Revista Română de Inginerie Civilă, Volumul 14 (2023), Numărul 4

Thermal analysis of storage tank PCM

Analiza termică a unui rezervor de stocare

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DOI: 10.37789/rjce.2023.14.4.5

Abstract. *In this research, we investigate the thermal behavior of storage tanks subjected to varying environmental conditions. Through numerical simulations and experimental analysis, we assess heat transfer mechanisms, temperature distribution, and energy consumption patterns of both insulated and non-insulated tanks. Our study aims to optimize tank design and insulation materials to minimize heat losses, improve energy efficiency, and enhance the safety and longevity of storage tanks. Findings reveal that incorporating optimal insulation materials and techniques can significantly reduce energy consumption and maintain the desired temperature range within the tank, thus providing valuable insights for future storage tank design and management.*

Keywords: Phase Change Materials (PCMs), Thermal energy storage, Computational Fluid Dynamics (CFD), Temperature distribution, Design optimization

1. Introduction

The increasing global demand for energy and the need to reduce greenhouse gas emissions have increased interest in efficient energy storage and management systems. Phase change materials (PCMs) have emerged as a promising solution for thermal energy storage due to their ability to store and release large amounts of latent heat during phase transitions, such as melting and solidification. In storage tanks, incorporating PCMs can significantly improve thermal performance, reduce energy consumption, and maintain temperature stability.[1, 2]

This research article focuses on the thermal analysis of storage tanks integrated with PCMs, aiming to optimize their design and enhance energy efficiency. The application of PCMs in storage tanks can have a wide range of benefits in various sectors, including solar thermal systems, building energy management, and industrial processes. To fully exploit the potential of PCMs in these applications, it is essential to understand the

complex heat transfer mechanisms, temperature distribution, and phase change dynamics within the storage tank. [3, 4]
Phase change materials (PCMs) have gained significant attention in recent years due to their high latent heat storage capacity and the ability to maintain a nearly constant temperature during phase transitions. Several types of PCMs, including organic, inorganic, and eutectic mixtures, have been investigated for thermal energy storage applications. Organic PCMs, such as paraffin waxes and fatty acids, are favored for their high energy density, low supercooling, and chemical stability. Inorganic PCMs, such as salt hydrates and metal alloys, offer high thermal conductivity and heat storage capacity but may experience phase segregation and subcooling issues. [5 ,6]
To improve the performance of PCM-based storage tanks, researchers have explored various techniques, such as using encapsulated PCMs, finned structures, and nanoparticle-enhanced PCMs (NEPCMs). Encapsulation enhances heat transfer and reduces the risk of leakage, while finned structures increase the surface area for heat exchange, improving the charging and discharging processes. NEPCMs, formed by dispersing nanoparticles into the base PCM, exhibit enhanced thermal conductivity and can reduce the charging/discharging time of the storage tank. [7, 8]
Computational Fluid Dynamics (CFD) analysis is a valuable tool for studying the complex heat transfer and phase change dynamics in PCM-based storage tanks. By solving the governing equations for mass, momentum, and energy conservation, CFD can predict temperature distribution, fluid flow patterns, and phase change rates within the tank. Researchers have employed CFD to optimize the design of storage tanks, investigate the influence of PCM properties, and develop effective control strategies for various applications. [9]

2. Material and method

In this study, we will conduct a comprehensive analysis of the thermal behavior of storage tanks containing PCMs by employing numerical simulations, experimental investigations, and analytical modeling. We will explore various factors that influence the performance of PCM-based storage tanks, such as PCM selection, tank geometry, and insulation materials. Moreover, we will evaluate the effect of different operating conditions on the thermal performance and energy efficiency of these systems.
The findings of this research will provide valuable insights into the design and optimization of PCM-based storage tanks and contribute to the development of more sustainable and efficient energy storage solutions. This work will address the current challenges in the field of thermal energy storage but also pave the way for the widespread adoption of PCM technology in various applications.
In this study, we will utilize CFD analysis to model the thermal behavior of PCM-based storage tanks under various operating conditions. We will employ the enthalpy-porosity method, which accounts for the latent heat associated with phase change and the varying porosity of the PCM during melting and solidification. The CFD simulations will be validated against experimental data to ensure the accuracy and reliability of the model.

The CFD analysis will provide insights into the temperature distribution, melting/solidification front progression, and the effect of PCM properties on the overall performance of the storage tank. Moreover, we will investigate the impact of different tank geometries, encapsulation techniques, and heat exchanger configurations on the thermal performance and energy efficiency of the system.

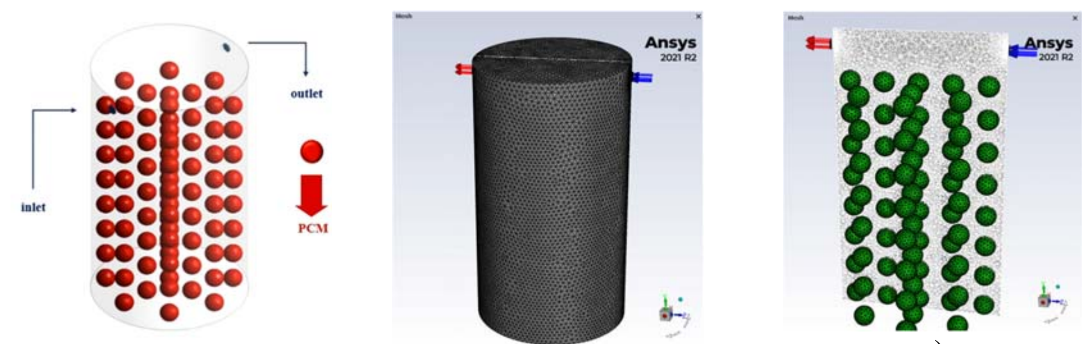
Through the CFD analysis, we aim to identify the optimal design parameters and operating conditions that maximize the energy storage capacity and minimize the energy losses in PCM-based storage tanks. The outcomes of this study will contribute to the advancement of PCM technology and its integration into various energy storage applications, promoting sustainable and efficient energy management solutions.

The 3-D domain of this simulation has been designed in ANSYS Design Modeler. Domain has an inlet and outlet and a wall for PCMs. (Figure 1)

The meshing of this present model has been generated by ANSYS Meshing software. The mesh grid is unstructured, and the total cell number is 339466 elements.

To simulate the present model, several assumptions are considered which are:

- The solver is pressure-based.
- The effect of gravity on the flow has yet to be considered.
- The present model is unsteady.



a) b) c)

Fig. 1. a) Storage geometry; b), c) boundary conditions and geometry meshing

3. Results

Computational Fluid Dynamics (CFD) analysis of a storage tank with Phase Change Materials (PCMs) (Figure 2) provides valuable insights into the thermal behavior and performance of the system. PCMs are used in thermal energy storage systems for their ability to absorb, store, and release large amounts of thermal energy during phase transitions. In the case of a storage tank, the PCM is typically encapsulated in containers or integrated with the tank structure.

Results from a CFD analysis of a storage tank with PCM may include:

- Temperature distribution: The analysis reveals the spatial distribution of temperature inside the tank and PCM containers, which is critical for understanding the heat transfer and energy storage processes.

● Phase change visualization: CFD simulation allows for the visualization of the melting and solidification of PCM, aiding in the optimization of the system for better thermal performance.

● Heat transfer rate: CFD analysis provides information on the heat transfer rate between the heat transfer fluid (HTF) and the PCM, as well as within the PCM itself. This helps to optimize the system's design and operational parameters.

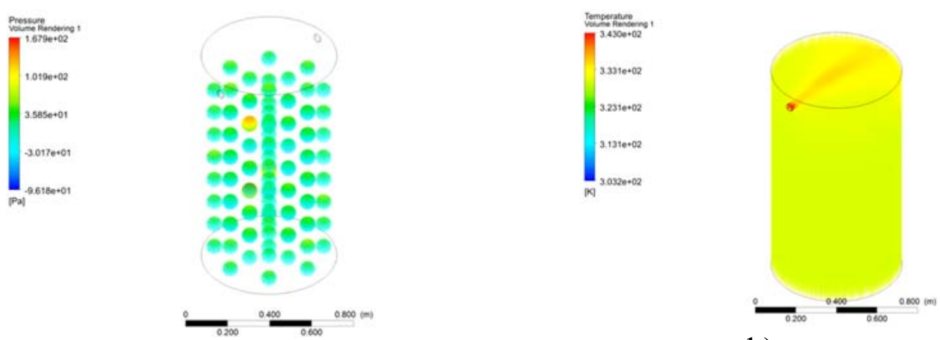
● Flow pattern and velocity distribution: CFD results show the flow pattern and velocity distribution of the HTF within the storage tank, which is essential for understanding the mixing and heat transfer processes.

● Energy storage capacity: The simulation can be used to calculate the total energy storage capacity of the system, which is essential for sizing and design considerations.

● System efficiency: The results from the CFD analysis can be used to evaluate the overall efficiency of the thermal storage system, helping to identify areas for improvement and optimization.

● Transient behavior: CFD simulation can provide insights into the transient behavior of the storage tank with PCM, which is crucial for understanding the dynamic response of the system during operation.

● Thermal stratification: The analysis can reveal the extent of thermal stratification within the storage tank, which is a crucial factor affecting the performance of thermal energy storage systems.



a) b)

Fig. 2. a) Contours of Pressure Magnitude; b) Temperature Magnitude

4. Discussion

A discussion over the CFD analysis of a storage tank with PCM may involve several aspects, such as the benefits and limitations of CFD analysis, factors affecting the accuracy of simulations, and the importance of validation and verification. Here are some points that can be considered for such a discussion:

● Benefits of CFD analysis: Using CFD for analyzing storage tanks with PCM allows engineers to gain insights into the complex fluid dynamics and heat transfer processes that are otherwise difficult to observe experimentally. CFD analysis enables the visualization of temperature distribution, phase change, and flow patterns, which helps in optimizing the design and operational parameters of the thermal storage system.

- Limitations of CFD analysis: Although CFD simulations provide valuable insights, they are based on mathematical models and assumptions that may not always perfectly represent the real-world scenarios. Factors such as mesh quality, turbulence modeling, and numerical schemes can affect the accuracy of the results. Additionally, CFD analysis can be computationally expensive and time-consuming, especially for large-scale or highly detailed simulations.
- Factors affecting CFD accuracy: The accuracy of CFD simulations depends on various factors, including the selection of appropriate boundary conditions, numerical models (e.g., turbulence models), discretization schemes, and the quality of the mesh. Proper selection of these factors is crucial for obtaining reliable and accurate results.
- Importance of validation and verification: To ensure the reliability of CFD analysis, it is essential to validate and verify the simulation results. Validation involves comparing the simulation results with experimental data or other established benchmarks, while verification ensures that the numerical solution converges and the discretization error is minimized. This process helps to build confidence in the simulation results and identifies areas where improvements can be made.
- Sensitivity analysis: A sensitivity analysis can be performed to evaluate the impact of various input parameters and assumptions on the CFD results. This helps to identify critical factors affecting the simulation outcomes and provides a better understanding of the uncertainties involved in the modeling process.
- Optimization of storage tank design: CFD analysis can be used to optimize the design of a storage tank with PCM, such as the shape and size of the tank, the configuration of PCM containers, and the placement of heat exchangers. This allows engineers to enhance the performance, efficiency, and reliability of the thermal storage system.
- Applications in different industries: The CFD analysis of storage tanks with PCM is applicable to various industries, including renewable energy (e.g., solar thermal power plants), building energy systems (e.g., heating and cooling), and process industries (e.g., waste heat recovery and storage). The insights gained from CFD simulations can help in the development of innovative and efficient thermal storage solutions.

5. Conclusion

In the first instance, the temperature of the environment increases with the addition of hot water, which raises the average temperature of the PCMs and demonstrates the melting process in 343 seconds, as shown by the graph of the average temperatures of the environment and PCMs.

Gives. The average temperature diagram shows the impacts of the flow of cold water entering the domain after 1500 seconds, which results in a fall in the domain's average temperature. All of the PCMs have entirely melted by this point. As a result, the average temperature of PCMs drops more slowly when the heat is gradually released.

The PCMs begin to solidify 500 seconds after being submerged in the cold water, and they finish solidifying 4500 seconds later.
You can get the geometry and mesh file you need as well as a thorough training movie that explains how to fix the issue and get the desired outcomes.

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