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DYNAMIC MODELLING OF LATENT HEAT THERMAL ENERGY STORAGE UNITS BASED ON PLATE-TYPE HEAT EXCHANGERS

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1. ABSTRACT

To effectively analyse the interaction of thermal energy storage units within complex energy systems, accurate yet simplified models are essential. Although three-dimensional models offer accurate simulation results, these demand significant computational resources. Following this line, a low-order, one-dimensional dynamic model for latent heat thermal store is presented. The store unit is based on plate-type heat exchangers to facilitate heat exchange between the heat transfer fluid and the phase change material.

2. INTRODUCTION

Energy storage have demonstrated their effectiveness to address the variability in energy demands within integrated energy systems. Electrical batteries in particular, have shown their capability to manage the intermittency associated with renewable sources, such as solar photovoltaics and wind turbines, thereby ensuring a constant power supply. Similarly, thermal energy systems benefit from the integration of thermal energy storage (TES) units. Energy sources, including electrical boilers and chillers may be supported by TES during periods of peak heating and cooling demand. This approach leads to a decrease in energy production cost through thermal load shifting.

Latent heat thermal energy storage (LH-TES) units use the energy released or absorbed by phase change material (PCM) during its phase transition. LH-TES systems are distinguished by their higher energy density compared to sensible heat thermal energy storage (SH-TES) units. However, the efficiency of LH-TES systems strongly depends on the optimal selection of storage capacity and the PCM's melting temperature. Mathematical models are critical for the analysis of real-world scenarios for the appropriate selection of LH-TES units. Despite the accuracy of three-dimensional (3-D) computational fluid dynamics models, their complexity often limits their applicability in the analysis of more complex energy systems, highlighting the need for simpler, yet accurate, mathematical models. One-dimensional (1-D) dynamic models have emerged as suitable alternative, offering a compromise between computational efficiency and accuracy. Within hybrid thermal-photovoltaic systems, plate-type heat exchangers have been recognized for their efficiency in converting solar energy into thermal energy, although the development of mathematical models remains essential for optimising heat transfer processes within these systems.

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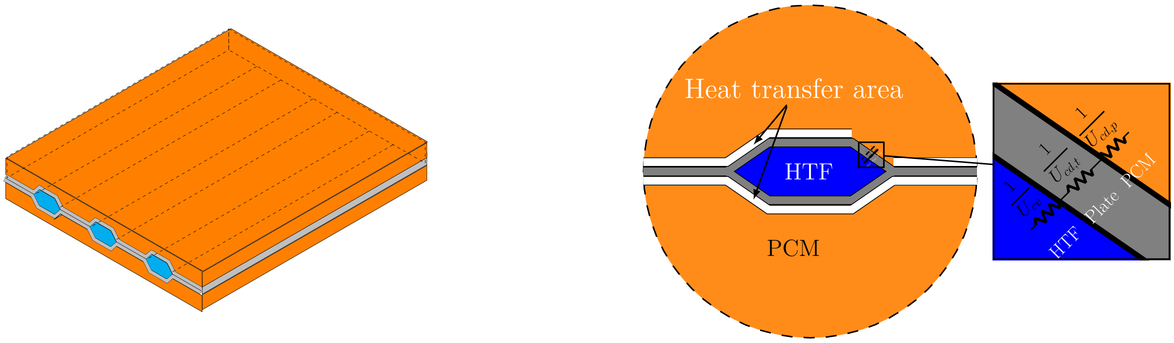
3. METHDOLOGY

In this study, 1-D dynamic model of a plate-type heat exchanger integrated with PCM is presented, as illustrated in Fig 1(a). The model employs an energy balance methodology, using the specific heat-temperature curve of the PCM to determine its latent heat value and dynamically calculate the overall heat transfer coefficient [1,2]. The plate is surrounded by PCM, a discretisation approach is adopted, resulting in a set of nonlinear differential equations that encapsulate the thermal dynamics between the HTF and the PCM control volumes. The heat transfer coefficient is derived from conduction between the HTF, the plate and the PCM around the plate channels, in addition to convection produced by the flow of the HTF, as it is shown in Fig 1(b) [3].

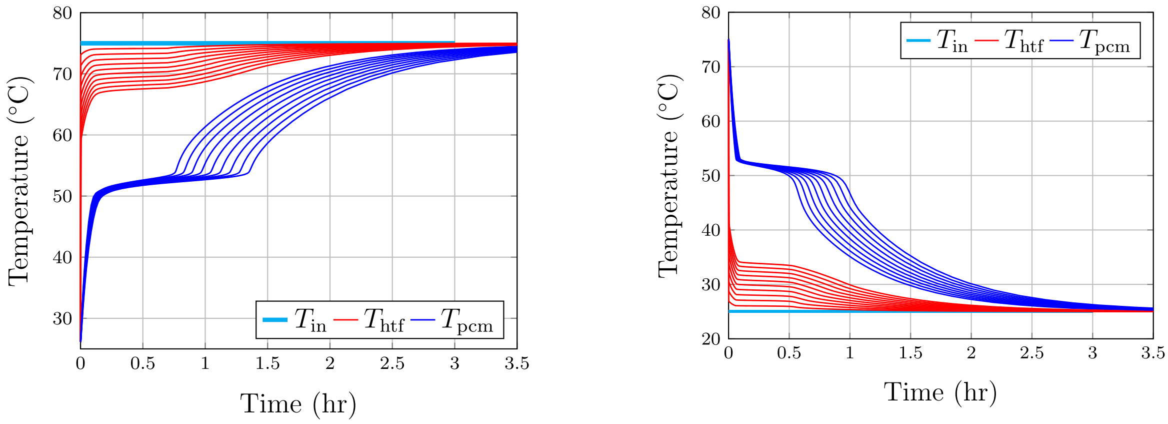


(a) (b)

Fig.1 (a) Schematic of the plate-type heat exchanger wrapped by PCM. (b) Frontal cross sections of the control volumes with the electrical analogy of the conduction and convection heat transfer coefficients.

4. RESULTS

The model was implemented using MATLAB software to simulate a serpentine channel configuration, employing Croda53 as the PCM with a melting temperature of 53°C. The dimensions of the plate were specified as a width of 0.466 m (W) and a length of 0.364 m (L), providing a total heat transfer area of 0.3392 m^2 on both sides of the plate, as depicted in Fig 1(b). The channel's cross-sectional area was 2.628×10^{-5} m^2. Simulations of both the charging and discharging processes were conducted under initial conditions of 25°C and 75°C, respectively, with a constant mass flow rate of the HTF set at 0.015 kg/s. The model solves the temperature of the HTF and the PCM control volumes, considering a discretisation of N=10 control volumes.



(a) (b)

Fig. 2 Input temperature of the HTF (T_{in}, cyan trace), temperatures of the HTF (T_{htf}, red traces) and PCM (T_{pcm}, blue traces) control volumes (N=10) during charging (a) and discharging (b) processes.

5. CONCLUSIONS

This paper presents a simplified 1-D dynamic model for a plate-type heat exchanger integrated with PCM. The model describes the thermal behaviour through a set of differential equations. Furthermore, the model is structured for straightforward implementation on any software platform that features an ordinary differential equation (ODE) solver. Such adaptability ensures the model's incorporation into complex thermal system analysis.

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