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Numerical and experimental analysis of interrupted perforated fins under natural convection.

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Abstract

The interrupted perforated fins are investigated by using numerical as well as experimental 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 effects of perforations in inline & staggered interruptions are investigated. 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, and Thermal analysis.

I. Introduction

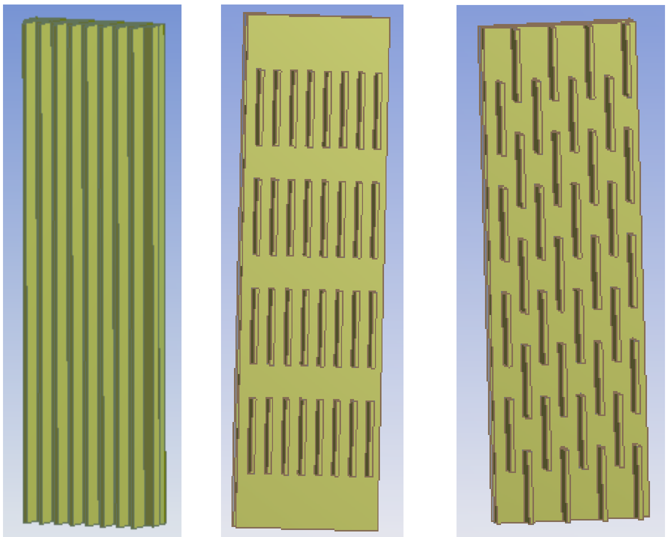
In many Engineering applications heat is produce at the time of process. This causes rise in temperature of system components. This rise in temperature can cause failure of components. Fins are extensively used in cooling of various mechanical and other electronic devices etc. They are very important 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.

Mehran Ahmadi et al 2014 [1] 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 [2] 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 [3] 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 [4] 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 [5] 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 [6] 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.

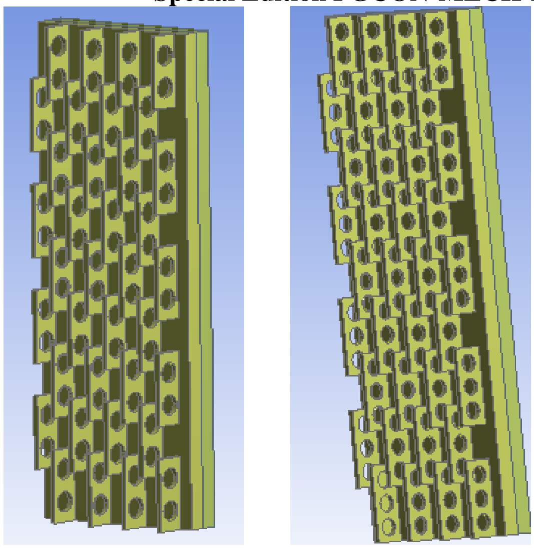
Baskaya et al. [7] used aluminum material for his geometrical study. They studied numbers of the variables of fin spacing, height, and length and temperature difference shows an effect on the overall heat transfer rate. The effects of a wide range of geometrical parameters like fin spacing, fin height, fin length and temperature difference between fin and surroundings; to the heat transfer from horizontal fin arrays were investigated. Tanda et al. [8] 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.[9] 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. [10] 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 experimental and 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 both the numerical and experimental 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 $^{\circ}$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 EXPERIMENTAL SETUP

The experimental setup is shown in following figure (Fig. 2).The sample is stationed inside a large wooden box housing 100 cm x 100 cm x 100 cm isolated from the atmosphere & insulated by a layer of dense insulation foam. Plate heater having dimension 305 mm x 101 mm x 10 mm is provided at the base of heat sink. Experimental studies are conducted on aluminum heat sink samples having base plate dimension 10 mm thick, 305 mm length and 101 mm height to evaluate their thermal performance in natural convection. During the experiments, in addition to the power input to the electric heater, surface temperatures are measured at various locations at the backside of the base plate. Electrical power is to be supplied through an AC power supply from Dimmer stat. The voltage and the current are measured to determine the power input to the heater. Six thermocouples (PT-100) are attached to the back side of the heat sink to avoid the disturbance of the air flow. And one more thermocouple is used to measure the atmospheric temperature during the experiments. To observe the temperature variation over the heat sink temperature is measured at six different positions. The average of these six readings is taken as the base plate mean temperature. Experiments are conducted on five types of samples of different fin arrangements i.e. continuous, inline interrupted, perforated inline interrupted, staggered interrupted & perforated staggered interrupted.

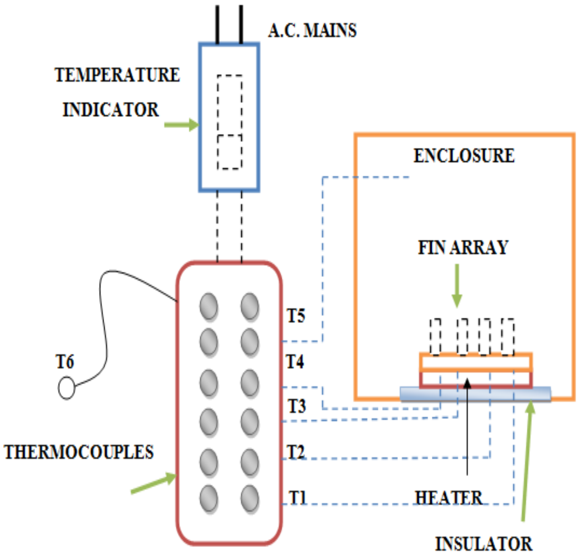


Fig.2 Schematic of the experimental setup

V EXPERIMENTATION METHODOLOGY

Experiment is to be carried out for different arrangement of heat sink arrays as shown in table:

Table 1. Details of Fin Geometry

Fin Arrangements	Geometry
Continuous Fins	* Base plate dimensions (305 mm x 101 mm x10 mm) * No of fins arrays (N) =8 * Height of fins (h) =17.4 mm * Thickness of fin (t) = 2.5 mm * Fin spacing (s) = 9.5 mm
Inline Interrupted & Perforated Inline Interrupted Fins	* Fin length (l) = 45 mm * No of interruption (n) = 4 * Fin interruption length (G) = 20 mm
Staggered Interrupted & Perforated Staggered	* Fin length (l) = 45 mm * No of interruption (n) = 4 * Fin interruption length (G) = 20 mm

Table 2. Details of Test Matrix

Fin Arrangements	Variable parameter
Continuous Fins	-
Inline Interrupted	* 2 Holes circular perforation *3 Holes circular perforation
Staggered Interrupted	* Fin interruption length (G) ➢ 10 mm ➢ 15 mm ➢ 20mm ➢ 25mm ➢ 30mm
Perforated Staggered Interrupted	**G = 20mm** *** 2 Holes circular perforation** Holes diameters (d) considered: 1) 10 mm 2) 12.50 mm Holes spacing (Hs) considered: 1) 20 mm 2) 25 mm *** 3 Holes circular perforation** Holes diameters considered: 1) 10 mm 2) 12.50 mm Holes spacing (Hs) considered: 1) 15 mm 2) 13.75 mm

VI CFD SIMULATION RESULTS

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.3 shows the temperature 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 5.5371 W/m^2K at lower temperature difference of 106.350° K as shown in fig. 3a.

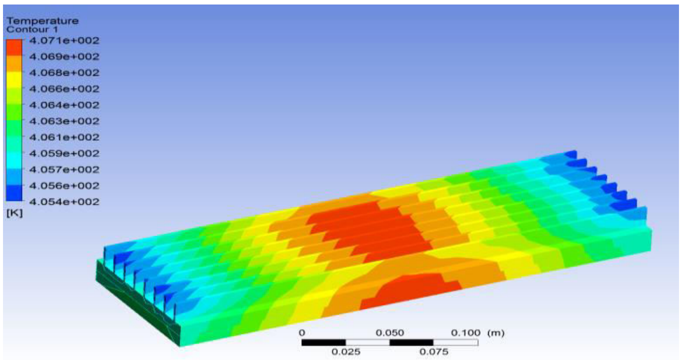


Fig. 3 Temperature contour for continuous fin

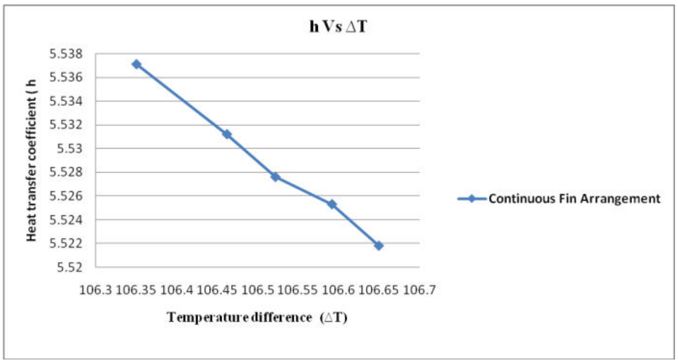


Fig. 3a. Variation of Heat transfer coefficient with temperature difference for continuous fins arrangement.

Fig.4 shows the temperature 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 7.776 W/m^2K at lower temperature difference of 102.660 ° K as shown in fig. 4a

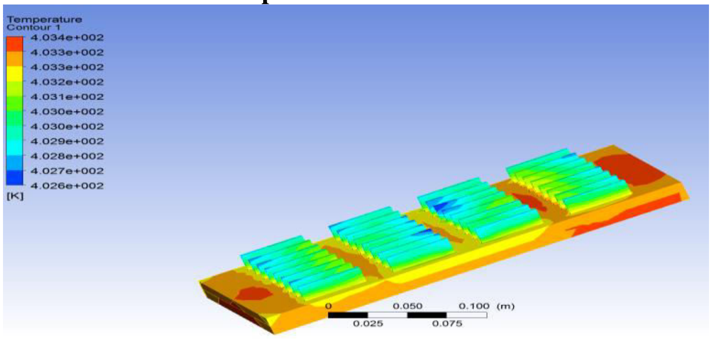


Fig. 4 Temperature contour for inline interrupted fin

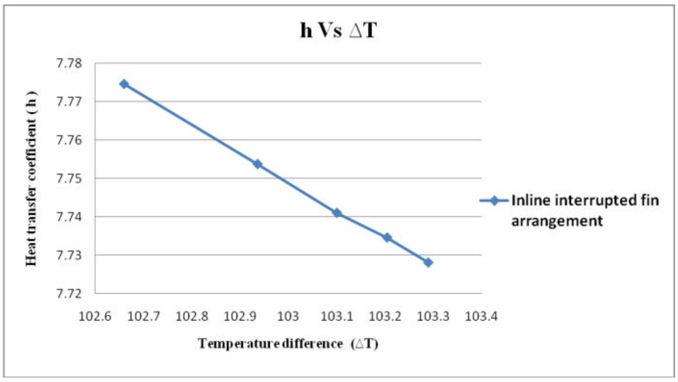


Fig. 4a. Variation of Heat transfer coefficient with Temperature difference for inline interrupted fins.

Fig.5 shows the temperature plot of inline interrupted fin arrangement with 2 holes circular perforation. As the perforations are provided to the inline interrupted fins, the flow turbulence is created due to this the temperature contour region shows slightly low temperature zone at the top region of fin as compared to plain inline interrupted fin. The heat transfer coefficient at the top region of fin is 9.4539 W/m^2K at lower temperature difference of 96.582° K as shown in fig. 7

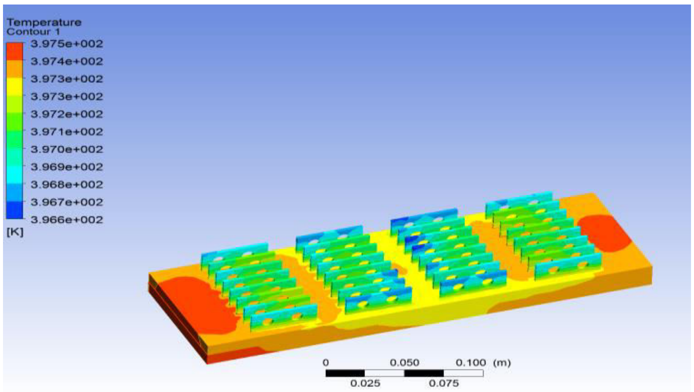


Fig. 5 Temperature contour for inline interrupted fin with 2 holes circular perforations.

Fig.6 shows the temperature plot of inline interrupted fin arrangement with 3 holes circular perforation. 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 as compared to plain inline interrupted fin & 2 holes inline interrupted fins. The heat transfer coefficient at the top region of fin is 9.9681 W/m^{2}K at lower temperature difference of 94.254° K as shown in fig. 7. From fig. 7 it is clear that the inline interrupted fin with 3 holes shows better performance as compared to 2 holes fins.

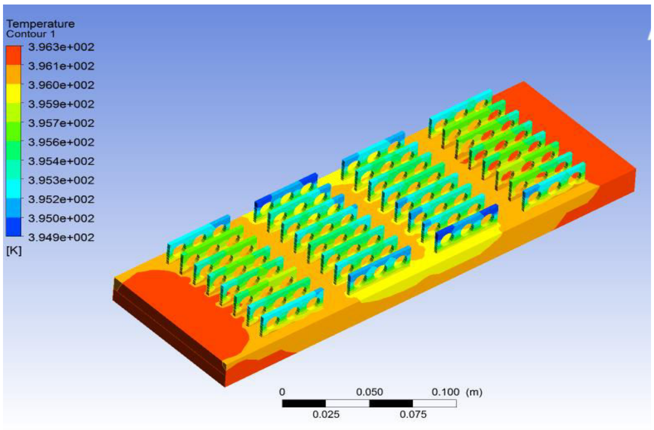


Fig. 6 Temperature contour for inline interrupted fin with 3 holes circular perforations.

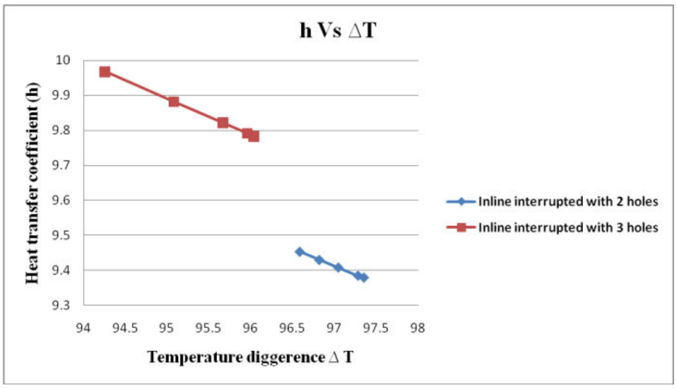


Fig. 7 Variation of Heat transfer coefficient with temperature difference for inline interrupted fins arrangement with 2 & 3holes perforation.

Fig.8 shows the temperature 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 8.7216 W/m^{2}K at lower temperature difference of 101.648 ° K as shown in fig. 8a

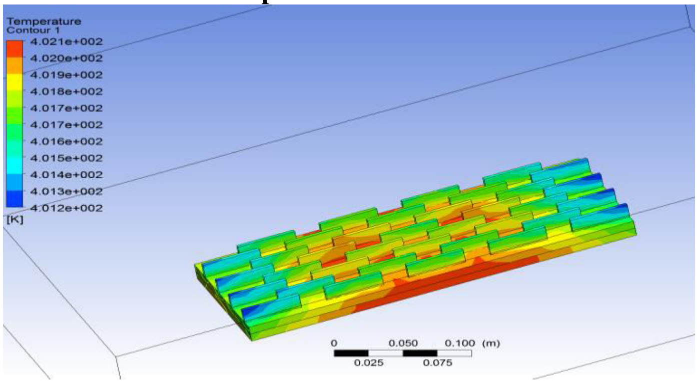


Fig. 8 Temperature contour for staggered interrupted fin (G = 20 mm)

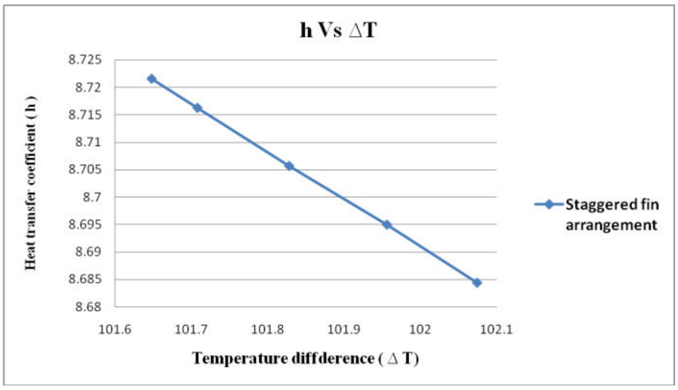


Fig. 8a. Variation of Heat transfer coefficient with temperature difference for staggered interrupted fins arrangement.

Fig.9 shows the temperature plot of staggered interrupted fin with 2 circular perforations arrangement. As the perforations are provided to the fins the flow turbulence is created due to which the heat flux is increases. The heat transfer coefficient at the top region of fins is 10.9453 W/m^{2}K.

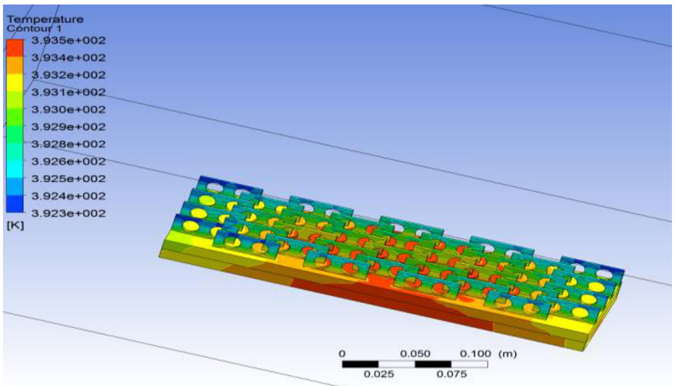


Fig. 9 Temperature contour for staggered interrupted fin with 2 circular perforations. (d =12.54 mm, Hs =20 mm)

Fig.10 shows the temperature plot of staggered interrupted fin with 3 circular perforations arrangement.

Temperature contour region shows slightly low temperature zone at the top region of fin as compared to continuous fins, inline & staggered interrupted fins due to higher flow turbulence. The heat transfer coefficient at the top region of fins is 11.3147 W/m²K.

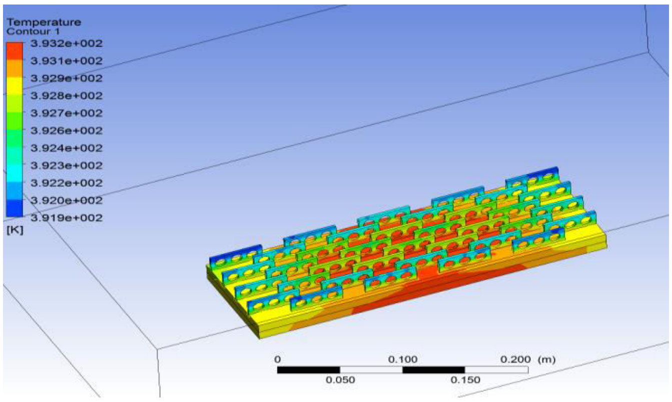


Fig. 10 Temperature contour for staggered interrupted fin with 3 holes circular perforations. (d = 10mm, Hs =13.75 mm)

From Fig. 11 it is clear that the staggered fin arrangement with 3 holes perforations performs better than staggered fins with 2 holes perforation arrangement due to increase in fluid velocity in terms of heat transfer rate.

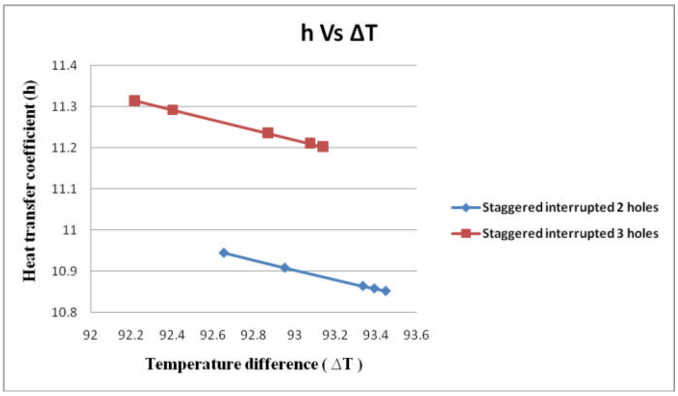


Fig. 11 Variation of Heat transfer coefficient with temperature difference for staggered interrupted fins arrangement with 2 & 3holes perforation

Staggered fin arrangements with perforations:

1) Results by changing G i.e. fin interruption lengths:

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, 30 mm etc. The temperature contours are as follows:

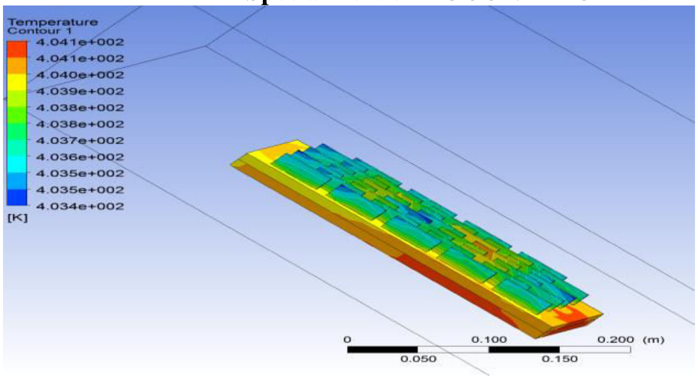


Fig. 12 Temperature contour for staggered interrupted fin (G = 10 mm)

Fig.12 shows the temperature plot of staggered interrupted fin with G = 10 mm. The heat transfer coefficient at the top region of fins is 5.7276 W/m²K.

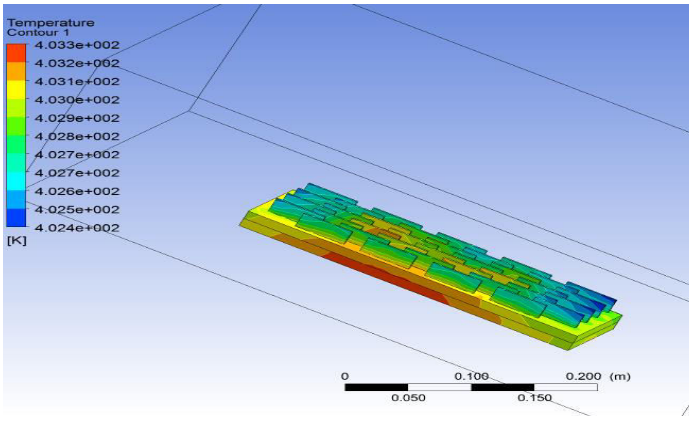


Fig. 13 Temperature contour for staggered interrupted fin (G = 15 mm)

Fig.13 shows the temperature plot of staggered interrupted fin with G = 15 mm. The heat transfer coefficient at the top region of fins is 5.7763 W/m²K.

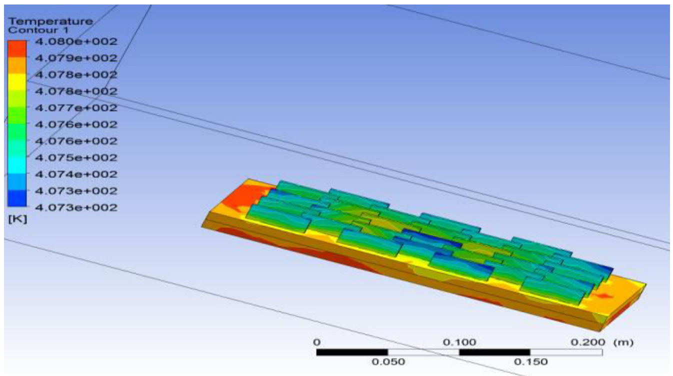


Fig. 14 Temperature contour for staggered interrupted fin (G = 25 mm)

Fig.14 shows the temperature plot of staggered interrupted fin with G = 25 mm. The heat transfer coefficient at the top region of fins is 7.1105 W/m²K.

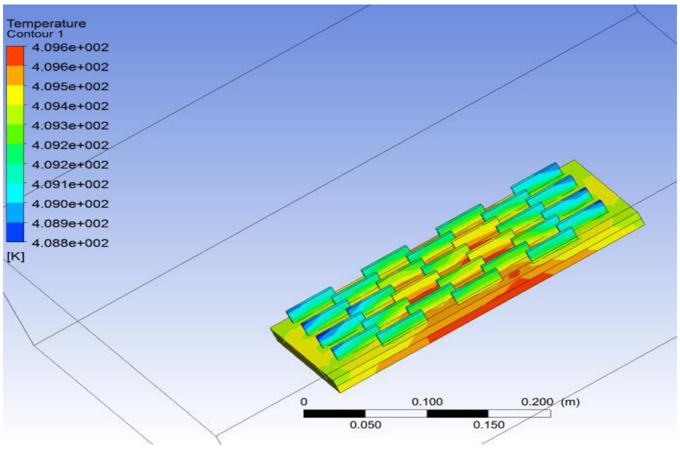


Fig. 15 Temperature contour for staggered interrupted fin (G = 30 mm)

Fig.15 shows the temperature plot of staggered interrupted fin with G = 30 mm. The heat transfer coefficient at the top region of fins is 6.9934 W/m²K.

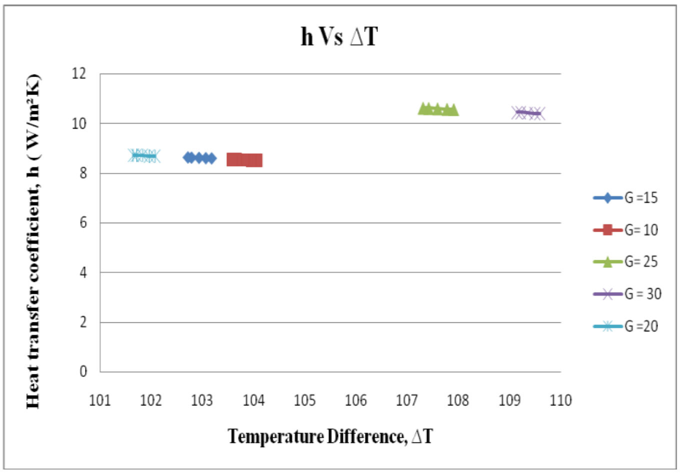


Fig.16 Variation of Heat transfer coefficient with temperature difference for staggered interrupted fins arrangement by changing value of G

From fig. 16 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 = 25 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 25 mm.

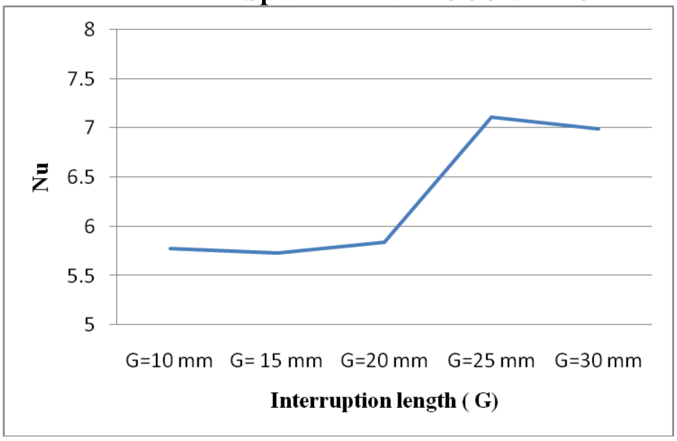


Fig.17 Variation of Nu with Interruption lengths (G)

Fig. 17 shows variation of nusselt numbers for various staggered fin arrangements by changing value of interruption lengths. Nu increases as interruption length increases. G = 25 mm arrangement shows optimum value of nusselt number. i.e. Nu is higher in case of G = 25 mm.

2) Results by changing hole diameter (d) & centre to centre distance between two holes (Hs).

- **For 2 holes staggered interrupted arrangement:**

1) d = 10 mm
   Hs = 20 mm

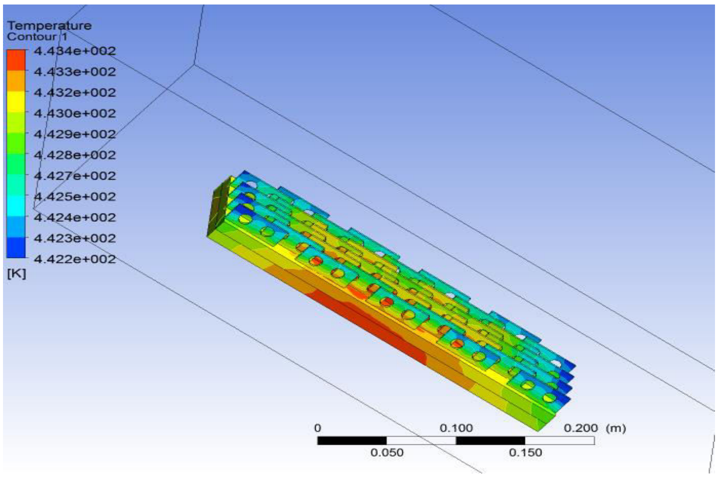


Fig. 18 Temperature contour for staggered interrupted fin with 2 circular perforations. (d =10 mm, Hs =20 mm)

2) d = 12.54 mm
   Hs = 25 mm

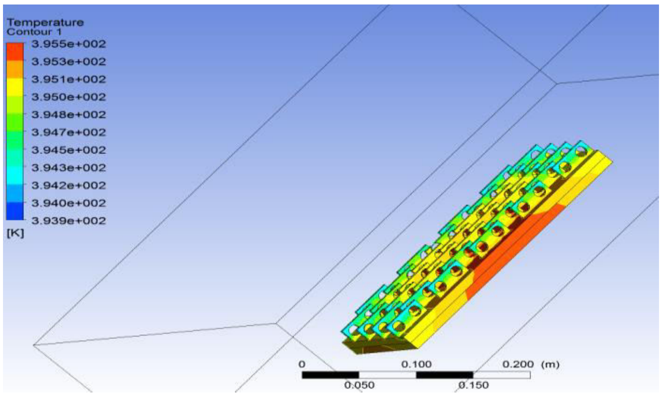


Fig. 19 Temperature contour for staggered interrupted fin with 2 circular perforations. (d =12.54 mm, Hs =25 mm)

Figure 9, 18 & 19 shows the temperature contour for 2 holes staggered interrupted arrangement by changing d & Hs. The arrangement with d = 12.54 mm & Hs = 20 mm shows better performance as compared to other two arrangements. i.e. .heat transfer coefficient is higher in this arrangement which is 10.94 W/m²K.

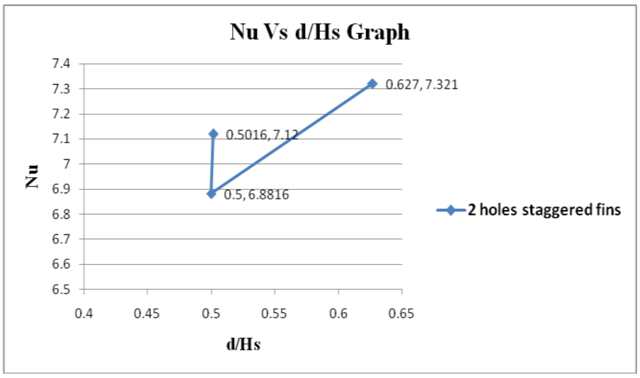


Fig.20 Variation of Nu with d/Hs for 2 holes staggered fins

From figure 20 it is clear that the Nu is increase as the ratio of d/Hs is increase. The arrangement with d = 12.54 mm & Hs = 20 mm shows better performance i.e. value of Nu is greater as compared to other two arrangements.

- **For 3 holes staggered interrupted arrangement:**

1) d = 12.54 mm
   Hs = 13.75 mm

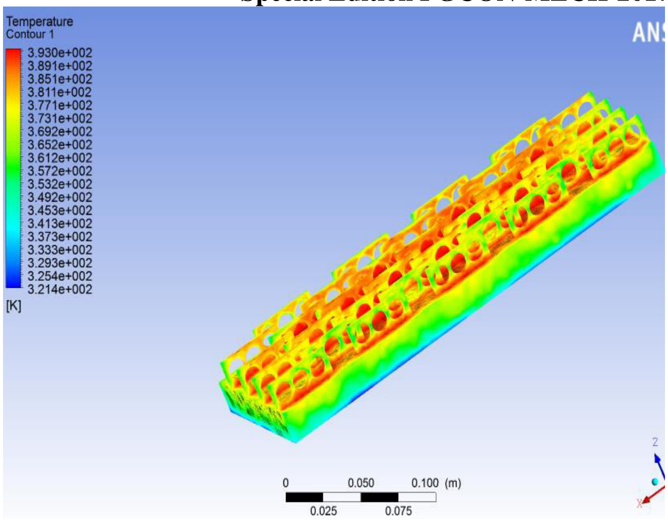


Fig. 21 Temperature contour for staggered interrupted fin with 3 circular perforations. (d =12.54 mm, Hs =13.75 mm)

2) d =10 mm
   Hs = 15 mm

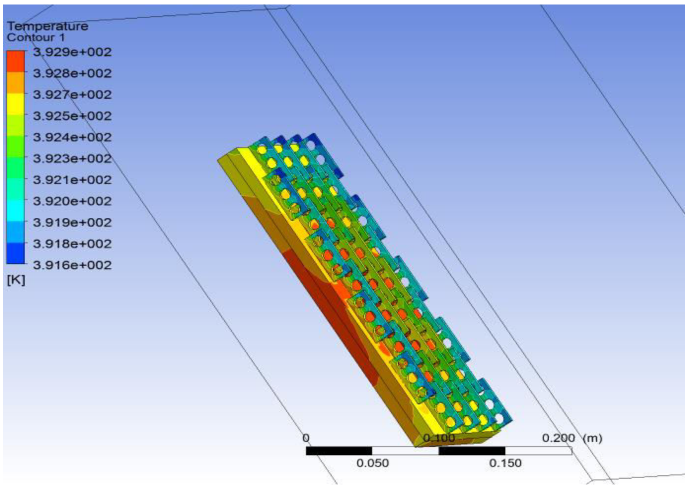


Fig. 22 Temperature contour for staggered interrupted fin with 3 circular perforations. (d =10 mm, Hs =15 mm)

Figure 10, 21 & 22 shows the temperature contour for 3 holes staggered interrupted arrangement by changing d & Hs. The arrangement with d = 12.54 mm & Hs = 13.75 mm shows better performance as compared to other two arrangements. i.e. .heat transfer coefficient is higher in this arrangement which is 11.76 W/m²K

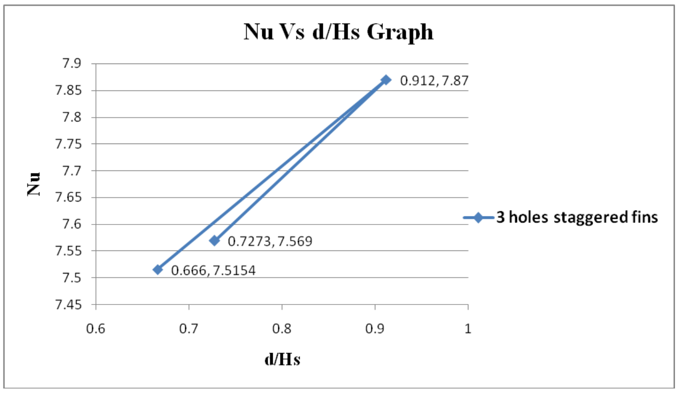


Fig.23 Variation of Nu with d/Hs for 3 holes staggered fins.

From figure 23 it is clear that the arrangement with d = 12.54 mm & Hs = 13.75 mm shows better performance i.e. value of Nu is greater as compared to other two arrangements.

VII CONCLUSION

- Perforated staggered interrupted with 2 holes and 3 holes arrangement provide better heat transfer rate in comparison with the inline interrupted & continuous fin arrangement.
- In case of staggered fin, arrangement with G = 25 mm shows optimum result i.e. higher heat transfer coefficient & Nu number.
- In case of 2 holes staggered fin, arrangement with d= 12.54 mm & Hs = 20 mm shows better thermal performance. Also for 3 holes staggered fin, d = 12.54 mm & Hs =13.75 mm shows better thermal performance.
- In the present operating conditions & for perforated staggered interrupted fin arrangement, the thermal performances of the perforated staggered fins with 3 holes are found to be better.

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