CFD ANALYSIS OF HYBRID HEAT SINK

Team members:
Smit Agrawal(20BSM053)
Yagnesh Shetty(20BSM060)

Mentor
Dr. Tushar Choudhary
Assistant Professor

Introduction

In recent years, the demand for high-performance electronic devices has surged, leading to increased power densities and heat generation in compact systems. Efficient thermal management has become critical to ensure the reliability and longevity of these devices. One of the promising solutions in thermal management is the use of heat sinks, which are designed to dissipate heat effectively from electronic components. Among the various types of heat sinks, hybrid heat sinks, which combine different thermal management techniques, have shown significant potential in enhancing heat dissipation capabilities.

This project focuses on the Computational Fluid Dynamics (CFD) analysis of a hybrid heat sink, utilizing ANSYS software to evaluate its thermal performance under various conditions. The primary objective is to explore the efficiency of the hybrid heat sink when subjected to different heat inputs and to investigate the role of Phase Change Materials (PCMs) in enhancing its thermal performance. PCMs are known for their high latent heat storage capacity, which can be leveraged to absorb and release heat during phase transitions, thereby stabilizing the temperature of the electronic components.

The study involves a detailed examination of the melting and solidification processes of PCMs within the hybrid heat sink. By employing contour plots generated through ANSYS simulations, we can visualize the temperature distribution and phase change phenomena, providing valuable insights into the thermal behavior of the heat sink under varying operational scenarios.

The specific goals of this project are as follows:

- To design a hybrid heat sink model incorporating PCMs.
- To conduct CFD simulations to analyze the thermal performance of the heat sink under different heat inputs.
- To evaluate the melting and solidification processes of the PCMs and their impact on heat sink efficiency.
- To generate and interpret contour plots to understand the temperature distribution and phase transitions within the heat sink.

Literature review

Author and year	Journal name	Key findings
Shatikian, V., G. Ziskind, and R. Letan.(2005)	Numerical investigation of a PCM-based heat sink with internal fins.	They conducted a numerical investigation on a phase change material (PCM)-based heat sink with internal fins. Their study focused on analyzing the thermal performance of the heat sink and assessing the effectiveness of internal fins in enhancing heat transfer. The results indicated that the PCM-based heat sink with internal fins demonstrated improved thermal performance compared to conventional heat sinks, with significant reductions in temperature gradients and enhanced heat dissipation capabilities.
Hosseinizadeh, S. F., F. L. Tan, and S. M. Moosania.(2011)	Experimental and numerical studies on the performance of PCM-based heat sink with different configurations of internal fins.	They conducted experimental and numerical studies to further investigate the performance of PCM-based heat sinks with various configurations of internal fins. Their research aimed to optimize the design of the heat sink to achieve maximum heat transfer efficiency. The findings of their study provided valuable insights into the influence of different fin configurations on the thermal performance of the heat sink, highlighting the importance of fin geometry and spacing in enhancing heat dissipation.
Kandasamy, Ravi, Xiang-Qi Wang, and Arun S. Mujumdar.(2008)	Transient cooling of electronics using phase change material (PCM)-based heat sinks.	The study focused on the transient cooling of electronics using PCM-based heat sinks. Their study aimed to evaluate the effectiveness of PCM-based heat sinks in mitigating temperature fluctuations and ensuring thermal stability during transient cooling processes. The research findings indicated that PCM-based heat sinks offered significant advantages in managing transient heat loads, providing efficient thermal management solutions for electronic devices subjected to dynamic operating conditions.

Objectives

The primary objective of this project is to conduct a comprehensive Computational Fluid Dynamics (CFD) analysis of a hybrid heat sink, with a focus on evaluating its thermal performance under various operational conditions.

The specific objectives are as follows:

- Design and Model Development: To design a hybrid heat sink model incorporating Phase Change Materials (PCMs) and develop a detailed CFD model using ANSYS software.

- Thermal Performance Analysis: To analyze the thermal performance of the hybrid heat sink under different heat inputs, assessing its ability to dissipate heat effectively.

- PCM Behavior Evaluation: To investigate the melting and solidification processes of the PCMs within the heat sink and their impact on the thermal management capabilities.

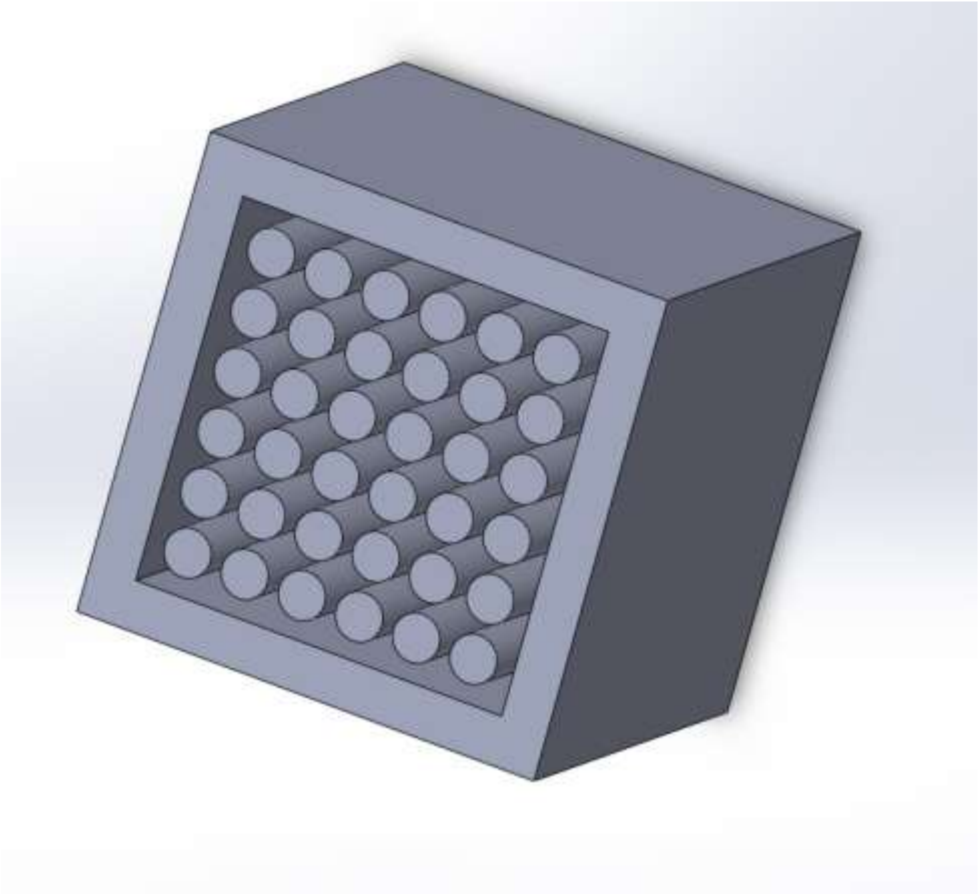
- Contour Plot Visualization: To generate and interpret contour plots that depict temperature distributions and phase transitions within the heat sink, providing insights into the thermal dynamics.

- Performance Optimization: To identify the optimal configurations and conditions that maximize the efficiency of the hybrid heat sink, offering practical recommendations for improving thermal management in high-power electronic devices.

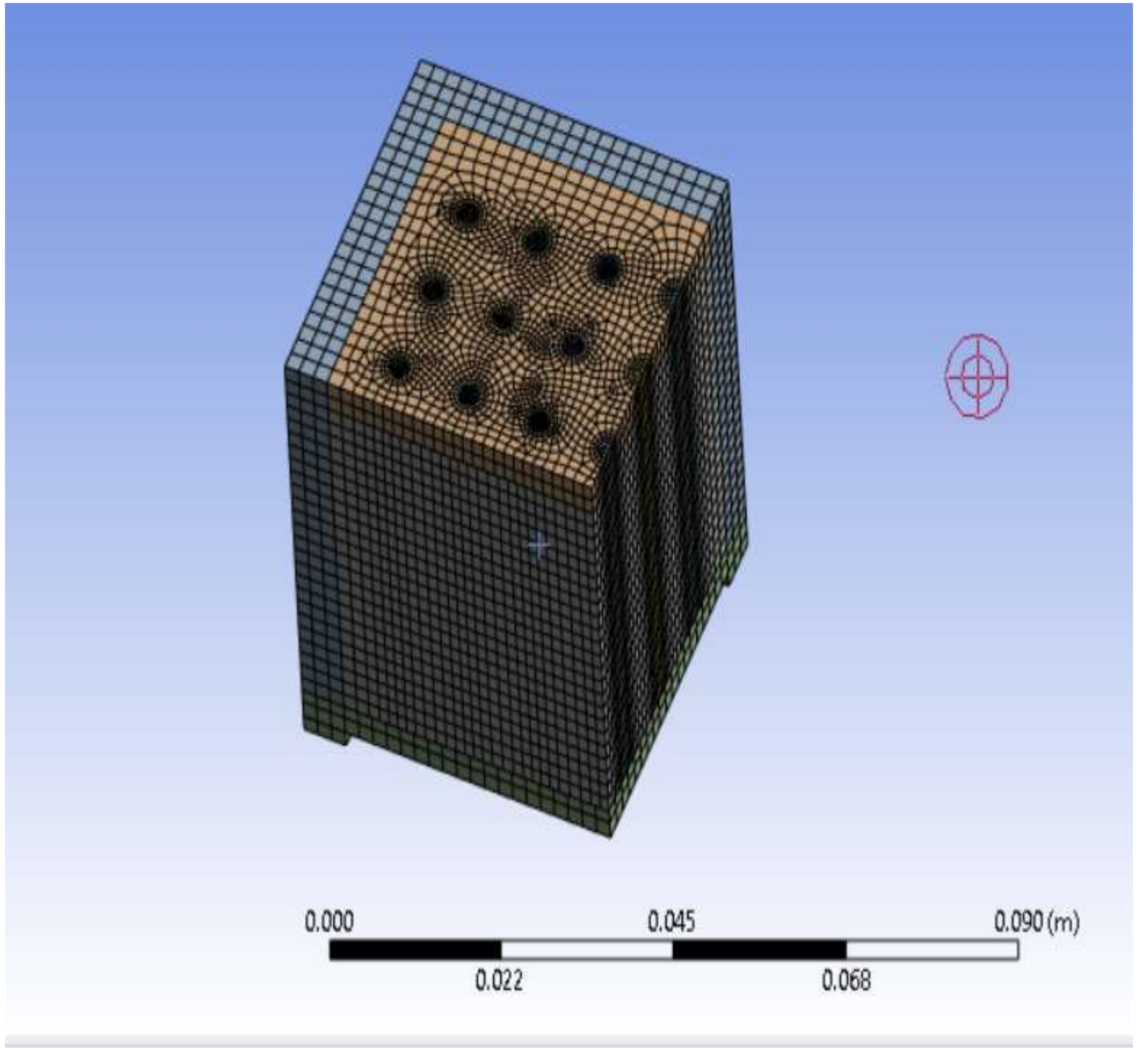
- Comparison and Validation: To compare the performance of the hybrid heat sink with traditional heat sinks and validate the simulation results with experimental data, ensuring the reliability of the findings.

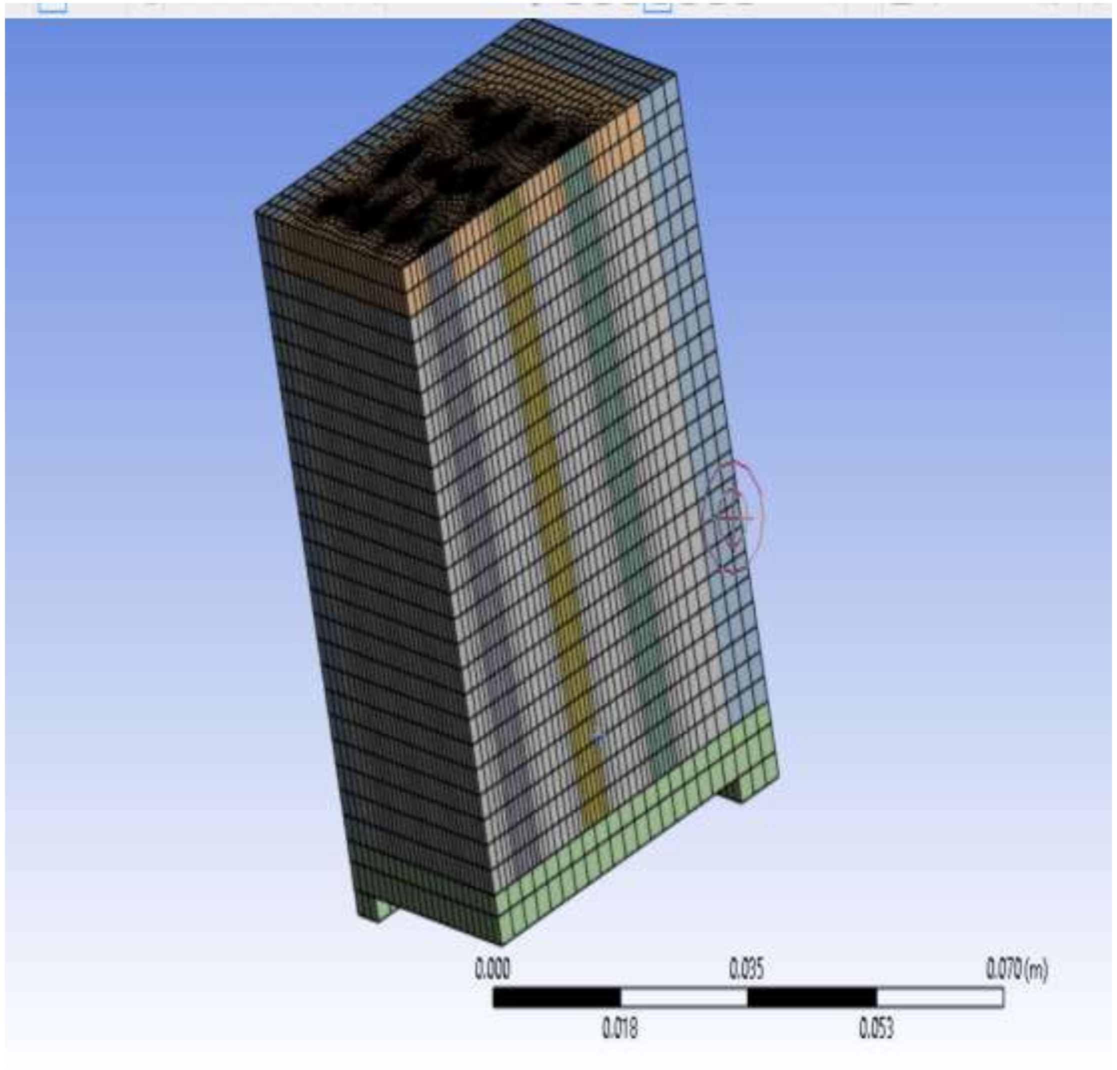
Experimental setup

3D MODEL FOR HEAT SINK



Mesh





Computational Fluid Dynamics Setup

CFD Model

The experimental study has been taken into consideration for choosing the geometrical and operational parameters for this investigation. Solidworks is used to generate a 3-D CFD model of the Hybrid Heat Sink with dimensions of 56 mm, 88 mm, and 88mm respectively. The base absorber plate of the heat sink with rectangle shape rib gap roughness. The lengths and radius of the fins are 50 mm and 7.5 mm respectively. The gap between fins is set at 10 mm to allow for thermal development of the flow before it leaves the test section. Other than the absorber plate, it is believed that the walls are smooth and insulated.

System Parameters

System parameters	Range/base values
Fins diameter	15 mm
Base plate width	4 mm
fins length	50 mm
fins gap	10 mm
Height of heat sink	56 mm
Length / Width of heat sink	88 mm

System Parameters

PCM properties	
Density(boussinesq)	1159 kg/m3
Viscosity	0.00252 kg/m-s
Solidus Temperature	352 K
Specific heat	1467 J/ kgK
Thermal conductivity	0.5 W/mK
Melting Heat	200000 J/kg
Liquidus Temperature	358 K

Grid Generation

Creation of a mesh grid is performed in the ANSYS Meshing module. To analyze the flow characteristics, the 3-D domain is divided into different components. Using standard “sizing” and “adaptive” functions, a 3d mesh of the pattern was created . The various meshing pattern applied on the model are :

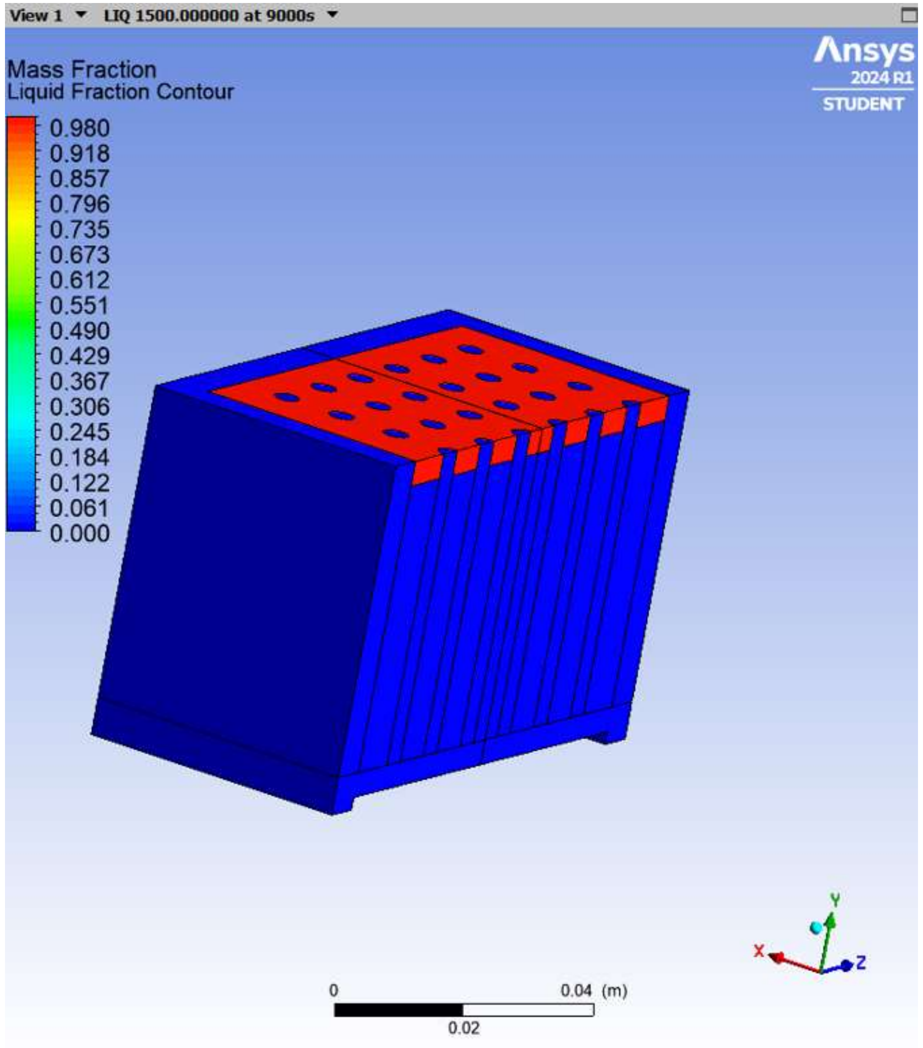
1) Sweep Method on Fins with 25 numbers of divisions.
2) Sweep Method on Side Walls with 25 divisions .
3) Sweep Method on PCM with 23 divisions .
4) Sweep Method on Air with 2 divisions .
5) Edge sizing on various edges with different parameters such as 19,22 divisions .
6) Face Meshing on the base plate of the heat sink .
7) Multizone Meshing on the base aluminum body of the heat sink .

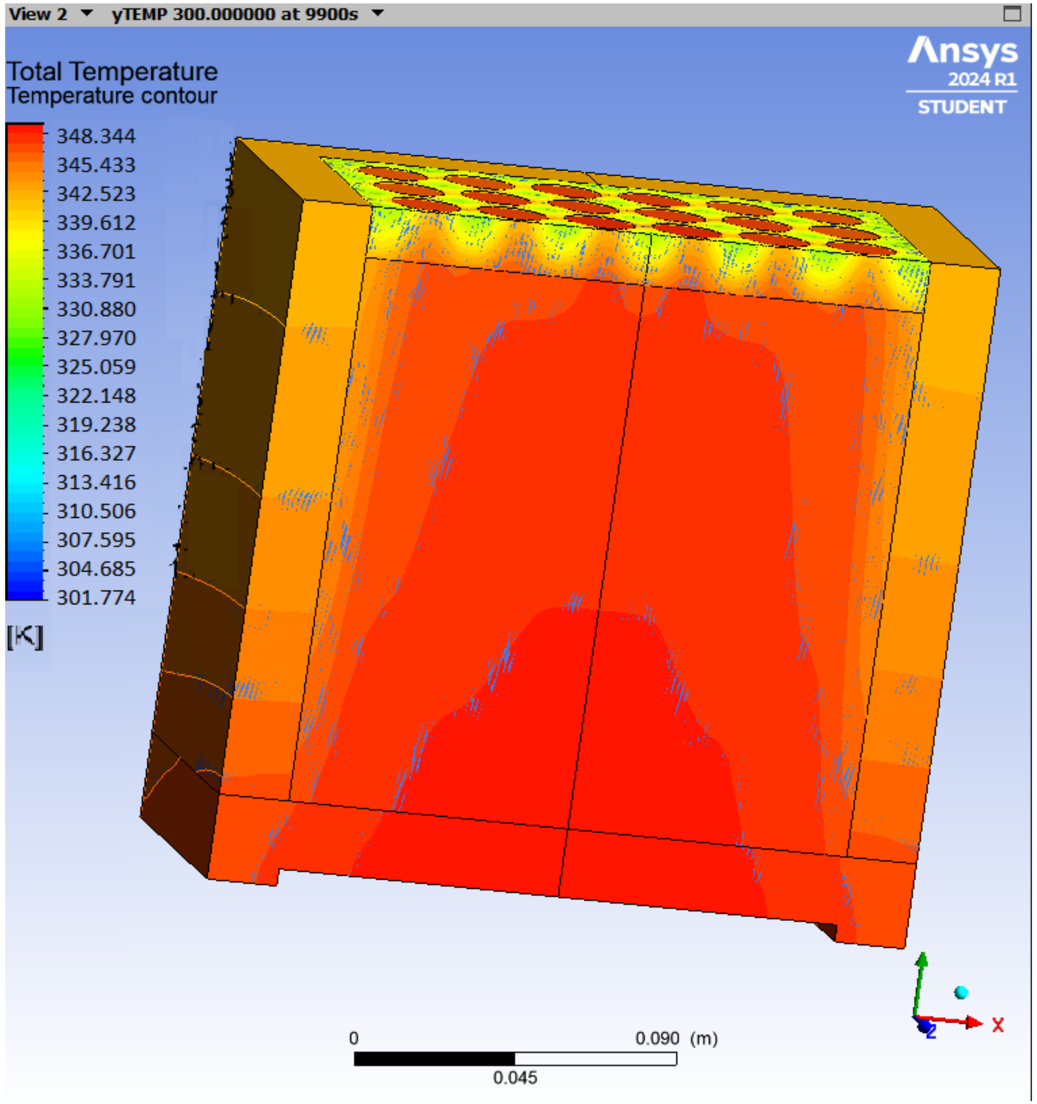
Meshing is a foundational step which will help us transform a continuous geometry into discrete elements, allowing for the numerical analysis of Hybrid heat sink . Good meshing practices are crucial for achieving accurate, efficient, and reliable simulation results.

Boundary Conditions

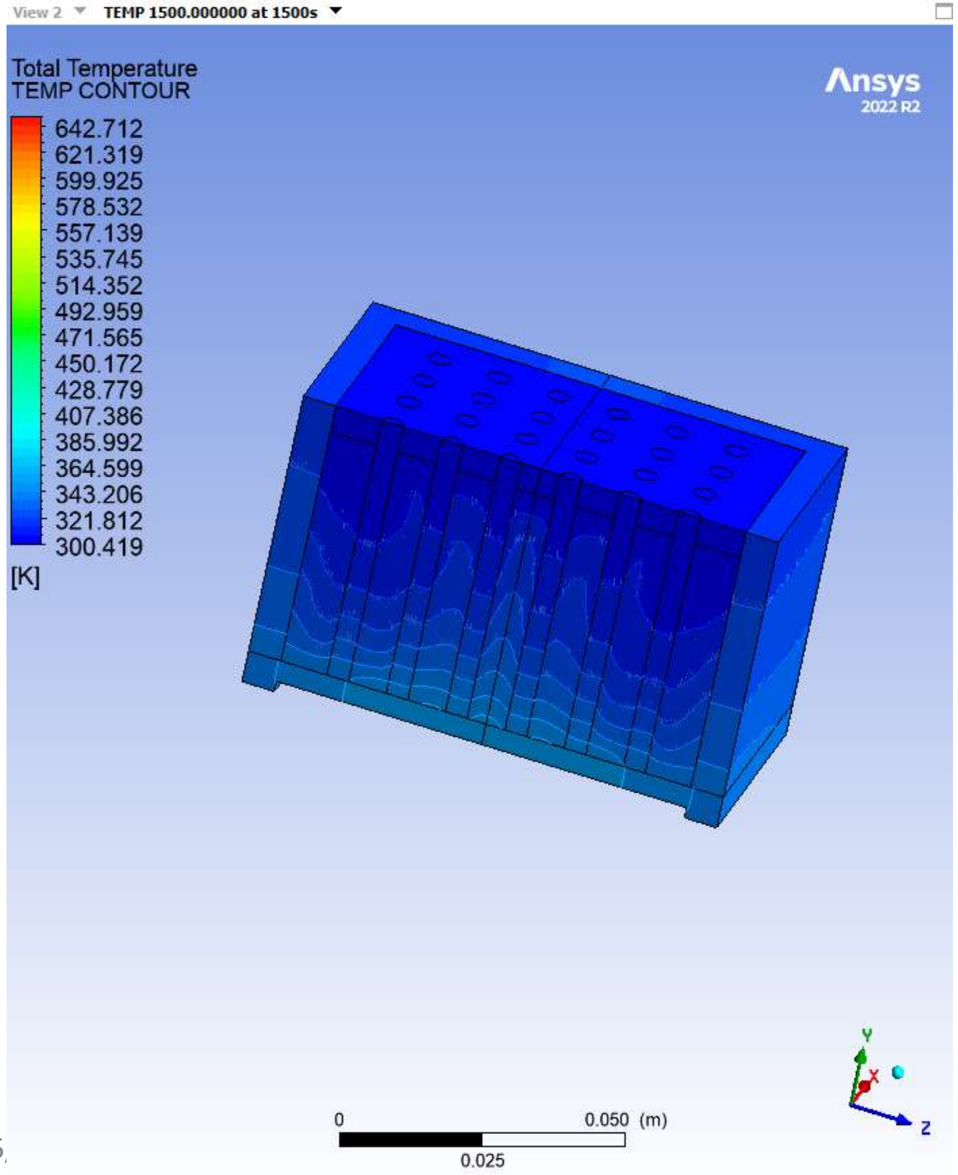
Boundary	Conditions
Air-top Convection	25 W/m2K
Fin-Top Convection	25 W/m2K
Heat Input	5000-200000 W/m2
Side-wall conveection	18 W/m2
Wall-Top Convection	25 W/m2
Base Side Walls	Insulated

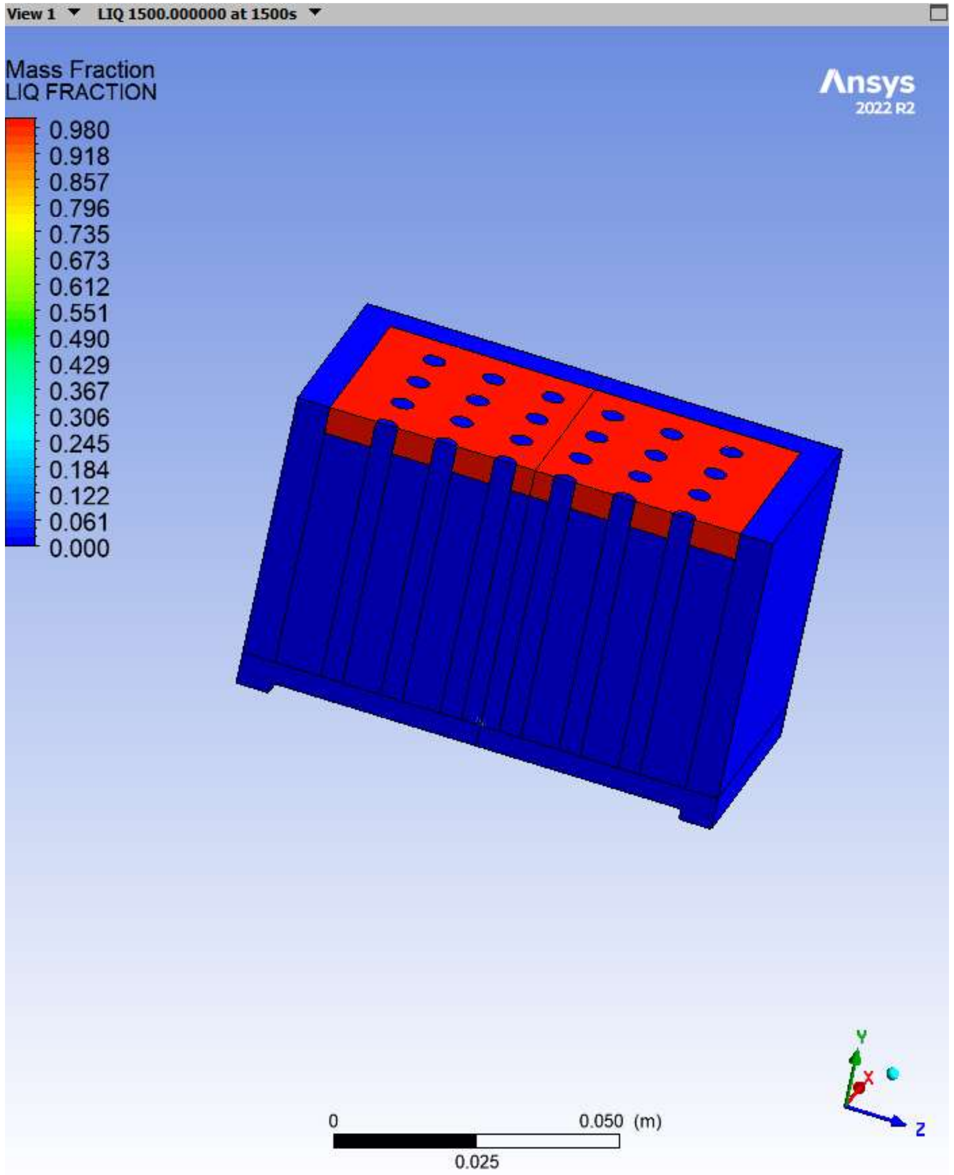
SIMULATION (5440 W/M2)



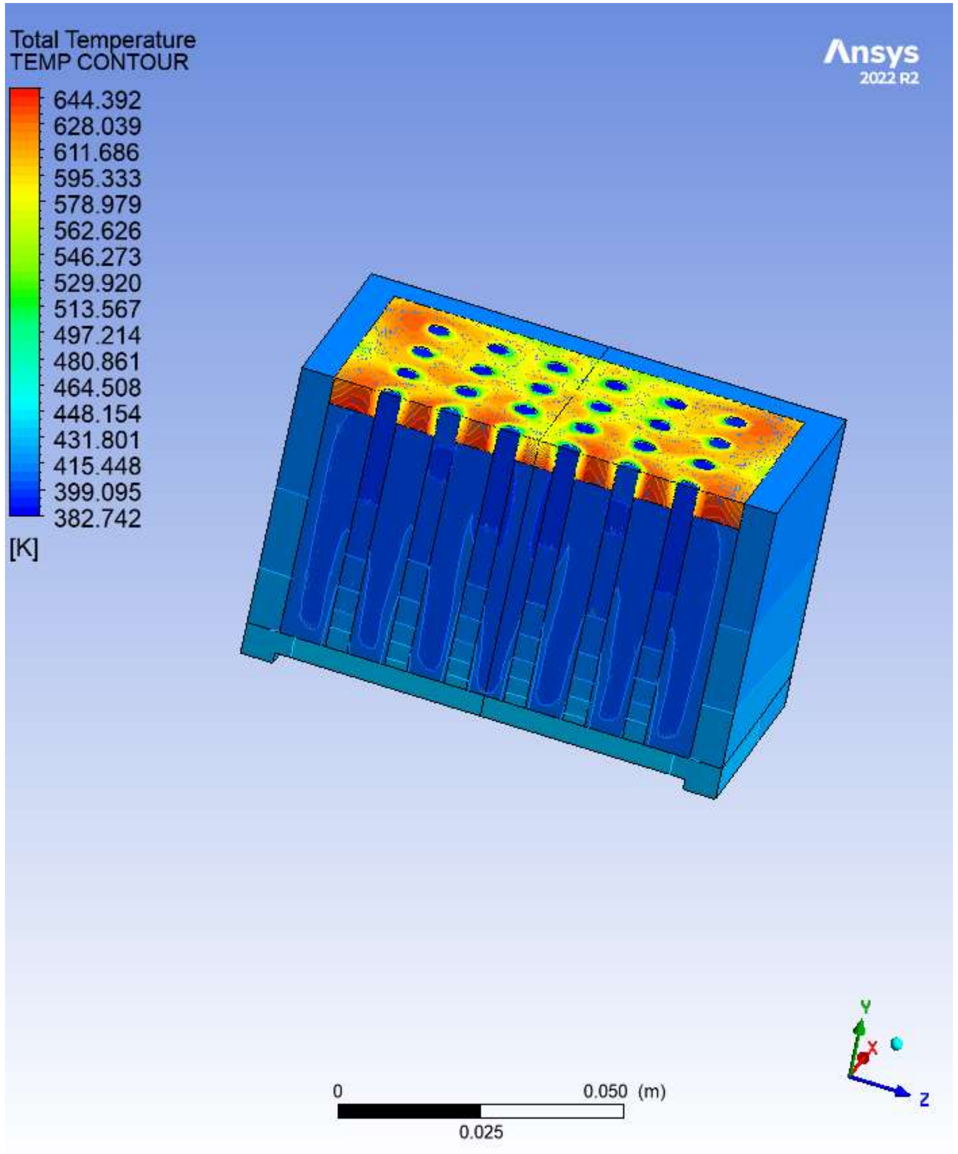


SIMULATION (100000 W/M2)



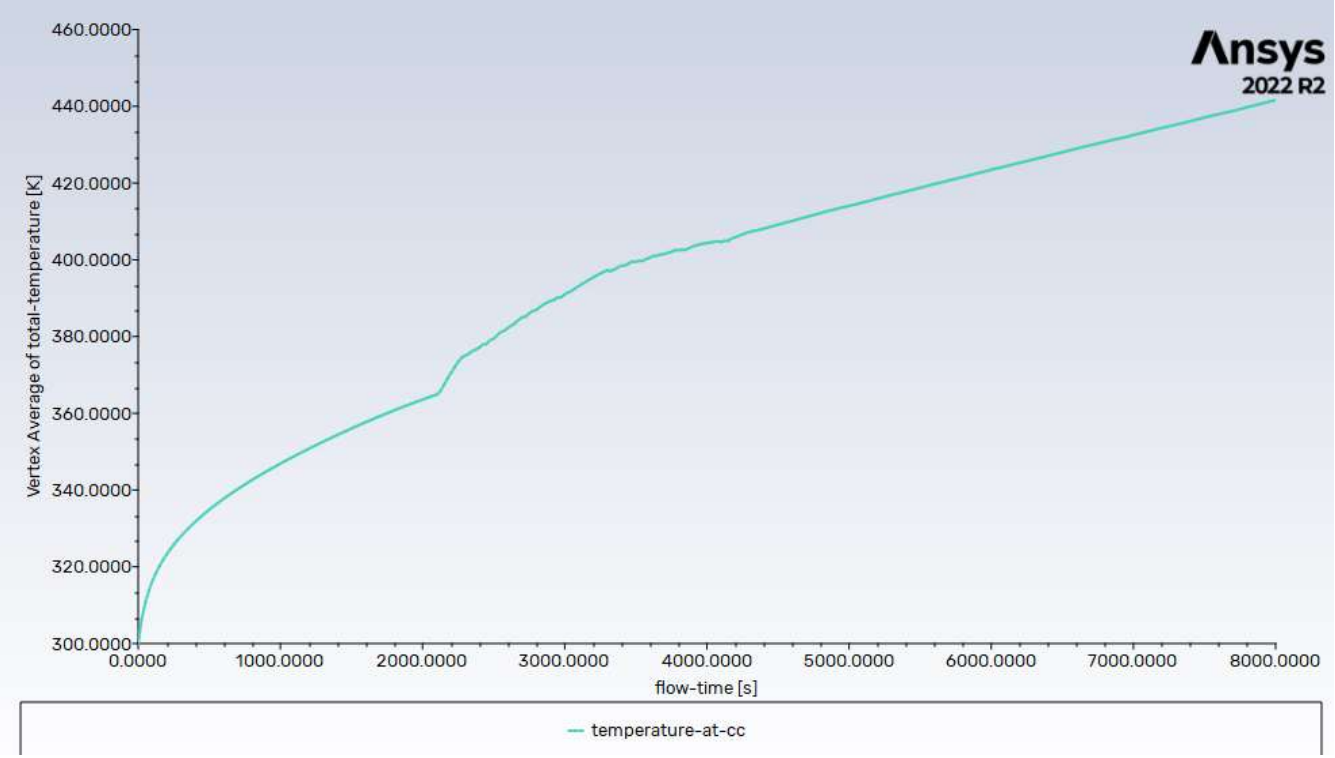


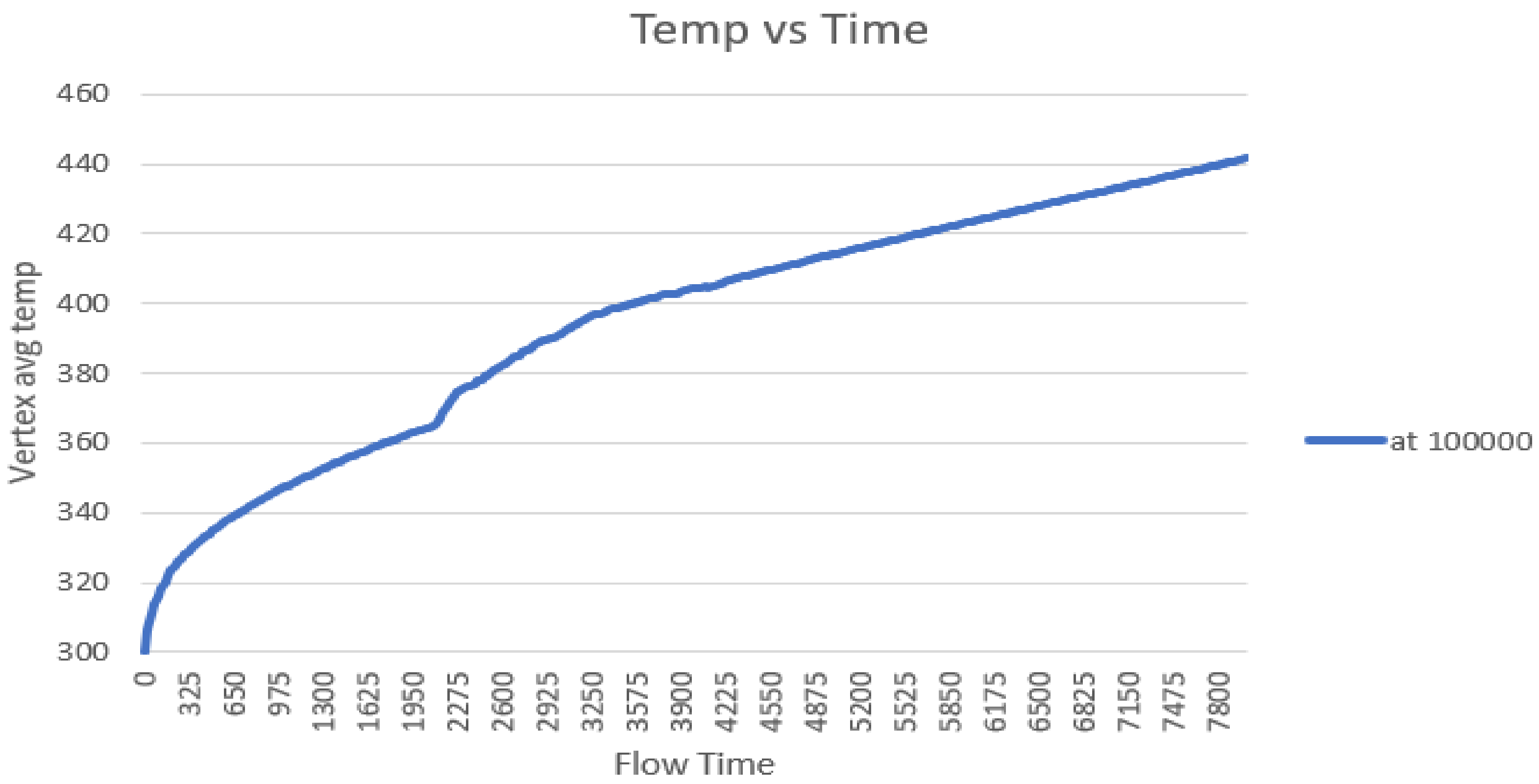
SIMULATION (100000 W/M2)



Results and Discussions:

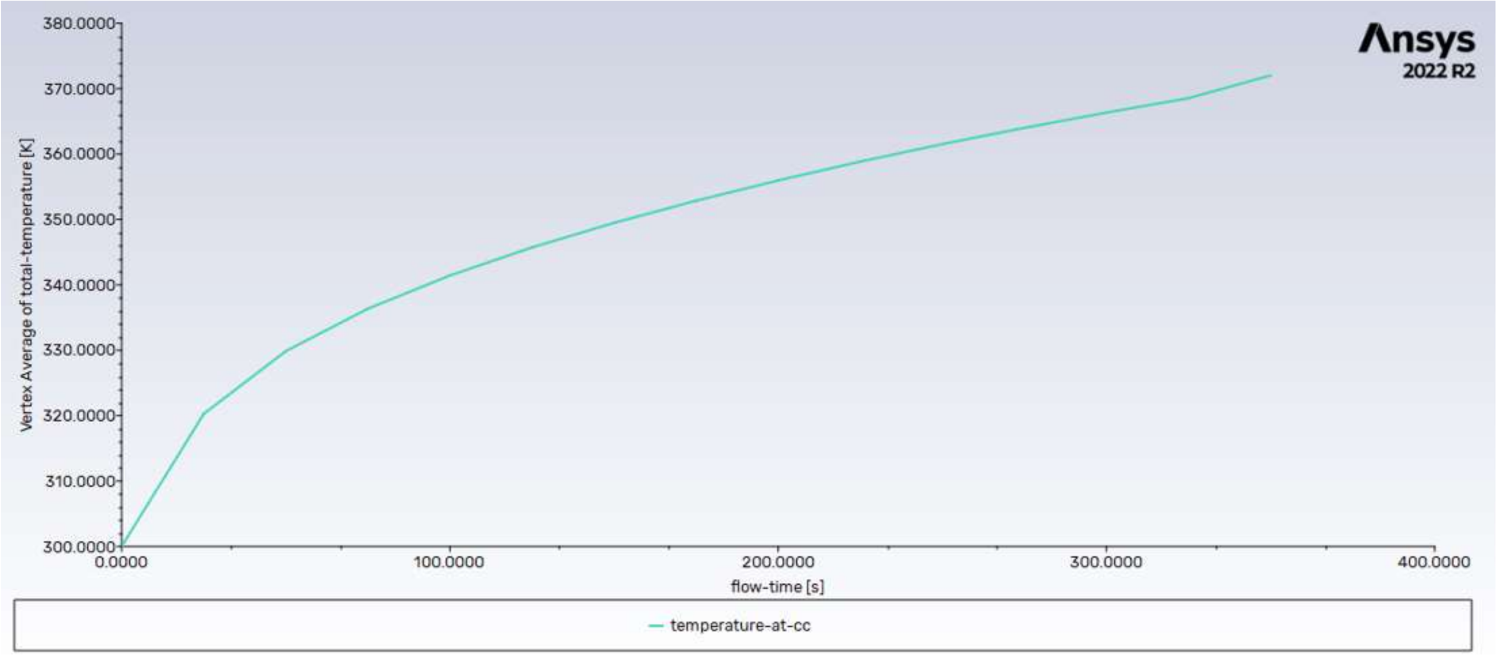
The results at 100000W/m2 are attached below.




Temp vs Time
Vertex avg temp
460
440
420
400
380
360
340
320
300
0
325
650
975
1300
1625
1950
2275
2600
2925
3250
3575
3900
4225
4550
4875
5200
5525
5850
6175
6500
6825
7150
7475
7800
Flow Time
at 100000

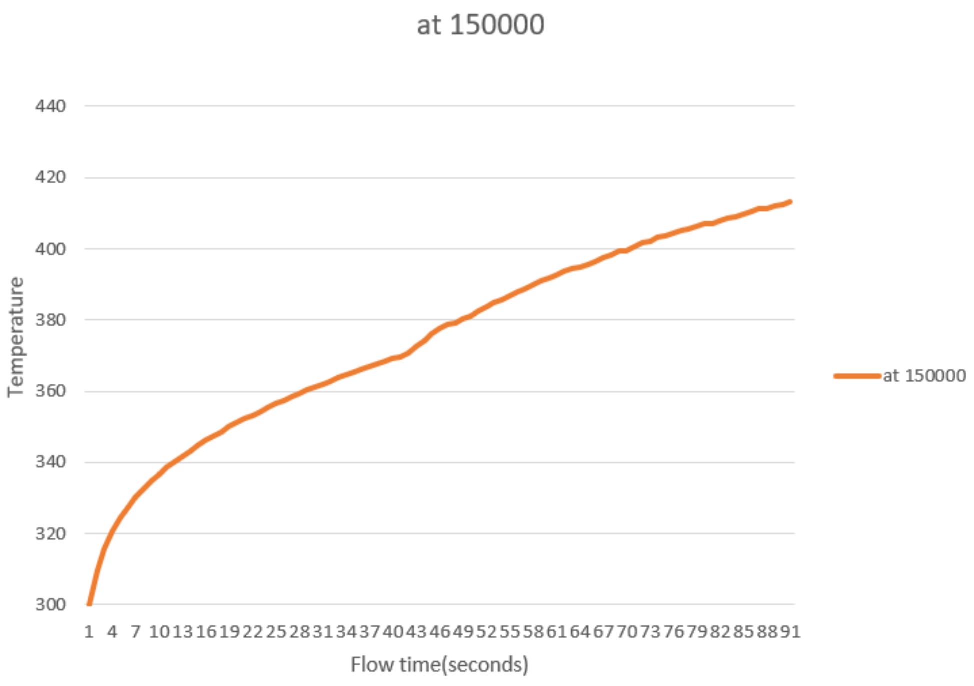
Results and Discussions:

The results at 150000W/m2 are attached below.



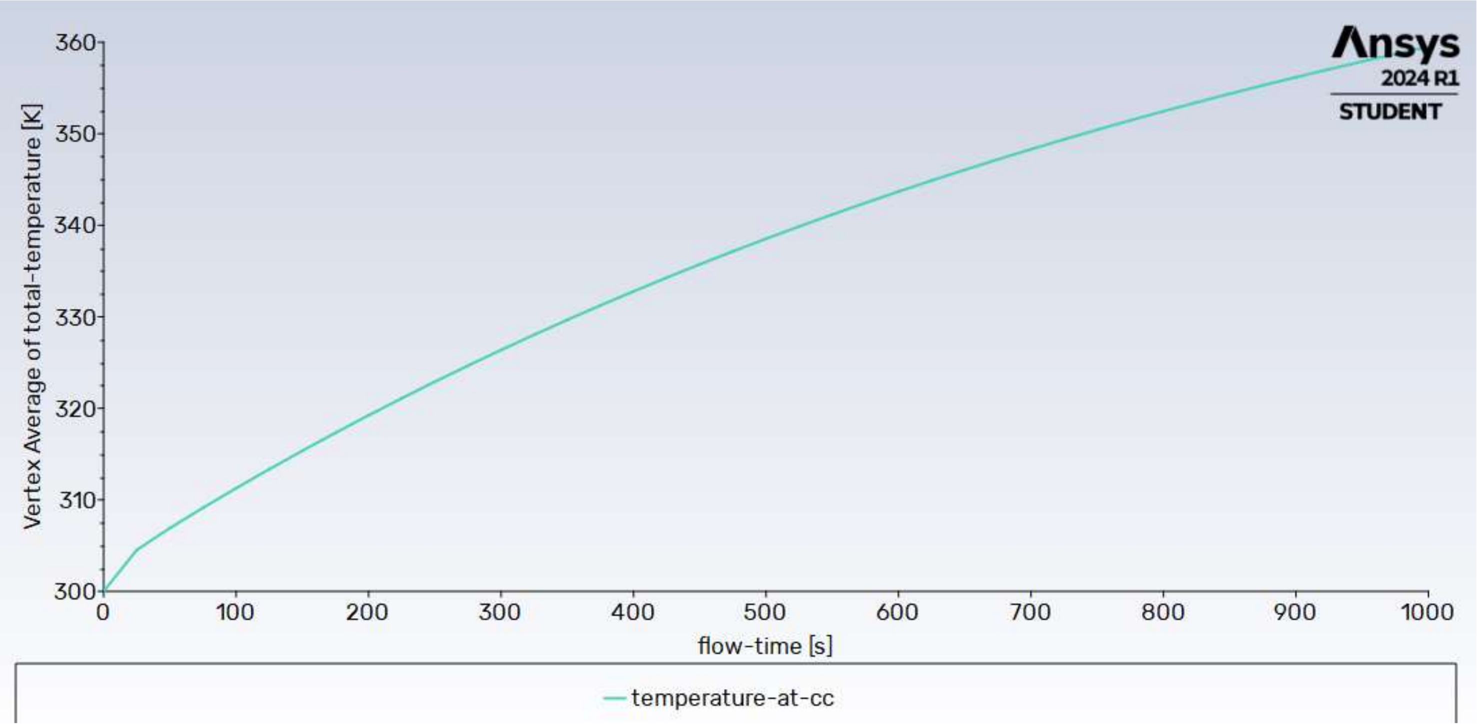
Results and Discussions:

The results at 150000W/m2 are attached below.



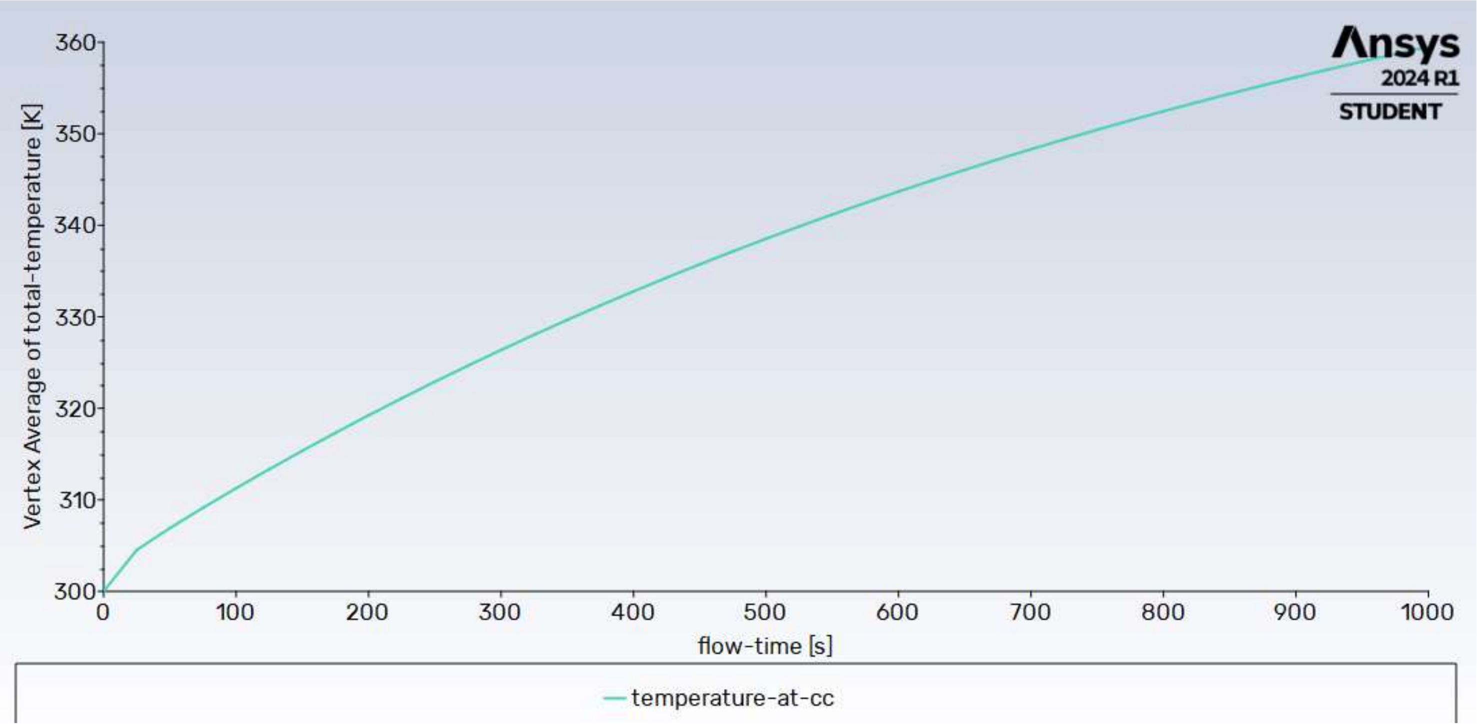
Results and Discussions:

The results at 5440 W/m2 are attached below.



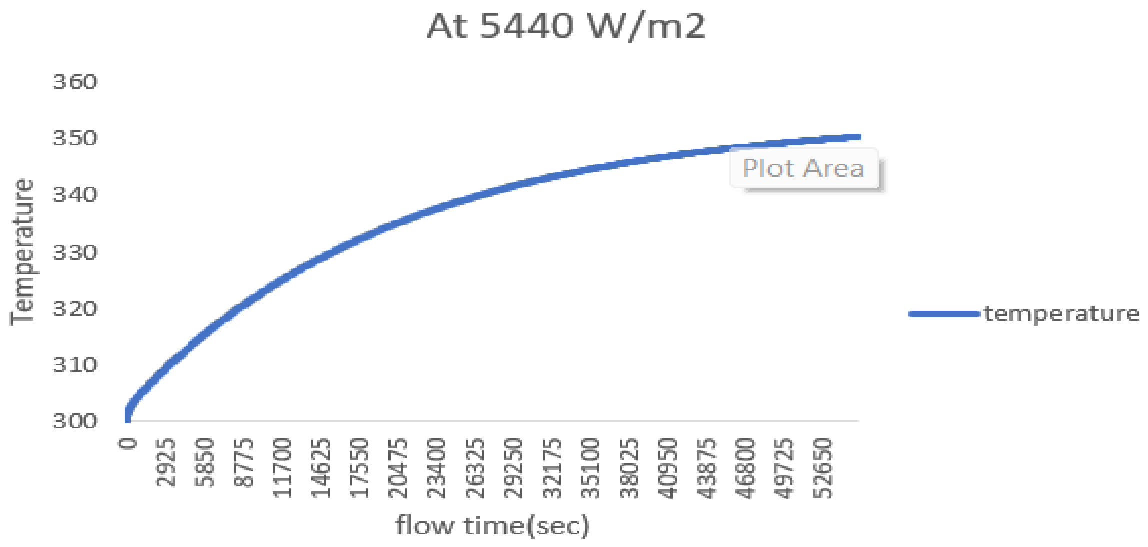
Results and Discussions:

The results at 5440 W/m2 are attached below.

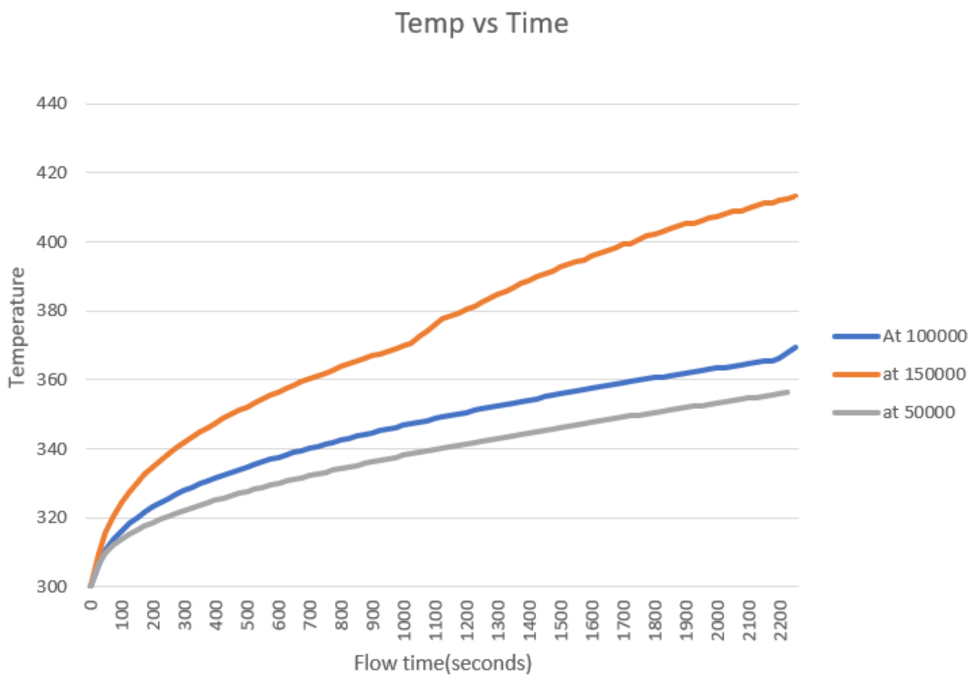


Results and Discussions:

The results at 5440 W/m2 are attached below.

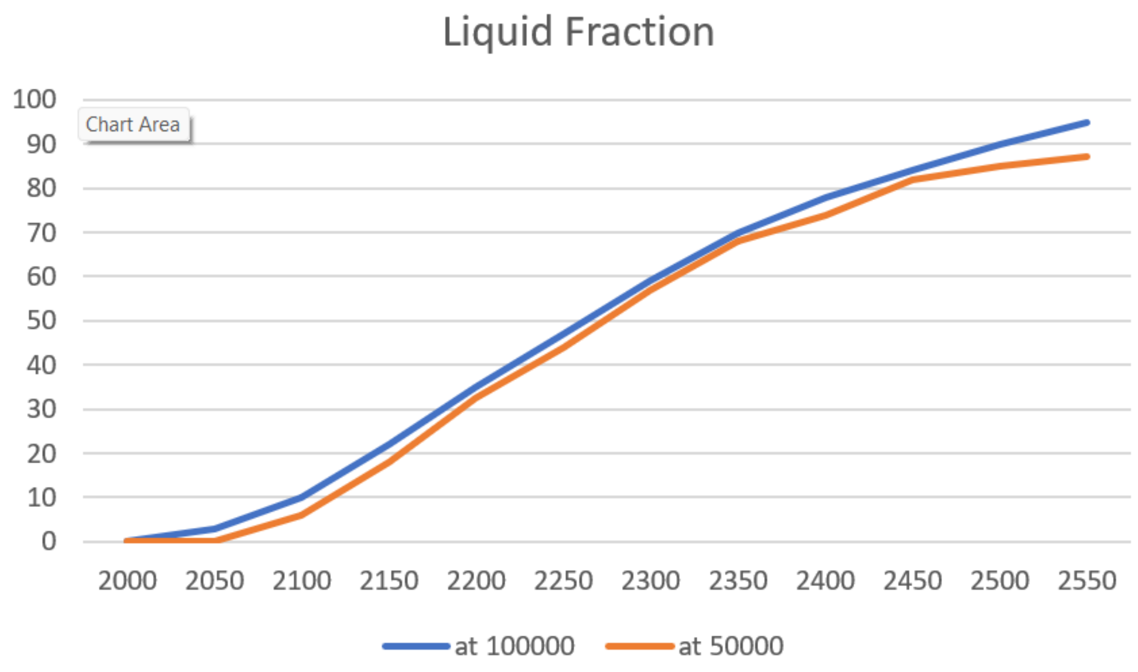


Combined Results



Results and Discussions:

LIQUID FRACTION GRAPHS



Results and Discussions:

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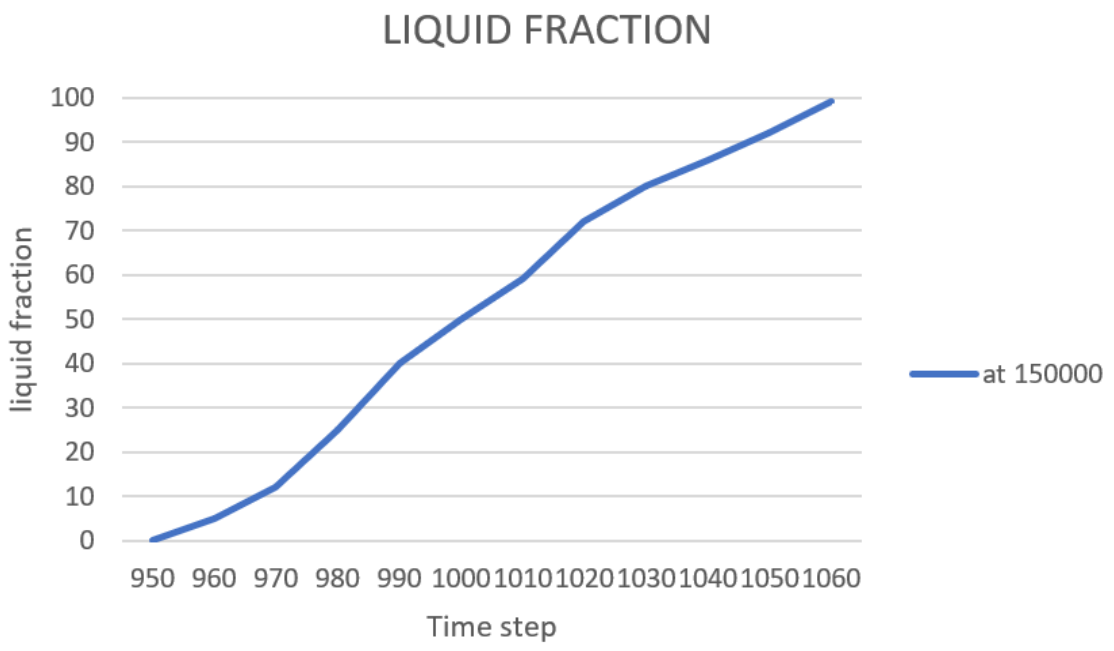
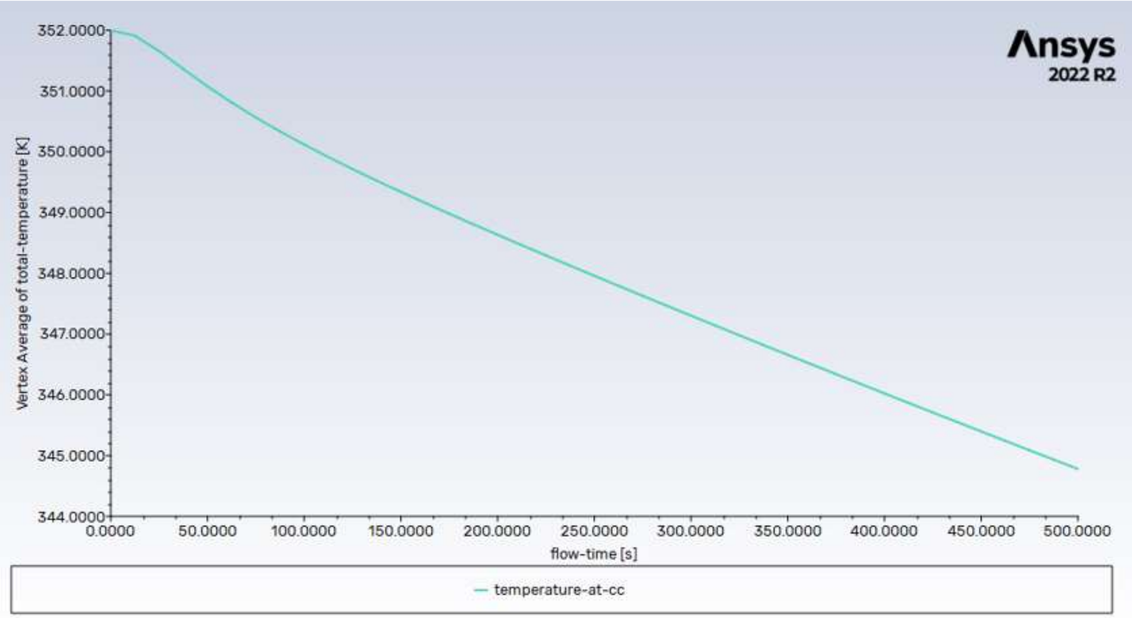


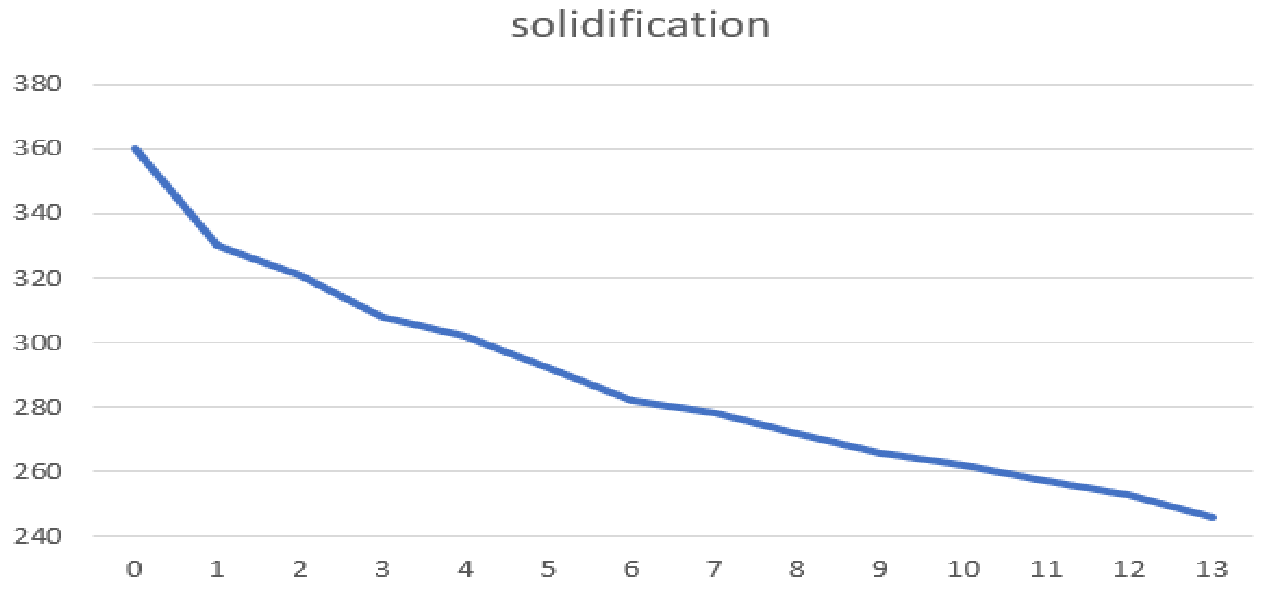
Results and Discussions:

SOLIDIFICATION GRAPHS



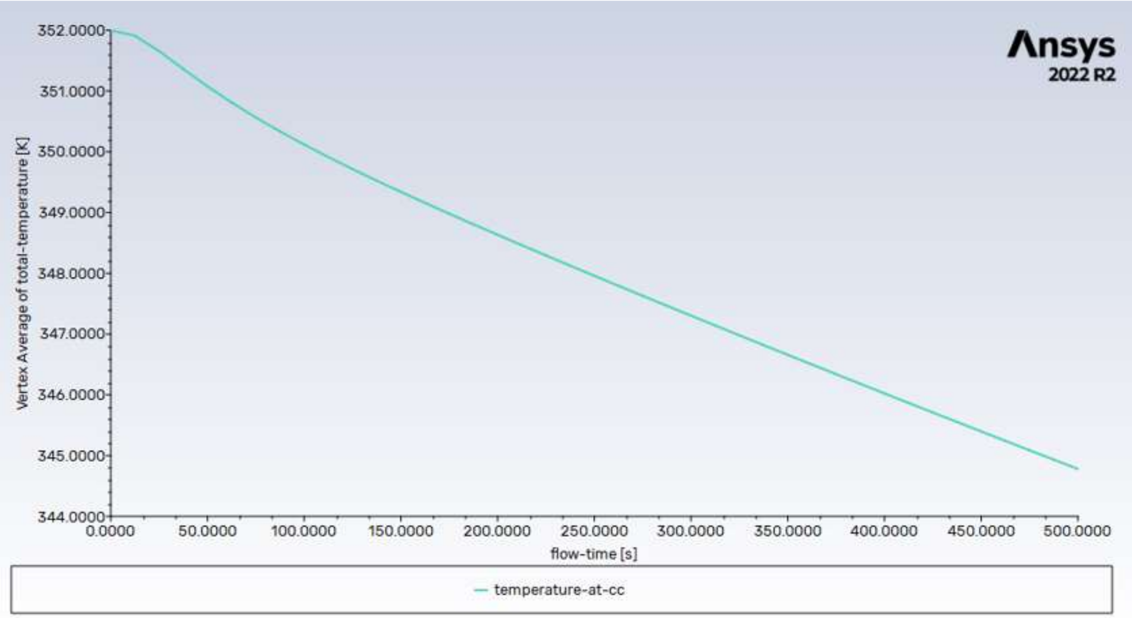
Results and Discussions:

SOLIDIFICATION GRAPHS



Results and Discussions:

SOLIDIFICATION GRAPHS



Results and Discussions:

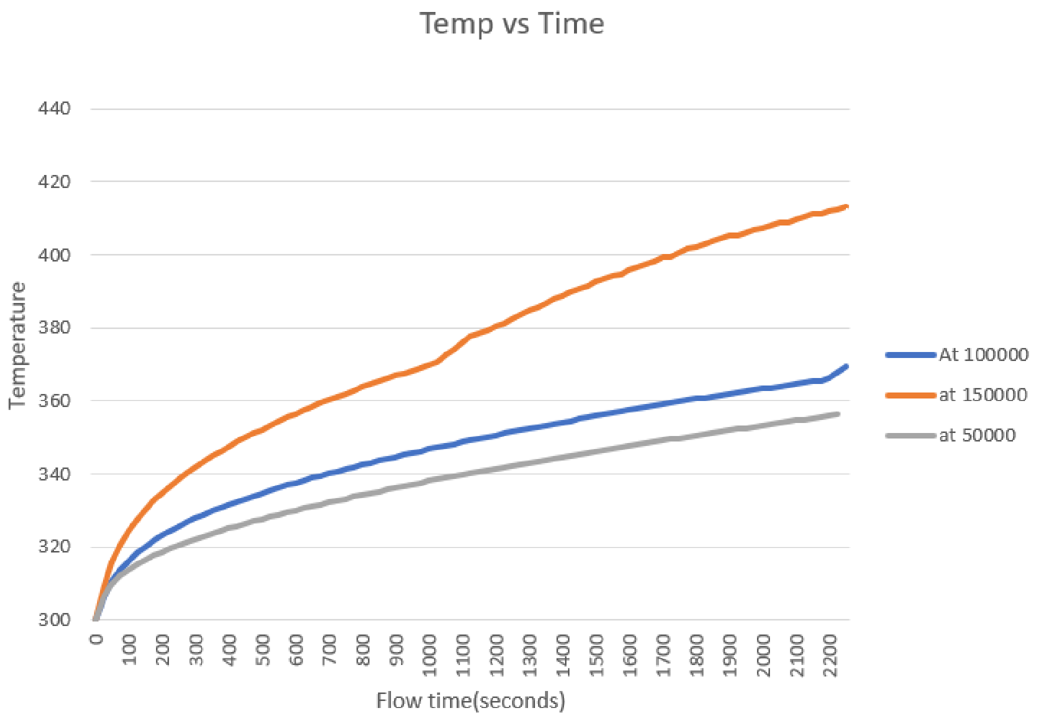
Explanation

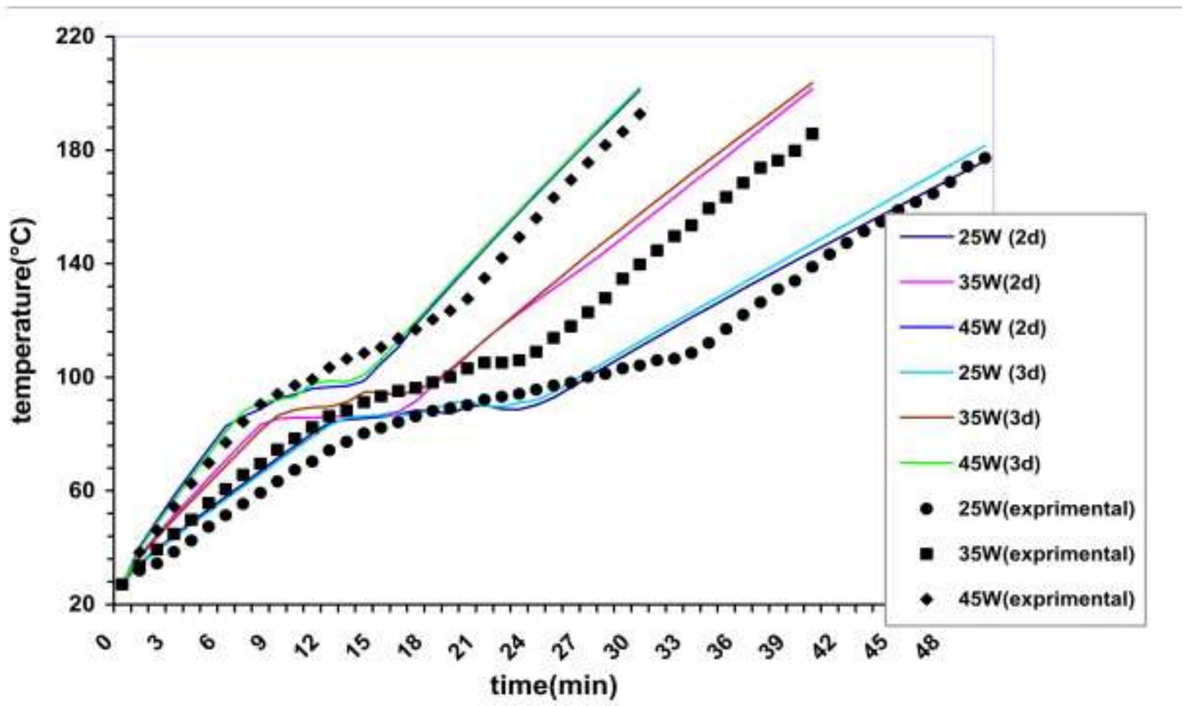
We can observe from the obtained results that when the heat sink is provided with different heat inputs of 5440W/m2 , 50000W/m2 , 100000W/m2 and 500000W/m2 we can see a deflection in their temperature graph at a temperature of approximately 360K .

Similarly we can observe a change in liquid fraction graph where at this range the pcm material changes from solid to liquid with respect to change in time step.
Results can be observed carefully with the help of the contours generated with the obtained files .

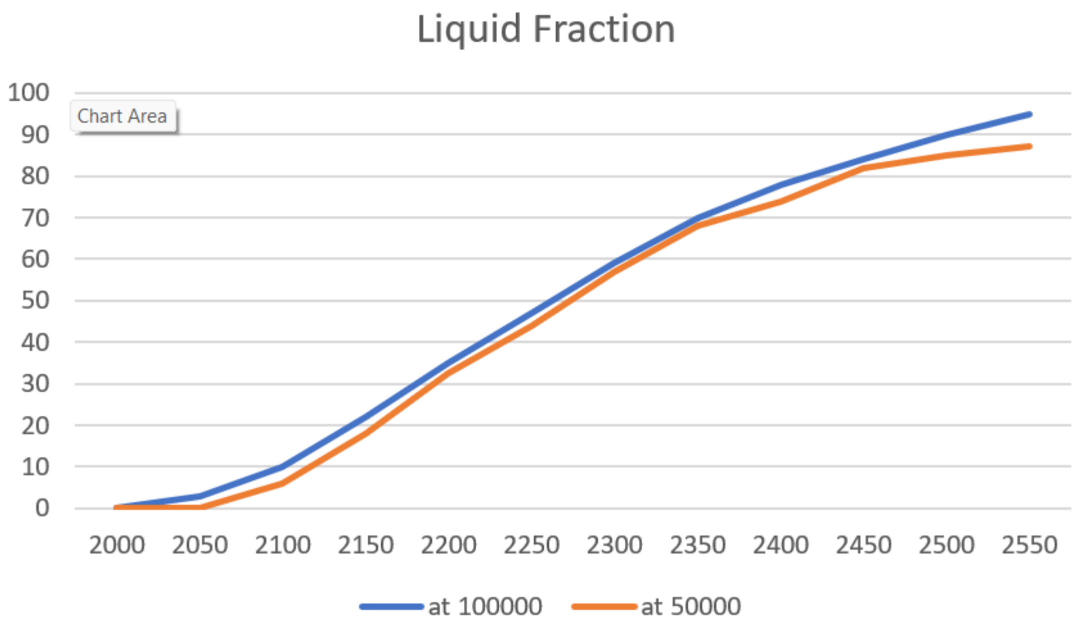
CFD Model Validation

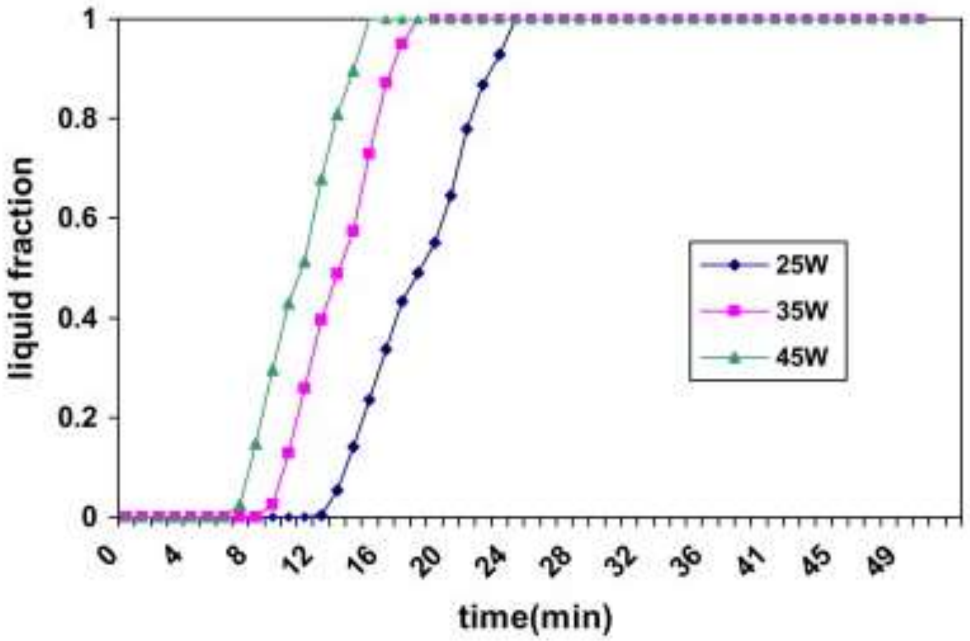
TEMP VS TIME



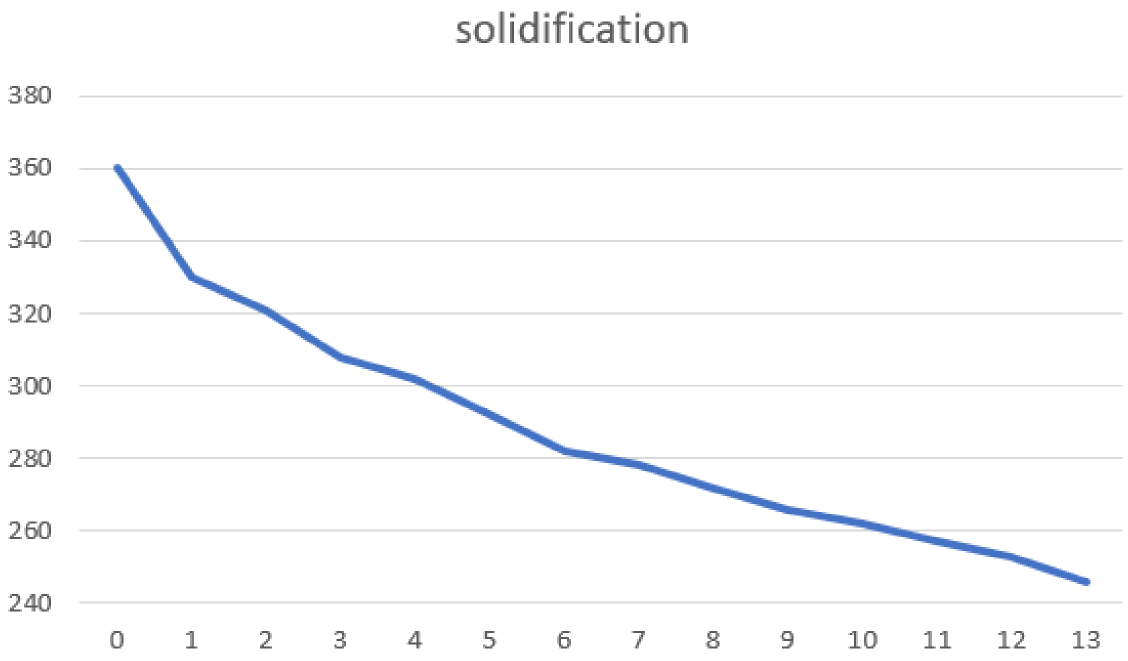


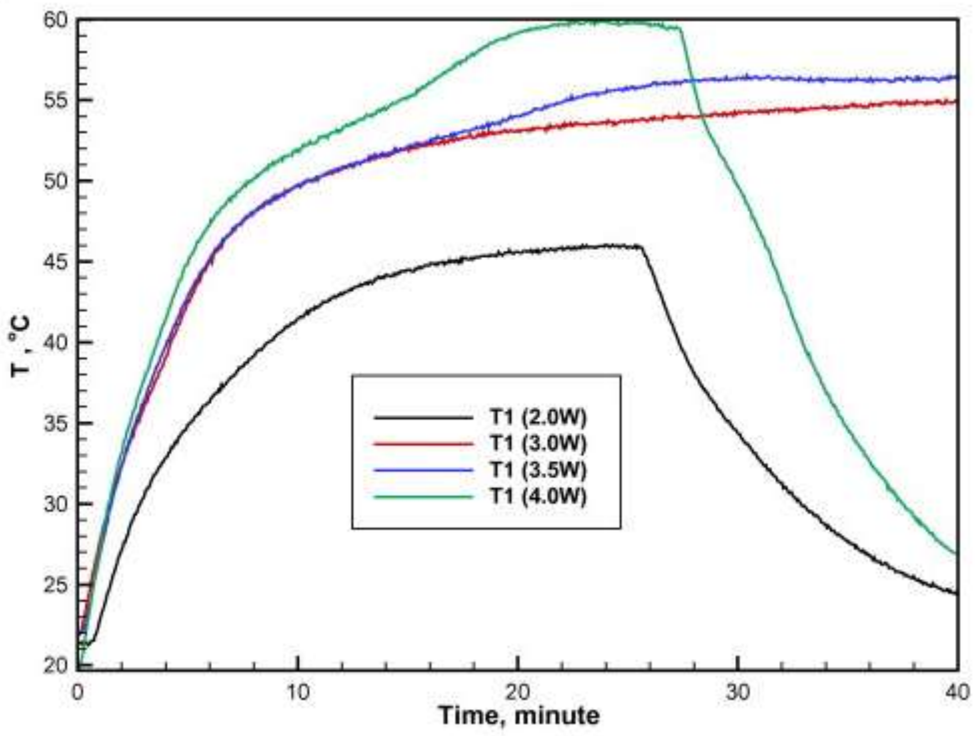
LIQUID FRACTION



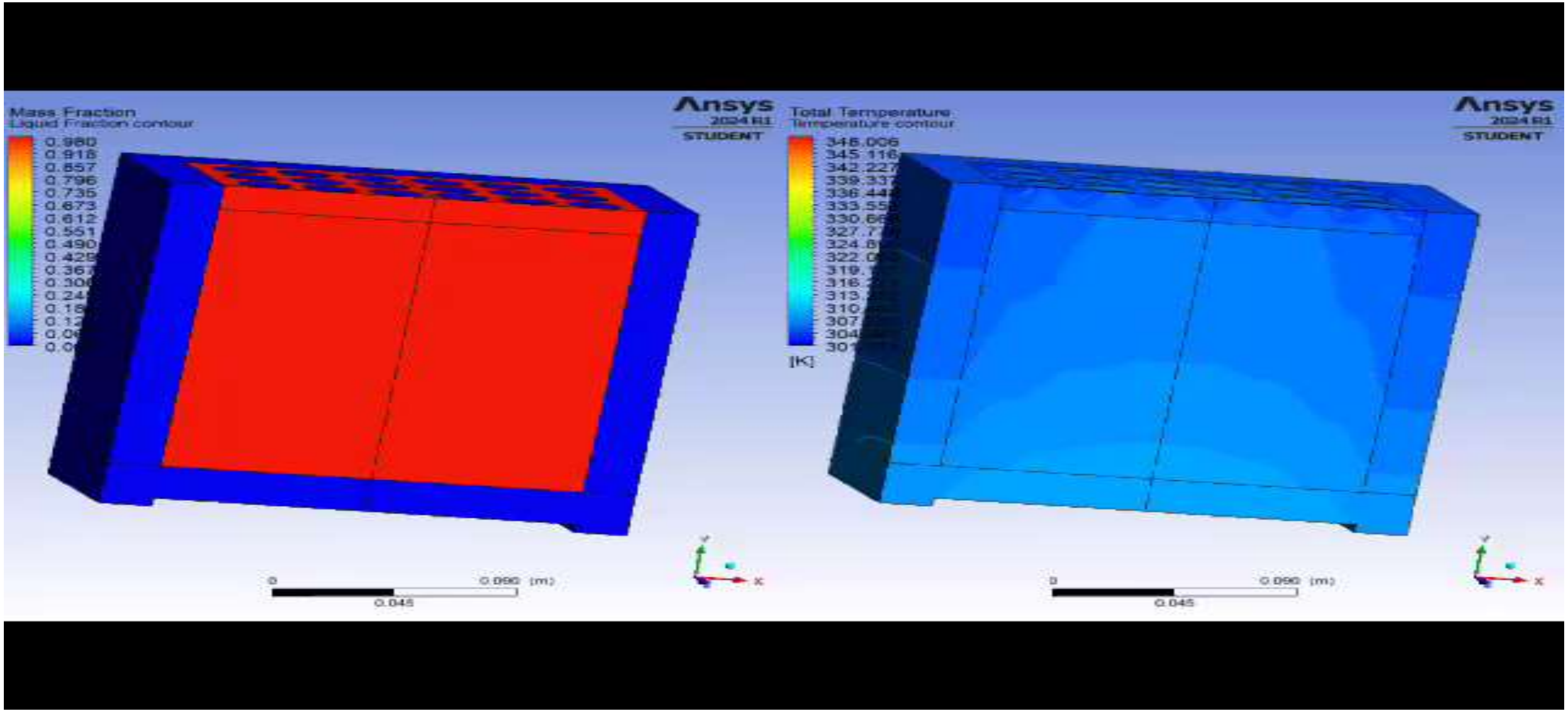


Solidification





Simulation Video



Summary

After studying the above plots and renderings as a result of CFD computation on different models and geometries under various conditions, the following conclusions have been obtained:

Role of Phase Change Materials (PCMs): The integration of PCMs within the hybrid heat sink significantly enhances thermal performance. The PCM's melting and solidification processes effectively absorb and release heat, stabilizing the temperature of the heat sink and preventing overheating of electronic components.

Impact of Heat Input Variations: The performance of the hybrid heat sink varies with different heat inputs. The CFD simulations reveal that higher heat inputs result in more pronounced phase changes in the PCM, demonstrating its capacity to manage higher thermal loads efficiently. Temperature Distribution and Contour Plots: The contour plots generated from the simulations illustrate that the hybrid heat sink achieves a more uniform temperature distribution compared to traditional heat sinks. This uniformity is crucial for preventing hot spots and ensuring the reliability of electronic components.

Performance Under Different Boundary Conditions: The study shows that the hybrid heat sink performs effectively under a range of boundary conditions. The selected boundary conditions accurately simulate real-world scenarios, validating the heat sink's practical applicability in various electronic cooling contexts.

References

- [1] Shatikian, V., G. Ziskind, and R. Letan. "Numerical investigation of a PCM-based heat sink with

    internal fins." International journal of heat and mass transfer 48.17 (2005): 3689-3706.

- [2] Hosseinizadeh, S. F., F. L. Tan, and S. M. Moosania. "Experimental and numerical studies on the

    performance of PCM-based heat sink with different configurations of internal fins." Applied Thermal Engineering 31.17-18 (2011): 3827-3838.

- [3] Kandasamy, Ravi, Xiang-Qi Wang, and Arun S. Mujumdar. "Transient cooling of electronics using phase change material (PCM)-based heat sinks." Applied thermal engineering 28.8-9 (2008): 1047-1057

Thank you