Solid-Liquid Phase Change Simulation Applied to a Cylindrical Latent Heat Energy Storage System
“Thermal energy storage (TES) is considered as one of the most crucial energy technologies”

---

Sensible Heat Storage: A heat storage system that uses a heat storage medium, and where the addition or removal of heat results in a change in temperature.

Thermochemical Storage: Storage of energy is the result of a chemical reaction.

Latent Heat Storage: The storage of energy is the result of the phase change (solid-liquid or solid-solid) of a phase change material (PCM). The process happening over a small temperature range.
Latent Heat Energy Storage Systems (LHESS)

- HVAC Systems
- Solar Thermal System
- Food Preservation
- Protection of Electronic Components
The main problem with using phase change materials in LHESS is their typical low thermal conductivity, which results in an increase in time for the charging (melting) and discharging (solidifying) process.

Example: $k_{\text{PARAFFIN}} = 0.21 \text{ W/m} \cdot \text{K}$

$k_{\text{COPPER}} = 400 \text{ W/m} \cdot \text{K}$

A factor of ~ 2000
Objectives

- Explore new ways of enhancing the apparent heat transfer properties of the PCM inside a LHESS from a geometric, or system, point of view; by properly designing the system so that it offers optimized surface areas for heat transfer;

  - Study the effects of the addition of fins in a cylindrical storage device:
    - on the overall rate of energy storage;
    - on the heat transfer rates in the system;
  in order to optimize the phase change process (melting) encountered in the phase change material (PCM);

  - To use the finite element method to simulate the phase change process encountered in the PCM;
Geometry Studied

Geometry & Fins
Copper Pipe:
Length = 1.4 m
Outside Diameter = 60 mm
Thickness = 3 mm

Cylindrical Storage Compartment
Length = 1 m
Outside Diameter = 0.6 m
Insulation Thickness = 10 mm

Fin thickness = 5 mm

Introduction of fins
Numerical Modeling
>> Cylindrical LHESS
Problem type: Transient thermal fluid*

Model used: Fluid-Thermal Incompressible Flow

Transient Analysis

This model encompasses:

- Incompressible Navier-Stokes;
- Heat transfer by conduction and convection.

Convection is neglected in the liquid phase of the PCM

Geometry is considered 2D axial symmetry

* The treatment of phase change renders the problem non-linear as well.
Element size: 27mm
Element Type: Triangular

Simulation Time: 12 hours

Maximum energy storage capacity:
~ 44 MJ
### Fluid Flow

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe Inlet Velocity</td>
<td>0.01 to 1 m/s</td>
</tr>
<tr>
<td>Pipe Outlet Condition</td>
<td>No viscous stress $P_0 = 0$</td>
</tr>
<tr>
<td>Pipe Wall Condition</td>
<td>No slip</td>
</tr>
</tbody>
</table>

### Thermal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Temperature</td>
<td>293 K</td>
</tr>
<tr>
<td>Pipe Inlet Temperature</td>
<td>350 K</td>
</tr>
<tr>
<td>Pipe Outlet Condition</td>
<td>Convective heat flux</td>
</tr>
<tr>
<td>Interior Boundary Condition</td>
<td>Continuity</td>
</tr>
<tr>
<td>Outer Surface</td>
<td>Thermal Insulation</td>
</tr>
</tbody>
</table>
Phase Change

\[ C_p = \begin{cases} 
  C_{p,s} & T < 313 \text{ K} \\
  C_{p,m} & 313 \text{ K} < T < 316 \text{ K} \\
  C_{p,l} & T > 316 \text{ K} 
\end{cases} \]

Where

\[ C_{p,m} = \text{Effective } C_p = 60.5 \text{ kJ/kg} \]

\[ C_{p,s} = \text{Solid phase } C_p = 2.5 \text{ kJ/kg} \]

\[ C_{p,l} = \text{Liquid phase } C_p = 2.5 \text{ kJ/kg} \]

\[ L = \text{Latent heat of fusion} = 174 \text{ kJ/kg} \]

\[ \Delta T_m = \text{Melting Temperature range} \]

Numerically

\[ C_p = (2.5 + 60.5 \times (313 < T) - 60.5 \times (T > 316)) \]
Modified Heat Capacity

PCM Melting Temperature Range: 313K-316K
Observed Melting

Fluid velocity = 1 m/s

Temperature (K) vs. Time (Sec)

Phase change reference point
Effect of Fins

Fluid Velocity: 1 m/s
Simulated Period: 12 hours
Effect of Fins

Pipe

Fluid velocity = 1 m/s

Temperature profile taken along line AB
Effect of Inlet Velocity

Simulated Period: 12 hours

0.01m/s  0.1m/s  0.3m/s  0.6m/s

13 fins
Effect of Inlet Velocity

Temperature profile taken along line AB

Temperature profile taken along line AB
Conclusion

- This preliminary work shows that the fluid flow, heat transfer and phase change processes can be numerically accounted using COMSOL Multiphysics;
- The phase change energy process and the melting front displacement can be simulated by modifying the specific heat of the PCM to account for the much larger value of the latent heat of fusion over the melting temperature range; however, this method is only useful so far if convection in the liquid PCM is neglected.
- An analytical validation is currently under way to quantify the accuracy of the phase change simulated results.