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NUMERICAL ANALYSIS OF A THERMAL ENERGY STORAGE SYSTEM WITH PHASE CHANGE MATERIAL BASED ON PLATE HEAT EXCHANGER WITH ROLL-BOND DESIGN

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1. ABSTRACT

This study investigates numerical performance of the latent heat thermal energy storage (LHTES) system based on plate-type heat exchanger with roll-bond (RB) pattern. A detailed 3D CFD model was developed to evaluate the PCM melting performance in the charging process of the LHTES unit. These investigations are beneficial for the optimum design of the RB pattern for thermal energy storage (TES) applications.

2. INTRODUCTION

Thermal energy storage (TES) systems play a crucial role in improving the energy efficiency of various industrial and residential applications. A significant number of the TES system, which incorporate phase change material (PCM) to store latent heat and thus reduce volume and improve storage density, are referred to as a Latent Heat Thermal Energy Storage (LHTES) device. However, PCM's low thermal conductivity presents a challenge for heat transfer within the TES device [1]. The Roll-bond (RB) technology design on the plate type heat exchanger is one of the solutions to improve the heat transfer in the LHTES unit owing to its larger contact area between the flow channel and PCM [2]. With the experimental and numerical results, the plate heat exchanger with RB designs shows potential method to enhance the heat transfer capabilities of PCMs [3].

RB technology presents an efficient and performant solution in refrigeration and photovoltaic modules. However, there are limited studies concerning RB pattern in the LHTES unit. This study utilizes a plate-type heat exchanger plate with RB pattern to explore the PCM melting performance in the LHTES system. This study introduces a 3-D Computational Fluid Dynamics (CFD) model developed in Ansys, presenting the PCM melting process in terms of liquid fraction and the temperature profiles for both the Heat Transfer Fluid (HTF) and the PCM. This comprehensive analysis provides new insights into the thermal performance and efficiency of the LHTES systems, highlighting the potential benefits of RB patterns.

3. METHDOLOGY

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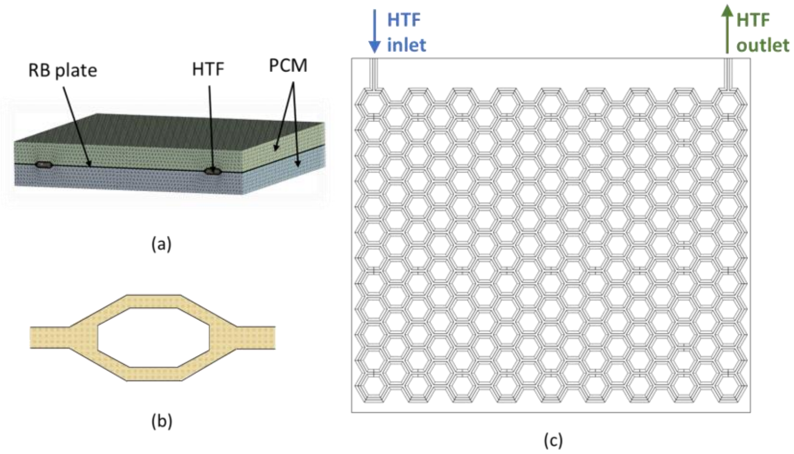
The investigated plate with RB pattern has the dimension at 540mmx430mmx2mm, with the heat transfer fluid (HTF) flows through the flow channel while PCM is filled outside the plate. The RB plate with double-sided hexagon pattern was assessed in Ansys fluent, as shown in Fig. 1.



(a)

(b)

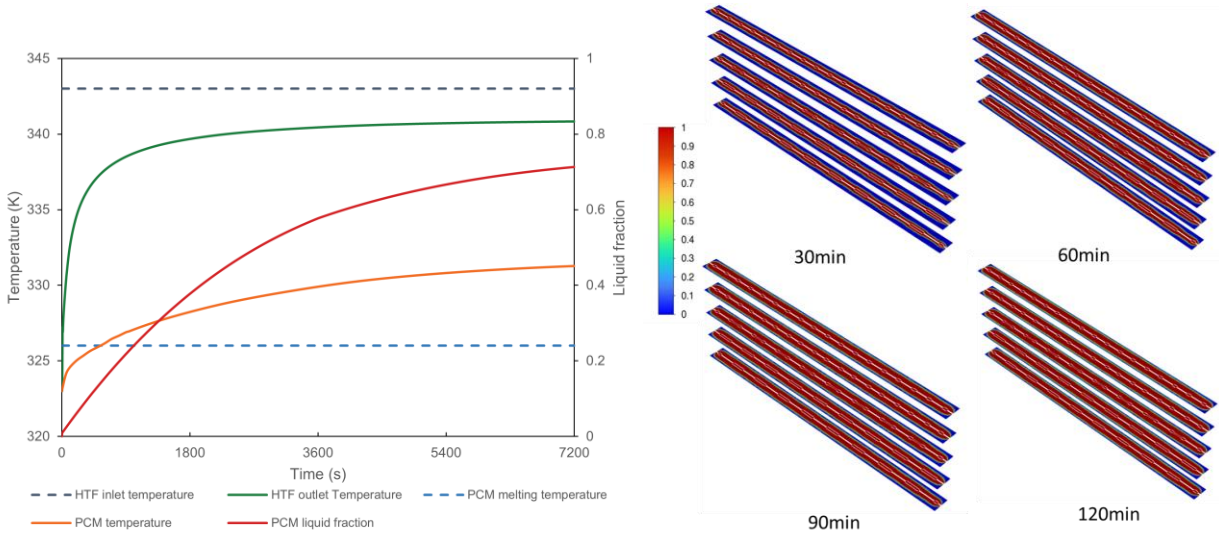
(c)

Fig. 1 Schematic diagram of (a) the unit system (b) Cross-section of the flow channel (c) Roll bond pattern.

The 3D geometrical model of the flat plate with the RB pattern is developed using SolidWorks, and then imported into Ansys Fluent 2023 for processing and post-processing of the CFD model. In this study, water was used as HTF, while Croda 53 with a melting temperature of 326K was used as PCM. The transient CFD model development on the flow is based on the following assumptions: (1) The thermo-physical properties of the HTF and PCM are independent of the temperature. (2) The effect of natural convection for the PCM is neglected. (3) There is no heat loss between the environment and the unit. The pressure-velocity coupling is performed using SIMPLE scheme. With respect to the initial conditions for charging process, the temperature of the PCM and the HTF are established as 323K and 339K, respectively. The inlet of the HTF has been set as the constant flow rate of 0.02kg/s and temperature of 343K.

4. RESULTS

Fig. 2 (a) shows the variation of temperature and liquid fraction of PCM during the melting process in 120 minutes. The PCM liquid fraction contour at five cross-section planes (y = 0.1, 0.05, 0, -0.05, -0.1) of the plate, at processing time of 30min, 60min and 120min are presented in Fig. 2 (b), respectively. The HTF outlet temperature initially rises rapidly and then stabilizes during the melting process, maintaining a steady temperature with a 4K difference from the HTF inlet temperature. The temperature of the PCM initially increases near the plate walls as the HTF moves along the channel from inlet (left) to outlet (right). Once PCM reaches the melting temperature, the melting initialises, resulting in a steady temperature regime. As the heat transfer between the HTF fluid flowing inside the RB channel and the PCM is dominated by conduction, the melting of the PCM begins from the layer closing to the outer plate wall and then propagates towards the inner layer until the PCM is fully melted. At 60min, more areas around plate are liquefied and temperatures are well above the melting point although the PCM temperature decreases gradually away from each tube outer surface. As time proceeds, 58 % and 71% of the PCM transforms into liquid state at 60min and 120min.



(a) Temperature and liquid fraction profiles (b) Liquid fraction of PCM at different time

Fig. 2 (a) Temperature and liquid fraction profile (b) Liquid fraction contour of PCM melting at different time.

5. CONCLUSIONS

In conclusion, this study assessed the thermal performance of the RB plate in the charging process of the LHTES unit by evaluating the PCM melting performance using a 3-D CFD model. By examining the temperature and liquid fraction profiles of PCM, the progress of heat transfer from the HTF through the plate was effectively visualized. The results showed that by 60 minutes and 120 minutes, approximately 58% and 71% of the PCM volume had melted, demonstrating high efficiency in thermal energy storage. Furthermore, the HTF outlet temperature initially increased rapidly and then stabilized, maintaining a steady temperature with a 3.8K difference from the HTF inlet temperature. These findings highlight the significant potential of utilizing RB patterns in LHTES systems, suggesting enhanced thermal performance and efficiency.

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