Numerical and Experimental Studies on Thermal Performance of Split-Hexahedral Fins under Natural Convection

Kaustubh Pande, Omkar Siras

***Abstract*—The component surface temperature of the electronic devices plays a major role in the performance of these devices, thus the need to keep these surfaces within the permissible temperature limits. Fins, which provide the heat removal mechanism under the natural convection conditions, had been researched very well for optimal shape, location. This research focussed on introducing spilt in the fins and its influence over the heat removal process. Fins of hexahedral shape were chosen for this study. The split distance was varied for three configurations [δ =0.083, 0.167, 0.25, 0.333]. The investigation was extended to varying operating thermal conditions [τ = 30, 50, 70 and 90 K]. Experimental and Numerical studies (CFD simulations) were conducted for these configurations. ANSYS Work Bench modules were utilized for performing the CFD simulations. The heat transfer rate from the heat sinks for these configurations was compared. It had been observed that the splitting of the fins resulted in ~40% increase in the heat transfer rate. Also, the results from CFD simulations were in close agreement with the experimental data.**

Index Terms:Extended Surface, Natural Convection Heat Sink, CFD Modeling, Hexahedral fins

I. INTRODUCTION

THE performance expectation from the modern day electronic devices had been on the rise. The component surface temperature plays a major role in the performance of these electronic devices. Its essential to design an efficient heat removal mechanisms for these components. Natural convection methods which don't require any moving components had been a preferable method among the designers. Natural convection methods applies the extended surfaces or fins for increasing the available heat transfer area and hence the improved heat removal process.

Fins had been researched very well for their optimal shape, location, arrangement e.t.c. The heat transfer rate from the heat sinks under the natural convection could be enhanced by designing the fins to improve the fluid motion. The hexahedral shaped fins would induce higher flow turbulence as compared to the conventional pin fins had been chosen for this research work.

This research focused on introducing spilt in the fins and its influence over the heat removal process. By splitting the fins, the surface area for the heat transfer area was also increased which was expected to increase the heat transfer rate. The figure 1 shows the comparison between the solid fins – without any splitting – and the fins with split.

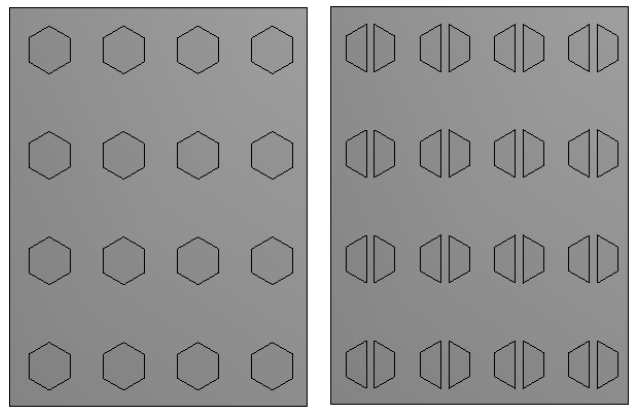

Fig.1 Geometrical description of Split Hexahedral fins

II. LITERATURE REVIEW

Rossano Comunelo**[1]** had studied the influence of neighborhood of fins under the natural convection field using vertical plates using ANSYS CFX for the CFD simulations. The pin-fins, fins with circular cross-section, were applied heat removal mechanism in the electronic packaging by Waqar Ahmed Khan**[2]**. The enhancement of fin effectiveness under the natural convection was investigated by varying the perforations on the fins by Gaurav A Chaudhari[3]. The plate fins, rectangular cross-sectional area, were considered by the authors in this experimental study. An annular composite fin for dissipating heat in the radial direction was studied experimentally by Padma Lochan Nayak[4]. The authors had also investigated the impact of surface coatings on the fin surfaces over the fin effectiveness. The zinc surfaces coatings were compared with the fin configuration of without any surface coatings. Mangesh D Shend[5] had analyzed a radial heat sink for heat removal mechanism in LEDs under the natural convection field with experimental study. The natural convection field formed inside a square cavity with horizontal adiabatic walls and vertical isothermal walls was investigated by Himsar Ambarita[6]They had investigated the heat transfer enhancement due to the addition of baffles. Ana Cristina Avelar[8] had conducted numerical and experimental analysis for optimizing the space between the plates that were under the natural convection heat transfer field. The laminar, 2-dimensional numerical simulation was carried out by the authors with the periodicity boundary condition for

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simplifying the simulation domain. Fins with various shapes for improving the heat transfer characteristics had been researched by multiple authors. Hamid Reza Goshayeshi[9] had investigated triangular shaped fins under the natural convection flow conditions over the influence on heat transfer rate. In an experimental investigation by Murtadha Ahmed[10], the square shaped fins with multiple variants – solid, hollow, perforated - were studied for the flow conditions corresponding to Ra = 12.45 X 106 to Ra = 58.59 X 106. The fins were attached to the base plate which was covered with two layers of insulation to prevent any heat loss. Electrical heater was used to supply the energy to the base plate. Sandhya Mirapalli[11] had employed triangular shaped fins and rectangular fins for heat removal mechanism from a cylinder that was at 200 C to 600 C. In their experimental investigation, the authors had also varied the length of the fins from 6 cm to 14 cm. Mehran Ahmadi[12] had, in their study, investigated the influence of the plate-fin arrangement over the natural convection heat transfer from a vertically heated plate. They had conducted the steady-state, 2-Diemensional CFD simulations using ANSYS FLUENT while the results were validated using their experimental work. The radiation heat transfer from these cases had been neglected. The application of natural convection heat transfer methods for removing the heat from LED panels had been explored by Jin-Cherng Shyu[13]. In their experimental study, 270 evenly distributed 1-W LEDs with an aluminum plate-fin array was considered. In their experimental work, Anagha Gosavi[14] had compared the heat transfer enhancements by changing the plate-fin configurations – continuous array, fin array with 40% staggering, fin array with 50% staggering. The thermal conditions were varied from 25 W to 125 W with an increment of 25 W. Saurabh Bahadure[15] had studied using the theoretical as well as experimental methods on enhancing the heat transfer of a pin-fin heat sink with four fin configurations – solid pin-fin, pin-fin with one perforation, pin-fin with two perforations, pin-fin with three perforations.

III. PROJECT DEFINITION

The heat sink base plate dimension was 150 mm X 200 mm. The heat sink contained a total of 16 fins arranged with 'in-line' fashion. The height of each fin was 50 mm. Figure 2 shows the heat sink with split hexahedral fins.

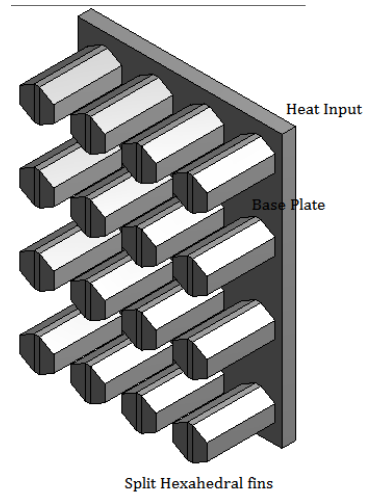

Fig.2 Split Hexahedral fins

The distance between the fins, classified as pitch, was maintained constant in this study. The variations in the fin' longitudinal and the lateral pitch will also have major influence the natural convection flow field and the resulting thermal performance. However, this had not been the scope of this research work and was investigated in this study.

A non-dimensional parameter, δ, was introduced to define the split distance. The definition for the same had been provided below.

$$\delta = \frac{split\ distance}{Hexagon\ side\ length}$$

In this research, the fin geometries with δ = 0.083, 0.167, 0.25 and 0.333 were chosen for the study. Higher values of delta could mean the split-fins would behave as an individual fins. So, the lower delta configurations were chosen.

Table 1 Geometrical configurations

Configuration	Non-dimension split distance, δ
Base Model	--
Case A	0.083
Case B	0.167
Case C	0.25
Case D	0.333

The figure 3 and 4 shows the split hexahedral fin geometry for all the configurations.

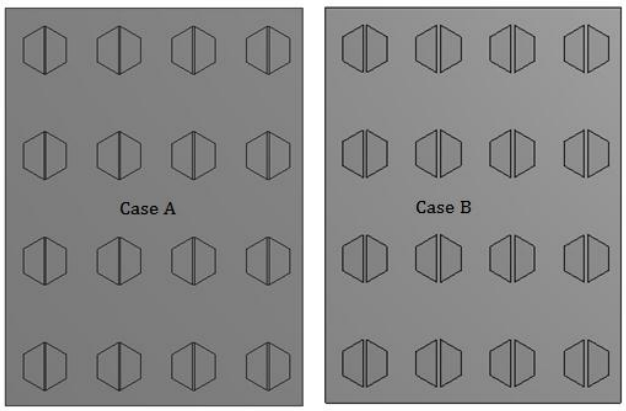

Fig.3 Split Hexahedral fins [Case A & B]

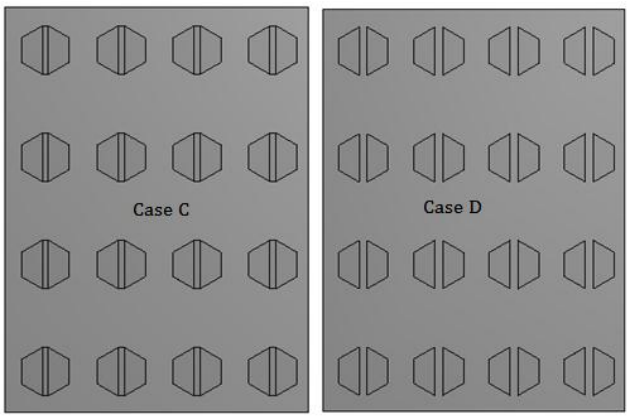

Fig.4 Split Hexahedral fins [Case C & Case D]

Heat sinks must be verified for the performance for various operating conditions. The electronic components may operate at different temperatures. The following non-dimensional parameter was defined for characterizing the operating conditions. τ = Tsurface – Tambient. The study was conducted for τ = 30, 50, 70, 90 K in this work.

IV. EXPERIMENTAL ANALYSIS

The heat sink assembly that contains the base plate and the fins were manufactured using Aluminum as material. Heat was supplied to the heat sink using the electrical energy. A total of 3 thermocouples were placed at the rear side of the heat sink. The assembly was kept in vertical position during the study. Steady state conditions in the experiment were ensured before the readings were observed. The temperature readings from the thermocouples were noted as well as the readings from the Voltmeter and Ammeter.

V. NUMERICAL SIMULATIONS

The heat sink geometry that contains the base plate and the fins were generated using ANSYS Design Modeler. The computational boundaries were placed away from the heat sinks for preventing any 'flow-reversal' phenomena during the simulations.

High quality hexahedra mesh elements were generated in the computational volume using ANSYS WorkBench V16.0. The total mesh count in the computational volume was approximately 1,250,000. Figure 6 provides the mesh distribution on the heat sink surfaces. The region near the fin surfaces would encounter sharp flow and thermal gradients. In order to predict these flow and thermal gradients, sufficient inflation layers were provided [Fig 7].

The heat input was specified using the 'constant wall temperature' boundary condition in the ANSYS FLUENT. Heat transfer from the computational boundaries, apart from the top and bottom surfaces, was prevented to reproduce the experimental conditions. These were achieved by modeling them as adiabatic walls.

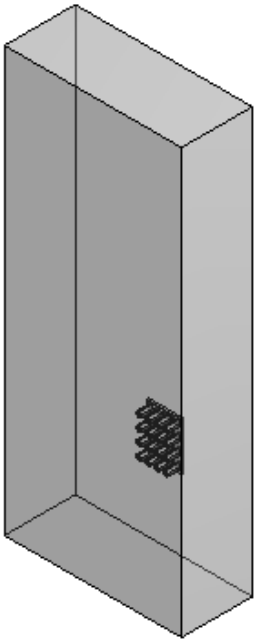

Fig.5 Computational volumes for the CFD simulations

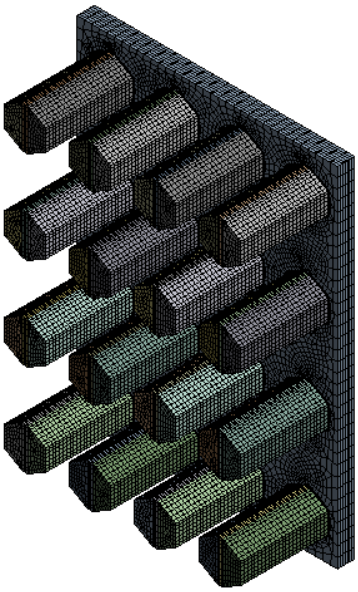

Fig.6 Mesh distribution on the Heat sink surfaces

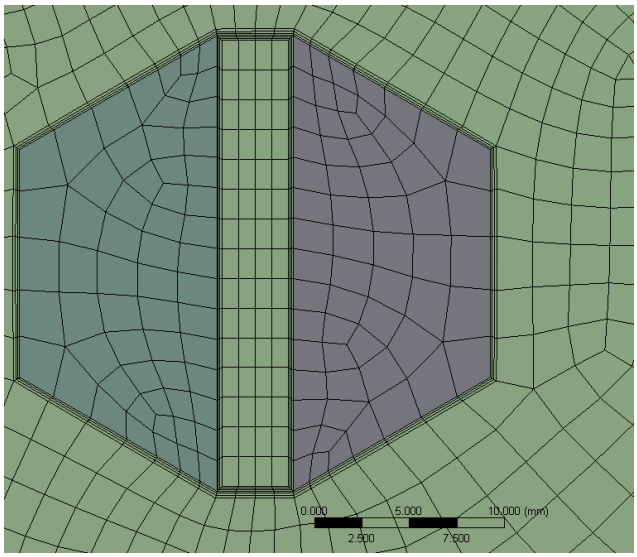

Fig.7 Inflation layers surrounding the split-hexahedral fins

Atmospheric conditions were imposed for the top and bottom surfaces of the computational volume. The simulations were performed until the energy balance between the inlet, outlet and the heat input surfaces. The same simulation procedure was followed for every configuration.

VI. VALIDATION

A comparative study between the experimental and CFD simulations for the solid hexahedral fins were conducted. The thermal conditions were kept identical. The results are plotted in Figure 8.

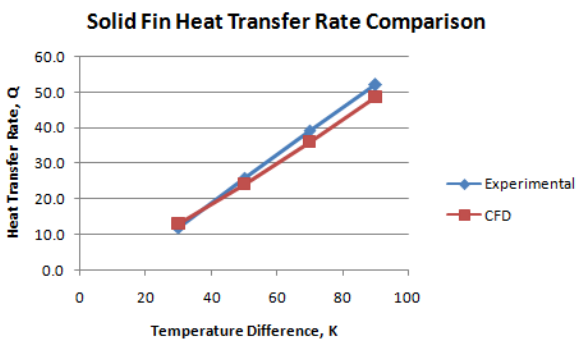

Fig.8 Validation study

It can be observed that the heat transfer rate prediction from both methods were in close agreement. The differences in results between these two approaches were within 10%. Based on this, it can be concluded that the validation for the numerical approach had been obtained. Similar trends in results comparison for the remaining configurations were observed. Hence, only the results from the numerical simulations had been discussed further.

VII. RESULT AND DISCUSSIONS

IN FIGURE 9, THE HEAT TRANSFER RATE PREDICTED FROM THE CFD SIMULATIONS FOR EACH CONFIGURATION HAD BEEN PLOTTED.

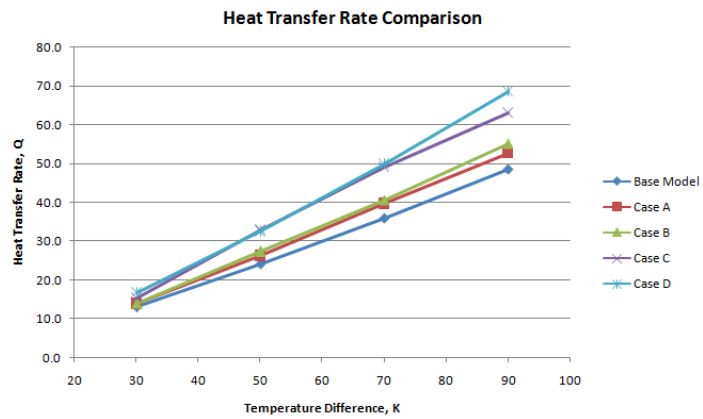

FIG.9 COMPARISON OF HEAT TRANSFER RATE FOR ALL CONFIGURATIONS

FROM THE GRAPH ON FIG 9, THE HEAT TRANSFER ENHANCEMENT DUE TO THE INTRODUCTION OF SPLITS IN THE FINS WAS ESTABLISHED. THE IMPROVEMENT FOR THE CASE A AND CASE B IN COMPARISON WITH THE SOLID FINS (BASE MODEL) HAD BEEN MARGINAL (~10%).

HOWEVER, AS THE SPLIT DISTANCE WAS INCREASED, THERE WAS A SUBSTANTIAL IMPROVEMENT IN HEAT TRANSFER ENHANCEMENT FOR THE CASE C AND CASE D (~40%) IN COMPARISON WITH THE BASE MODEL.

ANOTHER INTERESTING OBSERVATION WAS BOTH CASE C AND CASE D EXHIBIT IDENTICAL HEAT TRANSFER ENHANCEMENT FOR MOST OF THE OPERATING CONDITIONS. THIS COULD BE OBSERVED IN THE TABLE 2.

TABLE 2 HEAT TRANSFER RATE ENHANCEMENT COMPARISONS

HEAT TRANSFER RATE, WATTS			
TEMPERATURE DIFFERENCE, K	BASE MODEL	CASE C	CASE D
30	13.0	15.4	16.8
50	24.1	32.8	32.5
70	36.0	49.2	50.0
90	48.5	63.1	68.6

THIS MIGHT INDICATE THAT THE CASE C COULD BE HAVING THE OPTIMAL SPLIT DISTANCE. HOWEVER, FURTHER STUDIES WOULD BE NEEDED TO VERIFY THIS.

THE POTENTIAL CAUSES FOR THIS HEAT TRANSFER ENHANCEMENT HAD BEEN DISCUSSED WITH THE HELP OF TEMPERATURE AND VELOCITY CONTOUR PLOTS. THESE PLOTS WERE OBTAINED AT THE MID-SECTION OF THE FINS.

IN THE FOLLOWING IMAGES, THE TEMPERATURE CONTOURS HAD BEEN PLACED AT THE LEFT SIDE AND THE VELOCITY CONTOURS HAD BEEN ON THE RIGHT. THESE IMAGES WERE TAKEN FROM THE SIMULATIONS CORRESPONDING TO THE TEMPERATURE DIFFERENCE T = 70 K.

THE TEMPERATURE CONTOURS HAD BEEN PLOTTED FOR A COMMON SCALE OF 303 K TO 373 K WHILE THE VELOCITY CONTOURS WERE COLORED FOR A SCALE OF 0 – 0.5 M/S.

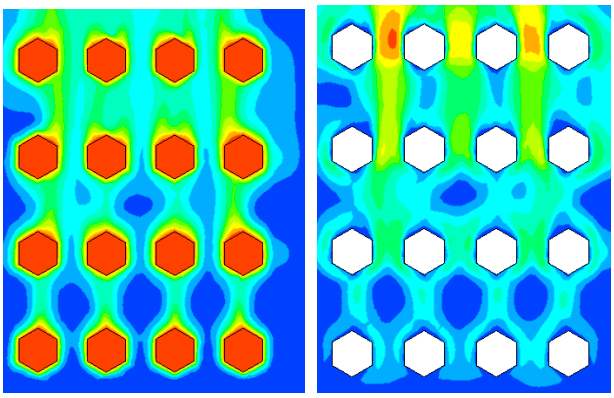

FIG.10 TEMPERATURE AND VELOCITY CONTOURS FOR SOLID FINS (BASE MODEL)

IN THE BASE MODEL, THE FLUID MOTION SURROUNDS THE FIN SURFACES AND BECAUSE OF THIS THE HEAT FROM THE HIGH TEMPERATURE FIN SURFACES WERE CARRIED BY THE FLUID. THE HEXAGONAL SHAPE INDUCES CONSIDERABLE FLUID MOTION AS CAN BE SEEN FROM THE VELOCITY CONTOURS

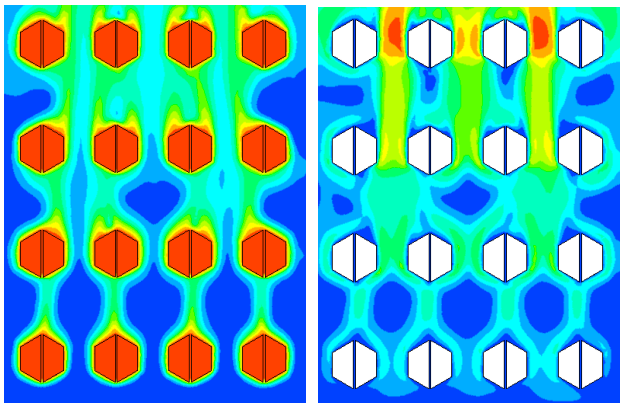

Fig.11 Temperature and Velocity contours for Case A

THE FLOW PROFILE FOR THE CASE A HAD LOT OF SIMILARITY WITH THE BASE MODEL LIKE THE STAGNATION ZONES BETWEEN THE BOTTOM TWO ROWS. THE NARROW SPLIT BETWEEN THE FINS WAS NOT SUFFICIENT ENOUGH FOR THE FLUID TO PASS THROUGH. THIS COULD BE OBSERVED FROM THE NEAR ZERO VELOCITY IN THOSE REGIONS IN THE VELOCITY CONTOUR PLOTS.

THERE'S A MARGINAL CHANGE IN THE FLUID FLOW PATTERN IN CASE B AS COMPARED TO THE BASE MODEL EVEN THOUGH THERE WERE SIMILARITIES OBSERVED. HOWEVER, WITH THE INCREASE IN THE SPLIT DISTANCE, THE FLUID MOTION WAS OBSERVED BETWEEN THE FINS, ALBEIT IN LOWER MAGNITUDE.

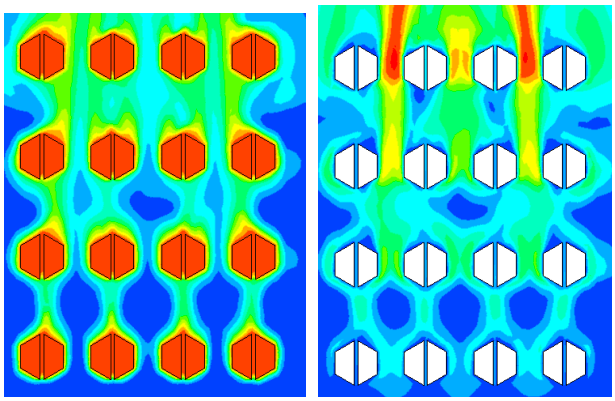

FIG.12 TEMPERATURE AND VELOCITY CONTOURS FOR CASE B

HOWEVER, THERE'S BEEN A SIGNIFICANT CHANGE FLOW PROFILE FOR THE CASE C. HERE, THE DISTANCE BETWEEN THE FINS WERE SUBSTANTIAL AND RESULTING IN ENHANCED FLUID MOTION IN THESE GAPS. THIS ENSURED THAT THE COLD AIR WERE ACHIEVING CONTACT WITH THE HOT FIN SURFACES, PROMPTING HEAT TRANSFER BETWEEN THESE TWO MEDIUMS. THE OVERALL IMPACT IS REMARKABLE IMPROVEMENT IN THE HEAT TRANSFER RATE (~30 - 40%)

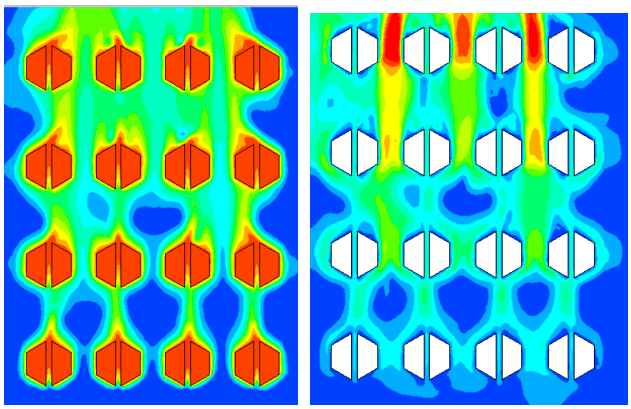

FIG.13 TEMPERATURE AND VELOCITY CONTOURS FOR CASE C

AN IDENTICAL FLOW PATTERN WAS OBSERVED FOR THE CASE D AS WELL. THE SPLIT DISTANCE NOW CLEARLY ACTING AS A CHANNEL FOR THE COLD AIR TO PASS THROUGH. THIS WAS QUITE EVIDENT FROM THE VELOCITY CONTOUR PLOTS.

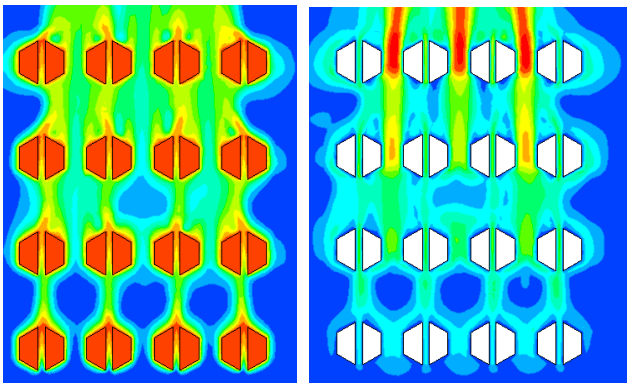

FIG.14 TEMPERATURE AND VELOCITY CONTOURS FOR CASE D

VIII. CONCLUSIONS

THE DISCUSSIONS BASED ON THE RESULTS OBTAINED FROM THE EXPERIMENTAL STUDIES AND NUMERICAL SIMULATIONS LEADS TO THE FOLLOWING CONCLUSIONS

1) FOR THE NATURAL CONVECTION STUDIES, THE RESULTS OBTAINED FROM THE EXPERIMENTAL APPROACH AND THE CFD SIMULATIONS WERE IN ACCEPTABLE LIMITS.

2) THE INTRODUCTION OF SPLITS ON THE FINS AND THE RESULTING NARROW PASSAGE WERE PRODUCING HEAT TRANSFER ENHANCEMENT FOR THE HEAT SINKS UNDER THE NATURAL CONVECTION FIELD.

3) THE HEAT TRANSFER ENHANCEMENT WAS OBSERVED TO BE INCREASING WITH THE INCREASE IN THE SPLIT DISTANCE.

4) THIS WAS OBSERVED FOR VARIOUS OPERATING CONDITIONS AND THE SIMILAR TREND IN THE HEAT TRANSFER CHARACTERISTICS WAS NOTED

5) NEARLY 40% IMPROVEMENT IN HEAT TRANSFER RATE WAS ACHIEVED IN THE SPLIT HEXAHEDRAL FINS AS COMPARED TO THE SOLID FINS.

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