An experimentally study the Influence of Axis Ratio of the Elliptical Fin Shape to the Heat transfer Performance by Natural Convection

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Abstract. All chemical petroleum and mechanical engineering industries specialize in how to transfer heat through heat exchangers with high efficiency, less cost, and volume by extended solid surface to increase the heat transfer performance. This prominent solid body is called fin. The rate of heat transfer depends on the fin materials, shapes, size parameters, and surface area of the fin. Elliptical annular fins are recommended for use in heat transfer from the primary surface of the fins base. The heat transfer using fin is expressed in terms of fin effectiveness, fin efficiency and thermal resistance of the variation of ambient temperature has been studied for a wide range of heat temperature from 100 to 260 ^{o}C. This article aims to study the process of influencing the change of the ratio of the oval fin diameters on the efficiency of heat transfer from the surface of this fin. This is done by different axis ratio (a\b) at natural convection in which the results showed that there is an optimum major and minor axis ratio for elliptical fin at (a/b = 2.65); that has a high performance of heat transfer by free convection than the other ratios. Also, the fin heat transfer performance has a significant change due to the axis ratio of elliptical fin shape for this wide temperature range used with overall fin efficiency of up to 60%.

Keywords: Heat transfer performance, elliptical fin, natural convection, axis ratio.

1 Introduction

Through the study survey in previous research and studies, we did not find research that examined the effect of the ratio of the primary axes of the elliptical shape of the fin to the heat transfer from the surface of the fin or the surface of the tubes surrounding it. Rather, we found that there are somewhat recent studies dealing with calculations for the performance of heat transfer based on computer software and numerical with a few practical experiments for several shapes of fins, the most important of which is the circular, oval, and rectangular shape, and this is explained in the manual for what these presented. Behnia et al. [1] numerically compare the heat transfer of different geometries using the usual circular, square, rectangular, and elliptical. [2] conducted experiments to compare the thermal performance of heat sinks with different fin designs. They evaluated the thermal performance by comparing the heat resistance of the medium-speed heat sink and the equivalent pressure drop. They observed elliptical fins at high speeds and circular fins at medium speeds. [3] had empirical results demonstrated the operational of pin-fin fan-sink assemblies. They used various geometries and found that the

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cylindrical hooks provided a reasonable performance. In addition, they found that sink heat resistance inversely proportional to applied pressure.

In [4] the performance of longitudinal, spine and annular fins were examined, whereas [5] investigated the performance of annular fins of different profiles according to the local heat transfer coefficient; in which the heat transfer efficiency for circular and elliptical annular fins was analyzed for different temperature ranges and environmental conditions. Elliptical efficiency is found better, if space constraints of a particular direction are present, whereas the perpendicular direction of the elliptic fins is relatively unlimited [6].

In [7] a comparative study of elliptical and circular fins made of the same type of metal; that shows the numerical results show a higher distribution of isotherms and an increase in the temperature distribution in the main axis of the elliptical fin. The experiment showed that the surface temperature of the elliptical fin inversely varied with the fin along the main axis. An empirical study to investigate the effect of three [elliptical, circular, and diamond] fins on heat transfer performance in natural convection and it is interesting that the elliptic fin shape performs more heat transfer than the other [8]. It was found through a historical survey of the research topic That no study investigated the effect of the change of the axial diagonals of the oval fin in particular or in general and the absence of a theoretical study, but only the analysis of the distribution of heat transfer on the surface of the fin was found by numerical analysis. So this research will bring us very close to the fact that the heat transfer is distributed on the surface and also the effect of the change in fin diameters with the ratio between them on the heat transfer performance of the fin.

2 Experimental Methods

In this present work, natural convection heat transfer of elliptic annular fin with different major and minor axis ratios (a/b) was studied experimentally. Eight sets specimens having constant elliptical annular fin the area of a cross-section with different aspect axis (a/b) ratios of 2,2.21, 2.44, 2.65, 2.88,3.13,3.38 and 3.65 at constant thickness were tested experimentally as shown in figure 1. The materials of fins and the fins base are 6061- an alloy of aluminum because of its good thermo-physical characteristics and small density and relatively low price. Following constant thermophysical properties of aluminum are used in our calculations

$$\rho = 2719 \text{ kg}/m^3, \qquad \text{Cp} = 871 \text{ j/kg k.,} \qquad \text{K} = 233 \text{ w/m. k.}$$

The specification of the elliptical fin is summarized in the next two tables.

Table 1. specification of fins and heat exchanger

Specifications for fins and heat exchanger	
Fin material	6061-Alloy
Fin thickness	1 mm
Heater type	Tubular
Heater temperature controller	PID for (J) type
Circular pipe material	Stainless steel
Pipe thickness	1 mm

Pipe diameter	19 mm
Pipe length	800 mm
Heat temperature variation between switching	2 ℃ +/-
Heat voltage	220 Volts AC

Table 2. Elliptical Fin major and minor axis ratio

Set no.	Major axis. (a, cm)	Minor axis (b, cm)	(a/b) ratio
1	8	4	2 (a_1/b_1)
2	8.4	3.8	2.21 (a_2/b_2)
3	8.8	3.63	2.44 (a_3/b_3)
4	9.2	3.47	2.65 (a_4/b_4)
5	9.6	3.33	2.88 (a_5/b_5)
6	10	3.19	3.13 (a_6/b_6)
7	10.4	3.07	3.38 (a_7/b_7)
8	10.8	2.96	3.65 (a_8/b_8)

The experiments were conducted at a constant temperature in air circumference excluding air currents with the constant surface area for the elliptical fin (0.0396 m^2) for all set used and achieve the article target.

Figure 1. Elliptical fins shape at different axis used in this experimental work for natural convection.

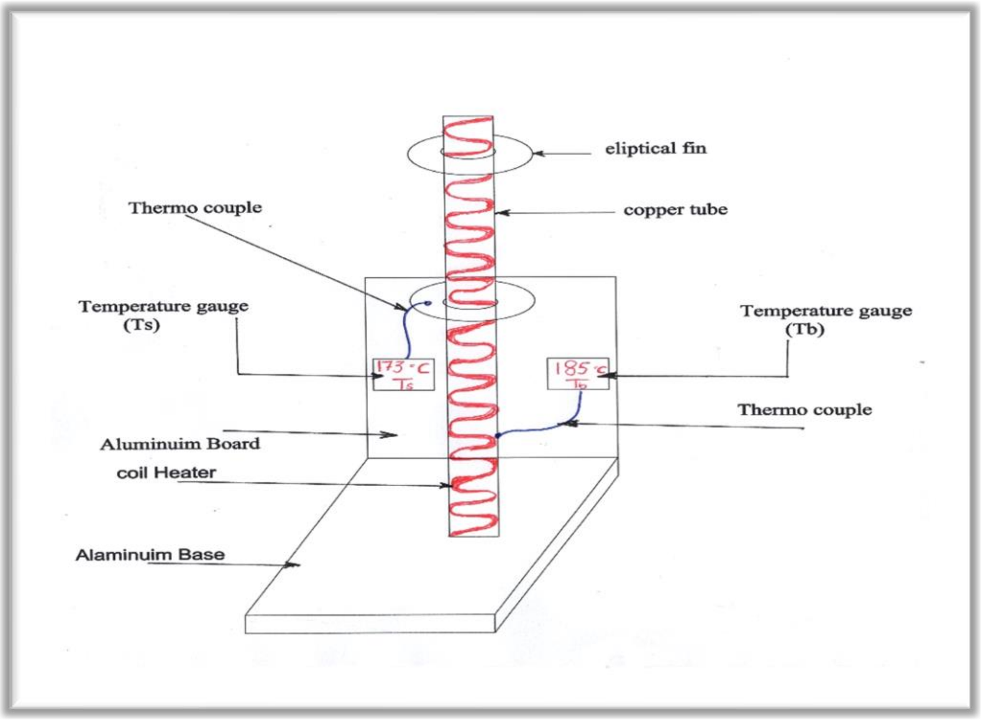

Figure 2. The rig diagram for this experimental work to the natural convection.

Solving the problem was based on the following assumption:
1-The Fin made of homogenous materials.
2- The temperature is uniform in the surrounding ambient atmosphere.
3- The heat transfer from the edge of the fin is neglected due to the thickness of the fin is small compared with its height & length.
4- A uniform temperature assumed for the tube base.
5- Neglect heat transfer in an axial direction.

3 Results and Discussions

The heat transfer coefficient (h) is a very important parameter through the heat transfer. This affected by the air velocity for all sets of (a/b) ratio of elliptical fin shape used. The set no. 4 (a/b =2.65) have the highest value of heat transfer coefficient to all range of temperatures used about 168 w/m^2 K as illustrated in figure 3. Also, there are conform to the results to the heat transfer coefficient at all the range of temperatures used from (160 to 260 C^o). The fin heat transfer rate using [12].

$$Q_{fin} = M * \tanh(mL) \quad (1)$$

Where: $M=\sqrt{h * p * k * Ac} * (T_b - T_\infty)$

$$mL = \sqrt{\frac{h*p}{k*Ac}}*L \tag{2}$$

Where : P = the fin perimeter, k = thermal conductivity
A_c = the cross-sectional area of the fin, L=Length of the fin.

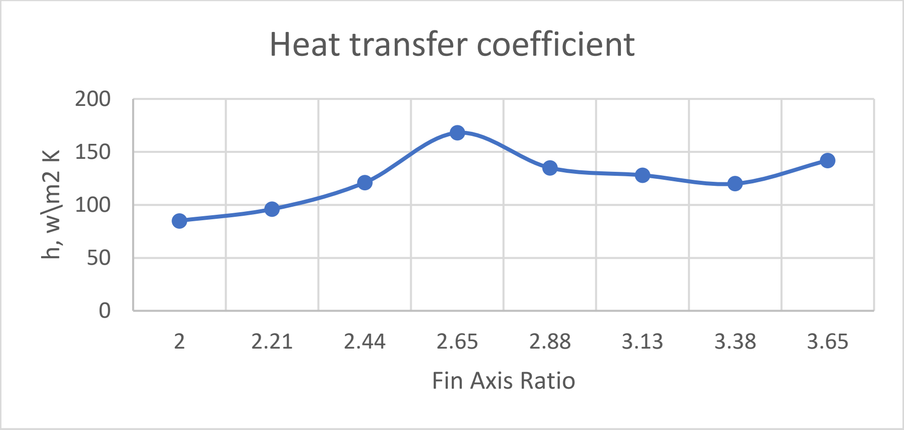

Figure 3. Average heat transfer coefficient with different elliptical fin axis ratio.

Fin heat transfer performance measured by estimation the fin effectiveness (E_f), fin efficiency ($Ƞ_f$), and overall fin thermal resistance (R_{to}). So, It decides to calculate each parameter and draw it separately. The heat transfer coefficient (h, $w\backslash m^2$ .K) can be predicted from [9-10].

$$h = \frac{Q_{fin}}{A_t * (T_s - T_\infty)} \tag{3}$$

Where: Q_{fin} or qf is the heat transfer at T_s,
A_t is the total fin surface area,
T_∞ is the ambient temperature.

The fin efficiency, η fin, is defined as:

$$\eta fin = \frac{qfin}{qfin\ max} = \frac{Acual\ heat\ ftrnsfer\ rate\ from\ the\ fin}{Ideal\ heat\ transfer\ rate\ from\ the\ fin}) \tag{4}$$

This will simplfy to compute the heat transfer from a fin for known efficiency. However, fins efficiency (η_o) could be expressed from [9-10].

$$\eta o = 1 - ((\frac{Afin}{At})(1 - \eta fin) \tag{5}$$

Therefore, the operation of fins based on the fin effectiveness ϵ_f might be given by:

$$\epsilon_f = \frac{q_f}{hA_{c,b}\theta_b} \tag{6}$$

Where $A_{c,b}$ is the surface area of the fins array (m^2).

θb is the temperature difference (Tb – Ts) and Tb is the temperature of the heater surface. if the dissipation power and thermal resistance are known the temperature rise can be computed using [11-12].

$$R_o = \frac{1}{h*Af*\mu f} \tag{7}$$

Where Af is the fin surface area (m^2), and [$\mu_{f=}$ η] is the fin efficiency. It should be noted that the small thermal resistance reflects the minimum temperature over the heat sink, and this improves fin efficiency. Figure (4) observed [R_o] is an effective resistance that describes the flow paths for conduction-convection in the fins. So to examine the effect of the elliptical fin axis ratio by natural convection to the fin performance, we calculate the three above parameters at the range of temperatures from 100 to 260 °C by using the above equations. It is found thermal fin resistance, fin efficiency, fin overall efficiency, and fin effectiveness increase with increasing the base temperatures [Tb] for all elliptical fin major and minor axis ratio.

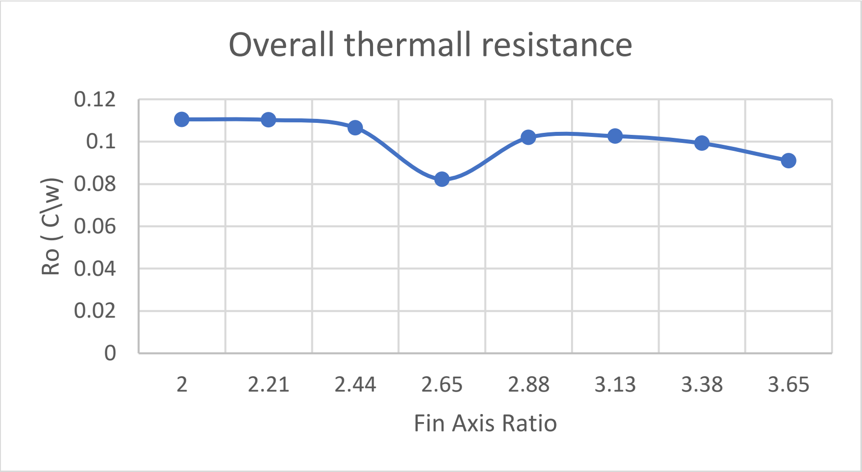

Figure 4. The overall fin thermal resistance [Ro].

It can deduce three important points from (figure 4,5,6 & 7) as follow:

1- The effectiveness is more than 1 for these sets (no.4, no.6, no.7, and no.8) at the range of temperatures used. It means that fins enhance heat transfer when fin is sufficiently larger than one.

2- The effectiveness less than1 for these sets (no.1, no.2,no.3, and no.5) at the range of temperatures from 100 to 170 °C. That's, indicates that the fin acts as *insulation*, slowing down the heat transfer from the surface.

3- These two sets [(a_4\$b_4$) and (a_8\$b_8$)] have a lower overall thermal resistance due to high fin efficiency for heat transfer.

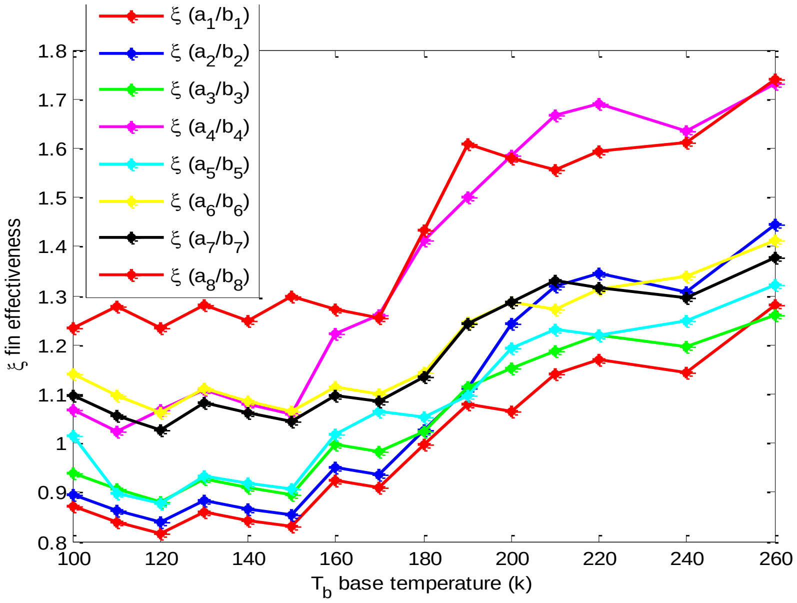

Figure 5.Fin effectiveness at different elliptical axis ratio with base temperatures.

The fin heat transfer performance represent for eight sets used of the elliptical fin is illustrated in (figures 8 to 10). The efficiency increase with increasing the base temperature and the high value is found at the set no.4 and set no.8 due to lower thermal distraction zone area than others elliptical fin axis ratio. The result of overall efficiency conforms to the base temperatures for all sets used.

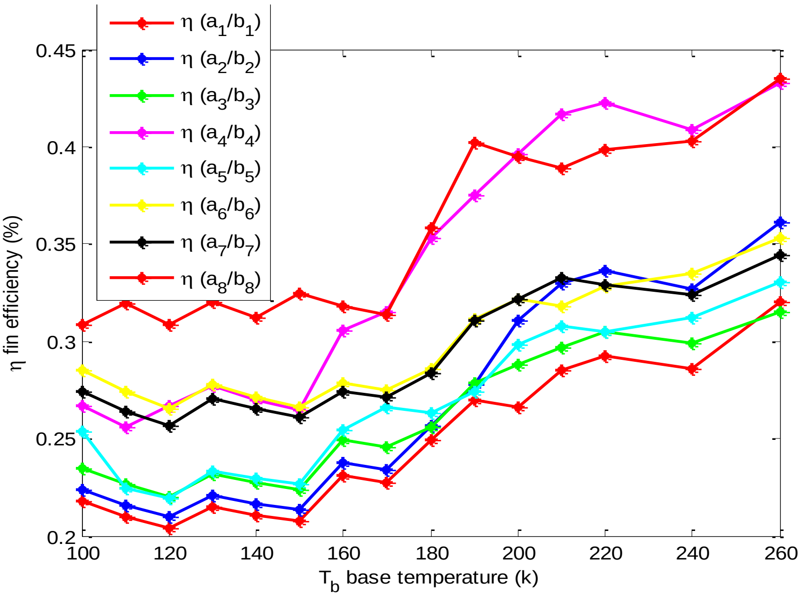

Figure 6. Fin efficiency verse the base pipe temperature for different elliptical fin axis ratio.

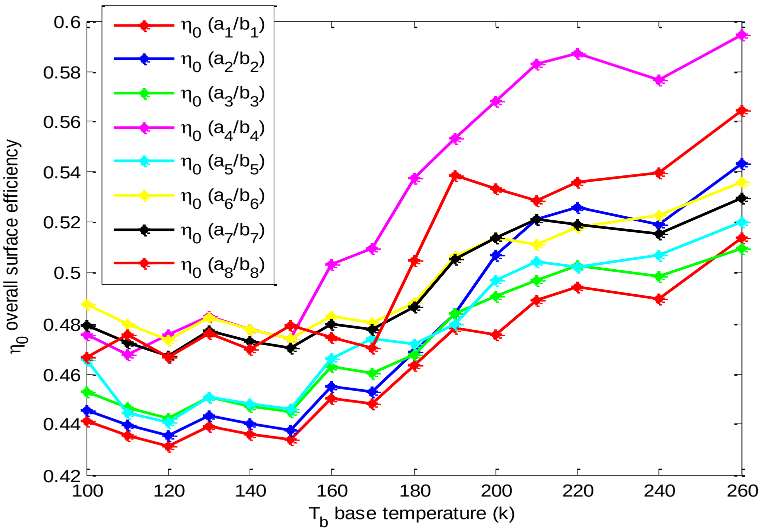

Figure 7. Overall surface fin efficiency verse the base pipe temperature for different elliptical fin axis ratio.

The real results analysis of elliptical fin performance to the all major and minor axis ratios by natural convection, expressed by calculated the average of thermal resistance, fin effectiveness, fin efficiency, and overall fin efficiency for the range of temperature from 100 to 260 ^{o}C as summarized in table 3.

Table 3. Performance of elliptical fin for all major and minor axis ratio of natural convection.

a/b	R_o (^{o}C/w)	ε	η_{fin}	η_o
2	0.11049	0.9844	0.2461	0.4614
2.21	0.11047	1.0592	0.2648	0.4746
2.44	0.10657	1.0395	0.2599	0.4706
2.65	0.08265	1.5404	0.3851	0.5344
2.88	0.10188	1.0663	0.2666	0.4746
3.13	0.10243	1.1858	0.2964	0.4957
3.38	0.09917	1.1692	0.2923	0.4925
3.65	0.09321	1.4151	0.3538	0.5016

It can be deduced from the following three figures, that s a heights value at set no.4 (a/b= 2.65) and set no.8 (a/b = 3.65) for average fin efficiency, overall fin efficiency, and fin effectiveness' by natural convection. While set no.1 (a/b = 2) have a lower value of elliptical fin heat transfer performance due to a large thermal distraction in the fin surface. The major and minor axis ratio very affects the fin heat transfer performance.

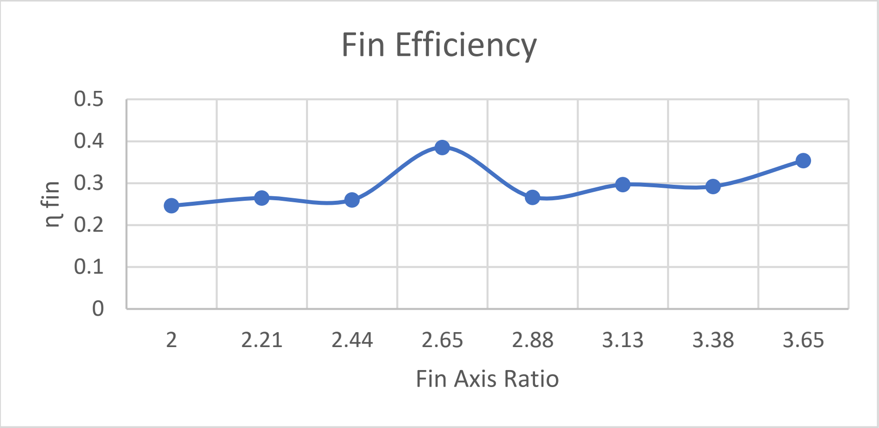

Figure 8. Average overall fin efficiency with the major and minor axis ratios (a\b) of elliptical fin shape for natural convection.

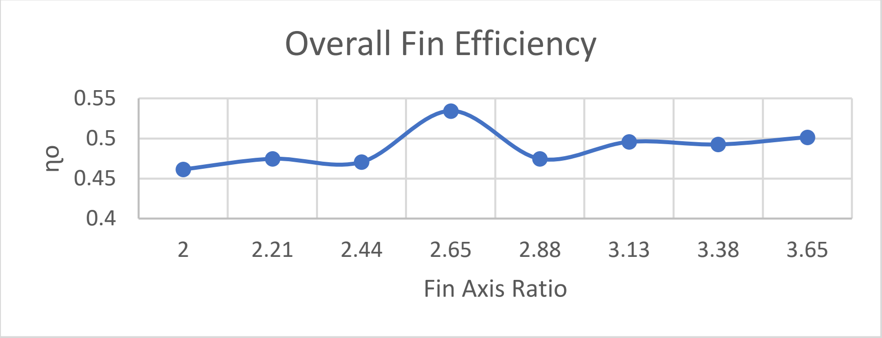

Figure 9. Average fin efficiency with the major and minor axis ratios (a\b) of elliptical fin shape for natural convection.

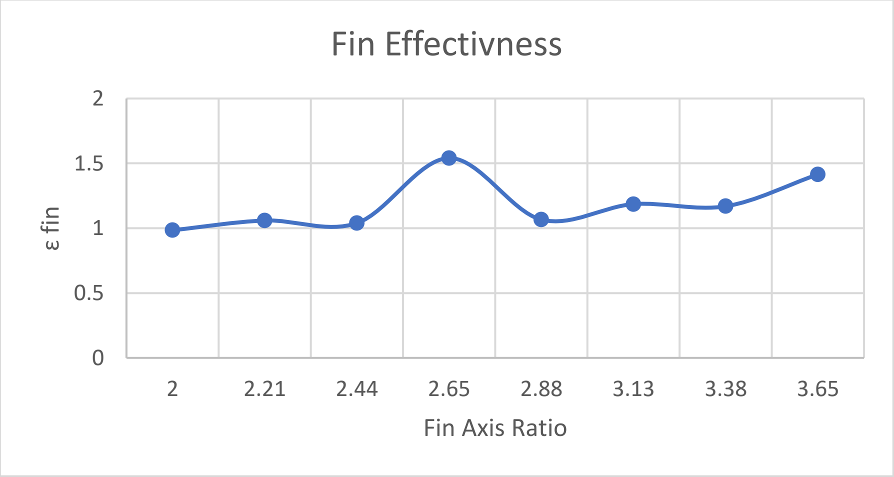

Figure 10. The major and minor axis ratios of the elliptical fin with average fin effectiveness.

4 Conclusion

The most important practical results obtained from this research are as follows. It is found an optimum value in the heat transfer performance of elliptical fin at set no. 4 (a/b = 2.65) by natural convection. It is found the fin effectiveness more than one for this optimum value, that's mean enhanced of heat transfer happen on the fin surface. Considering the above points, it is concluded from the experimental results shows a better heat transfer rate using elliptical fin. There is a clear change happen in the heat transfer performance within the change of elliptical fin shape axis at free convection for which the fin efficiency range is found between 45 to 59 %.

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