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Research Article

AN EXPERIMENTAL INVESTIGATION OF HEAT TRANSFER ENHANCEMENT FOR VERTICAL INTERRUPTED FIN IN FREE CONVECTION

Abbas Jassem Jubear

Department of Mechanical Engineering, Wasit University, Kut-Wasit-Iraq

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ABSTRACT

This paper investigates experimentally the effectiveness of the vertical rectangular interrupted fins on free convection heat transfer for steady state conditions. A specially testbed designed has been developed in order to conduct a comprehensive study for heatsinks. The fin length influence, continuous fin 300 mm and interrupted fins 10, 15, 20, 25, and 30 mm with different heat flux (78,175,317,496, and 715 W) were tested on the thermal performances of the heatsink. The results of this study indicated that the thermal performance of fins has been enhanced approximately 15% by adding interrupted to heatsink, the best performance of heat transfer at fin length was ℓ = 10 mm and the so bad at ℓ = 300 mm (continuous fins). In this study can be utilized this data to improve the heat transfer by natural convection within variety applications such as electronics, communication devices and power electronics.

INTRODUCTION

A high heat rate is generated from electronic devices, such us central processing unit (CPU) during their operation. Therefore, an efficient cooling system should be adopted to dissipate generated heat in order to avoid overheating and device failure. Different modes for cooling procedure can be used depends on the system device and the available resources. Passive cooling method can be the first option it is a quiet, cost effective, and reliable solution J. J.Magdum, *et al*. [1]. The best method to enhance the rate of heat transfer from the heatsinks devices, it was by using extended surface area (fins). Generally there are used aluminum or copper to manufacturing fins. A straight, circular, triangular and pin fins have been studied Bhushan S., *et al*. [2]. The most common fin geometry was a rectangular shape because of its high thermal effectiveness and low cost by V. S.Daund, *et al*. [3]. [4-5-6-7-8], they focused in these studies on the interrupted fins length. A group of researches discusses the influence of fin length on the thermal performance of heatsink. These advantages simulate extensive research on the development of effective finned technique of heatsinks and extension devices. Bhushans S., *et al*. [9], investigated numerically and experimentally the effect of staggered interruptions on the heat transfer rate for vertical rectangular fins by free convection. The numerical model used FLUENT software to study staggered interruption fins effect. A testbed was developed to test the different arrangement of aluminum allay fins, continuous, fixed path interrupted, and staggered interrupted. The result shows that the staggered interruptions fins can improve the thermal performance significantly than the fix path interrupted fins. MehranAhmadi, *et al*. [10], show that the heat transfer rate increase about 16% by adding interrupted fins on vertical heat sink and decreasing the fins weight. Which on the other hand lead to reduce the cost of manufacturing and material. Fujii[11], studied the influence of the inclined interrupted fins on the heat transfer coefficient. In this search, the thermal boundary layers of interrupted fins were tested. The result shows a new correlation of heat transfer coefficient and fitted with experimental results. Ahmed F. Khudheyer, *et al*. [12], studied experimentally the effect of five configurations type of fins (continuous, one interrupted, four interrupted, inclined and V- type) with various heat fluxes on free convection heat transfer. The COMSOL software was used to solve the mathematical model of fins numerically. The results show a good agreement between the experimental and numerical data. The investigator was found a new empirical correlation for Nusselt number and Rayleigh number. A. Daloglu, *et al*. and S. Nada, [13] and [14]. Investigated special cases of the heat transfer rate by internal free convection for interrupting fins. The objective of this study is to increase the heat transfer rate and then find the optimum length of rectangular interrupted for different heat flux. Used the interrupted led to reduce the weight and then low cost of

Corresponding author:* **Abbas Jassem Jubear
Department of Mechanical Engineering, Wasit University, Kut-Wasit-Iraq

manufacturing. The goal of the present study to investigate the effects of interrupted fin length with different heat input on the heat transfer performance of fin arrays protruding from a vertical rectangular base.

MATERIALS AND METHODES

Experimental Setup and Fin Design

A testbed device of the heat sink has been designed and manufactured to studies the effect of continuous and interrupted fins length on the heat transfer rate by free convection. A testbed was fabricated from a cast iron material with cross section area 100 mm * 320 mm. An aluminum sheet used to cover the body with 0.9 mm thickness and the device was insulated by a layer of thermal wool with 6 mm thickness. The reflector material with 0.5 mm thickness was installed behind the heat source or heaters. Three heaters with 1800 W were used as a heat source. The sliding channel is used to fit the model in the test section. An aluminum materials was used to fabricate fins because of its low emissivity at (20 °C) and high thermal conductivity. The fin arrangement was made using CNC machine and wire cut machine. The main dimensions in common, such as base plate volume (300* 110*10) mm, fins height H = 50 mm, fins thickness t = 5 mm, the spacing between interrupts fin in the row S = 11 mm, the interrupted fin length G = 10 mm and the number of fin columns N = 6. The different fin length used in this study for continuous fin ℓ = 300 mm and for interrupting fin was ℓ = 10, 15, 20, 25, and 30 mm as shown in Figure 1.

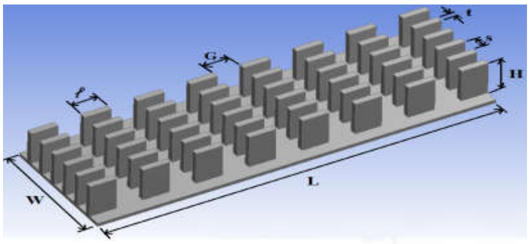

Figure 1 The fin geometry.

Experimental Procedure

The electrical circuit power consists of heating coil (heater) which has three thermal resistance to avoid the shortness in the electrical circuit and to reduce the thermal loss at the ends. The heating coil was placed inside a glass tube from Pyrex with diameter 20 mm and insulated with ceramic insulation at the ends.

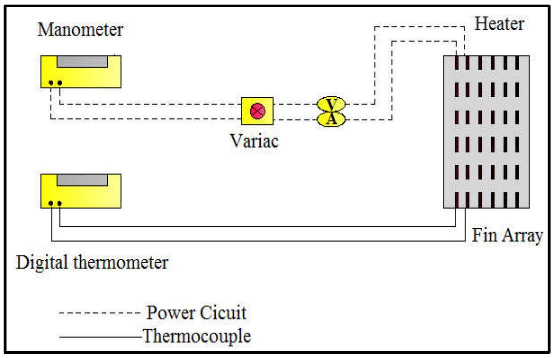

Figure 2 sketch of the electrical circuit.

The source (heaters) has provided the power by voltage regulator with different voltages (50, 75, 100, 125 and 150 V) to get various heat fluxes, see Figure 2.

Eight thermocouple (type K) have been used to measure the base-plate temperatures of interrupted fin arrays, at various locations as shown in Figure 3. This type of thermocouple was used because it's the wide range temperature measurements such as heaters because it uses a fiberglass braid and it most inexpensive. The thermocouples have been extended along the base, they fixed by a special thermal stripe**.** Moreover, the thermocouples were connected to the temperature scanner thermometer, manufactured by Altop Industries Ltd, India to read the base temperature.

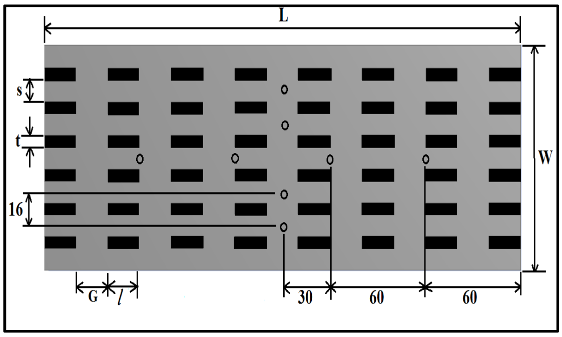

Figure 3 The location of thermocouples on the testbed.

The components of experimental test bed is shown in the Figure 4. The surrounding temperature and the base of interrupted fins temperature at various position are registered at the interval time of 30 min. The steady of these model was reached within approximately four hours.

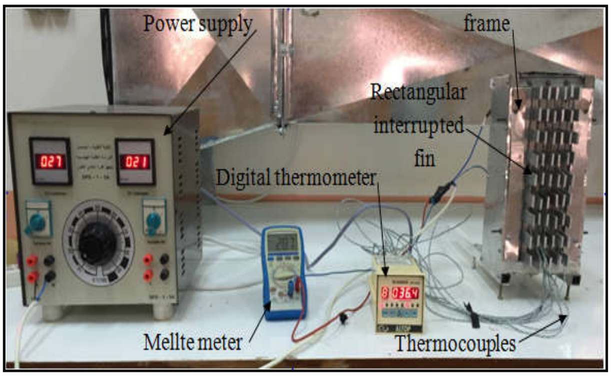

Figure 4 Photograph of the experimental RIG with the measuring instruments.

Calculation Procedure

The heat transfer models through the interrupted fin were considered as conduction, convection and radiation. The governing equations are:

$$Q_{g.} = Q_{conv.} + Q_{rad.} \tag{1}$$

The heat generation was calculated from

$$Q_{gen.} = Q_{conv.} + Q_{rad.} \tag{2}$$

And radiation heat transfer was:

$$Q_{rad.} = \sigma \times \varepsilon \times S_{sur} \times A_t(T^4_{\text{av.}} \quad T^4_{air}) \tag{3}$$

The coefficient of free convection heat transfer was calculated by Newton cooling law

$$= \frac{Q_{conv.}}{A_t \Delta T} \quad (4)$$

The total exposed area was

$$A_t = n \quad A_f + (A_b \quad \ell \quad t \quad n) \quad (5)$$

Where the base area and exposed interrupted fin area was

$$A_b = L \quad W \quad (6)$$

And

$$A_f = (\ell \quad H \quad 2) + (t \quad H \quad 2) + (\ell \quad t) \quad (7)$$

Nusselt number was calculate from

$$\mathrm{Nu} = \mathrm{h} \quad \mathrm{L/\ Kf} \quad (8)$$

Rayleigh number was calculated fron:

$$Ra = \frac{L^3\, g\, \beta\, (T_{av.} \quad T_{air})}{\nu^2} P_r \quad (9)$$

RESULTS AND DISCUSSION

In this section, two cases of vertical rectangular fins have six columns was investigated experimentally. The first case was related to interrupted fins and the other about continuous fins. The length of continuous fins was (ℓ = 300 mm) and the lengths of the interrupted fins were (ℓ = 10. 15. 20, 25, and 30 mm). Different heat flux generation were supplied to the models (78,175,317,496, and 715 W). The range of the Rayleigh Number was ($7.18 \times 10^7 \quad 1.47 \times 10^8$). The effect of interrupted fin length on temperature difference, heat transfer coefficient, and other dimensionless parameter (Nu) and (Ra) have been studied.

Temperature Different Variation

The relationship between the temperature difference and fin length for different heat generating is presented in Figure 5. The temperature difference is increased with the increase of fin length (ℓ). This due to the decrease in the number of fins in each column and increase fins length. Consequently, the average temperature will increase, while the ambient temperature remains constant. Therefore, the minimum value of temperature difference was at fin length 10 mm, and maximum value when the fin length was continuous 300 mm.

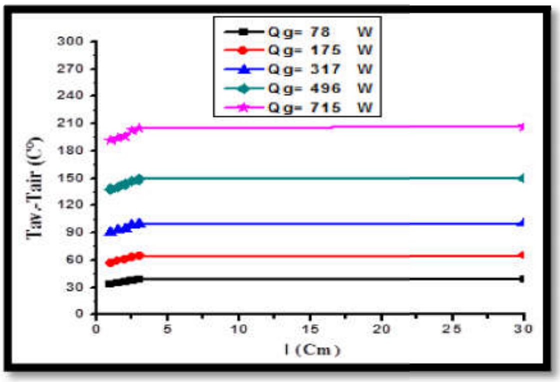

Figure 5 The influence of temperature difference on fin length at different heat flux.

Also, it's shown that the temperature difference was increased withonvection heat transfer rate, it's plotted depending on the temperature difference at different fin length and continuous fins. Figure 6 shows that the convection heat transfer rate depends on fin length, that lead to decreased in heat transfer rate whenever the fin length was increased. The heat transfer rate decreased with the increase in the fins length. The enhancement in heat transfer rate was 15%, which happened at fin length ℓ = 10 mm in comparison with the continuous fins. This improvement occurred due to the increase in the interruption fin length (G) which leads to interrupt the thermal boundary layer and enhance the heat transfer rate. Also can observe that the values of heat transfer rate at low temperature different are convergent but, at the maximum temperature difference tend to diverge from each other by a small value.

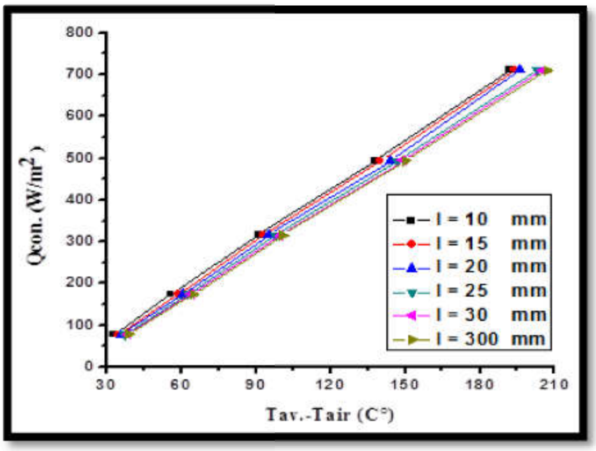

Figure 6 The influence of temperature difference on heat transfer rate at different fin length.

Heat Transfer Coefficient Variation

Figure 7 - 10 show the effect of heat transfer coefficient on several heat transfer variables with different fin length. Figure 7 showed that there is an increase in heat transfer coefficient when temperature difference increases and the maximum value was reached at fin length ℓ= 10 mm and becomes minimum at continuous fins 300 mm at the same value of heat flux.

The enhancement in the convection heat transfer coefficient reaches to 15.5% when ℓ = 10 mm, this improvement occur because of the interruption in the thermal boundary layer which is better at interrupted length than at continuous length. Moreover, the height temperature difference increase the buoyancy force and decrease the viscous force of the ambient air and this acting on the coefficient of convection heat transfer, this give the inverse relationship between the heat transfer coefficient and fin length when the fins gap was equal to 10 mm.

The relation between coefficient of convection heat transfer and free convection heat transfer rate for different fin lengths described in Figure 8. Observe that both variables depends on each other and it has proportional behavior. Moreover, the amount of rising in heat transfer coefficient value can be noticed clearly at a low value of convection heat transfer rate, but less than that occurs at the higher value of convection heat transfer.

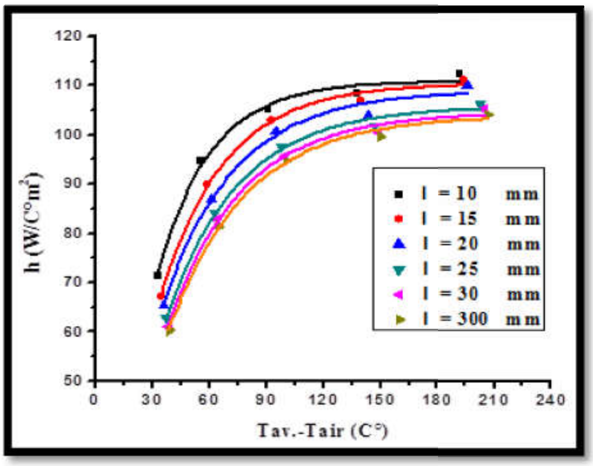

Figure 7 The influence of heat transfer coefficient on temperature different at varies fin length.

The reason for this is due to the high amount of convection heat transfer rate, the losing of heat tend to be stable and this lead to make the change in heat transfer coefficient value less.

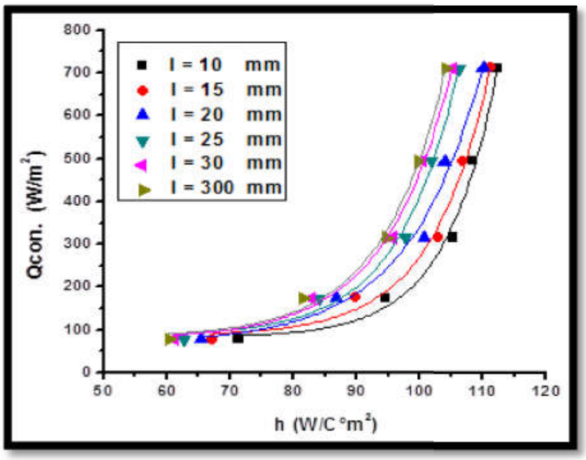

Figure 8 The influence of convection coefficient on heat transfer rate at different length of fin.

Figure 9 shows the relation between heat transfer coefficient and Nusselt number at different fin lengths. It observes that the Nusselt number increase, according to the rise in heat transfer coefficient at low heat flux and then if the heat flux increases more than that Nusselt number tend to decrease with an increase in heat transfer coefficient. The reason can be attributed to increase in average temperature which leads to raise in the heat transfer coefficient and thermal conductivity, therefore Nusselt number increases. Furthermore, thermal conductivity (conduction heat transfer coefficient) has a great influence compared with convection heat transfer coefficient, subsequently decreases in Nusselt number. Figure 9 explains that Nusselt number was measured at six lengths of fin are so adjacent at low values of heat transfer coefficient, while with maximum values of heat transfer coefficient Nusselt number tends to diverge.

Figure 10 presents the relation between heat transfer coefficient and Rayleigh Number at different fin lengths. It's shown that the heat transfer coefficient increase with the increase in Rayleigh Number due to a lower thermal resistance. "Consequent to the increased heat transfer surface area created by the incremented fin length and this will make enhancement in the convection heat transfer rate".

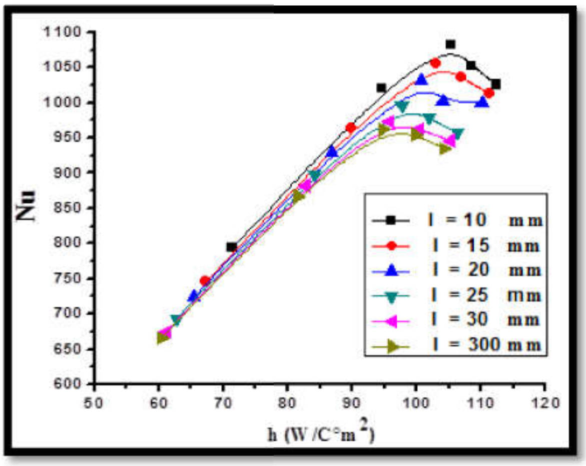

Figure 9 The influence of convection heat transfer coefficient on Nusselt number at difference fin length.

The figure shows that at minimum values of heat transfer coefficient, the value Rayleigh Number tend to diverge and opposite that when heat transfer coefficient increase.

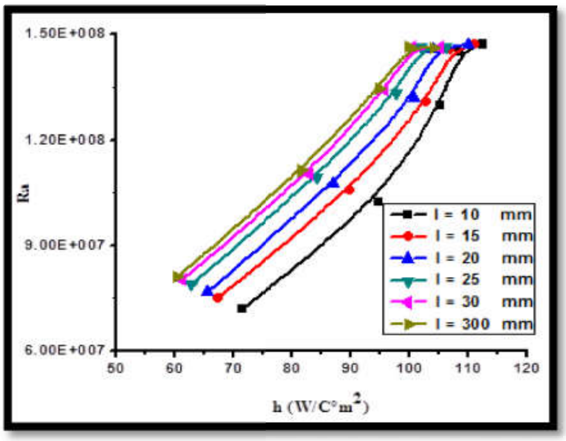

Figure 10 The influence of heat transfer coefficient difference on Rayleigh number at various fin length.

Figure 11 shows the relation between heat transfer coefficient and fin length for different heat power supply. The increase in the fin length cause decrease in heat transfer coefficient and the worst value at continuous fin, thus because that the increase in

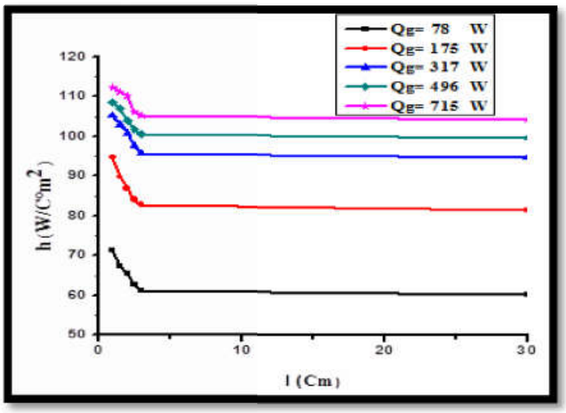

Figure 11 The influence of heat transfer coefficient on length of fin at difference heat flux.

fin length mean "lower thermal resistance resulted from the increased heat transfer surface area" and thus will increase the amount of convection heat transfer.

Nusselt Number Variation

Figure 12 shows the relation between Nusselt Number and temperature difference of six difference fin length and the figure observe that the increase in the temperature difference cause increase in Nusselt Number at a low value of temperature difference, but it decreases at higher values of temperature difference due to the thermal conductivity has a great influence compared with a heat transfer coefficient at a high temperature different.

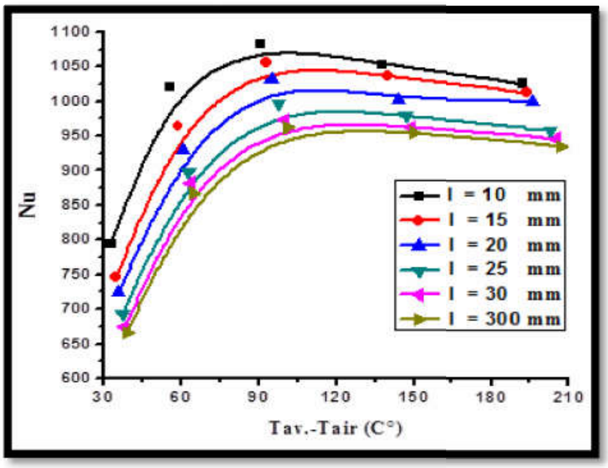

Figure 12 The influence of Nusselt Number on temperature different at viruses fin length.

The relation between Nusselt number and fin lengths of difference heat generation can be shown in Figure 13. Nusselt number decreases according to increase in the length of fin, due to the increased surface area of heat transfer and thus will lower thermal resistance. Figure 14 shows the relation between the logarithmic value for Nusselt number and logarithmic value for Rayleigh number. Initially the relationship between them is proportional and then the behavior of this relation has been opposite when the heat flux reaches to the maximum value, for all the fin length value. Logical explanation for this case is at height value of Rayleigh number the buoyancy force increase and the viscous force decrease this lead to interrupt the thermal boundary layer.

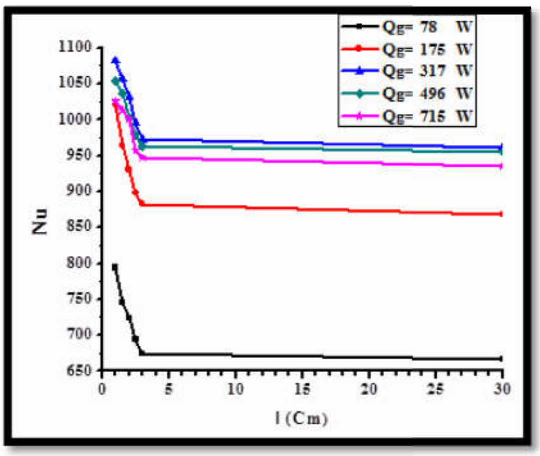

Figure 13 The influence of Nusselt number on fin length at difference heat flux.

Subsequently the convection heat transfer increase and the at maximum Rayleigh number causing decrease in the coefficient of the convection heat transfer this which cause decreasing in Nusselt number.

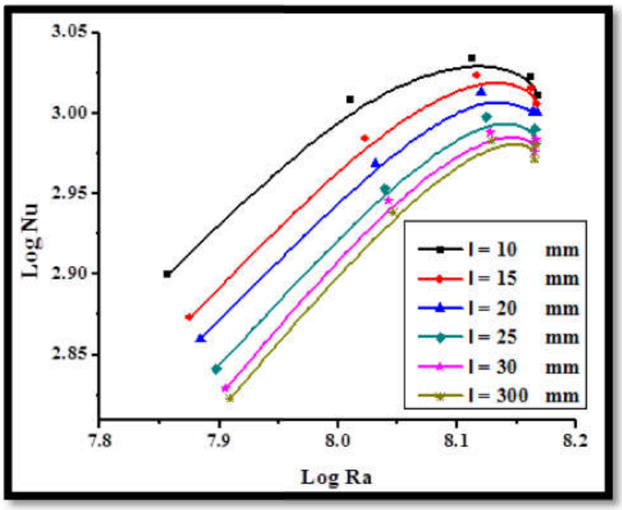

Figure 14 The influence of Nusselt number on Rayleigh number at different fin height.

CONCLUSIONS

In this search, the effect of vertical rectangular fins length, heat flux on the performance of heatsink by free convection was studied experimentally. The effect of continuous fin and interrupted fins has been tested in this work. The following conclusions can be extracted from this work.

- The better performance of heat transfer rate at the length of fin was ℓ = 10 mm but so bad at ℓ = 300 mm.
- The length of fins and heat generation were the main dominant on the free convection heat transfer.
- Fin's length has a significant effect on temperature difference between heat sink base and surrounding. It was shown in the results section that the temperature difference increases with the fin length.
- The greatest value of the convection heat transfer rates obtained at less fin length. Moreover, the enhancement of heat transfer rate by free convection was due to the decrease the fin length and reaches to 15% at ℓ = 10 mm compared to continuous fin.
- Heat transfer parameters such as, the rate of convection heat transfer, the heat transfer coefficient and Nusselt number was reached to the maximum value at fin length ℓ = 10 mm then decreases to a minimum value at continuous fin ℓ = 300 mm. The enhancement in the convection heat transfer coefficient because of decrease the fin length and reach to 15.5% at ℓ = 10 mm compared to continuous fin ℓ = 300 mm.

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