Experimentally Study the Effects of Fins Height and Space Ratio (H/S) to the Fin thermal performance by Natural Convections

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Abstract: Heat transfer enhancement devices are widely used in various industrial, transportation, or domestic applications such as thermal power plants, means of transport, heating and air conditioning systems, electronic equipments and space vehicles. In all these applications, improvements in the efficiency of heat exchangers can lead to substantial cost, space and materials savings. The research work summarized in this articles presents an experimental investigation on the effect of fin space (S) on the fin performance using rectangular plate type fins. The steady-state natural convection heat transfer from vertical rectangular fins extending perpendicularly from horizontal square base was investigated experimentally at high range of temperatures from 50 to 150 °C. The effects of fin space parameter, fin height-space (H/S) ratio and base-to-ambient temperature difference on the heat transfer performance of fin arrays were observed and the environmental condition were determined.. Five fin height-space ratios settings 1.31,1.43,1.67,1.85 and 2.27 with constant fin surface area were employed under free convection heat transfer conditions. The heat transfer area was kept the same. The performance of the fin expressed in terms of fin efficiency, effectiveness and thermal resistance as a function of the ambient temperature and fin space parameters has been study in this work. The dimensionless parameter Biot no. on the locally variable environmental condition is examined for different fin spaces and fin height-space (H/S) ratio to the fin heat transfer rate. Also, the effect of environmental condition is study at the same (H/S) ratio. Experimental results show that the effect of Height-Space ratio (H/S) on fin performance is more significant.. The maximum increase in convection heat transfer coefficient value obtained is about 19 percent. The increase in heat transfer coefficient value is also manifested by a corresponding decrease in the fin base temperature. Also, it is concluded from the experimental results that the performance of heat transfer rate increase with increasing the height-space ratio (H/S) and decreasing the fin space in respect of heat transfer coefficient, thermal resistance ,overall efficiency and effectiveness .

Keyword: Fin Height, Fin space, Fin H/S ratio, Rectangular Fin , Natural Convection, Heat Transfer Performance

1. Introduction
In the free-convection cooling of electronic and thermoelectric devices, as well as in improving the heat transfer in radiators for air conditioning and in other heat exchangers, finned surfaces are extensively used. Compared to a bare plate, a finned surface increases the heat transfer area. However, with the fins the flow rate reduced. Hence, if not properly designed it is possible that no improvement achieved in terms of overall heat transfer. Therefore, only if the fins properly designed, they are very attractive for these applications, since they offer an economical, trouble-free solution to the problem. Extended surfaces, which are popularly known as fins, are extensively used in air-cooled automobile
engines and in air-cooled aircraft engines. Fins are also used for the cooling of computer processors, and other electronic devices. Fins are used in the cooling of oil carrying pipe line which runs several hundreds of miles. Heat pipes are also used along with fins to enhance cooling rate. A great deal of research effort has been developed for developing apparatus and performing experiments to define the conditions under which an agentive technique will improve heat transfer. The more effective and feasible techniques have graduated from laboratory to full-scale industrial equipment. 

Stamer and McManus [1] study experimentally very early in the heat transfer performance for arrays of rectangular fins by natural convection. They used four sets of fins array at different position (horizontal, 45 degree and vertical) based on the main heater at constant temperature 40 °C. They found the heat transfer coefficient for vertical position less than others by 10 to 30%. Leung and Prober, [2] did another experimentally investigate the effect of fin height to the fin space for optimum ratio at two rectangular fins array positions (vertical and horizontal). The results for the range used from 20 to 40 °C, shows the optimum fin spacing value were 9 to 11 mm. It was also found that not affect orientation considering to the change of fin height and base-to-ambient temperature difference. Leung, Probert and Shilston [3] carried out experimental work for rectangular fins array at three different cases: vertical based on horizontal fins, vertical based on vertical fins and horizontal based on vertical base. This work for a temperature range from 40 to 80 °C at three different heights, namely 32mm, 60 mm and 90 mm. There result showed no affect of fin height to the change of position, but the fin space is most effective for vertical fins based on vertical base. The effects of changing fin length from 250 to 375 mm on the rate of heat transfer and the optimum fin spacing of vertical rectangular fins protruding from a horizontal or a vertical rectangular base have been investigated by Leung. Probers and Shilston [4] experimentally except fin length, other geometric parameters of several fin configurations were kept fixed for considered orientations. There result concerned at a constant base temperature, 40°C above that of the ambient environment. The experimental measurements for vertical base showed that the increase in fin length caused reduction in the rate of heat dissipation per unit base area from the fin array. In addition, the optimal fin spacing rose from 10 ± 1 mm to 11 ± 1 mm as a result of fin length increase. On the other hand, with horizontal base, large reduction in the rate of heat transfer per unit area occurred when the fin length was increased. The optimal fin spacing of horizontally based fin array increased from 11 ± 1 mm to 14 ± 1 mm as the fin length was increased from 250 mm to 375 mm. All these consequences revealed that the effect of fin length on heat transfer performance of fin arrays is significant.

Walunj, Daund, and Palande [5] studies various experimental have been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer. Effects of thermodynamic properties like heat input, base-to-ambient temperature difference are also studied by many researchers. Some investigators make known sets of correlations screening the relation between various parameters of heat sink. Experiments are taken by some researchers for upward and downward facing rectangular fins. Also, trivial investigation has been carried out for different angle of inclination of the heat sink. The sensitivity of inclination over geometric parameters found to be great importance. Welling and Wooldridge [6] performed another experimental study to compare actual rectangular fin experiments with those of vertical plate, enclosed duct and parallel plate data from previous studies. During the tests, guard heater plate was utilized to minimize the heat losses from the sides and rear of the set-up. Data obtained from experiments showed that with closely spaced fins, the heat transfer coefficients were smaller compared to wider fin spacing's, because of boundary layer interference, which prevents air inflow. It was observed that the heat transfer coefficients of finned arrays were smaller than those of vertical plate and greater than either those of enclosed ducts or those of parallel plates. For a given base-to-ambient temperature difference, an optimum H/s (fin height to fin spacing) ratio at which heat transfer coefficient is maximum was determined from the considered fin configurations. 

Mi sandar Mon, Ulrich Gross [7] reported that the effect of fin spacing on four row annular finned tube bundles in staggered and inline arrangements are investigated by 3D numerical study. To investigate the velocity and temperature distribution between fins. The flow behavior of the developing boundary layer, the horse shoe vortex system, and thermal boundary layer developments in the annular finned tube banks will be visualized. Azimifar A., Payan S [10] study the optimization of
characteristics of an array of thin fins using PSO algorithm in confined cavities heated from a side with natural convection. Hossein Z. and et.al. [11], investigate natural convection of a Nano fluid in an enclosure with an inclined local thermal non-equilibrium porous fin considering with respect of fin spaces. However Emel Evren S. and et.al . [12] experimentally study the effect of fins space on the transition to oscillating laminar natural convection in an enclosure. Khalil K., Abdalla AlAmiri [13] reported that the effect of fin space at laminar natural convection heat transfer in a differentially heated cavity with a thin porous fin attached to the hot wall. Ilker T., Mehdi M [14] studies various experimental have been made to investigate effect of fin height, fin spacing and fin length for inclined position over convective heat transfer. Recently Rishikesh and Kiran [15] presented the characterization of radial curved fin heat sink with the effect of fin heights.

2. Experimental methods
The experimental apparatus is comprised of a rectangular fin as cross-section to the U-heater shape direction in an open loop. The former is used to control the base temperature from 50 to 150 °C, and the latter sets the fins surface temperature. Figure 1. shows a schematic representation of the test rig, which is divided into the lower part, where the tests are carried out by different space and height-space ratio (H/S), and the upper part, where the power supply and temperatures gauges are work together. The rectangular aluminum table has a dimensions (90 cm x 60 cm) prove the base of the fins on the heater. So that the base of the fins has a constant area for five sets of fins and this base seek directly on the heater so that the transmitted heat conduction from the heater to the base of fins that contains a row of fins is working to expel heat to the surrounding environment, with an insulator between the heater and the base of the apparatus and demonstrate electrical panel containing gauges and switches in the front of the base of the apparatus as observed in figures 1.

Figure 1. Overall view of the experimental rig and associated instrument.

Five aluminum plates size (250 mm) * (250 mm), has thermal conductivity (233w/m²k) installed. On each one set of aluminum fins each fin height and width are constant (50 mm &250 mm) has the same surface area, number and the same specifications as the plates. The five sets of plate contains (6 fins) separated by a distance (22 mm), and the second plat separated by a distance (27 mm), the third base has distance 30mm, fourth plate has space equal to 35mm, while the fifth plat separated by a distance (38 mm) . Under each one fixed heater to gives temperature and thermocouple to measure temperature.
These results are utilized to reveal the effects of geometric parameters, fin space, fin height-space ratio ($H/S$), and the effects of the fin base temperatures of the steady-state heat transfer rates from finned surfaces. These ($H/S$) ratios are come from different fin space and constant height as illustrated in the following table (1).

**Table 1. Sets of fin heights and width (H/S) ratios.**

| Set no. | Fin height (H),mm | Fin Space (s),mm | Fin height-space ratio (H/S) |
|---------|-------------------|------------------|-----------------------------|
| 1       | 50                | 22               | 2.27                        |
| 2       | 50                | 27               | 1.85                        |
| 3       | 50                | 30               | 1.67                        |
| 4       | 50                | 35               | 1.43                        |
| 5       | 50                | 38               | 1.31                        |

The three horizontal electrical U-heaters are placed on 70 mm above the experimental table to avoid ground effect. Electrical heating coil with 2.25 kW capacity is kept inside the tube. Thermal conductivity of aluminum is 236 W/mK. Heat transfer coefficients is important fin parameters measured from the following formula: The heat transfer coefficient ($h$, w/m².K)) can be estimated from the following equation: [8]

$$ h = \frac{Q_{\text{fin}}}{A_t \times (T_s - T_{\infty})} \quad (1) $$

Where: $Q_{\text{fin}}$ or $q_f$ is the heat transfer from the fin surface at $T_s$,

$A_t$ is the total fin surface area,

$T_s$ is the ambient temperatures.

The fin efficiency of a any fin, $\eta_{\text{fin}}$, is defined as:

$$ \eta_{\text{fin}} = \frac{q_{\text{fin}}}{q_{\text{fin max}}} \quad (2) $$

**Figure 2.** Base of Aluminum plate with rectangular fins.
This relation enables us to determine the heat transfer from a fin when its efficiency is known. But the overall fins efficiency is express by the following formula:

\[ \eta_o = 1 - \left( \left( \frac{A_{fin}}{A_c} \right) \left( 1 - \eta_{fin} \right) \right) \] ..........................(3).

The performance of the fins judged on the basis of the enhancement in heat transfer relative to the no-fin case. the performance of fins expressed in term of the fin effectiveness \( \epsilon_f \) is defined as :

\[ \epsilon_f = \frac{q_f}{hA_{c,b} \theta_b} \] ..........................(4)

Where \( A_{c,b} \) is the surface area of fins array on the base \( (\text{m}^2) \)

\( \theta_b \) is the temperature difference \( (T_b - T_s) \)

Fin Thermal Resistance \( (R_{fin}) \) is defined as temperature rise per unit of power, analogous to electrical resistance, and is expressed in units of degrees Celsius per watt \( (^{\circ}\text{C}/\text{W}) \). If the device dissipation in watts is known, and the total thermal resistance is calculated, the temperature rise of the die over ambient can be calculated as express in the following formula: [8,9]

\[ R_{fin} = \frac{1}{h \cdot A_f \cdot \eta_f} \] ..........................(5)

Where \( A_f \) is the fin surface area \( (\text{m}^2) \), and \( \eta_f \) is the fin efficiency. This equation may be used to expression for the thermal resistance of a fin array. A small value of thermal resistance indicates a small temperature drop across the heat sink, and thus a high fin efficiency. \( R_o \) is an effective resistance that account of heat parallel flow paths for conduction-convection in the fins and by convection from the prime surface. The governing equation for one-dimensional conduction with convection is applicable to systems in which the lateral conduction resistance is small relative to the convection resistance. Under these conditions the temperature profile is one dimensional. The conditions for which Eq. (6) is valid are determined from the following criterion:

\[ \frac{hlc}{K} < 0.1 \] ..........................(6)

Where \( Bi \) is the Biot number based upon the maximum half thickness of the fin profile, \( K \) is K thermal conductivity of the Aluminum \( \text{Wm}^{-1}\text{K}^{-1} \) and \( lc \) is the corrected fin length mm.

The fin Biot number is simply the ratio of the lateral conduction to lateral convection resistance: [9]

\[ Bi = \frac{R_{conduction}}{R_{convection}} \] ..........................(7)

3. Results and Discussions

The mean point in our work is study the effect of \( (H/S) \) ratio to the fin performance at very important range base temperatures from 50 to 150 \( ^{\circ}\text{C} \). This range of temperatures has a huge application in the mechanical industries especially the internal combustion engine and power station. To examine the above ratio, we need estimated many parameters such as heat transfer coefficient, effectiveness, efficiency, thermal resistance, Biot number and heat transfer of fin surface. It decide to fixed the five sets of array of rectangular fin at a cross direction to the heater (power supply) as shown in the figure 3. There is a linear relationship between the average heat transfer coefficient \( (h_f \text{avg.}) \) for all base temperatures range used with \( (H/S) \) ratio. As the \( (H/S) \) ratio increase the heat transfer coefficient decrease due to low distance between the array of fins. There is a linear relationship between the average heat transfer coefficient \( (h_f \text{avg.}) \) for all base temperatures range used with \( (H/S) \) ratio.
Figure 3. The (H:S) ratio effect to the average fins heat transfer coefficient (hf_{avg}).

The average heat transfer from the single fin surface (Q_{avg}) has a range from 50 to 85 w from the power supplies by the fixed down heater and this decrease linearly with increasing the fin height-space ratio. The results of fins performance are summarized in the table 2.

| H:S  | \( \eta_0 \) | \( \dot{\epsilon} \) (avg.) | R_{\eta} (avg.) |
|------|--------------|-------------------------------|----------------|
| 1.32 | 0.685        | 0.273                         | 0.0497         |
| 1.43 | 0.712        | 0.284                         | 0.0521         |
| 1.67 | 0.746        | 0.299                         | 0.0539         |
| 1.85 | 0.761        | 0.311                         | 0.0558         |
| 2.27 | 0.784        | 0.326                         | 0.0574         |

Table 2. Fins Performance Parameters with (H:S) ratio at Am.

![Diagram](image1)

Figure 4. The overall fin efficiency with (H:S) ratio at Am condition.
It is clear from the above table and figures there is a linear relation between the average overall thermal resistance, overall fin efficiency and fin effectiveness with the height–space ratio (H:S) due to the decreasing the fin spaces as shown in figures 4, 5 and 6 at morning condition. Biot number is examined at the same five height-space ratio at morning condition as shown in figure 7. It is found the Biot no. decrease with increasing the (H:S) ratio due to decreasing the heat transfer coefficient.

**Conclusion**

The experiments were performed for five (H:S) height-space ratios (1.32, 1.43, 1.67, 1.85 and 2.27) conditions for wide range of temperatures used from 50 to 150 °C. The following conclusion can deduce from the present work:

1) It is found the heat transfer coefficient depends upon the space, temperatures and (H:S) ratio. If there are changes in environmental conditions, there is a small change in heat transfer coefficient and efficiency also.
2) Average heat transfer increase with decreasing the fin height-space ratio in Natural convection mode.
3) The range of Biot no. for all height-space ratio (H:S) is from 0.004 to 0.043, this mean a good distribution in the surface of rectangular fin.
4) The range of effectiveness for different (H:S) height-space ratio (1.32, 1.43, 1.67, 1.85 and 2.27) is from 0.27 to 0.33 less than one.
5) The overall fin efficiency has a range from 0.68 to 0.79 to the five (H:S) ratio used in our results.
6) As the height-space (H:S) ratio increase the overall thermal resistance, overall fin efficiency and fin effectiveness increase also.
7) In free convection heat transfer condition, the effect of change in fin height-space ratio on fin performance is slightly different between the morning and evening condition. Also, there was no real noticeable change in the fin base temperature and convection heat transfer coefficient with the change in environmental condition.

8) There is clear difference in the fin heat transfer performance with the change of fin height-space ratio at natural convection.

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