Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-9, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Experimental Investigation on Tapered Cylindrical with and without Perforated Pin Fins with Inline and Staggered Array Using Natural and Forced Convection

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Abstract- *In the present study, Experimental Investigation on Tapered Cylindrical with and without Perforated Pin Fins with Inline and Staggered Fins Array using Natural and Forced Convection, for a constant heat flux of 85 Watts over all the arrangements at varying air velocity from 1m/s to 5m/s. The taper pin fin is made out of Aluminium 6061 having dimensions of base diameter 20mm, top diameter 10mm and length 80mm. The number of pin fin used in inline and staggered arrangement are 9 and 8 respectively. Constant clearance ratio (C/H) and interfin distance ratio (S_y/D) 1.25 were used. The heat transfer takes place through a rectangular base plate with fins held in a rectangular tunnel. The Nusselt number and Reynolds number were considered as performance parameters. Correlated standard equations are used for finding the values of heat transfer coefficient, Reynolds number, Nusselt number and Effectiveness. By concluding all the result perforated taper cylindrical inline pin fins have higher heat transfer capability.*

Key words: *Pin fins, Taper cylindrical pin fin, clearance ratio(C/H), Interfin distance ratio (S_y/D), Nusselt number, Reynolds number, Heat transfer coefficient and effectiveness, etc.*

1. Introduction

Fins are surfaces that extend from the base surface to increase the rate of heat transfer to or from the environment through convection. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Thus, adding a fin to an object increases the surface area and is an economical solution to heat transfer problems. Pin fins have a height to diameter ratio in between 0.5 to 4 are short fins and if height to diameter ratio above 4 are long pin fins.[2][3][6][9]

Convective heat transfer is increased by increasing the surface area of the pin fin by providing a hole or perforation to enhance the air or fluid contacting surface area and also minimize the weight of the pin fin. And many studies are going on to increase more and more heat transfer by providing more number of perforation on the fin at different positions to give more surface area.[2][4]
Heat flow mainly depends on three factors,

- Area of the surface.
- Temperature difference.
- Convective heat transfer coefficient.[6][8][9]

Fins are most commonly used in heat exchanging devices such as radiators in cars, computer CPU heat sinks, heat exchangers in power plants, aerospace industry, electrical appliances, and fins are widely used in the trailing edges of gas turbine blades.[1][2][7]

2. Experimental set up

A square cross sectional wind tunnel duct is made up of mild steel sheet and the inner surface of tunnel is coated with fiber reinforced plastic or polymer for insulation to avoid heat loss from tunnel and to avoid rust of tunnel material. Dimensions of tunnel are length 600 mm, height150 mm, and breadth 150 mm. first parts are the inlet tube which is connected to air blower for forced convection experiment. The inlet tube is connected to cone shaped convex tube. The convex tube leads to square tunnel which is the experimental setup main part. The test rig consist of the main control unit having digital voltmeter and ammeter, digital temperature indicator with toggle switch to change the thermocouple readings, rheostat for controlling the heater power supply and another rheostat for blower control and a fuse is provided to ensure the electrical safety for the test rig. The experimental setup is as shown in the figure 1.

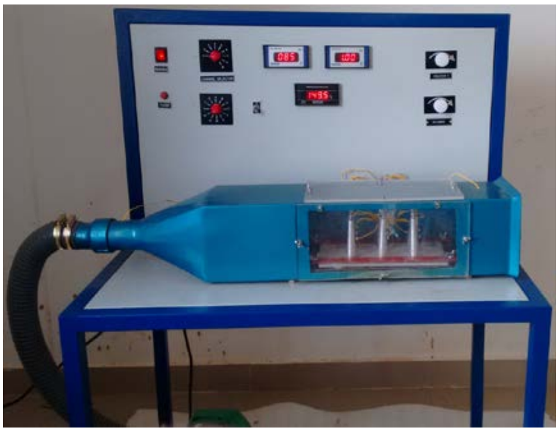

Figure 1. Experimental setup.

The blower used in this setup is of maximum air pressure of 400 mm of WC, air volume of 2.3m^3/min. Blower has a power of 355W, 230V alternative current of frequency 50Hz, 13000 RPM and 0.3 HP. Induction type mica space heaters is used in this setup, heater is placed between copper plate on top and below asbestos sheet and having capacity of 250W. 21 K-type thermocouple are used 18 of them use to determine temperatures of pin fins two thermocouples for each pin fins. Base plate, inlet and outlet air temperature is found by remaining three thermocouples. The aluminium base plate having taper cylindrical pin fins are place on the above the copper plate where the heater is placed beneath. The thermocouples are connected to the pin fins to measure exact temperature reading on the surface of the fin. The heater is providing constant heat supply and can be adjusted using rheostat controller. A digital anemometer vane probe has 4 Digit LCD display, air velocity will be measured in the range of 0.40 to 45m/s, resolution 0.1m/s calibrated to accuracy of ±2% +0.1m/s is used to measure the air velocity in forced convection.

2.1 Material of the Fin

The fins and base plate are made out of aluminium 6061 alloy with thermal conductivity values of 166 W/mK, 6061 is a hardened aluminium alloy, containing magnesium and silicon as major alloying elements. Originally called "Alloy 61S", it has good mechanical properties and exhibits good weld ability. It is most common alloys of aluminium for general-purpose use. 6061 has a density of 2.70 g/cm³, Young's Modulus is 10×106 psi (69 GPa). Annealed 6061 has maximum tensile strength no more than 18,000 psi (125 MPa), and maximum yield strength no more than 8,000 psi (55 MPa). The material has elongation of 25–30%.

3. Design and fabrication of pin fins

The design and fabrication of fins are processed after the selection of the material based on their mechanical and thermal property. The solid taper cylindrical fins and perforated tapered cylindrical fins are produced using lathe turning operations on the circular rod to a dimensions of base diameter 20mm, top diameter 10mm, length 80mm and for perforated fins the diameter of perforation is 6mm and the distance of perforation from the base is 25mm. The solid and perforated pin fin is as shown in figure 2 and figure 3 respectively. After the production of fins, the pin fins are arranged on inline and staggered arrays.

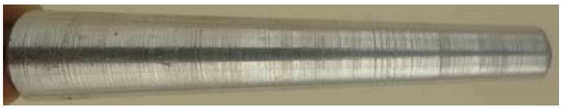

Figure 2. Solid taper pin fin.

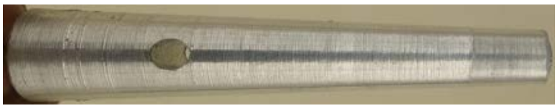

Figure 3. Perforated taper pin fin.

3.1 Inline arranged solid and perforated pin fins

Solid and perforated pin fins are arranged in inline arrangement with a horizontal spacing of 62.5mm and vertical spacing of 31.25mm from one pin fins center to another pin fin center respectively. Nine solid fins are placed above the base plate having a thickness of 6mm. The solid and perforated pin fins with inline arrangement is shown in figure 4 and figure 5 respectively.

Figure 4. Solid pin fins with inline arrangement.

Figure 5. Perforated pin fins with inline arrangement.

3.2 Staggered arranged solid and perforated pin fins

Solid pin fins are arranged in staggered arrangement pattern with a horizontal spacing of 62.5mm and middle line vertical spacing 41.67mm from one pin center to other pin center respectively. Eight solid pin fins are placed above the base plate having a thickness of 6mm. The solid and perforated pin fins with staggered arrangement is shown in figure 6 and figure 7 respectively.

Figure 6. Solid pin fins with staggered arrangement.

Figure 7. Perforated pin fins with staggered arrangement.

4. Mathematical relationship

Governing Equation:

The convective heat transfer rate Q convection from electrically heated test surface is calculated by using [2], [4]

$$\mathbf{Q_{conv.} = Q_{elect} - Q_{cond} - Q_{rad}} \quad (1)$$

Where: Q indicates the heat transfer rate in which subscripts conv, elect, cond, and rad denotes convection, electrical, conduction and radiation, respectively. The electrical heat input is calculated from the electrical potential and current supplied to the surface.

$$\mathbf{Q_{elect} = I \times V} \quad (2)$$

Where: I is current flowing through the heater and V is voltage.

The total area is equal to the sum of the projected area and surface area contribution from the pin fins. These two areas can be related to each other by [4]

A_{Total} = (number of fins × surface area of fins) + Wetted area of plate

Wetted area of plate (A_w) = [Cross sectional area of plate – (number of fins × Cross sectional area of fins)]

$$\mathbf{A_{Total} = (n \times A_s) + A_w} \quad (3)$$

The heat transfer from the test section by convection can be expressed as

$$\mathbf{Q_{conv.} = h \times A_s \times \left[T_s - \left(\frac{T_{in}+T_{out}}{2}\right)\right]} \text{ W} \quad (4)$$

Hence, the average convective heat transfer coefficient have could be deduced via

$$\mathbf{h} = \frac{Q_{conv.}}{A_s \times \Delta T} \text{ W/m}^2\text{-K} \quad (5)$$

Reynolds number

$$Re = \frac{V_{mean} \times d_h}{\vartheta} \quad (6)$$

Hydraulic diameter

$$d_h = \frac{4V_f}{A_f} \text{ m} \quad (7)$$

The general equation for Nusselt number is as follow

$$Nu = \frac{h \times d_h}{k} \quad (8)$$

For forced convection,

$$N_u = C(R_e)^n \quad (9)$$

Effectiveness

The effectiveness of the heat transfer for a constant pumping power, it is useful to determine enhancement of a heat transfer. The enhancement efficiency is the ratio of heat transfer coefficient with Fins to without Fins.[9]

$$\varepsilon = \frac{h_a}{h_s} \quad (10)$$

$$\varepsilon = 51.09 \times R_e^{-0.358} \times (1 + C/H)^{0.1028} \times (S_y/D)^{0.0812} \quad (11)$$

5. Results and discussion

The various heat transfer associated parameters evaluated above are used to analyze the influence on heat transfer with pin fins. The obtained results for individual parametric influence on heat transfer are discussed in combined.

5.1. Effect of Reynolds number on Nusselt number

The comparative studies on variation of Nusselt number at fixed electrical input power of 85Watts at various Reynolds number for solid and perforated tapered cylindrical pin with inline and staggered layouts is graphically represented on figure 8. The graph concluded that when the velocity of air flow or Reynolds number increases the Nusselt number also increases for all the arrangement. But for perforated inline array Nusselt number is more compare to other, because of higher surface area and fins are evenly spaced over the base plate, hence perforated inline fins.

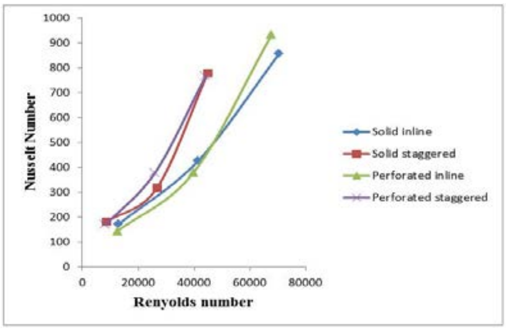

Figure 8. Comparison of Reynolds number v/s Nusselt number.

5.2. Effect of Heat transfer coefficient on Reynolds number

The comparative studies on variation of heat transfer coefficient at fixed electrical input power of 85Watts at various Reynolds number for solid and perforated tapered cylindrical pin with inline and staggered layouts is graphically represented on figure 9. When the velocity of air flow or Reynolds number increases the Heat transfer coefficient also increases for all the arrangement. But for perforated taper cylindrical inline array Heat transfer coefficient is more compare to other, because of higher surface area due to perforation and the inline arrangement gives easily heat will be transferred to the air through pin fins, hence perforated inline fins gives more heat transfer.

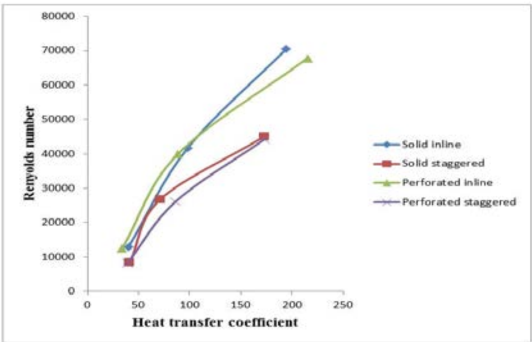

Figure 9. Comparison of Heat transfer coefficient v/s Reynolds number.

5.3. Effect of Heat transfer coefficient on Nusselt number

From the figure 10 Comparison of Heat transfer coefficient v/s Nusselt number for solid inline, solid staggered perforated inline and perforated staggered fins for forced convection. When the velocity of air flow or Reynolds number increases both Nusselt number and Heat transfer coefficient also increases for all the arrangement. But for perforated inline Heat transfer coefficient is more compare to other, because of higher surface area due to perforation and the inline arrangement gives easily heat will be transferred to the air through pin fins, hence perforated inline fins gives more heat transfer.

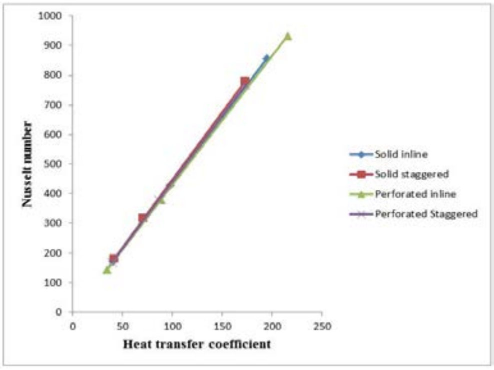

Figure 10. Comparison of Heat transfer coefficient v/s Nusselt number.

5.4. Effect of Reynolds number on Effectiveness

Comparison of Reynolds number v/s Effectiveness for solid inline, solid staggered perforated inline and perforated staggered pin fins shown in figure 11. The effectiveness is greater than unity for all investigation condition. It means that the use of pin fins leads to an enhancement of heat transfer. It is apparent that as Reynolds number increases the effectiveness decreases for all type of arrangement. Initially the effectiveness will be more on perforated inline fins because of more surface area and evenly spaced.

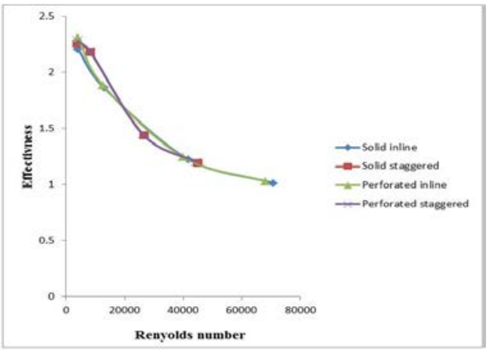

Figure 11. Comparison of Reynolds number v/s Effectiveness.

5.5. Effect of Natural convection

The graphical representation for comparison of Hear transfer coefficient on natural convection shown in figure 12. For solid inline pin fins array h is 7.252 W/m^2K, for solid staggered pin fins array h is 7.406 W/m^2K, for perforated inline pin fins array h is 7.589 W/m^2K, and for perforated staggered pin fins array h is 7.252 W/m^2K. From this Heat transfer is more even in natural convection for perforated inline arrangement.

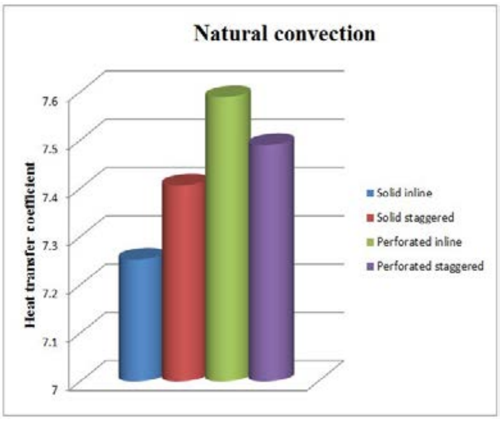

Figure 12. Effect of natural convection.

6. Conclusion

In this study, the heat transfer characteristics of solid and perforated taper cylindrical pin fin with inline and staggered arrangement. The effects of flow and geometry on heat transfer and effectiveness were obtained. The conclusions are summarized as,

- Design and fabrication of inline and staggered arrangement of tapered cylindrical with and without perforated pin fins arrays using Aluminium 6061 alloy.
- As the Reynolds Number increases Nusselt number also increasses.
- Varying Reynolds Number in terms of Heat Transfer Performance. The perforated taper cylindrical inline pin fin gives higher heat transfer rate.
- Effectiveness increased with decreasing Reynolds number. Therefore, relatively lower Reynolds number lead to an improvement in the heat transfer performance.
- In natural convection heat transfer will be more on perforated pin fins in inline arrangement.

8. Acknowledgement

I wish to express my sincere and heart full thanks to our guide Mr. Ganesha T, Assistant Professor, Department of Thermal Power Engineering, VTU PG Studies, Mysuru for his valuable guidance, patience, inspiration and continuous supervision during the entire course of this project work and successful completion of the same on time.

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