Comparative Study of Performance of Trapezoidal and Rectangular Fins on a Vertical Base Under Free Convection Heat Transfer

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Abstract

This paper concerned with Computational fluid dynamics (CFD) study of the steady-state natural convection heat transfer from vertical trapezoidal fins extending perpendicularly from vertical rectangular base. The effect of heat loads on base-to-ambient temperature difference and on the heat transfer performance of trapezoidal fin arrays for the optimum fin separation values has been studied with the help of simulation models. The heat inputs ranging from 25 W to 125 W has been supplied for fin configuration, and hence, the base and the ambient temperatures are measured in order to evaluate the heat transfer rate from fin arrays. The results are compared with those obtained experimentally & numerically for rectangular fins with same surface area, fin tip thickness & base plate dimensions.

Keywords: Natural convection, Extended surfaces, Optimal fin spacing, CFD

1. Introduction

Heat is generated as a by-product in many engineering applications. This usually unwanted by-product can decrease the performance of the systems since almost every engineering system is designed to work in a certain temperature limit.Using fins is one of the cheapest and easiest ways to dissipate unwanted heat. Natural convection from finned surfaces has been investigated in literature extensively both theoretically and experimentally. Numerical studies were also done to find a convenient model for the phenomena. Yazıcıoğlu [1] performed an experimental study on steady state natural convection heat transfer from vertical rectangular fins & found that the rate of heat transfer from fin arrays depends on the geometric parameters and the base-to-ambient temperature differences.Güvenç [2] investigated natural convection heat transfer from vertically oriented rectangular fin arrays experimentally & found that fin spacing is the most important variable for maximum natural heat transfer rate.Starner and McManus [3] study natural convection heat transfer from four different fin array configurations with three base types and heat transfer coefficients were calculated& concluded that fin height, fin spacing and base orientation have significant effect on rate of heat transfer from fin arrays.Leung and Probert [4] carried out experimental study on the effects of fin spacing and fin height for a limited number of both vertically and horizontally oriented fin arrays configurations &observed that optimum fin spacing was within 9.0 - 9.5 mm range for a fin array that has 150 mm length.Leung et al. [5] performed an experimental study on heat transfer from vertically placed fin arrays produced from an aluminum alloy & found that for different configurations the maximum heat transfer rate from the fin arrays was obtained at the fin spacing value of 10 mm. Yüncü and Anbar [6] conducted an experimental study of natural convection heat transfer from horizontally placed rectangular fin arrays&found that the natural heat transfer rate reaches to a maximum value as a function of fin height and fin spacing for a given base-to-ambient temperature. Vollaro et al. [7] analyzed natural convection from rectangular and vertical finned plates numerically in order to optimize the fin configuration. Dialamehet al. [8] conducted numerical study to investigate the natural convection from horizontally placed rectangular thick fin arrays with short lengths& observed that the free convection heat transfer coefficient increases with the increasing differences in temperature and fin spacing whereas decreases with increase in fin length. Nada [9] investigated experimentally the free convection heat transfer and flow characteristics of heated rectangular fin arrays in enclosures. Effects of fin length and fin spacing were observed for wide range of Rayleigh numbers. Saad M. J. Al-Azawi[10] study experimentally on natural convection heat transfer from longitudinal trapezoidal fins array heat sink subjected to the influence of orientation. Test results indicate that the sideward horizontal fin orientation yield the lowest heat transfer coefficient. However the sideward vertical fin orientation gave the best performance on the natural cooling.

Although, many previous researches were made to study the heat transfer performance of rectangular fin arrays on vertical base under natural convection, very little experimental & numerical data are available for trapezoidal fin. For this reason, the objective of this study is to determine the heat transfer performance of trapezoidal fins & compare it with that of rectangular fins for same surface area.

2. Methodology

In this study, the thermal performances of trapezoidal fins has been investigated by the aid of an academic CFD program, FLUENT 13 & the results are compared with those obtained experimentally & numerically for rectangular fins on same vertical base.

For analyzing the above mentioned matter, 3-dimentional flow is considered with physical properties, wall temperature more than the entrance free air flow temperature. So, upward flow is produced by buoyancy force on the surface. Two ends of the surface is open towards the environment with free flow temperature. Density difference caused by temperature changes are exerted by buoyancy force. The equation of conservation of mass, momentum and the energy for stable and flow is described follow:

Continuity equation: $$\frac{\partial(\rho u_i)}{\partial x_i} = 0. \quad \text{……… (1)}$$

Momentum equation:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_j}{\partial x_i}\right) - \frac{\partial p}{\partial x_j}. \quad \text{………… (2)}$$

Energy equation:

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_j}{\partial x_i}\right). \quad \text{……… (3)}$$

Momentum equation (2) and energy equation (3) should be solved simultaneously because velocity and temperature are both unknown, since temperature depends on the velocity and vice versa. Governing equations are solved using a finite volume approach. The convective terms are discretized using the power-law scheme, whereas for diffusive terms the central difference is employed. Coupling between the velocity and pressure is made with SIMPLE algorithm. The resultant system of discretized linear algebraic equations is solved with an alternating direction implicit scheme.

The procedure for solving the problem is:

i) Create the geometry.
ii) Mesh the domain.
iii) Set the material properties and boundary conditions.
iv) Obtaining the solution

Modeling software UNI-Graphics NX-7.5 creates the geometry and the geometry is imported to the Ansys workbench 14.0 where meshing is done, and exports the mesh to FLUENT. The boundary conditions, material properties, and surrounding properties are set through parameterized case files. FLUENT solves the problem until either the convergence limit is met, or the number of iterations specified by the user is achieved.

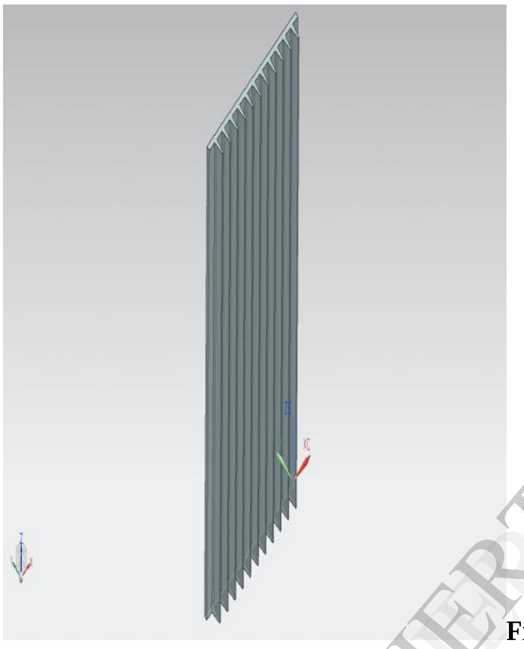

Fig.1 Trapezoidal Fin configuration geometry

In the present study model, the models consist of an aerated concrete block, a base plate for heat generation and fin array configuration. During analysis, in order to obtained results, trapezoidal fins having length 250 mm & thickness 5 mm at base & 3 mm at the tip has been employed. Fin height has been kept 5.93 mm in order to have surface area equivalent to that of rectangular fins. The heat inputs range from 25 W to 125 W has been supplied.

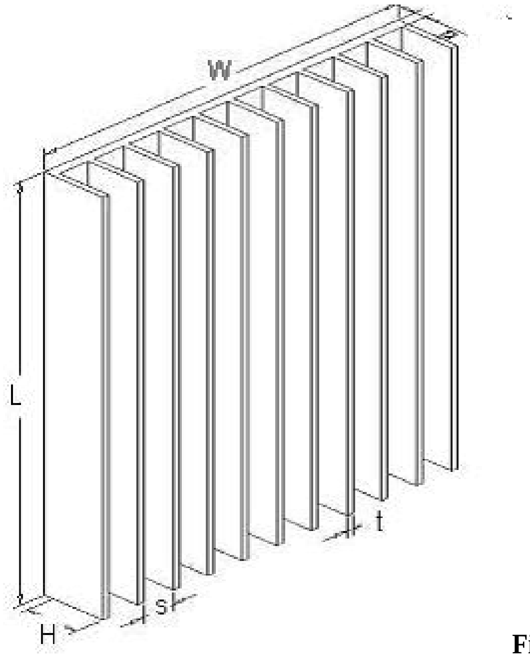

Fig. 2 Rectangular Fin Configuration used for experimental & numerical studies

3. Results & Discussion

In this paper, first vertical surface is considered and then fin Configuration is put on the surface. The results obtained from analyses for trapezoidal fins are given in this section and are compared with those obtained experimentally & numerically for rectangular fins.

Variation of base-to-ambient temperature difference (ΔT) with power input (W)

Fig.3 Comparison of Variation of base-to-ambient temperature difference with power input for trapezoidal & rectangular fins

The base-to-ambient temperature difference of fin arrays are plotted as a function of power input for fin spacing S=14.7 mm & for surface area of 76072 mm2 in figure 3. It can be seen from figure that base-to-ambient temperatures difference increases with power input & for a given power input, this difference is more for rectangular fins as compared to the trapezoidal fins.

Variation of Overall heat transfer coefficient (U) with power input (W)

The overall heat transfer coefficient for the fin arrays are plotted as a function of power input for fin spacing S =14.7mm & for surface area of 76072 mm2 in Figure 4. In figure, it can be observed that heat transfer coefficient increases with power input. For a given power input, its value for trapezoidal fins is higher as compared to rectangular fin which is desirable. However, for rectangular fins, the experimental results are different from the numerical ones.

Fig.4 Comparison of Variation of Overall heat transfer coefficient (U) with power input for trapezoidal & rectangular fins

Variation of Thermal Resistance (Rth) with power input (W)

The thermal resistance for the fin arrays are plotted as a function of power input for fin spacing S =14.7mm & for surface area of 76072 mm2 in Figure 5. In figure, it can be observed that the thermal resistance decreases with the increase in power input. For a given power input, the thermal resistance offer by trapezoidal fins is less as compared to the rectangular fins. It means that surface with trapezoidal fins offers less resistance to the heat flow rate.

Fig.5 Comparison of Variation of Thermal Resistance (Rth) with power input for trapezoidal & rectangular fins

Variation of Flow Temperature with Power Input

Temperature contours of the flow for different power inputs Qin=25W, 50W, 75W, 100W & 125W are shown in Figure 6 to Figure 10 respectively.

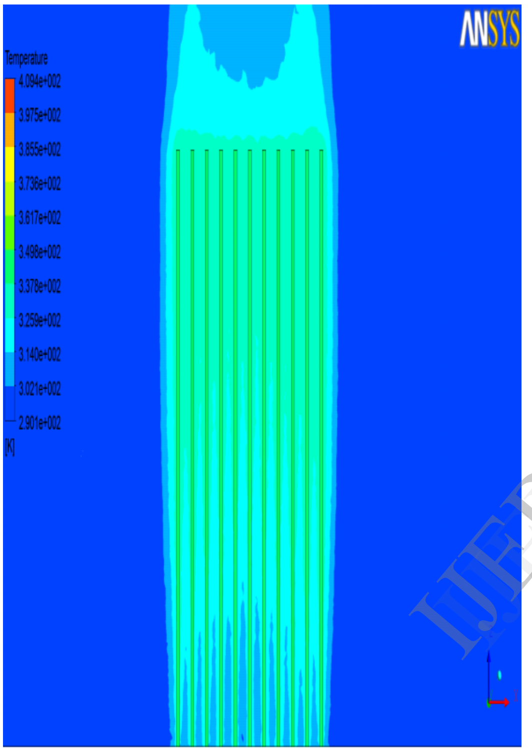

Fig. 6 Temperature Contour for Power Input Qin=25W

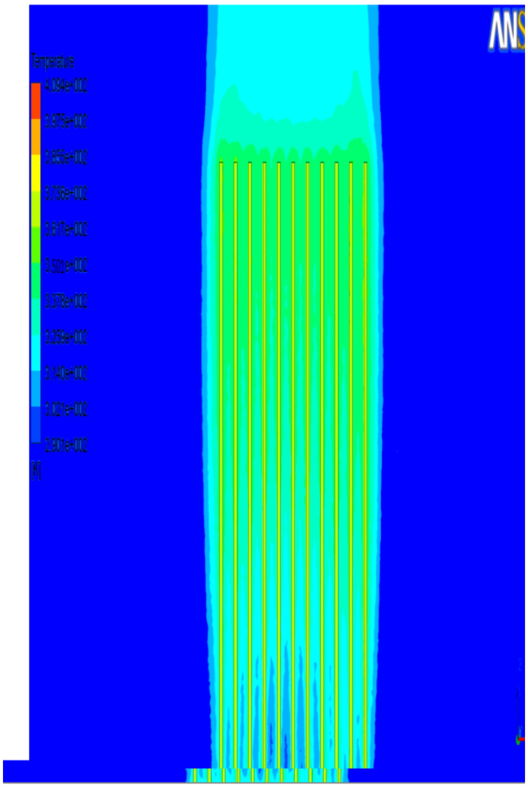

Fig. 7 Temperature Contour for Power Input Qin=50W

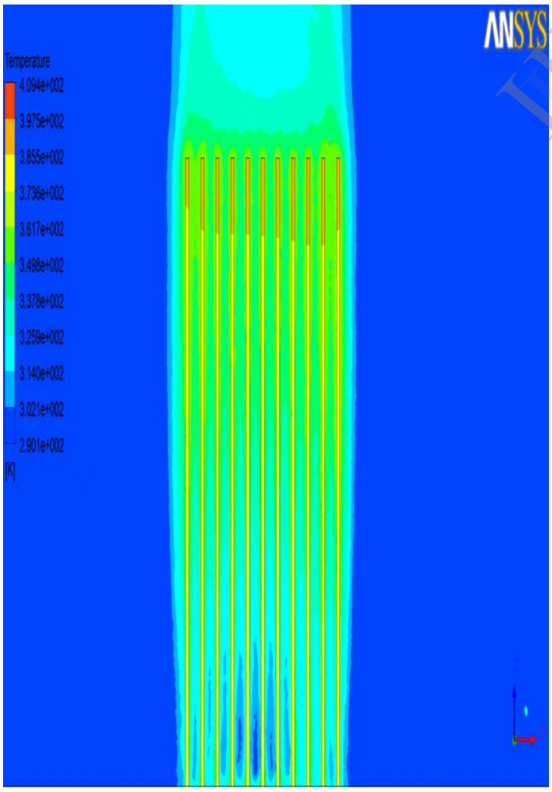

Fig. 8 Temperature Contour for Power Input Qin=75W

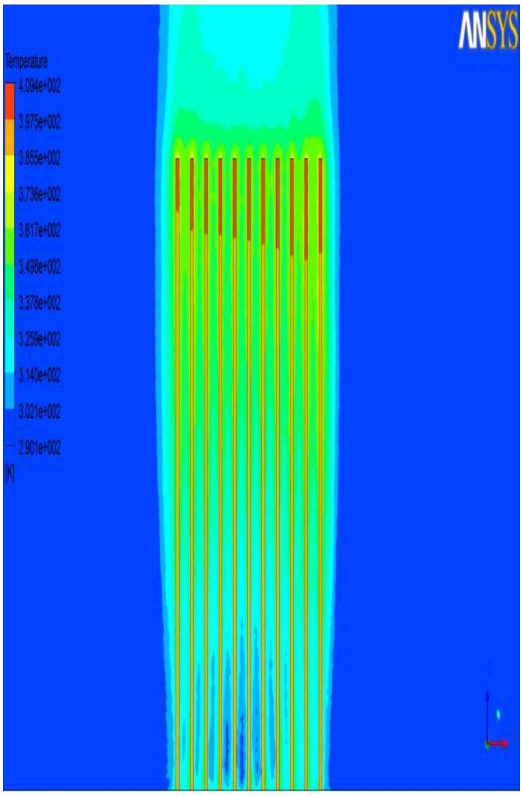

Fig. 9 Temperature Contour for Power Input Qin=100W

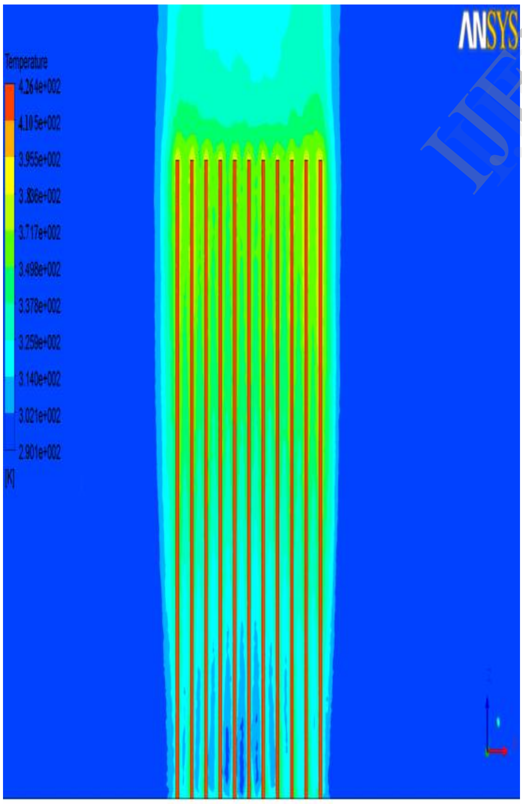

Fig. 10 Temperature Contour for Power Input Qin=125W

It can be seen from the figures that the temperature increases with the power input to the plate. The maximum temperature are obtained as 329.95 k,349.01 k,374.05 k,385.58 k & 396.58 k for heat inputs Qin = 25 W,50 W, 75 W,100 W and 125 W respectively. This is an expected result because the higher power input causes higher air temperature near to the fins. Since in natural convection the air moves because of the difference in density, higher temperature will increase the difference of density in air.

Variation of Surface Temperature with Power Input

Temperature contours of the surface for different power inputs Qin=25W, 50W, 75,100W &125 W are shown in Figure 11 to Figure 15 respectively.

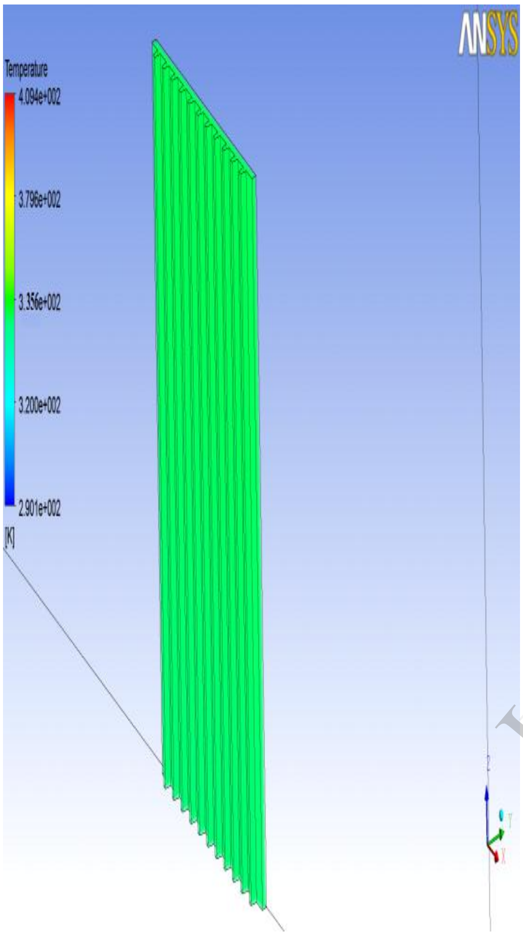

Fig. 11 Temperature Contour for Power Input Qin=25W

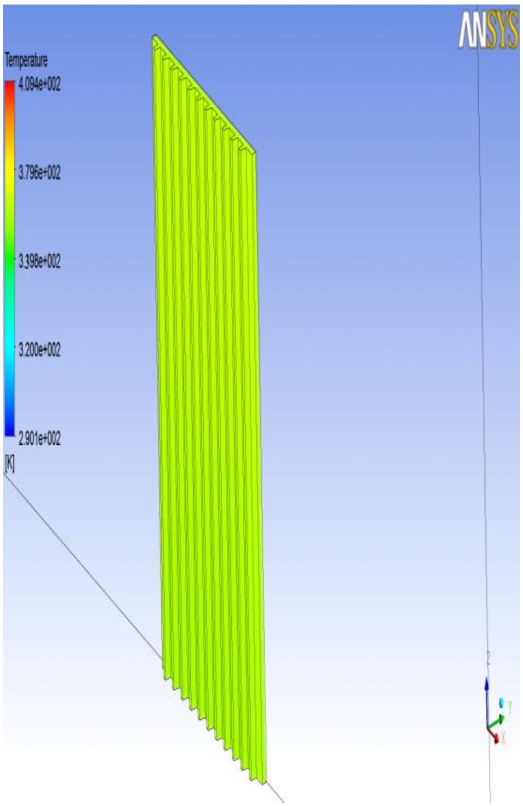

Fig. 12 Temperature Contour for Power Input Qin=50W

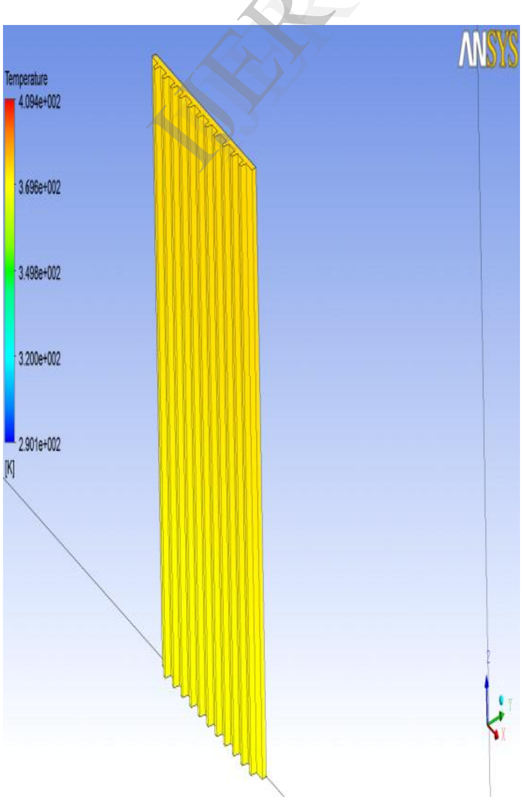

Fig. 13 Temperature Contour for Power Input Qin=75W

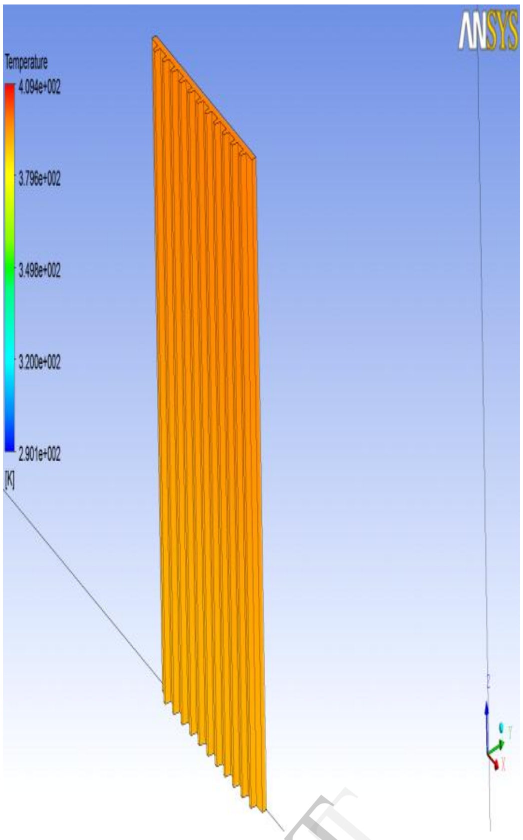

Fig. 14 Temperature Contour for Power Input Qin=100W

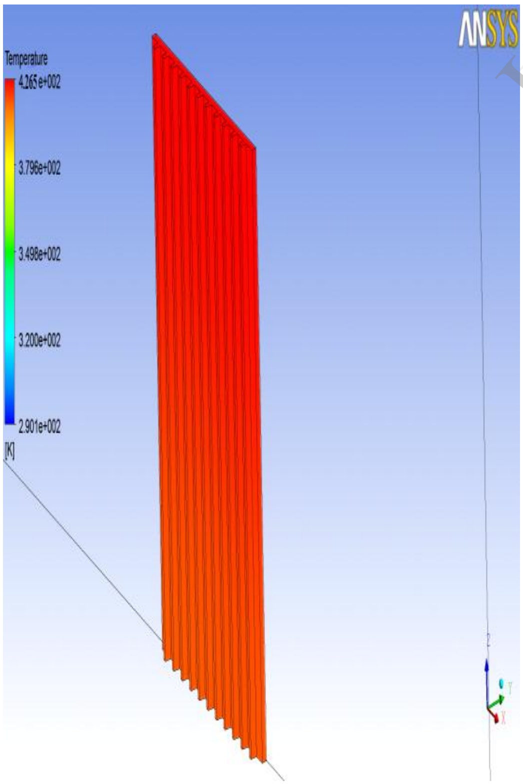

Fig. 15 Temperature Contour for Power Input Qin=125W

It can be seen from the figures that the temperature increases with the power input to the plate. The maximum temperature are obtained as 331.224 k,350.226 k,375.7118 , 401.94 k & 424.254 k for heat inputs Qin = 25 W,50 W, 75 W, 100 W and 125 W respectively. This is an expected result because the higher power input causes higher surface temperature. Larger the base-to-ambient temperature difference, higher will be the rate of convective heat transfer.

4. CONCLUSION

In this study, steady state natural convection heat transfer from vertically placed trapezoidal fin arrays are investigated by the aid of an academic CFD program, FLUENT 14. The main objective of this study is to determine the thermal performance of trapezoidal fins & compare with rectangular fins for same surface area, fin tip thickness & base plate dimensions under free convection heat transfer. The comparison is done on the basis of maximum fin temperature attained, overall heat transfer coefficient & thermal resistance for the power input values that ranges from 25 W to 125 W .The results obtained from the analyses shows that the maximum temperature attained by trapezoidal fins is minimum as compared to the rectangular fins which is desirable. The overall heat transfer coefficient is more for trapezoidal fins for the given power input. The thermal resistance offered by trapezoidal fins is minimum as compared to the rectangular fins for different inputs.So, as per the criterion for the selection of fins, the fins should have lowest thermal resistance and maximum heat transfer coefficient. The trapezoidal fins show the lowest thermal resistance and the maximum heat transfer coefficient. From the calculated values, we can find that the best fin configuration for this type of heat transfer is a surface with trapezoidal fin as they have the highest total heat transfer rate as it has the lowest maximum temperature attained compared to other, lowest thermal resistance along with highest surface heat transfer coefficient for a given heat load of 25W, 50W, 75W, 100W, 125 W.

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