Innovative Latent Heat Thermal Storage Elements Design Based on Nanotechnologies

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Outlines

1. Introduction
   - Thermal Storage Systems
   - Phase Change Materials

2. LHS Boiler
   - Layout
   - Design
   - Conclusions

3. Nano-doped PCMs
   - Introduction
   - Results
   - Conclusions
INTRODUCTION
**Sensible Heat Storage:**
- Well known system;
- Storage material is the work “material”;
- Storage material is very cheap (water);
- Low energy density;

**Latent Heat Storage:**
- High energy density;
- Storage material isn’t the work material;
- Storage material can be expansive;
- Corrosive behaviour;
- Instabilities;
Example: SHS vs LHS

**Sensible:**

\[ Q = mc_p(T_f - T_s) \]

for example, 1 kg of water \((c_p = 4186 J/kgK)\) between 50 and 70°C may store:

\[ Q = 1 \cdot 4186 \cdot (70 - 50) = 83720 J \approx 84 kJ \]

**Latent:**

\[ Q = mc_p(T_m - T_s) + m\lambda + mc_p(T_f - T_m) \]

for example, 1 kg of Sodium Acetate \((T_m = 58°C, c_p = 3600 J/kgK, \lambda = 288000 J/kg)\) between 50 and 70°C may store:

\[ Q = 1 \cdot 3600 \cdot (58 - 50) + 1 \cdot 288000 + 1 \cdot 3600(70 - 58) = 360000 J = 360 kJ \]

\[ \frac{Q_{LHS}}{Q_{SHS}} \approx 4 \]
Energetic VS Heat Transfer Problem

- Huge storage potentialities: \( \frac{Q_{LHS}}{Q_{SHS}} \approx 4 \)
- Very poor conductivity (\( 0.2 \div 0.7 \text{W/mK} \)) \( \Rightarrow \) Very inefficient heat transfer mechanism;
Overview

Introduction

LHS Boiler

Nano-doped PCMs

Thermal Storage Systems

Phase Change Materials

Overview

- **Fully commercialized, large scale:**
  - Water
  - Aqueous salt solutions

- **Commercialized:**
  - Paraffines

- **Under investigation:**
  - Salt hydrates and eutectic mixtures
  - Sugar alcohols
  - Salts and eutectic salt mixtures

- **Melting enthalpy [kJ/L]:**
  - 0 to 500

- **Melting temperature [°C]:**
  - -100 to +200
Salt-hydrates VS Paraffins

Salt-hydrates:
- Generally cheap;
- Good latent heat/density;
- Well defined phase change temperature;
- Non-flammable;
- Need careful preparation;
- Need additives to stabilise for long term use;
- Prone to supercooling;
- Can be corrosive to some metals;

Paraffins:
- Simple to use;
- Non-corrosive;
- No supercooling;
- Generally more expensive;
- Lower latent heat/density;
- Often give quite broad melting range;
- Can be combustible;
LHS Boiler
Project Data

Plant Properties:
- \(DHW = 200\ l/day\) (4 persons);
- Hot water from Thermal Solar Panels: \(m = 0.056l/s\);
- Temperature from hydraulic grid: \(15^\circ C\);

Boiler Properties:
- \(T_{inside} = 50 \div 70^\circ C\);
- \(T_{surr} = 20^\circ C\);
- \(\alpha = 10W/mK\);
Water Temperature from Solar Collector

Temperature [°C]

Hour

0:00 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00 10:00 11:00 12:00 13:00 14:00 15:00 16:00 17:00 18:00 19:00 20:00 21:00 22:00 23:00
Numerical Analysis

- C script;
- FVM;
- Implicit code;
- Enthalpy Method;
- PCM elements with onion-peel approach;
- Time step 30s;
- Total Time
  $7 \text{ days} = 604800 s$;
- CPU time < 15s;
SHS Boiler

Water Properties:
- $\rho_{H2O,62} = 982\, \text{kg/m}^3$;
- $c_p = 4188\, \text{J/kgK}$;
- $k = 0.656\, \text{W/mK}$;
- $Pr = 2.87$;
- $g\beta/\nu^2 = 2.54 \cdot 10^{10} (m^3K)^{-1}$;

Boiler Properties:
- Cylindrical shaped;
- $\Phi = 0.7\, \text{m}$;
- $H = 0.8\, \text{m}$;
- Volume = 308l;
- Mass = 302kg;
SHS Boiler

Graph showing temperature variations over days for Tank Water (red) and Collector Water (blue) with annotations for temperature and days.
PCM Container Properties

PCM Properties:
- Salt Hydrate $C_{58}$ by Rubitherm;
- $T_m = 58 \pm 0.5^\circ C$;
- $\rho = 1460 \text{ kg/m}^3$;
- $\lambda = 288000 \text{ J/kg}$;
- $c_p = 3600 \text{ J/kgK}$;
- $k = 0.5 \div 0.7 \text{ W/mK}$;

Elements Properties:
- Large external surface;
- Small dimension;
- $N$ cylinders filled up with PCM;
Final Remarks

In conclusion:

- Using PCM elements it’s possible storing large amount of energy in smaller volumes;
- Mass reduction of $30 \div 40\%$ of the system;
- Store energy for some days (good insulation);
Nano-doped PCMs
Tasks

- **Problem:** very low conductivity \((0.2 - 0.7\text{W/mK})\);
- Improve heat exchange: optimizing surface (fins,..), doping with highly conductive materials (macro and micro);
- Drawback of doping: reduction of melting enthalpy;

If we use **nano-doping**?
Material and Experimental Setup

- Single Walled Carbon Nanotubes (by Helix Material Solution) with high purity (90%), diameter $\phi = 1.3 \text{ nm}$ and length $L = 0.5 - 40 \text{ \mu m}$;
- Commercial Paraffin Wax, with melting temperature of $57^\circ C$;
- Several mixtures (pure PW, 0.1% - 0.2%... till 2% CNTs);
- 4 hours sonication at $75^\circ C$;
- 24 hours cooling time at room temperature;
- DSC analysis (Q100) between $42^\circ C$ and $70^\circ C$;
- Ramp signal $2^\circ C/min$;
## Results

### Table: DSC collected data

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<tbody>
<tr>
<td>Pure PW</td>
<td>0</td>
<td>122.10</td>
<td>-</td>
<td>122.10</td>
</tr>
<tr>
<td>CNT 0.1</td>
<td>0.1%</td>
<td>123.13</td>
<td>0.84%</td>
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<td>CNT 0.5</td>
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<td>125.60</td>
<td>2.87%</td>
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<tr>
<td>CNT 0.8</td>
<td>0.8%</td>
<td>127.55</td>
<td>4.46%</td>
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<tr>
<td>CNT 1</td>
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<td>129.05</td>
<td>5.69%</td>
<td>120.87</td>
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<td>CNT 2</td>
<td>2%</td>
<td>131.00</td>
<td>7.29%</td>
<td>119.66</td>
</tr>
</tbody>
</table>
Results

![Graph showing measured and theoretical latent heat vs. CNTs mass fraction.]

- **Measured Latent Heat**
- **Theoretical Latent Heat**
In conclusion:

- Nano-doping demonstrates an enhancement of latent energy storage of PCMs, unlike what happens with macro-doping; this improvement can be caused by intermolecular attraction between the molecules of nano-additives and wax;
- A similar enhancement is expected on the thermal conductivity;
- Highly conductive nano-particles seem to be very good candidates for doping thermal storage materials.
Thank you
for your attention

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