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EXPERIMENTAL STUDY TO MEASURE THE EFFECT OF FIN SHAPE ON THE FORCED CONVECTION HEAT TRANSFER

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Abstract

Forced convection, a mechanism where fluid motion enhances heat transfer, is significantly impacted by the design of heat exchanger fins. The fins improve the superficial effective area, thereby enhancing convectional heat transfer. The objective of this study to investigate experimentally how different fin shapes influence the efficiency of forced convection heat transfer. This study focused on the heat transfer forced convection by using three type fin shapes with different air velocity. Types of fins are rectangular, square and circle made of aluminium material. The cross section of the test device is square (12.5 × 12.5 cm), and length (100 cm). The location of the fins is in the middle the test device and the thermal heater is installed on base of the flat plate. The heater and fan are equipped by power providers. In this investigation the convection heat transfer is assumed with constant wall temperature. The experimental results demonstrated that regardless of air flow velocity and base temperature, The greatest temperature differential (ΔT) is produced by the circular fins, and it decreases as the flow rate rises. The circle fins give temperature difference 16.6% and 29% higher than for square and rectangular fins respectively. Also, The circle fins give thermal efficiency 29.5% and 38.6% higher than for square and rectangular fins respectively.

Keywords: Fin effect, Fin shape, Forced convection, Heat transfer.

1. Introduction

Convection heat transfer between heated surfaces and a cooler oceanic fluid is dictated by Newton's Law of Cooling, which asserts that the convection heat transfer rate is directly proportional to the temperature differential between the heated surface and the fluid, as well as the contact area between them [1, 2]. In order to maintain steady-state conduction, heat must be continuously dissipated to the environment through solids, walls, or boundaries. The effective surface area of a surface can be increased by attaching thin metal strips, known as fins, to the surface, which promotes convection heat transfer between the surface and the surrounding fluid [3, 4].

Heat exchangers are crucial in many industrial applications, including HVAC systems, automotive engines, and electronic cooling. The efficiency of these systems can be significantly improved by optimizing fin shapes [5, 6].

Fins, also known as extended surfaces, are industrial in various geometries depending on practical applications. Many engineering challenges require high-performance heat transfer components that are lighter, more compact, and cost-effective. Extended surfaces fins are widely used to increase heat transfer rates while optimizing weight, volume, and shape [7-9]. Recently, a multitude of studies have been released regarding methods for enhancing heat transfer, concentrating on natural convection, forced convection, and mixed convection across diverse cavity geometries [10-12].

Chandrakant et al. [13] a numerical and experimental analysis was carried out using two types of fin profiles. When comparing both profiles, the rectangular fin transferred a larger amount of heat than the triangular fin. Dhanawade and Dhanawade [14] an experiment was conducted to investigate heat transfer improvement over a horizontal flat plate surface using rectangular fin arrays with lateral square and circular perforations under forced convection. The results showed that the average heat transfer coefficient for the square-perforated fins was higher than that of fins with circular perforations of the same size.

Ehteshum et al. [15] an experimental analysis was conducted on the turbulent heat flow and convective heat transfer of solid and perforated fin arrays. The results showed that perforated fins enhanced the heat transfer rate compared to solid fins across all levels of heat input. Ibrahim et al. [16]. An experimental study was conducted on forced convection heat transfer in a duct using perforated fins, with results compared to those of solid fins. The experiment measured the heat transfer coefficient, efficiency, effectiveness of fins, and pressure drop at varying velocities, as well as with different sizes and numbers of perforations. The results indicated that perforated fins outperformed solid fins across all velocities.

Adhikari et al. [17]. The study presented that forced convection heat transfer exhibits an approximately linear connection between the Nusselt number and the Reynolds number. Chen et al. [18] demonstrate that adding square pin fins or plate fins can significantly increase waste heat recovery. The most suitable number of square pin fins equals 78, which raises the TEM's power generation by 24.14% when compared to plate fins.

Basyigit et al. [19] examined the effects of different fin types on radiated emissions from printed circuit boards in the S-C band. Their simulations compared the impact of

operating frequency on heat sinks with various designs, including parabola-plate fins, square-pin fins, and circular-pin fins with different orientations and placements. El-Said et al. [20] investigated experimentally how twist angles affect the thermo-hydraulic performance of square and hexagonal pins under forced flow. They discovered that raising the twist angle enhanced the heat transfer coefficient and Nusselt number. They also found that as the Reynolds number increased, hexagonal cross-sections generated a greater Nusselt number and decreased heat resistance.

Nilpueng et al. [21] examined how well heat sinks with various pin configurations performed thermally, and Haghighi et al. [22] showed that conical fins outperformed plate-fin heat sinks by more than 81% in terms of convective heat transfer efficiency. Karabulut [23] investigated the impact of rectangular baffle angles and heights on heat transfer and pressure drop in cross-triangular grooved rectangular ducts.

Kosdere et al. [24] focus on the effect of different fin geometry parameters on pure forced convection heat transfer. Parlak and Sertkaya [25] investigated experimentally the effects of forced convection heat transfer on the surfaces of pin plate heat exchangers with different geometries modified to the heat exchanger form Ali [26] explored the impact of rib configurations on heat transfer and fluid flow in a 2D horizontal channel. The objective of this study to develop and build fins of different shapes to determine the rate of heat transfer for each fin shape under forced convection and evaluate the outcomes which leads to choose the best fin shape for heat transmission.

2. Method

Fin design and fabrication

In the present experimental study, the forced convection heat transfer using three types of fins Rectangular, Circle-Section and Square-section made of pure aluminium metal for the same surface area as shown in Fig. 1. The dimensions and details of all fins shown in Table 1.

(a) (b) (c)

Fig. 1. Types of the fins.

Table 1. Geometric details of the fins.

	Fig. 1(a)	Fig. 1(b)	Fig. 1(c)
Type	Rectangular	Square	Circle
Cross section	2.74 cm × 0.5 cm	1.6 cm × 1.6 cm	d = 2 cm
Length	9 cm	9 cm	9 cm
Base of fin	10 cm × 10 cm	10 cm × 10 cm	10 cm × 10 cm
Distance between fins	1 cm	1 cm	1 cm
Fins No.	6	6	6

3. Experimental Setup

In order to investigate the heat transfer performance of the fin configurations, a controlled forced convection environment was established. The experimental procedure was carried out according to the following steps:

1. Set up the testing device to satisfy the condition of controlled forced convection environment as shown in Fig. 2.
2. The sample to be tested is installed on the base of the heater horizontally and normal to the air flow, and the temperature sensors are installed in their specified places on the sample and the sensor temperatures connected to the device Data Logger.
3. Setting the airflow device for the required air velocity.
4. Setting the heater device for the required current and voltage.
5. The thermocouples position in the inlet, outlet of the duct, the base of the heater and three thermocouples along the fin. The space between the thermocouple was 3 cm.

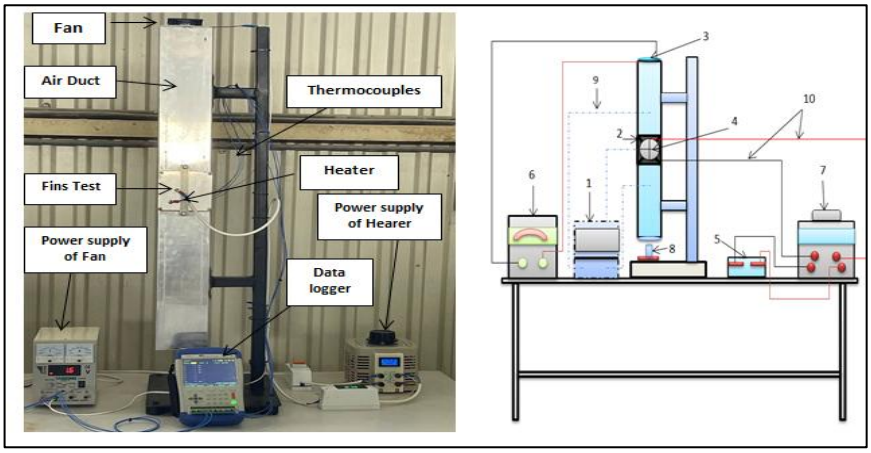

Fig. 2. Experimental test rig and diagram.
(1- Data Logger, 2- Heater, 3- Fan, 4- Fins Test, 5-Voltmeter and Ampere meter, 6-Power Supply of Fan, 7- Power Supply of Heater, 8- Digital Anemometer, 9- Thermocouple, 10-Electrical wires.)

3.1. Testing procedure

The experimental procedure was repeated for different operating conditions and fin geometries, ensuring systematic variation of current, voltage, airflow velocity, and fin shape to obtain comparative performance data.

- Attached the rectangular fin to a heated base.
- Set the current 1A and voltage 108 V for case-1
- Set the air velocity 1.5 m/s, 2.5 m/s and 3.5 m/s
- Measured the surface temperature of the fin and the temperature of the air before and after passing over the fin.

- Recorded data for a range of airflow velocities.
- Repeated 3, 4 and 5 for case-2 I=1.3 A and V=131 V
- Repeated 1,2,3,4 and 5 for square and circle fins.

3.2. Data analysis

Calculated the temperature difference, efficiency and temperature distribution along the fin for each fin shape.

Compared the results to determine which fin shape provides the highest temperature difference between inlet and outlet air.

Efficiency was calculated as follows [27].

$$\eta_f = \frac{Q_{actual}}{Q_{ideal}} \tag{1}$$

$$Q_{actual} = \sqrt{hPkA_c}\ \left((T_b - T_\infty) \cdot Tanh\,(mL)\right) \tag{2}$$

$$Q_{ideal} = IV \tag{3}$$

$$h = \frac{Q_{ideal}}{A_f\,(T_b - T_\infty)} \tag{4}$$

$$m = \sqrt{\frac{hp}{k\,A_c}} \tag{5}$$

$$T_\infty = (T_e + T_i)/2 \tag{6}$$

4. Results and Discussion

This section compares the coefficient heat transfer coefficient for different types of fins utilizing three different velocities values. The experimental results are investigated for the measurements of air velocity, entrance and output air temperatures, and fin temperature at several predetermined points.

Figures 3-5 show the profiles of the variation of difference between the into and out temperature of the air flow with the base temperature for three different fins shape for case-1. The many trends of the temperature difference profile observed in these figures were as follows:

- In all cases shown in Figs. 3-5 regardless of the fin shape, the measured temperature difference (ΔT) decreased as the flow rate increased. This occurred because the exit fluid temperature inside the heat sink decreased with the higher flow rate. From these figures it can be seen that the measured ΔT was 11.9 ℃ , 10 ℃ and 8.5 ℃ for circle, square and rectangular fin respectively for air velocity 1.5 m/s, which is reduced to 8 ℃, 6. 9 ℃ and 6 ℃ respectively for air velocity 3.5 m/s.
- As shown in all cases shown in Figs. 3-5 regardless of air flow velocity and base temperature, the circle fin gives the highest temperature difference (ΔT) which was 16.6% and 29% higher than for square and rectangular fins respectively for air velocity 1.5 m/s.

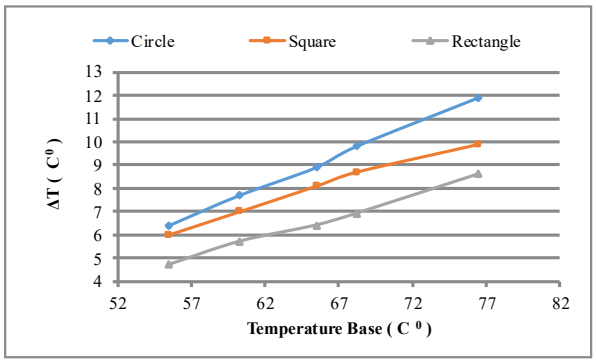

Fig. 3. Variation of temperature difference with base temperature at V=1.5 m/s.

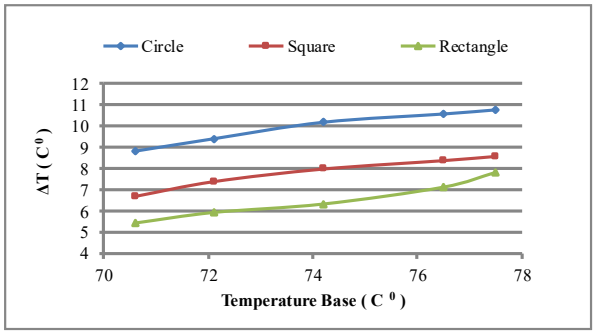

Fig. 4. Variation of temperature difference with base temperature at V=2.5 m/s.

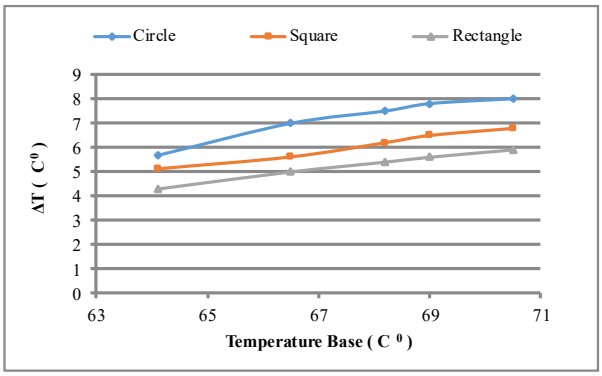

Fig. 5. Variation of temperature difference with base temperature at V=3.5 m/s.

Figures 6-8 shows the variation of temperature difference with the base temperature for different fin geometry and air velocity for case-2. As shown in these figures the trend is the same for case-1. Also, the temperature difference increase with increase current and voltage of heating coil due to increase the base temperature according to increase of heat sink. From these figures it can be seen that the measured ΔT was 15.4 ℃, 13 ℃ and 10.5 ℃ for circle, square and rectangular fin respectively for air velocity 1.5 m/s, which is reduced to 11.8 ℃, 9 ℃ and 8.5 ℃ respectively for air velocity 3.5 m/s.

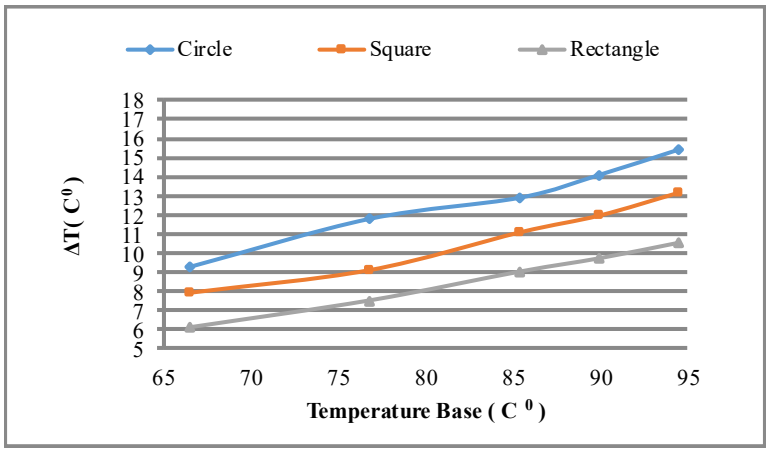

Fig. 6. Variation of temperature difference with base temperature at V=1.5 m/s.

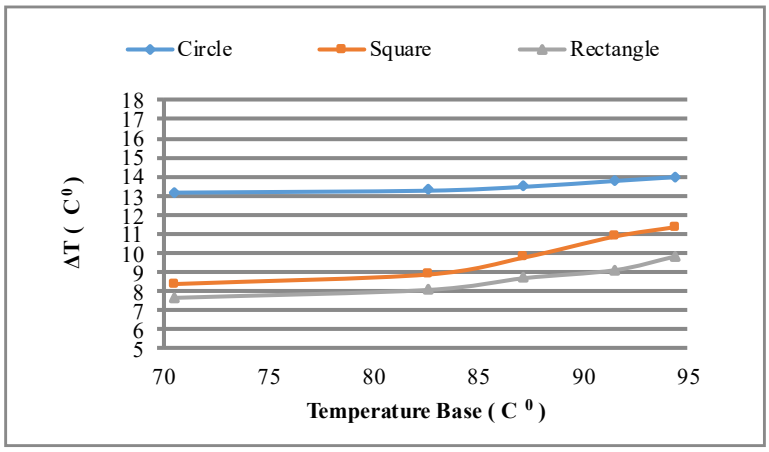

Fig. 7. Variation of temperature difference with base temperature at V=2.5 m/s.

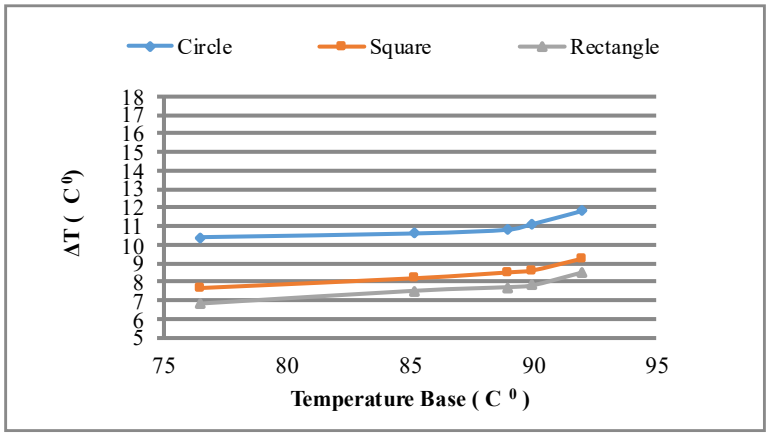

Fig. 8. Variation of temperature difference with base temperature at V=3.5 m/s.

Figures 9-11 shows the variation of efficiency with the base temperature for different fins. As shown in the figure as the base temperature increases, the efficiency of fins increases due to enhanced heat transfer. The shape of the fins has a significant effect on efficiency. Optimized designs usually show better efficiency at circle shape. The circular geometry promotes smoother airflow around the fin, reducing turbulence and enhancing convective heat transfer.

In contrast, rectangular and square fins can create more stagnation points, which may hinder heat transfer. Figure 9 shows that the efficiency of circle fin increased from 19% at base temperature 55 ℃ to the value 23% at base temperature 77 ℃. Also, the figure show that the values of fin efficiency at base temperature 77 ℃ for rectangle, square and circle were 16.2%, 17.2% and 23% respectively for air velocity 1.5 m/s. Moreover Figs. 10 and 11 show the relation between fin efficiency and the base temperature for different air velocities. As show in these figures the fin efficiency decreases with increase of air velocity due to decrease the temperature of the fin.

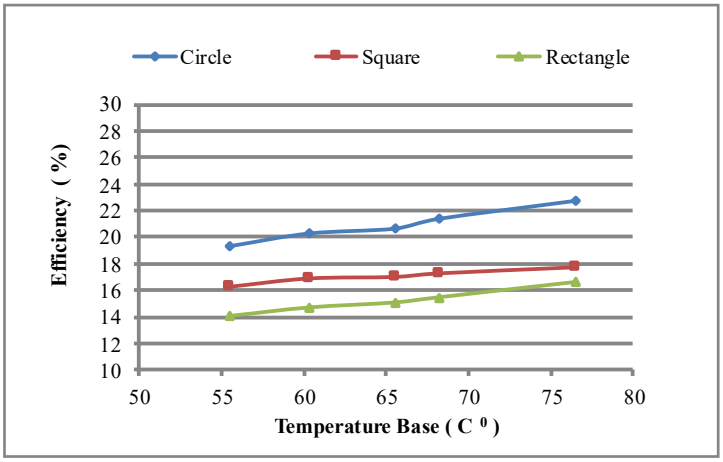

Fig. 9. Variation of efficiency with base temperature at V=1.5 m/s.

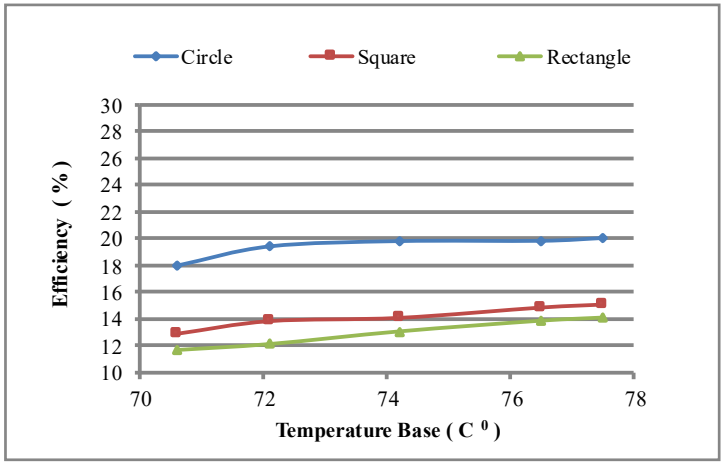

Fig. 10. Variation of efficiency with base temperature at V=2.5 m/s.

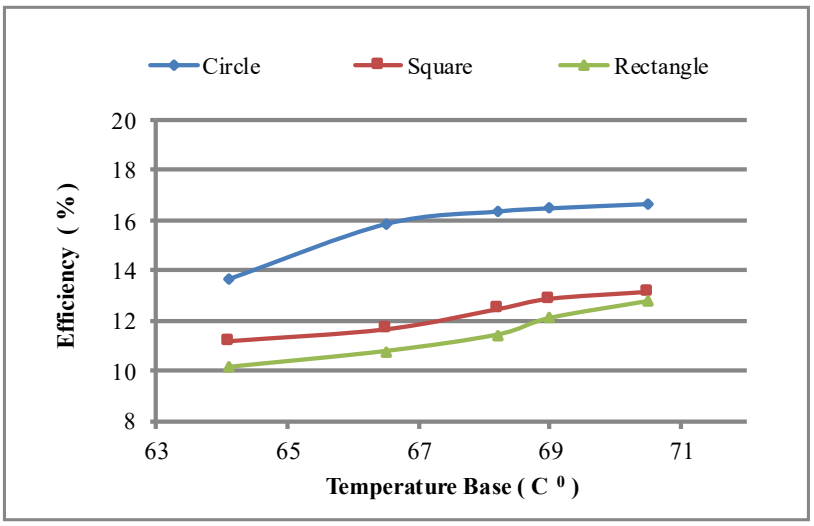

Fig. 11. Variation of efficiency with base temperature at V=3.5 m/s.

Figures 12-14 show the variation of efficiency with the base temperature for different fins for case-II. As shown in these figures the trend is the same for case-1. As shown in the figures as the base temperature increases, the efficiency of fins increase due to increase fin temperature. Also, the shape of the fins has a significant effect on efficiency and the better efficiency for circle shape.

As air velocity increases, the convective heat transfer coefficient typically rises. This enhanced convection improves the rate at which heat is removed from the fin surface, leading to higher efficiency. At lower air velocities, the boundary layer (the layer of fluid in immediate contact with the fin) can become thicker, which insulates the fin and reduces heat transfer. Higher velocities keep the boundary layer thinner, improving heat transfer efficiency.

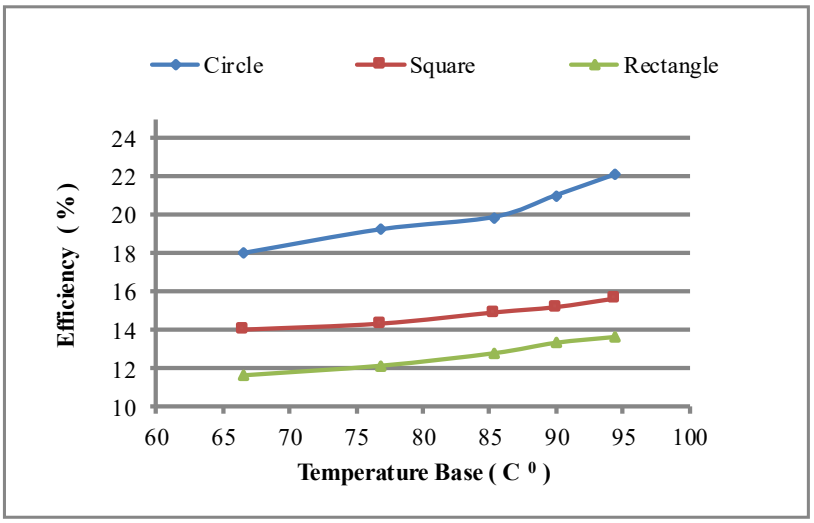

Fig. 12. Variation of efficiency with base temperature at V=1.5 m/s.

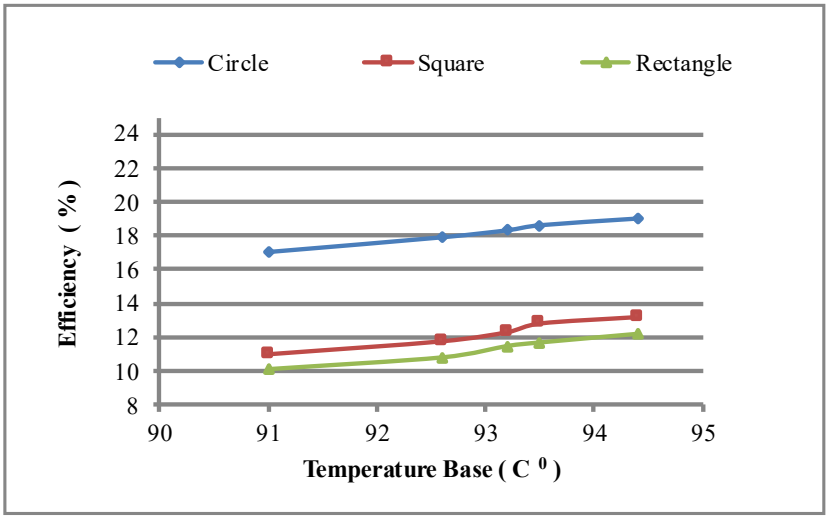

Fig. 13. Variation of efficiency with base temperature at V=2.5 m/s.

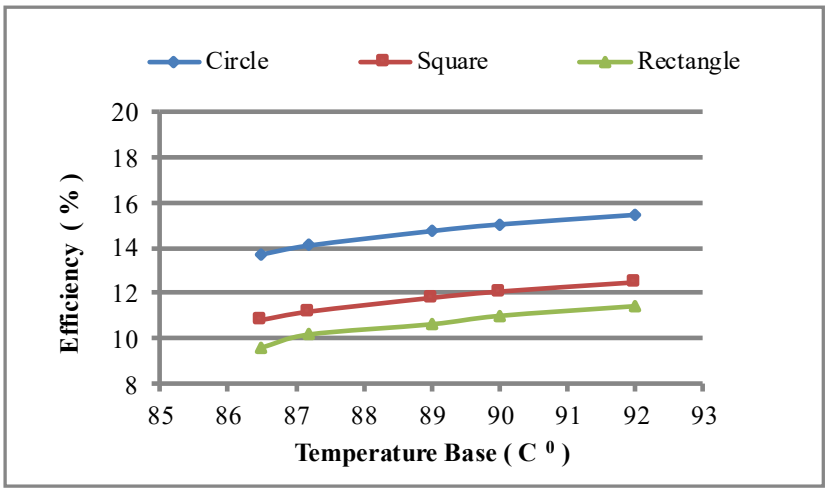

Fig. 14. Variation of efficiency with base temperature at V=3.5 m/s.

Figures 15-17 shows the temperature distribution along fins for different shapes rectangular, circular, and square. As shown in the figures the temperature along the length decreases from the base to the tip. For circle fin the tip experiences a sharper temperature drop compared to square and rectangular fins because of the smaller perimeter exposed to heat loss. Higher air velocities can lead to greater temperature differences between the fin and the surrounding air. Figure 15 shows that the fin temperature drops from the base temperature (92 °C) to tip temperature which were 79 °C, 74 °C and 68 °C for rectangle, square and circle fin respectively. Also, Fig. 16 and Fig. 17 show the same trend of the temperature drop. Moreover, as shown in these figures the tip temperature was low as compared to Fig. 15 due to increase the air velocity which lead to increase the convection heat transfer from the fin.

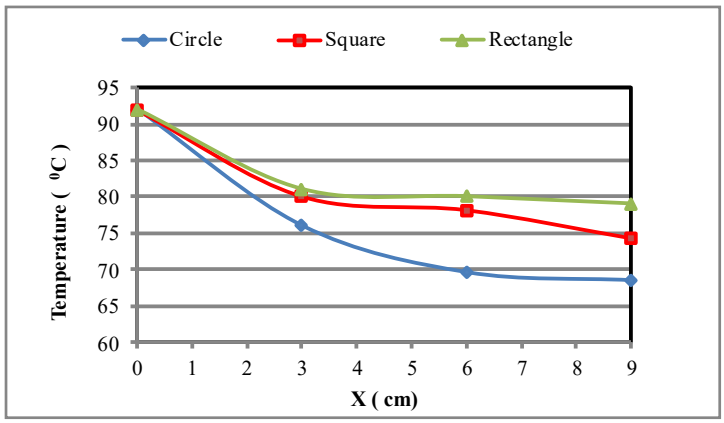

Fig. 15. Variation of fin temperature at V=1.5 m/s and Tb=92 °C.

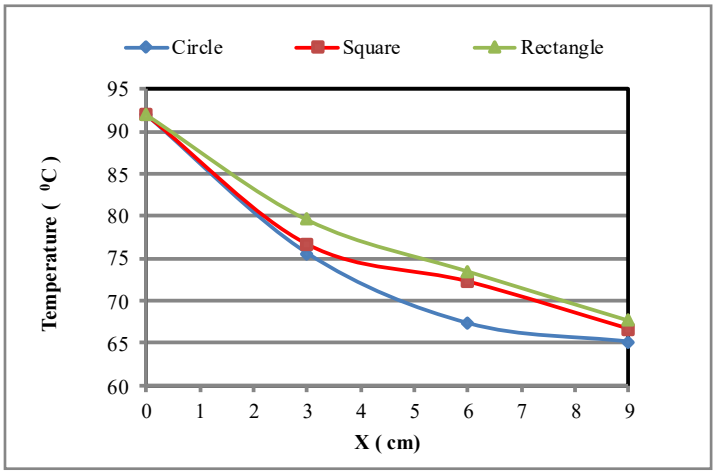

Fig. 16. Variation of fin temperature at V=2.5 m/s and Tb=92 °C.

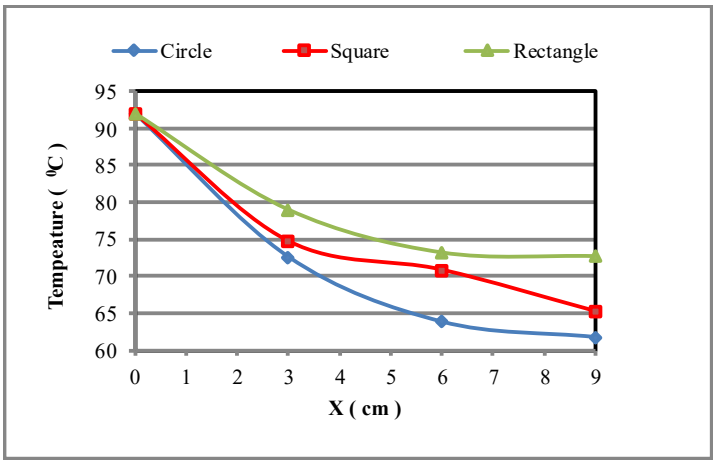

Fig. 17. Variation of fin temperature at V=3.5 m/s and Tb=92 °C.

5. Conclusions

The study conducted an experimental analysis about the effect of fin shape on the forced convection heat transfer. The study provided the following conclusions:

- For circle fin the tip experiences a sharper temperature drop compared to square and rectangular fins.
- Higher air velocities can lead to greater temperature differences between the fin and the surrounding air, further enhancing efficiency.
- The shape of the fins has a significant effect on efficiency. Optimized designs show better efficiency at circle shape.
- Regardless of air flow velocity and base temperature, the circle fin gives the highest temperature difference (ΔT).
- Regardless of the fin shape, the temperature difference (ΔT) decreased as the flow rate increased.
- The circle fins give temperature difference 16.6% and 29% higher than for square and rectangular fins respectively.
- The circle fins give thermal efficiency 29.5% and 38.6% higher than for square and rectangular fins respectively.

Nomenclatures

A_C	Cross sectional area of the fin, m^2
A_f	Surface area of the fin, m^2
C_p	Specific heat of air
H	Convective heat transfer coefficient, ($W/m^2 \cdot K$)
I	Current, A
K	Thermal conductivity, (W/m·K)
L	Length of fin, m
P	Perimeter of cross section, m
T_b	Base temperature, ℃
T_∞	Air Temperature, ℃
T_i	Inlet air Temperature, ℃
T_e	Exit air Temperature, ℃
V	Velocity, m/s

Greek Symbols

η_f	Fin efficiency
ρ	Air density, kg/m^3

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