SIU Southern Illinois University CARBONDALE

A STUDY ON THE THERMAL ENERGY STORAGE SYSTEM USING MULTIPLE PCMS

ASES SOLAR 2019
August 5-9, 2019 | Minneapolis, MN

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Abstract

Application of Phase Change Materials (PCMs) for energy storage has been found to exhibit high potential due to the high energy storing capacity. This study investigated the performance of multiple PCMs in a number of energy storage systems. The effects of conduction and natural convection on these systems were also studied. Numerical simulations based on the conservation equations were conducted on the defined geometries. It was found that natural convection has significant positive effects on the heat transfer in these systems. It was also found that application of multiple PCMs generally enhances performance. However, different effects were observed on the heat transfer mechanisms. The parallel configuration enhances conduction but suppresses convection while the series configuration does the opposite. It was also found that the vertical orientation enhances convection more than the horizontal orientation for the multiple PCMs configurations. Energy storage with the series configuration in vertical orientation was found to be superior with 47% and 60% reduction in complete melting time respectively, compared to the single configuration in vertical orientation and to the single and series configurations (horizontal and vertical) in the conduction only case.

Geometry

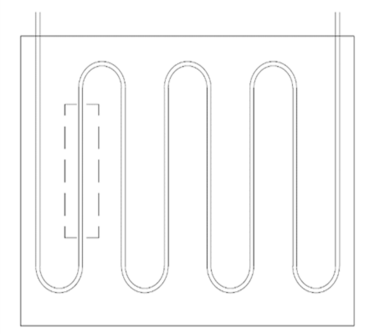

FIGURE 1: PCM CONTAINER WITH CIRCULATING WORKING FLUID

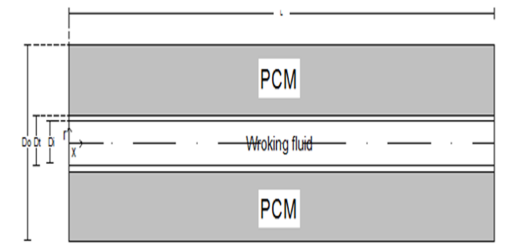

FIGURE 2: GEOMETRY UNDER INVESTIGATION

Introduction

Energy Crisis

- Increased Energy Demand
- Fossil Fuels Depletion
- Environmental and Ecological Concerns

Renewable Energy

- Solar, Wind, Hydro, …
- Present high potential to address energy challenges

Obstacle

- Fluctuation nature
- Efficient means of energy storage are needed

Thermal Energy Storage (TES)

- Reasonable Choice when considering Solar Energy
- Classified into three methods [1]:
  1. Sensible Heat Storage
  2. Thermophysical Storage
  3. Latent Heat Storage Using Phase Change Materials (PCMs)

Phase Change Materials (PCMs)

Advantage

- Have High energy storing densities

Disadvantage

- Have low thermal conductivities leads to low heat transfer rates and hence slow energy storage and recovery processes

Thermal conductivity enhancement with additives

No.	Title	Authors	Remarks
2	Heat transfer characteristics of phase change nanocomposite materials for thermal energy storage application	Li et al.	• Multi walled carbon nanotube, Graphite and Graphene dispersion enhancement by use of Poly Vinyl Pyrrolidone • 5% additives: strong influence on melting point and latent heat of steric Acid but reduced storage capacity
3	Thermal enhancement of paraffin as a phase change material with nanomagnetite	Sahan and Paksoy	• Nanomagnetite "Fe_3O_4" with Paraffin • 10% increment in heat storage capacity • Melting point range: 46-48ºC
4	Latent heat reduction mechanisms and a numerical study of effective thermal storage performance	Zabalegui et al	• MWCNT dispersed in Paraffin • Nano particles enhance thermal conductivity • But reduce latent heat of fusion.

Use of Multiple PCMs

No.	Title	Authors	Remarks
5	Experimental evaluation at pilot plant scale of multiple PCMs (cascaded) vs. single PCM configuration for thermal energy storage	Peiro et al	• D-Mannitol and Hydroquinone • Melting temp: 150 – 200ºC • 19.36% enhancement • Working fluid inlet and outlet temp difference is more uniform
6	Comparison between the single-PCM and multi-PCM thermal energy storage design	Aldoss and Rahman	• Spherical capsules filled with PCMs • M-PCMs enhances TES performance • No significant enhancement with applying more than three stages
7	Thermal energy charging behavior of a heat exchange device with a zigzag plate configuration containing multi-phase-change-materials	Wang et al	• M-PCMs strengthen charging process • PCMs with unequal mass ratios produce more enhancement • The larger the melting points difference the better

Configurations and Properties

- Three configurations of PCM were studied namely:
  (a) Single PCM configuration
  (b) M-PCMs in series configuration
  (c) M-PCMs in parallel configuration.
- Three PCMs were considered with
  - Melting temperatures that range from 430 to 520 K
  - Thermal conductivities from 0.4 to 0.5 W/m.K
  - Specific heats from 1400 to 1650 J/kg K
  - Densities from 1500 to 2000 Kg/m^3

Mathematical Model

- Heat transfer and fluid dynamics of this setup are governed by:
  - The mass conservation equation
  - The momentum conservation equations
  - The energy equation.
    - ❖ considered in the enthalpy form to account for the latent heat of melting
- Assumptions
  - No-slip boundary conditions
  - Negligible viscous dissipation and no heat loss to the surroundings.
  - All the thermophysical properties are constant except for the working fluid temperature dependent properties and the PCM's density
    - ❖ Boussinesq approximation is used to model variations in the momentum equation resulting from density variations in fluids.

Computational Method

- Transient numerical simulation of the governing equations using:
  - ANSYS FLUENT software
  - Finite volume method
  - "Solidification & Melting" model
  - "Semi-Implicit Method for Pressure Linked Equations" "SIMPLE" algorithm
  - pressure-based solver.

Model Validation

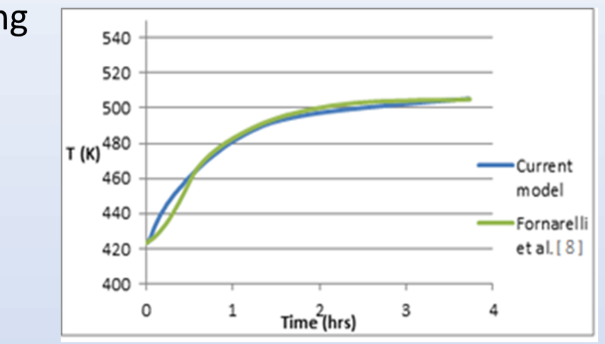

FIGURE 3: TEMPERATURE VARIATION WITH TIME AT A SPECIFIC LOCATION USING CURRENT MODEL AND FORNARELLI ET AL. [8]

Results

- **Conduction heat transfer only (Case 1)**
  - Single PCM configuration:
    - Complete melting time: 10 hours
  - M-PCMs in series configuration:
    - Promising start but no overall enhancement
    - Complete melting time: 10 hours
  - M-PCMs in parallel configuration:
    - Complete melting time: 6 hours
    - 40% reduction in melting time

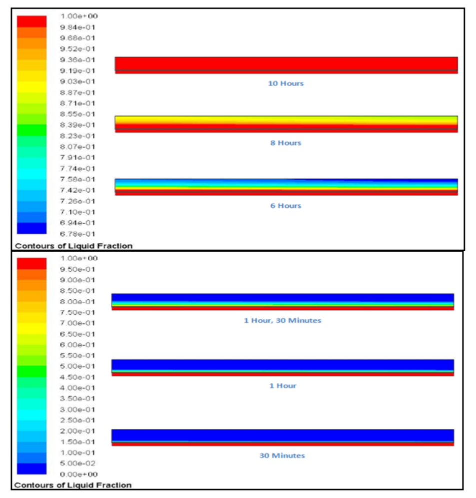

FIGURE 4: SINGLE PCM CONFIGURATION - CASE 1

- **Conduction and natural convection in vertical orientation (Case 2)**
  - Single PCM configuration:
    - Complete melting time: 7.5 hours
  - M-PCMs in series configuration:
    - Complete melting time: 4 hours
    - 47% & 60% reduction compared to the single PCM (case 2) and the m-PCMs in series (case 1)
  - M-PCMs in parallel configuration:
    - Complete melting time: 5 hours 50 mins
    - No significant enhancement compared to the m-PCMs in parallel (case 1)

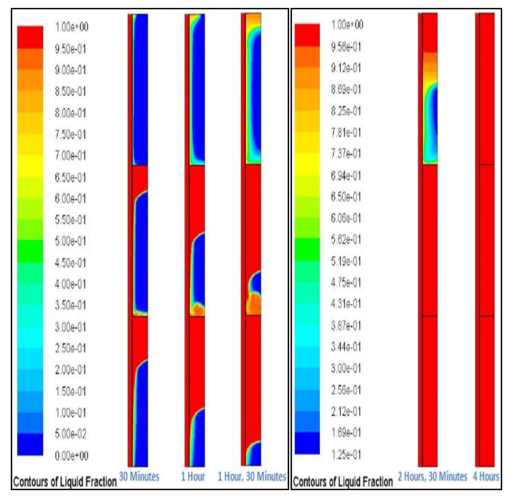

FIGURE 5: M-PCMS IN SERIES CONFIGURATION - CASE 2

- **Conduction and natural convection in horizontal orientation (Case 3)**

❖Axisymmetric assumption not valid

  - Single PCM configuration:
    - Complete melting time: 5 hours 55 minutes
    - Significantly better than case 1 and case 2 (41% and 21% reduction respectively)
  - M-PCMs in series configuration:
    - Complete melting time: 5 hours
    - Enhancement is not as significant as case 2
  - M-PCMs in parallel configuration:
    - Complete melting time: 5 hours 22 minutes
    - Enhancement is not as significant as case 2
    - Suppresses natural convection

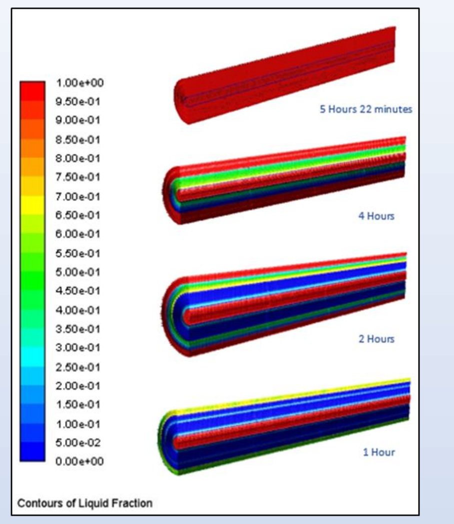

FIGURE 6: M-PCMS PARALLEL CONFIGURATION - CASE 3

Conclusion

- Natural convection has a significant positive effect on the heat transfer characteristics of the systems.
- The application of multiple PCMs generally enhances performance.
- Different configurations and orientations have different effects on the heat transfer mechanisms:
  - Parallel configuration enhances conduction but suppresses natural convection while series does the opposite.
  - The vertical orientation enhances natural convection more than the horizontal orientation for the multiple PCMs configurations.
  - Energy storage with the series configuration in vertical orientation was found to be superior with 47% and 60% reduction in complete melting time respectively, compared to the single configuration in vertical orientation and the single and series configurations (horizontal and vertical) in the conduction only case.

References

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