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NUMERICAL STUDY FOR INTERRUPTED RECTANGULAR FINS IN A NATURAL CONVECTION FIELD

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Abstract: *The heat sink with vertically rectangular interrupted fins investigated numerically in a natural convection field, and with steady-state heat transfer. Numerical study has been conducted using ANSYS Fluent software (R16.1) in order to develop a 3-D numerical model. The dimensions of fins are (305 mm length, 100 mm width, 17 mm height, and 9.5 mm space between fins). The number of fins used on the surface are eight. In this study, the heat input that is used as follow (20, 40, 60, 80, 100, and 120 watts). The study is focused on interrupted rectangular fins with different arrangement of fins. The results show that the addition of interruption fins in various arrangements will improve the thermal performance of the heat sink, and through the results, a better interruption rate obtained as an equation.*

Keywords: Heat sink, Heat transfer, free convection, interrupted fins, CFD.

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1. INTRODUCTION

Heat sinks are used in various engineering applications for the cooling of electronic and electrical appliances, communications equipment and vehicle components. These components can be either semiconductor devices or integrated circuits, and more accurately, uses passive cooling extensively in CPU cooling, amplifiers, and LED light bulbs. Natural convection heat transfer from vertical rectangular fins is a settled subject in the literature. Here it has been investigated numerically. Previous studies include numerical and experimental works, and further studies can be found elsewhere **Ranandan and Ramalingam, 2008**.

Salila and Panda, 2013, studied numerical model by using Ansys program in this project. The aim was to reduce the materials used, and made the fins with highly efficient and at relatively low cost. The fin form used is rectangular fin made of a metallic element and horizontal position, and exposed to the effect of natural convection. The results showed that when the heat input increased the heat transfer coefficient will increase and the Nusselt number will increase. **Mehran and Golnoosh, 2014,** investigated the numerical and experimental study of vertically rectangular interrupted fins in a natural convection field. In order to create a two-dimensional digital model, Ansys fluent was used to study the effect of interruptions numerically. The aim of this study is to add different interruption with a variable dimension to the vertical fins and then to find the optimum value of the interruption ratio. The results showed that the optimal interrupted length of the fin was obtained and related**. Ali and Abbas, 2015,** studied several models of interrupted fins, and with different interruption ratio under the natural convection effect. The governing equations of continuity, momentum, and energy equations have been solved with steady-state, laminar, two-dimension, and with Boussinesq approximation using the Fluent V15 software. The results show that the use of

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interruption technique cause to reset the boundary layer, which enhances the thermal performance of the fins and also reduce overall weight. **Bhushan S Rane, 2015**, studied different models of the heat sink which contained continuous, inline-interrupted and staggered fins by using the fluent software. The study concluded that interrupted fins are more effective than continuous fins and that staggered fins are better than the rest. The results showed that staggered fins can be used to improve the thermal performance of attachments for a variety of electronic, electrical appliances, and communications applications. **Suha K. Jebir, 2017**, explained heat transfer by free convection for two types of fins 1-interrupted and 4-interrupted rectangular, by placing fins horizontally, vertically, and inclined. The base of the fin is susceptible to constant heat flux. COMSOL 5.0 package was used to find the mesh generation and locate the results. The results showed that convection heat transfer of the fin with a horizontal position was less compared with the following two cases (vertical and inclined).

A numerical study was carried out starting from the continuous fin with dimensions of (101mm width, 305mm length, 2.5mm thickness, and 9.5 mm space between fins). After that, studied the effect of interrupting of the fin with different lengths of interruption (G = 10mm, 20mm, and 30mm) and numbers of interruption (N = 1, 2, 3, 4, and 5), in order to obtain the best ratio of the interruption (γ). After getting the best number of interrupting, changed the arrangement from inline interruption to staggered, with variable interruption length (G). The main purpose of this study is to obtain the best heat transfer coefficient and reduce the total weight.

2. PROBLEM STATEMENT

When the fin base plate is heated from the bottom, the heat passes through the conduction to the vertical fins and the thermal boundary layers begin to evolve from the lower edges of the fins. If fins are long enough, thermal boundary layers will be fully integrated **Bejan, 1984**. The interruptions of fin disrupt the growth of the thermal boundary layer while maintaining a thermal flow system, leading to higher natural heat transfer coefficient. Three-dimensional (CFD) models with dissimilar patterns of heat sinks have been presented through this study.

3. NUMERICAL ANALYSES

This section includes discussion of the following sub-sections, computational domain, the governing equations, mesh generation, and precondition. In addition, validation of present numerical study and another previous numerical study has been discussed.

3.1 COMPUTATIONAL DOMAIN

Different sample of fins have been modeled as shown in **Table 1**. The main species of fins (heat sinks) geometries are shown in **Fig. 1**.

Table 1: Dimensions of finned plate samples; interrupted and staggered fins.

Sample name	N (number of interruption)	G (mm)	*l* (mm)	n(number of fins)
Int.-1-10	1	10	147.5	16
Int.-2-10	2		95	24
Int.-3-10	3		68.75	32
Int.-4-10	4		53	40
Int.-5-10	5		42.5	48
Int.-1-20	1		142.5	16
Int.-2-20	2		88.33	24

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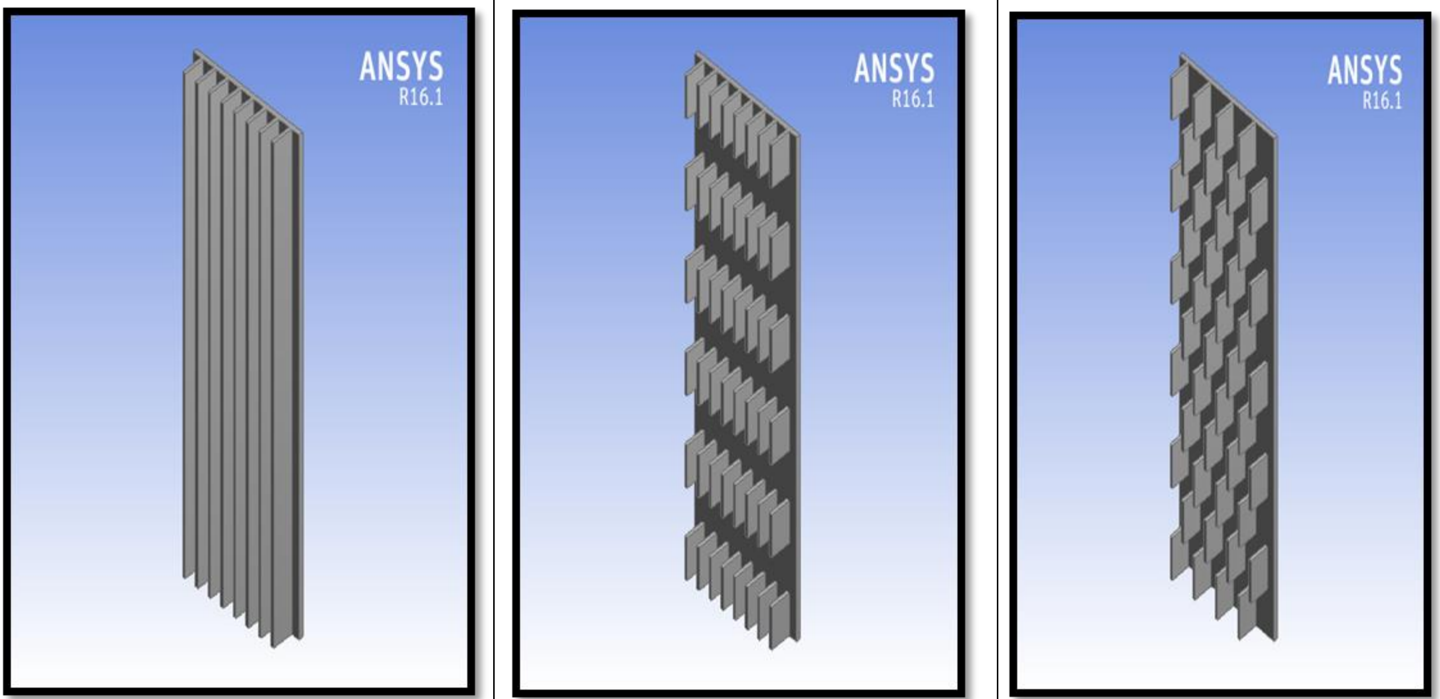
Int.-3-20	3	20	61.25	32
Int.-4-20	4		45	40
Int.-5-20	5		34.2	48
Int.-1-30	1		137.5	16
Int.-2-30	2		81.6	24
Int.-3-30	3	30	53.75	32
Int.-4-30	4		37	40
Int.-5-30	5		25.83	48
Stag.-5-10	5	10	42.5	44
Stag.-5-20	5	20	34.2	44
Stag.-5-30	5	30	25.83	44



Continuous fins arrangement | **In-line interrupted fins arrangement** | **Staggered interrupted fins arrangement**

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Fig.1: Considered Heat sink Geometries**.**

3.2 GOVERNING EQUATIONS

The dominant equations for the continuity, momentum, and energy are resolved by using the FLUENT R16.1 software. The processors of numerical study are divided into two parts. The first preprocessor is the program structure which creates the geometry and grid by using the FLUENT R16.1 software. The second post-processor is resolving governing equations which include conservation of mass, momentum, and energy for the purpose of obtaining the results. **Bocu and Altac, 2011.**

The governing equations for this study are as follows:

Mass conservation equation:

$$\nabla . V = 0 \tag{1}$$

Momentum:

$$(V.\nabla)V = -\left(\frac{1}{\rho}\right)\nabla P + \upsilon\nabla^2 V + g\beta(T - T_o)j \tag{2}$$

Energy:

$$(V \cdot \nabla)T = \alpha\, \nabla.(\nabla T) \tag{3}$$

The heat in the fins is dissipated by three methods, conduction, convection, and radiation. The temperature field is gained by settling the energy equation.

3.3 MESH GENERATION

For the choice of meshing size, proximity and curvature size operate are taken into account. For higher meshing at the fluid-metal interface, inflation layer is taken into account. Mesh independence study is performed for this study. **Fig.2** shows two different meshing model of a numerical model, which is created using ANSYS Fluent R16.1 software. The first model is for meshing with minimum cell size1 mm while the second model shows mesh generation using 0.5 mm minimum cell size. After the numerical simulation of the fins for both sizes of the grid, the maximum temperature was determined. Our result shows that selection of meshing size less than 1 mm has very less effect on temperature variation. For both the grid sizes the maximum temperature is about 154.5°C. Finer meshing only increases the computational cost without further changes in maximum temperatures, so 1 mm meshing size is selected for all the Ansys simulation in this study.

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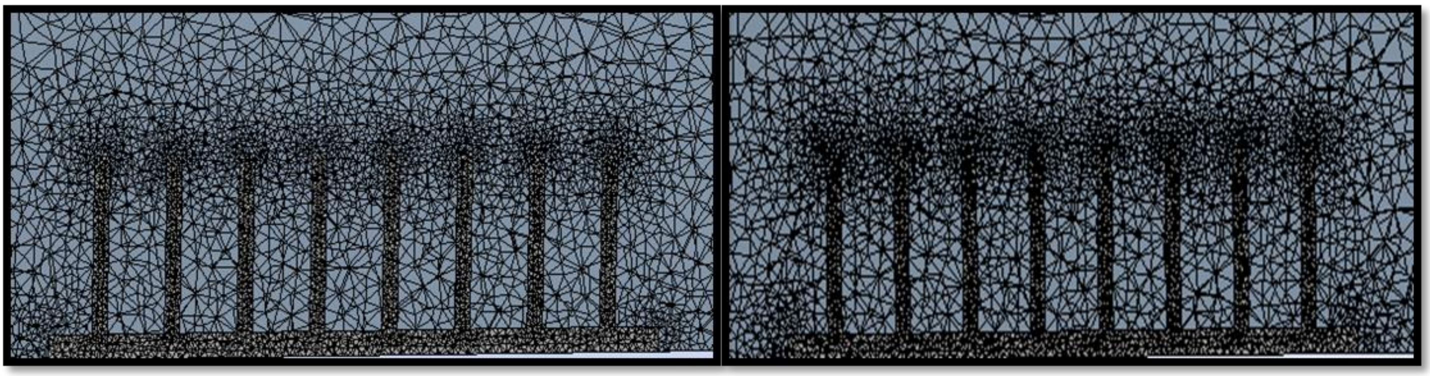

(a) (b)

Fig.2: Mesh independency of numerical model to thermal performance: (a) meshing with 1 mm minimum cell size; (b) meshing with 0.5 mm minimum cell size.

3.4 BOUNDARY CONDITION

The flow type in this numerical study is laminar. The effect of density variation with a temperature have been estimated by Boussinesq approximation. In the current study, there are different values of heat flux (649, 1298, 1948, 2597, 3246 and 3896 W/m^2) have been used. A very soft border layer mesh was used for areas close to the fin surface, In order to capture the flow behavior with high accuracy. The primary condition of the fin model at the base is a constant heat flux, the heat in the fin base is transmitted by conduction. At the surface of the fins, the heat transfer is carried out by convection and radiation as shown in **Fig.3**, where the emissivity of aluminum (0.5) has been used.

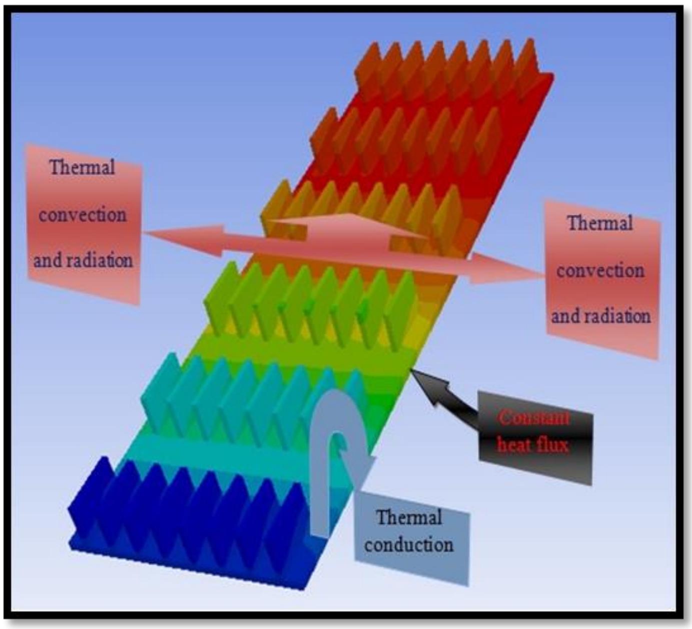

Fig. 3 Boundary condition.

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4. CFD MODELING

In this present study, the fins were placed on a base plate of dimension 305 * 100 mm2. The fin arrangement was put within the middle and therefore the bounding box was created as shown in Fig. 4. The boundaries of this process domain were placed sufficiently far from the fins to avoid any flow-reversal throughout the numerical simulations. The CFD meshing, process domain discretization was performed mistreatment ANSYS software, a processor. Combos of tetrahedral and prism parts were used. Because of the high-temperature distinction between the fin surfaces and therefore the surroundings, the buoyancy currents are going to be dominant. The prism layers generated close the fin surfaces would facilitate to numerically resolve the thermal boundary layers and this lead to the improved accuracy of the general heat transfer

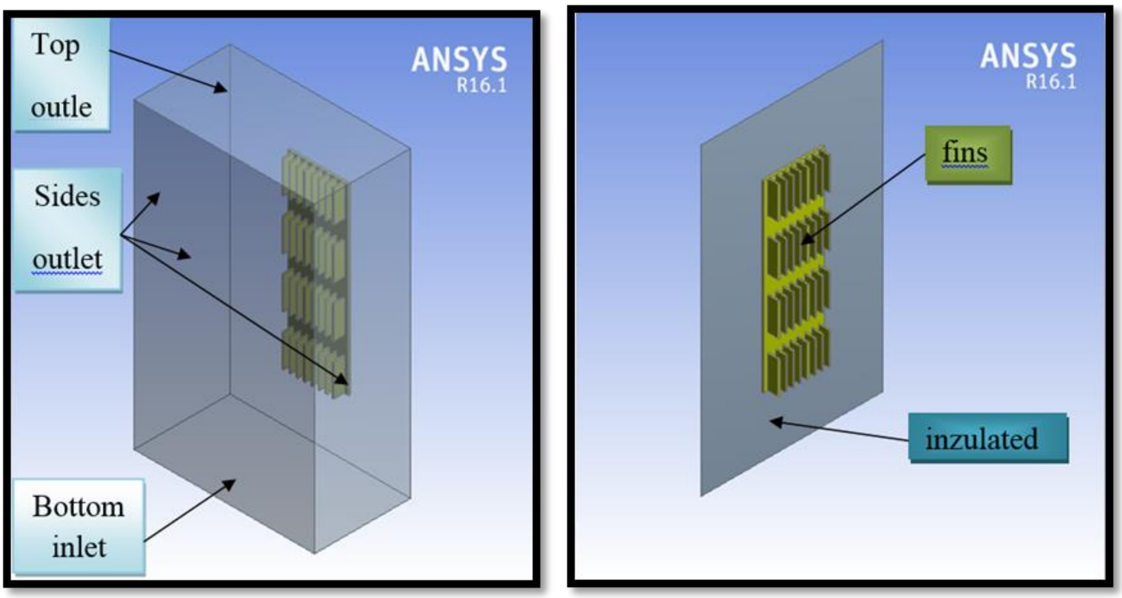

Fig.4 CFD modeling**.**

5. SIMULATION RESULTS

Shows the most important results obtained.

5.1 VALIDATION OF THE PRESENT STUDY:

For the purpose of starting the current numerical study, they have been verified by comparison with **Mostafavi et al., 2012**. Through comparison between two studies it is found that there was a good agreement between the results, and the error rate does not exceed 2.7%.This validation for continuous fins as shown in **Fig.5**.

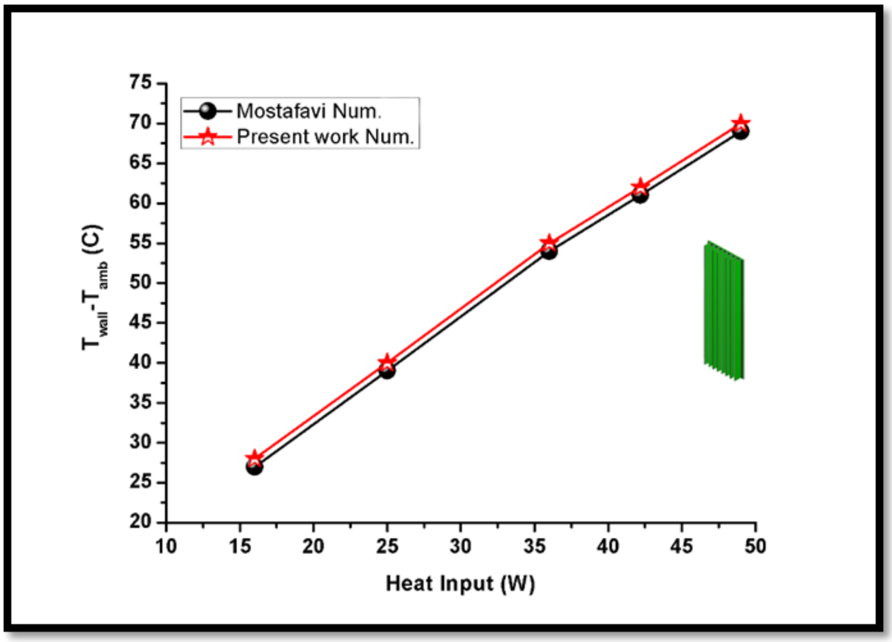

Fig.5 Validation of numerical analysis graph.

5.2 VELOCITY AND TEMPERATURE CONTOURS:

The main species of a heat sink has been chosen In order to show the effect of changing the arrangement on temperature and velocity through the contour. **Figs. 6, and 7** show the temperature and velocity flow contours for three models. From these contours shown the effect of interruption length on the thermal boundary layer noticeably. Where the length of the interruption prevents the growth of the adjacent thermal layer that causes resistance to heat transfer to the ambient. The development of flow in the fin can be seen through argument regions. The contour of the temperature and the velocity flow were created in a level at the mid-height of the fin, and at value of heat input = 60 watts.

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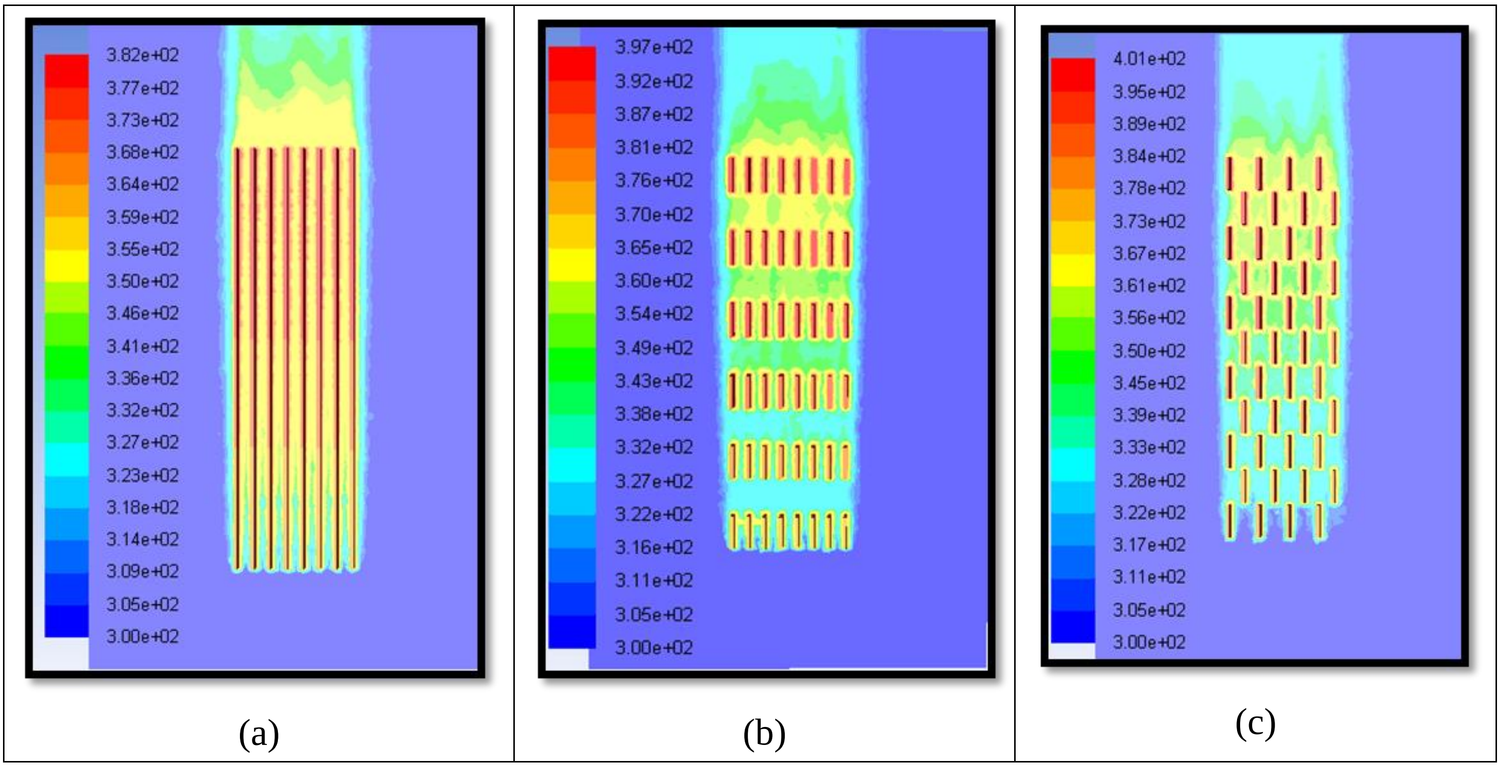

Fig.6: Temperature contours; (a) continuous fins ;(b) interrupted fins;(c) staggered fins.

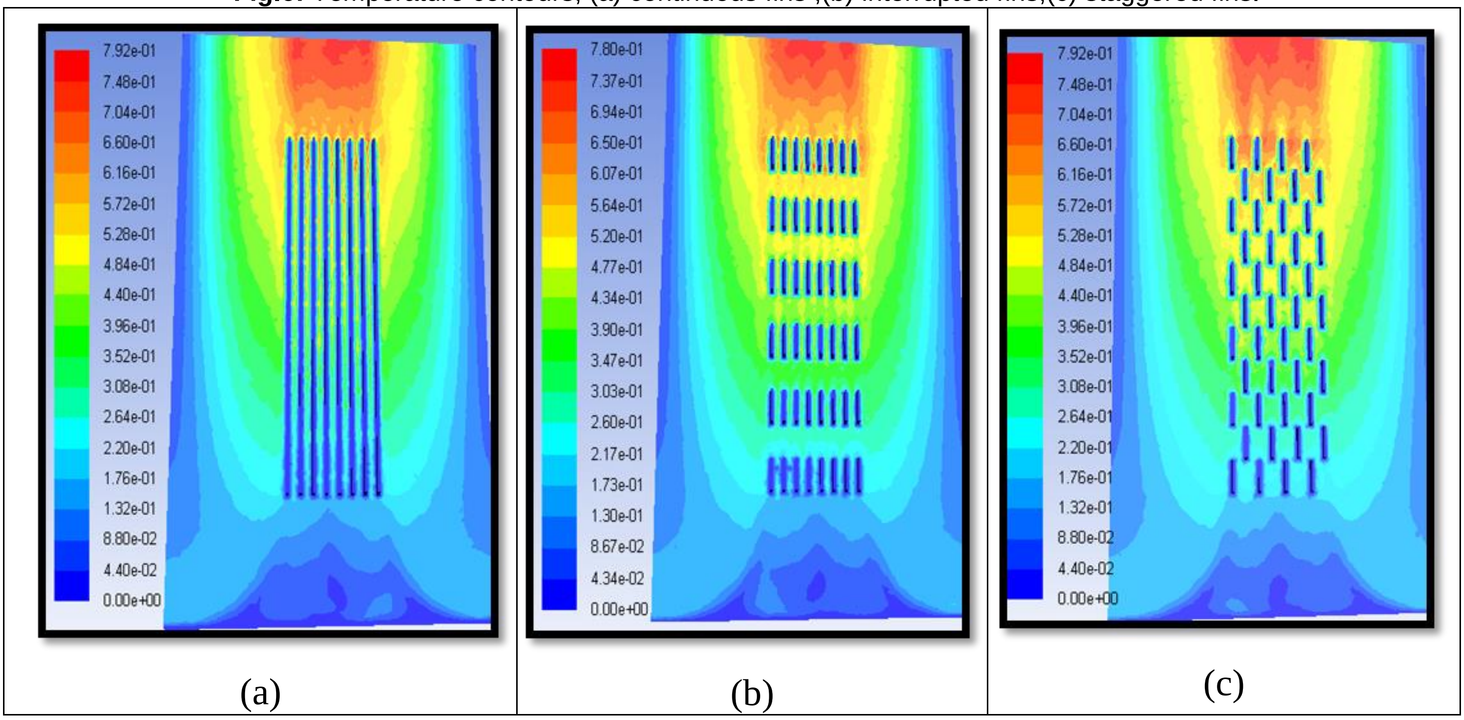

Fig.7: Velocity contours; (a) continuous fins ;(b) interrupted fins;(c) staggered fins.

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5.3 THE VARIATION BETWEEN INTERRUPTION RATIO AND HEAT TRANSFER COEFFICIENT:

The relation between heat transfer coefficient and interruptin ratio (**γ**) with different heat input can be seen in **Fig.8**. The reason for increasing the heat transfer coefficient is that when the interruption ratio increases, the surface area decreases and the flow velocity increases at the base of the fin, thereby increasing the coefficient of heat transfer through natural convection.

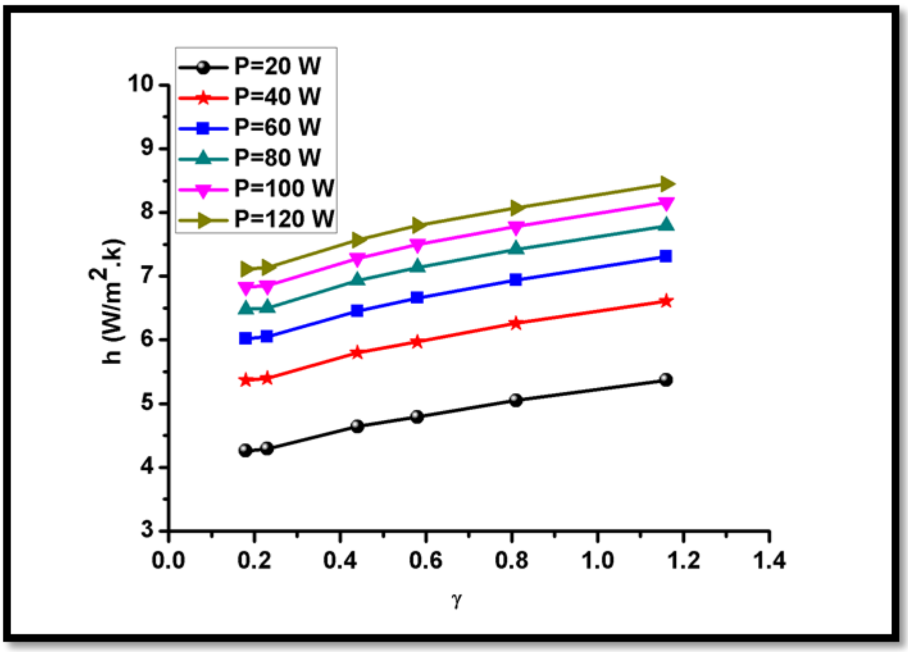

Fig.8: The effect of interruption ratio on heat transfer coefficient with different heat input.

5.4 THE EFFECT OF DIFFERENT HEAT INPUT ON TEMPERATURE AND NUSSELT NUMBER

Using the numerical results obtained, plotted a relationship between the heat flux and the difference in temperature for the interrupted fins (with different N and G) as shown in **Figs.9.to12**. Note from these figures that when increasing the length of the interruption (G) and the number of interruption (N) lead to increased temperature due to the decrease surface area of a heat sink. It is clear from **Figs. 13. to 16** depict the relation between different heat input and Nusselt number with different G. The exhibit that the heat transfer coefficient enhances when the heat input, G and N increase. That means the interruption length leads to a higher thermal performance because interrupted fins prevent the thermal boundary layer growth, lead to increased heat transfer coefficient and thus increase the Nusselt number with natural convection.

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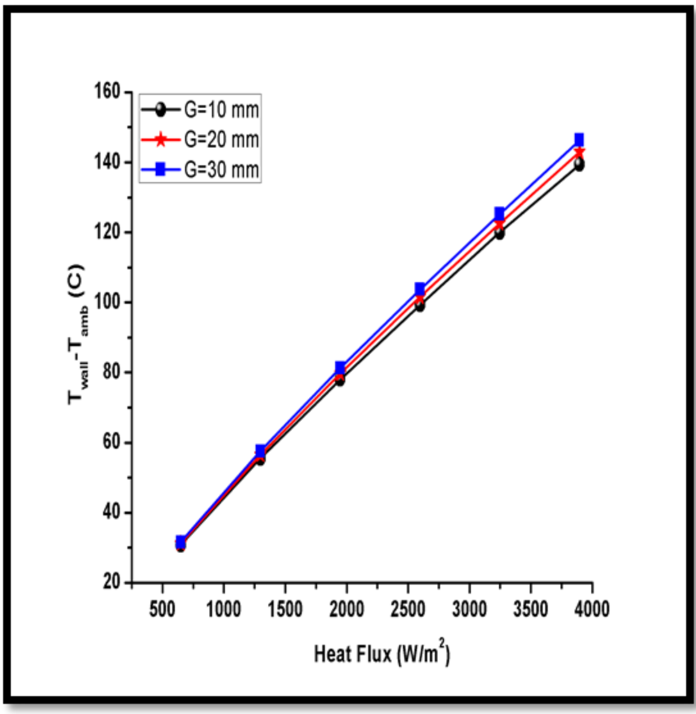

Fig.9: The effect heat flux on temperature different with different G at N=2.

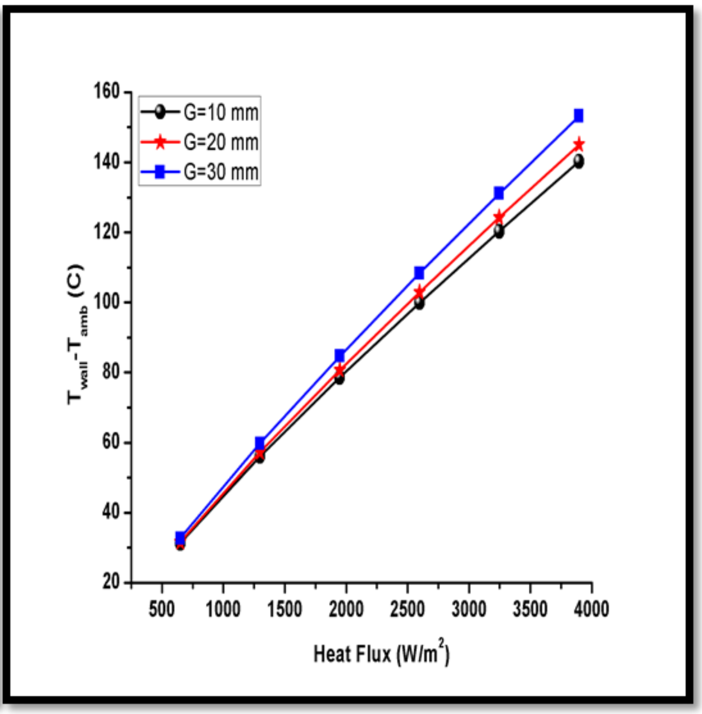

Fig.10: The effect of heat flux on temperature different with different G at N=3.

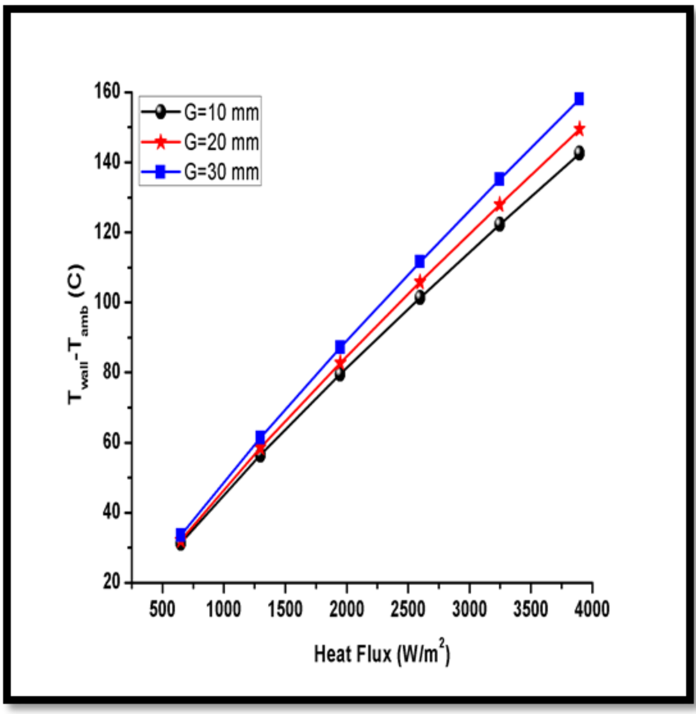

Fig.11: The effect of heat flux on temperature different with different G at N=4.

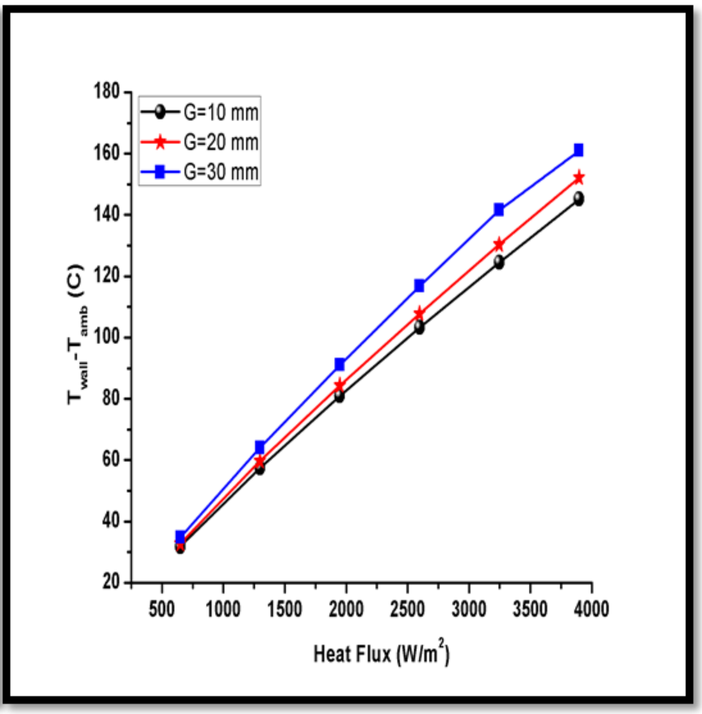

Fig.12: The effect of heat flux on temperature different with different G at N=5.

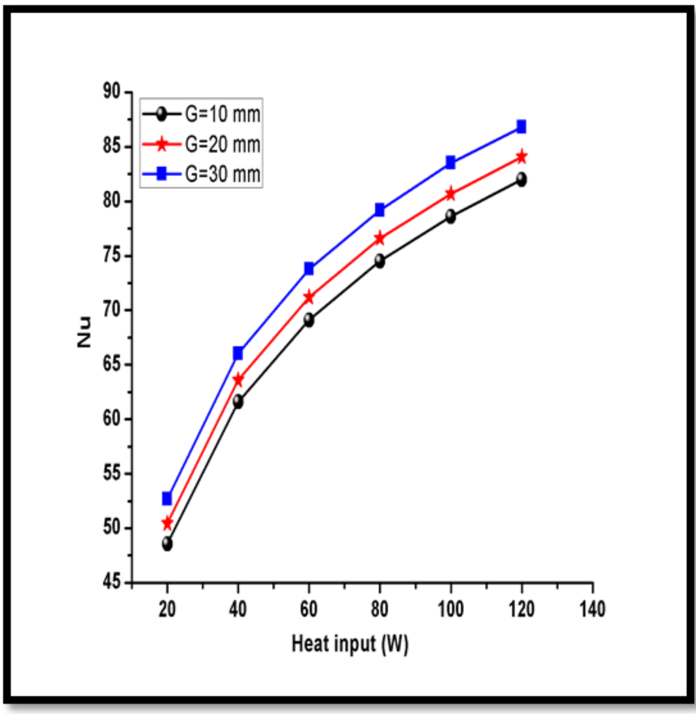

Fig.13: The effect of heat input on Nusselt number with different G at N=2.

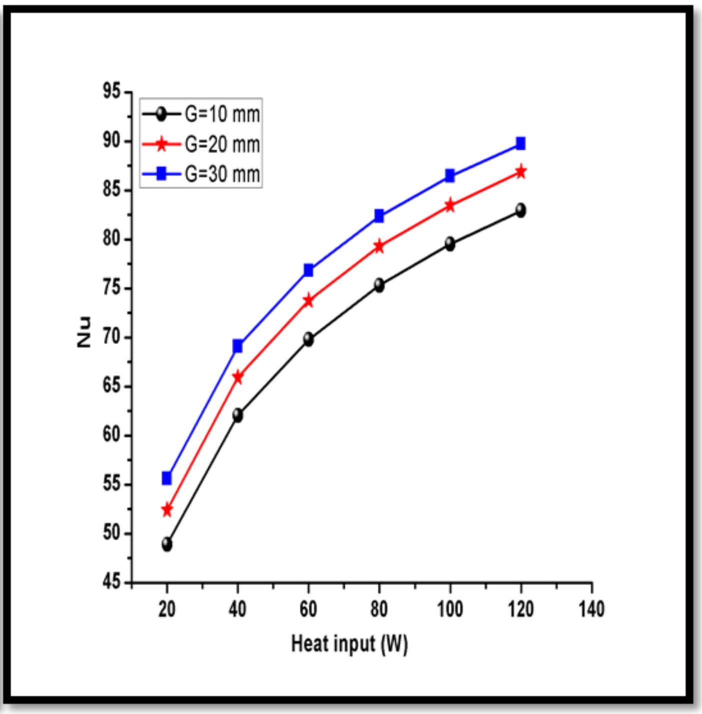

Fig.14: The effect of heat input on Nusselt number with different G at N=3.

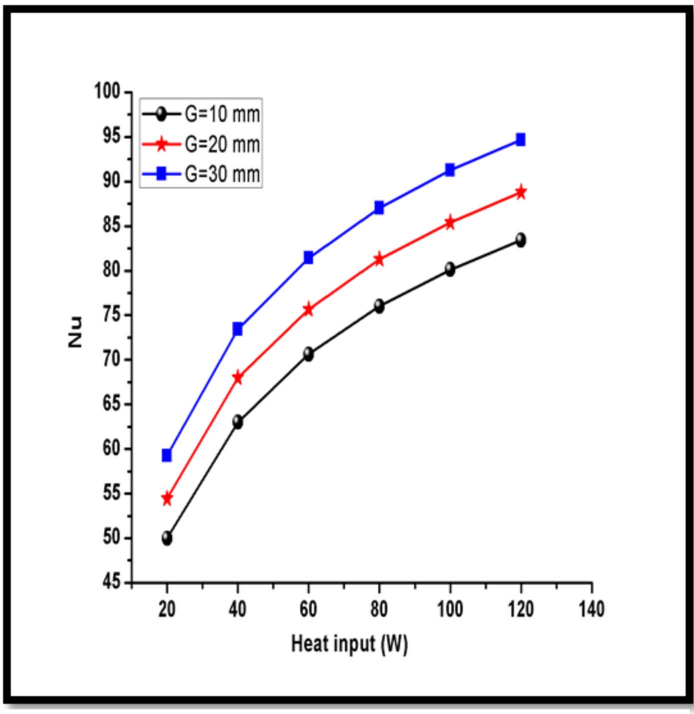

Fig.15: The effect of heat input on Nusselt number with different G at N=4.

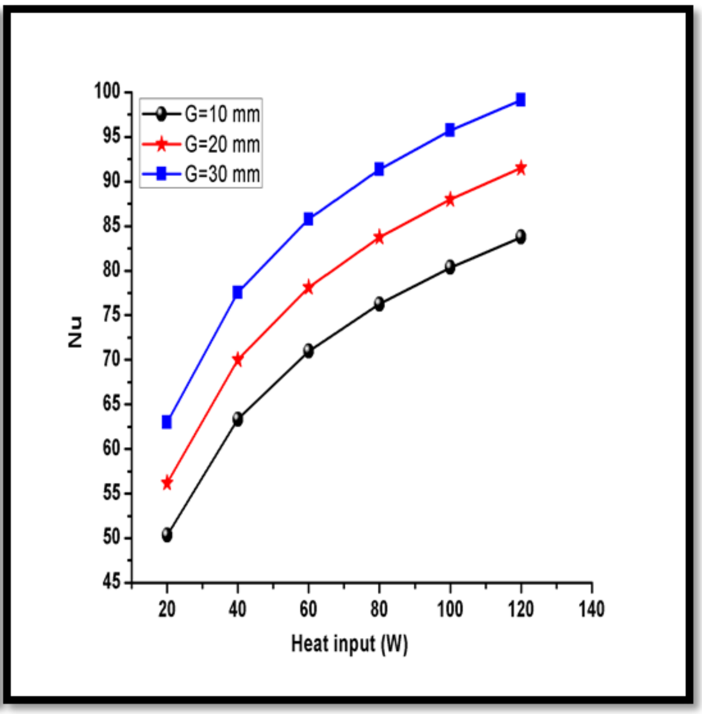

Fig.16: The effect of heat input on Nusselt number with different G at N=5.

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5.5 THE EFFECT OF CHANGE ARRANGEMENT ON TEMPERATURE AND NUSSELT NUMBER

Through the study of numerical and comparative between the continuous and In-line interrupted and staggered interrupted fins. The following **Fig.17 and 18**. Show that staggered interrupted fins are better compared to other species because the surface area subjected to heat transfer is larger, then giving greater heat exchange as well as an improvement in the Nusselt number.

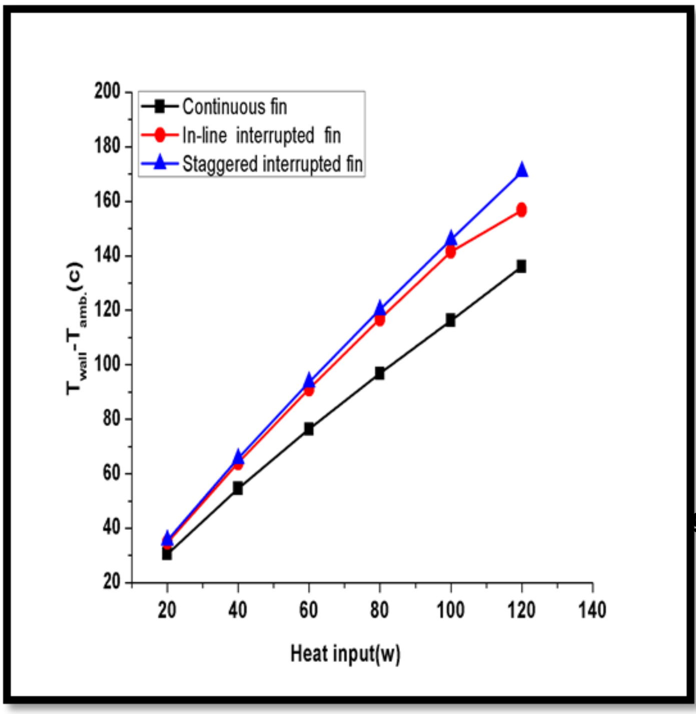

Fig.17: Effect of interruption on the temperature difference.

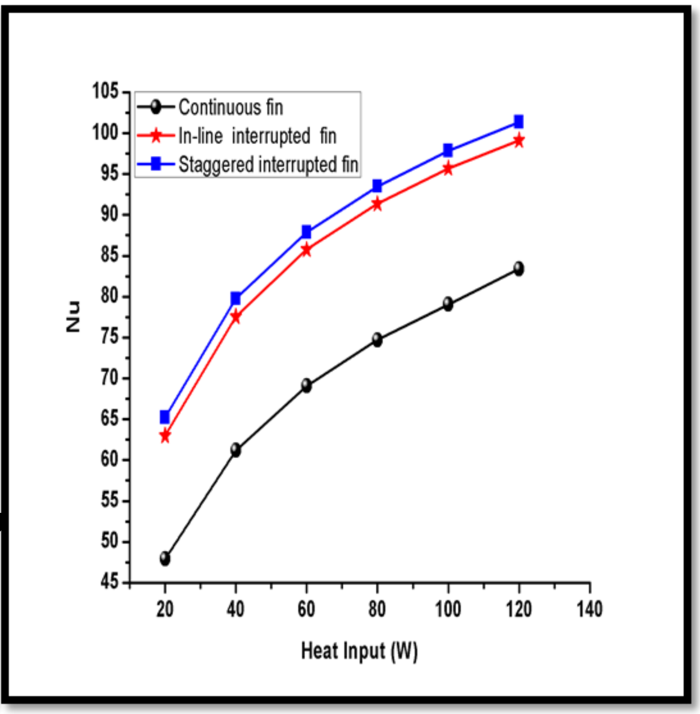

Fig.18: Effect of interruption on the Nusselt number.

6. CONCLUSIONS:

Numerical studies performed in order to establish optimum geometrical heat sink parameters for natural convection heat transfer from interrupted rectangular fin arrays with different arrangement.

The most important results of the numerical study can be listed as follows:

- The results are based on the fact that when the fin length is increased, especially in the case of the continuous fin, the heat transfer coefficient is low. Where the heat transfer coefficient reaches the lowest value at a length of 305 mm at same heat flux.
- When the interrupting length is increased, the heat transfer coefficient increased, and increasing the number of interruptions leads to a clear improvement in the heat transfer coefficient. The model in which the number of interruptions is five and the interrupting length is 30 mm better than the continuous fins by 22.3% In terms of heat transfer coefficient.
- The optimum interrupted ratio (γ_{opt}) is a function of surface temperature, For different lengths and within this range (12 mm< l <25 mm), as follows:

$(\gamma_{opt}) = 8112(T_{wall} - T_{amb.})^{-2.2}$

- Staggered interrupted fin arrangement provided better heat transfer rate in comparison with the in-line interrupted fin arrangement. The ratio of improvement is 2.4%.

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