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Experimental and Numerical Analysis of Cylindrical Pin Fins having Square Thread with and without Perforations by Natural and Forced Convection

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Abstract

Convective heat transfer is more when fins are used suitably, since the contact surface area for heat transfer increases, recently perforated fin design is considered for the sake of improving the heat transfer and many investigations have been done recently and types fins are used and different shapes of perforations are tried to know the effect of heat transfer and improve it for better design for greater rate of heat transfer. In this paper experimentally the rate of heat transfer and flow characteristics are studied. The heat transfer rate of Square Threaded pin fins with and without perforations in inline and staggered pattern are investigated experimentally. Trials were conducted for varying Reynolds number and results were found out respectively for each pin fins. The heat transfer rate of Square Threaded pin fin with perforations shows higher amongst each other.

Key Words: *Square thread pin fin, perforations, staggered arrangement, inline arrangement, heat transfer coefficient, Nusselt number, Reynolds number*

1. INTRODUCTION

1.1 Pin fins

Heating of a component under different working applications is a big problem for today's engineering applications therefore fast heat transfer from heated surfaces and reducing cost and material weight has turned into a major challenge for design of heat exchanger component. Improvement of super heat exchanger requires manufacture of efficient design techniques to exchange large amount of heat between body and ambient fluid.

Pin fins are broadly utilized as a part of heat exchanging body which results in enhances the heat exchange between the surface of the body and ambient fluid. Different types of heat exchanger pin fins, varying from relatively simple shapes, for examples, dropped shape, square, rectangular, barrel shaped, annular, or pin fins of various geometries has been utilized. One of the commonly utilized fins is the pin fin; these fins may protrude from either a cylindrical or rectangular base, a pin fin is a circular or other shaped body fixed perpendicular to a wall with the transfer fluid passing in cross flow over the body

1.2 Significance of heat dissipation

The energy losses in the power transformers are directly proportional to the load. These losses are converted into heat which leads to raises in the temperature that can high levels which causes dropped in the transformer efficiency which means durability and operational load reduces. For small transformer its own surface is sufficient by means of natural convection heat dissipation, For average and high transformers which requires more surface area method of cooling and generated heat should be removed effectively. To avoid above problems of power loss from the transformers pin fins are used in between radiators to get better efficiency naturally fins are inserted to plain tubes which causes more external surface area and more heat transfer efficiency, and smaller geometries. Several small and big companies are manufacturing such kinds of tubes. One of the most present interesting methods to increase heat exchanger design is pin fin technology. Pin fins ate suitable for several applications including processes using gasses, liquids, oil, diesel, high pressure water and steam. Pin fins can be produced using several different materials such as brass, aluminum, copper, stainless steel, copper/nickel, aluminum/brass, carbon steel. Pin fin technology is the most efficient technology used in recent years in heat sinks design for cooling electronic devices. Due to high thermal conductivity of copper, copper heat sinks are more and more favorable.

1.3 Techniques of heat dissipation

Heat transfer by convection is due to macroscopic motion and molecular motion of the fluid particles. There are two types of convection

- **Natural Convection**

  Natural convection is a heat transfer occurs when fluid motion is by buoyancy from difference in density due to temperature difference in the fluid.

- **Forced Convection**

  Forced convection is heat transfer occurs when fluid motion is induced artificially using a pump or fan to force fluid over the surface.

2. DESIGN AND FABRICATION OF PIN FINS

In this experiment Square Threaded pin fins with and without perforations in inline and staggered patterns are used which shown below

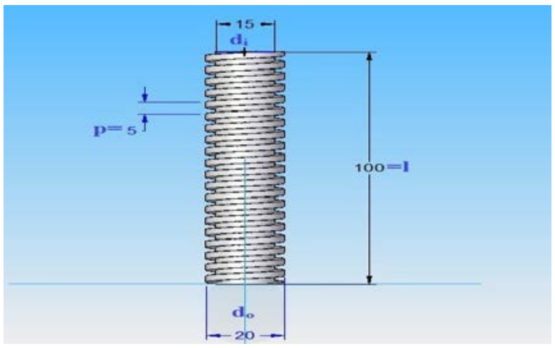

Fig 2.1 Square thread pin fin

Fig 2.1 shows the Design of Square thread which has outer diameter d_o is 20mm, inner diameter d_i is 15mm, pitch p is 5mm and total thread height l is 100mm.

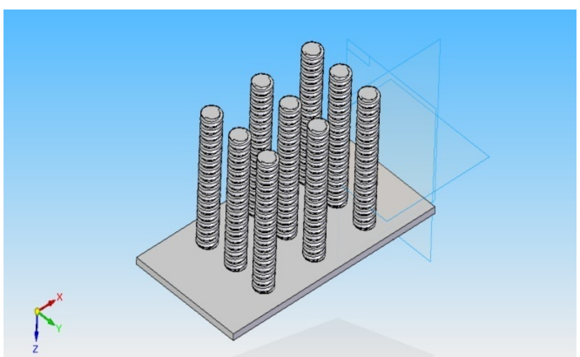

Fig 2.2 Square threaded pin fins in inline pattern

Square thread pin fins are arranged in inline pattern with a horizontal spacing 62.5mm and vertical spacing 36.25mm from one pin fin center to the other pin fin center respectively. Nine V-thread fins are used and diameter of each fin is 20mm.

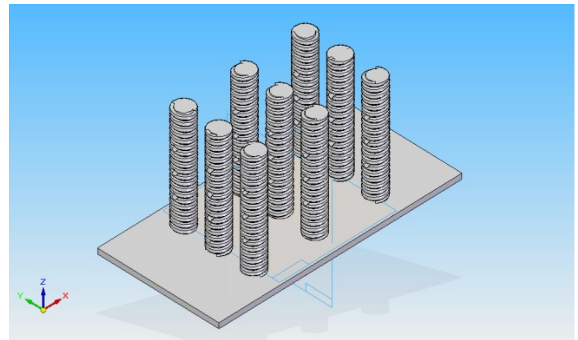

Fig 2.3 Square threaded pin fins with perforations in inline pattern

Square thread pin fin are arranged in inline arrangement with 3 perforations are done with perforation diameter 5mm on all nine pin fins at a distance 30mm 50mm 70mm from upper surface of base plate. Pin fins horizontal spacing 62.5mm and vertical spacing 36.25mm from one pin fin center to the other pin fin center respectively. Nine V-thread fins are used and diameter of each fin is 20mm.

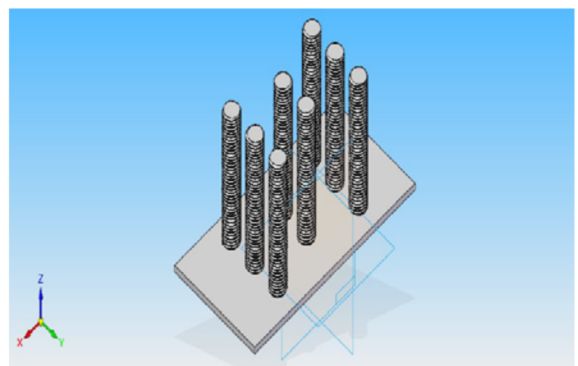

Fig 2.4 Square threaded pin fins in staggered pattern

Square thread pin fins are arranged in staggered arrangement with a horizontal spacing 62.5mm and vertical spacing 36.25mm from one pin fin center to the other pin fin center respectively. Nine V-thread fins are used and diameter of each fin is 20mm.

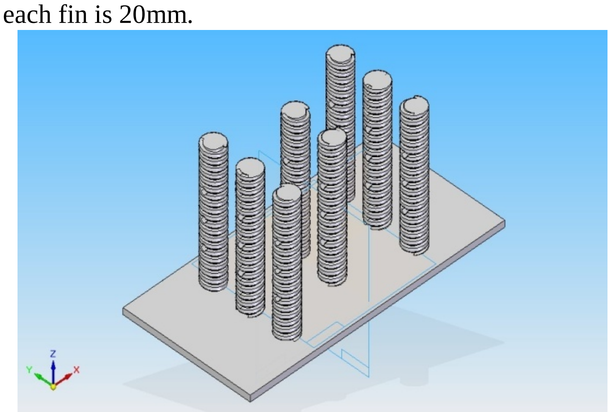

Fig 2.5 Square threaded pin fins with perforations in staggered pattern

Square thread pin fin are arranged in staggered arrangement with 3 perforations are done with perforation diameter 5mm on all eight pin fins at a distance 30mm 50mm 70mm from upper surface of base plate. Pin fins horizontal spacing 62.5mm and vertical spacing 125mm from one pin fin center to the other pin fin center respectively. Eight V-thread fins are used and diameter of each fin is 20mm.

3. EXPERIMENTAL SETUP

Fig. 3.1 Experimental Test Rig

Specifications of Heat Transfer Equipments

Specifications of various equipments used in Experimental Setup are as follows

1. Digital voltmeter – AC, single phase, 0-300V.
2. Digital ammeter – AC, single phase, 0-20A.
3. Digital temperature indicator – AC single phase, 0-200℃.
4. Electric heater – Mica heater 250W.
5. Thermocouple – K type length 0.9m.
6. Specimen – metal used Aluminum, bar fins.
   a. Base plate – 250mm × 125mm × 5mm (l×b×h).
   b. Fin size 20mm × 100mm (d×l).
   c. Fin position i) Inline ii) Staggered.
7. Air Blower
   a. Air pressure – 400mm of water column.
   b. Air volume – 2.3 m^3/min.
   c. Power – 355W, 230V, AC.
8. Duct-150mm× $150mm \times 150mm$ $(l \times b \times h)$
   a. Material used – Mild steel sheet.
   b. Insulation – FRP.

Threaded fins are attached to base plate with the help of screw thread and rivets. Test model is placed on mica heater which has same dimension as base plate of 125mm × 250mm. Glass wool material is placed in between heater and Air duct frame which acts as insulator.

Thermocouples are connected at bottom and top side of each pin fin, Base plate, Inlet and outlet air duct. One end of the air duct is connected to suction side of the blower and other end is open to the atmosphere. Base plate is heated by mica heater. At some period base plate temperature attain constant then measure the Temperature at bottom and top side of each pin fins, base plate, inlet and outlet of air repeat experiment with different test model for natural convection.

For forced convection Air is supplied by blower with constant velocity say 2m/s, 3m/s, 4m/s, 5m/s is regulated by knob. Base plate is heated by mica heater. At some period base plate temperature attain constant then measure the Temperature at bottom and top side of each pin fins, base plate, inlet and outlet of air in the air duct. Collecting the different readings from the control panel fallowing parameters to be calculated such as Reynolds number, Nusselt number, and Heat transfer coefficient. Repeat the experiment for different test model.

Mathematical Relationship

Various governing equations used in the experiment are as follows:

Hydraulic diameter of duct

$$A_t = \frac{\Pi}{4} \times \left(d_p - 0.9381 \times P\right)^2$$

At =Cross section area of thread pin fin, d_p =Pitch diameter of V-thread, P =Pitch distance

The total volume of fluid can flow inside the duct where the pin fins are placed.

$$V_f = BHL - N_f \times A_v \times h_f$$

V_f = Volume of fluid, B=Breadth of duct, H=Height of duct, L=Length of duct.

N_f= Number of fins, h_f=Height of fin

Air is supplied to duct from blower, the maximum contact surface between the air media and surface of the pin fins is the Wetted surface area A_f of V-thread pin fin is given

$$A_f = 2(B + H)L + N_f\left(L_p h_f - 2A_t\right)$$

A_f=Contactsurface area L_p=Perimeter length of pin fin

Hydraulic diameter of duct

$$D_h = \frac{4 \times V_f}{A_f}$$

Natural Convection

Grashof's number (G_r) is

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$$G_r = \frac{g \times \beta \times \Delta T \times D_h^3}{\nu^2}$$

Where, $\Delta T = T_s - T_\infty$ T_s=Surface temperature of pin fin, T_∞ =Ambient temperature.

ν=Kinematic viscosity

The Relationship of Nusselt number is

$$N_u = C \times (G_r P_r)^n$$

P_r=Prandtl number

Co-efficient of Heat transfer is

$$h = \frac{Nu \times k}{D_h}$$

Forced Convection

Array of fins inside the duct,

$$(S_t - D) < 2\sqrt{\left(\frac{St}{2}\right)^2 - S_l^2} - 2D$$

$$V_{max} = \frac{S_t}{S_t - D} \times U$$

$$Re = \frac{V_{max} D_h}{\vartheta}$$

$$Nu = C\,(Re)^n$$

$$h = \frac{Nu \times k}{D_h}$$

RESULTS AND DISCUSSION

Table 1

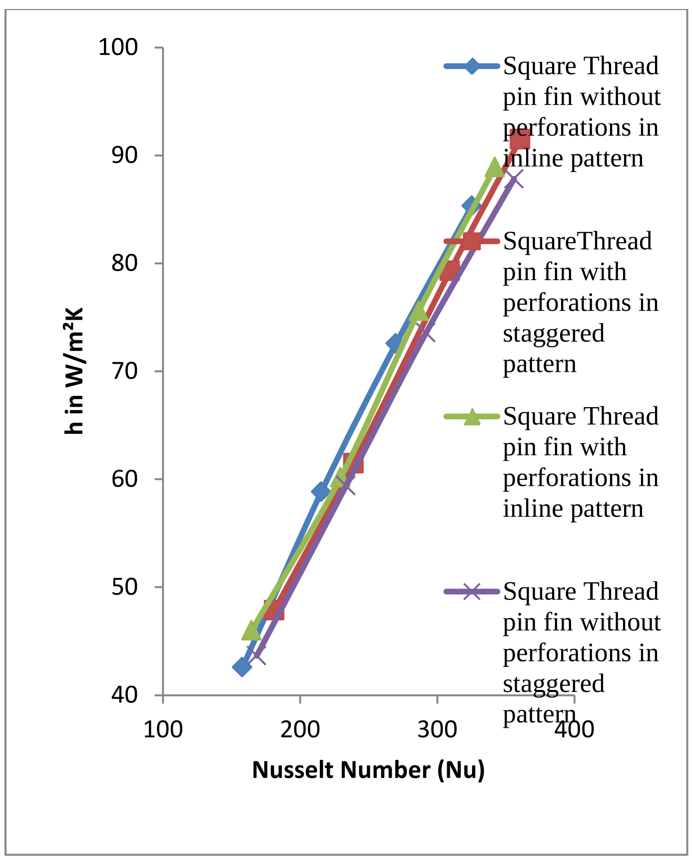
Calculations table of forced convection for Square Threaded pin fins in inline and staggered pattern

Type of pattern	U in m/s	Re	Nu	h in W/m²K
Square Thread pin fin in staggered arrangement	2	30394.4	168.368	43.652
	3	47522.3	233.457	59.385
	4	65204	291.8	73.567
	5	83643.4	355.97	87.829
Square Thread pin fin with perforations in staggered arrangement	2	31464.8	181.21	47.856
	3	49195.9	239.14	61.476
	4	67500.3	309.3	79.288
	5	85619.1	360.43	91.493
Square Thread pin fin in inline arrangement	2	28791.4	158.02	42.587
	3	45168.4	215.423	58.8223
	4	61014.1	269.916	72.5764
	5	78390.9	325.265	85.3177
Square Thread pin fin with perforations in inline arrangement	2	29211.63	164.708	45.9974
	3	46326.5	229.57	60.1631
	4	63032.1	286.551	75.5926
	5	80628	342.124	88.9259

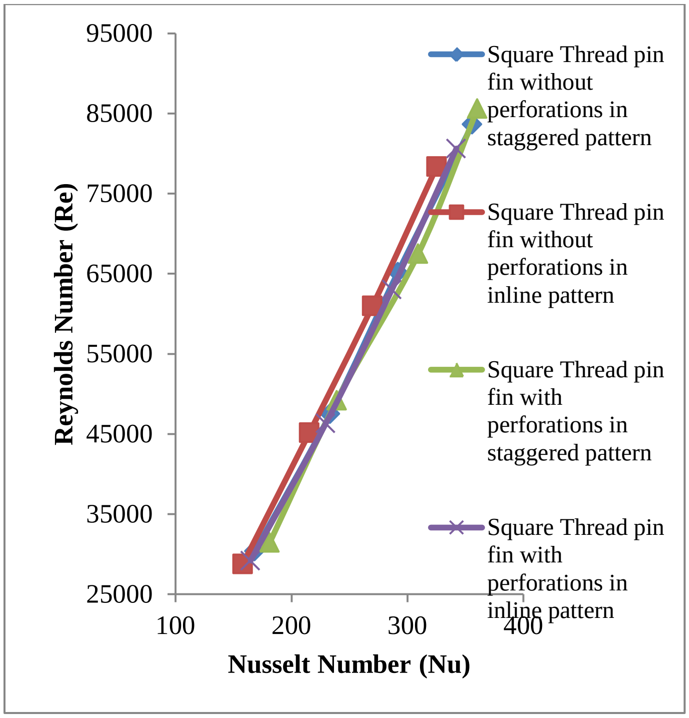
Table 2

Heat transfer coefficient for Square Threaded pin fins in inline and staggered pattern

Type of Pattern	h in W/m²K
Square Threaded pin fin in inline pattern	7.32
Square Threaded pin fin with perforation in inline pattern	7.46
Square Threaded pin fin in staggered pattern	7.65
Square Threaded pin fin with perforation in staggered pattern	7.83



Graph.1 Effect of heat transfer co-efficient & Nusselt number on Square threaded pin fins in inline and staggered pattern



Graph.2 Effect of Reynolds number & Nusselt number on Square threaded pin fins in inline and staggered pattern

The analysis is done in both free and forced convection with 2 m/s, 3 m/s, 4 m/s and 5 m/s air velocity. In natural convection heat transfer co-efficient varied from 7 to 8 W/m²K. In forced convection maximum heat transfer co-efficient varied from 47.856 to 91.493W/m²K, for Square Threaded pin fin with perforations in staggered pattern

CONCLUSION

The effect of modification of Square threaded surface geometry pin fin in natural and forced convection has been investigated experimentally. Square thread with and without perforations pin fins are used and also varying the design of pattern such as inline and staggered. The heat transfer rate in Square Threaded pin fin with perforations in staggered arrangement higher among each other arrangements in natural and forced convection. Because of obstruction, more circulation, irregularity, Zigzag positions pin fins in the array leads to increase Reynolds number & Nusselt number of air in flow along the pin fin arrays.

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