Thermal behaviour of integrated solar collector/storage unit with 65 °C phase change material

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Abstract

A transient finite volume model was used to predict collection and retention of heat for rectangular cross section solar collector/storage systems when filled with water and various concentrations of phase change material (PCM) slurries with a 65 °C phase change temperature. It was found that the PCM slurry systems collected heat marginally less effectively than water filled stores. Retention of heat at higher temperatures in the PCM slurry systems may allow higher solar savings fractions to be realised depending on heat demand patterns.
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1. Introduction

Energy storage in phase change materials allows very high energy densities to be achieved at well defined temperatures. Due to the low thermal conductivity of many phase change materials it is difficult to get high rates of heat transfer and rapid charging unless, (i) high thermal conductivity materials are embedded in the phase change material, (for example fins [1]), (ii) the phase change materials are encapsulated in nodules and a heat transfer fluid flows around them, or (iii) the phase change materials are microencapsulated and suspended in a carrier fluid to form a slurry.

If the carrier fluid has higher thermal conductivity than the PCM or convection occurs in the microencapsulated PCM slurry an increased charging rate can be achieved. In the present study simulations are performed for an integrated collector storage solar water heater system [2] when filled with water and selected concentrations of phase change material slurries with a 60 °C phase transition temperature.

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2. Mathematical model

The basic mathematical model used is based on that of Eames and Norton [3] with an addition of a specific heat capacity that varies with temperature. Phase change is assumed to occur between 58 and 60 °C. The properties used for water and the phase change material slurries are summarised in Table 1.

The density of the microcapsules was assumed to be similar to that of the water carrier fluid. The concentration of microcapsules was limited to 30% due to the rapid increase in viscosity that occurs for higher concentrations significantly reducing convective heat transfer.

A schematic of the system modelled is illustrated in Fig. 1. The collector store is a tank that is 0.975 m high by 1 m long by 0.125 m deep inclined at an angle of 30° to the vertical.

The tank walls are 1 mm thick, the front made from copper the others from steel, the heat loss coefficients from the front, top, bottom and back surfaces to the ambient environment at 12.5 °C are 5, 1, 0.5 and 0.5 $Wm^{-2} K^{-1}$, the end surfaces of the store are assumed to be adiabatic allowing a two dimensional rectangular slice through the store to be modelled. The initial store temperature was set to 30 °C. To investigate the heating and cooling cycles for this system a 10 h period was simulated, in the initial 5 h the radiation incident on the front of the store is 1000 Wm^{-2}, for the remaining time it is zero.

The model used calculates the two dimensional velocity and temperature profiles within the store and allows the accumulated energy and maximum, minimum and average store temperatures to be plotted with time. The maximum time step used in the simulations was 0.2 s.

Table 1
Material properties used in the simulations

	Kinematic viscosity ($mm^2 s^{-1}$)	Specific heat capacity ($J kg^{-1} K^{-1}$)	Specific heat capacity at phase transition ($J kg^{-1} K^{-1}$)
Water	1	4200	–
10% PCM	2	3960	11120
15% PCM	4.5	3840	14580
20% PCM	8	3720	18040
25% PCM	12	3600	21500
30% PCM	18	3480	23760
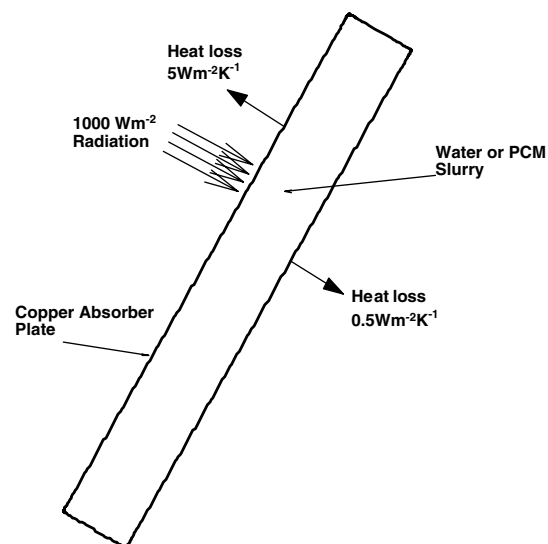
Fig. 1. A schematic diagram of the system simulated.