Small Smart Sustainable Systems for future Domestic Hot Water (4S-DHW)

Mohamed Fadl, Philip C. Eames
m.s.fadl@lboro.ac.uk; philip.c.eames@lboro.ac.uk

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Centre for Renewable Energy Systems Technology (CREST); Loughborough University Loughborough (Leicestershire) LE11 3TU, United Kingdom
Overview of 4S-DHW.

Loughborough objectives, focus and methodology.

Progress summary.
Overview of 4S-DHW

• Address the challenge of providing domestic hot water (DHW) using low carbon heat pump technology.
• Develop new heat pump technologies integrated with advanced thermal storage to provide affordable low-carbon DHW without the need of a conventional large DHW storage tank.
• Design Thermal Storage to
  o A small buffer store to overcome starting transients (5 mins).
  o A large capacity store to provide a bath-full of water quickly.
Hot water demands in dwelling.

- **Hand basin**
  - $V=0.15 \text{ L/s}$
  - $T=40 \degree \text{C}$

- **Kitchen sinks**
  - $V=0.2 \text{ L/s}$
  - $T=60 \degree \text{C}$

- **Showers**
  - $V=5 \text{ L/min}$
  - $T=42 \degree \text{C}$

- **Bath**
  - $V=100 \text{ L}$
  - $T=40 \degree \text{C}$
Loughborough objectives, focus and methodology.

Design

- Experiments to determine the effect of liquid PCM motion (natural convection) on PCM crystallisation.

Develop

- Experimental thermal storage test systems and characterise the performance of a range of prototype laboratory scale thermal energy storage systems.

Validate

- Appropriate thermal store simulation tools to enable effective prediction of thermal store performance and analysis of design limitations.

PCM (Phase change materials)
Thermal Energy Storage System Design

Loughborough objectives, focus and methodology.

Applied Research

Fundamental Research
A$_{mush}$

- Fluent use enthalpy porosity formulation for modelling phase change.
- The enthalpy-porosity technique treats the mushy region (partially solidified region) as a porous medium.
- The porosity in each cell is set equal to the liquid fraction in that cell.
- In fully solidified regions, the porosity is equal to zero.
- The momentum sink due to the reduced porosity in the mushy zone takes the following form

\[ S(T) = A_{mush} \frac{(1-\varphi(T))^2}{(\varphi(T))^3 + \epsilon} \]

- High $A_{mush}$ values corresponded to slower melting rates and the smallest $A_{mush}$ values resulted unphysical predictions of the melt front development.
Model geometry and boundary conditions.

Thermophysical Properties of Lauric Acid

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_m$</td>
<td>316.65 K</td>
</tr>
<tr>
<td>$\rho_s$</td>
<td>940 kg/m$^3$</td>
</tr>
<tr>
<td>$\rho_l$</td>
<td>885 kg/m$^3$</td>
</tr>
<tr>
<td>$c_{p,s}$</td>
<td>2180 J/kg·K$^*$</td>
</tr>
<tr>
<td>$c_{p,l}$</td>
<td>2390 J/kg·K</td>
</tr>
<tr>
<td>$k_s$</td>
<td>0.16 W/m·K</td>
</tr>
<tr>
<td>$k_l$</td>
<td>0.14 W/m·K</td>
</tr>
<tr>
<td>$\mu_l$ at 43 °C</td>
<td>0.008 kg/m·s</td>
</tr>
<tr>
<td>$\mu_l$ at 70 °C</td>
<td>0.004 kg/m·s</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.0008 K$^{-1}$</td>
</tr>
<tr>
<td>$L$</td>
<td>187,200 J/kg</td>
</tr>
</tbody>
</table>

Thermophysical Properties of Plexiglass

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$\rho_{pg}$</td>
<td>1180 kg/m$^3$</td>
</tr>
<tr>
<td>$c_{pg}$</td>
<td>1464 J/kg·K</td>
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<tr>
<td>$k_{pg}$</td>
<td>0.19 W/m·K</td>
</tr>
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</table>

Figure 1. Schematic diagram of the simulation geometry with details of the boundary conditions imposed.
Comparison of Melt fraction front development for the experiment and CFD for different $A_{mush}$ constant, The darker image represents the liquid material
Comparison of Melt fraction front development for the experiment and CFD for different $A_{mush}$ constant. The darker image represents the liquid material.
Figure 4 Melt Fraction with time for selected values of the mushy zone parameter, $A_{mush}$ during the charge process.
Progress summary

Experimental Work

Large scale prototype of rectangular enclosure filled with PCM

Diagram showing a large scale prototype of a rectangular enclosure filled with PCM. The diagram includes various components such as PC, multimeter, variable voltage transformer, power supply, controller unit, data logging device, and a DSLR camera. The enclosure has layers marked as 2.0 mm thick copper sheet and 12.0 mm thick polycarbonate sheet.
Progress summary

Experimental Work

Large scale prototype of rectangular enclosure filled with PCM
Progress summary

<table>
<thead>
<tr>
<th>Original photo</th>
<th>Grayscale photo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropped photo. white:solid PCM, black:liquid PCM</td>
<td></td>
</tr>
</tbody>
</table>
Progress summary

Melt fraction variation versus time for different wall heat flux

$q''=675 \text{ W/m}^2$
$q''=960 \text{ W/m}^2$
$q''=1295 \text{ W/m}^2$
Contours of temperatures measured by infrared camera on the front wall of PCM compartment

<table>
<thead>
<tr>
<th>T</th>
<th>$q''_{wall}=675$ W/m$^2$</th>
<th>$q''_{wall}=960$ W/m$^2$</th>
<th>$q''_{wall}=1295$ W/m$^2$</th>
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</thead>
<tbody>
<tr>
<td>30</td>
<td>![Contour Image]</td>
<td>![Contour Image]</td>
<td>![Contour Image]</td>
</tr>
<tr>
<td>60</td>
<td>![Contour Image]</td>
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<tr>
<td>90</td>
<td>![Contour Image]</td>
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Thank You for the attention