A Study on Latent Heat Thermal Energy Storage System with Tree-like Branching Fin

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Shridhar Bandaru1, Prof. Prakash Katdare2

[1]*Research Scholar, Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal*
[2]*Professor, Department of Mechanical Engineering, Sagar Institute of Research and Technology, Bhopal*

Abstract
It is important to improve the energy charging and discharging efficiency of thermal energy storage systems to help mitigate energy crises and environmental concerns. The thermal storage is a key component of many energy storage methods. The purpose of this research is to optimize the thermodynamic properties of a Tree-like Branching Fin for use in increasing the LHTES device's thermal efficiency. There are three types of heat storage methods: "sensible heat thermal energy storage (SHTES); latent heat thermal energy storage (LHTES); and thermochemical energy storage (TCHS)." A CFD model that accounts for the system's thermal behavior is used to conduct the study. The thermal transfer phenomenon is characterized by the measured temperature and the solid fraction..

Keyword: Latent Heat Energy Storage, Heat Exchanger, Tree like fin; CFD model.

INTRODUCTION

Thermal energy storage systems are cost efficient, reduce greenhouse gas emissions and a promising step towards less carbon future. They also improve the performance, authenticity and reliability on Energy storage systems. Some types of LHTES system have been shown in Figure: 1. [1][2] Given its potential to effectively store thermal energy, the development of LHTES systems has garnered considerable interest during the last two decades. Now days, several methods exist for storing heat. It is possible to store energy at extremely low or very high temperatures for later use, and this is known as thermal energy storage. Using solar energy during the day to charge batteries that can then be used at night is the simplest option. A typical charging-discharging process includes charging the system when energy is readily available and using it when needed. This process is concurrent, and the system repeatedly acts the same way. LHTES system is measured a significant technology that allows a lasting use of renewable energy systems. [3][4]

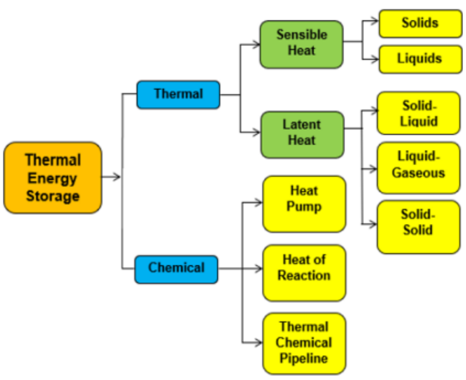

Figure 1: Classification of thermal energy storage

Latent Heat Thermal Energy Storage Systems (LHTESS)

"Latent heat storage thermal energy storage system (LHTESS)" uses phase transition phenomenon for the extraction of energy. Commonly, energy may be extracted by changing the solid's phase to a liquid. Solidification and melting are two common processes involved in the LHTES system. In melting process heat is transferred and stored in the material and later in solidification this heat releases and respective amount of energy is obtained. PCMs are the materials which are used in LHTES system. Due to non-toxic, non- poisonous behavior of PCMs, LHTES system are considered as one of the environment friendly thermal storage systems. Moreover, they have higher energy density they require less volume as compare to sensible storage systems. [5]

In fact, LHTES systems may be used in a variety of contexts. They may be used to store energy that can later be turned into electricity and used in heating and cooling systems. Electronics, air conditioning, refrigeration, chilling lithium-ion batteries, cold food packing, and so on are only some of the many uses for cooling technology. Building heating, waste heat recovery (from sources including vehicle exhaust and industrial boilers), and solar food drying apparatus are all examples of heating applications. [6][7]

Concentrated solar power (CSP) generating systems are one kind of solar power storage used in the broader context of energy storage. Smart fabrics, which can be used to either warm or cool the wearer, have even found their way into medical settings.[8][9]

OBJECTIVES OF THE STUDY

The primary goals of this research are to investigate and create an LHTES system for use in high-temperature environments. The literature reports inadequate work on encapsulating strategies for the high-temperature range, despite the fact that a great deal of research has been done on PCMs. For that reason, the aims of this study are:

- To increase the performance of LHTES by changing fins design.
- To analyse the optimum design of the LHTES system.
- To study the effect of temperature in the LHTES system.
- To study the effect of solid fraction in the LHTES system.
- To study the effect of fins length on LHTES system.

RESEARCH METHODOLOGY

The ANSYS Design simulation tool was used for the modelling, and ANSYS was used for the numerical analysis. Figure 2 depicts the whole process of numerical simulation.

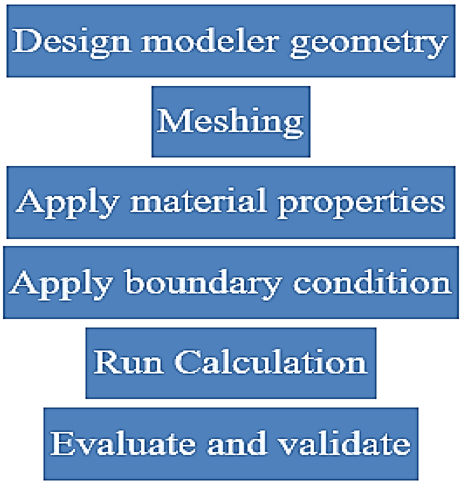

Figure 2: Working methodology

A. Design Validation

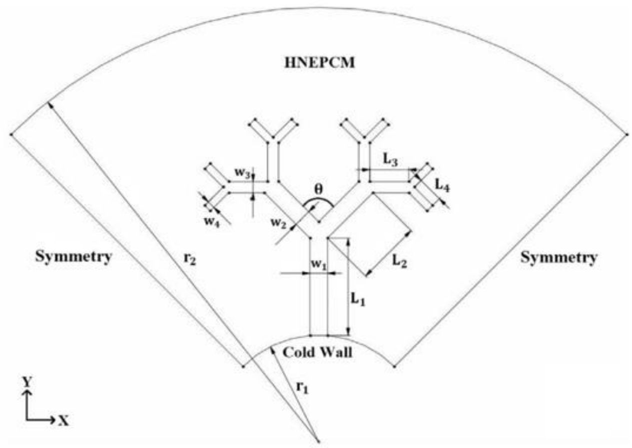

Figure 3: Design

B. Meshing

Mesh generation plays an important role in CAE simulations. The mesh has an effect on the precision, integration, and convergence speed of solutions. In addition, it often takes a long time to acquire the results of CAE solutions because to the length of work spent developing the wiring of the model.

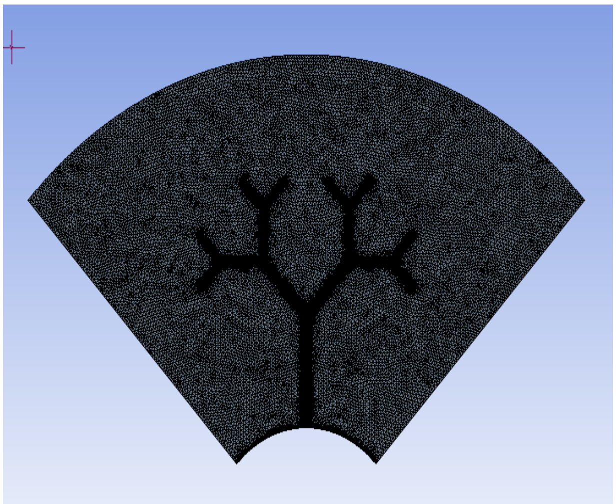

Figure 4: Meshing

Table.1 Number of nodes and elements in the meshing.

Number of Nodes	181236
Number of elements	78494

RESULTS AND DISCUSSION

The HNEPCM is contained inside the circular gap between the inner tube and the working fluid storage. "Tree-like branching fins" are connected to the outside edge of the inner tube to increase the heat penetration depth.

Table.2 Parameters

Geometry parameters	values
L1	6.25 mm
L2	4.42 mm
L3	3.125 mm
L4	2.21 mm
θ	90 °
W1	0.5 mm
W2	0.3535 mm
W3	0.25 mm
W4	0.177 mm
r1	7.5 mm
r2	30 mm

A. Temperature Contours

Temperature contours have been taken for pcm and fins after 100sec, 200sec, 300sec respectively and it is showing in below figure. Below figure is showing temperature at 100, 200 and 300 seconds.

Case 1 - L1 = 6.75 mm

Maximum and minimum temperature are observed for case 1 where L1=6.75mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

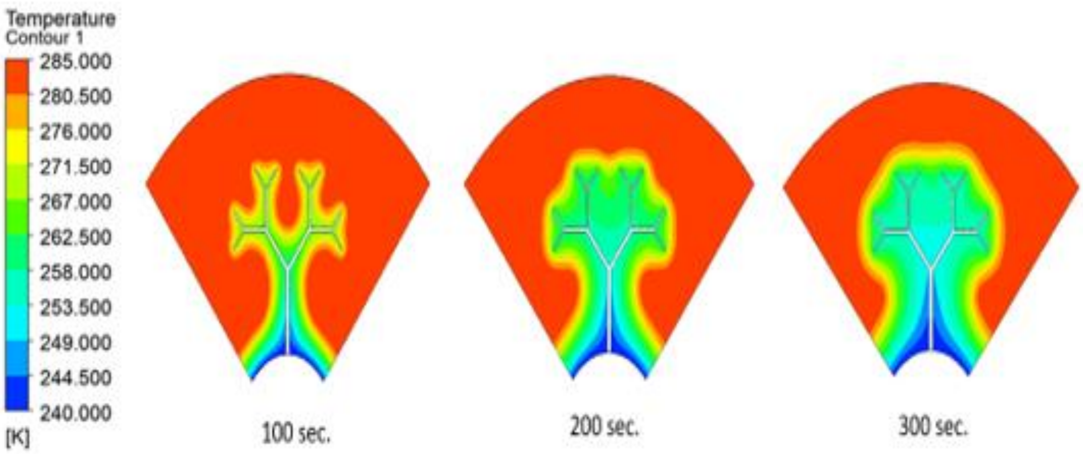

Figure 5: Temperature Contour for L1=6.75mm

Case 2 – L1 = 7.25 mm

Maximum and minimum temperature are observed for case 2 where L1=7.25mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

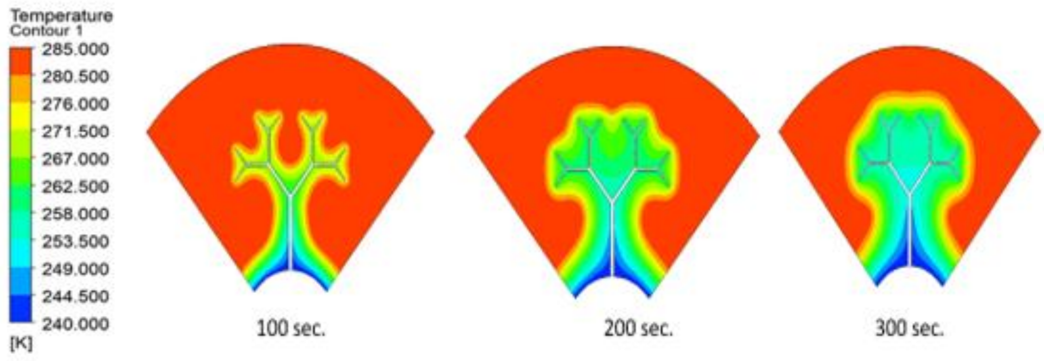

Figure 6: Temperature Contour for L1=7.25mm

Case 3 - L3= 3.375 mm

Maximum and minimum temperature are observed for case 3 where L3=3.375mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

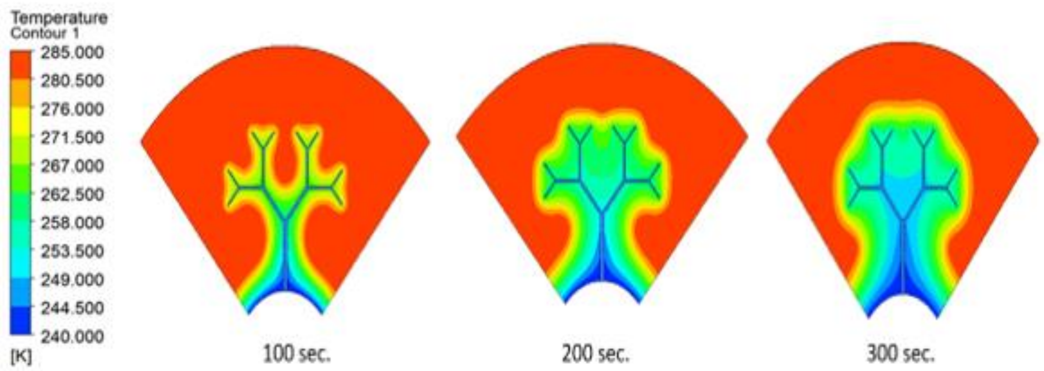

Figure 7: Temperature Contour for L3=3.375mm

Case 4 - L3= 3.625 mm

Maximum and minimum temperature are observed for case 4 where L3=3.625mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

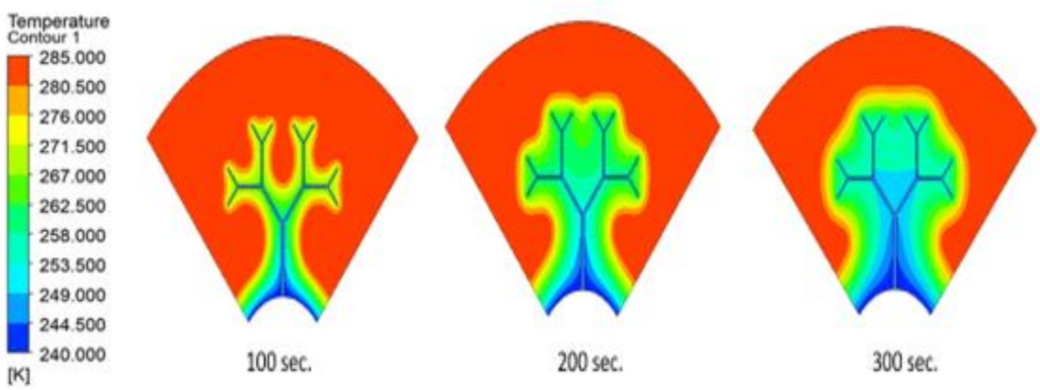

Figure 8: Temperature Contour for L3=3.625mm

Case 5 - L4= 2.46 mm

Maximum and minimum temperature are observed for case 5 where L4=2.46mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

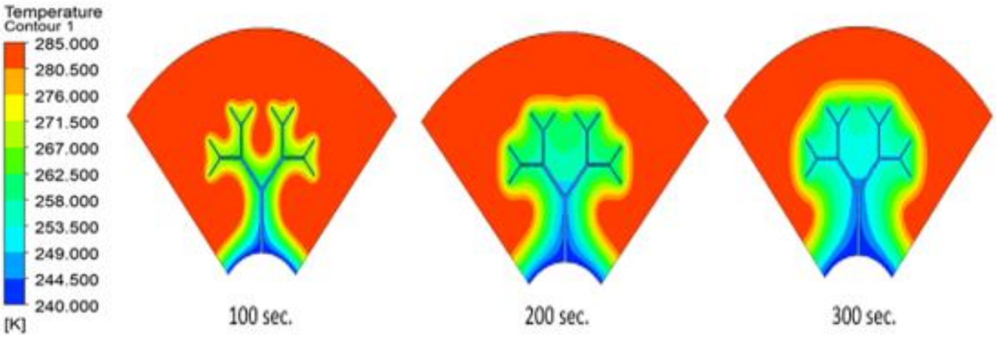

Figure 9: Temperature Contour for L4=2.46mm

Case 6 - L4= 2.71 mm

Maximum and minimum temperature are observed for case 6 where L4=2.71mm. Temperature contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

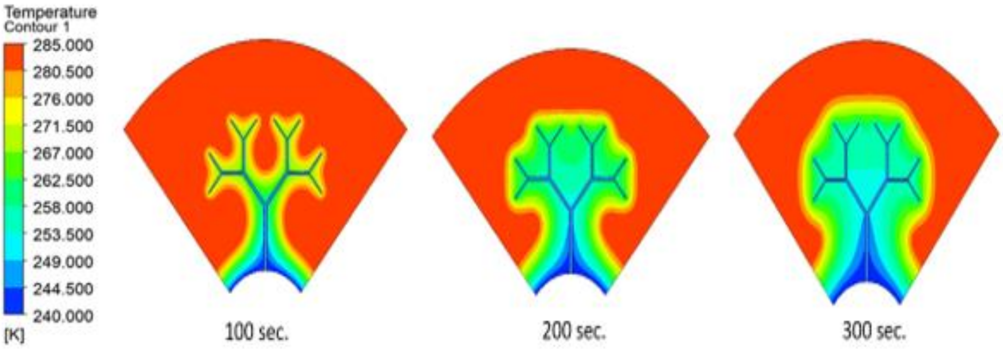

Figure 10: Temperature Contour for L4=2.71mm

B. Solid Fraction Contours

Solid fraction contours have been taken for PCM after 100sec, 200sec, and 300sec respectively. PCM material getting cold by the time which can be observed in above figure and value of liquid region is decreasing according to time.

Case 2 – L1 = 7.25 mm

Below figure shows variation in liquid fraction by the time for case 2 where L1=7.25mm. Solid fraction contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

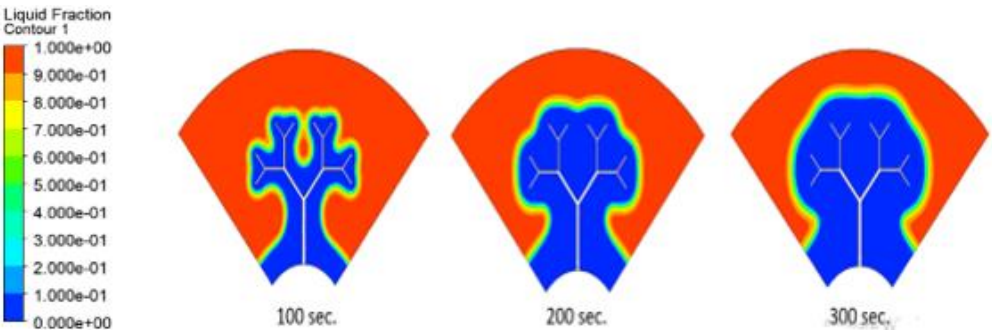

Figure 11: Solid fraction Contour for L1=6.75mm

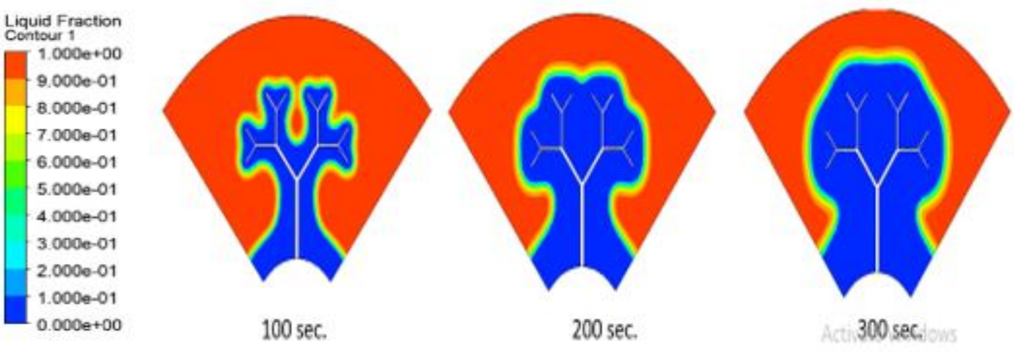

Figure 12: Solid fraction Contour for L1=7.25mm

Case 3 - L3= 3.375 mm

Below figure shows variation in liquid fraction by the time for case 3 where L3=3.375mm. Solid fraction contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

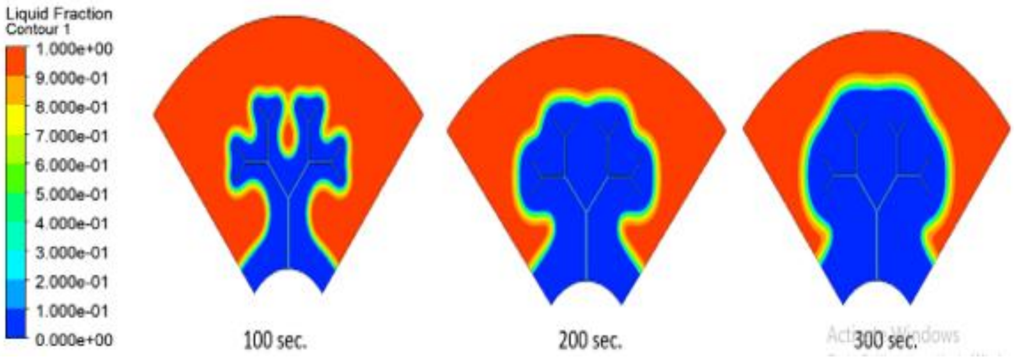

Figure 13: Solid fraction Contour for L3=3.375mm

Case 4 - L3= 3.625 mm

Below figure shows variation in liquid fraction by the time for case 4 where L3=3.625mm. Solid fraction contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

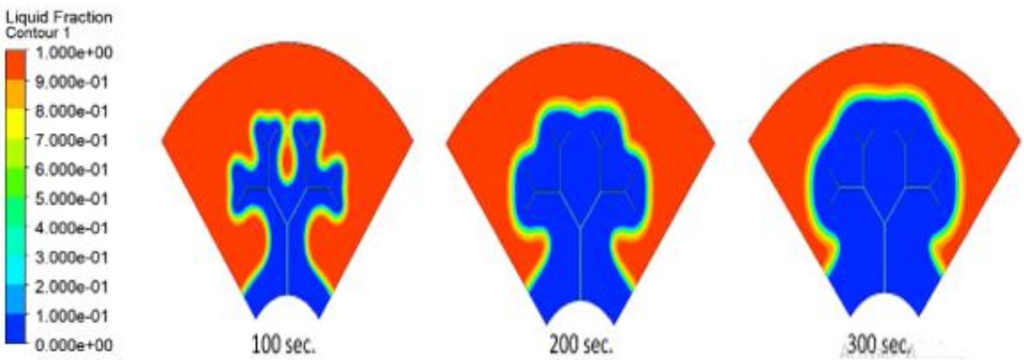

Figure 14: Solid fraction Contour for L3=3.625mm

Case 5 - L4= 2.46 mm

Below figure shows variation in liquid fraction by the time for case 5 where L4=2.46mm. Solid fraction contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively

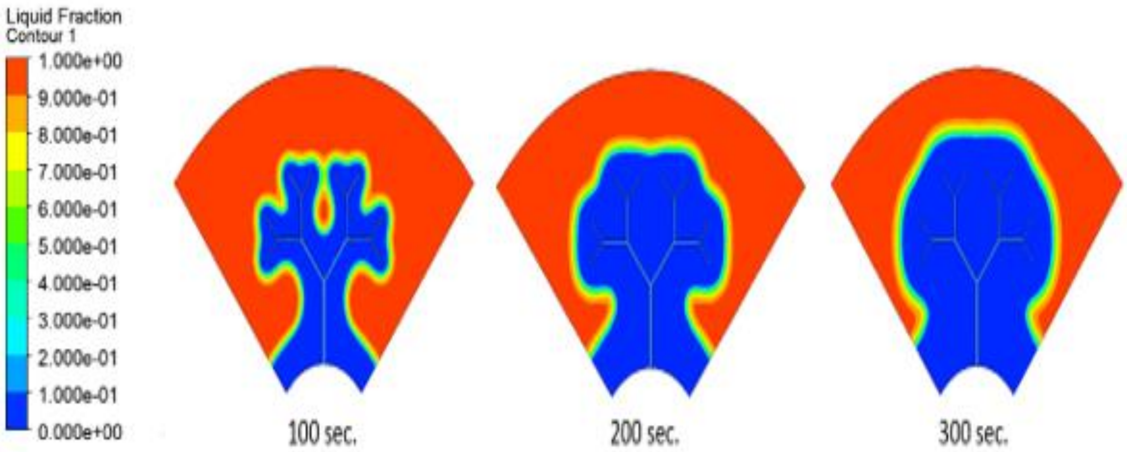

Figure 15: Solid fraction Contour for L4=2.46mm

Case 6 - L4= 2.71 mm

Below figure shows variation in liquid fraction by the time for case 6 where L4=2.71mm. Solid fraction contours have been taken for PCM and fins after 100sec, 200sec, 300sec respectively.

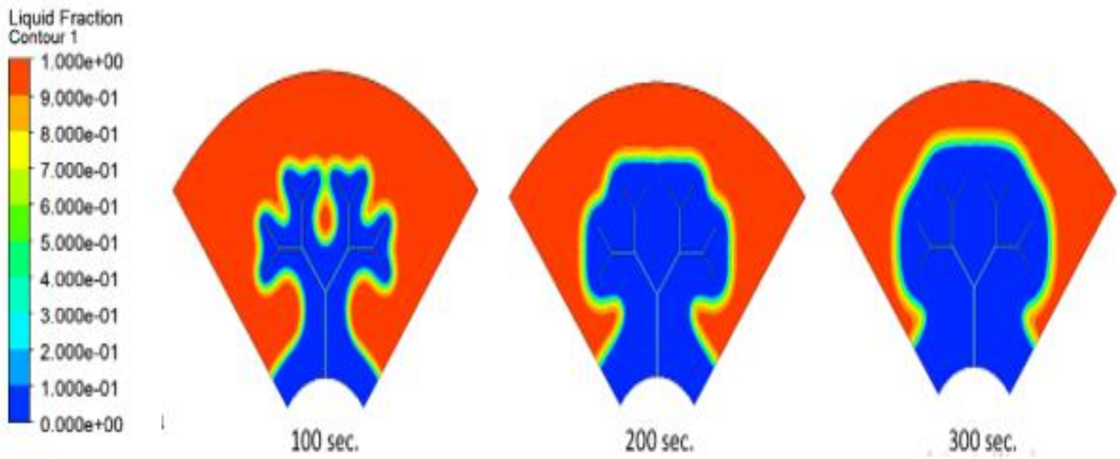

Figure 16: Solid fraction Contour for L4=2.71mm

C. Comparison of solid fraction of all cases.

Case 1 and case 2

Below mentioned graph represent linear change in solid fraction with respect to time for case 1 and case 2.

Time	Case 1 - L1 = 6.75	Case 2 – L1 = 7.25
100	0.277	0.270
200	0.413	0.409
300	0.504	0.504

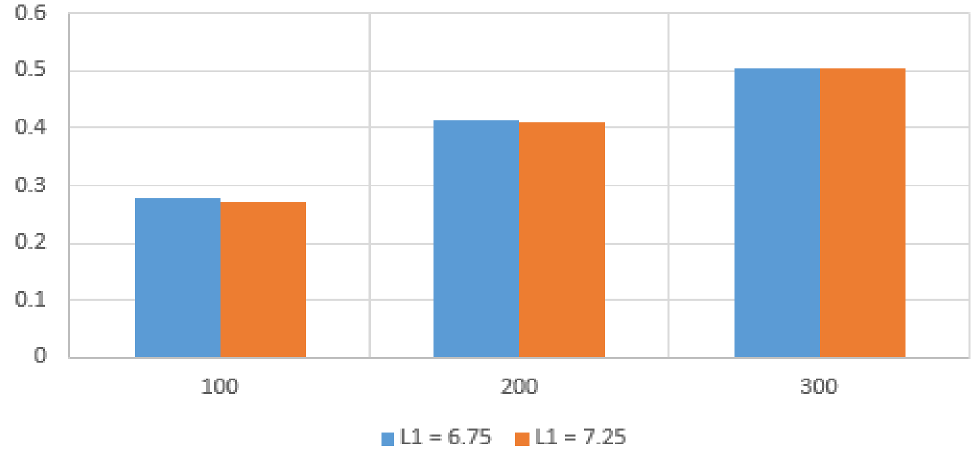

Figure 17: Comparison of solid fraction of Case 1 and Case 2

Case 3 and case 4

Below mentioned graph represent linear change in solid fraction with respect to time for case 3 and case 4.

Time	Case 3 – L3 =3.375	Case 4 – L3 = 3.625
100	0.282	0.284
200	0.418	0.424
300	0.509	0.518

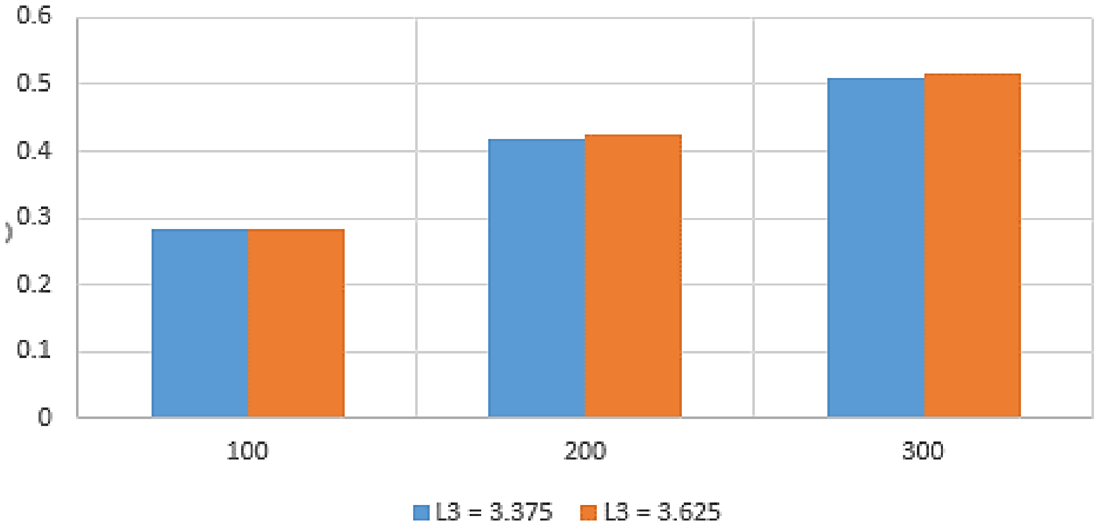

Figure 18: Comparison of solid fraction of Case 3 and Case 4

Case 5 and case 6

Below mentioned graph represent linear change in solid fraction with respect to time for case 5 and case 6.

Time	Case 5 – L4 = 2.46	Case 6 – L4 = 2.71
100	0.291	0.281
200	0.424	0.432
300	0.515	0.525

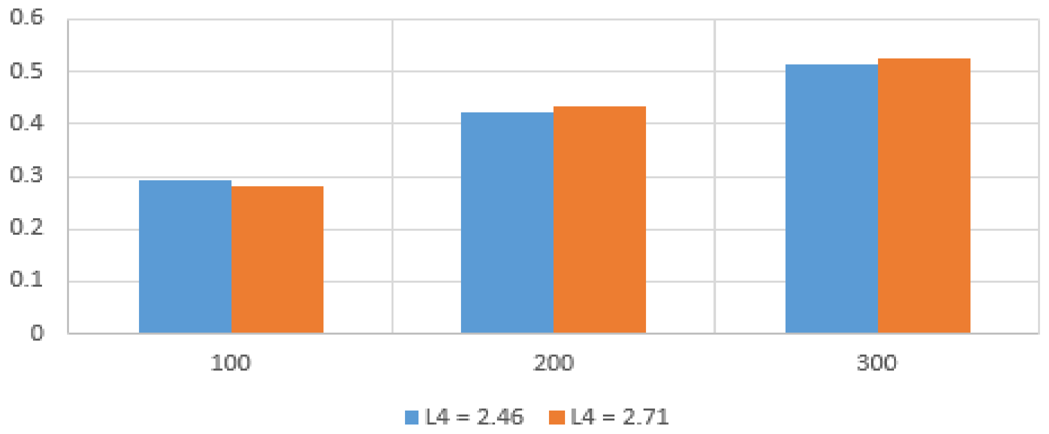

Figure 19: Comparison of solid fraction of Case 5 and Case 6

D. Comparison of temperature contour of design

Case 1 and case 2

Below mentioned graph represent linear change in temperature contour with respect to time for case 1 and case.

Time	Case 1 L1 = 6.75	Case 2 – L1 = 7.25
100	280.791 [k]	281.019 [k]
200	276.746 [k]	277.103 [k]
300	273.788 [k]	274.081 [k]

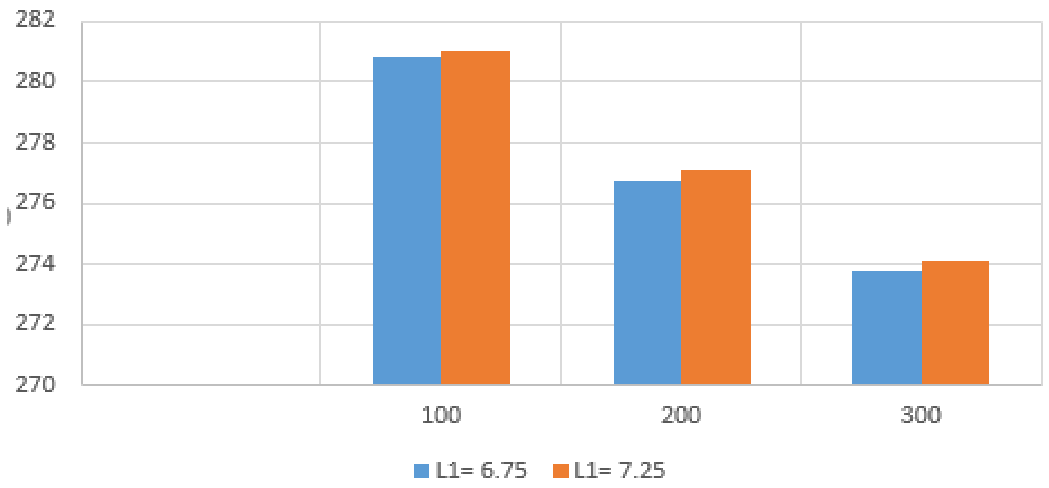

Figure 20: Comparison of temperature contour of Case 1 and Case 2

Case 3 and case 4

Below mentioned graph represent linear change in temperature contour with respect to time for case 3 and case 4.

Time	Case 3 – L3 =3.375	Case 4 – L3 = 3.625
100	280.604 [k]	280.729 [k]
200	276.254 [k]	276.592 [k]
300	273.182 [k]	273.439 [k]

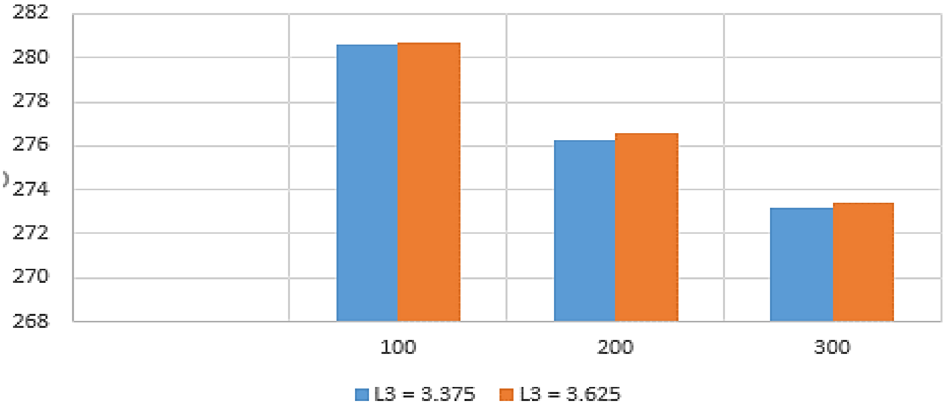

Figure 21: Comparison of temperature contour of Case 3 and Case 4

Case 5 and case 6

Below mentioned graph represent linear change in temperature contour with respect to time for case 5 and case 6.

Time	Case 5 – L4 = 2.46	Case 6 – L4 = 2.71
100	280.435 [k]	280.773 [k]
200	275.739 [k]	276.067 [k]
300	272.977 [k]	273.131 [k]

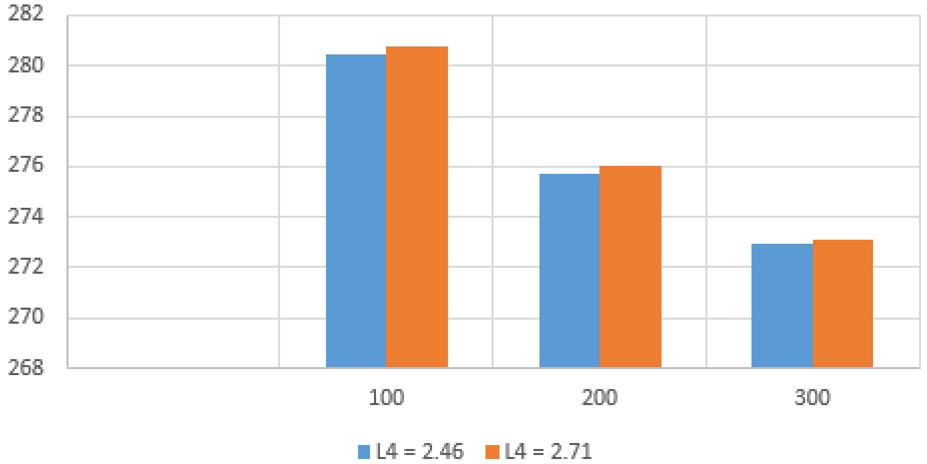

Figure 22: Comparison of temperature contour of Case 5 and Case 6

V. CONCLUSION

It is recommended that a Tree-like Branching Fin be used to improve the system's thermal transmission. The average melting temperature of PCM was compared with experimental tests to verify the numerical model, and a satisfactory agreement was observed. Thermophysical parameters of the HNPCM have also been estimated using the mathematical equations.

The following conclusions are drawn from this investigation:

- Solidification time is depending on conduction and convection through PCM material.
- PCM material has less viscosity. Convection effect is dominant at start, it decreases as time passes. Because of this in starting it cool down faster in starting and cooling time got increased as the time passes.
- In Case 6 – L4 = 2.71 mm solid fraction value is 0.525 in 300 sec which is better than remaining cases.

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