Imperial College London

EXPERIMENTAL AND COMPUTATIONAL INVESTIGATION OF A THERMAL STORAGE SYSTEM BASED ON A PHASE CHANGE MATERIAL

Ajay Gupta, Richard Mathie, and Christos N. Markides

Clean Energy Processes Laboratory, Department of Chemical Engineering, Imperial College London, London SW7 2AZ, UK

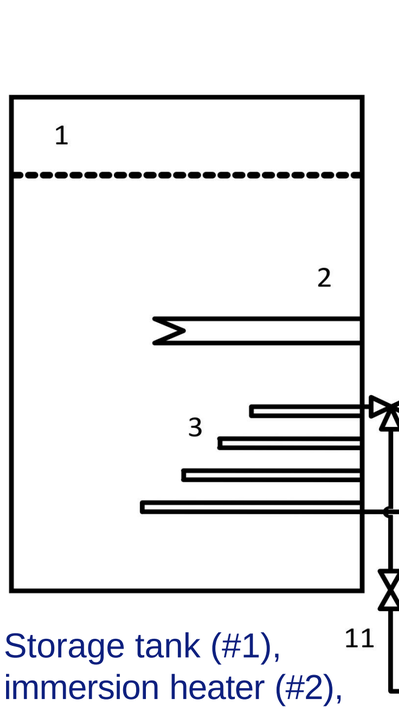
AIM AND MOTIVATION

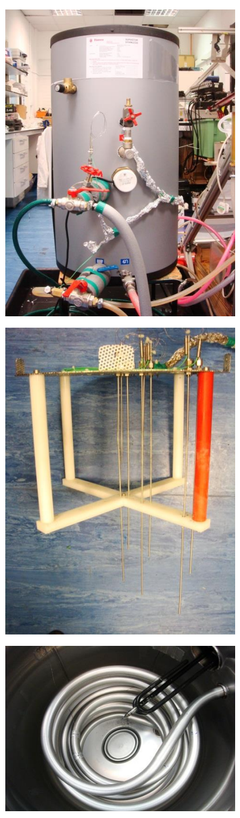
Smart and efficient future energy systems must:

- Reduce the mismatch (in time or rate) between energy production or availability, and energy consumption
- Reduce energy costs by shifting heating/cooling loads to night-time hours and storing low-cost electricity as thermal energy

Aiming to characterise the dynamic behaviour and performance of an active thermal storage system for domestic applications, we have undertaken an investigation involving computational predictions complemented by experimental measurements in order to capture the time-varying interplay between fluid flow and heat transfer in the system.

EXPERIMENTAL CONFIGURATION





Storage tank (#1), immersion heater (#2), internal coil (#3), boiler (#4), pump (#5), rotameters (#6, 7), valves (#8, 9, 10, 11)

Property	Value
Phase change temperature (solid-liquid)	331 K
Density	1505 kg/m^3
Latent heat capacity	145 kJ/kg
Volumetric heat capacity	218 MJ/m^3
Specific heat capacity	2.55 kJ/kg K
Thermal conductivity	0.69 W/m K

Thermophysical properties of the solid state PCM used in the present study (Phase Change Material Products, 2013).

MODELLING AND SIMULATION

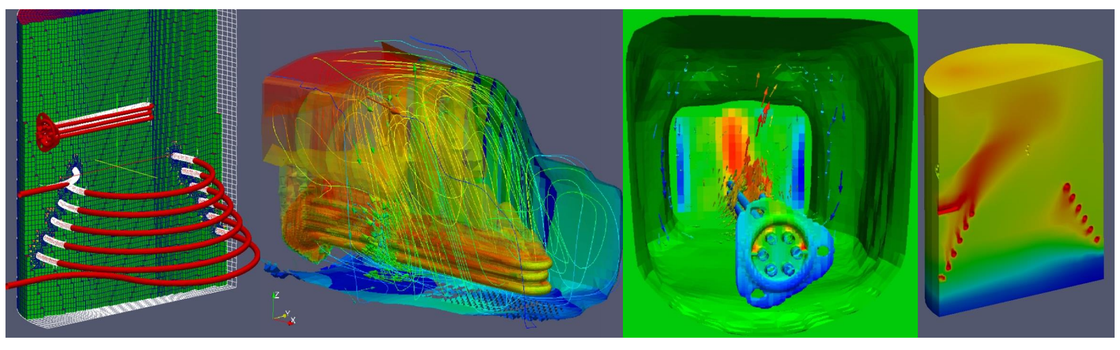
Numerical model was developed based on work by Rosler & Bruggemann*. It applies Boussinesq approximation for the PCM's density change with temperature and solves the following equations:

$$\nabla.(u) = 0 \qquad \text{(mass conservation)}$$

$$\frac{\mathrm{D}(\rho u)}{\mathrm{D}t} = \nabla.(\mu\,\nabla u) - \nabla^2 P + S_\mathrm{d} + S_\mathrm{b} \qquad \text{(momentum conservation)}$$

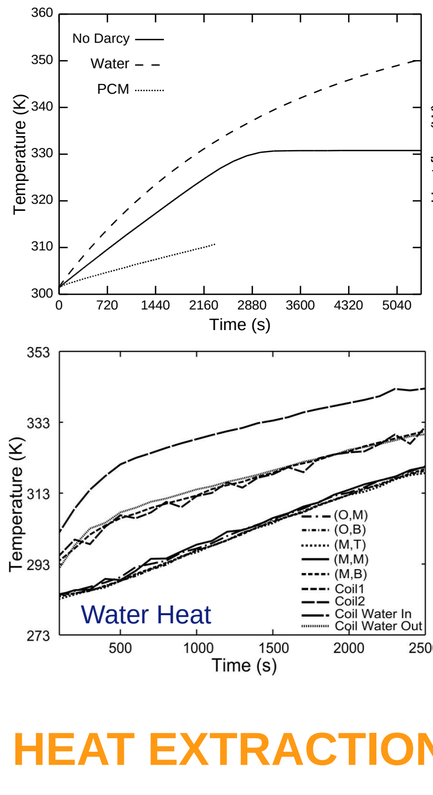
$$\frac{\mathrm{D}(\rho h)}{\mathrm{D}t} = \nabla.(k\,\nabla T) \qquad \text{(energy conservation)}$$

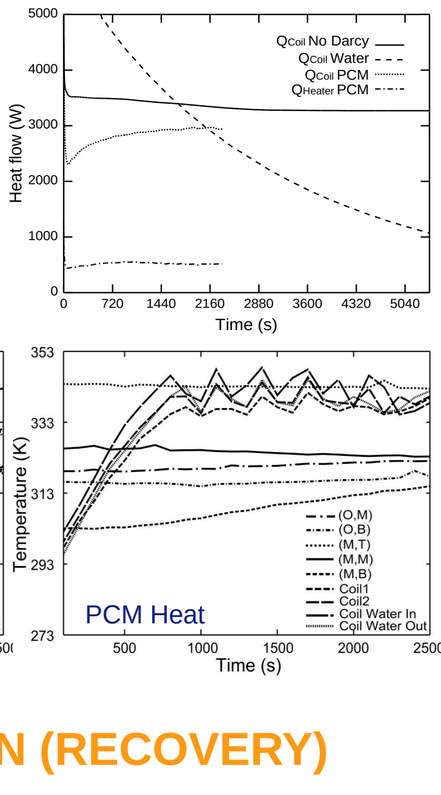
*Rosler, F., and Bruggemann, D. Shell-and-tube type latent heat thermal energy storage: Numerical analysis and comparison with experiments. Heat and Mass Transfer, vol. 47, pp. 1027-1033, 2011.



Meshed (170k cells) PCM vessel, immersion heater and internal flow coil along with images of the 3-D simulated flow field in the thermal storage tank. Mesh refinement was implemented in the vicinity of melting front. Isothermal or isoflux boundary conditions were set on the heater surface.

HEAT ADDITION (STORAGE)





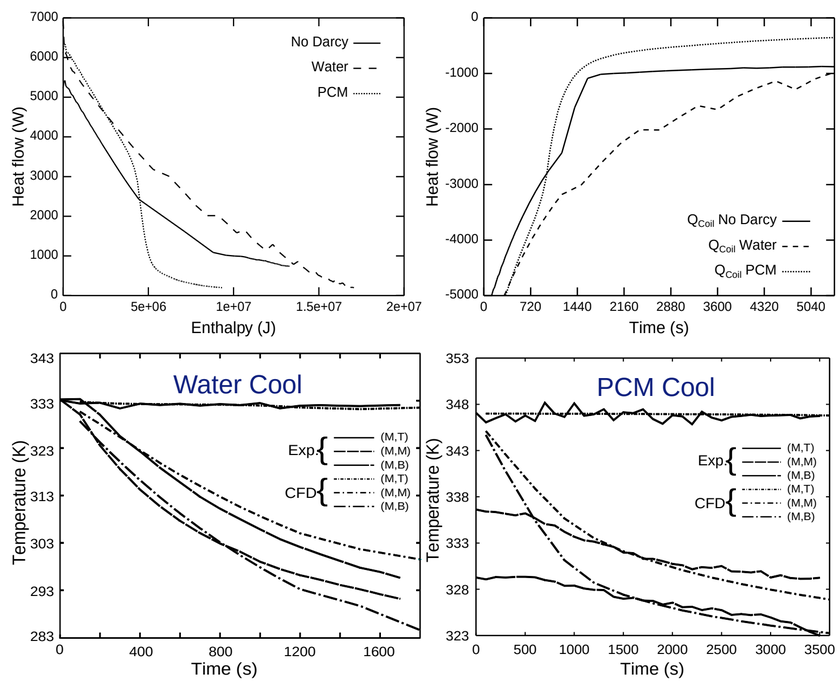
Water tank: High magnitudes of heat flux that decrease over time; tank is divided into two thermal layers.

PCM tank: Lower but constant heat flux for isothermal heat addition); multiple thermal layers; PCM in immediate vicinity of heat transfer area melted.

HEAT EXTRACTION (RECOVERY)

Water tank: Upper portion of water tank remained hot. Natural convection assisted cooling effectively in lower portion of the tank.

PCM tank: High initial heat flux which declined due to high viscosity of PCM melt and ice formation (PCM solidification on heat exchanger surfaces).



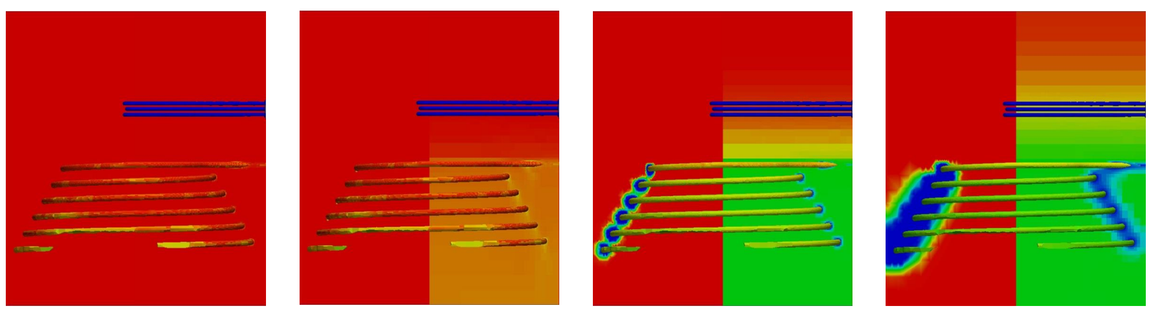
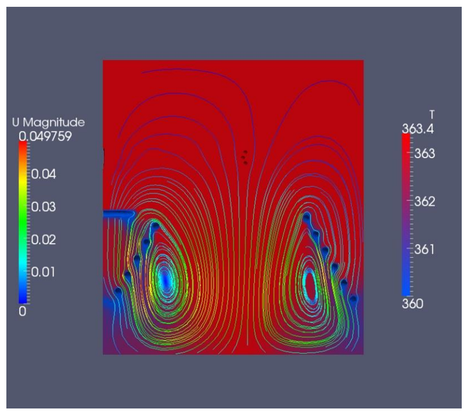


Image sequence, lasting 4 hours, showing gradual thermal stratification and ice formation on the heat exchange coil from a CFD cooling simulation. The left-hand side of each image shows the phase fraction field (red/dark: liquid phase and blue/light: solid phase), and the right-hand side the temperature field in the tank (red/dark: hotter regions and blue/light: cooler regions).

CONCLUSIONS

Experimental test results showed good agreement with CFD predictions, with the heat removal (recovery) performance being the limiting factor when compared to a water-based system. It was confirmed that the PCM solution has the capability to store a large amount of heat effectively. Next generation designs will target improvements to the heat transfer arrangement by using fins, changing coil locations, and employing PCM emulsions or encapsulated spheres, while ensuring that the PCM retains the maximum possible volume available within the tank.



CFD velocity magnitude contours and streamlines around the coil as heat is extracted from a CFD cooling simulation.