RESEARCH ARTICLE OPEN ACCESS

# The Effect of Fin Orientation on Thermal Fin Performance by Natural Convections: An Experimental Investigation

Dhia SUKER[1], Hazim Abed Mohammed AL-JEWAREE[2] ,and Ahmed BACKAR[1]

*1) Mechanical EngineeringDepartment, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah, 21955, Saudi Arabia.*
*2) Petroleum Engineering Department, College of Engineering, AlKitab University, Iraq.*

**ABSTRACT**
To guarantee a high rate of heat dissipation, the majority of industrial engineering systems that involve heat transfer employ various kinds of heat exchangers. All heat exchangers include solid protrusions with metal fins in a variety of geometric designs. The objective of these protrusions is to maximize the heat transfer rate by raising the transmission coefficient and the performance of the fin. In this study, an experimental inquiry is conducted to examine the performance impact of fins orientation utilizing square plate type for broad temperature ranges ranging from 60 to 110$^{o}$C. Due to the fins' vertical position and the fact that they are formed of metals with defined length, breadth, thickness, and material type, the system exhibits a steady natural load. Three different orientations of the fins—intersecting, parallel, and 45° inclined—were used to determine the heat transfer coefficients. All tests have used the same region for heat transmission. The overall efficiency and thermal resistance as a function of ambient temperature are the metrics used to assess the performance of the fins. The experimental findings demonstrate a significant variation in the fin heat transfer efficiency for various orientations. Furthermore, regardless of the variation in embient temperature employed in the testing range, positioning the fin base orientation perpendicular or transverse to the heat source has higher heat transfer performance than the other two orientations.

**Keywords:** Fin base Orientation, Rectangular Fin, Natural Convection, Heat Transfer Performance.

---

Date of Submission: 04-12-2022 Date of Acceptance: 15-12-2022

---

## I. INTRODUCTION

Numerous studies have looked at the procedure of analyzing the typical heat transfer rate for free convection of an array of fins for various geometric designs. To get the optimum heat transfer rates from the fins' outer surfaces, theoretical and experimental research is carried out.

Early experimental research has been done on the effectiveness of heat transmission utilizing natural convection in rectangular fin arrays [1]. The four sets of rectangular fins were heated to a constant temperature of 40°C and employed in various configurations (vertical, horizontal, slanted at 45° and 75°). According to the authors, fins in the vertical position may achieve a 10 to 30% lower heat transfer coefficient than those in other locations. However, in addition to the direction, the height and area of the fins also have a role. Leung and Probert's empirical study [2] utilizing fins spaced 9 to 11 mm apart at temperatures ranging from 20 to 40°C revealed that the direction does not significantly affect the fins' height and area. The project is completed with a precise ratio of the area for two directions to the height of the fins (horizontal and vertical).

A rectangular fin was experimentally studied by Leung, Probert, and Shilston [3] in three distinct orientations: horizontally on the basis of the vertical fins, vertically to the basis of the horizontal fins, and horizontally on the basis of the vertical fins. The job is carried out at three distinct heights—32 mm, 60 mm, and 90 mm—for a temperature range of 40 to 80°C. For vertical fins with a vertical base, the fin area is more efficient. The findings revealed that fin height has no impact, but fin length, which ranges from 250 to 375 mm, has an impact on the rate of convolution transfer. The optimal fin spacing between vertical fins protruding from a horizontal or vertical rectangular base were investigated by Leung et al [4]. Except for the fin length, other geometric parameters were kept constant for consideringthe orientations effects. The experiments are conductedwith a constant core temperature of 40°C which is above ambient temperature. Experimental reults showed that an increase in the fin length caused a decrease in the rate of heat dissipation per unit core area of the fin array.

The impact of rectangular fins on vertical base convective heat transport was examined by Yüncü and Güvenc [5]. While other factors like fin spacing and height are modified, the trials are based on fins with set length, breadth, and thickness. Different outcomes were seen for various heat inputs.

Fhimnia et al. [7] 's experimental examination on convective heat transfer, which was expanded to computer heat sinks, found a link between the convective heat transfer rate with a fin array and a base plate without fins. The natural convection heat transmission may be improved with the right fin spacing..

To better understand how fin height, spacing, length, and thickness affect convective heat transport, a number of experimental experiments have been carried out [8]. The impacts of thermodynamic properties—specifically, heat input and ambient temperature difference—are also taken into account in this research. A series of well-known correlations that describe the link between the various characteristics of the heat fins have been used to end this study.

The author's preliminaryexperimental work on the effect of fin height and space ratio concluded that the fins heat transfer rate performance increases with the increase of the height to space ratio. Additionally, thermal resistance, efficiency and overall effectiveness have also increased [9].Furthermore, the effect of the fins length to width ratio is also proportional to the thermal performance of rectangular fins [10]. This ratio is also effected by the fin heat transfer performance for the set of core fin temperatures and air speeds.

## II. EXPERIMENTAL PROCEDURES

The apparatus is designed for the practical experiments includes an aluminum plate with square cross-section and a rectangular fin made of the same raw material and a heating system using direct heater. The former is used to control the temperature of the fin bases and surface fins temperatures,as well as the heat flow rate in different fin array directions. Figures 1, 2, and 3 depict various angles of the test device, which has two distinct parts: the bottom half, where a heater heats the base fins, and the top section, where measurement and control tests are conducted. A U-shaped heater with an 8 mm diameter and 90 cm length and a square base covered in copper metal is used to initially warm the air in the bottom portion. Three rectangular fins will be arranged in an array and heated in turn by connections from the base. Fin surface and air temperature are measured using a grid of J-type thermocouples and another grid is used to measure fin surface temperatures with a maximum uncertainty of 0.4°C.

**Figure 1. Experimental setup of the fins base at inclined direction.**

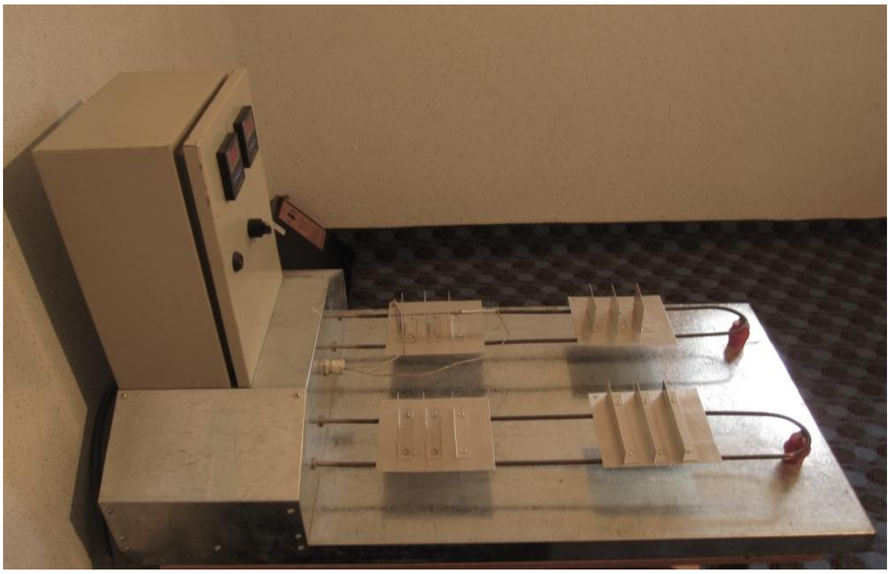

**Figure2. Experimental apparatus setup of thecross fin direction.**

**Figure 3. Parallel fins and the based heat source.**

Fin heat transfer performance measurements includethe fin thermal resistance ($R_{fin}$), overall thermal resistance ($R_o$), fin efficiency ($\eta_{fin}$), total fin efficiency ($\eta_o$) and fin efficiency ($\eta_{fin}$). To calculate the heat transfer performance with the effect of fin orientation, this can be accessed by measurements of thermal resistance and fin efficiency as expressed in equations (1) and (2):

For a fin with an adiabatic tip the fin thermal resistance ($R_{tf}$) is expressed as [9]:

$$R_{t,f}=\frac{(Tb-T\infty)}{qf}=\frac{1}{\sqrt{hpkAc}[\tanh(mL)]} \quad \text{..........(1)}$$

While the fin efficiency ($\eta_f$)is expressed as:

$$\eta_f=\frac{actual\ heat\ transfered}{heat\ which\ would\ be\ transferred\ if\ entire\ fin\ area\ were\ at\ base}=Q_{fin}/Q_{fin\ max} \quad \text{.........(2)}$$

reworking the eqution with respect to $Q_{fin}$:

$Q_{fin}=\ \eta_f \times Q_{finmax}=\ \eta_f \times (hA_{fin}\ (TB - T_\infty))$.................(3)

where $A_{fin}$is the total area of the fin. This relationship determines the heat transfer with respect to the efficiency.

Fin performance is evaluated based on the ratio of enhanced heat ransfer relativeto the no-fin condition. The fineffectiveness ($\epsilon_f$) is expressed by equation (4):

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

The temperature profile is considered to beone dimensional under the test conditions.
The test conditions are valid under the following criterion defined by equation (5):

$$B_i = \frac{R\ conduction}{R\ convection} \quad ..............................(5)$$

where $B_i$ is the Biot number which is a function of the maximum half thickness of the fin coil. The Biot number can be calculated by working out the ratio of lateral conduction to lateral load resistance [10].

## III. RESULTS AND DISCUSSIONS

The results of intersecting, parallel and sloping fins orientation of the rectangular fins are summarized in Table 1. The fin base temperature ($T_b$) ranges from 60 to 110°C to examine all the above parameters. Morning experiments are performed between 08:00 and 12:00 and evening results between 16:00 and 24:00. The night temperature drops to 4 to 7°Cduring February, March, April and Mayduring an average spring.

It is decided to use three fins for base orientation, cross, parallel and sloping respectively to reach the best performance of fin heat transfer at fin height - width ratio 0.35 as it is the optimum value that is reached in previous work [11]. Table 1 shows true comparison between these three directions of all fin heat transfer parameters.

**Table 1. Experimental results for three fins orientation.**

| Direction | mean h w/m$^2$ | Biot No. $B_i$ | $\eta_{fin}$ | $\mathcal{E}_{fin}$ | $R_{fin}$ °C/w | $R_o$ °C/w | HTRF % |
|---|---|---|---|---|---|---|---|
| Cross | 1889 | 0.3083 | 0.59 | 16.8 | 0.35 | 0.22 | 93 % |
| Parallel | 2051 | 0.3564 | 0.57 | 16.1 | 0.3 | 0.17 | 90% |
| Inclined | 1993 | 0.3262 | 0.58 | 16.3 | 0.32 | 0.20 | 91% |

The heat transfer rate percentage to the surface fins (HTRF %) is computed for three directionsusing equation (6).It is derived from the practical research work:

HTRF% = ($Q_{fin\ max}$/heat supply)× 100% …………(6)

Results of the wide temperature range used in three directions are summarized in Table 1. The cross direction of the rectangular fin array is found to have high heat transfer compared to the other direction as shown in Figure 4.

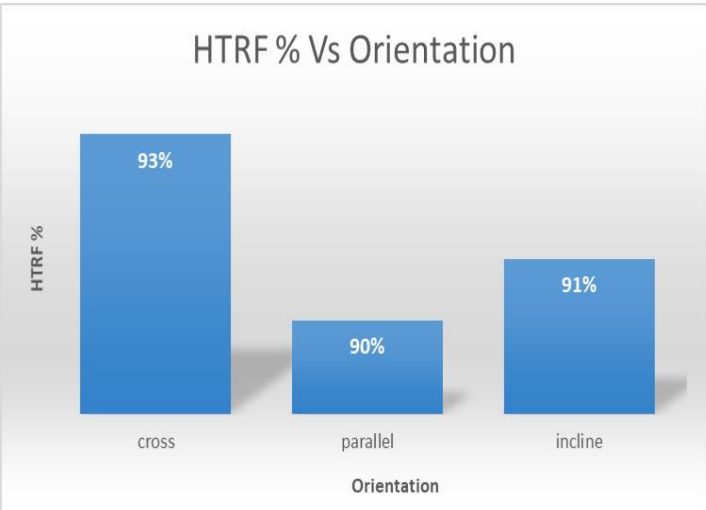


**Figure 4. Bar graph represents the result of the percentage of transferring heat (HTRF %) with base fins orientation**.

The heat transfer coefficient for this range of temperatures is calculated as (*meanh*) for the three types of fin array orientations. The cross direction has a lower value, that is to say, it will result in a higher fin heat transfer performance as shown in Figure 5.

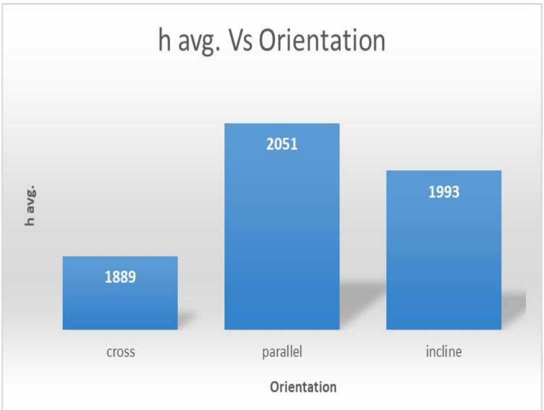


**Figure 5. Bar graph represents the result of the heat transfer coefficient $^{O}$C/w [$h_{avg.}$] with basefins orientation.**

The effectiveness of the fins is ranged from 16.4 to 17 in the cross direction, from 15.86 to 16.54 in the parallel direction, and from 16.1 to 16.6 in the direction of the inclination of the base of the fins. The effectiveness of the fins >1 indicates that the fins enhance heat transfer from the surface, as they should. The average fin efficiency resultsfor the temperature range with the direction of the fins is shown in Figure 6.

The overall fin efficiency ($\eta_o$) ranged from 0.54 to 0.62 °C/W to the three-way rectangular fin assembly used for the base of the fins to the heat supply in the temperature range used. This is observed in Figure 7.

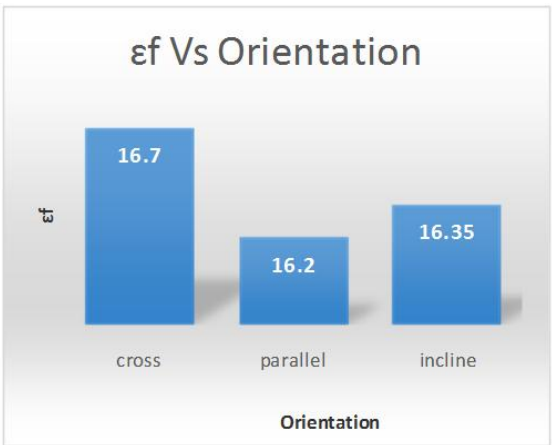


**Figure 6. Bar chart represents resultsof the fin effectiveness ($\varepsilon_f$)for base fins orientation.**


**Figure7. Bar chart represents resultsof overall fin efficiency ($\eta_o$)for the three fins base directions.**

Thermal resistance ($R_f$) is found to change with three directions of the fin assembly with high cross direction value as shown in Figure 8. The values of these parameters range from 0.29 to 0.37 $^{o}$C/w for all temperatures used with different weather conditions.

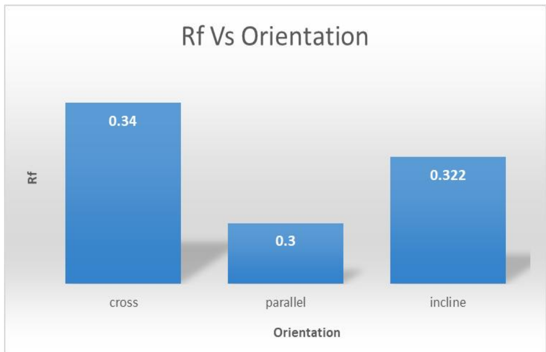


**Figure 8. Real comparative of average fin thermal resistance ($R_{f.}$) among the three types of fins base direction for all the temperatures range of fins used**.

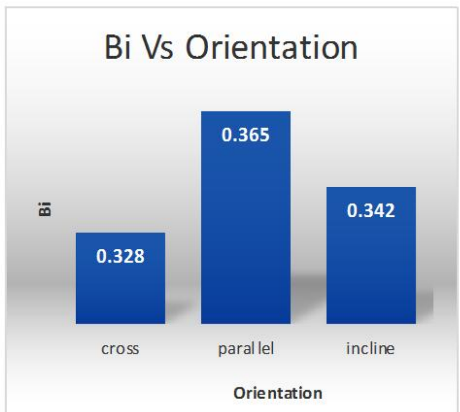


**Figure 9. Bar chartrepresents resultsof theBiot number with base fins orientation.**

It is clear from Figure 9 that there is little difference in Biot number between the three directions of the fin base with respect to the heat source, and the experimental result show that the maximum value of Biotnumber is not observed. At a temperature of 110°C, the minimum value of Biot number is observed. In addition, at a temperature of 60°C in the cross direction of the base of the fin. While a small difference in the Biot number is found in this temperature range for the other direction.

## IV. Conclusion

This empirical investigation discovered that the direction of the fins' bases affects the temperature differential at their surfaces. While the fin orientation in the usual convection position and the high value present in the cross direction affect the heat transfer rate percentage (HTRF%). Additionally, it is stated that the Biot number value is less than 1 for all directions employed for temperatures ranging from 0.25 to 0.36. This indicates that all of the fin orientations employed in the current investigation have a decent distribution of surface temperatures .

For all of the temperatures employed in this experiment, the fins' overall efficiency, effectiveness, and thermal resistance have high values for the cross direction in comparison to others. With a core temperature range of 60°C to 110°C, a rectangular tri-fin array with three orientations for the fin base exhibits varying fin heat transfer performance.

## REFERENCES

[1] Starner K.E. and McManus H.N., "An Experimental Investigation of Free Convection Heat Transfer from Rectangular Fin Arrays", Journal of Heat Transfer, pp. 273-278, 1963.

[2] Leung C.W. and Probert S.D., "Thermal Effectiveness of Short-Protrusion Rectangular, Heat-Exchanger Fins", Applied Energy, pp. 1-8, 1989.

[3] Leung C.W., Probert S.D. and Shilston H.A., "Heat Exchanger Design: Thermal Performances of Rectangular Fins Protruding from Vertical or Horizontal Rectangular Bases", Applied Energy, pp. 123-140, 1985.

[4] Leung C.W., Probert S.D. and Shilston H.A., "Heat Transfer Performances of Vertical Rectangular Fins Protruding from Rectangular Bases: Effect of Fin Length", Applied Energy, pp. 313-318, 1986.

[5] Yüncü H. and Güvenc A., "An Experimental Investigation on Performance of Rectangular Fins on a Vertical Base in Free Convection Heat Transfer", Heat and Mass Transfer, pp. 409-416, 2001.

[6] Murtadha A. and Abdul Jabbar N.K , International Journal of Innovation and Applied Studies.ISSN 2028-9324, Vol. 9, No. 3, pp. 1043-104,2014.

[7] Mahdi Fahiminia, Mohammad Mahdi Naserian, Hamid Reza Goshayeshi and H. M. Heravi. (2012), Experimental investigation of natural convection heat transfer of the fin arrangement on a computer heat sink, Scientific Research and Essays Vol. 7(36), pp. 3162-3171, ISSN 1992-2248 ©2012 Academic Journals.

[8] Walunj,A.A., Dound V.S. and Poland, D.D. , International Journal of Innovation and Applied Studies ISSN 2028-9324 Vol.6, No.2, pp.232-238,June2014.

[9] Al-Jewaree, H.A.M.,"Experimentally Study the Effects of Fins Height and Space Ratio (H\S) to the Fin thermal performance by Natural Convections, International J. of Materials Science &Application ,Vol.7, No.6, 2018 and also IOP Conf. Series: Materials Science and Engineering, Vol. 454, 2018, 012128.

[10] Al-Jewaree, H.A.M., "Study Practically the Effect of fin length and Width (L\w) ratio on the Heat Transfer Performance by Forced Convection", Middle east International conference on contemporary scientific studies. 2 September, Gaziantep, Turkey, 2019.

[11] Al-Jewaree, H.A.M., "Experimentally Study the Effects of Fins Height and Width (H\W) Ratio to the Fin Thermal Performance by Natural Convections", International Journal of Scientific Engineering and Technology (IJSET), Vol. 4, Issue 10, pp. 541-544,2015.