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Heat Transfer simulation in encapsulated phase change materials for energy storage application

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1. Introduction

As the global demand for sustainable energy solutions intensifies, the integration of advanced technological methods becomes paramount in addressing future energy challenges. Encapsulated Phase Change Materials (EPCM) have emerged as a notable solution in this exploration, primarily due to their exceptional heat storage capabilities. This unique functionality offers the potential for efficient energy storage and release, positioning EPCM as an essential component in various sustainable energy applications. However, while the merits of EPCM are undeniable, its widespread adoption is not without challenges[1]. One of the most pressing concerns with EPCM is its structural integrity throughout operational cycles. Inherent characteristics of conventional EPCM indicate uneven thermal distribution during the phase transition process. Moreover, the intrinsic volume changes in phase change materials can result in the accumulation of localized stresses. Without sufficient control mechanisms, these phenomena might eventually lead to structural fracturing or rupture. Such structural failures not only compromise the efficiency of energy storage and release but could also pose significant environmental risks due to potential leaks. These leakages can have multifaceted impacts, from direct environmental harm to eroding public confidence in EPCM technologies, thereby hindering their mainstream adoption [2].

Recent academic endeavors have delved deep into simulating EPCM behaviors, aiming for a better understanding to mitigate these challenges. However, a significant gap has been observed in the literature, as many of these simulations are based on the assumption of constant volume during phase transitions. While this assumption simplifies the simulation process, it does not replicate the complex stress states EPCM undergoes in real-world applications [3]. The simulation framework in this report was designed to reflect the complex interactions within a turbulent environment involving encapsulated phase change materials (PCMs).

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2. METHDOLOGY

The simulation framework was designed to reflect the complex interactions within a turbulent environment involving encapsulated phase change materials (PCMs). The model featured a singular spherical solid shell encapsulating an inner PCM, positioned within a turbulent environment to focus the heat transfer phenomena in application condition. Notably, the simulation meticulously scrutinized both the convective heat exchange between the spherical shell and the turbulent environment as well as the conductive heat transfer within the shell towards the encapsulated PCM. Furthermore, an in-depth analysis of the spatial distribution of heat transfer coefficients was conducted to elucidate potential hotspots of thermal stress concentration, a crucial aspect for further investigations pertaining to the structural integrity of PCM encapsulation systems.

3. RESULTS

The study conducted 2D simulations of the heat transfer process of spherical encapsulated phase change materials (PCM) in turbulent environments. The overall simulation of conjugate heat transfer was achieved by dividing the multiphase flow region.

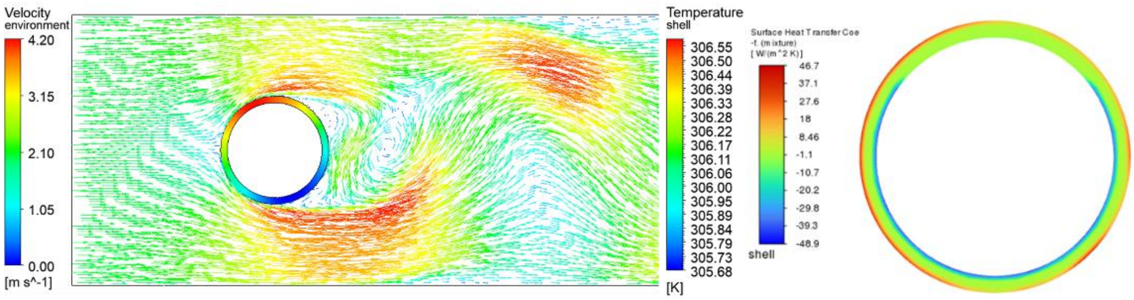

Figure 1 Left: Edited legend of shell temperature distribution combined with velocity vector of turbulent flow
Right: Surface heat transfer coefficient of the shell material.

The simulation results indicate that turbulence in the environment is a significant factor causing uneven heating of the shell's outer surface. During this process, the appearance of the separation phenomenon of the boundary layer significantly reduces the convective heat transfer between the corresponding parts of the shell and the turbulent environment while the eddies keep the heat transfer coefficient remain a high level. Another important factor is the contact between different materials inside the shell and the inner surface of the shell. Due to the different heat transfer properties between different materials, the intense variation in convective heat transfer capacity occurs at the interface between them and the inner surface of the shell. These factors leading to uneven heating impose significant thermal stress variations on the shell material, thereby increasing the likelihood of rupture problems. For the further study, optimization of the rupture issue can be achieved through selection of material properties and arrangement geometry of encapsulated phase change materials in turbulent environments.

Keywords: Conjugate Heat Transfer, Encapsulated Phase Change Material, CFD Simulation Model, Energy Storage.

References

[1] Xiaolin Qiu, Wei Li, Guolin Song, Xiaodong Chu, Guoyi Tang, Fabrication and characterization of microencapsulated n-octadecane with different crosslinked methylmethacrylate-based polymer shells, Solar Energy Materials and Solar Cells, Volume 98, 2012, Pages 283-293

[2] Yahya Sheikh, Mohammad O. Hamdan, Said Sakhi, A review on micro-encapsulated phase change materials (EPCM) used for thermal management and energy storage systems: Fundamentals, materials, synthesis and applications, Journal of Energy Storage, Volume 72, Part C, 2023.

[3] Suraj Arun Tat, P. Muthukumar, Pranab Kumar Mondal, Design, development and performance investigations of a latent heat storage with PCM encapsulation, Journal of Energy Storage, Volume 72, Part E, 2023