Phase Change Materials for Household and Process Heating Systems

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Progress

• Material review was expanded to access the compounds between 0 and 250 °C temperature range;
• Test results for the selected compounds in the review were completed and the most promising compounds were selected;
• Numerical model for compact and encapsulated analysis was calibrated with experimental data from other authors;
• Rig test results were inconclusive due to improper rig design:
  • Very small heat transfer area and reduced diameter of heat transfer tube led to very turbulent flows and inconclusive characterization to the storage container;
• New solutions are being designed in order to obtain more reliable data;

Index:
• Progress;
• Material Analysis:
  • Obtained results;
  • Future work;
• Modelling analysis:
  • Calibration results;
• Container Analysis:
  • Obtained results;
  • Future work;
### Material Analysis

#### Obtained Results

<table>
<thead>
<tr>
<th>Compound Name</th>
<th>T$_{\text{melt}}$</th>
<th>$\Delta$H$_{\text{fusion}}$</th>
<th>$C_p$</th>
<th>$C_p$</th>
<th>$\rho$</th>
<th>$E_{\text{density}}$</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0</td>
<td>333</td>
<td>2.0</td>
<td>4.2</td>
<td>1000</td>
<td>109</td>
<td>0</td>
</tr>
<tr>
<td>CaCl$_2$(H$_2$O)$_6$</td>
<td>30</td>
<td>125</td>
<td>1.4</td>
<td>2.2</td>
<td>1710</td>
<td>64</td>
<td>93</td>
</tr>
<tr>
<td>Urea - CH$_3$COONa(H$_2$O)$_6$ (62/38)</td>
<td>32</td>
<td>138</td>
<td>2.5</td>
<td>3.4</td>
<td>1370</td>
<td>62</td>
<td>206</td>
</tr>
<tr>
<td>Ca(NO$_3$)$_2$(H$_2$O)$_4$</td>
<td>42</td>
<td>128</td>
<td>1.9</td>
<td>2.5</td>
<td>1896</td>
<td>76</td>
<td>167</td>
</tr>
<tr>
<td>Paraffin wax*</td>
<td>51</td>
<td>221</td>
<td>2.0</td>
<td>2.7</td>
<td>916</td>
<td>58</td>
<td>421</td>
</tr>
<tr>
<td>Na$_2$S$_2$O$_3$(H$_2$O)$_5$</td>
<td>52</td>
<td>193</td>
<td>1.8</td>
<td>3.0</td>
<td>1666</td>
<td>97</td>
<td>199</td>
</tr>
<tr>
<td>CH$_3$COONa$_2$(H$_2$O)$_3$</td>
<td>59</td>
<td>249</td>
<td>2.0</td>
<td>3.1</td>
<td>1450</td>
<td>109</td>
<td>233</td>
</tr>
<tr>
<td>Mg(NO$_3$)$_2$(H$_2$O)$_6$</td>
<td>93</td>
<td>98</td>
<td>2.5</td>
<td>3.1</td>
<td>1640</td>
<td>55</td>
<td>131</td>
</tr>
<tr>
<td>MgCl$_2$(H$_2$O)$_6$</td>
<td>120</td>
<td>141</td>
<td>2.0</td>
<td>2.4</td>
<td>1569</td>
<td>68</td>
<td>56</td>
</tr>
<tr>
<td>KNO$_3$NaNO$_2$NaNO$_3$(53/7/40)</td>
<td>147</td>
<td>76</td>
<td>1.0</td>
<td>1.2</td>
<td>2006</td>
<td>47</td>
<td>469</td>
</tr>
<tr>
<td>Adipic Acid</td>
<td>155</td>
<td>222</td>
<td>1.8</td>
<td>2.1</td>
<td>1360</td>
<td>91</td>
<td>584</td>
</tr>
<tr>
<td>d-Mannitol</td>
<td>169</td>
<td>269</td>
<td>1.7</td>
<td>2.4</td>
<td>1490</td>
<td>120</td>
<td>1027</td>
</tr>
<tr>
<td>LiNO$_3$NaNO$_3$(48/52)</td>
<td>198</td>
<td>250</td>
<td>1.8</td>
<td>3.2</td>
<td>2317</td>
<td>173</td>
<td>3084</td>
</tr>
<tr>
<td>KNO$_3$NaNO$_3$(54/46)</td>
<td>226</td>
<td>94</td>
<td>1.1</td>
<td>1.2</td>
<td>2028</td>
<td>58</td>
<td>482</td>
</tr>
<tr>
<td>LiNO$_3$NaCl(87/13)</td>
<td>230</td>
<td>412</td>
<td>1.8</td>
<td>2.6</td>
<td>2350</td>
<td>276</td>
<td>5254</td>
</tr>
</tbody>
</table>

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- Water is the most important PCM near 0°C, the only compound that expands during solidification;
- Salt hydrates appeared very promising, but sub-cooling needs to be accessed;
- Most organic compounds didn’t performed above 100°C;
- Sodium and Potassium Nitrate seems the most promising for process heating applications due to its cost;
Material Analysis

Future Work

- Thermal analysis of selected compounds:
  - Thermal conductivity measurement
    - Using the TA flash diffusivity device;

- Melting expansion measurements
  - TMA device can’t measure accurately a melting expansion;
  - Measuring process explained in the diagram on the right;

- Corrosion testing with common metals (aluminium, copper, SS):
  - Weight loss measurement;
  - SEM microscopical analysis of the corroded surface;
Modelling Analysis

Calibration results

• Pure diffusion Model follows the experimental work in the solid phase;
• Natural convection among the liquid phase considerably enhances heat transfer within the PCM;
• Solidus-liquidus temperature difference is critical defining the phase change, and varies with different compounds;

Figure 1: Schematic view of the experimental work done in [1]

Figure 2: Graphics comparing the model and the experimental work from [1]

Modelling Analysis

Calibration results

- Pure diffusion Model more according with experimental work;
- Melting process with fewer error than solidification process;
  - Poor convective heat transfer correlation;
  - Incorrect PCM physical properties;

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Container Analysis

Rig Assembled

- Huber Tango heat source (-40 to 200 °C);
- Initially tested with Paraffin wax ($T_{\text{melt}}=42^\circ \text{C}$);
- Closed water loop purged with gravity pressure;
- Container isolated with Fibre glass wool;
- Pipe connections isolated with Expanded Polyurethane;

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Container Analysis

Test results

- Inlet-Outlet temperature difference is too small;
  - Minimum measured flow allowed is 3.6 l/min, giving for a 6.5 mm tube a very turbulent flow with a Reynolds number of 11,729;
  - Literature experiments work usually in laminar flow regions for the HTF (50<Re<600);
- Inlet-outlet temperature difference goes negative during charging;
  - Probably due to poor isolation
Container Analysis

Future Work

• In order to have an acceptable Inlet-Outlet temperature difference, testing solutions need to have higher heat transfer areas;

• Latent heat storage systems could be integrated according to these three diagrams;
Container Analysis

Future Work

• Domestic heating;
  • With electrical heat supply;

• Integrated directly into the heating network;

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Future Work

• Process heating;

• Higher power outputs require larger parallel arrays;

• This solution, with 2m height and a section of 800mmx800mm could store up to 827 L of PCM;

• Integrating 10 solutions into a 20 foot cargo container could store up to 8270L of PCM;

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Thank You for the attention