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Prediction of Fin Performance under Natural Convection using Finite Element Method

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ABSTRACT

This study examines the heat transfer enhancement from a vertical rectangular fin embedded with circular perforations under natural convection compared to the equivalent solid (non-perforated) fin. The parameters considered are geometrical dimensions and thermal properties of the fin and that of the perforations. The study considered the heat transfer coefficients of vertical plates due to number of perforations in the natural convection. The experimental setup of the literature is used for comparison. The same experimental setup is simulated with the help of ANSYS. The heat transfer through rectangular fins with different number of circular perforations in rectangular pitch is compared with experimental results of the literature, non-perforated (solid fin) fin of same dimension and of triangular pitch circular perforated plate and also compared with circular and triangular combination of perforations and circular perforation with increase in diameter. In the study it is found that ANSYS metal temperatures are matched with experimental thermocouple results within ±10%. Also, non-perforated plate shows significantly higher temperatures. Change of perforation type with equivalent cross sectional area or pitch of perforation doesn't change the metal temperatures much. But increase in perforation diameter resulted in reduced metal temperatures compared to all other variations & is one of the best idea to implement for the better heat removal.

Keywords *– Heat Transfer, Conduction, Perforation, Temperature, Ansys.*

1. INTRODUCTION

Enhancement of heat transfer is of vital importance in many industrial applications. One of the methods of enhancing heat transfer is the use of extended surfaces. The use of perforated material is limited by the lack of reliable strength and stiffness properties for the use in design. The thermal systems must be designed and sized to generate, transmit, or dissipate the appropriate amount of unwanted heat with required demand.

A heat exchanger is a device used to transfer heat from a hot fluid to cold fluid across an impermeable wall. Fundamental of heat exchanger principle is to facilitate an efficient heat flow from hot fluid to cold fluid. This heat flow is a direct function of the temperature difference between the two fluids, the area where heat is transferred, and the conductive/convective properties of the fluid and the flow state. This relation was formulated by Newton and called Newton's law of cooling, which is given in Equation (1).

$$Q = h \times A \times \Delta T \quad (1)$$

Where h= is the heat transfer coefficient [W/m^2K], where fluid's conductive/convective properties and the flow state comes in the picture,

A = is the heat transfer area [m^2], and

T = is the temperature difference [K].

Heat exchangers are one of the vital components in diverse engineering plants and systems. So the design and construction of heat exchangers is often vital for the proper functioning of such systems. It has been shown in [1] that the low temperature plants based on Linde – Hampson cycle cease to produce liquid if the effectiveness of the heat exchanger is below 86.9%. On the other hand in aircrafts and automobiles, for a given heat duty, the volume and weight of the heat exchangers should be as minimum as possible.

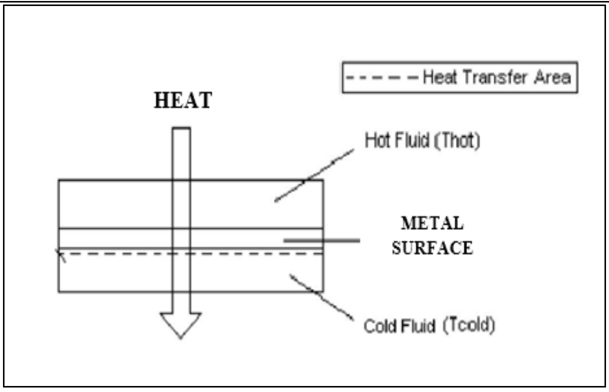


Fig 1: Shows the Basic Heat Transfer Mechanism.

1.1 Objectives of the Study

Several researches reported a similar trend for interrupted, perforated and serrated surfaces, attributing the improvement to the restarting of the thermal boundary layer after each interruption. In the light of the above, the present work focused on

1. Literature study related to heat transfer through perforated fins.
2. The main objective of the present study is to investigate the effect of introducing circular perforations on heat transfer enhancement on a vertical rectangular fin subjected to natural convection through ANSYS.
3. The modified fin i.e. perforated fin is compared to a corresponding solid fin in terms of temperature.

2. SOURCE OF DATA AND EXPERIMENTAL RESULTS

2.1 Source of Data

Science direct paper of “Enhancement of natural convection heat transfer from the rectangular fins by circular perforations” by Wadhah Hussein Abdul Razzaq Al- Doori. In which the experiments were carried out in an experimental facility that was specifically designed and constructed for this purpose.

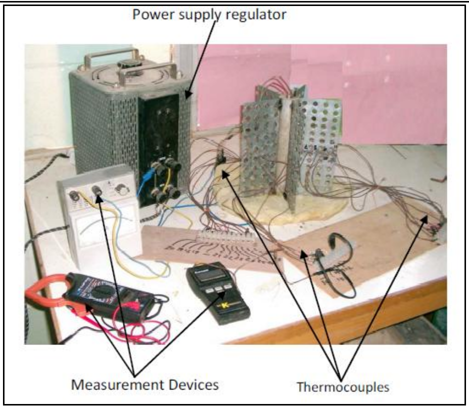
Fig 1 shows view of the experimental apparatus. The experimental setup includes a heat sink supplied with heating elements and data acquisition system. The heat is generated within the heat sink by means of one heating element power of 670W. All the experimental data are recorded by the data acquisition system. The heat sink chosen for experiments are aluminum cylinder of 50.8mm diameter and 270mm length (Fig 2). One hole was drilled in the cylinder in which one heating element was pressed. The power supplied by heating element was 670W. Five aluminum straight fins were fitted radially. The fins are 100mm long, 270mm wide and 2mm thick. These fins were divided into five groups as Table 1.

Case	Perforated fins diameter (mm)	Number of perforation per fin
1	12	24
2	12	32
3	12	40
4	12	48
5	12	56

Table 1: Five Cases of Perforated Fins Diameter with Number of Perforation per Fin.

2.2 Experimental Data

A variable transformer of type 50B with input 220V and 50-60Hz and output 0-240V, 20A and 7.5kVA were used to regulate the voltage supplied to the heating elements. The experimental data were measured by twenty seven calibrated thermocouples of type-K to measure the temperature at different locations. One thermocouple fixed on the outside diameter of the aluminum cylinder in order to measure the base temperature of the fin. One thermocouple is used to measure air temperature. Twenty five of thermocouples were divided five fins equally. Each thermocouple was fixed to the surface of the test fin at equal space (20 mm) locations along the fin length. The apparatus was allowed to run for about 70 minute, until the steady state was achieved. The recording of temperature was begun after steady state had been reached.



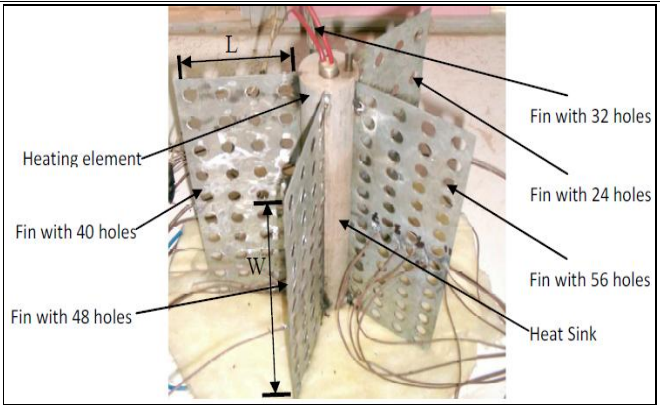
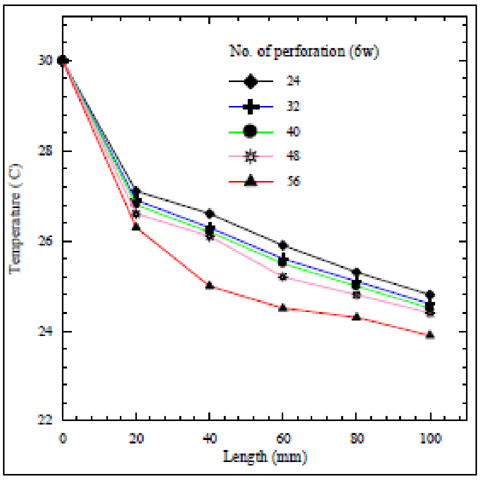


Fig 2: Experimental Apparatus. Fig 3: View of the Heat Sink.

2.3 Experimental Results-Thermocouple Data for Different Power Levels

For different plates of multiple perforations, temperature was measured using thermocouples. Experiment was conducted at multiple power levels. The thermocouple results are shown below.



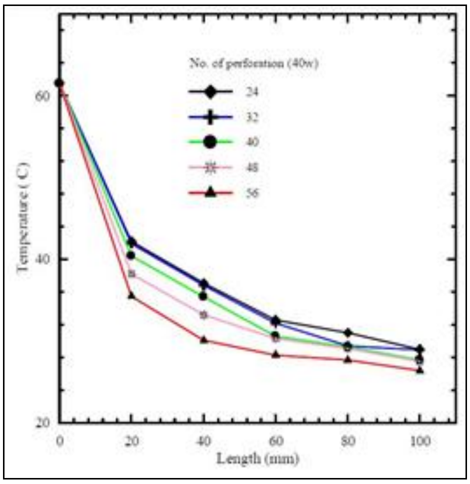


Fig 4: Results of 6W. Fig 5: Results of 40W.

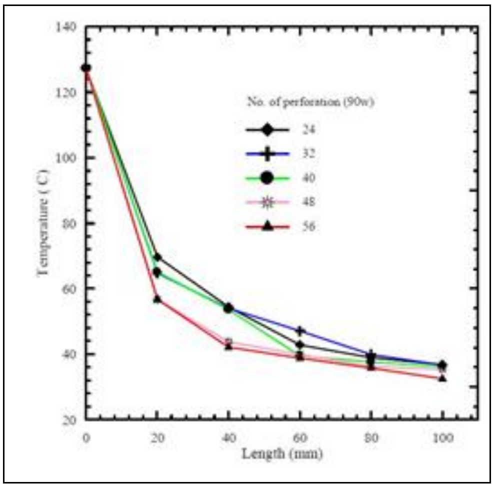


Fig 6: Results of 90W.

3. GEOMETRY AND FE MODELLING

3.1 Geometry Details

Model is created using Solid works software. Dimensions are same as the experimental setup of source data [38] which is explained above. In the model five rectangular fins with different number of circular perforations are arranged in rectangular array as shown in fig7.

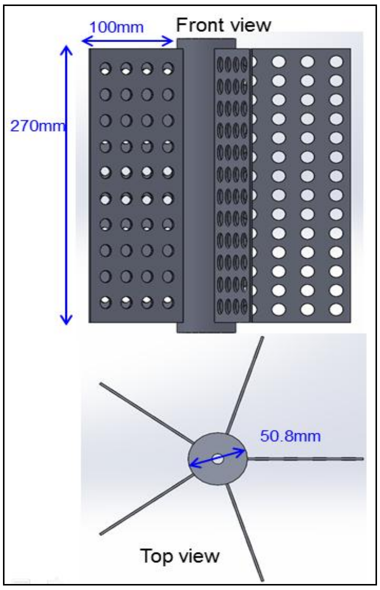


Fig 7: Front and top view of Geometry.

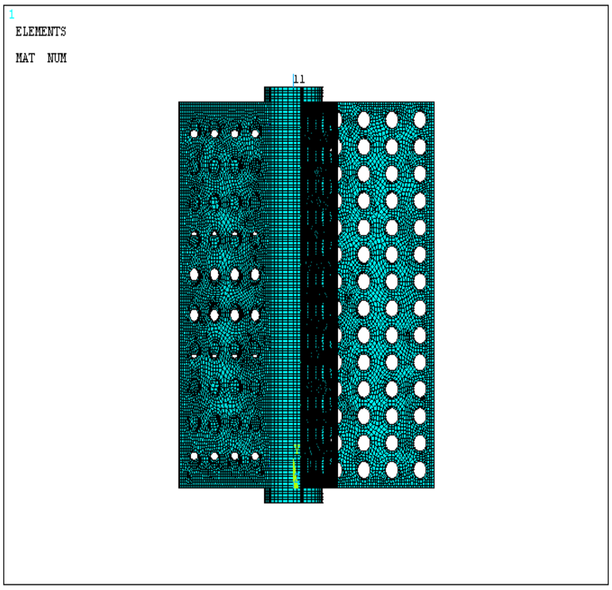


Fig 8: FE model of the Geometry.

3.2 FE Modelling

Geometry was imported to ANSYS and several volume cut were performed to make it meshable. Good quality hexahedral mesh is performed. An overall mesh density of 2mm is chosen for better accuracy which generated 198368 Number of Nodes and 240017 no of Elements. The FE model is as shown in the above fig 8.

3.3 Boundary Condition

HTC can be calculated using vertical plate correlation of free convection. But, because of perforations, boundary layer detachment & re-attachment phenomenon occurs. So, HTC is more compared to vertical plate HTCs. Correlation from literature [1, 2] is used for estimating HTCs. Below is the summary of HTC calculation for different power levels of experiment.

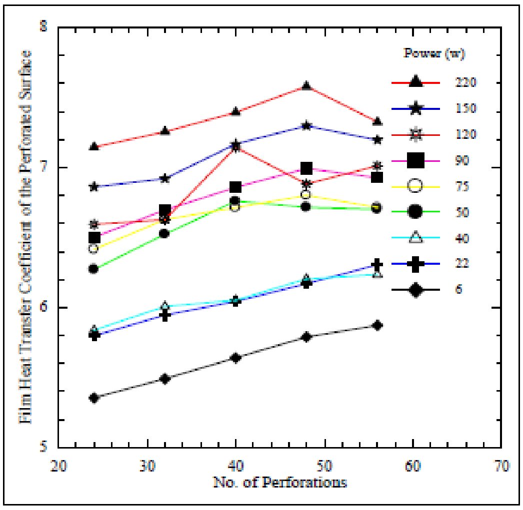


Fig 9: HTC Calculation for Different Power Levels of Experiment.

Table captions appear centered above the table in upper and lower case letters. When referring to a table in the text, no abbreviation is used and "Table" is capitalized.

4. GEOMETRY AND FE MODELLING

Cylinder & plate will have sharing nodes. This enables heat transfer from cylinder to plate & vice versa. But, after performing certain iterations, it is understood that this is not possible due to below reasons.

In the experiment, plates are welded to cylinder only at two locations (just to hold). So, heat transfer mechanism is captured based on "thermal contact phenomenon". Power source in experiment was simulated as nodal temperatures in simulation. ID areas of cylinder are applied with base temperatures. Source temperature varies as per each test condition

4.1 FE and Experimental Results Comparison

Thermocouple locations are selected based on the experimental setup. Below figure shows the snapshot highlighting nodal locations used in the analysis.

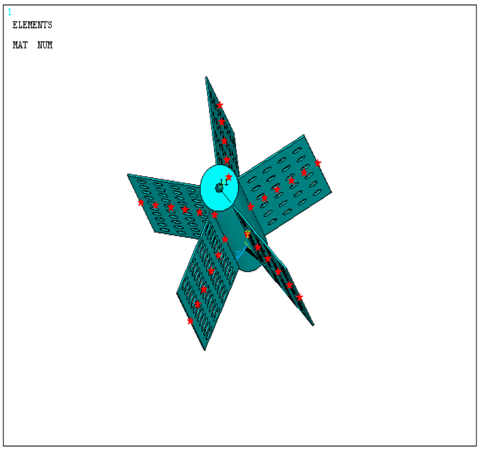


Fig 10: Thermocouple Location

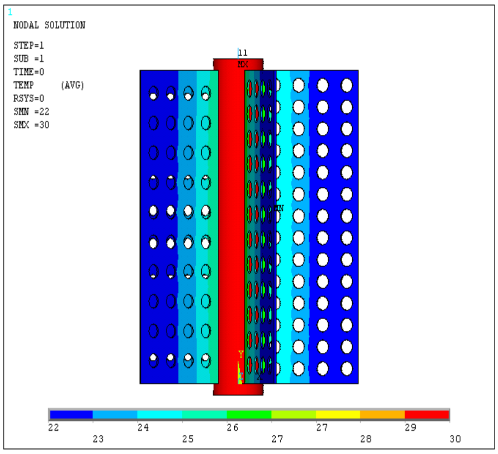


Fig 11: Temperature Plots.

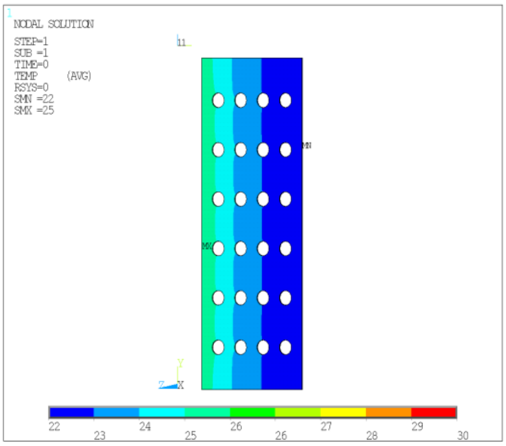


Fig 12: Temperature Plots of plate with 24holes.

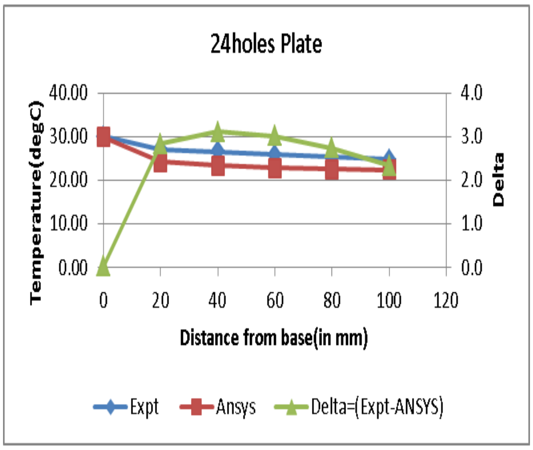


Fig 13: Results Comparison for plate with 24holes.

From the above pic, it is clearly seen that the experimental and FE results are matching closely with in+/-3deg, this is clearly shown in the above fig 13.

Since the experimental and FE results are closely matching, same approach has been adopted for the fallowing iteration. This thesis 3 iteration has been carried out, they are as listed below.

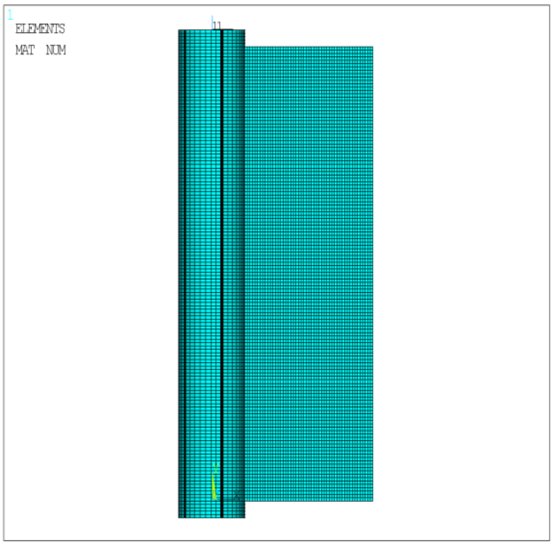
Iteation#1: Non-perforated plate "90W" power with node-to-node connectivity.

Iteation#2: Analysis with different perforated plates in case of 90W power level.

Iteation#3: Analysis with increased perforation diameter in case of 90W power level in case of 52holes plate.

4.2 Iteartion#1

In this iteration the perforation holes has been removed and the analysis is been carried out with same mesh density, so that the results variation due to mesh density can be avoided.



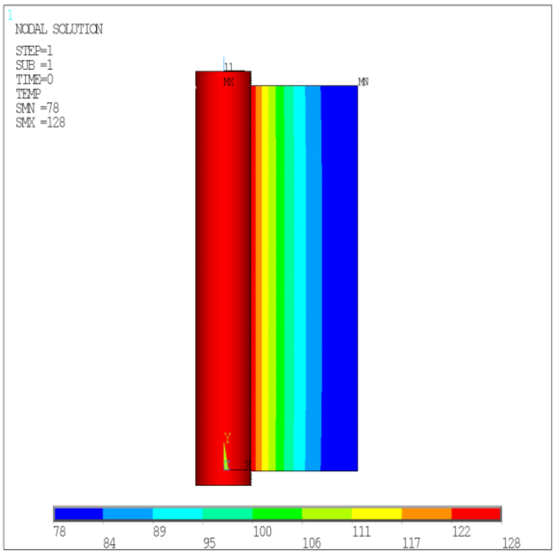
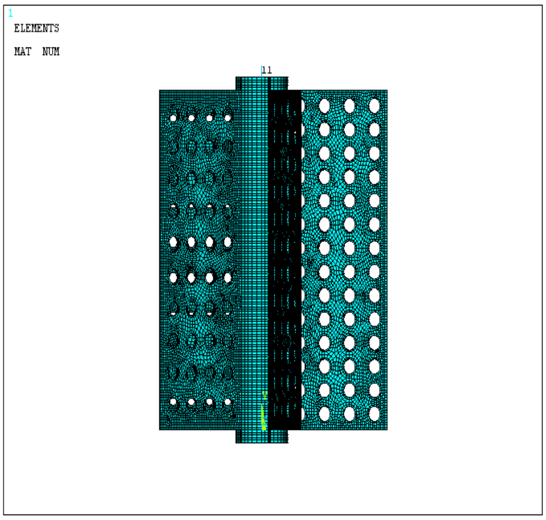


Fig 14: FE model of non-perforated plate. Fig 15: temperature plot of non-perforated plate.

It can be concluded that the non-perforated fins have more temperature at their trailing edge and hence better iteration need to carried out. Further, heat transfer can be increased by adding perforation to the plate.

4.3 Iteartion#2

In the below model, node-to-node connectivity is maintained for the heat transfer b/w cylindrical source & plate



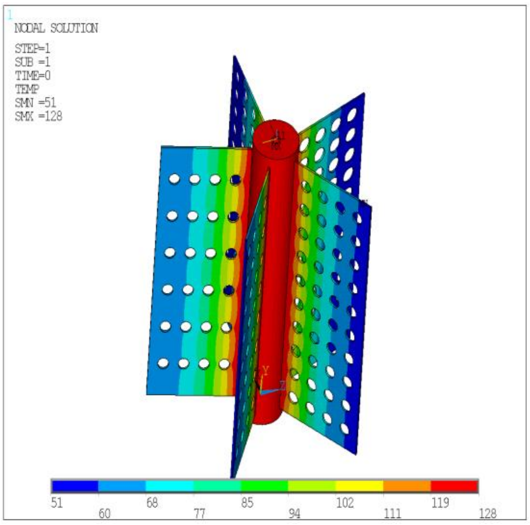


Fig 16: FE Model of Different Perforated Plate. Fig 17: Temperature Plot of Different Perforated Plate.

By comparing the results of iteration #1 & #2 (i.e. non-perforation & with perforation), it is explicitly visible that the perforation can increase the heat transfer. By comparing the thermal results of different perforation plates, it can be concluded that heat transfer is directly proportional to number of perforations of the plate. Further, optimization iterations are performed to increase the heat transfer.

4.4 Iteartion#3

Hole diameter is increased from 12mm to 14.4mm which accounts to 20%. Good quality hexa mesh is performed

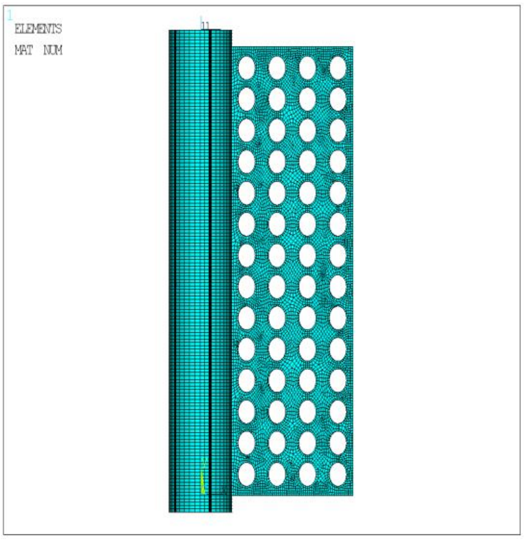


Fig 18: FE Model of Different Perforated Plate.

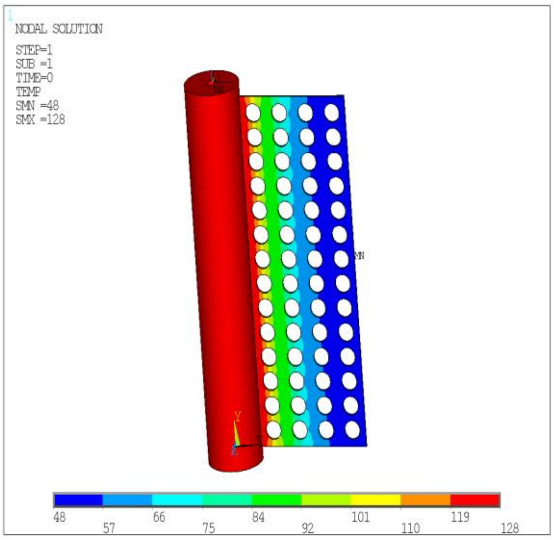


Fig 19: Temperature Plot of Different Perforated Plate.

By comparing the results iter#2 with iter#3, it can be observed that the increase of hole diameter further increases the heat transfer. This directly suggests that heat transfer depends upon on the amount of area which is exposed to ambient environment.

5. CONCLUSION

- Design & simulation model of experimental setup of plates with different perforation was developed.
- Heat transfer coefficients are calculated.
- Thermal contact phenomenon is modelled in a more realistic manner.
- Experimental temperatures of plates with different perforation are matched with in +/-10% of source temperatures.
- Later, these results are compared with non-perforated plate which shows a significantly higher temperatures.
- This confirms the increase of heat transfer & reduction in fin temperatures using perforations.
- Changing the hole pattern doesn't have any influence on metal temperatures.
- Change of perforation type with equivalent cross sectional area doesn't change the metal temperatures much.
- Increase of circular perforation diameter increases the convection surface area & decreases the fin temperature. This quantitative difference depends upon the base temperature or input heating power.

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