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Development and Performance Evaluation of Heat Transfers on Different Fin – Shapes

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Abstract*:* This research work focused on comparing the effect of fin shapes on the rate of heat transfer. A Test Rig was fabricated for comparing the rate of heat transfer through fins of different geometries. Three geometries of fin, namely: Square fin, Circular and triangular fin, were considered. The visualization tools for carrying out the analysis were efficiency and effectiveness. Triangular fin has efficiency of 90.55 %; square fin 68.54 % whilst circular fin is 59.95 % efficient. Square fin at various temperatures and time considered had the highest values for the effectiveness, followed by triangular and circular fins. It was found that triangular fin is the most efficient fin geometry whilst circular fin is the least..Also, square is the most heat enhancing surface as it had highest effectiveness values, whilst circular fin is the least and could be considered an insulator as it effectiveness value is less than unity ($\varepsilon_{fin} < 1$)..

Keywords: heat transfer rate, fins, geometries, efficiency, effectiveness

1. Introduction

Heat has always been perceived to be something that produces in us a sensation of warmth; according to Yunus *et al*., (2011), heat is the form of energy that can be transferred from one system to another as a result of temperature difference, Excessive heat retains by a system could cause short-term overheating, long-term overheating, thermal shock, graphitization, cracking, dissimilar metal weld, malfunctioning and ultimately failure (e.g. rupture of pipes as in the case of steam thermal plants and discomfort in case of human being) **Ayodeji, O (2011)**' **Yunus, A. C & Michael, A. B. (2012):**.. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length) in the direction; the larger the temperature gradient, the higher the rate of heat transfer Yunus *et al*., (2011).

Fins are used to enhance convective heat transfer in a wide range of engineering application, and offer a practical means for achieving a large total heat transfer surface area without the use of excessive amount of primary surface area. The amount of conduction, convection or radiation of an object determines the amount of its heat transfer.. by increasing the temperature difference between the system and the environment, increasing the convection heat transfer coefficient or increasing the surface area of the system increases the heat transfer. However, for a given Log-Mean-Temperature-Difference (LMTD), it is not economical or feasible to change the first two options, adding a fin to a system increases the surface area and can sometimes be an economical solution to heat transfer problem **Yunus, A. C & Michael, A. B. (2012):**

Materials and Design Methods

The experiment was carried out on apparatus, termed Test Rig, fabricated locally at Mechanical Engineering Workshop, Rufus Giwa Polytechic, Owo, Ondo State It consisted of a 100 mm effective length of circular Copper duct/capillary, on which the fins were arranged at equal pitch of 10. 6 mm; the capillary tube was held between centres of an MS barrel, which served as the casing, by two Teflon-made-lid having holes drilled at their centres to serve as steam inlet and discharge chutes. A delivery pipe, connected between one of the capillary tubes and the pressure pot, served as a source of steam inlet to the Test Rig. The Pressure pot was mounted on Kerosene stove which served as the source of heat. Positioned at four locations on the Test Rig were five (5) Thermocouples to read the temperatures at the designated positions. These temperatures were

- steam exit temperature from the pressure pot, t_{C1}
- steam inlet temperature to the Test Rig, t_{C2} ,
- Fin Base Temperature, t_{C3}
- Fin Tip Temperature, t_{C4} and
- Steam Exhaust Temperature, t_{C5}.

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Other temperatures recorded were the initial and final ambient temperatures. Fig.1,Fig. 2,Fig. 3 and Fig. 4 shows the Test Rig, Square Fins ,Triangular Fins and Circular Fins respectively, below shows schematic view of these set up

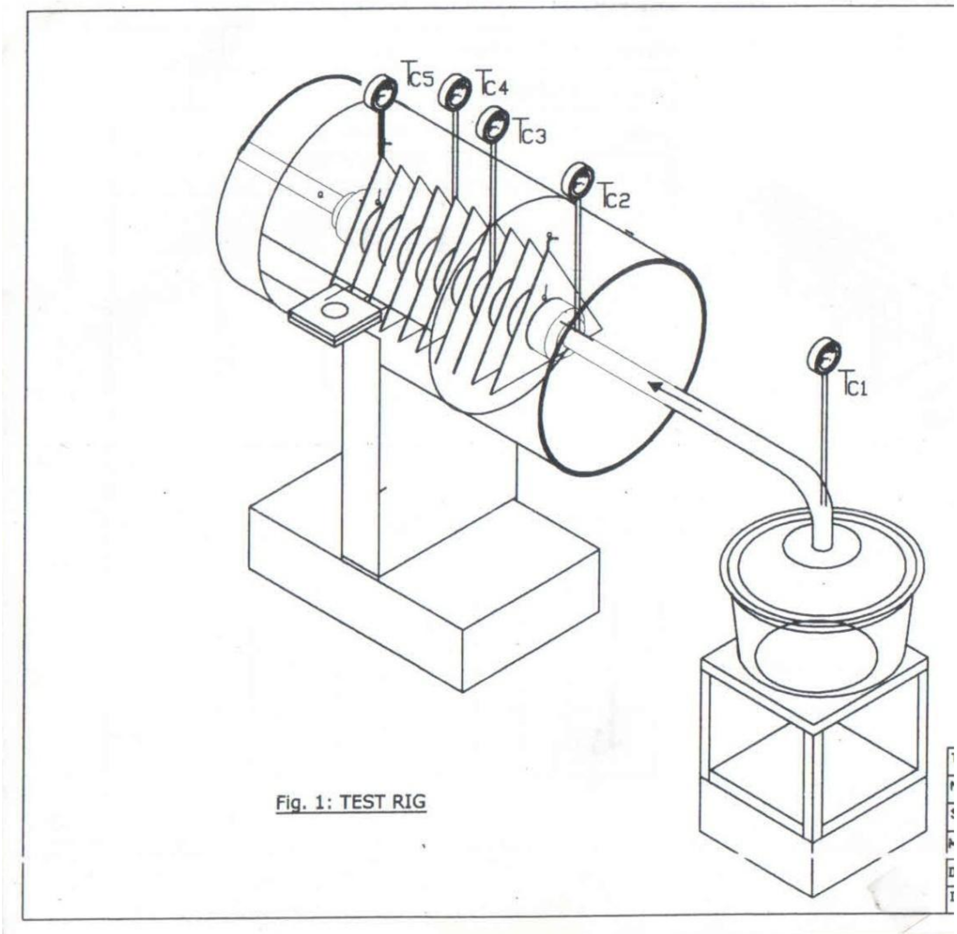


Fig. 1: TEST RIG

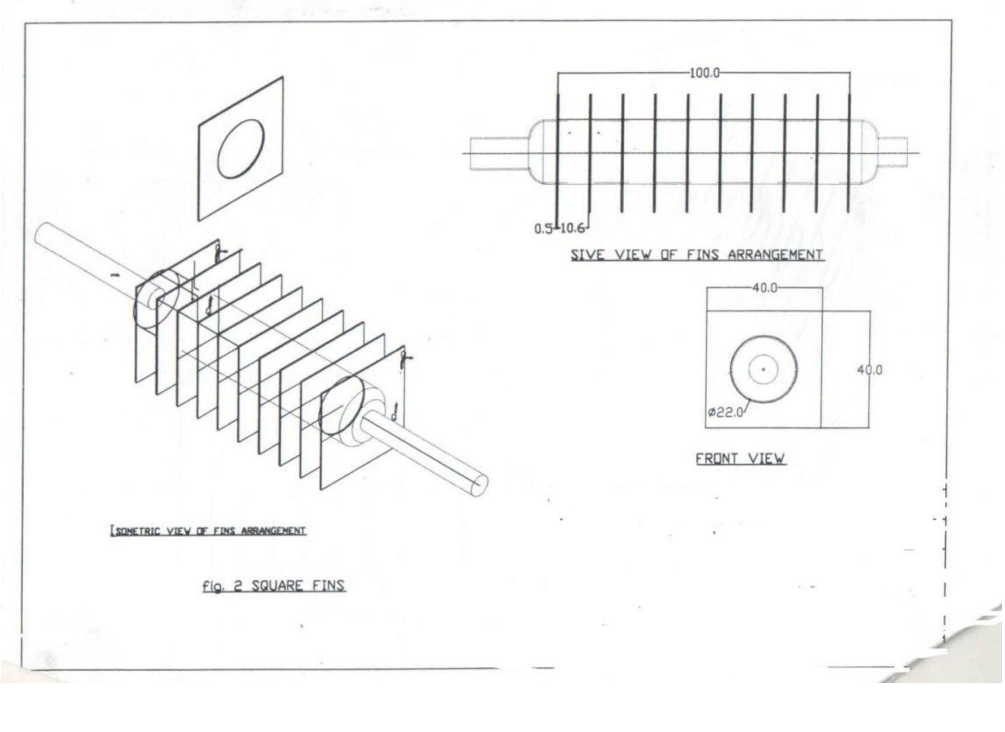
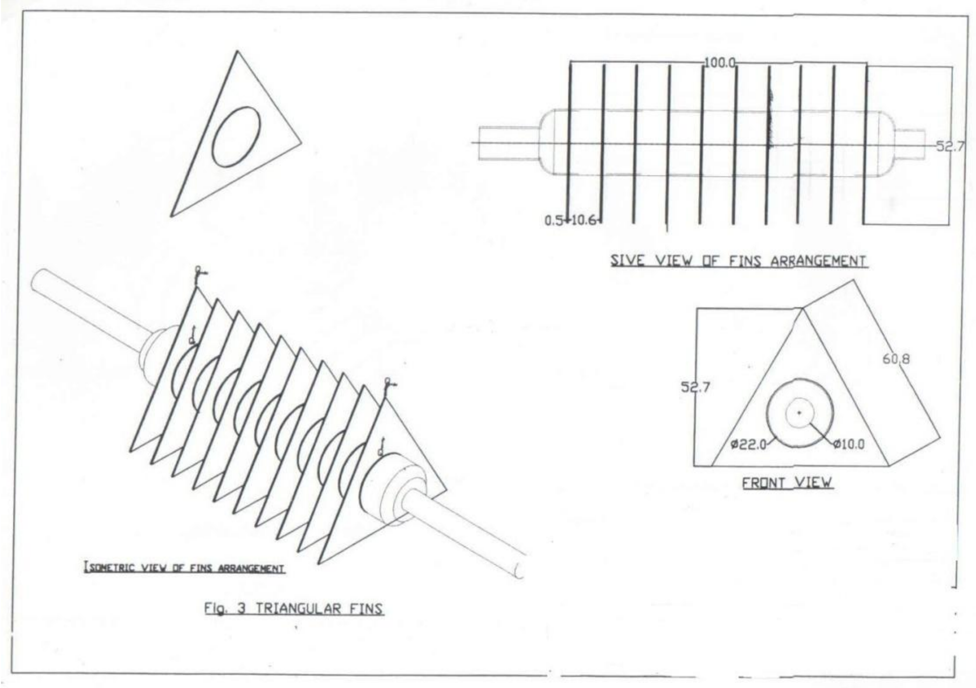
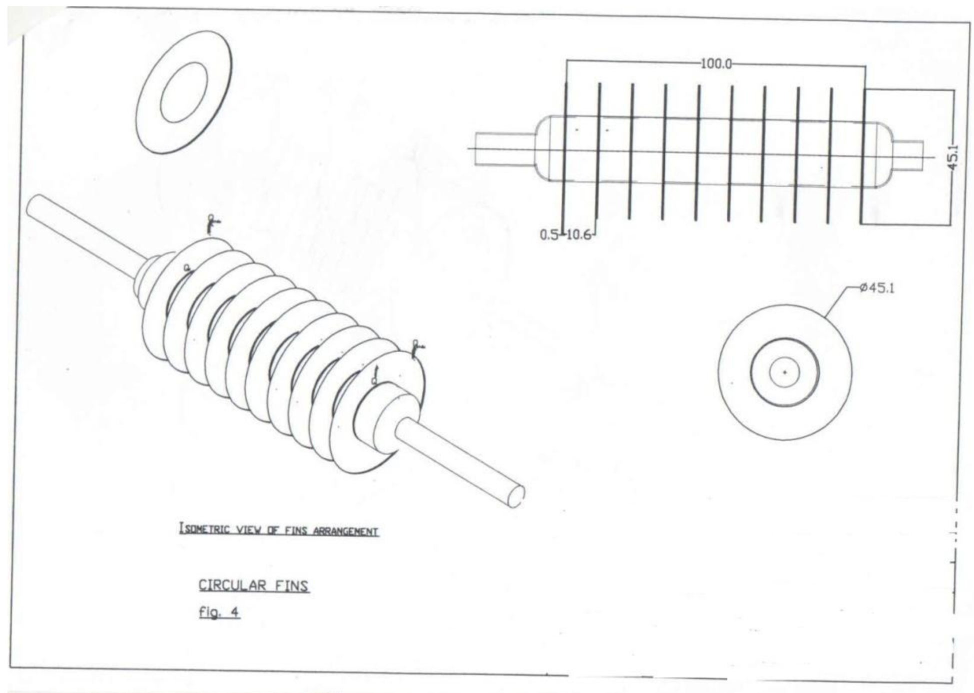


fig. 2 SQUARE FINS





Experimental Procedures:

The experimental procedure are

1. Fill a clean pressure pot with fresh clean water
2. Arrange 10 pieces of fin of the same shape (e.g square fin) along the length of the capillary tube at a fin pitch of 10.6 mm
3. Secure the capillary tube carrying the fins between the centres of Teflon-made lids fixed at the two ends of M S pipe
4. Insert thermocouples at the designated holes as shown in fig. 1. Above
5. Connect the Test Rig to the pressure pot using Φ6.35 mm copper capillary tube , this serves as steam inlet port

6. Mount the water-charged- pressure Pot on ignited stove
7. Record the initial ambient temperature with a thermometer, $T_{\infty 1}$
8. Raise the water to boiling
9. Supply steam to the Test Rig and allow a steady flow to continue for 5 minute, record the appropriate temperatures
10. Repeat procedure (9) above for 10, 15 and 20 minutes durations
11. Record the final ambient temperature, $T_{\infty 2}$
12. **Repeat the experimental procedure for the other fin shapes (circular and triangular fins)**

Result and Discussion

Table of Fin Efficiencies

Fin Shape	Heat Rate (Q_{fin})	Efficiency
Square	$\sqrt{PhkA_{CS}}\theta_o \left[\frac{Tanh(mL) + h/_{km}}{1 + \left(\frac{h}{km}\right) Tanh(mL)}\right]$	$\frac{\sqrt{phkA_{CS}}}{hA_{fin}} \cdot \left[\frac{Tan\,h(mL) + h/_{km}}{1 + \left(\frac{h}{km}\right) Tan\,h(mL)}\right]$
Triangular	$b\sqrt{2}hky.\,\theta_o.\frac{I_i(2B\sqrt{L})}{I_o(2B\sqrt{L})}$	$\frac{b\sqrt{2}hky}{hpl}.\frac{I_i(2B\sqrt{L})}{I_o(2B\sqrt{L})}$
Circular	$\frac{4\pi r_o h}{m}.\theta_o.\frac{I_i(mr_o)k_i(mr_o) - k_i(mr_e)I_i(mr_o)}{I_o(mr_o)k_i(mr_e) + I_i(mr_e)k_o(mr_o)}$	$\frac{4\pi r_o}{mA_f}.\frac{I_i(mr_o)k_i(mr_o) - k_i(mr_e)I_i(mr_o)}{I_o(mr_o)k_i(mr_e) + I_i(mr_e)k_o(mr_o)}$

Source: **Yunus, A. C & Michael, A. B. (2012)**

4.3.2 Fin Effectiveness (ε_{fin})

Effectiveness of fin is the ratio of the heat transfer rate to the heat transfer rate that would exist without fin; mathematically, it can be expressed as:

$$\varepsilon_{fin} = \frac{Q_{with\ fin}}{Q_{without\ fin}}$$

For Square fin, the effectiveness is given by:

$$\varepsilon_{fin} = \frac{hA_{fin}\,\eta_{fin}\,[T_{C4} - T_\infty]}{h_c A_{no\ fin}\,[T_{c3} - T_\infty]}$$

$$\text{Or} = \frac{hA_{fin}\,\eta_{fin}}{h_c A_{no\ fin}}\left[\frac{T_{C4} - T_\infty}{T_{c3} - T_\infty}\right] \qquad 45$$

$$\varepsilon_{fin} = \frac{\sqrt{phkA_{cs}}(T_{c4} - T_\infty)\left[\frac{Tan\,h(mL) + h/_{km}}{1 + \left(\frac{h}{km}\right) Tan\,h(mL)}\right]}{h_c A_{cs}(T_{c3} - T_\infty)}$$ **[Yunus, A. C & Michael, A. B. (2012)]s**

The use of fin on a surface, as an enhanced surface, cannot be recommended unless the enhancement in heat transfer justifies the added cost and complexity associated with the fins (Yunus & Afshin, 2011). The idea of using effectiveness to test the performance of fin enables materials to be classed as either an insulator or heat sink. An effectiveness of ε_{fin} =1 indicates that the addition of fins to the surface does not affect heat transfer at all. That is, heat enhanced to the fin through the base area is equal to the heat transfer red from the same area to the surrounding medium. An effectiveness of ε_{fin} <1 depicts that the fins function as insulation, slowing down the heat transfer from the surface. An effectiveness of ε_{fin} >1 indicates that the fins are enhancing heat transfer from the surface, as they should (Yunus & Afshin, 2011 and Rajput, 1999)

Data Analysis

The developed Test Rig was tested with three (3) fin shapes (Square, triangular and circular). Five kinds of temperatures were recorded with thermocouples mounted along the Test Rig, apart from the ambient temperature. Tables 2a – 2c Show the measured, calculated parameters and obtained experimental results

Table 2a: Measured and Calculated Data for Circular Fin

S/N	Time (minutes)	T_{ci} (°C)	T_{c2} (°C)	T_{c3} (°C)	T_{c4} (°C)	T_{c5} (°C)	η_{fin}	ε_{fin}
1	0.00	28.00	28.00	28.00	28.00	28.00	0.5995	
2	2.00	46.00	47.00	48.00	48.50	50.00	0.5995	0.6080
3	4.00	47.00	49.00	50.00	50.20	50.50	0.5995	0.5816
4	6.00	48.00	68.00	70.00	72.50	72.50	0.5995	0.7448

5	8.00	54.00	88.00	85.50	91.00	96.00	0.5995	0.8537
6	10.00	55.00	99.00	86.00	92.00	97.00	0.5995	0.8437
7	12.00	56.00	100.00	87.00	93.00	98.00	0.5995	0.8438
8	14.00	57.20	100.00	87.40	93.10	98.40	0.5995	0.8439
9	16.00	58.00	100.00	87.60	93.50	99.00	0.5995	0.8440
10	18.00	60.00	100.00	90.00	94.00	100.00	0.5995	0.8441

Table 2b: Measured and Calculated Data for Square Fin

S/N	Time (minutes)	T_{ci} (°C)	T_{c2} (°C)	T_{c3} (°C)	T_{c4} (°C)	T_{c5} (°C)	η_{fin}	ε_{fin}
1	0.00	26.00	26.00	26.00	26.00	26.00	0.69	
2	2.00	46.00	53.00	46.00	46.50	48.00	0.69	61.48
3	4.00	47.00	74.00	60.00	68.00	68.00	0.69	61.49
4	6.00	48.00	75.00	68.00	69.00	72.00	0.69	61.50
5	8.00	49.00	76.00	69.00	70.00	73.00	0.69	61.51
6	10.00	49.50	76.00	69.20	70.60	74.60	0.69	61.52
7	12.00	50.00	77.00	70.20	71.30	74.50	0.69	61.53
8	14.00	54.00	79.00	72.00	73.10	77.10	0.69	61.54
9	16.00	55.00	80.00	72.40	73.10	77.10	0.69	61.54
10	18.00	55.00	80.00	72.00	73.00	74.40	0.69	61.55

Table 2c: Measured and Calculated Data for Triangular Fin

S/N	Time (minutes)	T_{ci} (°C)	T_{c2} (°C)	T_{c3} (°C)	T_{c4} (°C)	T_{c5} (°C)	η_{fin}	ε_{fin}
1	0.00	27.00	27.00	27.00	27.00	27.00	0.91	
2	2.00	42.00	38.00	37.00	40.00	44.00	0.91	28.18
3	4.00	43.00	45.00	44.00	46.00	50.00	0.91	28.18
4	6.00	44.00	40.00	44.00	50.00	52.50	0.91	28.19
5	8.00	45.00	41.00	41.40	50.20	54.00	0.91	28.59
6	10.00	46.00	46.20	47.00	49.00	50.00	0.91	28.60
7	12.00	47.00	47.80	50.00	50.10	50.20	0.91	28.62
8	14.00	47.50	50.00	52.20	52.50	54.00	0.91	28.64
9	16.00	50.00	52.50	54.00	55.60	56.00	0.91	28.66
10	18.00	52.00	54.00	56.50	57.00	58.70	0.91	28.68

Conclusion

In general, the results of the analysis are quite encouraging as they offer solutions to why certain fin geometries are being preferred to other in enhancing heat transfer in engineering applications, but more could still be done to improve on this by evaluating other fin geometries. Computer application packages should be used to further development in this system.

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