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COMPARATIVE STUDY AND PERFORMANCE ANALYSIS OF POROUS CIRCULAR PIN FIN ARRAY

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Abstract:-Heat transfer enhancement has become a great deal as the advancement of new technology. In this project, convective heat transfer by using porous circular pin fin array has been investigated. The main objective was to bring a new version of fin that would provide maximum cooling performance in heat engine taking less cost energy to consume. Porous circular shape of aluminum fin having fin height (h) =70 mm, base diameter (d) =10.2 mm, fin spacing (s) = 35 mm, hole diameter (d_2) = 4 mm, hole depth (H) = 10.2 mm of staggered arrangement has been selected for better performance. There are seven pin fins have used in this experiment. Heat transfer coefficient for free convection has been investigated. A comparative study of porous circular pin fin efficiency and circular pin fin efficiency has been calculated. This work has compared with the previous work done using circular pin fin shape without pores. It has found that with the same power for porous circular pin fin array has 12% higher efficiency and it has 6.02% higher heat transfer coefficient and material usage reduced 36.78% materials cost reduction 35% than existence. Heat transfer coefficient was increased with the increase of temperature difference between the walls and ambient.

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

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1. INTRODUCTION

Driving energy in a system of nature always allows to flow until equilibrium is reached. Heat leaves the warmer body or the hottest fluid, as long as there is a temperature. A heat exchanger follows this principle in its endeavor to reach equalization. With a plate type heat exchanger, the heat penetrates the surface, which separates the hot medium from the cold one very easily. It is therefore possible to heat or cool fluids or gases which have minimal energy levels. The theory of heat transfer from one media to another, or from one fluid to another, is determined by several basic rules. 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. In the study of heat transfer, a fin is a surface that extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The study of extended surface heat transfer in most of the cases comprises two factors that may conveniently be separated. One factor is only the movement of heat within the fin by conduction. The other factor considers how the fin exchanges heat with the surroundings. The amount of conduction, convection or radiation of an object determines the amount of heat it transfers. The 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. Adding a fin to an object increases the surface area becomes an economical solution to heat transfer problems. Finned surfaces are manufactured by extruding, welding, or wrapping a thin metal sheet on a surface. Heat transferred through the fin can be take place by conduction, convection and radiation. Sometimes heat transferred by radiation is neglected.

Heat transfer rate of pin fin is largely affected by the fin height (H/d), and other affecting factors include the 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 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, Gerald Vanfossen and Beard-Ann Brigham[1] studied the heat transfer by short pin-fins in staggered arrangements. According to their study, longer pin fins (H/d = 4) transfer higher heat than shorter pin-fins (H/d = ½ and 2) and the array-averaged heat transfer with eight rows of pin-fins slightly exceed that with only four rows.Their results also showed that the mean heat transfer coefficient on the pin surface would 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 favour the heat transfer, while substantially reducing pressure. Yusuf et al. [3] showed rectangular shape of fin more efficient than parabolic shape. Ramiz F. Babus'Haq 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 poly tetra fluro-ethane pin-fins, mild-steel pin-fins and duralumin pinfins respectively. Mohammad Shariar Hossain et al. [5] showed that pin fin array of cylindrical shape would more efficient than other types of fins.Khaled et al.[6] performed his work in which that had shown that conical pin fin was 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 was to investigate the heat transfer coefficient, fin efficiency and fin effectiveness for free convection using porous pin fin array based on the experimental results. These are

- Transfer of heat was considered as one dimensional flow.
- During the experiment, no heat was generated internally .
- Heat transfer by radiation was neglected.
- Across the whole surfacearea of the fin, convection was considered uniform.

2. EXPERIMENTAL FACILITIES

2.1 Experimental Apparatus

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

2.2 Test Section

The test section consist of an array of seven porous circular shape of aluminum fin having fin height (h) =70 mm, base diameter (d) =10.2 mm and fin spacing (s) =35 mm of staggered arrangement were used. Figure 1 represents the graphical illustration of the pin fin array which is drawn with the helpof SOLID WORKS. 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 laboratory of CUET.

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.

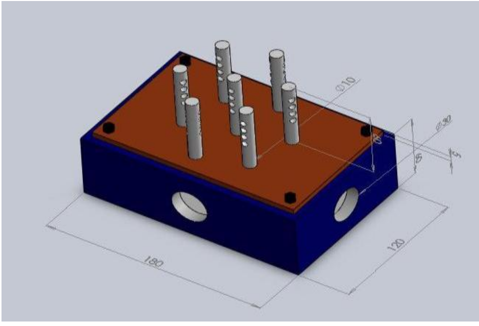

Fig 1: Porous circular pin fin arrangement\

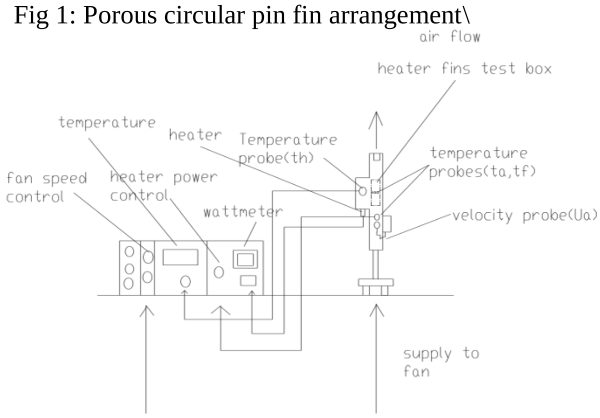

Fig 2 : Schematic diagram assemble of extended surface with electrical console.

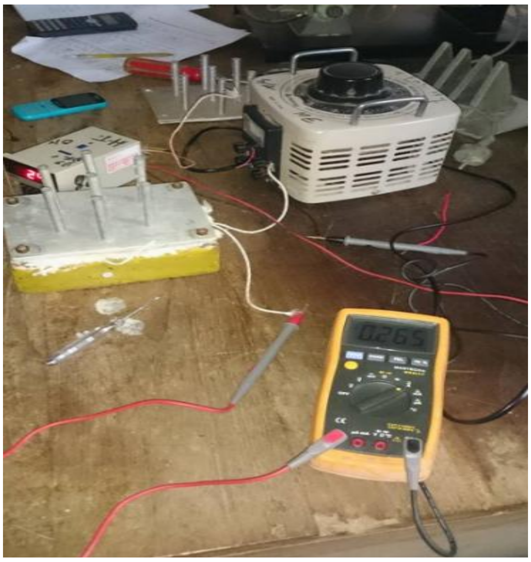

Fig. 3: Experimental set-up

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 from Eq(1)

$Q=VIcos\boldsymbol{\theta}$ …………….. (1)

Where V is voltage supplied, I is current and Cosθis Power factor ≈0.8 (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).

$$Q = h\, A_H(t_H-t_A) + h\,(t_{FAV}-t_A) \quad (2)$$

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

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 temperature and t_{FAV} is the average temperature along the length of fins which may be approximated as meantemperature of three temperature measured along length.

Heat transfer through pin fin was calculated as,

$Q_F = h\,A_F(t_{FAv}-t_A)$ ………………………… (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 atthe base temperature. Efficiency of the fin was calculated by

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

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. 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 Effectiveness,

$$\boldsymbol{\varepsilon} = \frac{Heat\ transfer\ rate\ from\ fin\ of\ base\ area\ A_b}{Heat\ transfer\ rate\ from\ surface\ area\ A_b}$$

$$\boldsymbol{\varepsilon}_f = \frac{Q_{fin}}{Q_{nofin}} = \frac{Q_{fin}}{hA(T_b-T_a)} \ldots \quad (3.5)$$

4 RESULTS AND DISCUSSINS

4.1 Heat Transfer Coefficient

Figure shows the change of heat transfer coefficient with the increase of temperature difference between the wall and ambient temperature for porous pin fin array. Along with enlarge surface area higher temperature difference helps heat transfer rapidly.

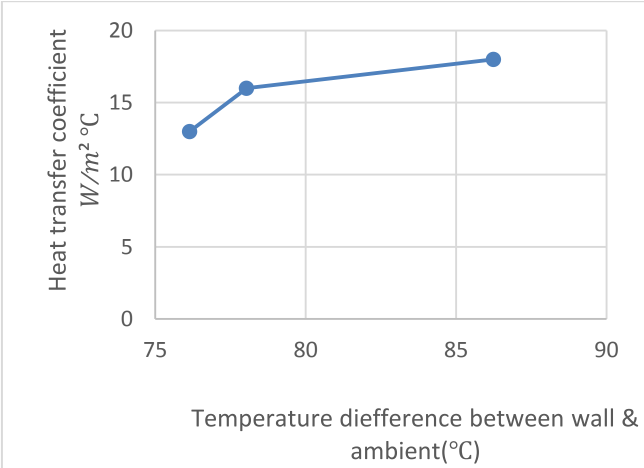

Fig. 4: Temperature difference vs. heat transfer Coefficient

From the above it is observed that, it is observed if temperature difference heat transfer would increase ultimately heat transfer coefficient would increase with the increase of 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 depicts the increase of efficiencywith the increases of temperature difference between wall and ambient.

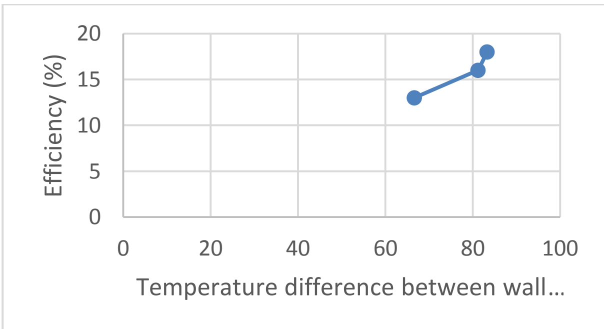

Fig. 5: Temperature difference vs. efficiency

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. As Effectiveness is increases this fin would be efficient in practical purposes .

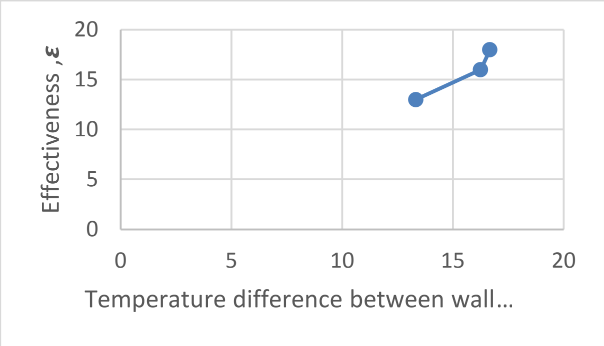

Fig. 6: Temperature difference vs. effectiveness

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

Test no.	Free convection			
	h (W/m^2 °C)	η (%)	ε_f	Q_F (watt)
1	76.15	66.67	13.33	7.85
2	78.04	81.25	16.25	11.62
3	86.25	83.33	16.67	14.63

4.4 Performance Evaluation.

The present result obtained from porous circular pin fin array was compared with the nonporous circularpin fin array.It is evident from this experiment that,porous circular pin fin is more efficient than nonporous circular pin fin array.From the result it was shown that efficiency was increased relative to nonporous circular pin fin array by 12% in free convection.Theheat transfer coefficient was improved by 5.16% for porous conical pinthan that of non-porous pin. Fin effectiveness also increased by 11.1% for porous circular pin. Khaled et al. [6] reported that, cylindrical pin fin array is 12.16% less efficient than circular pin fin array. Figure (7) shows the relation between the heat transfer coefficient and power supply for porous and nonporous circular pin fin array respectively. It had been shown that for any amount of power supply,porous circular fin had the higher heat transfer coefficient compared with nonporous pin. Figure (8)
representsthe 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.

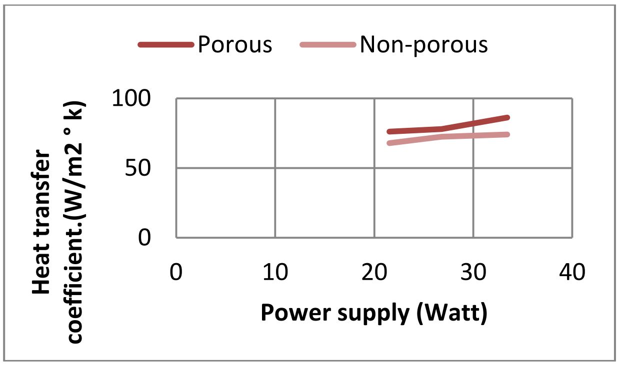

Fig. 7: Comparison of heat transfer coefficient between porous and Non-porous circular pin fin.

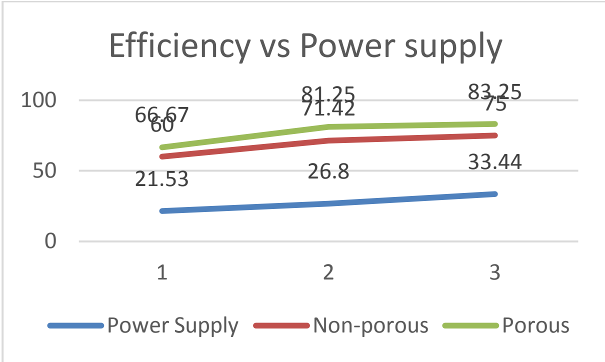

Fig. 8: Comparison between the efficiency (η_f%) of Porous and Non-porous circular pin fin

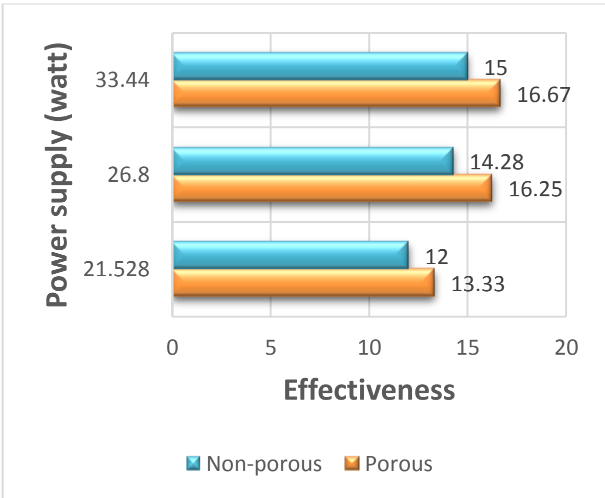

Fig. 9: Comparison of effectiveness between porous and Non-porous pin fin

5 CONCLUSION

An experimental study was performed to investigate the performance of seven circular pin fin array.Theseexperimental results were compared with a porouscircular 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 circular 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 6.02 % for porous circular pin than that of non-porous pin.
- Fin effectiveness was increased by 11.1% for porous circular pin.
- Efficiency was enhanced relative tonon porous circular pin fin array by 12% 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.	$W/m^2\,°C$
A_H	Area on heated wall	m^2
A_F	Area of all fins	m^2
t_H	Heated wall temperature.	°C
t_{FAV}	Averagetemperature	°C
η_f	Fin efficiency	