Investigation of mass and heat transfer process in latent heat storage

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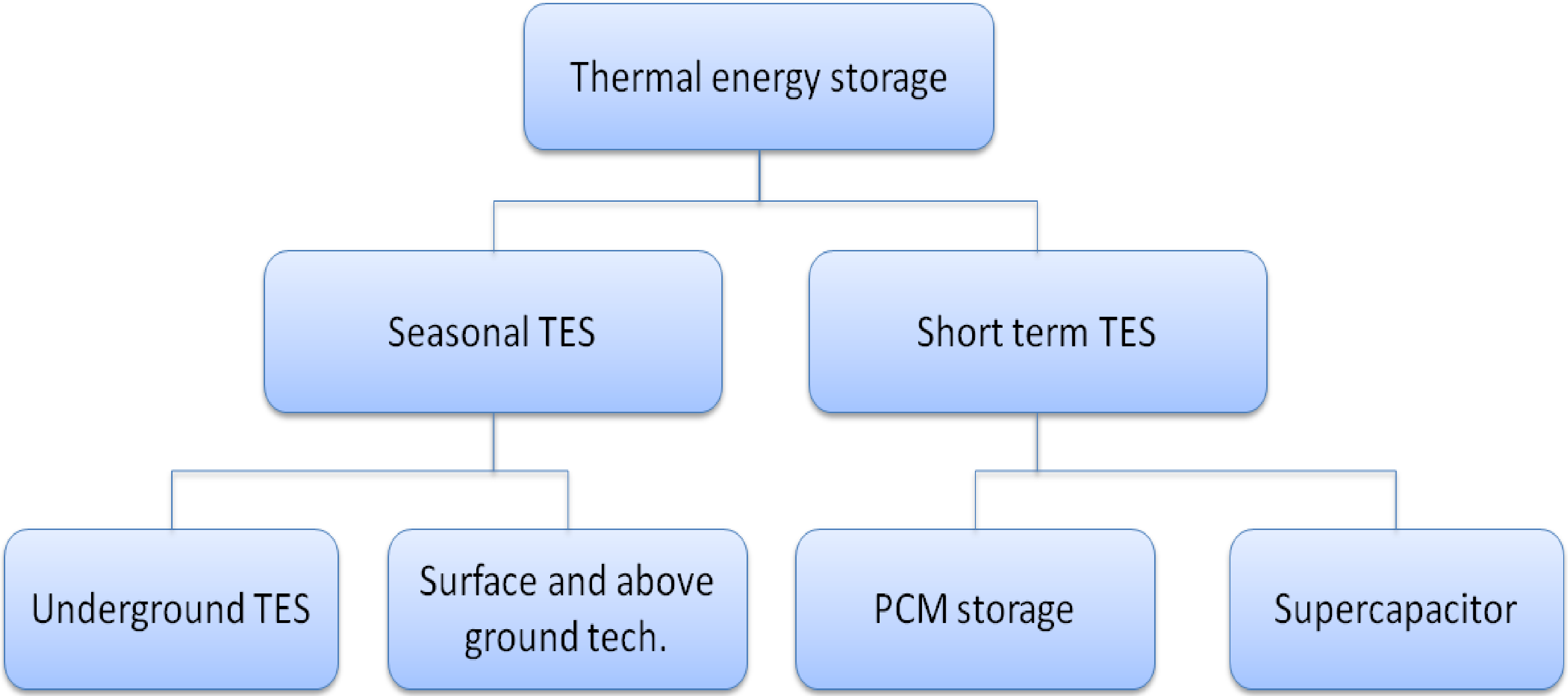
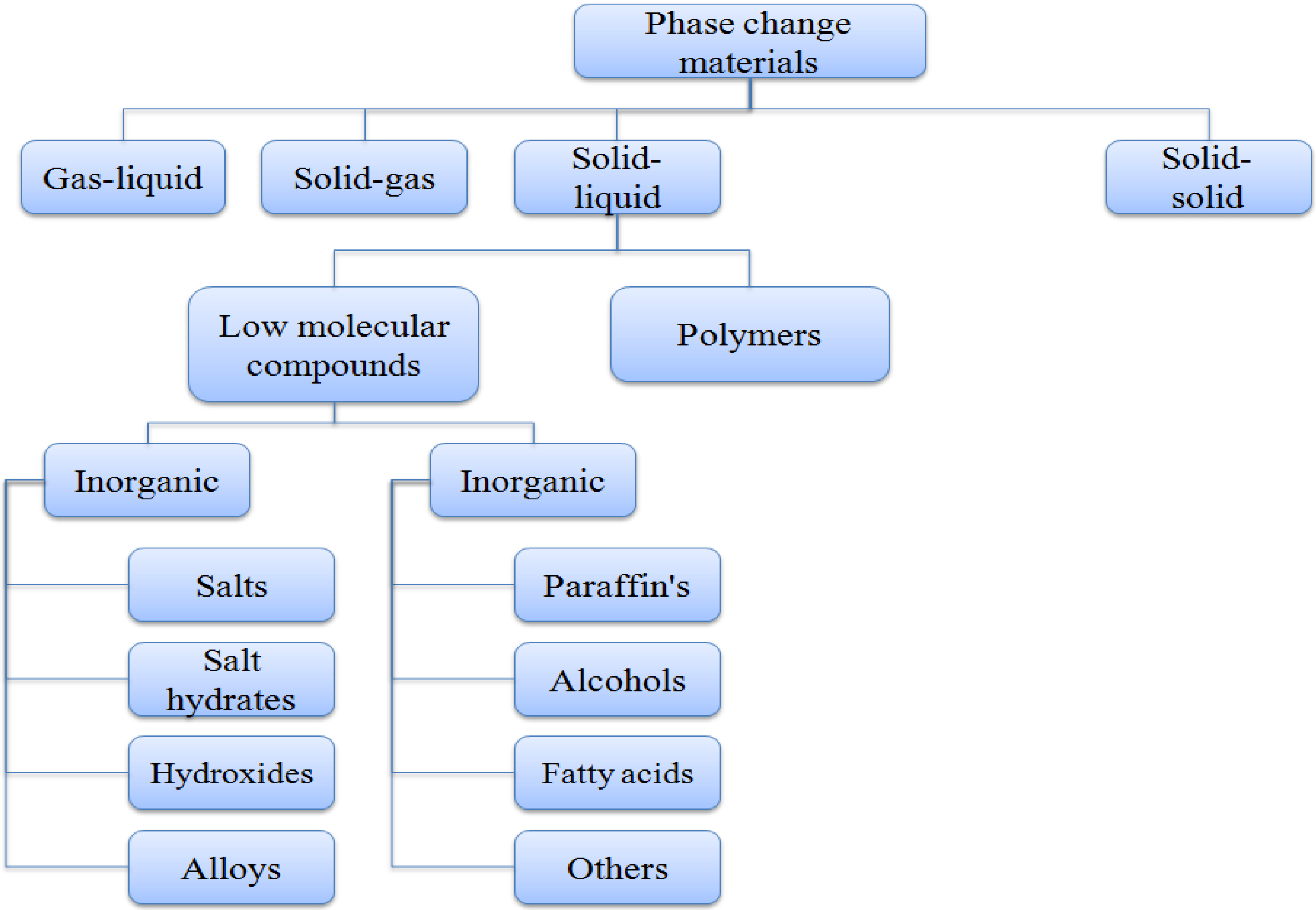
- **Relevance of the research topic:** The use of alternative energy sources will significantly reduce the consumption of natural resources currently considered as the main sources of energy, which will make it possible to reduce emissions to the atmosphere and keep the planet clean for future generations. Solar energy is the cleanest source of energy and has great potential for use in heating, ventilation and air conditioning of buildings, etc.
- **Purpose of the work:** The purpose of the dissertation is the experimental and numerical study of mass and heat transfer processes in **latent heat storage**.
- **Task of the study:** development of a mathematical model of mass and heat transfer process in latent heat storage.
- **Object of investigation: latent heat storage**.
- **The subject of the study:** mass and heat transfer processes in latent heat storage.
- **Research methods:** experimental methods and mathematical modeling.
- **Theoretical and practical significance of the research:** the designed and installed design of latent heat storage can be used for determining of thermal properties of the soil, which will be used as storage of solar thermal energy.

RENEWABLE ENERGY

Classified of thermal energy storage by the time of insanity



PHASE CHANGE MATERIALS (PCM)



Latent heat storage material

Thermal properties:

- a melting temperature in the desired operating range,
- a high phase transition latent heat per unit volume,
- a high specific heat, to provide significant additional SHS,
- high thermal conductivity of both phases.

Physical properties:

- a small volume change on phase transformation,
- a low vapour pressure at the operating temperature,
- favourable phase equilibrium,
- congruent melting of the PCM,
- a high density

Kinetic properties:

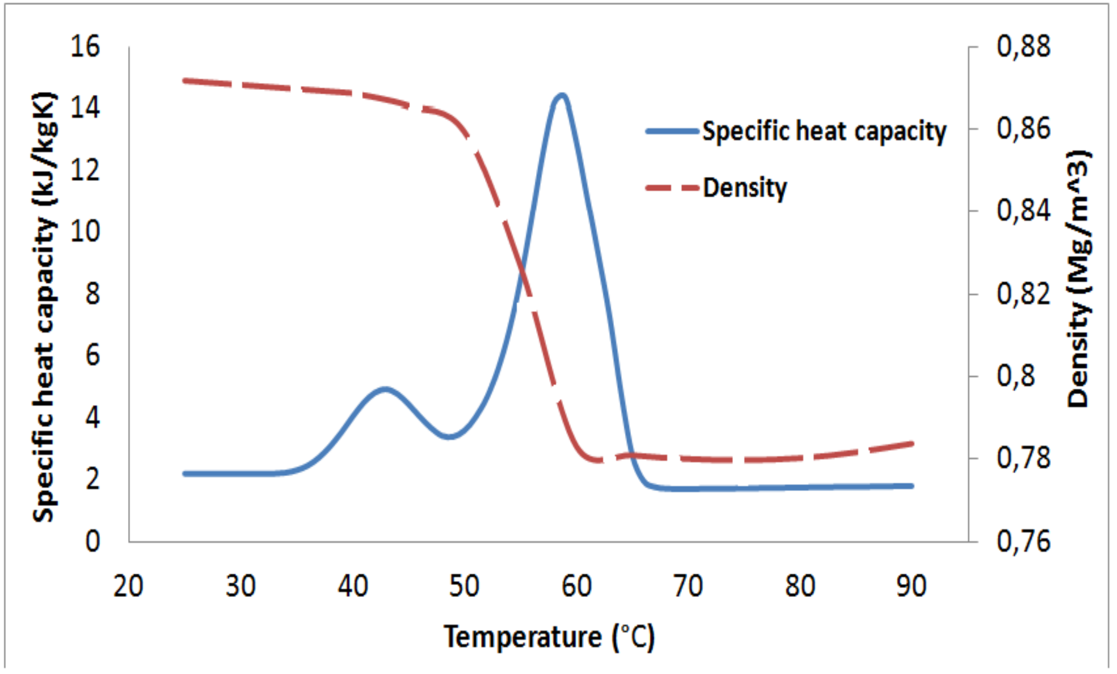
- no supercooling
- a high nucleation rate
- an adequate rate of crystallization

Chemical properties:

- long-term chemical stability
- a completely reversible freeze/melt cycle
- compatibility with the construction materials
- no corrosion influence on the construction materials
- it should be non-toxic, non-flammable and non-explosive to ensure safety

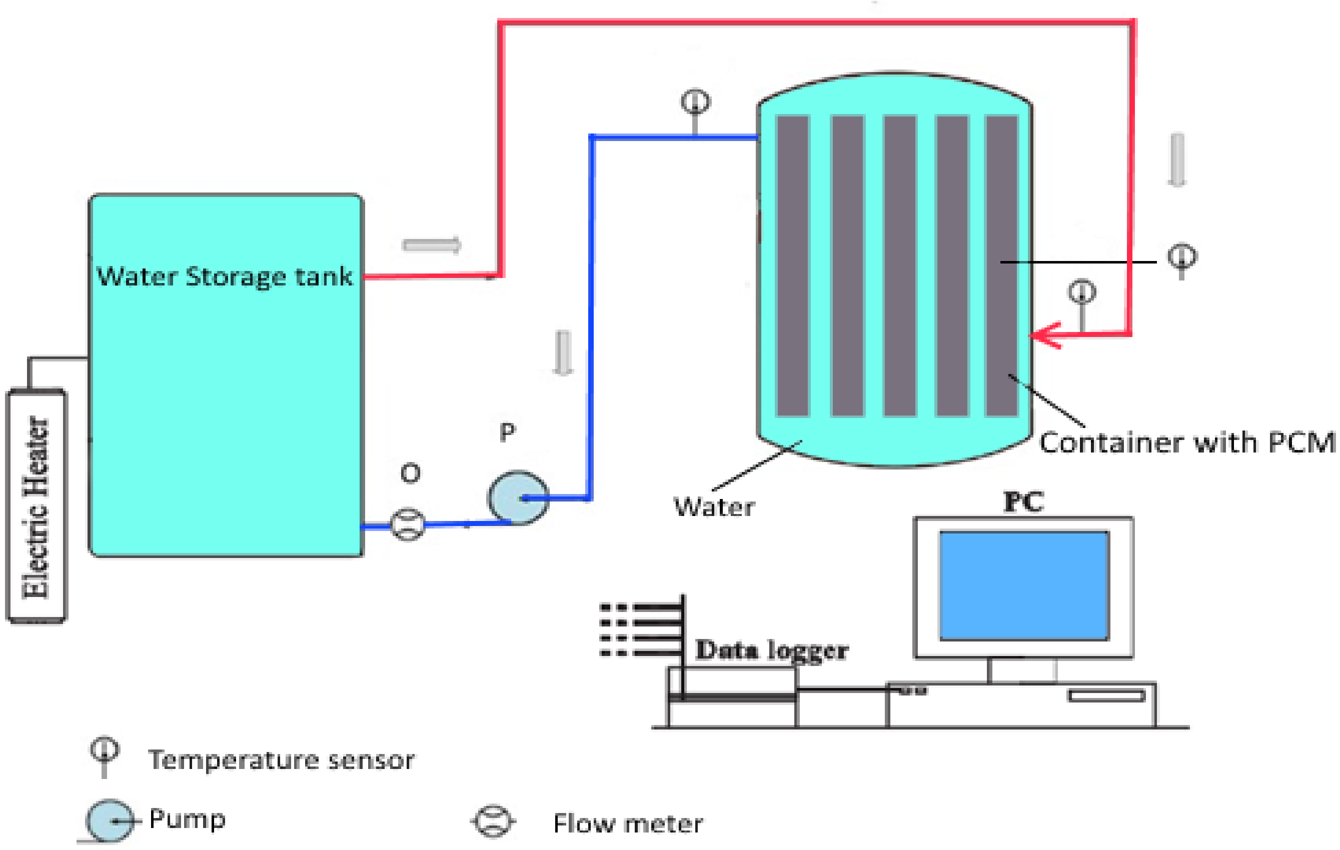
EXPERIMENTAL STUDIES OF PCM
Characterization of PCM

- Thermal properties of paraffin E53

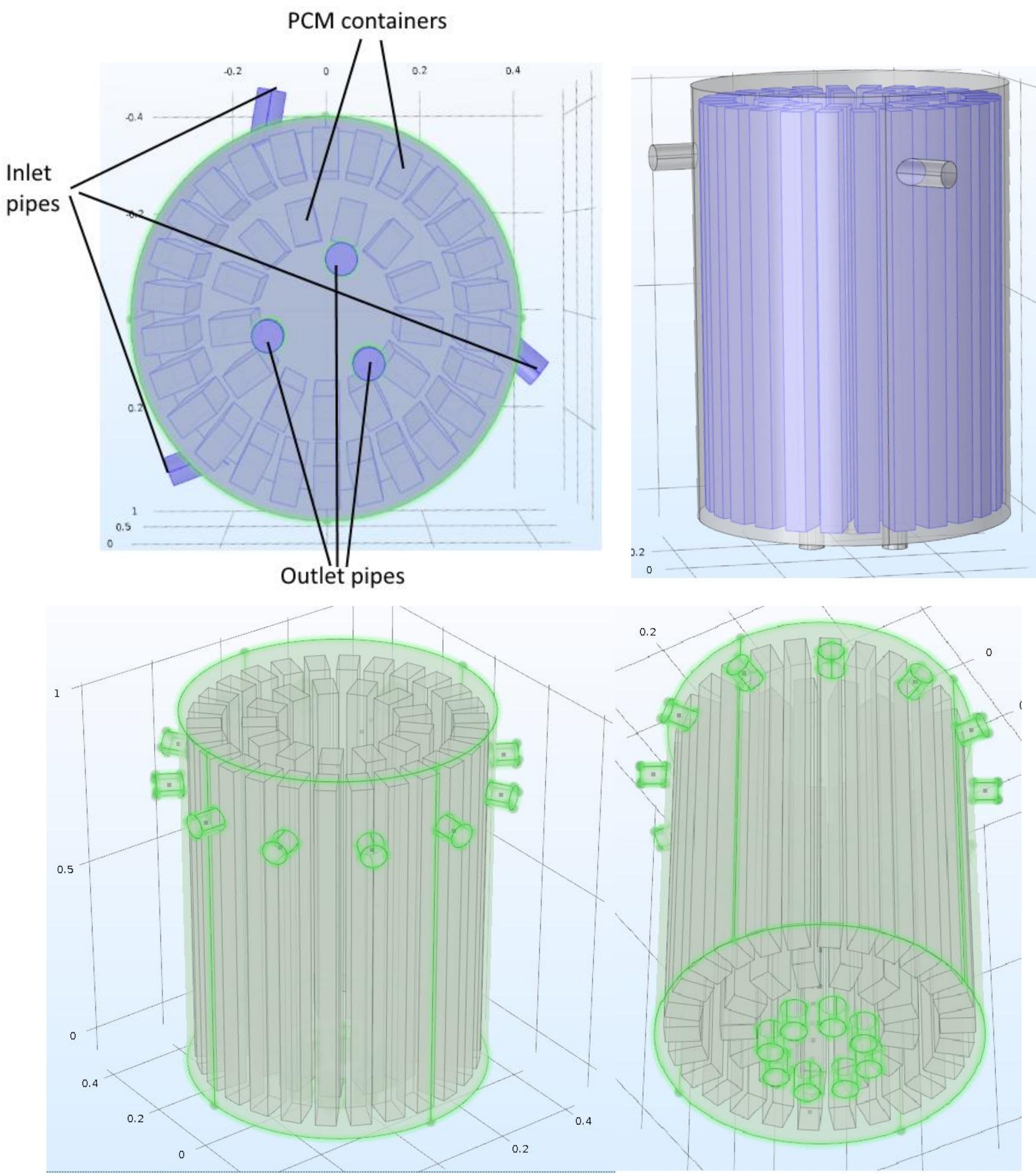


Methodology of test

- Experimental setup

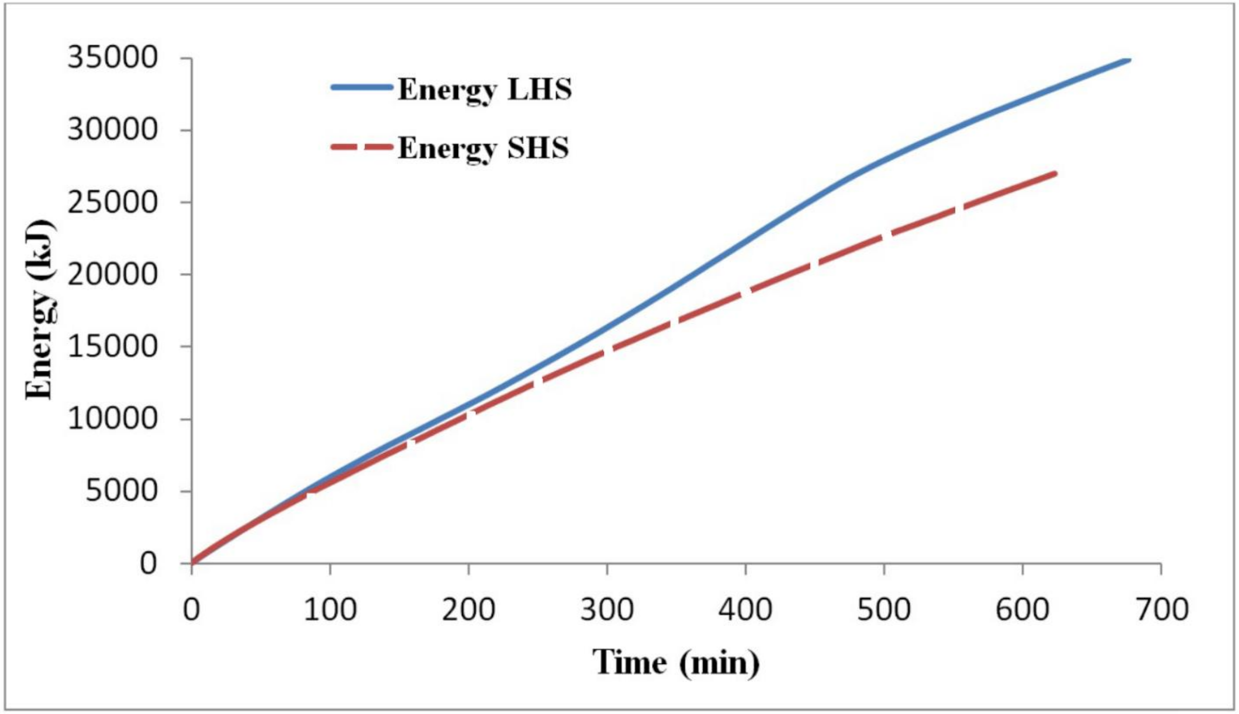


Design features of the latent heat storage

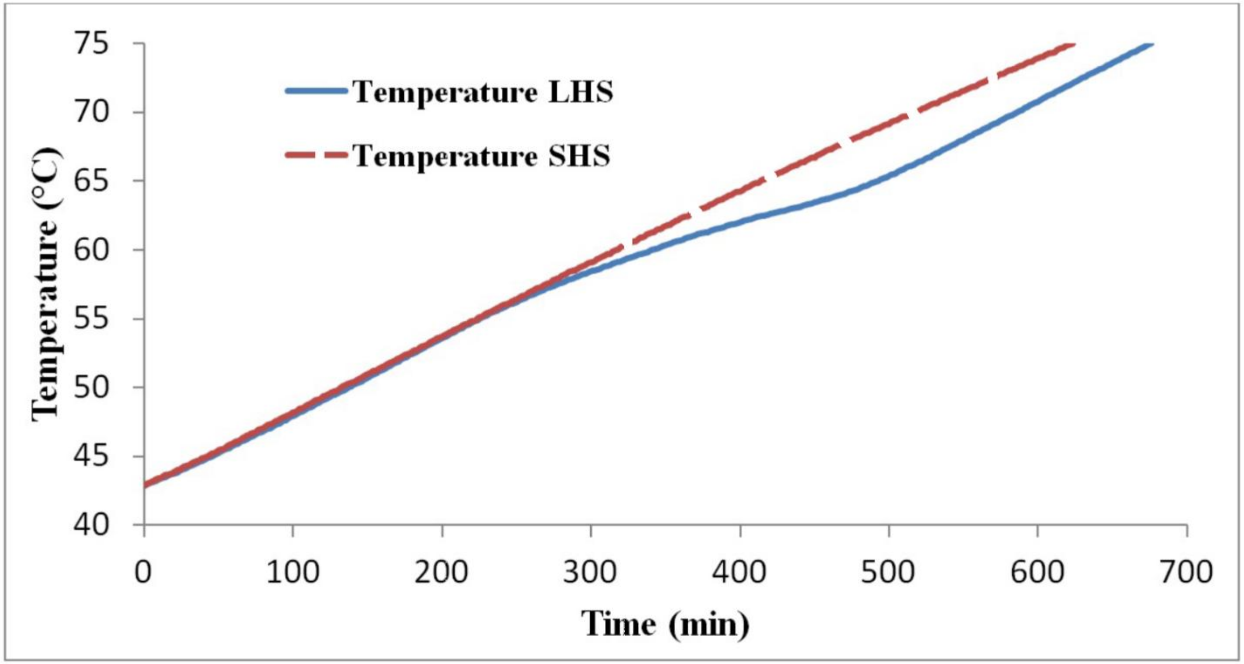


Experimental results

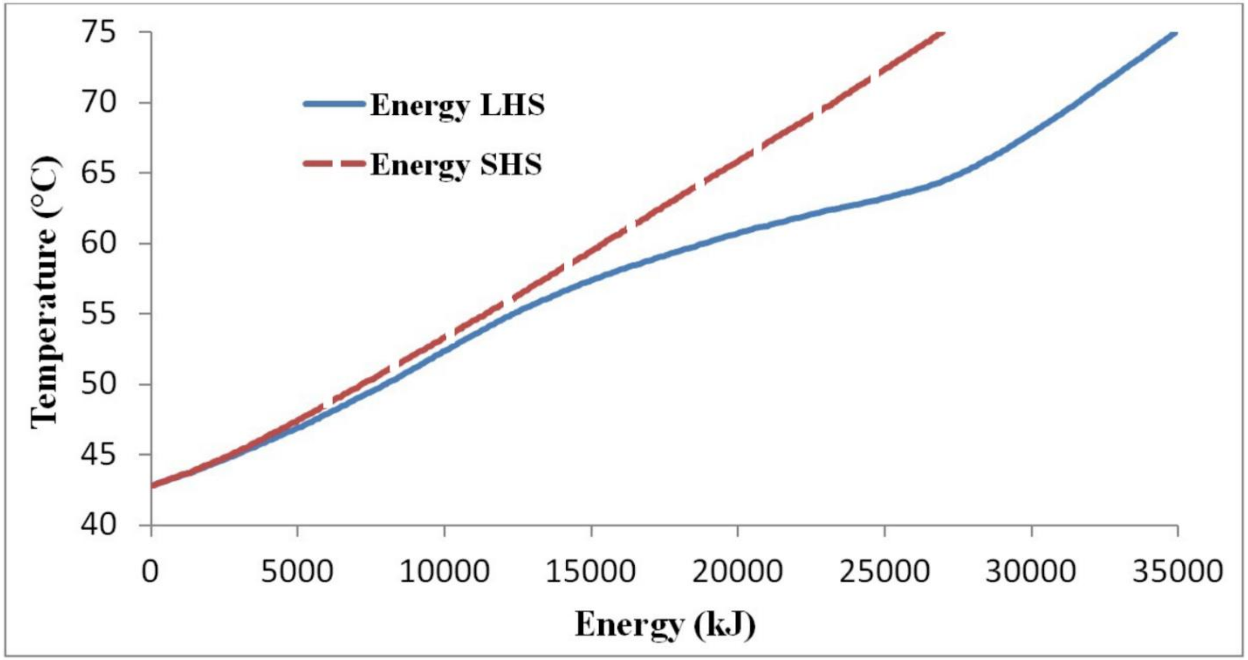
- Comparison of Cumulative energies in LHS and SHS systems



Temperature histories of HTF during SHS and LHS charging process

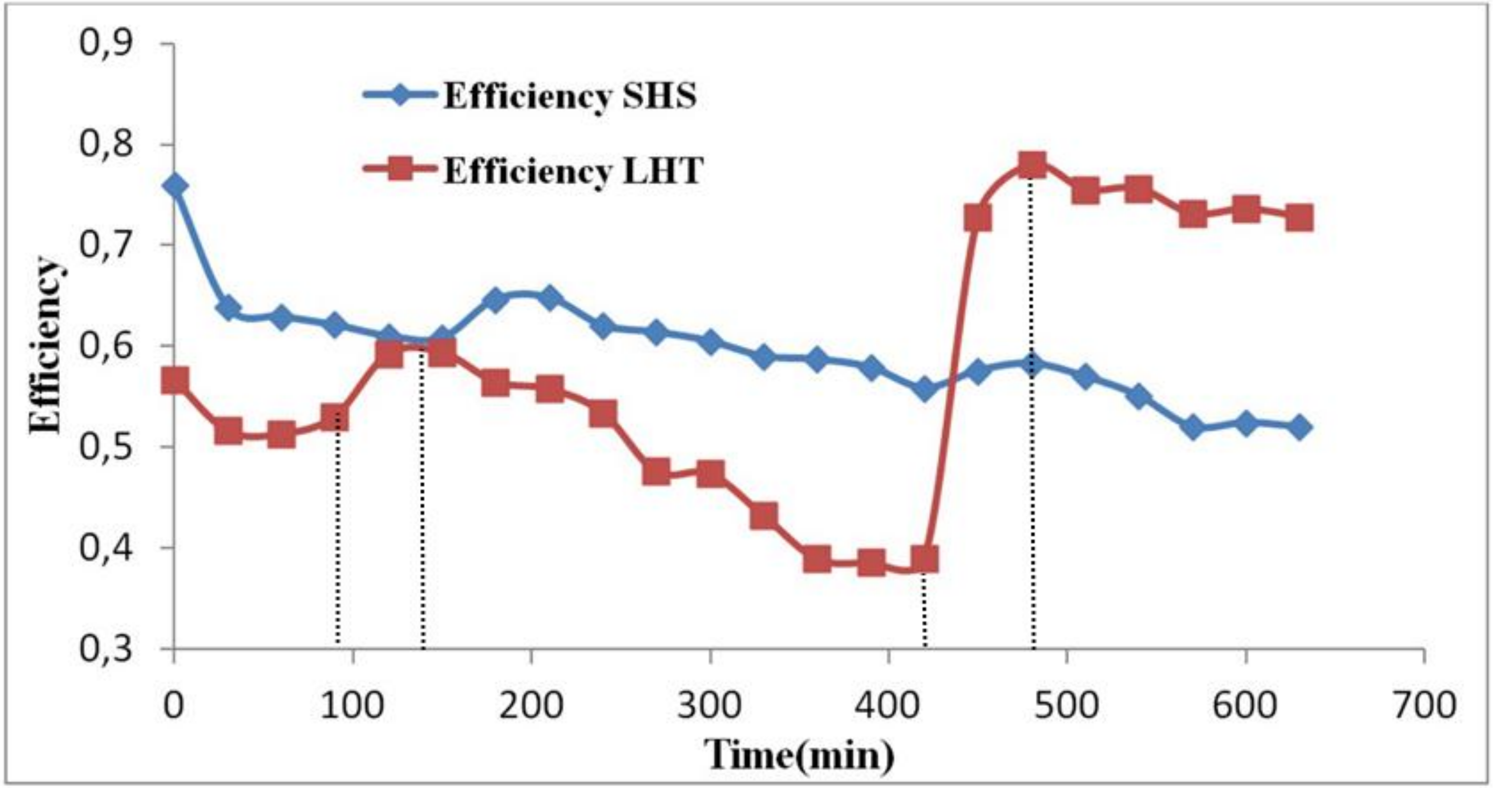


Temperature histories of HTF during SHS and LHS charging process



Effectiveness of heat exchanger system during charging of LHS and SHS

$$\varepsilon = \frac{T_{in} - T_{out}}{T_{in} - T_{HE}}$$



Mathematical model

Method of enthalpy

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\partial}{\partial x}\left(\nu\frac{\partial u}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu\frac{\partial u}{\partial y}\right)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = \frac{\partial}{\partial x}\left(\nu\frac{\partial v}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu\frac{\partial v}{\partial y}\right) + \rho g\beta(T - T_C)$$

$$\rho c_p\left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = \frac{\partial}{\partial x}\left(\nu\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(\nu\frac{\partial T}{\partial y}\right)$$

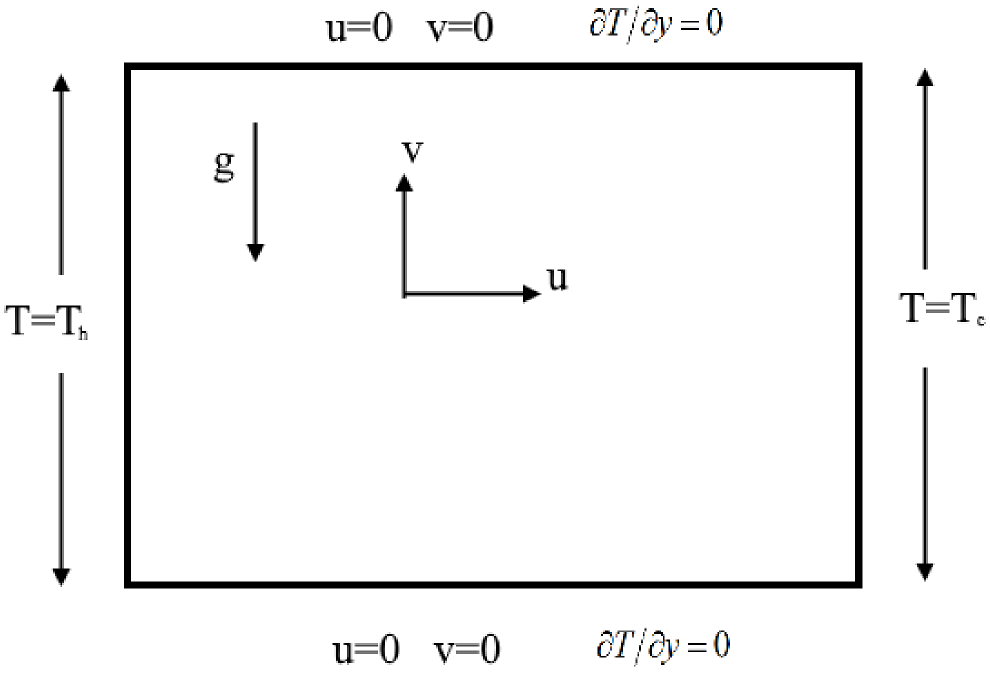
$$H = c_p T$$

$$\rho\frac{\partial H}{\partial t} + u\frac{\partial H}{\partial x} + v\frac{\partial H}{\partial y} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)$$

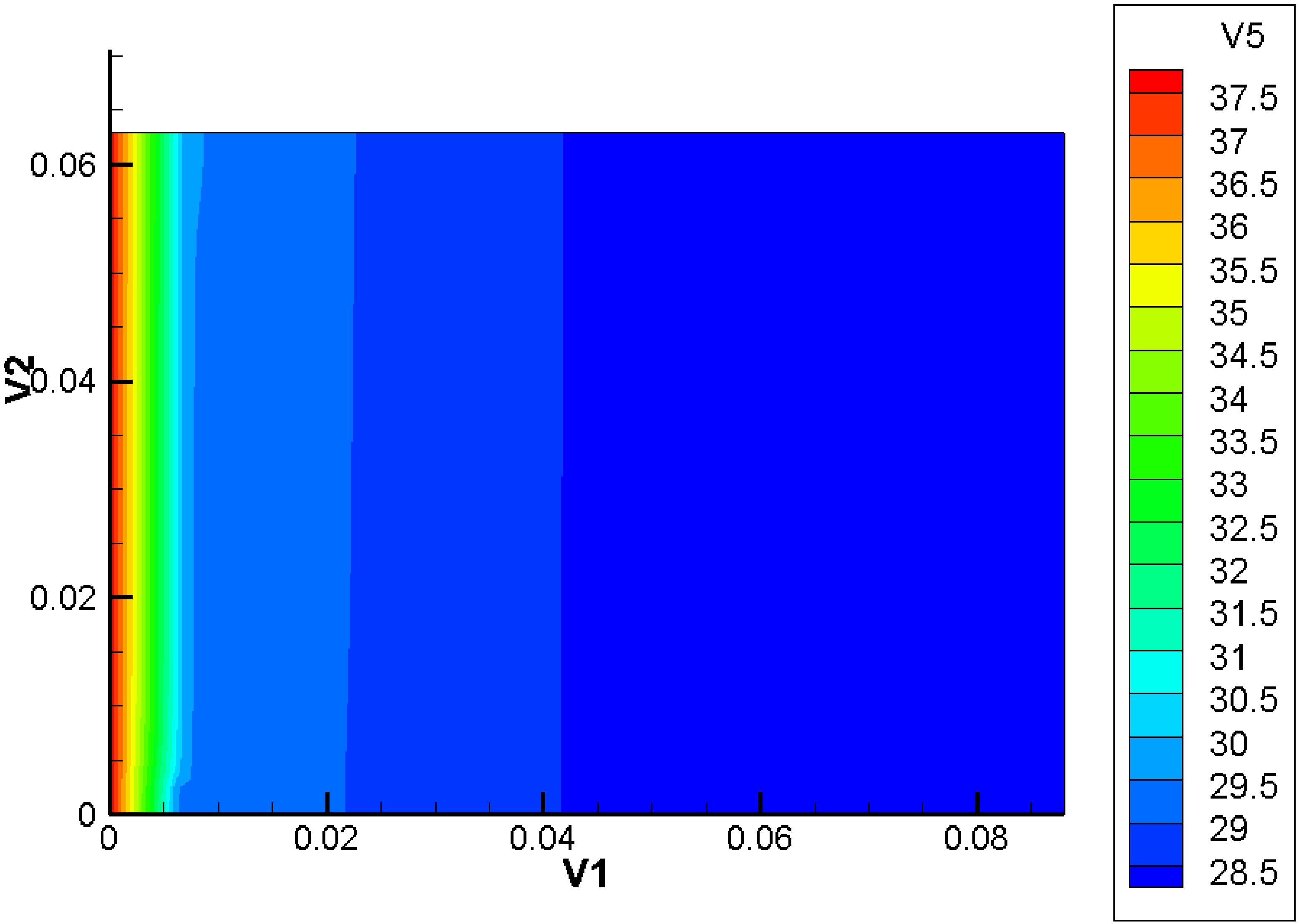
$$T = \begin{cases} H/c, & H \le cT_m \\ T_m, & cT_m \le H \le cT_m + L \\ (H - L)/c, & H > cT_m + L \end{cases}$$

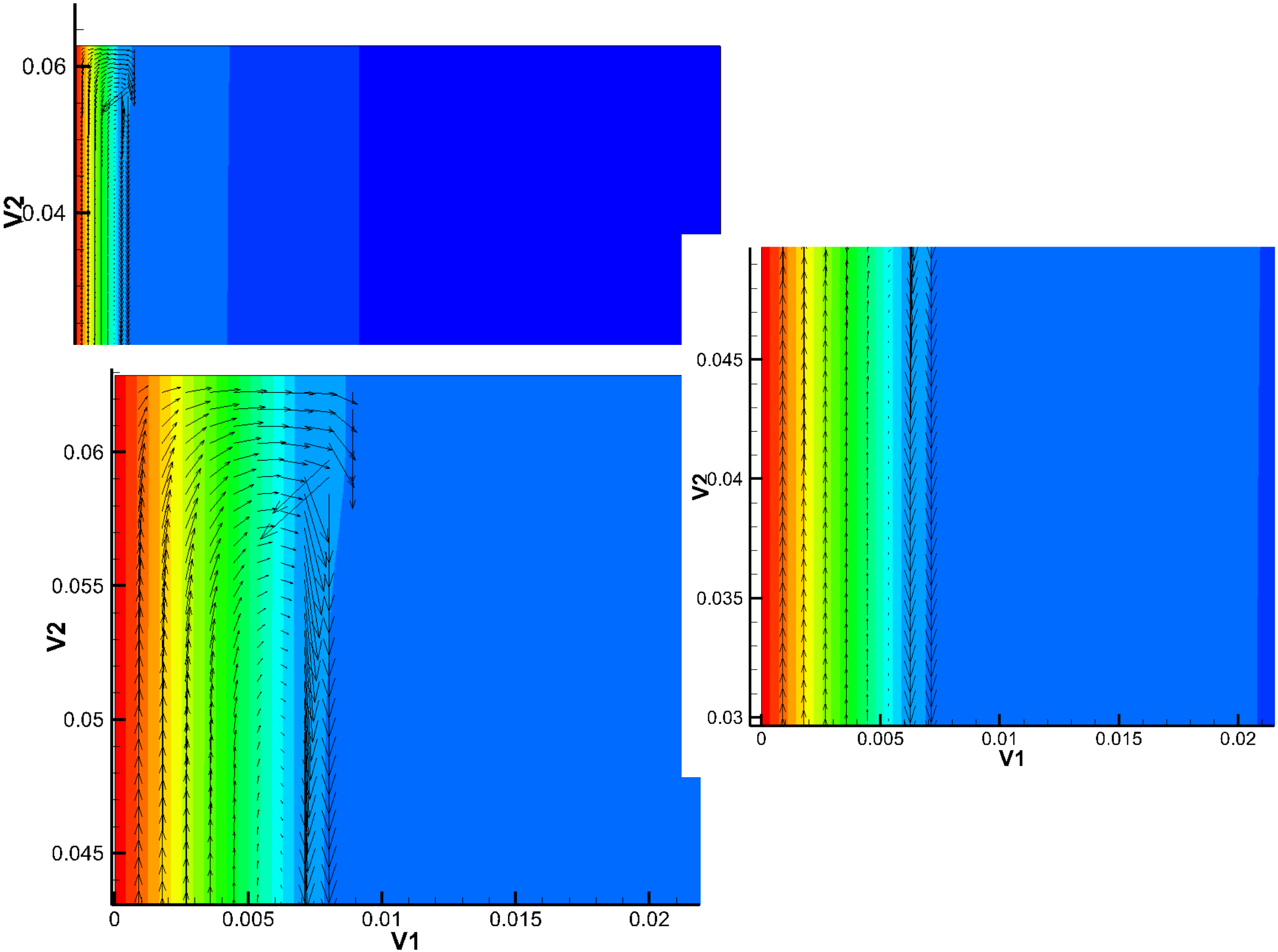
$$H(T) = \begin{cases} cT & T < T_m \\ cT + L & T > T_m \end{cases}$$

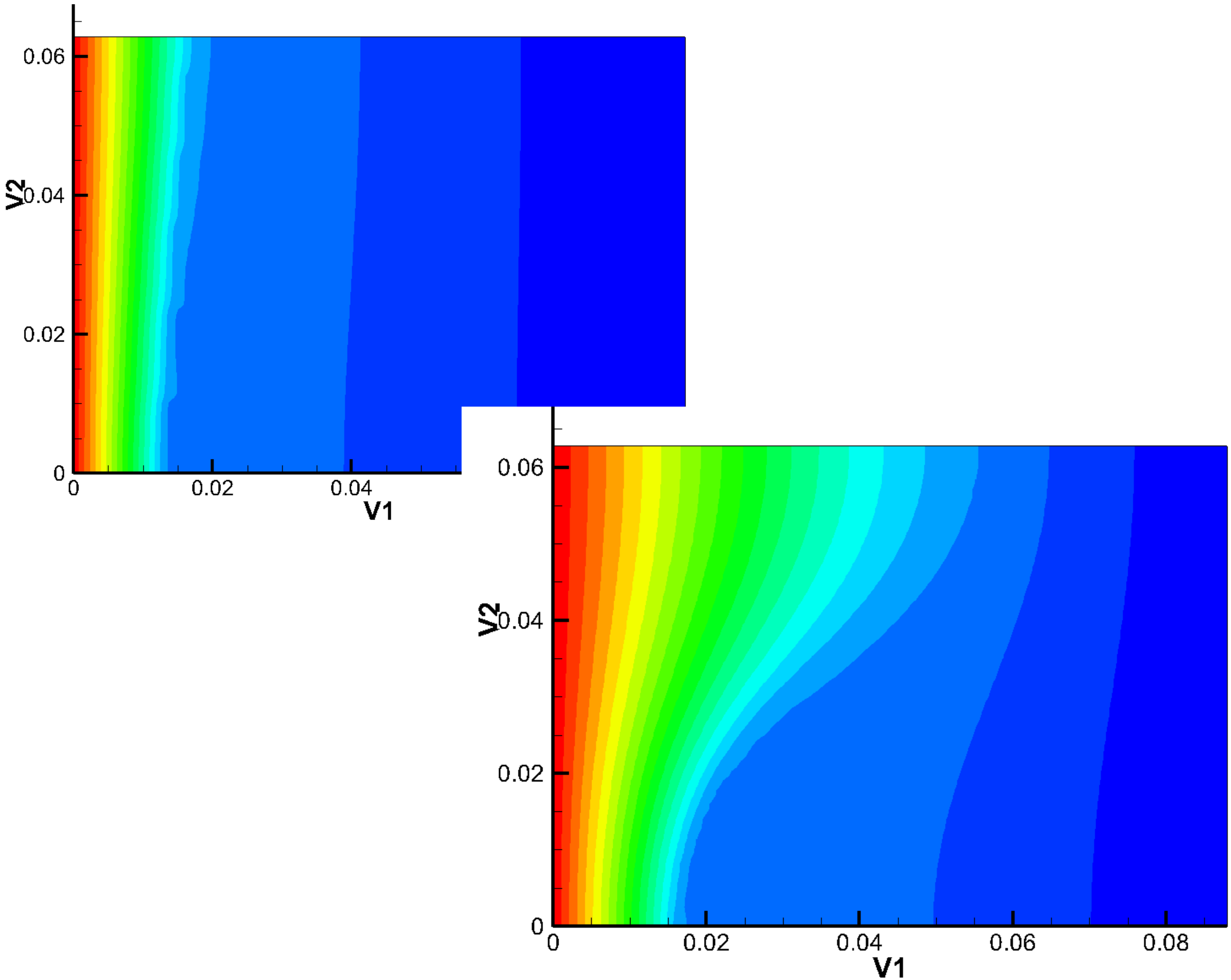
Initial and Boundary conditions



Results


V5
37.5
37
36.5
36
35.5
35
34.5
34
33.5
33
32.5
32
31.5
31
30.5
30
29.5
29
28.5
V2
0.06
0.04
0.02
0
0
0.02
0.04
0.06
0.08
V1


0.06
0.04
V2
0.06
0.055
0.05
0.045
V2
0
0.005
0.01
0.015
0.02
V1
0.045
0.04
0.035
0.03
V2
0
0.005
0.01
0.015
0.02
V1



V2
0.06
0.04
0.02
0
0.02
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V1
V2
0.06
0.04
0.02
0
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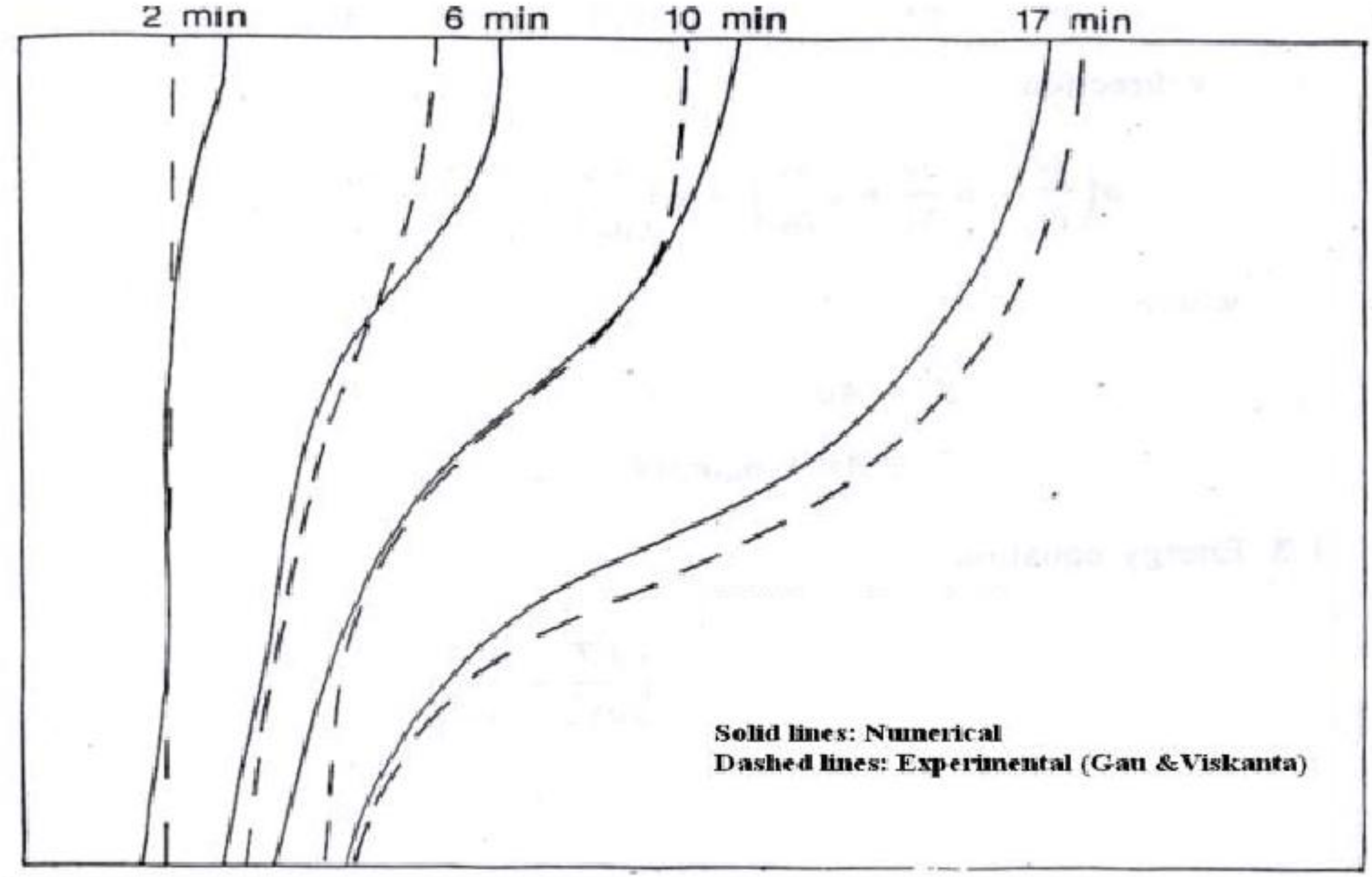
0.02
0.04
0.06
0.08
V1


2 min
6 min
10 min
17 min
Solid lines: Numerical
Dashed lines: Experimental (Gau &Viskanta)

Three-dimensional model for LHS

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0$$

$$\frac{\partial u}{\partial t} + (u \cdot \nabla) u = -\frac{1}{\rho} \nabla p + \nu \nabla^2 u + F$$

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u \cdot \nabla T = \nabla \cdot (k \nabla T)$$

$$k = \theta_1 k_{phase1} + \theta_2 k_{phase2}$$

$$c_p = \theta_1 c_{p,phase1} + \theta_2 c_{p,phase2} + L \frac{d\alpha}{dT}$$

$$\rho = \frac{\theta_1 \rho_{phase1} c_{p,phase1} + \theta_2 \rho_{phase2} c_{p,phase2}}{\theta_1 c_{p,phase1} + \theta_2 c_{p,phase2}}$$

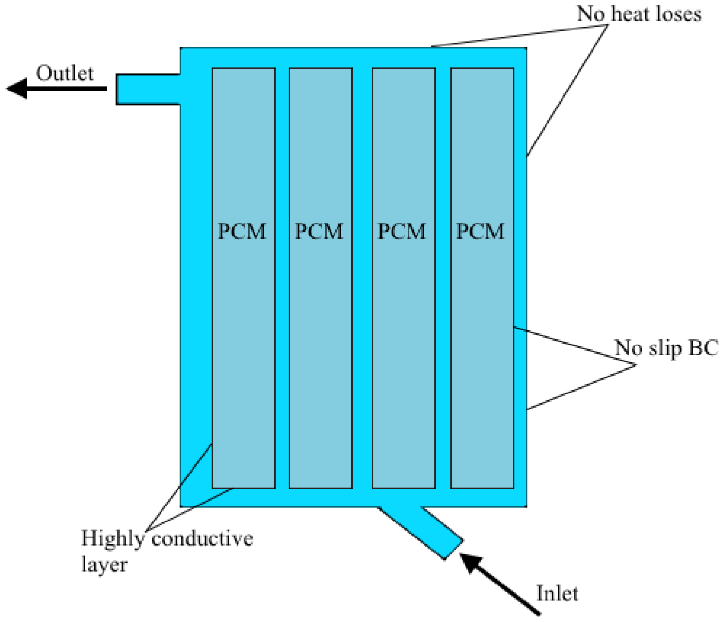
$$\theta_1 = 1 - \alpha \qquad \theta_2 = \alpha$$

$$\alpha = 0 \qquad T < T_{solid}$$

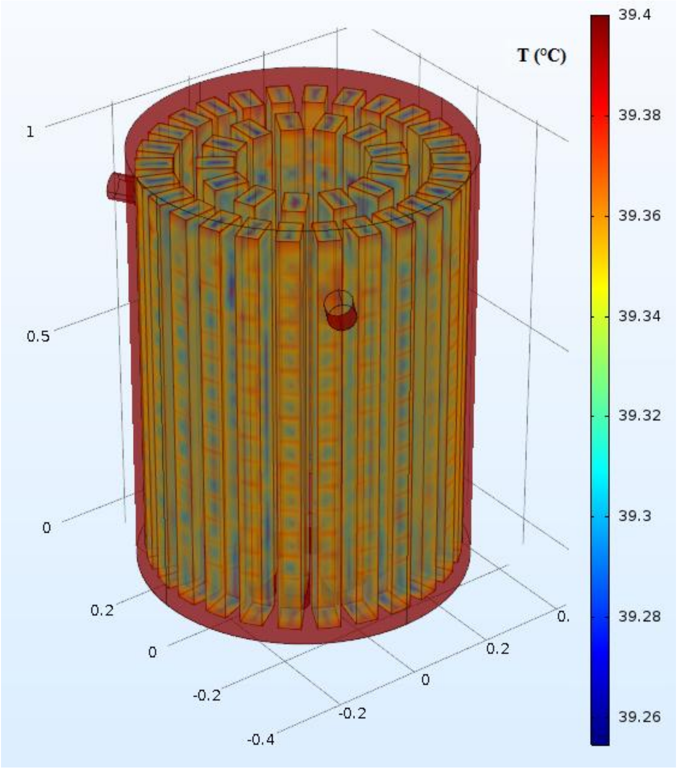
$$\alpha = \frac{T - T_{solid}}{T_{liquid} - T_{solid}} \qquad T_{solid} \le T \le T_{liquid}$$

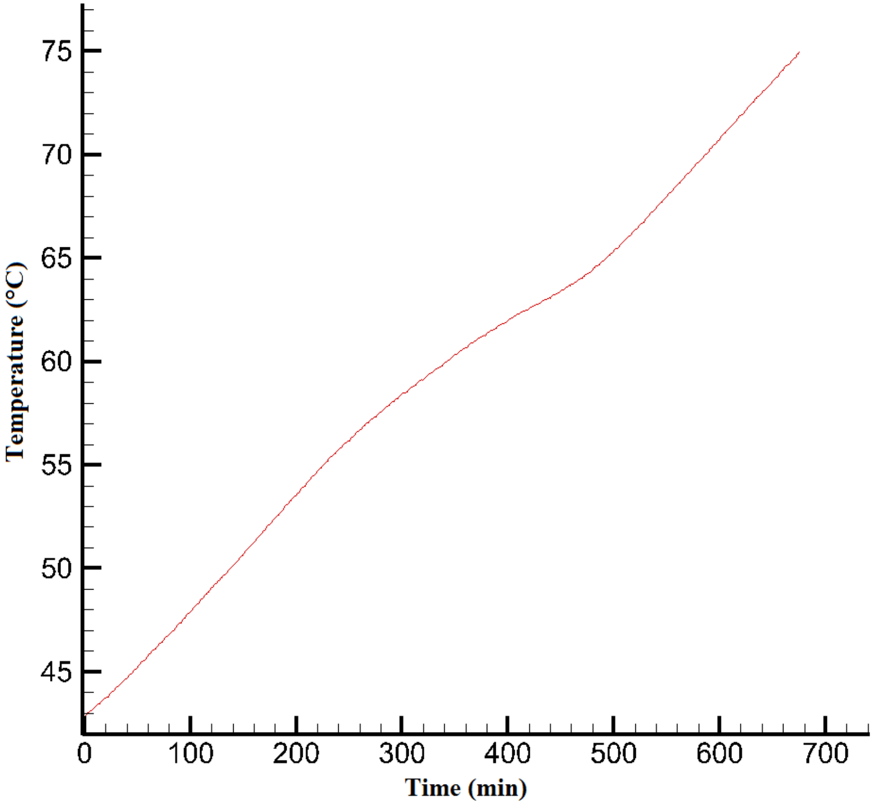
$$\alpha = 1 \qquad T > T_{liquid}$$

Boundary conditions

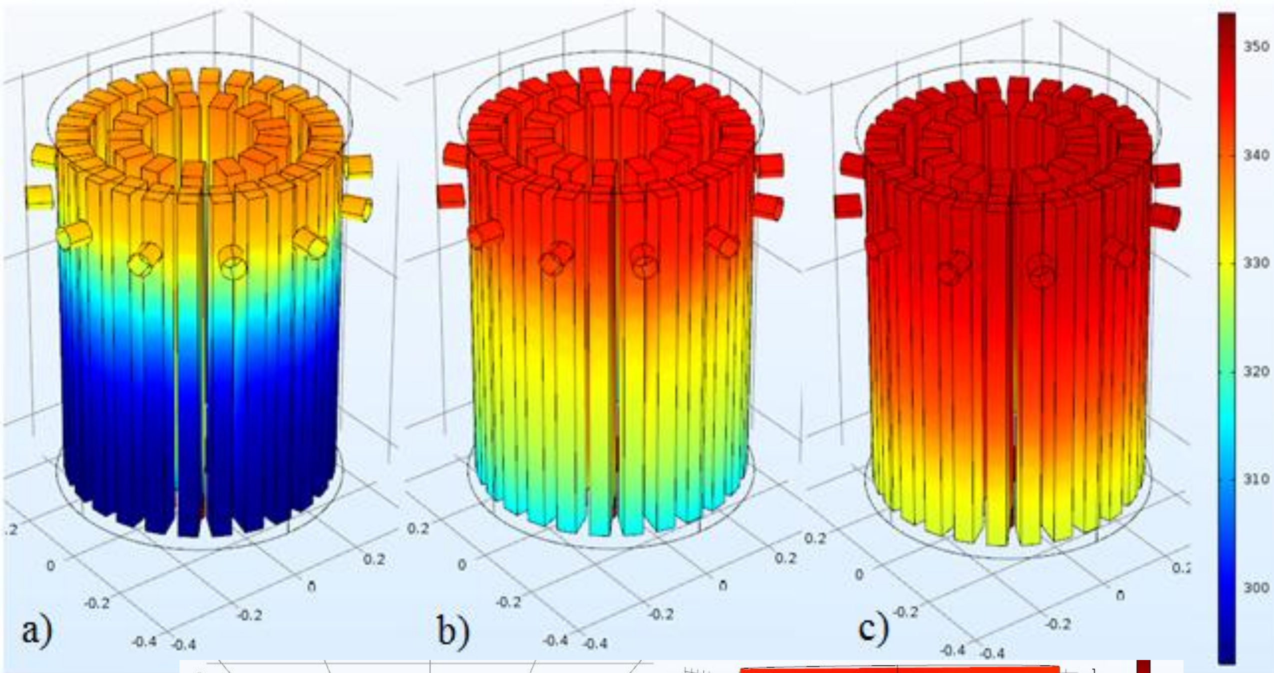


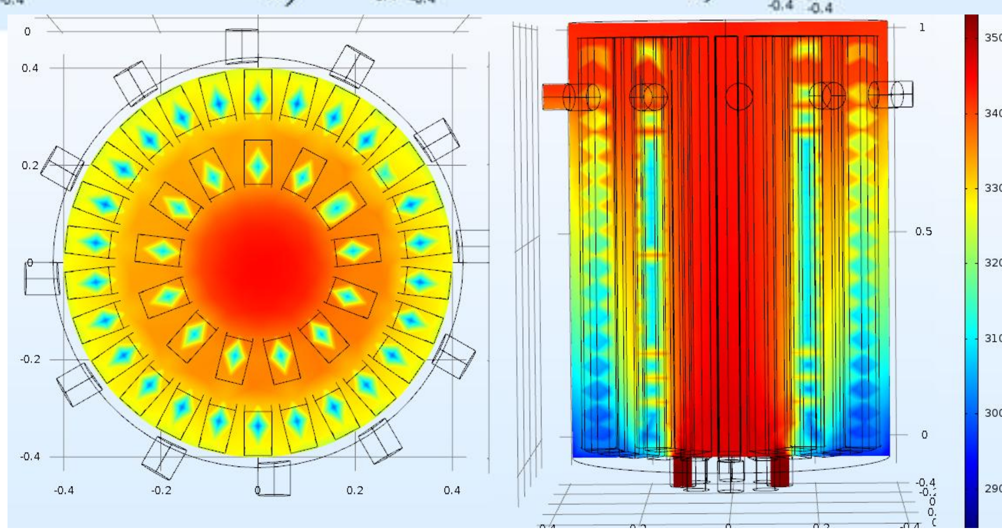
Initial conditions



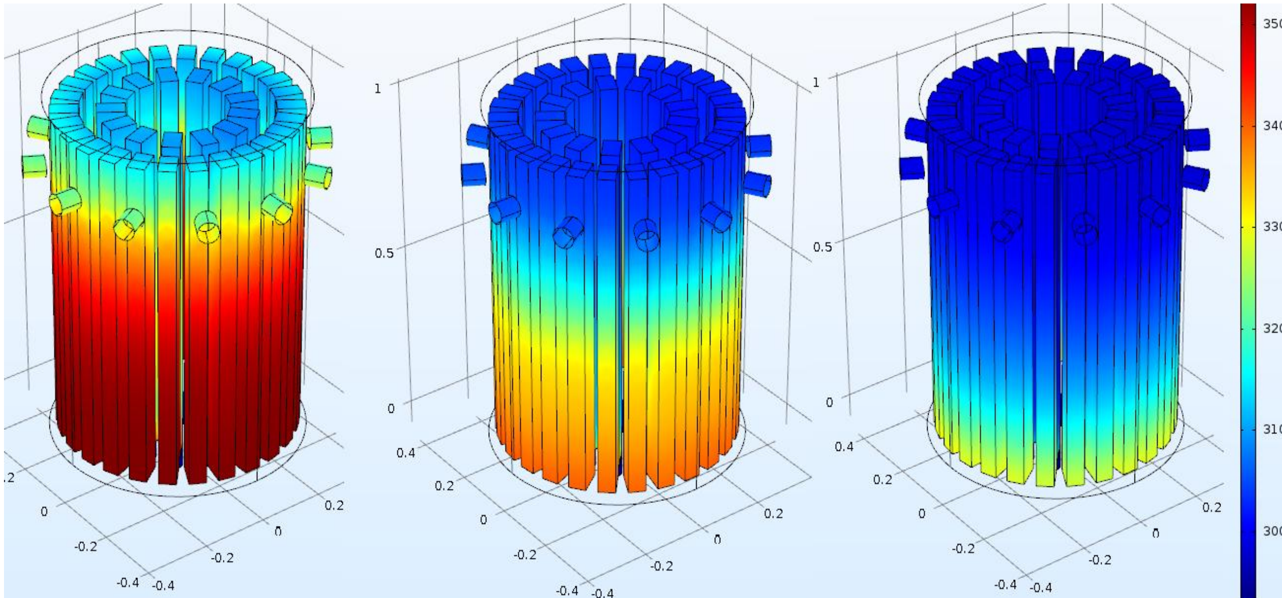


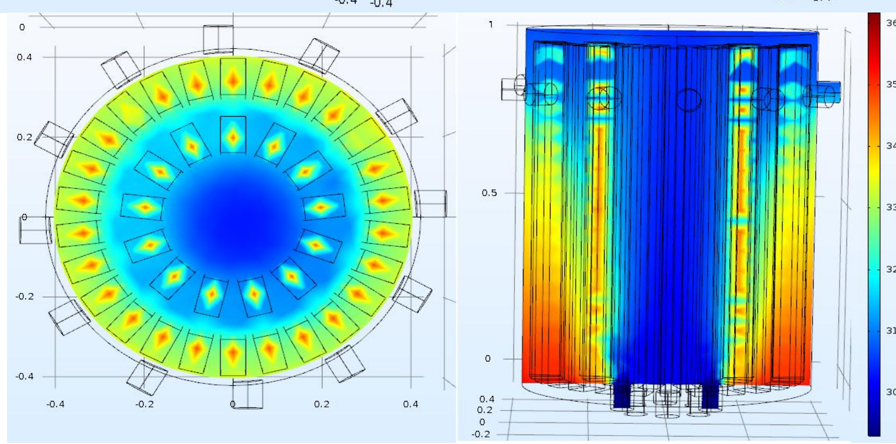
Results (Charging)



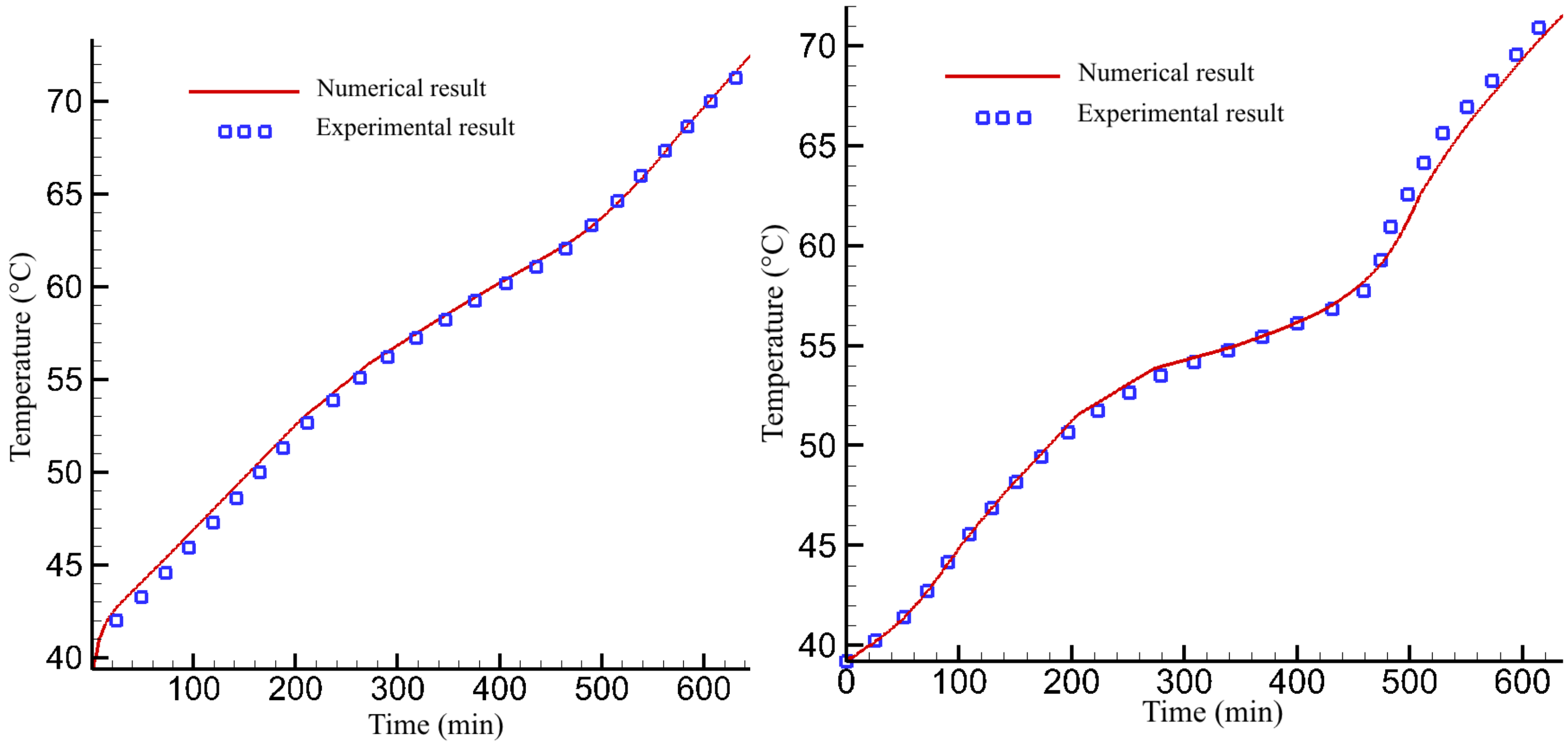


Results (Discharging)



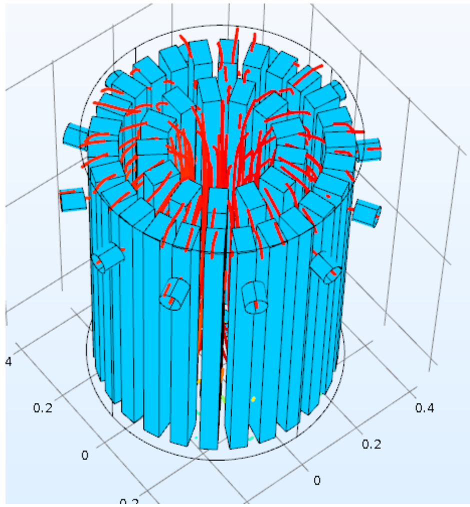


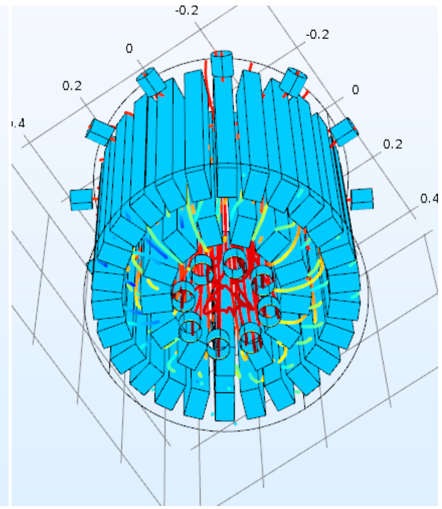
Comparison of numerical and experimental results



CONCLUSION

- The purpose of this study was to study one of the pilot LHS installations developed at the Technical University of Sofia, Plovdiv Branch (Bulgaria), from the point of view of numerical simulation methods. Based on the results of such numerical studies, a more effective LHS will be built for experimental studies at the Kazakh National University (Kazakhstan) Al-Farabi.
- we presented the processes of charging and discharging latent heat storage in terms of simulation tools, taking into account the physics of fluid flow and heat transfer in the tank and phase change processes in PCM containers. The phase transition temperatures and latent heat of melting / solidification were obtained from the experimental and applied to the purposes of numerical simulation.
- The results are illustrated in terms of the temperature field to examine how the PCM containers and flow rates were loaded to understand how the fluid flow process in the storage domain occurs. In addition, after that, the PCM containers were loaded, which were in the inner circle, loaded first in a short time and into containers with the outer circle. It can be concluded that the containers with the outer ring PCM are very close to the walls of the reservoir, so these areas do not allow to intensify the processes of fluid flow and heat transfer.
- The aim of the study was to find out how efficiently LHS based on E53 paraffins can store thermal energy compared to a tank with a similar size without PCM (for example, SHS). In addition, the LHS charging regime has been numerically studied in order to estimate the thermal field in the reservoir. Such an assessment allows to visualize the thermal field in PCM containers, as well as in the storage tank, including in the flow field of the heat transfer fluid, and to fully understand the charging processes.


0.2
0
0.4
0.2
0


-0.2
-0.2
0
0
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0.4