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COMPARATIVE STUDY OF POROUS CONICAL PIN FIN ARRAY BASED ON FREE CONVECTIVE HEAT TRANSFER

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Abstract*-Heat transfer enhancement has become a great deal as the advancement of new technology. In this experimental work, free convective heat transfer by using porous conical pin fin array was investigated. An array of seven porous conical shape of aluminum fin having fin height (h)=70 mm, base diameter (d)=15 mm and fin spacing(s)=45 mm of staggered arrangement were used. Heat transfer coefficient, fin efficiency and effectiveness for free convection were prompted. These experimental results were resembled with a conical pin fin array without pores. The experimental results showed that heat transfer coefficient, fin efficiency and effectiveness were increased for porous conical pin fin. Heat transfer coefficient, fin efficiency and effectiveness were found to be increased up to 5.16, 7.39 and 22.19% respectively than that of non-porous pin fin for the same power supply. Heat transfer coefficient was increased with the increase of temperature difference between the walls and ambient.*

Keywords: Conical pin fin, heat transfer coefficient, fin efficiency, fin effectiveness, free convection.

1. INTRODUCTION

Heat transfer by convection between solid surface and the surrounding fluid can be increased by increasing heat transfer area by attaching to the surface thin strips of metals called fins. Heat transfer can be increased by increasing the convection heat transfer coefficient or increasing the surface area of an object or increasing the temperature difference between the object and the environment. Fins are widely introduced to enhance convective heat transfer in a wide range of engineering applications, and offer practical means for gaining a large total heat transfer surface area without the use of an excessive amount of primary surface area. Fins are generally used for heat management in electric appliances such as computer power supplies or substation transformers. Other applications include IC engine cooling, such as Fins in a car radiator. Adding a fin to an object, however, increases the surface area which has become an economical solution to heat transfer problems.

Heat transfer rate of pin fin is largely affected by the fin height (H/d), and other affecting factors include the velocity of fluid flow, the thermal properties of the fluid, the cross-sectional shape of the pin-fins like perforation, the relative inter-fin pitch, the arrangement of the pin-fins like in-line, staggered arrangement and others.

Several research works have been carried out to augment heat transfer by increasing heat transfer area from the beginning of the twentieth century by several scientists. G.J.Vanfossen and B.A.Brigham [1] studied the heat transfer by short pin-fins in staggered arrangements. According to their study, longer pin-fins (H/d = 4) transfer more heat than shorter pin-fins (H/d = ½ and 2) and the array-averaged heat transfer with eight rows of pin-fins slightly exceeds that with only four rows. Their results also showed that the mean heat transfer coefficient on the pin surface is around 35% greater than that on the end walls. Metzger et al. [2] investigated the impacts of pin-fin geometry and array orientation on the heat transfer and the pressure loss in pin-fin arrays. According to their results, the use of cylindrical pin-fins with an array orientation between staggered and in-line can sometimes boost the heat transfer, while substantially reducing pressure. Yusuf et al. [3] showed rectangular shape of fin more efficient than parabolic shape. R.F. BabusHaq et al. [4] reported that the optimal ratio of the inter-fin pitch to the pin fin diameter in the transverse direction was 2.04 for all pin-fin systems. However, the optimal ratios in the longitudinal direction were 1.63, 1.71 and 1.95 for polytetrafluroethane pin-fins, mild-steel pin-fins and duralumin pin-fins respectively. M. S. Hossain et al. [5] showed that pin fin array of cylindrical shape is more efficient than other types of fins. Khaled et al.

[6] performed his work in which it had shown that conical pin fin is 12.16% more efficient than that of other fin in heat rejection. A conical porous pin fin array was designed flat plate wall. The objective of this experimental study is to investigate the heat transfer coefficient, fin efficiency and fin effectiveness for free convection using porous pin fin array based on the experimental results.

In order to make easy experiment, data collections, comparison and analysis, some assumption were made in this experimental process which created some limitations in the experimental results. These were,

1. Transfer of heat was considered as one dimensional flow.
2. During the experiment, no heat was generated internally.
3. Heat transfer by radiation was neglected.
4. Across the whole surface area of the fin, convection was considered uniform.

2 EXPERIMENTAL FACILITIES

2.1 Experimental Apparatus

To perform the experiment properly, several materials were used. Aluminum metal was used to construct the pin fin array. One multi meter was used for measuring current flow through the base, voltage regulator for regulate voltage supply at a particular heat supply, a digital thermocouple for measuring fin temperature at base and surface at different locations. We used insulator to reduce heat loss from the base box to the surroundings. G.I. sheet, asbestos and Aluminum pest were also used in this experiment.

2.2 Test Section

The test section consists of an array of seven porous conical shape of aluminum fin having fin height (h) =70 mm, base diameter (d) =15 mm and fin spacing(s) =45 mm of staggered arrangement were used. Figure 1 represents the graphical illustration of the pin fin array which is drawn with the help of SOLIDWORKS. Figure 2 shows the schematic diagram of the experiment and Figure 3 represents the whole experiment set up and the test section that was used to rub the experiment. The experiment was conducted in the heat engine lab of CUET.

3 MATHMATICAL DATA REDUCTION

The experimental data were used to determine convection heat transfer coefficient, fin efficiency and fin effectiveness for free convection. By evaluating this three parameters, fin performance was measured.
Total amount of heat supplied was calculated fromEq (1)

$$Q = VIcos\theta \quad (1)$$

Where V is voltage supplied, I is current and $Cos\theta$is Power factor ≈0.8 (assume for this experiment).
From Eq (2), the rate of convection heat transfer from the extended surface was obtained and coefficient of convective heat transfer was evaluated from Eq (3).

$$Q = hA_H(t_H - t_A) + hA_F(t_{FAV} - t_A) \quad (2)$$

$$h = \frac{Q}{A_H(t_H-t_A)+A_F(t_{FAV}-t_A)} \quad (3)$$

Where $h$is the convection heat transfer coefficient (assumed constant),$A_H$is the area of heated wall only,A_F summed area of all fins, t_H is heated wall temperatureand t_{FAv} is the average temperature along the length of fins which may be approximated as mean temperature of three temperature measured along length.
Heat transfer through pin fin was calculated as,

$$Q_F = hA_F(t_{FAv}-t_A) \quad (4)$$

Where $t_A$is the ambient temperature.
Fin performance can also be characterized by fin efficiency. This is the ratio of the fin heat transfer rate to the heat transfer rate of the fin if the entire fin were at the base temperature. Efficiency of the fin was calculated by

$$\eta_f=\frac{t_{FAv}-t_A}{t_H-t_A} \times 100 \quad (5)$$

Fin efficiency will always be less than one. This is because assuming the temperature throughout the fin is at the base temperature would increase the heat transfer rate.
The performance of the fins is judged on the basis of the enhancement in heat transfer relative to the no-fin case. The performance of fins expressed in terms of the fin effectiveness. It is the ratio of the fin heat transfer rate to the heat transfer rate of the object if it had no fin. The effectiveness of fin was calculated by

$$\varepsilon_f= \frac{Q\,fin}{hA(t_B-t_A)} \quad (6)$$

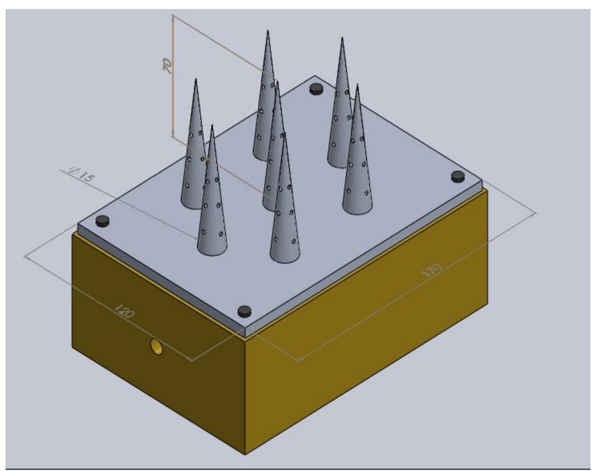

Fig. 1: Porous conical pin fin array arrangement

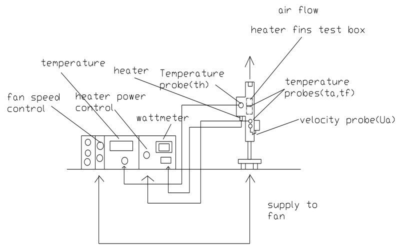

Fig. 2: Schematic diagram.

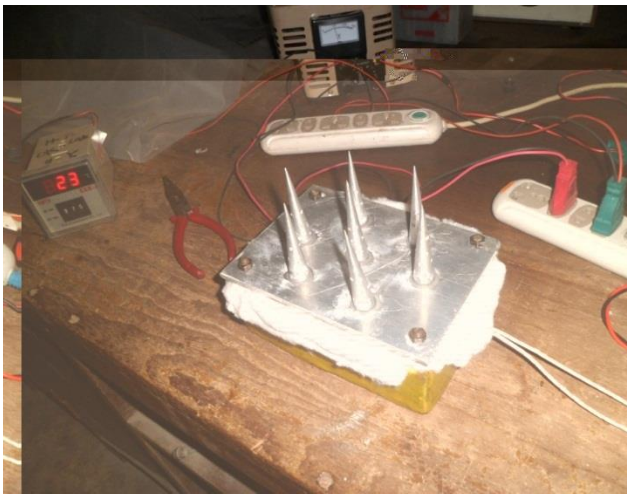

Fig.3: Experimental set-up

4 RESULTS AND DISCUSSINS

4.1 Heat Transfer Coefficient

Figure (4) shows the change of heat transfer coefficient with the increase of temperature difference between the wall and ambient temperature for porous pin fin array.

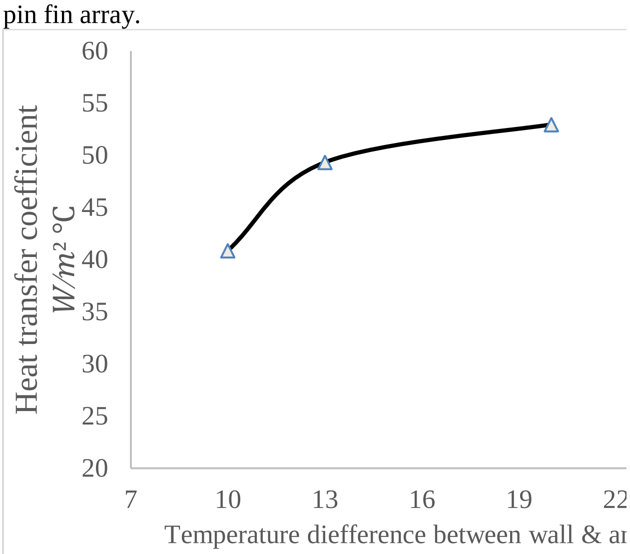

Fig. 4: Temperature difference vs. heat transfer coefficient

From the above it is observed that, it is observed that the heat transfer coefficient increase withthe increaseof the temperature difference between wall and ambient for free convection.

4.2 Fin Efficiency

Efficiency of the fin for porous conical pin fin array also increased as heat transfer coefficient increases. Figure (5) depicts the increase of efficiency with the increases of temperature difference between wall and ambient.

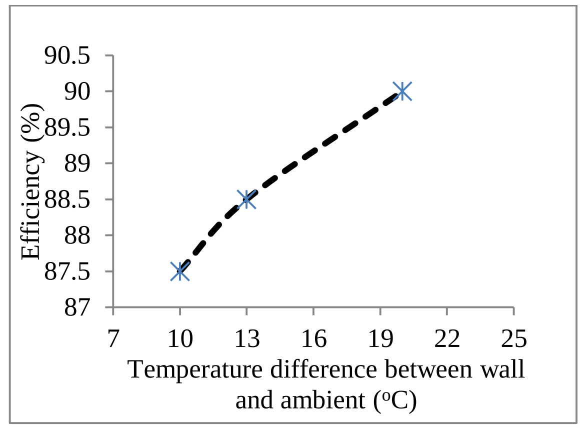

Fig.5: Temperature difference vs. efficiency

4.3 Fin Effectiveness

Fin effectiveness is another important parameter to evaluate fin performance. Figure (6) shows the increase of fin effectiveness with the change of the difference between wall and ambient temperature.

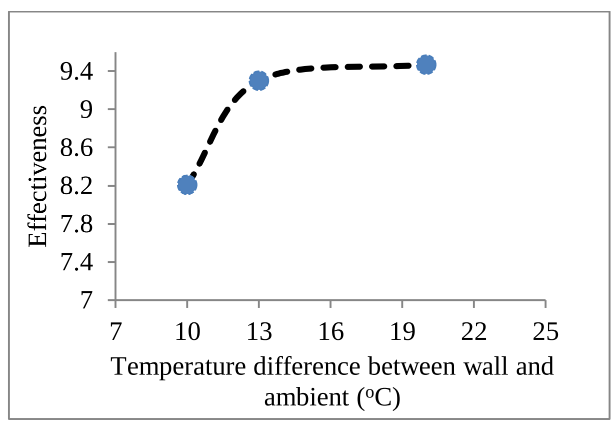

Fig.6: Temperature difference vs. effectiveness.

Table (1) shows the calculated experimental data from mathematical equation.

Table 1: Data of heat transfer coefficient, fin efficiency and effectiveness

Test no	Free convection				
	Q Watts	h W/m^2	η_f%	ε_f %	Q_F Watt
1	12.43	40.85	87.5	8.21	4.65
2	19.584	49.31	88.46	9.30	7.38
3	32.296	52.51	90	9.47	12.31

4.4 Performance Evaluation.

The present result obtained from porous conical pin fin array was compared with the nonporous conical pin fin array. It is evident from this experiment that, porous conical pin fin is more efficient than non-porous conical pin fin array. From the result it was shown that efficiency was increased relative to non-porous conical pin fin array by 7.39% in free convection. The heat transfer coefficient was improved by 5.16% for porous conical pin than that of non-porous pin. Fin effectiveness also increased by 22.19% for porous conical pin. Khaled et al. [6] reported that, cylindrical pin fin array is 12.16% less efficient than conical pin fin array.

Figure (7) shows the relation between the heat transfer coefficient and power supply for porous and nonporous conical pin fin array respectively. It had been shown that for any amount of power supply, porous conical fin had the higher heat transfer coefficient compared with nonporous pin. Figure (8) represents the variation of efficiency for different power input for porous and nonporous conical fin. It can be seen that porous fin was more efficient for every unit of power supply and the difference between the efficiency was very high.

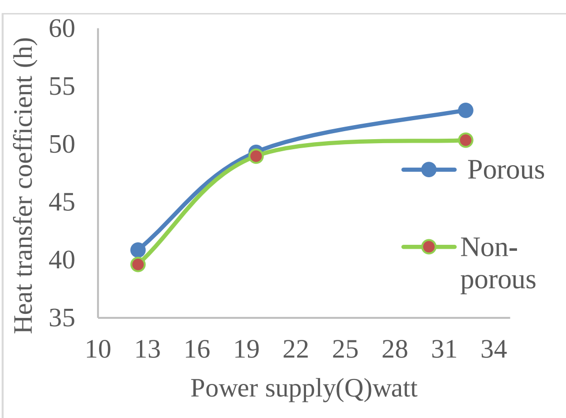

Fig. 7: Comparisonof heat transfer coefficient between porous and Non-porous conical pin fin.

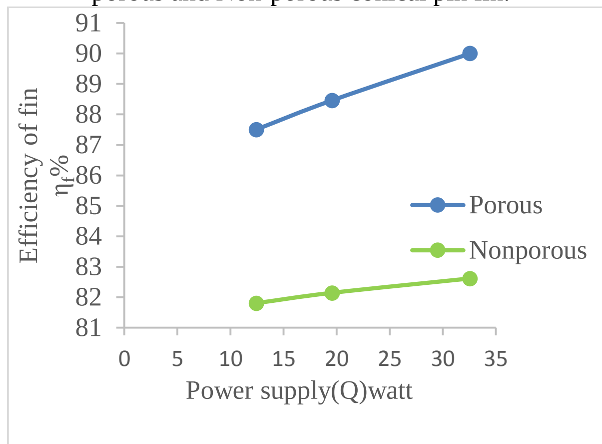

Fig. 8: Comparison between the efficiency (η_f%)of Porous and Non-porous conical pin fin

Figure (9) shows the effectiveness for porous and non-porous fin. From this figure, it was clear that porous conical pin fin was more effective than nonporous one.

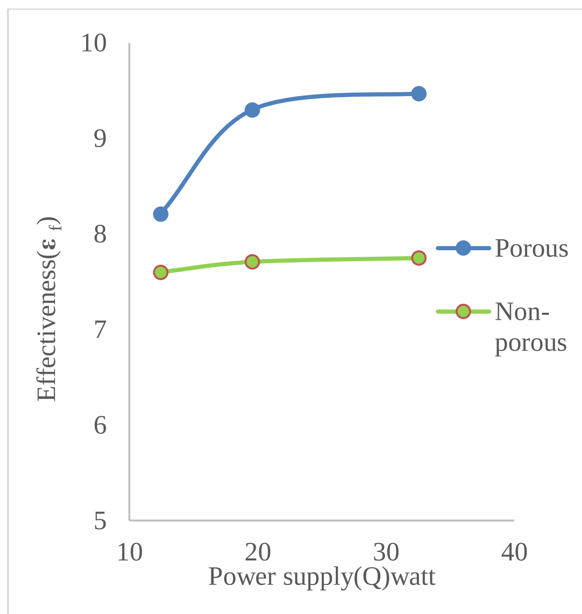

Fig. 9: Comparison of effectiveness between porous and Non-porous pin fin.

5 CONCLUSION

An experimental study was performed to investigate the performance of seven conical pin fin array. These experimental results were compared with a porous conical pin fin array for free convection heat transfer process. The use of porous shape into the conical pin fin provided significant augmentation of heat transfer compared with non-porous fin. Based on the experimental results, some key outcomes of this experiment can be listed as follows:

- The porous conical pin fin offered a significant improvement in the case of heat transfer coefficient, fin efficiency and fin effectiveness.
- The heat transfer coefficient was improved by 5.16% for porous conical pin than that of non-porous pin.
- Fin effectiveness was increased by 22.19% for porous conical pin.
- Efficiency was enhanced relative to non-porous conical pin fin array by 7.39% in free convection.

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Nomenclature

Symbol	Meaning	Unit
Q	Heat Supplied	W
V	Voltage input	V
I	Current	A
Cosθ	Power factor	
h	Coefficient of heat transfer.	$W/m^{2o}C$
A_H	Area oh heated wall	m^2
A_F	Area of all fins	m^2
t_H	Heated wall temperature.	^0C
t_{FAv}	Average temperature	^0C
η_f	Fin efficiency	
t_A	Ambient temperature	^0C
ε_f	Fin effectiveness	