air ambience for computational work and found that V-fin gives more heat transfer coefficient than horizontal and vertical fin. It was also found that V-fin acts as a flow turbulator. After this one of the researchers have used multiple V-fins for his experimental work and observed that multiple V-fins on base plate give more heat transfer coefficient than horizontal and vertical rectangular fin. So it is decided to work on V-fin array for experimental work, as V-fin gives greater heat transfer coefficient. In the present work it is introspected experimentally and computationally to verify the performance of Vertical Heated plate with S fins and Short length V fin in heat transfer enhancement. For this new geometry S fins and short length V fins is used as a test channel. The intention behind this modification is to actually investigate the heat transfer enhancement over vertical heated plate and its effectiveness on different fin geometry. The Vertical plate with S fin and short length V fin are attached on vertical plate and performance is tested for varying the temperatures.

III. Experimental set up
The setup consists of a square M.S plate box on which rheostat i.e.; Dimmer stat is attached with Digital Temperature Indicators. The test plate of 250*250*3mm thickness is used for experimentation. Vertical Plate with spring coil is attached on the aluminium plate. Input to heater is controlled through rheostat. Seven thermo couples T1, T2, T3, T4, T5, T6 and T7 are embedded on the heated plate and fins of the test section to measure the change in temperature of base plate and plate is observed after every 20 minutes. Average temperature of plate is evaluated by summation of temperatures from T1 to T4 and fins temperatures are observed by thermocouples T5, T6 and T7. The digital device Digital Temperature Indicator is used to display the temperature measured by thermocouple at various position. The temperature measured by instrument is in 0C. Heated plate is cooled till ambient temperature to measure better heat transfer coefficient from the vertical plate.

The following are the objectives of this Setup:

i) To heat up the outer base plate surface uniformly to 400 0 C.
ii) To measure the temperature at different point.
iii) To calculate Nusselt Number for laminar and turbulent flow of air.
iv) To calculate heat transfer coefficient of Each plate
v) To calculate effectiveness of the fins . According to the objective the arrangement of block dig.shown Fig. 1.

Fig. 1 Block diagram of required set up
Fig. 2 Experimental set up
Components of setup are :

  i)Thermocouples: K type Thermocouple is used to measure the surface temperature of the tube, which is having range -200 °C to 1200 °C
  ii)Digital Temperature Indicator: D.T.I. is used to measure the temperature. Accuracy is about (27 ± 6) 0C
  iii)Rheostat: Heats com model Volt=230, Watt=3000 is used to give a control voltage and amp to give control rate of heating by using heating coil.
Finally the setup has made by bringing all components together, and what we get is presented in the picture Fig.2 having components 1. Dimmer stat, 2. Test plate, 3. Heating Coil, 4. Digital Temperature Indicator, 5. T1 to T7 Thermocouples. The experimental set up is as shown in the fig.2. The base plates used for the experiment were made of 3mm – thick 250mm – high, 250mm – wide aluminium. Aluminium glue was used to stick all the fins as per different combination on plain vertical plate of aluminium. Tapping was done at different suitable locations (5 points) to tie the thermocouples. Aluminium plates of 3 mm thick, 250mm long and 20mm wide were used as a material for generating vertical S fins and different V-type fins. The rated power of 400 Watts, 2 Amp at 230 volts, is supplied to the plate. Mica claded, thin plate type, 250 mm long and 250 mm wide square electrical heater wire was sandwiched between the symmetrical vertical base plates. The spread of the sandwiched electrical heater ensured almost uniform surface temperature of the test plates. The heater was supplied with stabilized a/c current through dimmer stat and wattmeter. Multi range wattmeter of 75V/150V/300V/400V and 1A/2A was also used. For the purpose of local temperature measurement of the test plates, seven calibrated thermocouples were put up on the test plates at suitable location. Out of these, four were centrally tapped on the plate and three were put up at fin corners. In case of V-plate fins, one thermocouple was placed below the V corner and another in the V corner. A separate thermocouple was used to measure the ambient temperature in the enclosure. A calibrated digital temperature indicator was used to measure the thermocouple output. Heat inputs of 50, 75, 100, 150, 250, 300, 325 and 400 watt were used. The assembled set up was hung in vertical position; in a box type enclosure under ensured good natural convection conditions. All the readings were recorded under steady state conditions.

**IV. Experimental procedure**

Following steps are followed for experimental work

i) Switch on the Heater input.

ii) Using thestat increase the supplied air heater input.

iii) Vertical Base plate is our heating source which must be heated till 400 0C.

iv) Start taking readings once the plate temperature drops down from 400 0C to ambient air temperature.

The reading was observed after every 15 – 20 minutes for better results. Heat input was measured as product of Voltage and current. Base plate temperature were recorded which is noted as Ts. Ambient air temperature is recorded as Ta.

Initially the readings on plain vertical plate were observed then Vertical plate with S fin and V fin were tested. This is to validate and compare the performance of vertical plate with vertical plate with fins. The temperature readings Ti (Initial temperature), T1, T2 to T4 (temperatures at different location in test section) were recorded with the help of Digital Temperature Indicator present with the apparatus. T5, T6 to T7 were recorded for fin base temperature at different locations.

**V. Results and discussion for S fin array**

<table>
<thead>
<tr>
<th>Plate temp °C</th>
<th>Ts = 360</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length L = 250 mm</td>
<td></td>
</tr>
<tr>
<td>$t_i = (360+28.5)/2 = 194.25$ °C</td>
<td></td>
</tr>
</tbody>
</table>

The thermo physical properties of air at 194.25 °C are,

- Density of air $(\rho_a) = 0.7459$ kg/m$^3$
- Thermal conductivity of air $(k) = 0.03779$ W/m K
- Kinematic Viscosity of Air $(\mu) = 3.455 \times 10^{-5}$ m$^2$/s
- Prandtl No= 0.69

$\beta = 1/T = 1/(273+360) = 0.00214$
\[
\text{Gr} = \frac{\rho \beta \Delta T L^3}{\mu^2} = (0.25)^3 \times (0.00214) \times 9.81 \times (360 - 28.5) / (3.455 \times 10^{-5})^2
\]

\[
= 91.09 \times 10^6
\]

\[
\text{Gr} \times \text{Pr} = 91.09 \times 10^6 \times 0.69
\]

\[
= 62.85 \times 10^6 \text{ which is the case for Laminar Flow}
\]

For Laminar Flow,

\[
\text{Nu} = 0.59 \times (\text{Gr} \times \text{Pr})^{1/4}
\]

\[
\text{Nu} = 52.53
\]

Since,\( \text{Nu} = \frac{h L}{k} \)

\[
h = \frac{0.03779 \times 52.53}{(0.25)}
\]

\[
h = 7.94 \text{ W/m}^2 \text{ K}
\]

Table 1. Observation Table Vertical heated plate with S Fin array

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Mean film temp. Tf oC</th>
<th>Grashloff Number (Gr)</th>
<th>Prandtl Number (Pr)</th>
<th>Nusselt Number (Nu)</th>
<th>Heat transfer Coeff. (h) W/m² K</th>
</tr>
</thead>
<tbody>
<tr>
<td>360</td>
<td>194.25</td>
<td>91.09 \times 10^6</td>
<td>0.69</td>
<td>52.53</td>
<td>7.94</td>
</tr>
<tr>
<td>311</td>
<td>169.25</td>
<td>11.09 \times 10^6</td>
<td>0.7014</td>
<td>93.92</td>
<td>13.19</td>
</tr>
<tr>
<td>205</td>
<td>116.25</td>
<td>10.98 \times 10^7</td>
<td>0.7073</td>
<td>55.39</td>
<td>7.16</td>
</tr>
<tr>
<td>165</td>
<td>96.25</td>
<td>10.73 \times 10^7</td>
<td>0.711</td>
<td>55.14</td>
<td>6.82</td>
</tr>
<tr>
<td>110</td>
<td>68.75</td>
<td>92.77 \times 10^7</td>
<td>0.71</td>
<td>53.15</td>
<td>6.12</td>
</tr>
</tbody>
</table>

Similarly the readings are taken and calculations are done for short length V fin array and are listed in table below.

Table 2. Observation Table For Vertical heated plate with short length V fin array

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Mean film temp. Tf oC</th>
<th>Grashloff Number (Gr)</th>
<th>Prandtl Number (Pr)</th>
<th>Nusselt Number (Nu)</th>
<th>Heat transfer Coeff. (h) W/m² K</th>
</tr>
</thead>
<tbody>
<tr>
<td>352</td>
<td>190</td>
<td>10.33 \times 10^7</td>
<td>0.6992</td>
<td>54.39</td>
<td>7.95</td>
</tr>
<tr>
<td>301</td>
<td>164.25</td>
<td>11.09 \times 10^7</td>
<td>0.7014</td>
<td>90.92</td>
<td>14.45</td>
</tr>
<tr>
<td>195</td>
<td>111.25</td>
<td>10.31 \times 10^7</td>
<td>0.7073</td>
<td>54.59</td>
<td>6.75</td>
</tr>
<tr>
<td>130</td>
<td>78.5</td>
<td>91.09 \times 10^7</td>
<td>0.711</td>
<td>52.53</td>
<td>7.94</td>
</tr>
<tr>
<td>92</td>
<td>66.75</td>
<td>10.73 \times 10^7</td>
<td>0.7</td>
<td>55.39</td>
<td>7.16</td>
</tr>
</tbody>
</table>

These are the tables of reading for the cases of Vertical Heated plate with S fin array and Vertical heated plate with Short length V fin array. For one case minimum five to six set of readings has been taken, from those all above are approximately best readings has been chosen, and become a base for further calculations. Using these readings for calculating fin Effectiveness all the three cases are taken into account for comparison.

VI: Observations, results and discussion for effectiveness of S fin array:

To Calculate Effectiveness of S fin:

\[ Q \text{ fin} = (P h k Acs)^{1/2} \times \text{Temperature difference} \]

Perimeter \( P = (2b + 2y) \)

\[ = (2 \times 0.2 + 2 \times 0.03) \]

\[ = 0.46 \text{ m for one Fin} \]

As we total 8 fins Total \( Q \text{ fin} = 0.46 \times 8 = 3.68 \text{ m} \)

\[ Acs = b \times y = 0.2 \times 0.03 \]

\[ = 6 \times 10^{-3} \text{ m}^2 \]

\[ Q \text{ fin} = (3.68 \times 7.94 \times 225 \times 6 \times 10^{-3} \times 380) \times (0.5) \times 380 \]

\[ = 2386 \]

\[ Q \text{ without Fin} = 9.6 \times 10^{-6} \times (250 \times 3) \times (360-28.5) \]

\[ = 434 \text{ W} \]

Effectiveness fin = \[ \frac{Q \text{ fin}}{Q \text{ without fin}} = 6.04 \]
Table 3. Effectiveness comparison for short length V fin and S fin array

<table>
<thead>
<tr>
<th>Temperature Vertical Plate 0 C</th>
<th>h W/mm² K</th>
<th>Q without fin (W)</th>
<th>Q for S fin</th>
<th>ε fin S fin</th>
<th>Q for V fin</th>
<th>ε fin V fin</th>
</tr>
</thead>
<tbody>
<tr>
<td>360</td>
<td>9.6 x 10^-6</td>
<td>434</td>
<td>2622</td>
<td>6.04</td>
<td>5282</td>
<td>12.17</td>
</tr>
<tr>
<td>311</td>
<td>8.4 x 10^-6</td>
<td>340</td>
<td>2286.8</td>
<td>6.72</td>
<td>4635</td>
<td>13.63</td>
</tr>
<tr>
<td>205</td>
<td>7.1 x 10^-6</td>
<td>241</td>
<td>2001.47</td>
<td>8.3</td>
<td>4056</td>
<td>16.8</td>
</tr>
<tr>
<td>165</td>
<td>5.85 x 10^-6</td>
<td>180</td>
<td>1719.72</td>
<td>9.55</td>
<td>3485</td>
<td>19.3</td>
</tr>
<tr>
<td>110</td>
<td>5.5 x 10^-6</td>
<td>145</td>
<td>1531.5</td>
<td>10.56</td>
<td>3104</td>
<td>21.4</td>
</tr>
</tbody>
</table>

The results are given here to understand the variations in average heat transfer coefficient (ha) for different setups and comparison of the same designs for fin effectiveness for better results. The various equations used for calculating the Parameters under study are given below.

\[
ha = \frac{q}{As (T_s - T_a)} \tag{1}
\]

\[
As = \text{Area of base plate} + \text{Area of V-Type Partition Plate.} \tag{2}
\]

\[
Nu = \frac{ha L}{K} \tag{2}
\]

\[
Pr = \frac{C_p \mu}{K} \tag{3}
\]

\[
Gr = \frac{\rho g \beta (T_s - T_{\infty}) L^3}{\mu^2} \tag{4}
\]

The air properties at mean film temperature were used. For the purpose of comparison, the Test Plate area including area of the partition plates (if any) was kept same in all the cases. The variations of the average heat transfer coefficient (ha) with temperature difference (Δt) for vertical plate with S fin, vertical plate with Short length V fins are shown in the Fig no.5.

Fig. 5 Variation of (ha) Vs (Δt)0 C for S fin and short length V fin array and short length V fin array

Fig. 5 Shows the Variation in Average Heat transfer coefficient, the increase in the average heat transfer coefficient (ha) is steep in the initial stage and tapers down later. From the graph average heat transfer coefficient for vertical heated plate with short length V fin is greater than S-fin array because of no flow obstruction to flow of the fluid. Fig. 6 shows variation in effectiveness of S fin and short length V fin. Effectiveness for Short length V fin is better as compared to S fin base.

Fig. 6 Variation of (ε fin) Vs (Δt) 0 C for S fin and short length V fin array

Fig. 7 Ansys graph variation of (ha) Vs (Δt)^0 C for different fin arrays
The above discussion on experimental work indicates that the highest heat transfer coefficient for short length V fin is better. Hence the models for the same Vertical Plate with three different orientations are designed and are Analyzed using Ansys 15.0. The graph is plotted for heat transfer coefficient in W/mm²K versus various temperatures in 0 C. From the graph it is clear that the average heat transfer coefficient is maximum, for short length V fin. The value of the heat transfer coefficient goes on increasing, reaches a maximum value at 10 W/mm²K and slowly decreases.

VII Conclusion

In this investigation work a totally new heat transfer technique is found out to increase the rate of natural convection heat transfer on vertical heated plate. For the same surface areas the Short length V-type partition plates gave better heat transfer performance than S fin array. Better fin effectiveness for short length V fin array is observed as compared to S fin array. Ansys 15.0 workbench and experimental setup showed the similar trend. Ansys computational results show 20% more heat transfer coefficient than experimental results. During experimental reading and evaluations more heat loss may take place from bottom, top and end corners of fins and due to this heat loss the value of experimental heat transfer coefficient is less than computational heat transfer coefficient. It is anticipated that a low pressure suction region is created in the nose region on the downstream side of each short length V-fin which eventually admits the low temperature ambient fluid from surrounding. This immensely helps to allow the inflow of the low temperature fluid into the separation region and increases the heat transfer rate.

VIII References