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Research Article

Numerical Investigation and Statistical Analysis on Tree Shaped Fin for Natural Convection

A.Pavani Priyanka[†], K.Pavan Kumar[‡*] and D.V.Parameswara Rao[‡]

[†]Visakha Technical Campus, Visakhapatnam, India
[‡]GVP College for Degree and PG Courses, School of Engineering, Visakhapatnam, India

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Abstract

Extended surfaces are widely used for the cooling of heat generating devices either internally or externally in natural convection process. In the current work tree shaped fin is preferred for analysis. CFD analysis (ANSYS 15) is done on the tree fin placed in an enclosure using FLUENT and heat input in the form of temperature is given to the base of the fin. The heat transfer characteristics were calculated for various temperature inputs. In order to increase the performance of the system, heat transfer rate is to be enhanced. Considering this, the orientation of the fin is varied simultaneously for each temperature input. The heat transfer characteristics have acquired better results for temperature input 363K and orientation 90⁰. Taguchi and ANOVA analysis are performed and concluded that the temperature is having more influence on the system performance.

Keywords: *Tree Fin, Heat Transfer Characteristics, Taguchi, ANOVA*

1. Introduction

Many Engineering systems results in the generation of heat during various operations. The heat generated should be within the recommended working temperatures and operating conditions, because it may lead to overheating and malfunctioning of the system. Several researches are done to increase the effectiveness in heat transfer by reducing the volume to weight ratio of the heat exchanging bodies.

The devices getting miniaturized day-by-day in engineering applications thereby the volume allocated for heat dissipation units also reduced, which resulted to the use of extended surfaces or fins, enhances heat transfer in many modern engineering applications like electronic industry, compact heat exchanger sector, power plants, refrigeration and air conditioning, transformers, air compressors etc., In order to achieve the desired rate of heat dissipation with the least amount of material, the optimal combination of fin geometry and orientation of the finned surface is necessary. Among several available techniques for escalation of heat transfer in heat exchanger tubes, the use of internal fin appears to be very capable method, has shown a remarkable result of the past investigations. Forced convection requires auxiliary units for heat dissipation leads to additional economic constraints, space, power consumption etc., but in natural convection additional mechanisms are not required to extract the heat. The methodology of natural convection process over a fin in an enclosure is of major concern to dissipate heat from its base to the surroundings. The design of fin with enhanced heat dissipation capabilities has been indefinable and affects various factors. To maximize the heat rejection and minimizing the mass, it is important to optimize the design of extended surfaces.

In the engineering as well as the real world entity dissemination the tree shaped flow paths are the common ones. The pragmatic view inherited from the natural sciences is that tree-shaped flows are examples of impulsive self-organization and self-optimization. The purpose of a tree network is to make a flow connection between one point (source or sink) and an infinity of points (area or volume). The tree architecture are the results of a process of optimization of global flow performance subject to constraints (Bejan, 2000). Tree designed to flow between a volume and one point. The objective is to achieve maximum global performance subjected to global constraints like fixed volume of the system and the fixed space of heat dissipation units. Heat rejection performance from tree like fins is studied by various parameters like bifurcation angle, surface emissivity, material, width to thickness ratio and base heat rate in MATLAB software and these results are compared with different configurations and concluded that parabolic fin can be

*Corresponding author **K.Pavan Kumar** is working as Assistant Professor; **D.V.Parameswara Rao** as Professor and **A.Pavani Priyanka** is a Scholar

adapted like tree fin to increase heat transfer (V Nandhivarman, V T Koushic, G Sridharan, S Velmurugan, 2014). The system parameters like base temperature, fin height, fin spacing effects the heat transfer rate and effectiveness of vertical fin array and concluded that fin spacing is the most significant parameter and has an optimum value. The optimum performance cannot be concluded by concentrating on 1 or 2 parameters (Senol Baskaya, Mecit Sivrioglu, Murat Ozek, 2000; Dr. P V J Mohan Rao, 2014). Fin spacing and Grashof number plays a vital role in heat transfer characteristics in natural convection and obtained a relation between Nusselt number and fin spacing for triangular fins, compared the result with rectangular fin arrays attained good results(N G Narve, N K Sane, R T Jadhav, 2013). Heat transfer through Pin-fin arrays subjected to forced convection environments are experimentally investigated to find the dependencies of Nusselt number on Reynold's number (Tahat M, Kodah Z.H, Jarrah B.A, Probert S.D, 2000).

Fins and fin arrays attached to a heated horizontal base was studied under the effect of natural convection heat transfer process (Sobhan C. B., Venkateshan S. P., Seetharamu K. N., *Wärme Stoffübertragung*, 1990). Analysis of Forced convection through tree shaped fins attached to a flat and symmetrical wedge shaped base plate is studied and was proven that tree fins attached to wedge shaped base yielded the high heat dissipation rates (K. Pavan Kumar*, P. V. Vinay, R. Siddhardha, 2014). The size of fins peripheral design, the amount of fin, the gap between fins and the area, all have an exhaustive relationship on enhancing the convection effect and the increase in heat sink ability (A.D. Kraus, A. Bar-Cohen, 1995; S.H. Kim, N.K. Ananda, 1994). The optimum design and the selection of geometry of the heat sink module has become the major problem for electronic industry and so the statistical analysis is performed to attain the optimum results. Taguchi method for design of experiments (DOE) and the analysis of variance (ANOVA), are widely employed to sieve the combination of optimized design parameters (C. Taguchi, 1990).

In the present work the process of heat dissipation from a tree shaped fin placed in an enclosure under natural convection heat transfer process is analyzed by using CFD (fluent). The base temperature of the fin and the orientation are varied simultaneously and the results are tabulated. Taguchi and ANOVA (Analysis of Variance) were performed to analyze the impact of parameters on the process.

2. Solution Procedure

The present study explains the natural convection heat transfer from a tree shaped fin placed in an enclosure. The fluid in the enclosure is assumed to have constant properties as the conservation of mass, momentum and energy in the fluid, are based on it. Equations (1-5) represent the governing equations. For density-temperature relation the Boussinesq approximation equation is considered. The governing equations are given below:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (1)$$

$$\rho(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z})=-\frac{\partial P}{\partial x}+\mu\nabla^2 u+\rho g_x \quad (2)$$

$$\rho(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z})=-\frac{\partial P}{\partial y}+\mu\nabla^2 v+\rho g_y \quad (3)$$

$$\rho(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z})=-\frac{\partial P}{\partial z}+\mu\nabla^2 w+\rho g_z \quad (4)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\alpha\nabla^2 T \quad (5)$$

where, y is taken along the gravitational acceleration direction and x and z are taken normal to the gravitational acceleration, the three fluid velocity components along the x, y and z directions are u, v and w respectively.

2.1 Design and Modelling

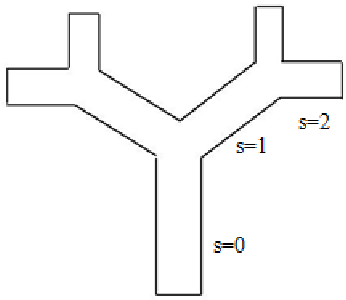

Fig.1 Sketch of the Proposed Tree Fin

Table 1: Dimensions given to the Tree Fin

Stem Numbers(s)	Length(cm)	Width(cm)	Depth(cm)
0	2.5	1	0.5
1	1.77	0.71	0.5
2	1.25	0.5	0.5

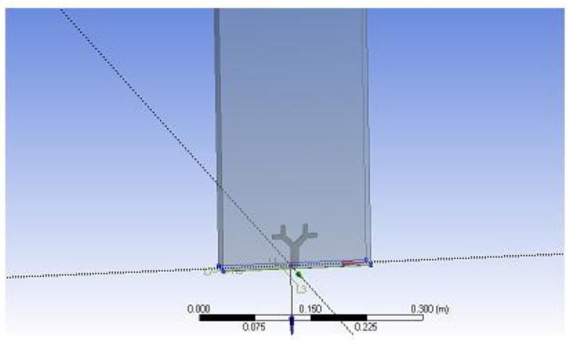

Fig.2 Modeling of tree fin with enclosure

A Tree shaped fin (Figure 1) is designed in CATIA which is having three branches with an included angle between them as 90^0 (Calamas David, Baker John, 2013) and height of the fin is 5.52cm. These fins find its application in heat generated components where the effective area is of primary importance mainly in natural convection. The fin is imported to Ansys and an enclosure of dimensions 0.2X0.025X0.495m is generated and a Fin with above said dimensions is placed at the base of the enclosure as shown in Figure2. The material of the fin is taken as aluminium and the surrounding medium as air. At the base of the fin, temperature inputs (323K, 333K, 343K, 353K and 363K) are given and the orientation of the fin (0^0, 45^0, 90^0, 135^0 and 180^0) is also varied corresponding to it. The temperature gradient between the fin and the air inside the enclosure thus creates density differences which set up the buoyancy forces and free convection currents, as the heat transfer mainly depends on fluid motion which is governed by a balance between buoyancy and viscous forces.

The direction of air is from top due to gravitational force and so the orientation of fin is taken basing on the gravity as it effects the natural convection. For the effective utilization of area of contact of the fin, the orientation of the fin plays a major role in it by increasing the air contact time with the fin. The restriction caused to the movement of air increases the heat dissipation rate.

2.2 Mesh Independent Study

Meshing is the process of discretisation of space in which flow takes place. The outer enclosure is discretized into tetrahedral elements and the tree fin is discretized into hexahedral elements.

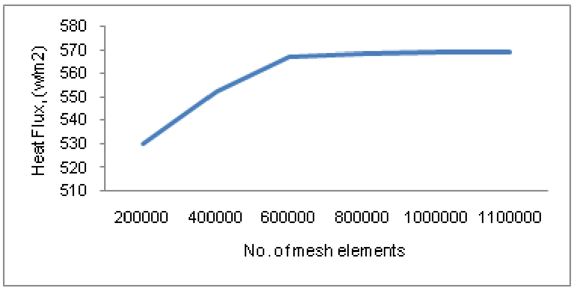

Fig.3 Graph Showing the Heat flux along the Vertical

Line and the No. of mesh elements along the horizontal line.

The above Figure 3 explains the variation of heat flux with the no. of mesh elements. The refinement of solution is observed at 1100000 mesh elements in the graph. There is no perceptible change in the value of heat flux even with further increase in no. of mesh elements.

2.3 Boundary Conditions

The base of the Fin is supplied heat in terms of temperature, wall of the enclosure is maintained at 300K atmospheric temperature with the density considered as buoyant and coefficient of thermal expansion as 0.0032 for air. The fluid circulation in the enclosure is caused due to buoyant force, which comes into play because of density variations due to temperature difference.

2.4 Results and Discussion

The material of the tree fin is chosen as aluminium and the base of the fin is given temperature inputs as 323K, 333K, 343K, 353K and 363K with the corresponding change in the angles 0^0, 45^0, 90^0, 135^0 and 180^0 for each temperature input and the parameters such as Nusselt number, convective heat transfer coefficient, heat flux, wall shear stress, enthalpy and entropy are evaluated in all the cases.

Convection heat transfer is governed by Newton's law of cooling, and the relation is

$$Q = h\,A\,(T_s - T_a) \tag{6}$$

The above equation states that the rate of heat transfer depends on, surface area, the temperature difference between the surface temperature and the ambient temperature and the convective heat transfer coefficient.

The flow of air in the enclosure is assumed to be laminar basing on the relations given below,

$$Ra = Gr.\,Pr \tag{7}$$

$$Ra = \frac{g\beta(Ts-Ta)l^3}{\alpha\upsilon} \tag{8}$$

The Rayleigh number (Ra) is less than 10^9 ($Ra < 10^9$), hence the flow of fluid in the enclosure is taken as laminar. The Nusselt number is a function of Grashof number and prandtl number in natural or free convection.

$$Nu = f(Gr\,,Pr) \tag{9}$$

The Nusselt number can be calculated using the below equation.

$$Nu = \frac{h*d_{hydraulic}}{K} \tag{10}$$

$$Gr = \frac{g\beta(Ts-Ta)l^3}{\upsilon^2} \tag{11}$$

$$Pr = \frac{\mu C_p}{K} \tag{12}$$

The Grashof number is the ratio of the buoyancy force to the viscous force in the fluid. The buoyancy force develops acceleration to the particles of the fluid thereby increasing the velocity of fluid in the enclosure.

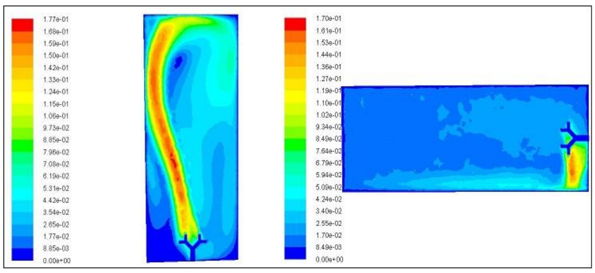

Fig.4 Velocity contours of orientation 0^0 and 90^0 for 333K base temperature

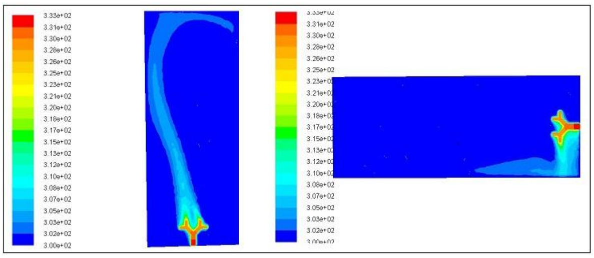

Fig.5 Temperature contours of orientation 0^0 and 90^0 for 333K base temperature

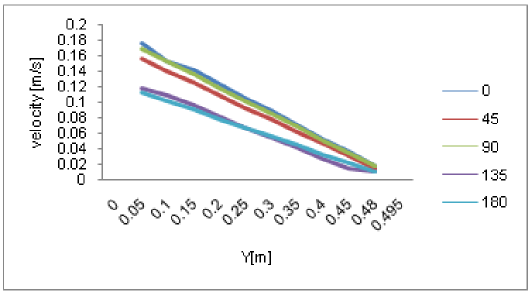

Fig.6 Graph Showing the Velocity along a Vertical Line for the different angles

From the Figure 6 it is clear that the velocity of the fluid is more when the fin is placed in the orientation of 90^o. The increase in the velocity increases the heat transfer rate from the fin. The convection currents so developed carries away the heat from the source more effectively. Hence the heat dissipation rate in that case will be more when compared to other cases.

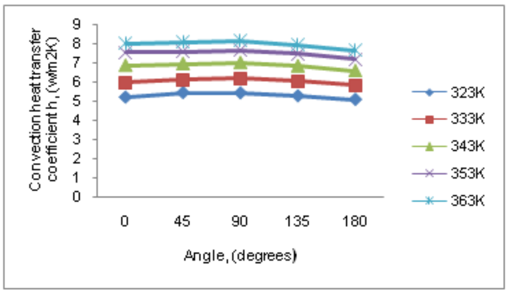

Fig.7 Graph Showing the Convection heat transfer coefficient along a Vertical Line for different orientations and base temperatures

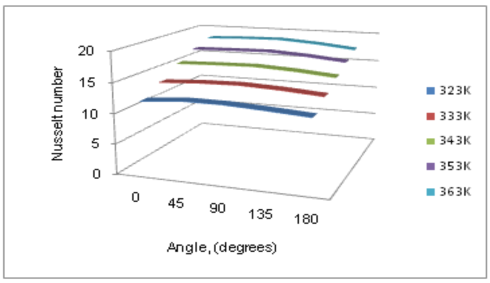

Fig.8 Graph Showing the Nusselt number along a Vertical Line for the different orientations and base Temperatures

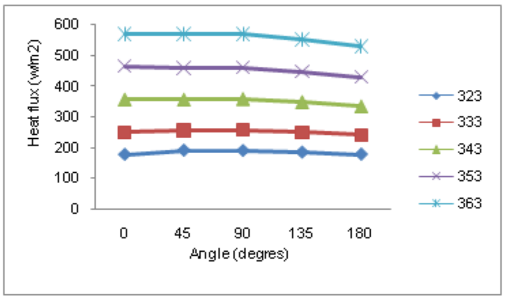

Fig.9 Graph Showing the Heat flux along a Vertical Line for the different orientations and base temperatures

Convective heat transfer coefficient is mostly influenced by temperature applied to base rather than angle (Figure 7).The convective heat transfer coefficient for the fin placed in an enclosure has obtained a greater value for 363K and 90^0 orientation probably as the air heated was been circulating inside the tree shaped fin, as well as enclosure was constraining the air near the fin as shown in Figure 4. The high temperature air is been more stagnant near tree fin for 90^0 angle as shown in Figure 5 which again affirms that heat transfer coefficient to be maximum for 363K and 90^0 orientation.

It is clear from Figure 8 that for every base temperature at orientation 90^0 the Nusselt number is maximum, indicating the maximum heat transfer rate. Nusselt Number has an increasing and decreasing tendency starting from 0^o to 180^0. As the heat transfer coefficient increases, the heat flux also increases in the same manner, as heat flux is directly proportional to convective heat transfer coefficient, shown in the Figure 9.

2.4.1 Taguchi Method

The Taguchi method is used to improve the quality of the parameters and the process. To study the effects of various process parameters on the performance of the fin and to solve the problems by objectively laying out the investigative experiments, the Design of Experiments using the Taguchi approach has become more attractive tool and is proven to be the best method in getting optimized results. The study of the performance of individual parameters and to determine either which parameter is having more or less influence on the fin and the heat flux. To determine robust design, experiments are conducted under the influence of various noise factors. An "Orthogonal Array" is used to reduce the number of noise conditions obtained by the combination of various noise factors. Five levels and two parameters were taken basing on the Taguchi design of experiments L25 orthogonal array as in Table 2. Totally 25 experiments were conducted. The signal to noise ratios (S/N) are log functions which are used in prediction of optimum results by analyzing the data input given to it.

For different orientations and temperature inputs the heat flux values are calculated. These values are used to conduct the statistical design analysis. The heat flux values obtained for corresponding changes in the temperature as well as the orientation of fin are tabulated in Table 3.

2.4.1.1 Signal to Noise ratio

S/N ratio is a quality based approach. The main objective is to increase the heat transfer rate from the extended surfaces, tree shaped fins placed in an enclosure. For the effective heat transfer the heat flux should be higher. Hence S/N ratio calculated should be higher in order to get the better results. Base on the above concept, the expression for S/N ratio is selected.

$$\text{MSD}= \{ \frac{1}{Y_1^2} + \frac{1}{Y_2^2} + \frac{1}{Y_3^2} + \ldots\ldots\ldots\ldots + \frac{1}{Y_n^2} \Big/ n \} \qquad (13)$$

For Bigger is Better

S/N = - 10 x Log (MSD) for all characteristics (14)

Where, MSD is Mean Squared Deviation.

Table 2 Control factors and levels

Item	control factor	units	level1	level2	level3	level4	level5
T	Temperature	Kelvin	323	333	343	353	363
A	Angle	Degrees	0	45	90	135	18

Table 3 Heat Flux and S/N ratio value for tree shaped fins

	Coded Value			
Exp No	Temperature	Angle	Heat Flux (w/m2)	S/N ratio for heat flux
1	1	1	178.32	45.024
2	1	2	192.27	45.6782
3	1	3	191.6	45.6479
4	1	4	185.89	45.3851
5	1	5	179.09	45.0614
6	2	1	250.418	47.9733
7	2	2	256.55	48.1834
8	2	3	258.38	48.2452
9	2	4	251.49	48.0104
10	2	5	241.67	47.6645
11	3	1	355.58	51.0187
12	3	2	355.68	51.0212
13	3	3	357.59	51.0677
14	3	4	347.76	50.8256
15	3	5	333.85	50.471
16	4	1	465.56	53.3595
17	4	2	459.45	53.2448
18	4	3	461.53	53.284
19	4	4	448.41	53.0335
20	4	5	430.3	52.6754
21	5	1	569.38	55.108
22	5	2	567.43	55.0782
23	5	3	569.4	55.1083
24	5	4	552.95	54.8537
25	5	5	530.26	54.4898

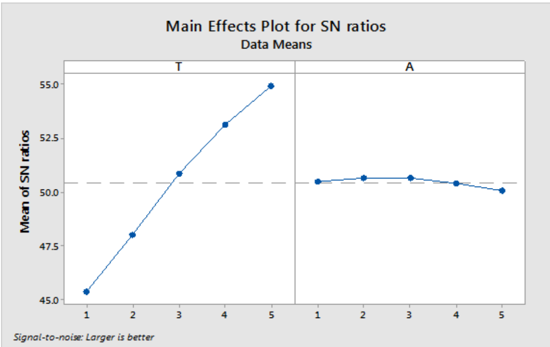

Fig.10 Factor effect diagram of S/N ratio for tree shape fin, heat flux

Level 5 of T and level 3 of A is having the maximum effect increasing the heat flux. Fascinatingly, T5 and A3 is the best combination, the temperature 363K and the Angle 90^0 is giving the high heat flux. From the graphical analysis the temperature is having more influence on the heat flux from the Figure (10). Based on the experiments, the optimum parameters of design are T5A3. In the analysis of fin, the basic parameters are temperature and angle, among these two parameters the temperature ranked one for heat flux, which is having more influence on the heat transfer characteristic.

2.4.2 ANOVA Analysis

ANOVA is a statistical method stands for analysis of variance. The purpose of ANOVA is to explore how the independent variables influence the response of the dependent variables in the heat transfer process. It also determines the parameters that mostly influence the process in improving the performance of the system. In the present work the two independent variables taken are temperature and angle. The R-square (R^2) value obtained for heat flux is 99.86% and in ANOVA analysis it indicates the reliability of the result. The value of 'p' 0.000 is significant for both temperature and angle. The output of ANOVA analysis of variance is represented in table 5. Larger F value indicates that the parameter is having more influence on the process. The value of F obtained for temperature (2794.35) is more than the F value of angle (12.65). Hence with the variation in the temperature there will be significant changes in the heat transfer process rather than variation in angle. Captivatingly, the result of the ANOVA analysis validates the Taguchi results.

Table 4 S/N ratio effect for heat flux

Factor Rank	evel1	Level2	Level3	Level4	Level5	Delta	Rank
Temperature	45.36	48.02	50.88	53.12	54.93	9.57	1
Angle	50.5	50.64	50.67	50.42	50.07	0.6	2

Table 5 ANOVA for the heat flux

Source	Degree of Freedom	Sum of squares(SS)	Adj. Means of squares (MS)	Factor(F)	P
T	4	450579	112645	2794.35	0
A	4	2040	510	12.65	0
Error	16	645	40		
Total	24	453263			

Significant, S = 6.34914 R-Sq = 99.86% R-Sq (adj) = 99.79%

Conclusion

The tree fin placed in an enclosure is having more heat dissipation rate when the fin placed in orientation 90^0 at 363K temperature. The heat transfer characteristics of the fin like heat flux (569.4w/m^2), convective heat transfer coefficient(8.1894w/m^{2}K) and Nusselt number(18.612) has obtained high values in this case.
From the analysis it is concluded that both orientation and base temperature affect the performance of the fin. With the increase in base temperature the heat transfer characteristics increased, but in the case of orientation the characteristics increased up to 900, as the restriction caused to the fluid is optimum at 900, with further increase in orientation the air between the enclosure and fin is immobile at the base due to more obstruction, which led to the limiting of heat transfer rate, and there is a gradual decrease in the values is observed. From Taguchi and ANOVA analysis, it is inferred that the temperature is having more impact on the fin compared to the orientation.

Nomenclature

A Surface area m^2
C Specific heat J/kgK
$d_{hydraulic}$ Hydraulic diameter, m
g Acceleration due to gravity, m/sec^2
h Convection heat transfer coefficient, W/m^{2}K
K Thermal Conductivity, W/mK
l Distance, m
n no. of experiments
p pressure, Pa
Q Rate of heat transfer W
T Temperature, K
u flow velocity in x direction, m/s
v flow velocity in y direction, m/s
w flow velocity in z direction, m/s
x direction normal to the fin surface
y direction along the fin surface
Y response value
z direction normal to the fin surface

Greek Symbols

μ fluid viscosity, kg/m s
ρ density, kg/m^3
α thermal diffusivity, m^2/s
β coefficient of volume expansion, 1/K
ν kinematic viscosity, m^2/s

Subscripts

a ambient
p constant pressure
s surface

Notations

$\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}, \frac{\partial}{\partial T}$ partial derivatives

Non-dimensional Numbers

Nu Nusselt number
Ra Rayleigh Number
Gr Grashof number
Pr Prandtl number

References

Bejan (2000), A Shape and Structure Engineering to Nature, Cambridge, UK, Cambridge University Press.

V Nandhivarman, V T Koushic, G Sridharan, S Velmurugan (2014), Effective Heat Rejection in Tree Like Fins, Transaction on Engg. & Sciences, ISSN(e) pp 2347-1964,2347-1875.

Senol Baskaya, Mecit Sivrioglu, Murat Ozek (2000), Parametric Study of Natural Convection Heat Transfer from Horizontal Rectangular Fin Arrays, Int. J. Therm. Sci., 39(8), pp 797–805.

Dr. P V J Mohan Rao (2014), A Numerical Study of Laminar Natural Convection Heat Transfer and Radiation from a Rectangular Vertical Fin Array using Quasi-3D approach, IOSR Journal of Engineering (IOSRJEN), 4(1), ISSN (e): 2250-3021, ISSN (p): 2278-8719.

N G Narve, N K Sane, R T Jadhav (2013), Natural Convection Heat Transfer from Symmetrical Triangular Fin Arrays on Vertical Surface, International Journal of Scientific & Engineering Research, 4(5), ISSN 2229-5518.

Tahat M, Kodah Z.H, Jarrah B.A, Probert S.D (2000), Heat Transfers from Pin-Fin Arrays Experiencing Forced Convection, Appl. Energy, 67(4), pp 419–442.

Sobhan C.B., Venkateshan S.P., Seetharamu K.N (1990), Experimental Studies on Steady Free Convection Heat Transfer from Fins and Fin Arrays, Wärme Stoffübertragung, 25(6), pp 345–352.

K. Pavan Kumar*, P. V. Vinay, R. Siddhardha (2014), CFD Analysis of Tree Shaped Fin Array on Flat and Symmetrical Wedge Shaped Base Plate, J. Thermal Engg. & Applications (JoTEA) STM Journals.

A.D. Kraus, A. Bar-Cohen (1995), Design and Analysis of Heat Sinks, John Wiley and Sons, Inc., New York.

S.H. Kim, N.K. Ananda (1994), Laminar developing flow and heat transfer between a series of parallel plates with surface mounted discrete heat sources, Int. J. Heat Mass Transfer, 37 (15), pp 2231-2244.

C. Taguchi (1990), Introduction to Quality Engineering, Asian Productivity Organization, Tokyo.

Calamas David, Baker John (2013), Behavior of Thermally Radiating Tree-like Fins, J. Heat Trans., 135(8), 9 pages.