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Comparison of Effect of Fin Pitch and Flow Dynamics on the Performance of Rectangular Fins with and without Circular Perforations by Experimental Investigation

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Abstract

Rapid heat removal from heated surfaces and reducing material weight and cost become a major task for design of exchanger equipments like I C engines. Development of super heat exchangers requires fabrication of efficient techniques to exchange great amount of heat between surface such as extended surface and ambient fluid. The research work summarized in this paper presents the comparison of effect of fin pitch and flow dynamics on the performance of rectangular fin, with and without circular perforations by experimental investigation. The experiment was carried out in the laboratory using a test rig having provisions for attaching rectangular fins with and without circular perforation to a flat base plate. The number of circular perforation done in a rectangular fin is 15. The experiment is conducted for different fin pitch settings. Three rectangular plate type fins were used in this study. Three fin pitch settings 1cm, 2cm, 3cm were employed under free and forced heat transfer conditions. The heat transfer area was kept same. The fin size of both solid and perforated were (100mm×68mm×2mm).The fin performance parameters heat transfer coefficient, base temperature and temperature profile along the length of the fin were studied and compared for different cases. The result of perforated fin arrays has been compared with its external dimensionally equivalent solid fin arrays. It shows that enhancement in heat transfer of perforated fin arrays than solid fin arrays. The increase in heat transfer coefficient value is also manifested by a corresponding decrease in the fin base temperature

Keywords- Heat transfer enhancement, solid fins, Perforated fins, Fin pitch, Forced convection.

1. Introduction

Extended surfaces that are well known as a fin are commonly used to enhance heat transfer in many applications. Therefore, various types of fins like rectangular plate fins, square pin-fins and circular pin-fins are commonly used for both natural and forced convection heat transfers. Extended surface heat transfer plays a very important role in heat exchangers involving a gas as one of the fluids. A heat exchanger is a device which is used to transfer thermal energy between two or more fluid, between a solid surface and a fluid, or between solid particulates and a fluid, at different temperatures and in thermal contact. Not only are heat exchangers often used in the process, power, petroleum, air-conditioning, refrigeration, cryogenic, heat recovery, alternative fuel, and manufacturing industries, they also serve as key components of many industrial products available in the market. The heat exchangers can be classified in several ways such as, according to the transfer process, number of fluids and heat transfer mechanism. Plate type extended surface heat exchangers have corrugated fins mostly of triangular or rectangular cross-sections sandwiched between the parallel plates. These are widely used in automobile, aerospace, cryogenic and chemical industries, electric power plants, propulsive power plants, systems with thermodynamic cycles i.e. heat pump, refrigeration etc. and in electronic, gas-liquefaction, air-conditioning, waste heat recovery systems etc. They are characterized by high effectiveness, compactness (high surface area density), low weight and moderate cost. The next category is Tube-Fin Heat Exchangers, These heat exchangers may further be classified as (a) conventional and (b) specialized tube-fin exchangers. Tube-fin exchangers are employed when one fluid stream is at a high pressure and or has a significantly higher heat transfer coefficient than that of the other fluid stream. In a conventional tube-fin heat exchanger, the transfer of heat takes place by conduction through the tube surface. **Kadir Bilen et al. [1]** carried out experimental study on the heat and friction loss characteristics of a surface with cylindrical fins in a channel having rectangular cross section with larger fin diameter and different channel geometry, employing a finned heating surface kept at a constant temperature of 45oC for two-fin arrangement inline and staggered. Regarding studies about perforated fins **Sparrow** and **Carranco Ortiz** [2] experimentally determined heat transfer coefficient on an upstream facing surface and how they are related to diameter ratio and Reynolds number. **Wadhah Hussein Abdul Razzaq Al Doori** [3] discuss enhancement of natural convection heat transfer from the rectangular fins by circular perforations. **K. H. Dhanawade et al** [4] discuss enhancement of forced convection heat transfer from fin arrays with circular perforation. The results of perforated fin arrays have been compared with its external dimensionally equivalent solid fin arrays. It shows that enhancement in heat transfer of perforated fin arrays than solid fin arrays. . **D. Abdullah H. AlEssa** [5] determined augmentation of heat transfer of a fin by rectangular perforations with aspect ratio of three. The magnitude of heat dissipation enhancement depends upon the fin thickness, its thermal conductivity, the perforation dimension, lateral and longitudinal spacing. Finally, the study showed that, the perforating of the fins enhances heat dissipation rates and at the same time decreases the weight of the fin. **M.R. Shaeri et al. [6-8]** three-dimensional array of rectangular perforated fins with square windows was arranged in lateral surface of fins. Three –dimensional incompressible laminar and steady fluid flow with constant properties, and heat transfer of a heated array of rectangular perforated and solid fins attached on the flat surface, perforations with rectangular cross section was along the length of bluff plates was studied numerically. **Abdullah H. AIEssa et al. [9-12]** found that numerically enhancement of natural convection heat transfer from a fin by triangular perforations, square perforation, and rectangular perforation by using finite technique. **Bayram Sahin et al. [13, 14]** experimentally investigated overall heat transfer, friction factor and the effect of various design parameters on heat transfer and friction factor for heat exchanger equipped with square and circular cross sectional perforated pin fins in a rectangular channel. **Torii and Yang [15]** studied two dimensional, incompressible thermal- fluid flows over both sides of a slot – perforated flat surface, which was placed in a pulsating free stream. The object of the present study is to determine thermal performance of a new design of perforated fins with circular perforations and without perforations. Thus, turbulent fluid flow and convective heat transfer around arrays of solid and perforated fins are studied experimentally. In this experiment two types of perforated fin arrays are compared with solid fin arrays, details are given in Table I. The external dimensions (L×H×t) of all fins were kept constant. Weight of both types of perforated fins was same.

2. Experimental Setup

Fig.1 shows the schematic diagram of the experimental setup. It consist of a vertical rectangular duct supported by a bench mounted stand .A test section which consist of a base plate, pinned and plate type fin may be installed in the duct and secured by a quick release catch on each side. An electric heating element is fitted at the back side of the base plate. With thermostatic protection of overheating, the temperature at the base is monitored by a thermocouple sensor with connecting lead. A fan is situated at the top of the duct provides the air stream in the duct with variable speed. Air velocity in the duct, whether natural or forced, is indicated on a portable anemometer. The anemometer probe is inserted through the wall of the duct. A thermocouple probe permits measurement of air temperature, together with surface temperature of pins and fins. These temperatures are determined by inserting the probe through access holes in the duct wall. An independent bench mounted-console contains temperature measurement, power control, and fan speed control circuit with appropriate instrumentation. Temperature measurement, to a resolution of 0.1°C, is affected using thermocouple sensor with direct digital read- out in °C. An electric console incorporates a solid state power regulator with a digital read-out to control and indicate power supply to exchanger on test. The exchanger is connected to the console via the supply lead. Power is supplied to the equipment via a supply lead connected to the rear of the electric console. The power control circuit provides a continuously variable, electrical output of 0-100W with a direct read-out in Watts.

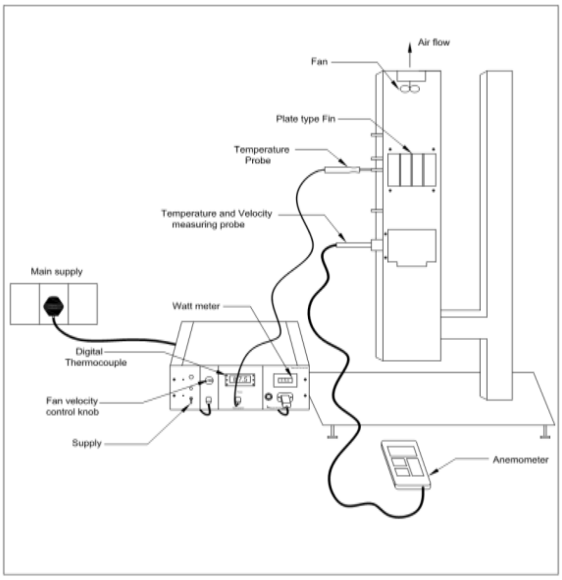

Figure 1. Schematic diagram for the experimental setup

Figure 2 shows the photograph of the test section. Figure 3 and 4 shows the arrangement of solid plate fin and circular perforated fins at pitch distance 1 cm.

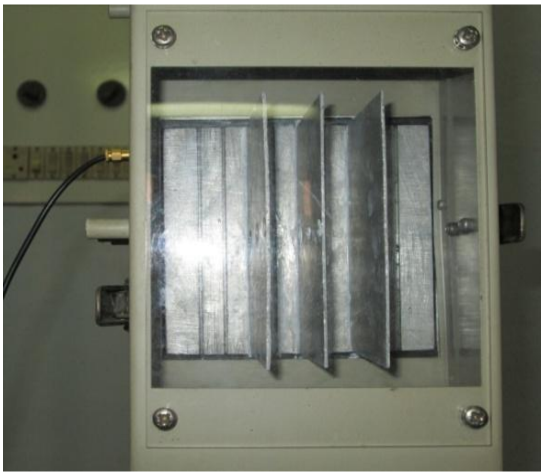

Figure 2. Photograph of the test section

Figure 3. Solid Plate fin at 1cm pitch

Figure 4. Circular perforated plate fin at 1cm pitch

Table 1. Details of fin array tested at 1, 2 and 3cm Pitch

Aluminium fin size in (mm), (L×H×T)	Perforation of diameter (mm)	No. of holes/fin	No. of arrays
100×68×2	Solid	-	3
100×68×2	7	15	3

3. Fin Analysis Methodology

The rate of heat transfer from the fin

$$Q_o = [phKA]^{\frac{1}{2}}\left[\frac{\frac{h}{mK}+\tanh(ml)}{1+\frac{h}{mK}\tanh(ml)}\right](T_s - T_\infty)$$

The energy balance for experimental set-up is

$Pinput = qu + n \times Qo$, where $Pinput$ =Power input to the base plate.

$$P_{input} = h[A_u(T_s - T_\infty)] + n\sqrt{phKA}\left[\frac{\frac{h}{mK}+\tanh(ml)}{1+\frac{h}{mK}\tanh(ml)}\right](T_s - T_\infty)$$

where qu is the heat lost by uncovered area of base plate, Qo is heat lost by one fin, n is the number of fins used, Au is the uncovered area of base plate. The above equation is used for calculating the heat transfer coefficient in the experimental investigation. The pitch distance between two fins is fixed at 1cm, 2cm and 3cm. Three plain plate type fins were used. The power input was set at 35W.

For Perforated fin-

$Q=h_{pf}\ A_s\ (T_{s(av)}-T_\infty)$

Where $A_{S=}$ Total heat transfer area for plate type circular perforated fins

h_{pf}= Heat transfer coefficient for plate type circular perforated fins

$T_{s(av)=}$ Average base temperature

T_∞= Ambient temperature

Total heat transfer area (As) = Open area of base + total surface area contribution from the fins

4. Result and Discussion

In this section, the experimental results of solid plate fins and circular perforated fins on temperature and distance are presented. The experiments were carried out by varying the fin pitch and blower fan speed. Figures 5, 6 and 7 show the variations in temperature with distance from base plate at different sold fin pitches. Fig 5 shows the results when the solid fin pitch was kept 1cm. The experimental results at five settings of blower fan speed are plotted in the Fig 5. It can be seen from the figure that when the fan is switched off (fan velocity zero), which corresponds to the case of free convection, the temperature at the solid fin base and at different locations is highest. After switching on the blower fan, i.e. under forced convection conditions the temperature of the fin reduces. The experiments were performed for four different settings of fan speed under forced convection. From the Fig 5, It is observed that as the fan velocity increases the fin temperatures at different locations reduced progressively as can been seen from figures 6 and 7 show results at fin pitch 2cm and 3cm at the blower fan velocity settings similar to 1 cm fin pitch case. It is obvious from the Figures 6 and 7 that a similar trend of temperature variations is observed. However, the absolute values of temperatures recorded are different. It is observed that when the blower fan velocity is zero, the temperature recorded for the different fin pitch settings are nearly the same. No perceptible change in the fin base temperature or temperature at different locations along the length of the fin is observed. When the blower fan speed increases the temperature of the fin is observed to be less when the fin pitch distance is increased. The reduction in the temperature with the increase in fin pitch is more pronounced when the higher blower fan speed is selected

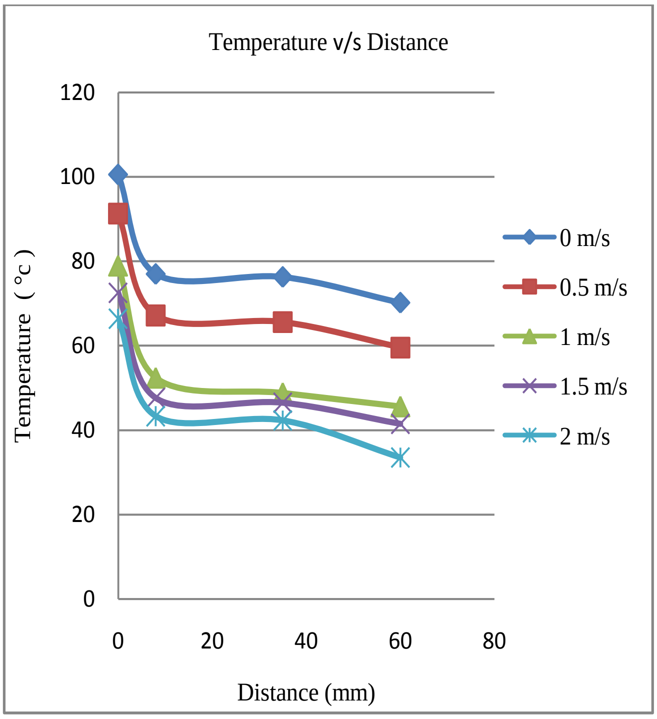

Figure 6. Variation of temperature with distance from base plate for solid fin at pitch 2cm

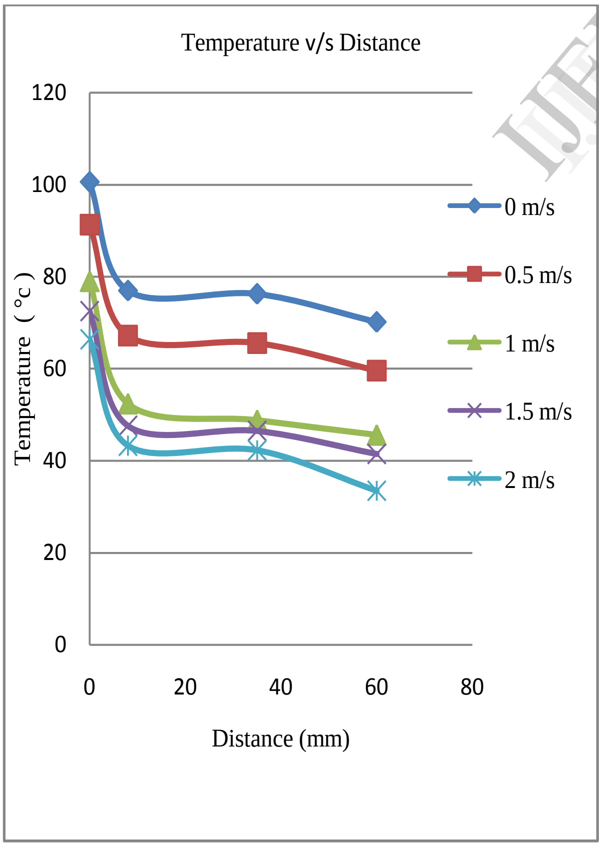

Figure 5. Variation of temperature with distance from base plate for solid fin at pitch 1cm

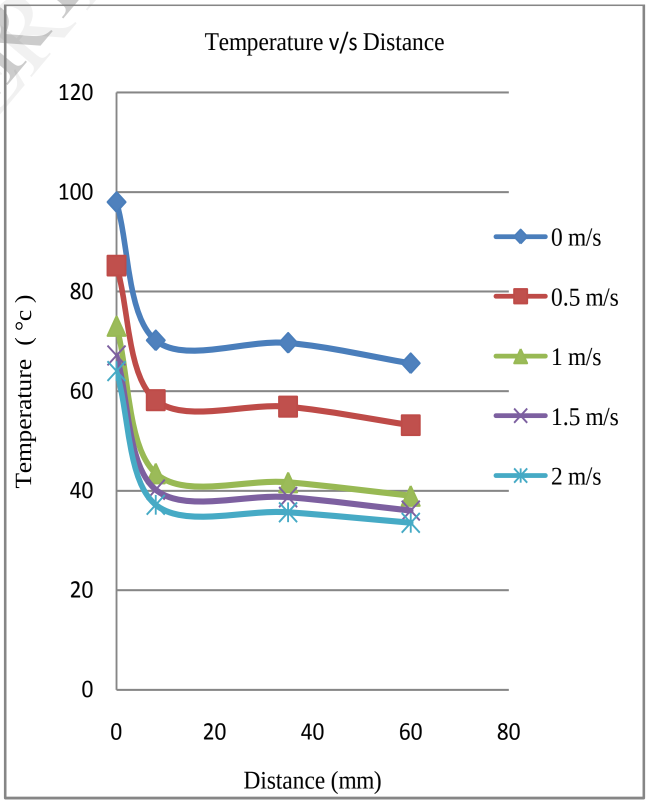

Figure 7. Variation of temperature with distance from base plate for solid fin at pitch 3cm

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Similarly we find out the variations in temperature with distance from base plate at different circular perforated fin pitches. Figure 8, 9 and 10 shows the variations in temperature with distance from base plate at different circular perforated fin pitches. No perceptible change in the fin base temperature or temperature at different locations along the length of the fin is observed. When the blower fan speed increases the temperature of the fin is observed to be less but when the fin pitch distance is increased the temperature of the fin is shows small increment at higher blower fan speed. The reduction in the temperature with the increase in fin pitch is more pronounced when the higher blower fan speed is selected but after sometime with the increase in fin pitch at higher blower fan speed it shows the small increment in temperature.

It is observed that from the figure 5, 6 and 7 of solid and figure 8, 9 and 10 of perforated fins that, there is a decrement in the temperature at different locations along the fin length compared to the same case when no circular perforation was done but after sometime for circular perforated fin as we increase the blower fan speed we observe the small increment in temperature as the fin pitch increases.

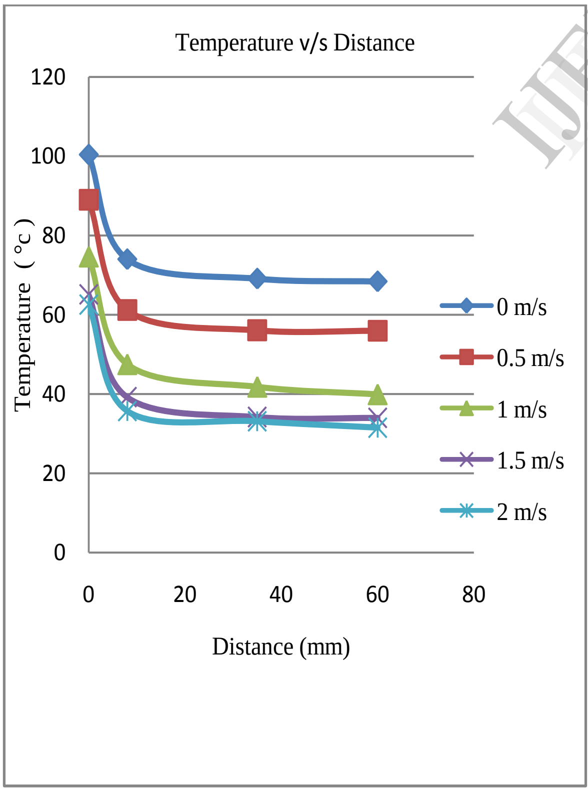

Figure 8. Variation of temperature with distance from base plate for circular perforated fin at pitch 1cm

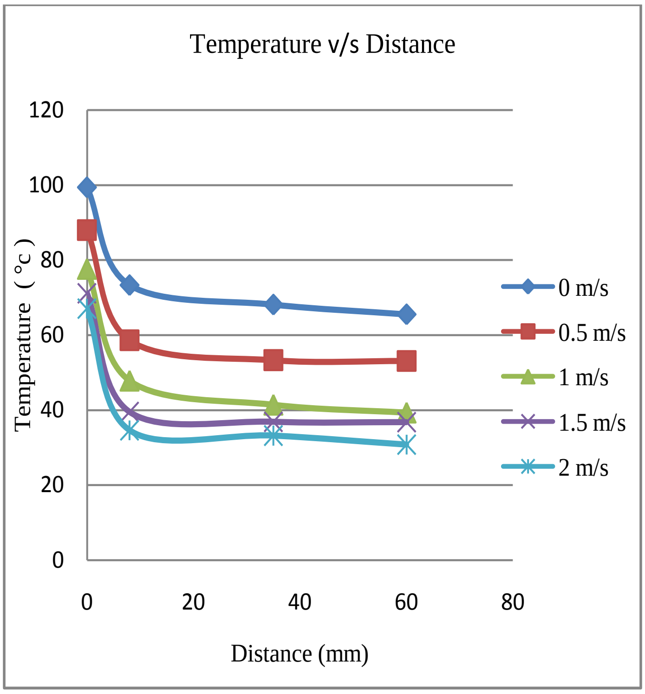

Figure 9. Variation of temperature with distance from base plate for circular perforated fin at pitch 2cm

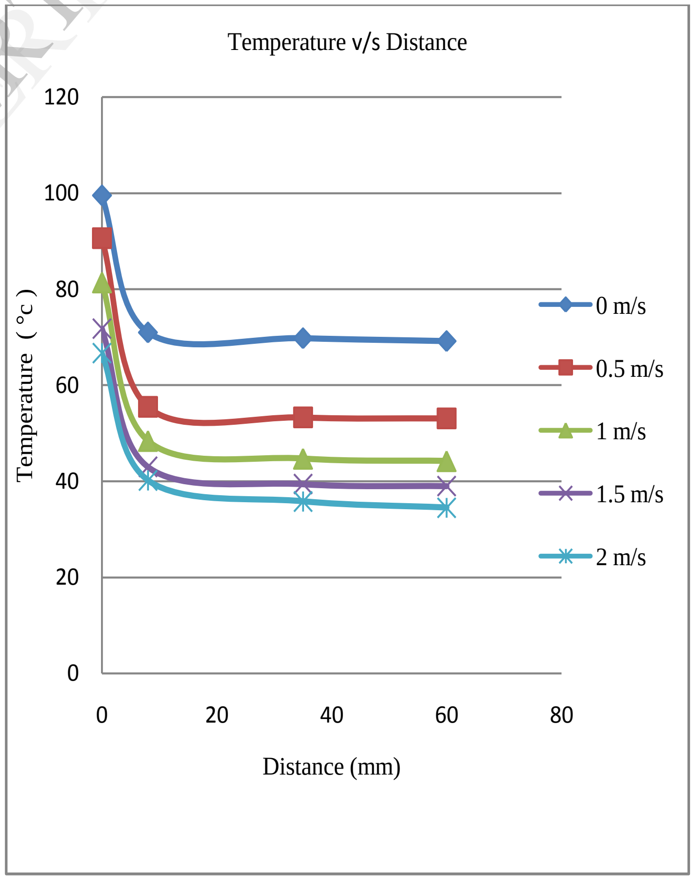

Figure 10. Variation of temperature with distance from base plate for circular perforated fin at pitch 3cm

A comparative study of the effect of fin pitch on the base temperature for both solid and circular perforated fin Fig 11 and 12 presents a comparative picture of the effect of fin pitch on the base temperature for both solid and circular perforated fin respectively. Figure 11 and 12 shows that under free convection condition i.e. when the blower fan velocity is zero, the base temperature curve shows small decrement in the base temperature along the fin pitch. Fig 11 and 12 further shows that when the velocity of the blower fan is increased the slope of the temperature curve changes. It can be seen from the figures that when the velocity is 0.5 m/s, we see a drop in the fin base temperature at different fin pitch settings (1cm, 2cm and 3cm). When the blower fan velocity is increased further to 1 m/s, 1.5 m/s and 2 m/s it can be very clearly seen from the Fig 11 and 12 that as the fin pitch increases there is a conspicuous drop in the fin base temperature.

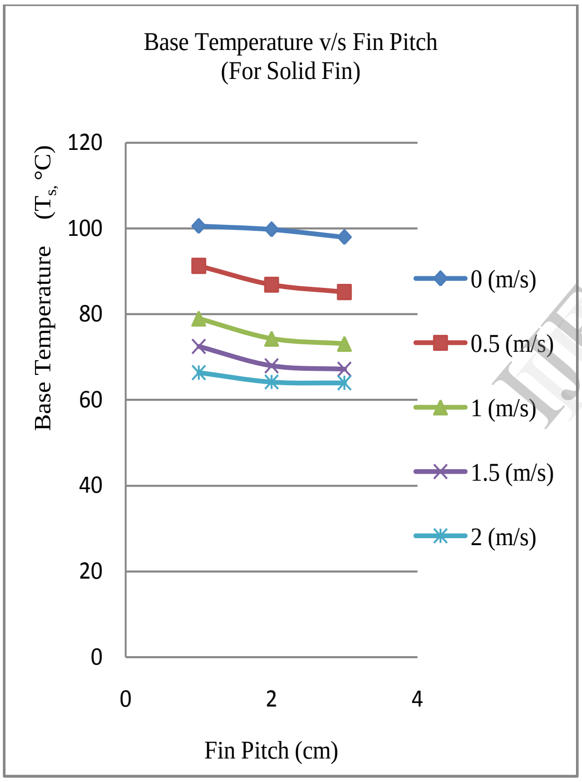

Figure 11. Effect of fin pitch and base temperature for solid fin

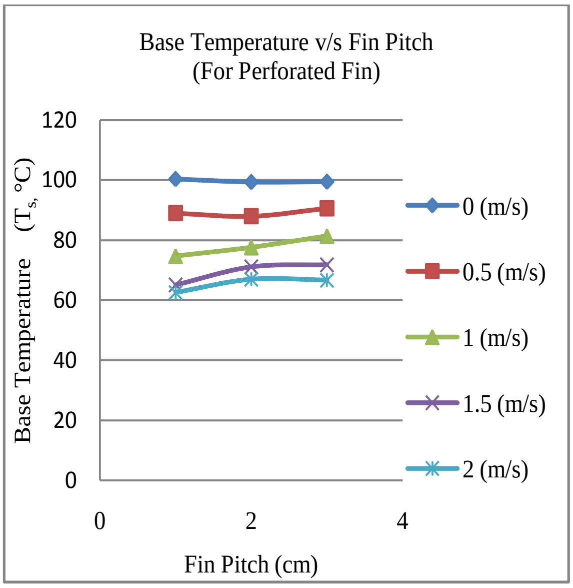

Figure 12. Effect of fin pitch and base temperature for perforated fin

A comparative picture of effect of fin pitch and fan velocity on heat transfer coefficient for both solid and circular perforated fin-

Fig 13 and 14 shows the variations in convection heat transfer coefficient with different fin pitch at different blower fan velocities for solid fin. These curves show that under free convection condition there is no effect of fin pitch change on the convection heat transfer coefficient is observed. Under force convection at 0.5 m/s velocity, for different fin pitch we see the small increment in convection heat transfer coefficient. From figures 13 and 14 which show that as the blower fan velocity is set at higher values of 1 m/s, 1.5 m/s and 2 m/s a noticeable increase in the convection heat transfer coefficient is observed.

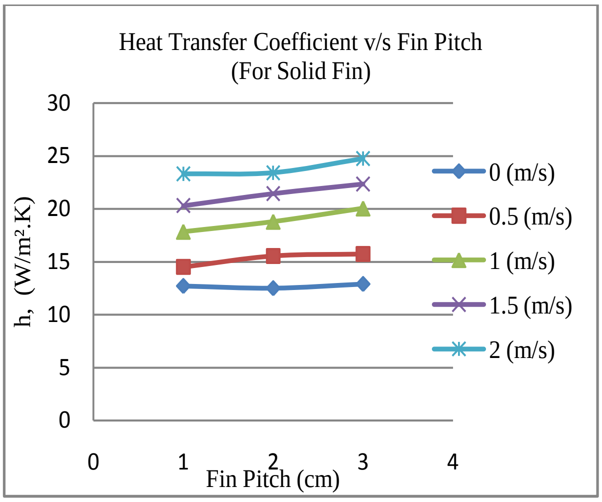

Figure 13. Effect of fin pitch and heat transfer coefficient for solid fin

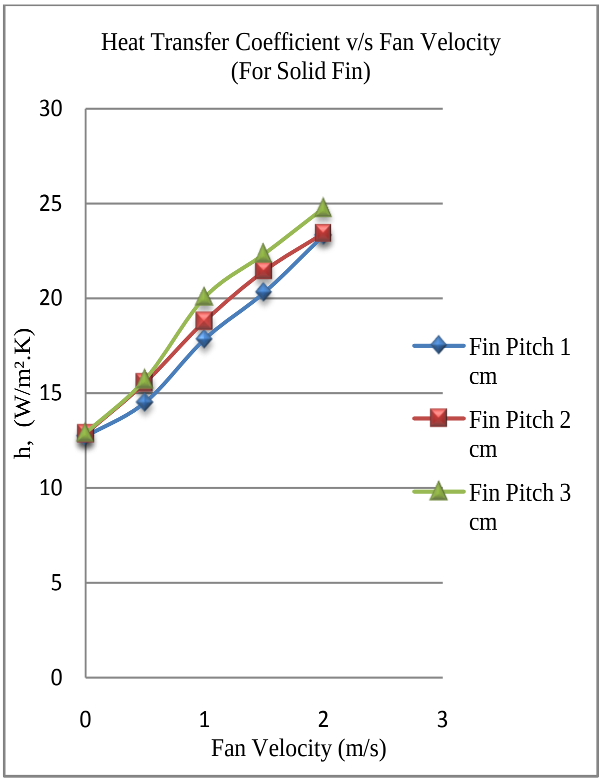

Figure 14. Effect of fan velocity and heat transfer coefficient for solid fin

Fig 15 and 16 shows the variations in convection heat transfer coefficient with different fin pitch at different blower fan velocities for circular perforated fin.

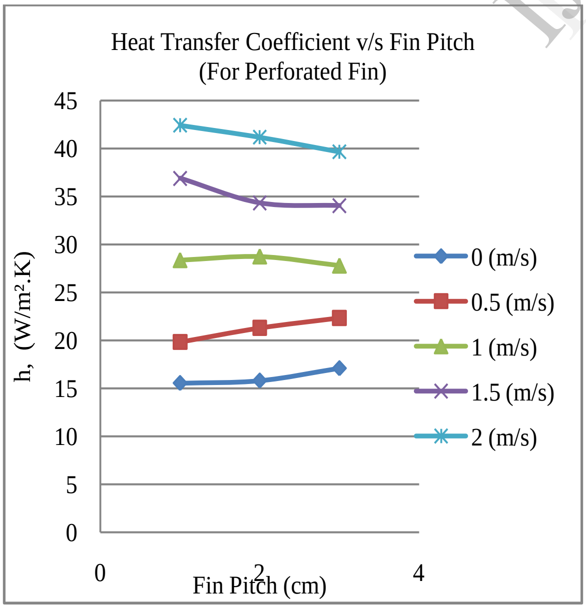

Figure 15. Effect of fin pitch and heat transfer coefficient for perforated fin

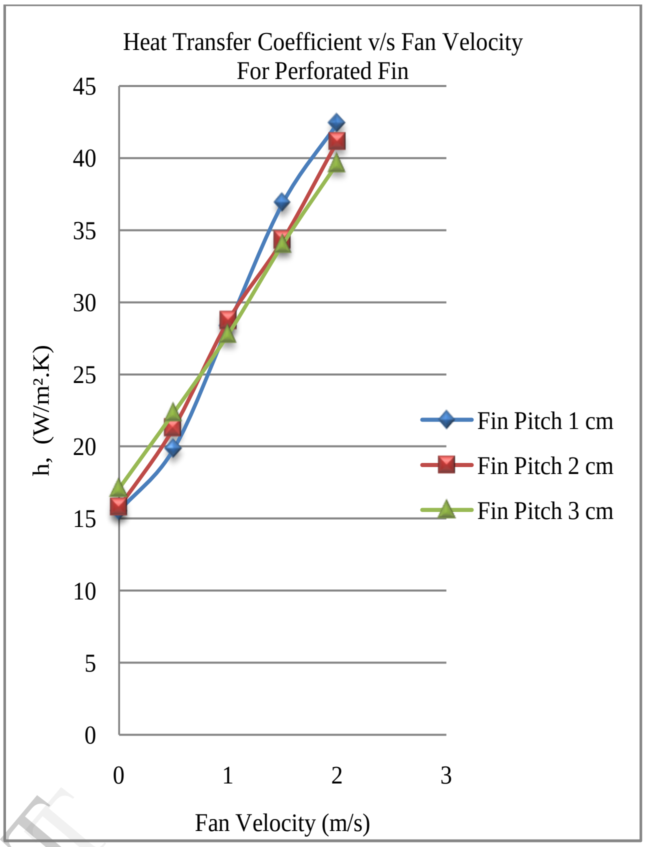

Figure 16. Effect of fan velocity and heat transfer coefficient for perforated fin

These curves show that under free convection condition as the fin pitch increases, the convection heat transfer coefficient also increase, but we see that figure 15 and 16 show that higher the value of fin pitch we get higher heat transfer coefficient. Under force convection at 0.5 m/s velocity, for different fin pitch we see the increment in convection heat transfer coefficient. From figures 15 and 16 which show that as the blower fan velocity is set at higher values of 1 m/s, 1.5 m/s and 2 m/s a noticeable increase in the convection heat transfer coefficient but we also see from the figure 15 and 16 that as the fin pitch increases from 2 cm to 3 cm we see the small decrement in the convection heat transfer coefficient for perforated fin.

Thus, it emerges from the above experimental observations that the fin pitch has a significant effect on the fin performance. The effect is not significant under free convection condition for solid fin but we see the increment in convection heat transfer coefficient for circular perforated fin as the fin pitch increases. But as the condition changes from free to forced convection heat transfer, the effect of fin pitch on the fin performance begins to show. At lower velocities, the effect is moderate but at higher velocity settings the effect is considerable for both solid and perforated fin but we see the noticeable increment in convection heat transfer coefficient for circular perforated fin as we increase the fin pitch from 1 cm to 2 cm, but at fin pitch 3 cm we see the decrement in convection heat transfer coefficient at higher fan velocities.

The effects of circular perforation on fin performance are as follows-

1. Circular perforation in a solid fin decreases the weight of fin.
2. The temperature drop along the perforated fin length is consistently higher than, that in the non-perforated fin.
3. Circular perforation in a solid fin shows the enhancement in the heat transfer coefficient in comparison to solid fin without perforation.

With the figure 17, 18 and 19 we clearly see the increment in the heat transfer coefficient of circular perforated fin in comparison to solid fin at different fin pitches. In case of solid fins, the heat transfer coefficient value nearly almost constant on different pitches for free convection condition but for forced convection condition as we increase the fin pitch and fan velocity value of heat transfer coefficient increases. But in case of circular perforated fins, we see a significant increment in the value of heat transfer coefficient in both free and forced convection condition in comparison to solid fin at different pitches. But when we compare the heat transfer coefficient of only perforate fin on different pitches (1cm, 2cm and 3cm) under free and forced convection condition at lower velocity, value of heat transfer coefficient shows increment but at higher velocity it shows decrement.

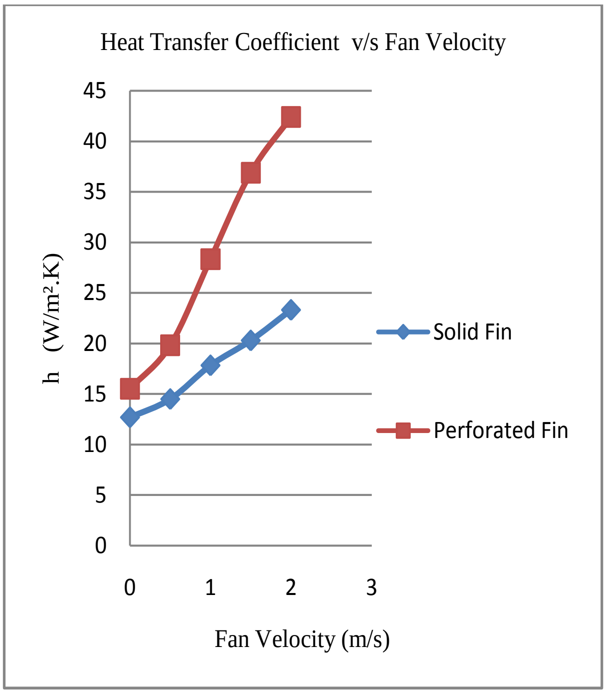

Figure 17. Effect of fan velocity and heat transfer coefficient for solid and perforated fins for 1 cm pitch

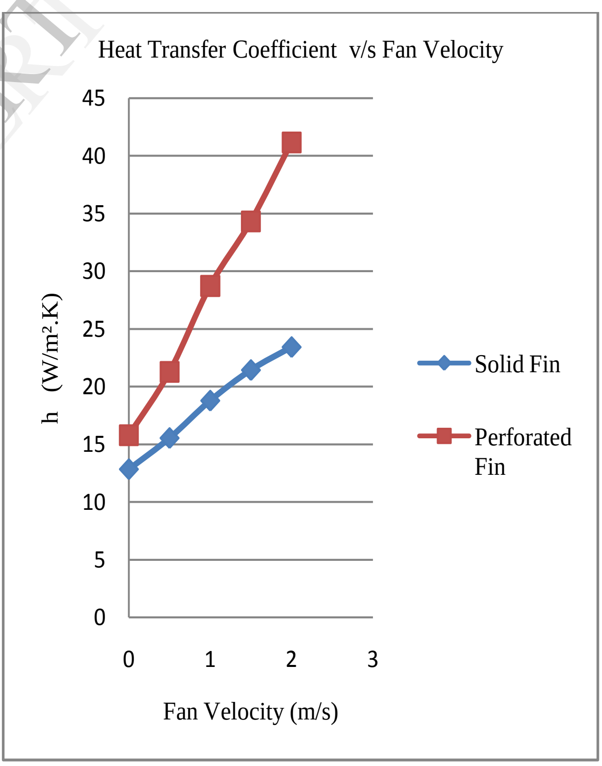

Figure 18. Effect of fan velocity and heat transfer coefficient for solid and perforated fins for 2 cm pitch

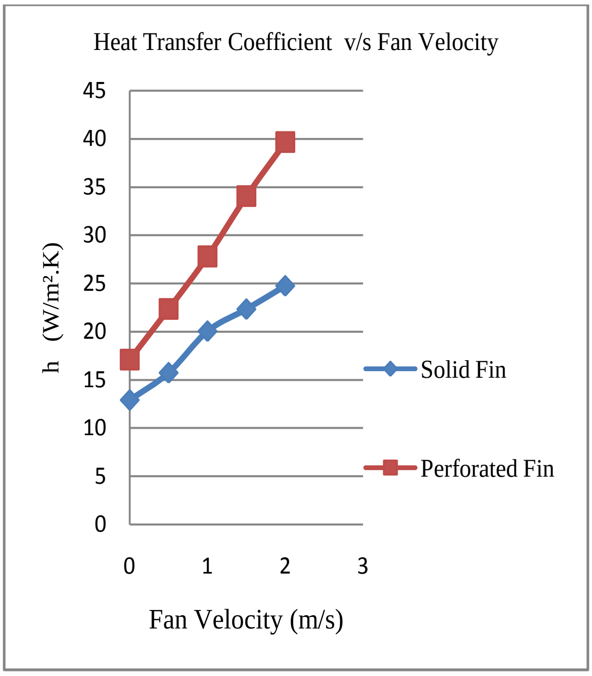

Figure 19. Effect of fan velocity and heat transfer coefficient for solid and perforated fins for 3 cm pitch

5. Conclusion

The experiments were carried out for different fin pitch settings under different conditions of free and forced convection heat transfer conditions for solid and circular perforated fins. The experiments were performed for five flow conditions, one free and four forced heat transfer conditions. The flow was both laminar and turbulent in all the experiments.

1. For solid fin, under free convection heat transfer condition, the effect of change in fin pitch on fin performance is not significant. There was no noticeable change in the fin base temperature and convection heat transfer coefficient.

2. For circular perforated fin, under free convection heat transfer condition, the effect of change in fin pitch on fin performance is significant and it shows a increment of 9.97 percent when fin pitch changes from 1 cm to 3 cm.

3. For solid fin, under forced convection heat transfer condition, the effect of change in fin pitch on fin performance is clearly visible. The effect is more pronounced at higher air flow velocities over the fin surface. At 0.5 m/s velocity, the convection heat transfer coefficient value increases by about 8.41 percent when fin pitch setting is changed from 1cm to 3cm. When the velocity is increased to 1m/s under similar condition, the increase is about 12.39 percent. When the velocity is further increased to 1.5m/s, the increase in convection heat transfer coefficient value is about 10.04 percent, which is a significant increase. Further when the velocity is increased to 2 m/s, we see the increment of 6.17 percent in convection heat transfer coefficient when fin pitch setting is changed form 1 cm to 3 cm. The increase in heat transfer coefficient value is also manifested by a corresponding decrease in the fin base temperature.

4. For circular perforated fin, under forced convection heat transfer condition, the effect of change in fin pitch on fin performance is clearly visible. The effect is more pronounced at higher air flow velocities over the fin surface. At 0.5 m/s velocity, the convection heat transfer coefficient value increases by about 12.65 percent when fin pitch setting is changed from 1cm to 3cm. When the velocity is increased to 1m/s under similar condition, the increase is about 2 percent. When the velocity is further increased to 1.5m/s, the increase in convection heat transfer coefficient value is about 7.72 percent, which is a significant increase. Further when the velocity is increased to 2 m/s, we see the increment of 6.50 percent in convection heat transfer coefficient when fn pitch setting is changed form 1 cm to 3 cm. The increase in heat transfer coefficient value is also manifested by a corresponding decrease in the fin base temperature.

5. In order to study the effect of changed air flow pattern on the fin performance, circular perforation was done in a solid fin. The performance of three rectangular solid plate fins were compared with three rectangular circular perforated fins at different fin pitches (1 cm, 2 cm and 3 cm) under free and forced convection heat transfer conditions. The circular perforated fin arrangement in free convection case showed about 22.26 to

32.48 percent increase in the convection heat transfer coefficient, while in forced convection condition the increase ranged from about 36.66 percent to 81.86 percent in comparison to solid fin.

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