ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com
International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 3, Special Issue 5, February 2016 in association with
HEERA COLLEGE OF ENGINEERING AND TECHNOLOGY, THIRUVANANTHAPURAM
Organizes
NATIONAL CONFERENCE ON ENGINEERING FOR LIFE (NCEL – 2016)
(12th -13th February 2016)

Numerical study on heat transfer performance of wavy fins with different geometries

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***Abstract*—Over the past few decades considerable attention has been devoted to heat transfer enhancement in thermal devices due to increased demands by industry for efficient and cost-effective heat exchange equipments. Extended surfaces (fins) are one of the heat exchanging devices that are employed extensively to increase heat transfer rates. Fins are used to Enhanced convective heat transfer in a wide range of engineering applications, and offer a practical means of achieving a large total heat transfer surface area without the use of an excessive amount of primary surface area. Heat transfer in fins can be enhanced by making some modifications in the geometry of fin surfaces. Computational Fluid Dynamics (CFD) analysis was conducted to investigate the heat transfer performance of wavy fins and result was compared with that of rectangular fin of same configuration. The result shows better heat transfer performance of wavy fin. Studies were also conducted by changing the geometric parameters of wavy fin like amplitude, fin height, fin spacing and wave length etc.**

***IndexTerms*—wavy fin, Heat transfer enhancement, Natural convection, wave amplitude,Fin array**

I.INTRODUCTION

Fins or extended surfaces have wide variety of industrial or domestic applications in Electronic equipment's, space vehicles and heat exchangers as a means to remove the excess heat generated in components. Extended surfaces are widely used passive techniques to enhance heat transfer. Whenever it is difficult to increase the rate of heat transfer either by increasing heat transfer coefficient or by increasing the temperature difference between the surfaces and surrounding fluid, the fins are commonly used. Natural convection heat transfer is often augmented by provision of rectangular fins on horizontal or vertical surfaces in many electronic applications, motors and transformers. The current trend in the electronic industry is miniaturization, making the overheating problem more acute due to the reduction in surface area available for heat dissipation. Fins come in various shapes; such as rectangular, circular, pin fin rectangular, pin fin triangular etc. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness. Study of influence of geometric parameters viz. fin length, fin height, fin spacing over heat dissipation found important. Further enhancement in heat transfer can be obtained by proper selection of form of extended surface or by making some modifications in the geometry of surfaces.The rate of heat transfer depends on the surface area of the fin.

Ashish Dixit[1] conducted a review on Extended surfaces and techniques have been investigated on enhancement of heat transfer rate. Bergles classified heat transfer intensification methods in to three categories- Active techniques, Passive techniques and combination of these two. But it has been reported that in many cases heat transfer enhancement through passive methods are used as this technique do not require any external power source for this purpose. Passive method generally uses surface or geometrical modifications to the flow channel by incorporating inserts, artificial roughness or material removal from the surface. Passive methods when adopted particularly in Heat exchanger applications proved that the overall thermal performance improved significantly. This paper presents the review on heat transfer enhancement using

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passive methods and explores how extended surfaces with geometrical modifications like dimples, protrusions, grooves etc., improves heat transfer characteristics.

Bassam A/K Abu-Hijleh studied the effect of several combinations of number of fins and fin height on the average Nusselt number over a wide range of Rayleigh number. Permeable fins provided much higher heat transfer rates compared to the more traditional solid fins for a similar cylinder configuration. The ratio between the permeable to solid Nusselt numbers increased with Rayleigh number, number of fins, and fin height.

Junqi Dong, Lin Su, Qian Chen, Weiwu Xu [2]conducted experimental study on thermal performance of wavy fin and tube heat exchanger. They conducted the study by changing the various geometric parameters of the wavy fin like fin amplitude , wave length and fin height. It is showed that the amplitude and length of a wavy fin were the most important factors for the heat exchanger's overall thermal hydraulic performance. The wavy fin has been one of the enhanced fins widely used in recent years due to its good heat transfer and pressure drop performances as well as its resistance to dust adherence and blockage, especially under a severe operating environment.

M.Khoshvaght Aliabadi, M.Gholam Samani, F.Hormozi, A.Haghighi Asl [4] conducted CFD analysis on wavy fins. They studied the effects of the five geometrical factors of fin pitch, fin height, fin length, fin thickness, and wavy amplitude are investigated over a wide range of Reynolds number. The CFD simulation results express that the geometrical parameters of wavy fins havesignificant effects on heat transfer characteristics and Reynolds number. The numerical simulation results implied that with the increase of the wave angles, decrease of the fin pitch, and decrease of the tube row number, the heat transfer of the finned tube bank enhances, but with some penalty in pressure drop.

Mukesh Didwania, Gopal Krishan ,Ravikant[3] studied the rate of heat transfer and pressure loss for different shape fins with rectangular duct when surface area is same for all. The purpose of this study is to determine the optimum dimensions and shapes for rectangular longitudinal fins, cylindrical pin fins by including transverse heat conduction. This analysis completed to calculated Maximum Heat transfer rate of fin Surface and Minimum Pressure loss in Duct due to shape change. They also investigated the effect of a variable heat transfer coefficient on the optimum dimensions of the aforementioned fins.

P.Srinivasan, M.Muthukumaran, K.Akilan, V.Dhanasekar[6] investigated the performance of wavy fin array of varying geometry.The study of wavy fin is to increase the heat transfer rate from the heated surface to avoid the excess heat generation which will leads to damage of the mechanical parts is the key area of research in modern industry. This study focuses in particular, the increase in heat transfer rate in order to optimize the fin spacing and fin height by means of replacing the straight fin by wavy fin. This project shows a comparative study of the effect of fin spacing and height with the straight and wavy fins to attain maximum heat transfer rate.Flow velocity between the fins also a major component for maximum heat transfer. How long the cold flow stays inside the passage will observe more heat from the source. In straight fins passage the cold fluid leaves without any disturbance and it will not observe that much heat from the source. But in wavy fins, the cold flow stays longer than in the straight fins. This results in observing the heat from the source much better than in straight fins. Also in wavy fins the flow recirculate between the fins and tends to absorb more heat and leaves the passage. Christo Ananth et al. [7] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

Junqi Dong , Jiangping Chen , Wenfeng Zhang , Jinwei Hu[11]carried out a detailed experimental and numerical study of convection heat transfer and pressure drop of wavy fin. Three-dimensional numerical simulation results using the CFD code FLUENT6.1 were compared with experimental data to select the best the turbulence model. The heat transfer and pressure drop with different geometry pattern was then studied numerically using the selected turbulence model. And the velocity field and temperature distribution of air flow in the wavy fin are presentedwith different geometry patterns. In addition the enhancement heat transfer mechanism of wavy fin is explained in view of field synergy principle. These results provide insight into improved designs of wavy fin-and-flat tube heat exchangers.The waviness amplitude has the distinct effect on the heat transfer and pressure drop of wavy fin, while the wavy fin profile (Triangular, Sinusoidal and Triangular round corner) has little effect on the heat transfer performance This wavy fin is a non-louvered fin to avoid dust plugging, which are usually used in those no-road vehicle.

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Rush et al. conducted flow visualization test for sinusoidal wavy passages to investigate the local heat transfer and flow behavior of the fluid in the laminar and transitional flow region. However, it should be noted that, in these studies most researchers only studied the wavy fin in a periodic channel, including the two-dimensional and three-dimensional numerical simulation.

II.PROBLEM FORMULATION

A. Problem specification

In this study I have considered a solid fin having dimensions 25mmx75mmx75mm with 10 fin arrays, where it have a thickness of 1mm and fin spacing of 6mm.Problem is analysed on Natural convection environment under the effect of gravity. The material considered for the fin arrays is Aluminum. The fluid domain considered for convective environment is air and properties of aluminium are considered to be constant and air as Boussinessq over the operating range. Here the amplitude of the wavy fin and the fin height are changed and studied the heat transfer rates at different parameters

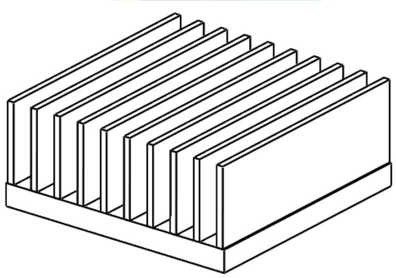

Fig 1 : model of solid fin

The cases considered are shown in the following table.

Table 1: cases considered for study

.CASES	FIN AMPLITUDE	FIN HEIGHT (MM)	HEAT FLUX (W)
Case1	2 mm	20,25,30 and 35	15,20,25,30
Case 2	2.5 mm	20,25,30 and 35	15,20,25,30
Case 3	3 mm	20,25,30 and 35	15,20,25,30

B.Boundary conditions

Boundary conditions play a vital role in execution of analysisSince chimney flow pattern was used, the air enters from two sides to the fin arrays by grieving through the fin spacing area. so there are two inlets for the domain. Here inlet taken is along positive z and negative z directions while the gravity along negative x direction. Obviously there is outlet with perpendicular direction to the incoming flow, other faces were kept symmetry. Region between fin array and air domain was selected and given as interfaces for fin. Heat flux was given to the base of block, with heat input as 15W, 20W, 25W and 30W respectively. Velocity of air entering the domain was taken as 0.1 m/s due to natural convection.

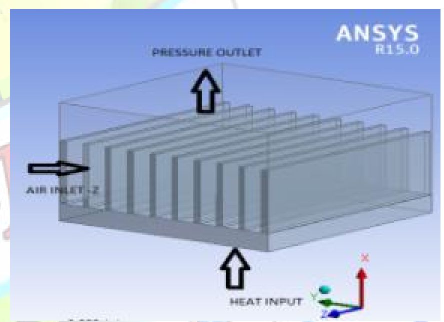

Fig 1: boundary conditions

III. METHODOLOGY

A. Geometry creation

The geometry was created in Solid Works and imported to Ansys workbench Design modeler for analysis. Air domain was selected as 42mm width from base block so as to avoid boundary effects. Boolean operation was carried out to subtract the fins from air domain. Problem was carried out as Natural convection type with absolute velocity, pressure based gravity driven. Air properties are Boussinessq type and that of aluminum as constant. Chimney flow pattern was considered for the air.

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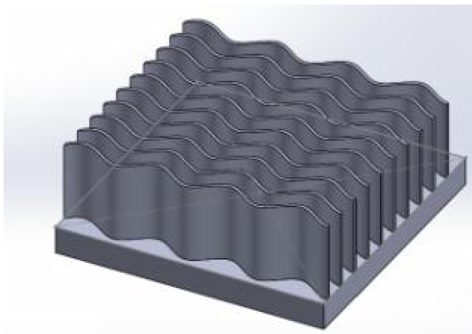

Fig 2 : wavy fin geometry

B. Mesh generation

Geometry was opened in Ansys Mesh Module. Edge sizing was executed along with biasing for fins. Sizing was based on number of divisions .Biasing with a factor of 10 is made to have better result along the region fin-base block .since it is the region prone to heat input and boundary effects. For the air domain also edge sizing was done without biasing. Finally multi zone method was executed to make more hex dominant mesh sizes. Figure 3 shows meshing of wavy fin.

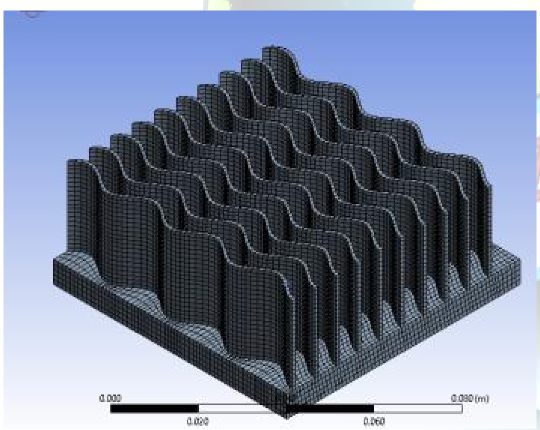

Figure 3: Meshing

C. Model assumptions

The 3-D model employed for the simulation of the heat transfer problem relies on the following assumptions:

1. Steady state.
2. Laminar and incompressible flow.
3. Negligible radiation heat transfer.
4. Boussinessq approximation for fluid.
5. Gravitationaleffects are considered.

D. Governing differential equations

The Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

The Momentum Equation

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v}\vec{v}) = -\nabla p + \nabla \cdot \left[\mu \left(\nabla \vec{v} + \nabla \vec{v}^{T} \right) \right] + \rho \vec{g} + \vec{F}$$

Energy equation

$$\rho c_p \left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} \right) = k \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + \Phi$$

Nusselt number correlation

$$Nu = hl/k$$

h= Heat transfer coefficient (W/m^2K)
l= Characteristic lengh (m)
k= Thermal conductivity (W/mK)

Skin friction coefficient is given by;

$$c_f = \frac{\tau}{\rho v_\infty^2 / 2}$$

E. FLUENT

- 3D Natural convection problem with absolute velocity ,pressure based gravity driven type.
- Air properties – Boussinessq
  Aluminium – Constant
- Boundary conditions applied.
- Solution Method : SIMPLE
  Pressure : PRESTO!
  Momentum : Second order upwind
  Energy : First order upwind

IV . RESULT AND DISCUSSIONS

A.Effect Of Heat Input

ΔT is observed to increase as the heat input increases in all these cases. For same heat input and same configuration , ΔT for all the wavy fins is less as compared to rectangular straight fins. It shows that the wavy fins run cooler as

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compared to straight fins under the same operating conditions. Here for our convenience 15W, 20W, 25W, and30W (2670 W/m^2, 3560W/m^2, 4400W/m^2 and 5300W/m^2) heat input was given to the base block. However it has seen that, value of Heat transfer coefficient (h) increases with heat inputs.

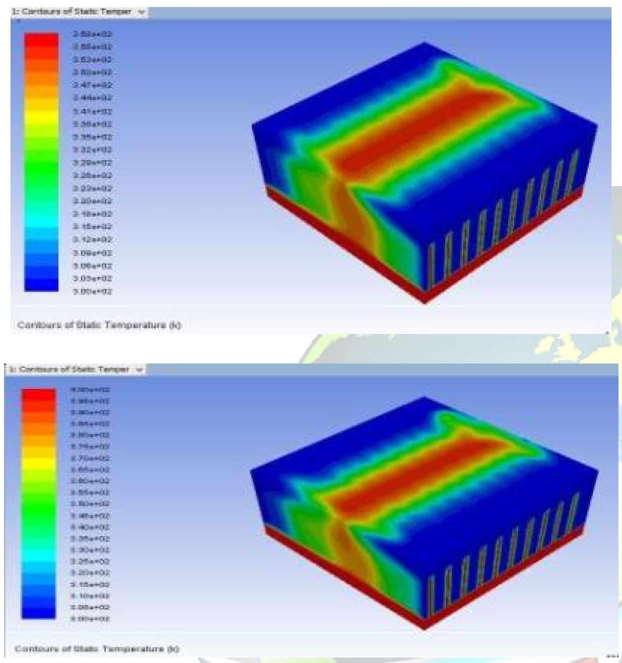

Figure 5: Temperature contours for straight and wavy fins

B. Effect of Heat Transfer Coefficient on fin height

We know that the performance of the fin depends highly on fin height. Here the fin height of 20mm , 25mm , 30 mm and 35mm were considered for study. When we increase the fin height , the surface area is increasing and there by enhances the heat transfer. but after some value we can find that the heat transfer goes down on increasing fin height. So there was some optimum range where we get maximum heat transfer. It depends on the geometry, heat source and other conditions. In this study for each type of wavy fin the analysis was conducted for all the above specified fin heights.In rectangular straight fin the optimized value in which the maximum heat transfer was found with fin height of 25 mm. Among the wavy fins the fin height depends on the geometric parameters. For 2.5mm wavy amplitude fin the maximum heat transfer is achieved in fins having height of 25 mm .But in the case of 3mm amplitude fin array maximum heat transfer was found in fins of height 20mm whereas in 2 mm amplitude fin the heat transfer of fin with heights 25mmand 30mm are somewhat closer. So we can go for both the fin heights. The variation of heat transfer coefficient with different fin heights is illustrated in the Fig 6

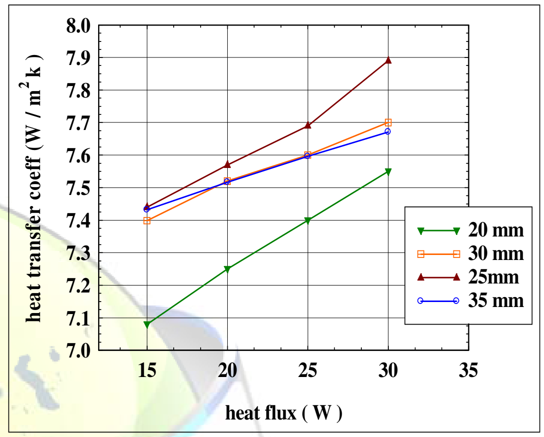

Figure 6: Effect of fin height

C. Effect of fin amplitude.

Another important factor which determines the performance of wavy fin is the amplitude of the fins. In this study there are three different amplitudes are analyzed within the geometrical constraints. The amplitudes of 2mm , 2.5mm and 3 mm are taken in this study. when we increase the fin amplitude the flow turbulence and surface area also increases , there by enhances the heat transfer rate. Christo Ananth et al. [7] proposed a system, this fully automatic vehicle is equipped by micro controller, motor driving mechanism and battery. The power stored in the battery is used to drive the DC motor that causes the movement to AGV. The speed of rotation of DC motor i.e., velocity of AGV is controlled by the microprocessor controller.This is an era of automation where it is broadly defined as replacement of manual effort by mechanical power in all degrees of automation. The operation remains an essential part of the system although with changing demands on physical input as the degree of mechanization is increased.

But for this also there is an optimum value in which heat transfer is maximum. The above three amplitudes is selected to accommodate the same number of fins in the base plate. Although the heat transfer changes with respect to the fin

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height, maximum heat transfer is with the 2.5mm amplitude wavy fin. For all heat fluxes the surface heat transfer coefficient is more with 2.5mm amplitude fin compared to other. The variation of surface heat transfer coefficient of different amplitude fins is shown in the fig 7and fig 8.

For 3 mm amplitude fin , the maximum heat transfer is obtained in fin height of 20mm whereas for2mm amplitude fin the maximum heat transfer was found in 25mm fin height. However apart from fin height the maximum heat transfer with respect to fin amplitude were found in2.5mm amplitude wavy fin. At the maximum heat flux of 30W(5300 w/m2) the heat transfer coeff is 7.875 w/m2k in 2.5mm amplitude fin.

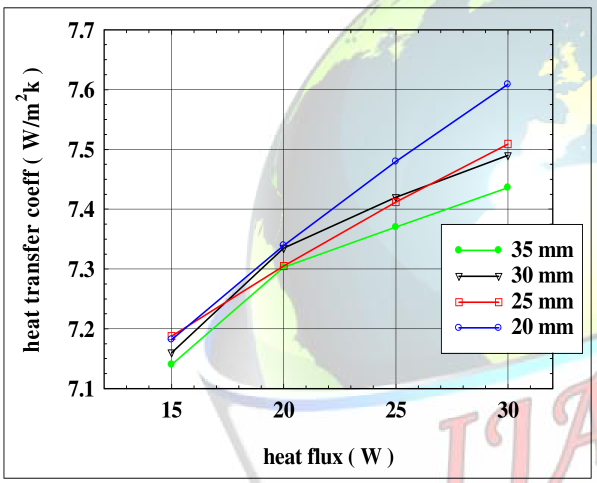

Fig 7 : Wavy fin of 3 mm amplitude

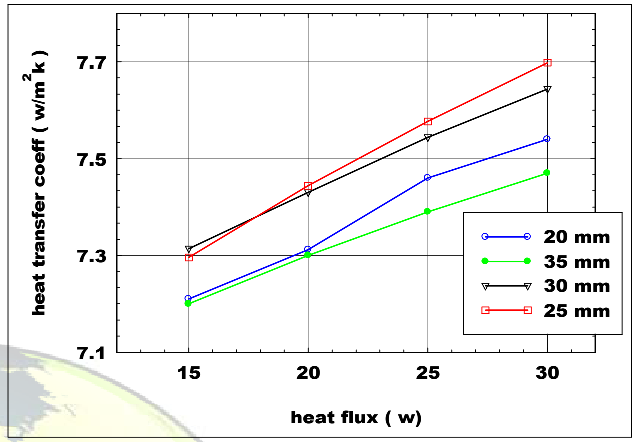

Fig 8: Wavy fin of 2 mm amplitude

In case of 2 mm amplitude fin ,the maximum heat transfer was with the fin height of 25 mm . The surface heat transfer coefficient of 7.712 w/m2k at heat flux of 5.300 w/m2.The maximum heat transfer is found with 2 mm amplitude fin than 3mm amplitude fin.

V. CONCLUSION

Flow characteristics from horizontal rectangular fin arrays were investigated numerically using a finite volume based computational fluid dynamics (CFD) code. The Natural convection heat transfer from various shaped wavy fin-arrays on a horizontal base plate has been analyzed. In the present numerical study, Effect of fin height, Effect of Heat input, effect of wave amplitude, Skin friction coefficient for each case weight through the fin channels have been analyzed and corresponding heat transfer coefficients have been determined for each of the fin array considered. The temperature difference is found to be smaller in case of wavy fin compared to straight rectangular fins. This shows the efficiency of wavy fin in heat transfer enhancement. The wave amplitude and fin height are two important factors which affect the heat transfer of fins.

By replacing the straight fins by wavy fins, the surface area of heat transfer increases will leads to increase in heat transfer rate. Flow velocity between the fins also a major component for maximum heat transfer. How long the cold flow stays inside the passage will observe more heat from the source. In straight fins passage the cold fluid leaves without any disturbance and it will not observe that much heat from the source. But in wavy fins, the cold flow stays longer than in the straight fins. This results in observing the heat from the source much better than in straight fins. From this study we can find that

- The wavy fin enhances heat transfer in a better way than straight fin of same dimensions and configuration.
- Out of the three amplitudes selected for analysis better performance is shown by 2.5mm amplitude fin.
- Fin height also influences the heat transfer from fins and 25mm fin height show good performance.

ACKNOWLEDGMENT

The authors wish to thank Computational Fluid Dynamics Lab, Department of Mechanical Engineering, College of Engineering, Adoor, and Kerala, India for providing the computational facility for carrying out the research work with the help of TEQIP-II Project

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