NUMERICAL ANALYSIS OF INTERRUPTED PERFORATED FINS UNDER NATURAL CONVECTION

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Abstract: The interrupted perforated fins are investigated by using numerical methods under natural convection. The numerical analysis is to be done for investigation of fin interruption effects. The continuous, inline interrupted, perforated inline interrupted, staggered interrupted & perforated staggered interrupted aluminium alloy heat sinks are designed & tested by changing various geometrical parameters. The numbers of perforations and the size of perforations are decided by calculating blanking ratio. Fin spacing (s) used in this analysis is 6.5 mm, 8 mm, 9 mm, 9.5 mm, 10.50 mm, 11 mm etc. And interruption lengths (G) 10 mm, 15 mm, 20 mm, 25 mm etc are considered. The effects of perforations, fin spacing & fin interruption length in inline & staggered interruptions are investigated numerically. In the present operating conditions & for perforated staggered interrupted fin arrangement, the thermal performances of the perforated staggered fins with blanking ratio 2.5 with 3 holes are finding to be better. Staggered arrangement & perforation will enhance the heat transfer rate. Staggered interrupted arrangement with perforation shows better performance as compare to inline interrupted with perforations.

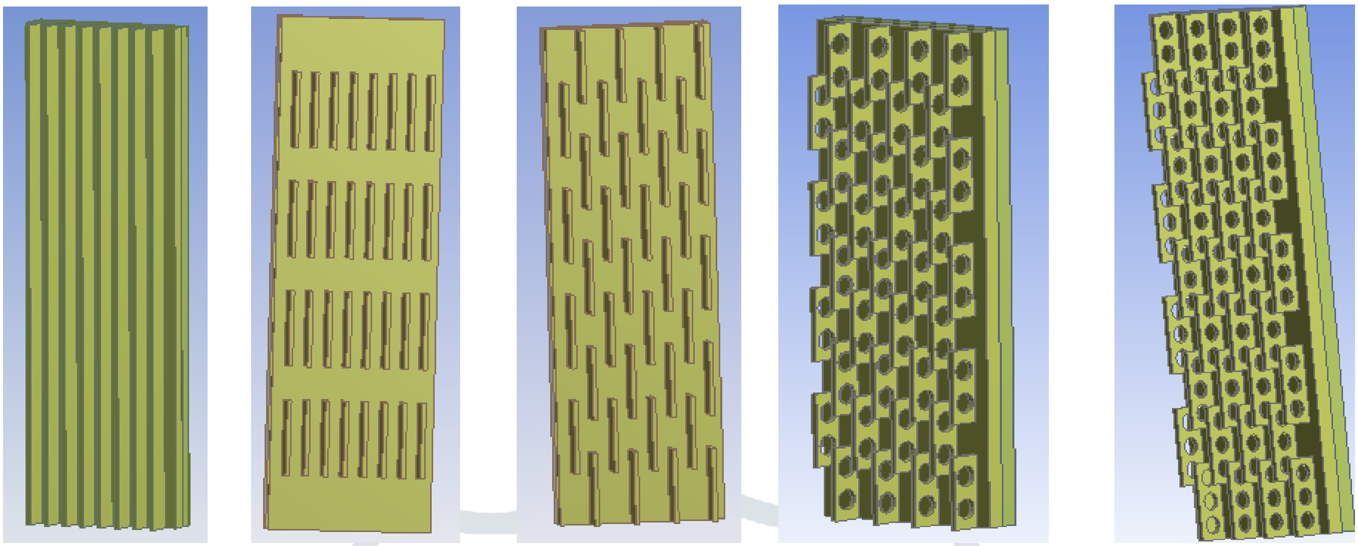
Keywords: Staggered arrangement, Interrupted perforated fins, Natural convection.

I. INTRODUCTION

In many Engineering applications heat is produce at the time of process. This causes rise in temperature of system components. This rise in temperature can cause failure of components. Fins are extensively used in cooling of various mechanical and other electronic devices etc. They are very important aspect in geometry of heat sinks. The present work focus on perforated staggered interrupted fins. The objective of this work is to enhance the heat transfer rate by providing perforations on interrupted fins. The perforated staggered interruption arrangement improves the heat transfer rate as compare to inline interruption arrangement.Shardul R Kulkarni et al 2015 [1] represents experimental investigation of heat transfer from plain heat sink and modelling, simulation in CFD to investigate the fluid flow and heat transfer characteristics of a fin arrays with lateral circular perforation under mixed convection mode. The simulation was carried out using the fluid flow ICEM- CFD of ANSYS V14.0. In this study, results showed that formation of the stagnant layer around the solid fin array which slow-downs the heat dissipation rate. The increase in the fluid flow movement around the fin results increase in the heat dissipation rate. It could be achieved by creating perforation to the fins. The analysis was carried out with CFD model to investigate flow pattern, temperature variations in computational domain, heat transfer coefficients & Nusselt no .Analysis was carried with both plane and perforated fin arrays with different size of CFD domains in order to ensure results with different fin spacing. A constant heat flux was assumed for heat sink. Mehran Ahmadi et al 2014 [2] the effects of interruptions on heat sinks were studied numerically and experimentally. The interruptions could increase the heat transfer rate by resetting/interrupting the thermal and hydrodynamic boundary layers. Siddiqui. M. Abdullah, et al 2015 [3] performed experimental analysis of heat transfer over a flat surface equipped with Square perforated pin fins in staggered arrangement in a rectangular channel. The Fin dimensions were 100mm in height & 25mm in width. Y.Q. Kong, et al 2016 [4] two kinds of rectangular slot configurations, continuous slots and alternating slots, were presented and the effects of the slots on the air-side thermo-flow performances of the plain finned tube bundles in in-line and staggered configurations were analyzed by means of numerical simulations, which were validated by the experiment. Umesh V. Awasarmol et al 2015 [5] the main objective of this experimental study was to quantify and compared the natural convection heat transfer enhancement of perforated fin array with different perforation diameter (4–12 mm) and at different angles of inclination (0–90_). In this study, the steady state heat transfer from the solid fin and perforated fin arrays were measured. Bhushan S Rane et al 2015 [6] focused on staggered interrupted fin arrangement and investigated its effects on the overall system performance by both the numerical and experimental methods. Staggered interrupted fin arrangement and in-line interrupted fin arrangement provided better heat transfer rate in comparison with the continuous fin arrangement. Anagha Gosavi et al 2012 [7] array with staggered fins had higher values of Nusselt number for all values of heater input and increases when percentage of staggering was increased and the experiment gave the same results. For 38mm height, nusselt number increased up to 3.5 to 25% and 1 to 45% for 48 mm height. Baskaya et al. [8] used aluminum material for his geometrical study. They studied numbers of the variables of fin spacing, height, and length and temperature difference shows an effect on the overall heat transfer rate. The effects of a wide range of geometrical parameters like fin spacing, fin height, fin length and temperature difference between fin and surroundings; to the heat transfer from horizontal fin arrays were investigated. Tanda et al. [9] two staggered vertical plates cooled by air in free convection were experimentally studied by considering the thermal field and the heat transfer characteristics of a system. The parameters which were investigated included the inter plate spacing, the magnitude of the vertical stagger, and the Rayleigh number depended on the overall convective heat flux from each plate. Starner et al.[10] Free-Convection Heat Transfer from Rectangular staggered-Fin Arrays were studied and average heat- transfer coefficients were presented for four fin arrays positioned with the base vertical, 45 degrees, and horizontal while dissipating the heat to room air. The fins were analyzed as constant-temperature surfaces since the lowest fin efficiency encountered was greater than 98 %. It showed that for the vertical arrays coefficients fell about 10 to 30 percent below those of similarly spaced parallel plates. The 45-degree arrays showed results from 5 to 20 percent below to those of vertical plates. L.Dialameh et al. [11] performed a numerical study to predict the natural convection from an array of aluminum horizontal rectangular thick fins of 3 mm $< t <$ 7 mm with short lengths (L=50 mm) attached on a horizontal base plate.

II. PROBLEM DEFINITION

The present study is focused on numerical analysis of interrupted & perforated interrupted fin arrangement under natural convection and compared the results with the continuous fins arrangement. Also to investigates its impact on the overall system performance by the numerical approaches. Fig. 1 shows the geometries of heat sink which are investigated numerically.



Continuous Fins | In-line interrupted Fins | Staggered Interrupted Fins | Perforated Staggered Interrupted Fins (2 Holes) | Perforated Staggered Interrupted Fins (3 Holes)

fig. 1 considered heat sink geometries

III NUMERICAL (CFD) MODELING

In the experiment studies, the fins are placed on a base plate having dimensions of 305 X 101 mm. The set-up is placed in a Steady condition room. For the CFD simulations similar conditions are created. ANSYS FLUENT is used for performing of CFD meshing and computational domain discretization. The tetrahedral elements having elements size 10 mm are considered in sizing of mesh. And patch confirming method is used. Due to the high temperature difference between the fin surfaces and the surroundings, the buoyancy currents will be dominant. Steady state CFD formulation is employed to model this problem in ANSYS FLUENT. Energy method & viscous laminar method are used in models. The gravitational forces that are acting in negative Z direction, in this case, are activated. The radiation effects from the fin surfaces to the atmosphere are not considered. Fluid density (1.125) can be set up as a function of temperature using a Boussinesq method with operating temperature as 27°C. The accuracy of the CFD simulations will depend upon the selection of the spatial discretization schemes. Second order spatial discretization schemes for the Momentum and Energy are chosen for the simulation while Green-Gauss Node based scheme is used for the gradient calculations. Body forced weighted scheme is used for pressure simulations.

IV METHODOLOGY

The study focused on numerical analysis of interrupted (i.e. inline & staggered) & perforated interrupted fin arrangement under natural convection. It also investigates its impact on the overall system performance by both the numerical and experimental approaches. The effect of fin spacing, fin interruption length (G) and blanking ratio on heat transfer rate investigates numerically. The no of perforations and the size of perforations are decided by calculating blanking ratio. Fin spacing used in this analysis is 6.5 mm, 8 mm, 9 mm, 9.5 mm, 10.50 mm, 11 mm etc. And interruption lengths 10 mm, 15 mm, 20 mm, 25 mm etc are considered. The heat input considered are 10W, 20W & 30W. Numerical analysis is to be carried out for different arrangement of heat sink arrays as shown in table: The fixed parameters are height of fin (H= 17.5mm) & thickness of fin (t= 5mm).

Table 1. Details of Fin Geometry

Fin Arrangements	Geometrical Parameters	Parameters	Heat Input
Continuous Fins	-	-	
Inline Interrupted		➢ BR= 3.5 (3 Holes) circular perforation ➢ BR= 5 (2 Holes) circular perforation	
Staggered Interrupted & Perforated Staggered Interrupted	Fin length (l) = 45 mm Fin Interruption length (G) = 15 mm	**Fin interruption length (G)** 10 mm , 15 mm, 20 mm, 25 mm **Blanking ratio considered:** 2, 2.5, 3, 3.5, 4, 5 No of holes considered= 2, 3 ,4 **Fin spacing (s) considered are:** 6.5 mm, 8 mm, 9 mm, 9.5 mm, 10 mm, 10.50 mm, 11 mm.	10W 30W 50W

V CFD SIMULATION

The temperature contour of the fin is generated to study the thermal characteristics of the system as shown in following figures. The temperature contours in figure indicate high temperature zones at the top region of the fins in the continuous fin arrangement. While in the staggered fin arrangement, the flow temperatures around the fins are much less compared to the continuous fins and inline interrupted arrangement. The flow turbulence is created by the staggered arrangement enhances higher fluid velocity which in turn improves the heat transfer rate from the surfaces. Fig.2 & 3 shows the temperature and velocity plot of continuous fin arrangement. The temperature contours in figure indicate high temperature zones at the top region of the fins in the continuous fin arrangement. The heat transfer coefficient at the top region of fin is 4.010 W/m^{2}K at lower temperature difference of 107.1 °K

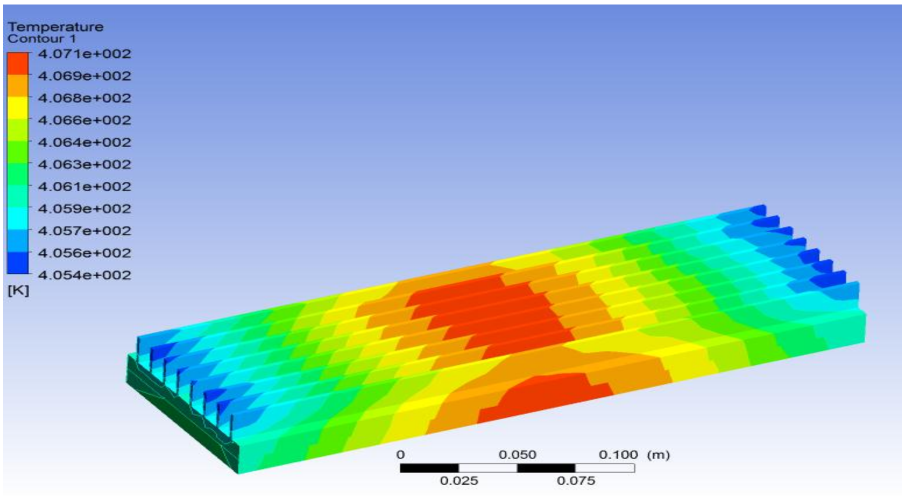


Fig.2 Temperature contour for continuous fin (30W)

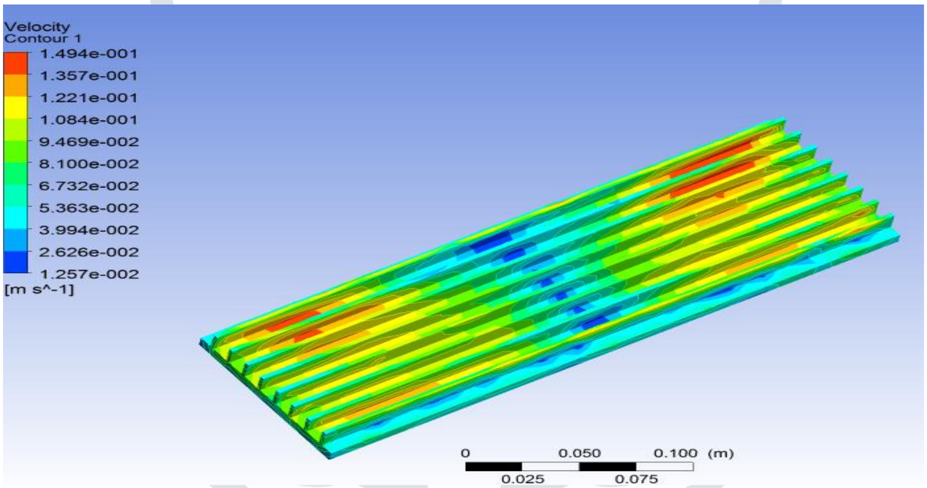


Fig. 3 Velocity contour for continuous fin

Fig.4 & 5 shows the temperature and velocity plot of inline interrupted fin arrangement. When interruptions are added to fins, the temperature contour region shows slightly low temperature zone at the top region of fin as compared to continuous fin. The heat flux is increases due to the fin interruption as thermal boundary layers are interrupted. The heat transfer coefficient at the top region of fin is 4.989 W/m^{2}K at lower temperature difference of 103.4 °K.

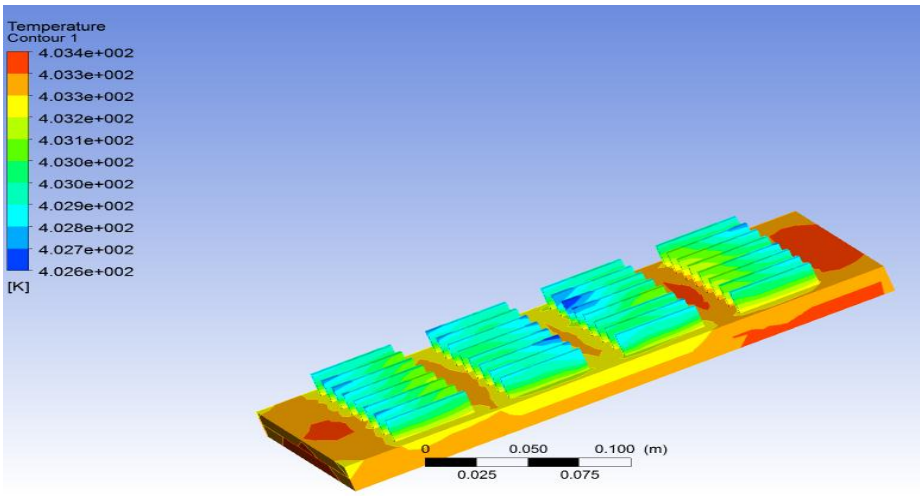


Fig.4 Temperature contour for inline interrupted fin (30W)

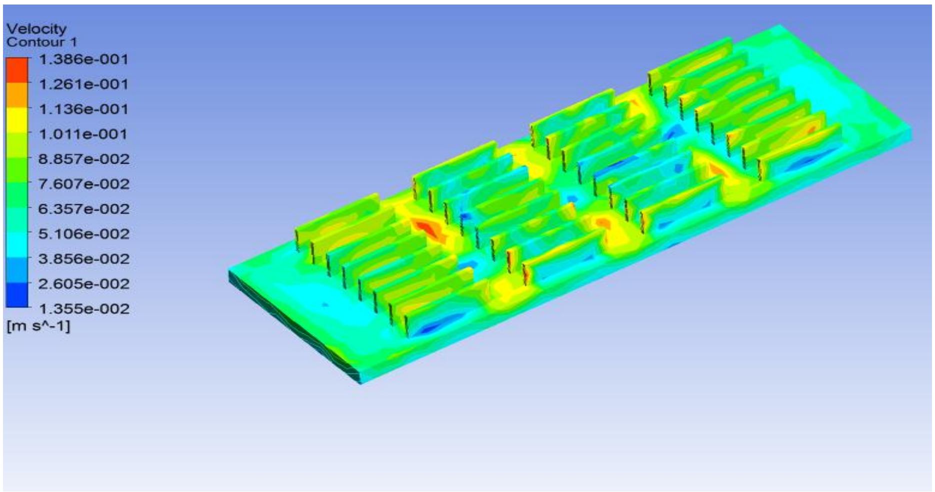


Fig. 5 Velocity contour for inline interrupted fin

Fig.6 & 7 shows the temperature and velocity plot of staggered interrupted fin arrangement. The flow velocity is observed to be higher in case of staggered fin arrangement as compared to the other fin arrangements. The temperature contour region shows slightly low temperature zone at the top region of fin as compared to continuous fins & inline interrupted fins. The heat transfer coefficient at the top region of fin is 5.4227 W/m^2K at lower temperature difference of 102.1 °K.

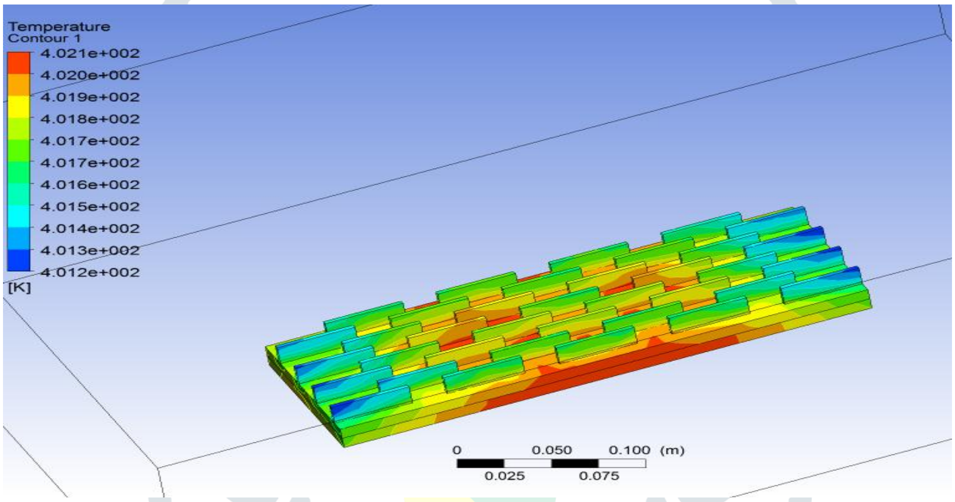


Fig. 6 Temperature contour for staggered interrupted fin.

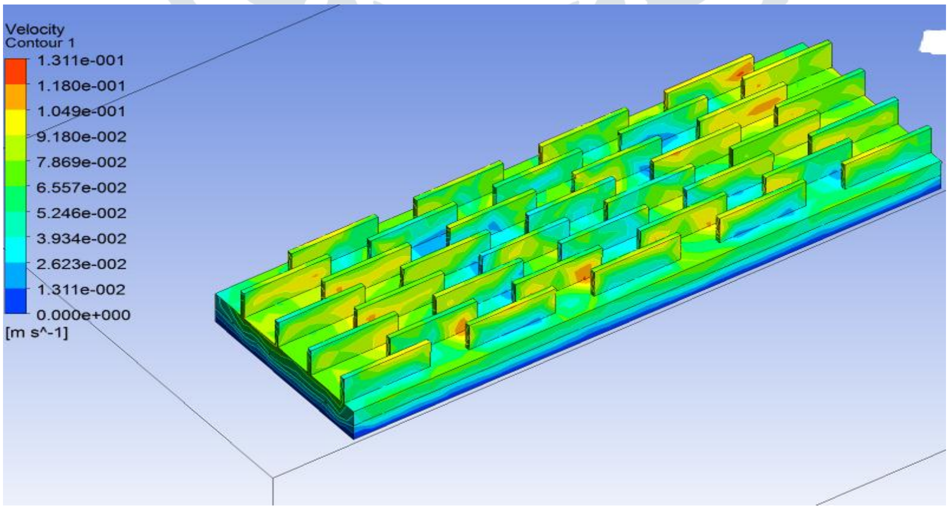


Fig.7 Velocity contour for staggered interrupted fin.

Staggered fin arrangements with perforations (Geometry Selections)

1) Effect of fin interruption lengths (G):

For deciding the geometry of fin arrays various analysis are to be performed on staggered fin arrangement by changing interruption lengths i.e. G = 10 mm, 15 mm, 20 mm, 25 mm, etc. The temperature contours are as follows:

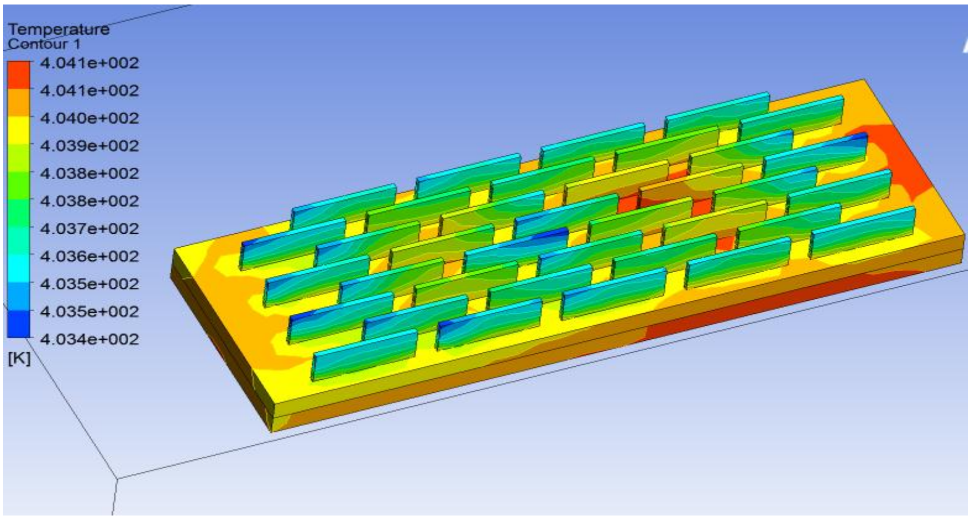


Fig. 8 Temperature contour for staggered interrupted fin (G = 10 mm)

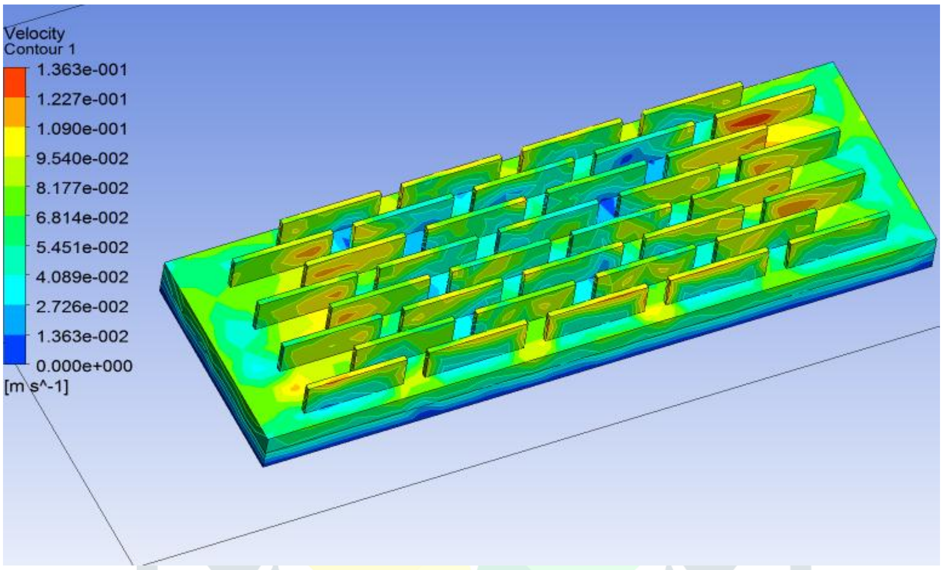


Fig.9 Velocity contour for staggered interrupted fin (G = 10 mm)

Fig.8 & 9 shows the temperature & velocity plot of staggered interrupted fin with G = 10 mm. The heat transfer coefficient at the top region of fins is 5.4906 W/m^{2}K.

It is clear that as length of interruptions i.e. G increases the temperature contour region at the top of the fin region shows high temperature zone. G = 15 mm arrangement shows optimum temperature zone as compared to other value of interruption lengths. Hence for next analysis i.e. for perforated staggered analysis we choose value of interruption as 15 mm and interruption number as five.

2) Effect of fin spacing (s)

For deciding the geometry of fin arrays analysis are to be performed on staggered fin arrangement by changing fin spacing i.e. s = 6.5 mm, 8 mm, 9 mm, 9.5 mm, 10.50 mm, 11 mm etc. The temperature & velocity contours of s = 6.5 mm & 10.50 mm are as follow

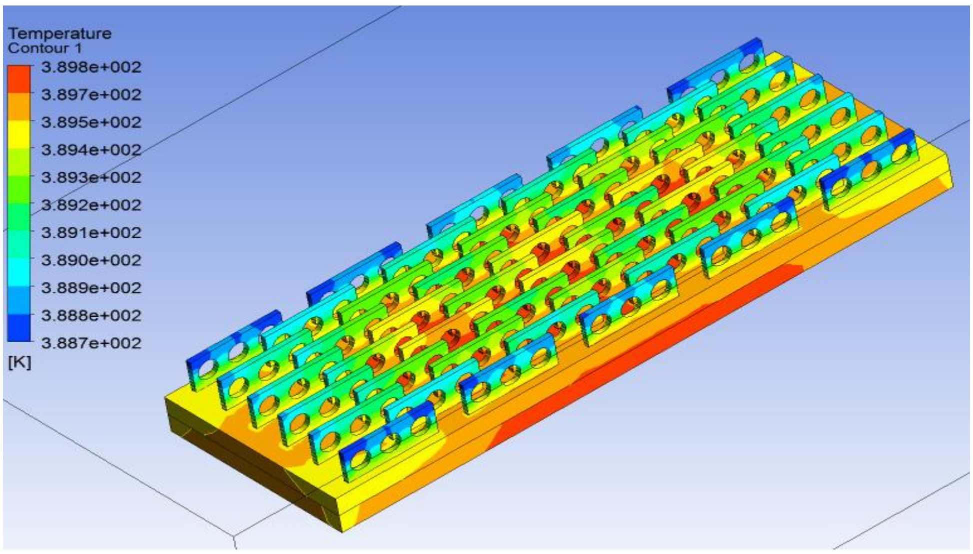


Fig.10 Temperature contour for staggered interrupted fin (s = 6.5 mm)

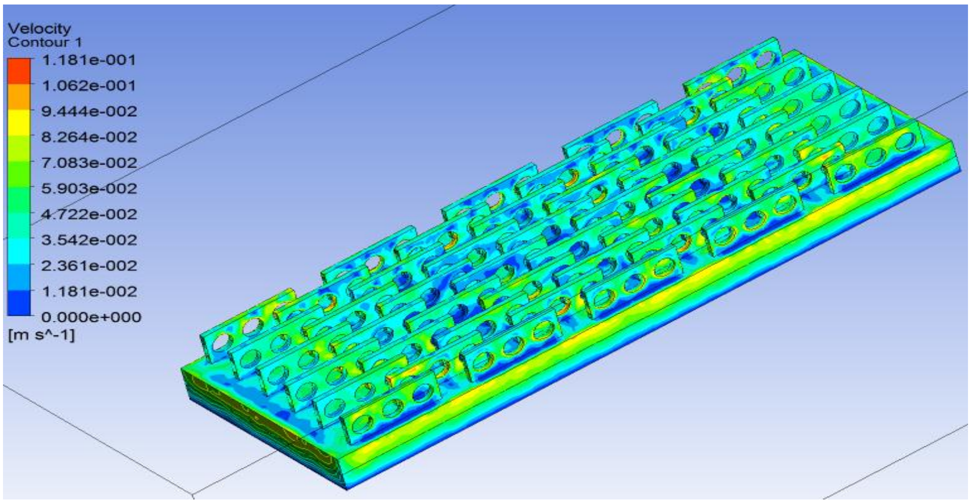


Fig.11 Velocity contour for staggered interrupted fin (s = 6.5 mm)

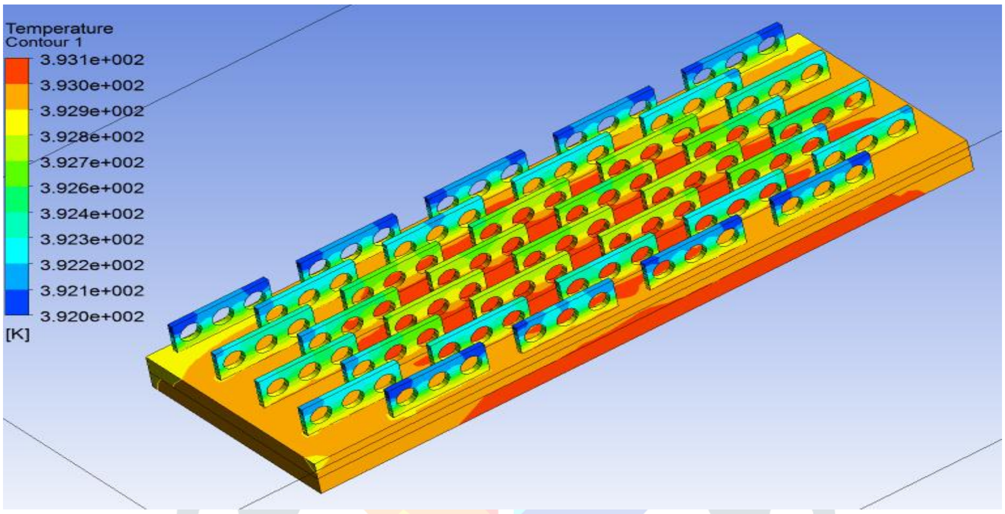


Fig.12 Temperature contour for staggered interrupted fin (s = 10.5 mm)

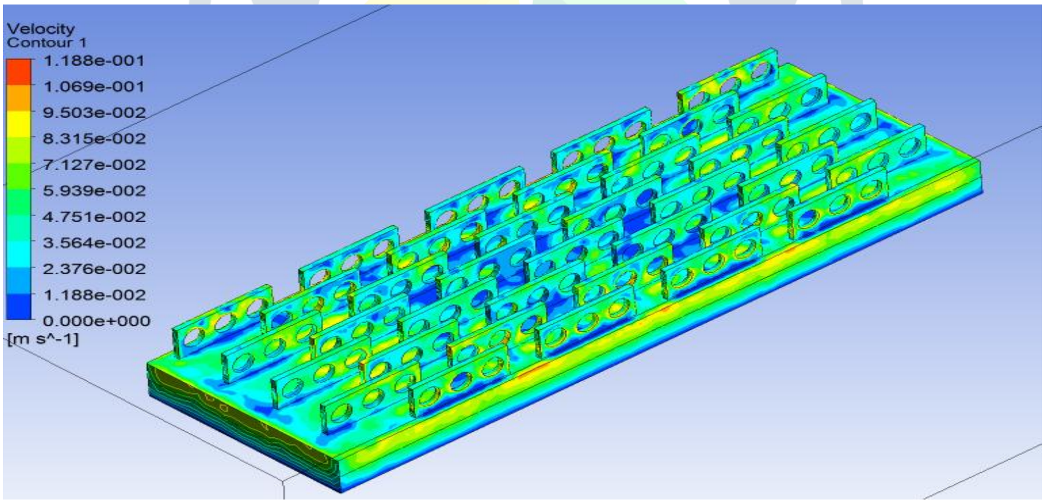


Fig.13 Velocity contour for staggered interrupted fin (s = 10.5 mm)

One of the most crucial parameters in designing a heat sink was the fin spacing, s. Closely packed fins will have greater surface area for heat transfer, but a smaller heat transfer coefficient, since for closely spaced fins or for relatively long channels, the fluid velocity attains its fully developed profile, leading to an increased heat transfer resistance. Heat sinks with widely spaced fins have a higher heat transfer coefficient but smaller surface area, due to wide spacing. As such, the fins appear to have little influence upon one another and a developing flow regime occurs. Thus, an optimum spacing exists that maximizes the natural convection from the heat sink to the surroundings. Heat sink with spacing equal to 9.5 mm shows optimum results.i.e. There is an optimum fin spacing that maximizes the heat transfer rate for different average surface temperatures.

3) Effect of blanking ratio (To decide diameter & no. of perforations)

For deciding the diameter & no of perforations of fin arrays blanking ratios are decided & analysis is to be performed on staggered fin arrangement. The blanking ratios considered in these cases are 2, 2.5, 3, 3.5, 4, 5, 7, & 9. The temperature & velocity contours are as follows:

1) Blanking Ratio = 3

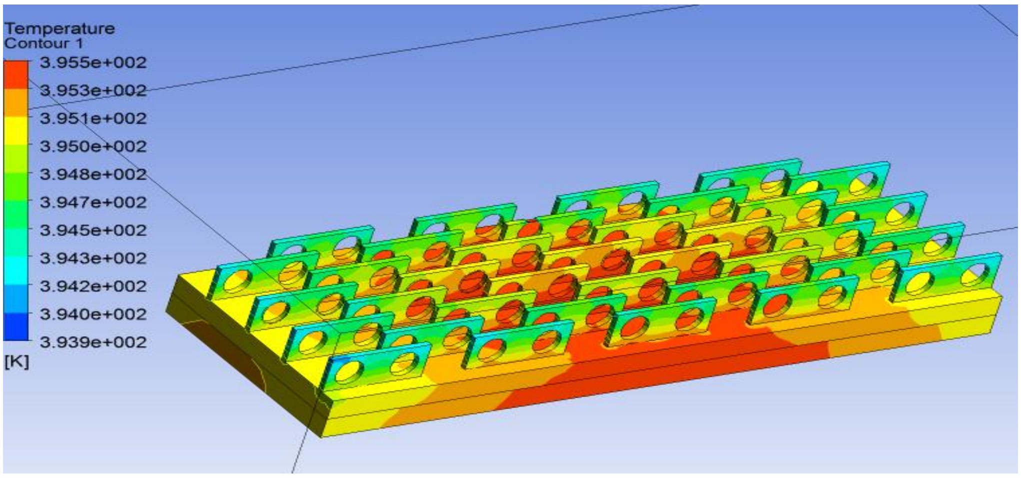


Fig.14 Temperature contour for staggered interrupted fin with BR= 3, (2holes) circular perforations. (d =12.54 mm, Hs =25 mm)

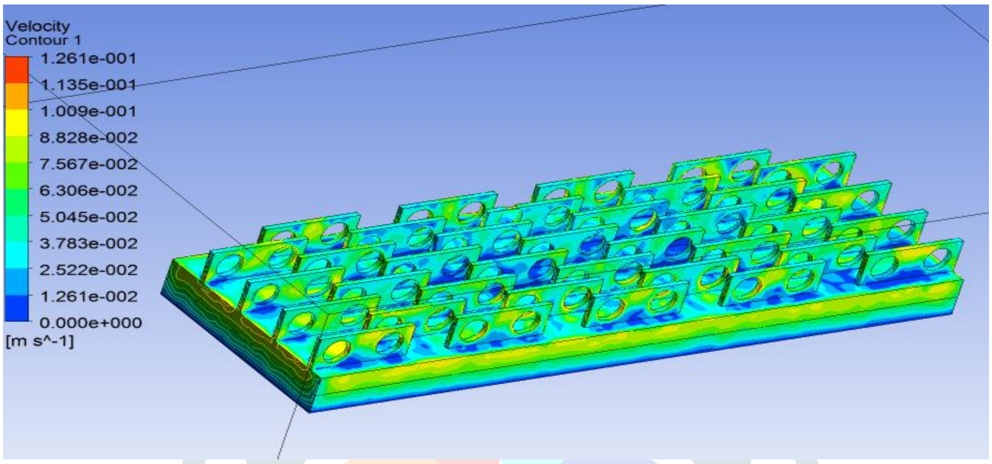


Fig.15 Velocity contour for staggered interrupted fin with 2 circular perforations. (d =12.54 mm, Hs =25 mm)

Blanking ratio is the second parameter in designing of the heat sink. As the blanking ratio increases from 2 to 9, the heat transfer coefficient also increases. Perforated fins with smaller blanking ratio have greater surface area for heat transfer, but a smaller heat transfer coefficient, since for Perforated fins with smaller blanking ratio or for relatively long channels, the fluid velocity attains its fully developed profile, leading to an increased heat transfer resistance. A heat sink with larger diameter will have a higher heat transfer coefficient but smaller surface area, due to large hole size. Thus, an optimum blanking ratio exists that maximizes the natural convection from the heat sink to the surroundings. Heat sink with blanking ratio equal to 2.5 with 3 holes shows optimum results i.e. there is an optimum blanking ratio that maximizes the heat transfer rate for different average surface temperatures.

From above discussion staggered fin with perforation arrangement shows better results with interruption length 15 mm, fin spacing 9.5 mm and blanking ratio 2.5 as compared to other arrangements.

VI RESULTS OF CFD SIMULATIONS

1) Continuous, Inline Interrupted, Staggered Interrupted Finned Heat Sink

The temperature contours indicate high temperature zones at the top region of the fins in the plain plate & continuous fin arrangement. The averaged surface temperature, heat transfer coefficient & Nusselt numbers are measured for various heat inputs i.e. at 10W, 30W, & 50W. The heat transfer coefficient at the top region of fin is 4.039 W/m^2K at lower temperature difference of 106.350°K

When interruptions are added to the inline interrupted fins, the temperature contour region shows slightly low temperature zone at the top region of fin as compared to continuous fin. The heat flux is increases due to the fin interruption as thermal boundary layers are interrupted.

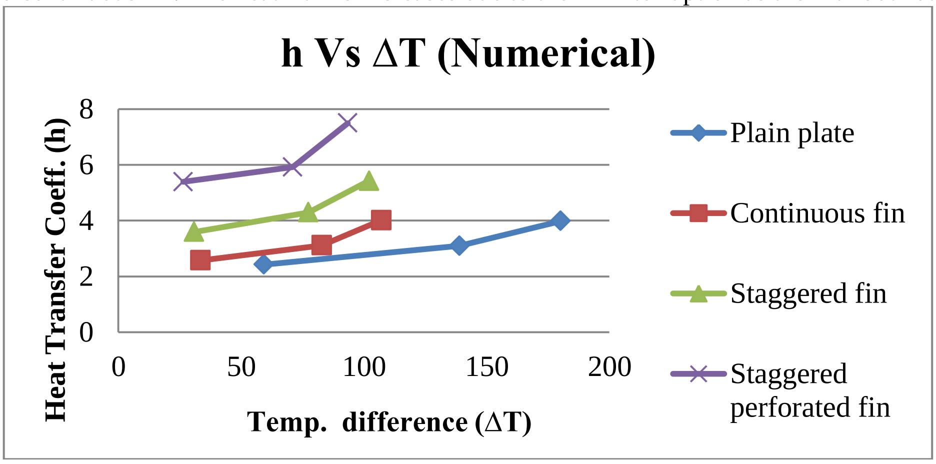


Fig.16 Variation of Heat transfer coefficient with temp. difference for different fin arrangements

The flow velocity is observed to be higher in case of staggered fin arrangement as compared to the other fin arrangements. The temperature contour region shows slightly low temperature zone at the top region of fin as compared to continuous fins & inline interrupted fins. The heat transfer coefficient at the top region of fin is 5.4468 W/m^2K at lower temperature difference of 101.648 °K.

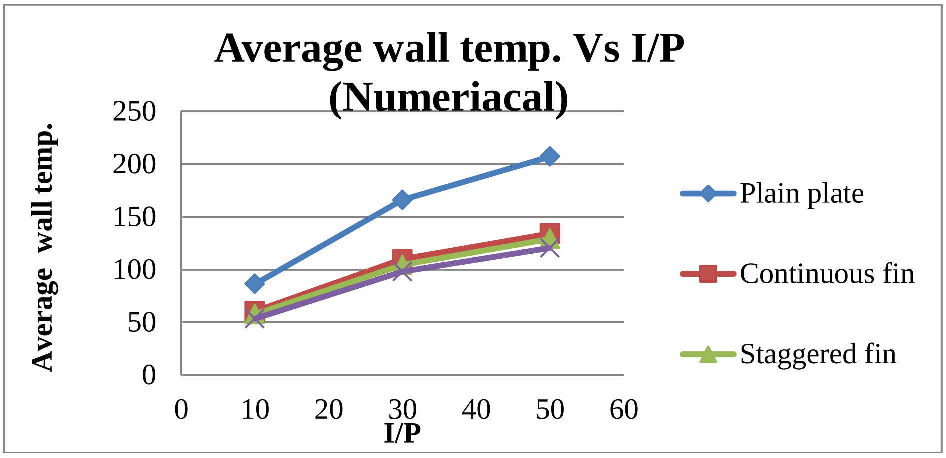


Fig.17 Variation of Average wall temperatures with input power for different fin arrangements

In the staggered fin arrangement, the flow temperatures around the fins are much less compared to the continuous fins and inline interrupted arrangement. The flow turbulence is created by the staggered arrangement enhances higher fluid velocity which in turn improves the heat transfer rate from the surfaces. As the no of perforations are increases the higher turbulence generated which in turns increases the fluid velocity & due to this the temperature contour region shows slightly low temperature zone at the top region of fin and higher heat transfer rate as shown in fig. 16 Also average wall temperature decreases from plain plate to staggered perforated fin. And as input power increases average wall temperature increases as shown in fig.17.

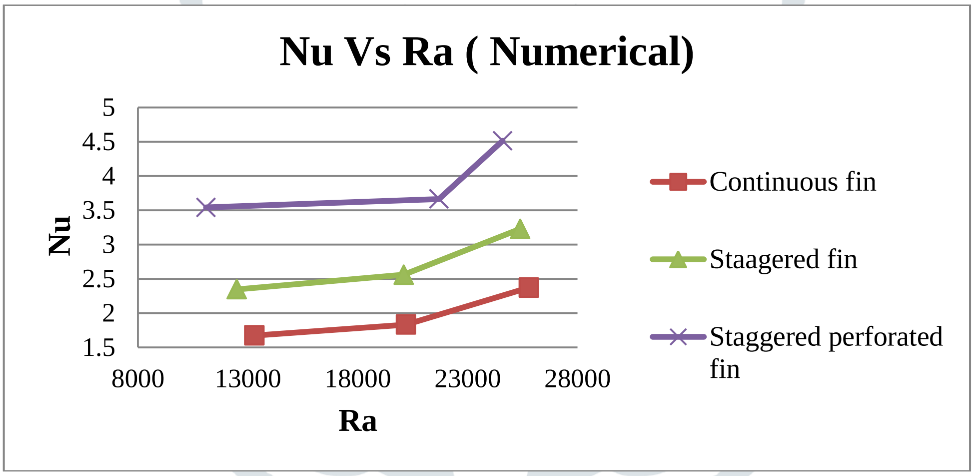


Fig.18 Variation of Nusselt number with Rayleigh number for different fin arrangements

The Nusselt number is increases as Rayleigh number increases. The flow turbulence is created by the staggered arrangement enhances higher fluid velocity. Due to this staggered perforated fin arrangement have higher Nusselt number as compared to other fin arrangement as shown in fig.18.

2) Results by changing fin interruption lengths (G)

Fig.19 shows the effect of interruption length on natural convection heat transfer. As can be seen from Fig.24 increasing the number of interruptions would cause an increase in heat flux, which is a result of the frequent resets, which are imposed on the thermal boundary layer due to adding interruption along the fins. G = 15 mm arrangement shows optimum temperature zone as compared to other value of interruption lengths.

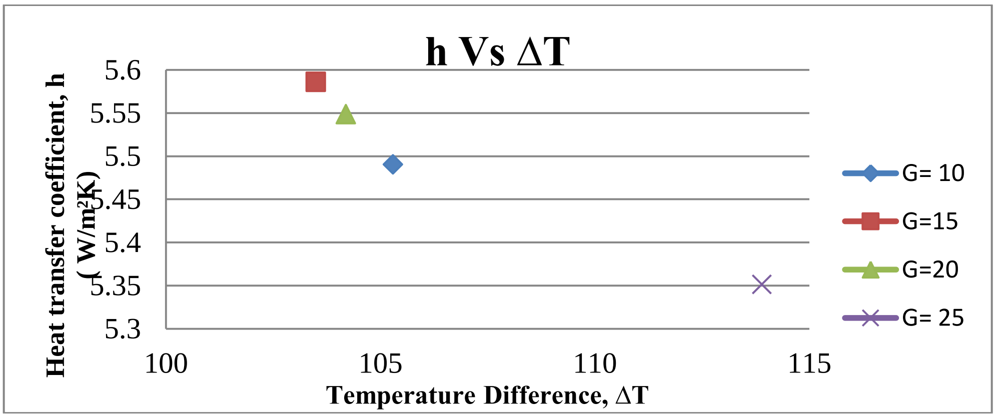


Fig.19 Variation of Heat transfer coefficient with temperature difference by changing fin interruption length (G)

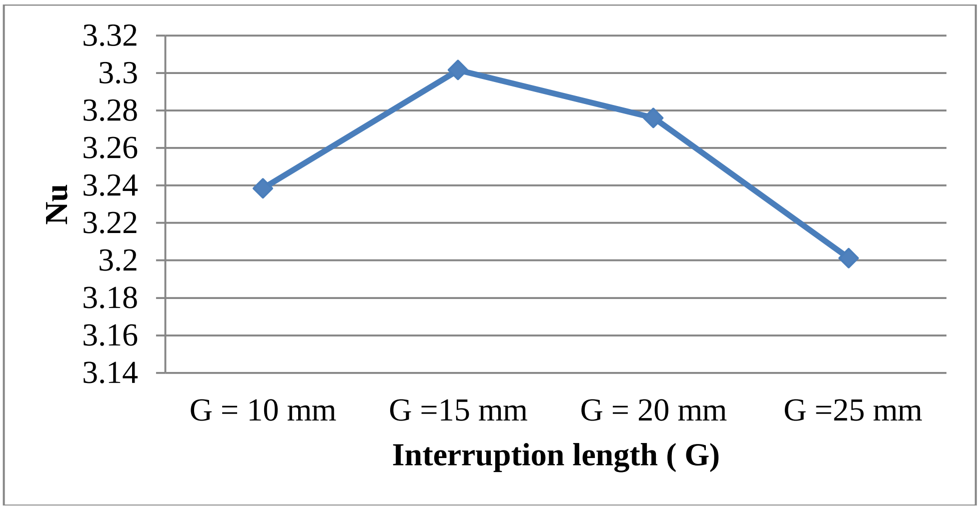


Fig.20 Variation of Nusselt number with fin interruption length (G)

The following can be concluded from Figs. 19 & 20

- Increasing the fin interruption length causes an increase in the heat flux as well as Nusselt number because of "better" interruption in the thermal boundary layer.
- Increasing the number of interruptions increases the heat flux as well, which is a result of the frequent resets imposed on to the thermal boundary layer.

3) Results by changing fin spacing (s)

One of the most crucial parameters in designing a heat sink is the fin spacing; *s*. closely packed fins will have greater surface area for heat transfer, but a smaller heat transfer coefficient, since for closely spaced fins or for relatively long channels, the fluid velocity attains its fully developed profile, leading to an increased heat transfer resistance. A heat sink with widely spaced fins will have a higher heat transfer coefficient but smaller surface area, due to wide spacing. As such, the fins appear to have little influence upon one another and a developing flow regime occurs. Thus, an optimum spacing exists that maximizes the natural convection from the heat sink to the surroundings.

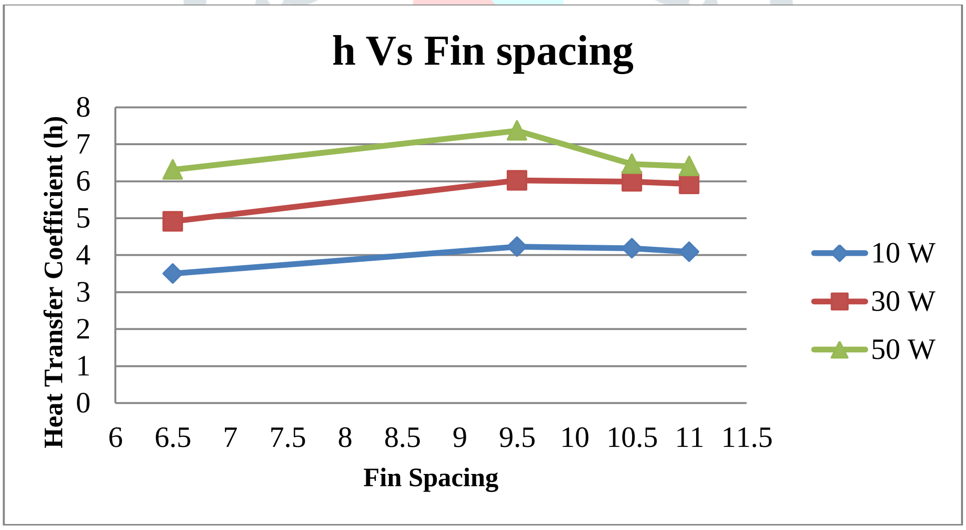


Fig.21 Variation of Heat transfer coefficient with Fin spacing

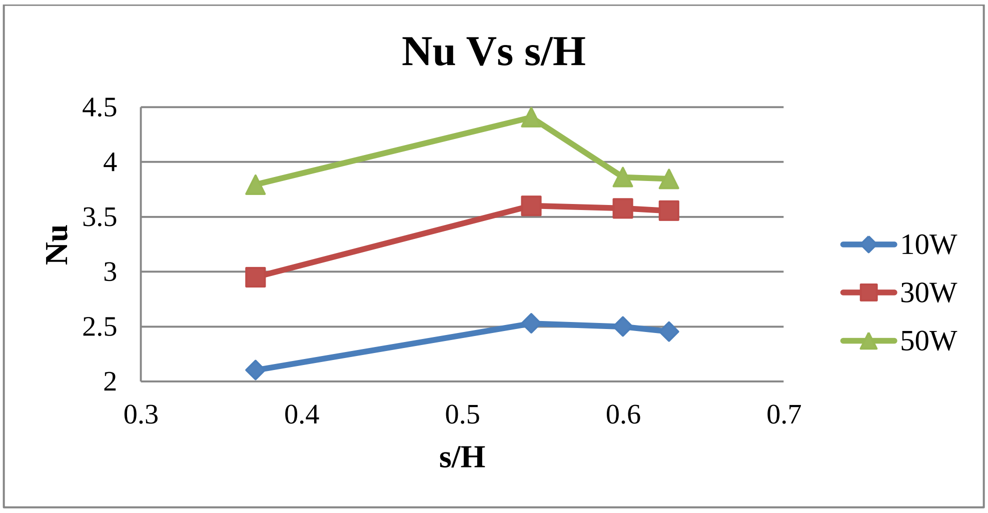


Fig.22 Variation of Nu with s/H

Heat transfer coefficients & Nusselt numbers are plotted as a function of the fin spacing for the samples considered in this study in Fig. 21 & 22. The data are for heat sinks with fin lengths of L = 305 mm, fin heights of H = 17.5 mm and fin spacing of s = 6.5, 8, 9.5, and 10, 10.50, 11 mm, respectively. The power inputs to the heater are kept as 10W, 30W & 50 W. As can be seen in Fig.26 & 27 there is an optimum fin spacing of 9.5 mm that maximizes the heat transfer rate. Also as input power increases heat transfer coefficient increases. The input power 50 W shows higher result.

4) Results by changing Blanking ratio (To decide diameter & no. of perforations)

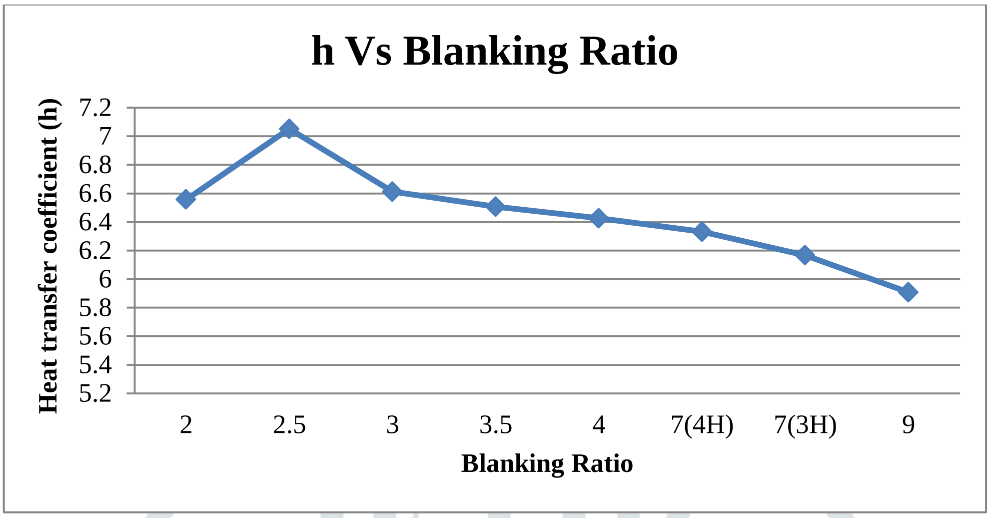


Fig.23 Variation of Heat transfer coefficient with Blanking ratio

Blanking ratio is the second parameter in designing of the heat sink. As the blanking ratio increases from 2 to 9, the heat transfer coefficient also increases. Perforated fins with smaller blanking ratio have greater surface area for heat transfer, but a smaller heat transfer coefficient, since for Perforated fins with smaller blanking ratio or for relatively long channels, the fluid velocity attains its fully developed profile, leading to an increased heat transfer resistance. A heat sink with larger diameter will have a higher heat transfer coefficient but smaller surface area, due to large hole size. Thus, an optimum blanking ratio exists that maximizes the natural convection from the heat sink to the surroundings. Heat sink with blanking ratio equal to 2.50 shows optimum results.i.e. There is an optimum blanking ratio that maximizes the heat transfer rate for different average surface temperatures as shown in fig.23.

VII CONCLUSION

Numerical study is performed in order to establish optimized geometrical fin parameters for natural convection heat transfer from interrupted rectangular fin arrays. The continuous, inline interrupted, staggered interrupted & perforated staggered interrupted aluminium alloy heat sinks are designed & tested by changing various geometrical parameters i.e. fin spacing, fin interruption length & blanking ratio numerically.

The following highlights this project finding:

- From numerical analysis it is cleared that, heat transfer enhancement is better in case of staggered perforated arrangement as compared to other three arrangements. And 50W input power shows higher average wall temperature also heat transfer rate. i.e. heat transfer performance increases by increasing input power.
- Perforated staggered interrupted fin with fin spacing 9.5 mm provides better heat transfer.
- In case of staggered fin, arrangement with G = 15mm shows optimum result i.e. higher heat transfer coefficient & Nu number.
- In the present operating conditions & for perforated staggered interrupted fin arrangement, the thermal performances of the perforated staggered fins with blanking ratio 2.5 with 3 holes are found to be better.

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