Experimental investigation of natural convection heat transfer enhancement from rectangular fin arrays with combination of V-notch and perforations

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Abstract- *Experimental investigation of the combination of V-notch and perforated horizontal rectangular fin array under natural convection was conducted. Four cases of fin array have been employed. One case without notch (un-notched) and three cases with combination of V-notch and perforations for different percentage of area removal from fin were used. L/H and S/H ratios are kept constant as 4.44 and 0.222 respectively. The base plate has been heated with different electrical heat input such as 30W, 60W and 90W. The object of this experimentation is to determine optimum combination of V-notch and perforation and to enhance heat transfer under natural convection. The experimental results shows that due to the combination of notch and perforation, both surface area and turbulence increases this allows more fresh air comes in contact with fin and thus HTC increases greatly. Perforation helps to increase turbulence as well as heat dissipation rate. Among all fin arrays, (20% V notched + 10% perforated) fin array shows maximum HTC 8.6157, 9.1913 and 9.59169 W/m²k at 30W, 60W and 90W respectively.*

Key Words: Fin array, notches, perforations, natural convection and heat transfer coefficient

1. INTRODUCTION

Thermal energy present in any matter when comes in thermal contact with another matter having different thermal energy causes the occurrence of heat transfer. Temperature difference is the main cause of heat transfer. If there is no temperature difference, then heat transfer does not occur even if there is lot of thermal energy in two bodies. Heat transfer is energy in transit and it is also known as boundary phenomenon. Fins are the surfaces that lengthen from a heated object to augment the rate of heat transfer by the phenomenon of convection. The amount of heat transfer of an object is depending on the amount of conduction, convection or radiation of the object. By raising the temperature gradient between the fin body and the surrounding, heat transfer can be increased and this also achieves increase in convection heat transfer coefficient. By adding fin to a heated object surface area increases and this becomes cost-effective.

The following are the area where the rectangular fin are used widely and they are,

- Motor, transformers, microcontroller data analogue system and CPU circuit boards.
- Around the scooter and motor cycle engine cylinders, rectangular or triangular profile fins are commonly employed.
- Refrigerating systems of evaporators and condensers.
- Car radiator and cooling of fuel heaters usually has rectangular fins.

Notch concept in fin array comes for lengthwise short fin array. In lengthwise short fin array single chimney flow pattern is present. Bottom central portion of fin flat becomes less effective due to the presence of already heated air comes in its contact. In this type of fin array the air enters from both sides and gets heated as it moves inwards. Temperature of the air gets increases and decrease in density of air rise upwards. Hence, only less portion of air comes in contact with the central bottom portion of the fin channel. Due to this stagnation zone occurs near the central bottom portion of the fin channel as shown in figure. In order to overcome this complexity some portion of fin is removed near the stagnation zone (notch), to increase the HTC.

2. EXPERIMENTAL SETUP

Heat transfer equipment is as shown in below figure1. This heat transfer equipment is used to conduct the experiment in order to obtain natural convective heat transfer characteristics of different horizontal rectangular fin arrays. In this type of fin array the air enters from both sides and gets heated as it moves inwards. Temperature of the air gets increases and decrease in density of air rise upwards. Hence, only less portion of air comes in contact with the central bottom portion of the fin channel. Due to this stagnation zone occurs near the central bottom portion of the fin channel as shown in figure. In order to overcome this complexity some portion of fin is removed near the stagnation zone (notch), to increase the HTC.

Fig -1: Experimental setup

The mica heater of dimension 200*125*2 mm is used as heater and its capacity is 150W. A 2 mm thickness copper plate of dimensions similar to base plate is placed between the heater and base plate in order to supply constant heat to the fins base. Total 16 thermocouples are used to determine temperature at various points of test section, in which 10 are used to measure fin tip temperature, 3 are used to measure thermo stone block temperature to calculate heat losses, 2 are used to measure base plate temperature and one thermocouple is used to measure atmospheric temperature. K-type thermocouples are used to measure the temperature of fins, base plate and insulating block. The maximum temperature range of the thermocouple is 380 to 400°C. Display panel consists of main switch at the left top corner, fuse, temperature indicator and heater controlling knob. Display panel also consist of digital voltmeter and ammeter indicator to measure the voltage and current. Digital temperature indicator can show reading up to 199.9°C. Aluminum alloys of 1100 series are commercially available pure Aluminum of different thickness and these are purchased from the local market easily. A 6 mm deep rectangular pocket has milled on the top surface of a thermo stone block to place the fin array and heater. Thermo stone block of dimensions are 300 mm length* 250mm width* 150 mm thickness. It's an excellent thermal insulator with a low thermal conductivity range from 0.13 to 0.15 W/mk. Thermo stone block of dimensions are 300 mm length* 250mm width* 150 mm thickness. It's an excellent thermal insulator with a low thermal conductivity range from 0.13 to 0.15 W/mk. Base plate is made out of same material as fins. Al 1100 T6 of 5 mm thickness is used as base plate material. This plate is cut; machined and 10 slots are made on this to mount the fins with an equal space of 10 mm.

2.1 Fin arrays used for experimentation

The following fin arrays were used for experimental study as follows,

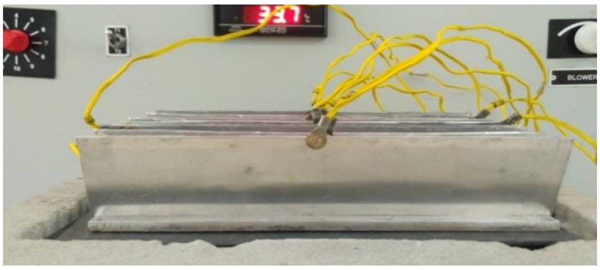

Fig -2: Un-notched (solid) fin array

Fig -3: Combination of V-notched (10%) and perforation (10%) fin array

Fig -4: Combination of V-notched (20%) and perforation (10%) fin array

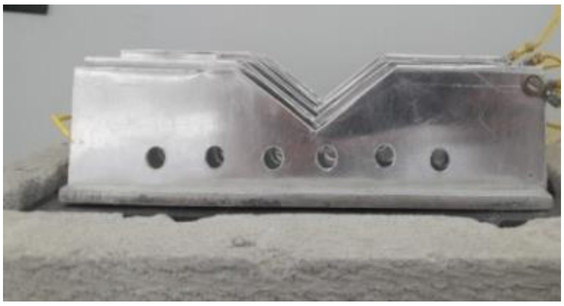

Fig -5: Combination of V-notched (10%) and perforation (20%) fin array

2.2 Experimental Procedure

The following procedure is adopted for carry out the experimental study as follows,

1. Fin array is assembled and placed in the position, with thermocouples and heaters connected as per requirement.
2. Turn on the experimental setup
3. Check the entire digital meter and thermocouples working and its electric connections.
4. Using rheostat regulating current and voltage turn on heater for a particular value.
5. Make sure current and voltage are constant over the period of experiment.
6. Heat the base plate to stabilized temperature.
7. Keep checking the temperature of fins and base plate with the help of thermocouple reading.
8. When the temperature attains a steady state that is temperature reading of fins repeat twice for a particular value make sure it is constant and note down that value.
9. Note down all the required temperature of fins and base plate.

Repeat the above procedure for different value of heat input say 30W, 60W and 90W.

3. CALCULATION PROCEDURE

The formulae that are used for calculating heat transfer coefficient are taken from, "Heat and Mass Transfer Data Hand book" by C P Kothandaraman and S Subramanyan [9].

3.1 To Find Average Temperature of Fins (T_f):

$$T_f = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8 + T_9 + T_{10}}{10}$$

Where, T_1, T_2, T_3, T_4, T_5, T_6, T_7, T_8, T_9 and T_{10} are the temperatures of tip of fins in ° C.

3.2 To Find Temperature of Whole Body (T_{body}):

$$(T_{body}) = \frac{T_f + T_b}{2}$$

Where, T_b is the temperature of base plate in °C

3.3 To Find Temperature Difference between Body (T_{body}) & surrounding temperature (T_{surr}) :

$$\Delta T = (T_{body} - T_{surr}) \text{ in °C}$$

3.4 To Find Mean Film Temperature (T_m):

$$T_m = \frac{T_{body} + T_{surr}}{2} \text{ in °C}$$

From this temperature find out following properties of fluid

υ = kinematic viscosity of the fluid, m^2/s
Pr = Prandtl number
k = Thermal conductivity of fluid, W/m-K

3.5 To Find Grashof Number (Gr):

$$Gr = \frac{g\,\beta\,\delta T\,L_c^3}{\vartheta^2}$$

Where,
L_c = height of the fin, m

3.6 To Find Coefficient of Volume Expansion (β):

$$\beta = \frac{1}{T_m + 273} \ K^{-1}$$

3.7 To Find Rayleigh Number (Ra):

$$Ra = Gr*Pr$$

If $10^4 <$ Gr*Pr$< 10^9$, then, Nu = 0.59 $(Gr * Pr)^{1/4}$
If $10^9 <$ Gr*Pr$< 10^{12}$, then, Nu = 0.59 $(Gr * Pr)^{1/3}$

3.8 To Find Heat Transfer Coefficient (h):

$$Nu = \frac{hL_c}{K}$$

Where, h is heat transfer coefficient, W/m^2K
Using these formulae h is calculated.

4. RESULTS AND DESCUSSION

Using the calculation procedure as shown above heat transfer coefficient for different fin arrays for different heat input under natural convection is tabulated as shown in table 1.

4.1 Heat Transfer Coefficient for Notched Fin Array

From this table it is clear that (20% V-notch + 10% Perforation) fin array shows maximum HTC 8.6157, 9.1913 and 9.5916 W/m^{2}k at 30W, 60W and 90W respectively.

Table -1: Heat Transfer Coefficient for combination of V-notch and perforation

FIN ARRAY/ HEAT INPUT	30W	60W	90W
Un-notched	8.3913	9.0861	9.3841
10% V-notch + 10% perforated	8.5182	9.1345	9.4642
20% V-notch + 10% perforated	8.6157	9.1913	9.5916
10% V-notch + 20% perforated	8.5272	9.1909	9.4959

4.2 Effect of % area of combination of V-notch and perforation

Combination of V-notch and circular perforation is used in a horizontal rectangular fin array under natural convection. In this graph (20% V-notch + 10% Perforation) fin array shows maximum heat transfer coefficient 9.59169 W/m^{2}k at 90W.

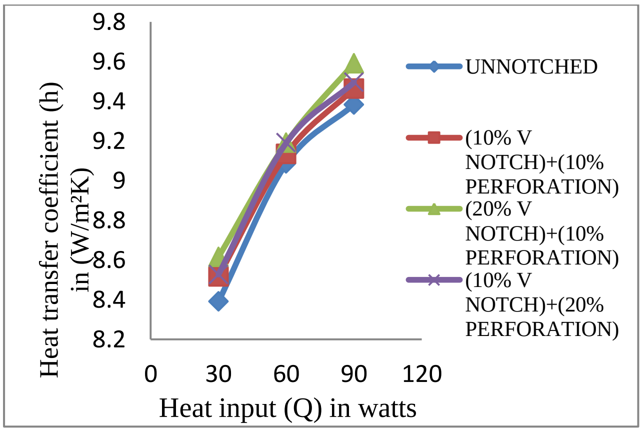

Chart -1: Heat transfer coefficient vs. Heat input for different % area of combination of V-notch and perforation

Due to the combination of notch and perforation, both surface area and turbulence increases this allows fresher air comes in contact with fin and thus HTC increases greatly. Perforation helps to increase turbulence as well as heat dissipation rate. Due to increase in % area of, notch and perforation, and heat flux value of air density decreases hence air moves against the gravity and thus increase in HTC. However (10% V-notch + 10% Perforation) and (10% V-notch + 20% Perforation) notched fin arrays also shows increase in HTC in comparison with un-notched fin array.

4.3 Nusselt Number Variations (Nu)

Among these fin arrays, (20% V notched + 10% perforated) fin array shows maximum Nusselt number 13.541, 14.086 and 14.527 at 30W, 60W and 90W respectively. As the Nusselt number increase heat transfer coefficient also increases

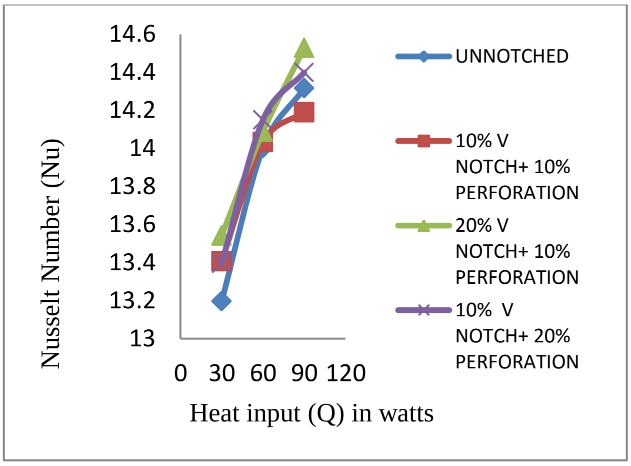

Chart -2: Nusselt number vs. Heat input for different % area of (V+P) notched fin arrays

4.4 Temperature Difference Variations (ΔT)

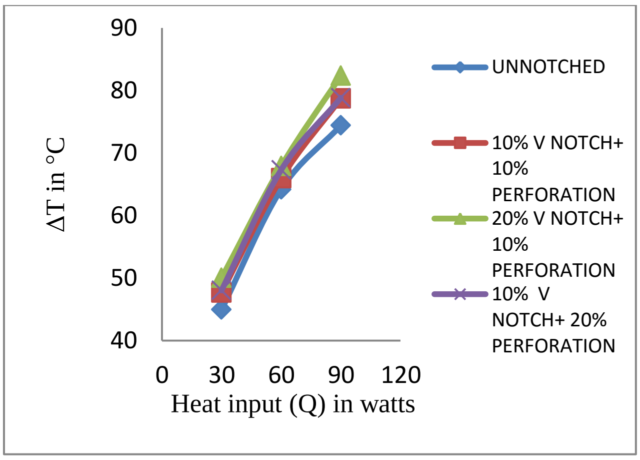

Chart -3: Temperature difference vs. Heat input for different % area of (V+P) notched fin arrays

5. CONCLUSION

This experimental investigation shows the heat transfer performance of various, V-notched and combination of V-notch and perforated fin arrays under natural convection. Experimentation shows how heat transfer coefficient (h) varies with the increase in heat input for, different % area of V-notched fin array and combination of V-notch and perforated fin arrays when compared with un-notched fin array.

- Among all fin arrays, (20% V notched + 10% perforated) fin array shows maximum HTC 8.6157, 9.1913 and 9.59169 W/m^{2}k at 30W, 60W and 90W respectively.
- Due to the combination of notch and perforation, both surface area and turbulence increases this allows more fresh air comes in contact with fin and thus HTC increases greatly. Perforation helps to increase turbulence as well as heat dissipation rate.
- Due to increase in % area of, notch and perforation, and heat flux value of air density decreases hence air moves against the gravity and thus increase in HTC.
- 20% V notched + 10% perforated fin array shows maximum temperature difference (ΔT) 49.995, 67.89 and 82.375 at 30W, 60W and 90W respectively. As the temperature difference (ΔT) increases heat transfer coefficient also increases.
- 20% V notched + 10% perforated fin array shows maximum Nusselt number 13.541, 14.086 and 14.527 at 30W, 60W and 90W respectively. As the Nusselt number increase heat transfer coefficient also increases.

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SYMBOLS AND ABBREVIATIONS

Q	Heat transfer in W
h	Heat transfer coefficient, W/m^2K
T_s	Fin surface temperature in °C or K
T_a	Ambient temperature °C or K
ΔT	Temperature difference
T_f	Average Temperature of Fins °C or K
T_{body}	Temperature of Whole Body °C or K
T_m	Mean Film Temperature °C or K
k	Thermal conductivity of fluid, W/m-K
Gr	Grashof Number
L_c	Height of the fin, m
Ra	Rayleigh Number
υ	kinematic viscosity of the fluid, m^2/s
β	Coefficient of Volume Expansion
HTC	Heat transfer coefficient
V + P	V-notched and perforated

BIOGRAPHIES

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