

Numerical Simulation of Heat Release in Aluminium-Silicon Phase Change Devices

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ABSTRACT

High-temperature thermal energy storage (TES) technologies play a crucial role in mitigating supply-demand imbalances in energy systems. This study investigates the heat release dynamics of an aluminum-silicon phase change material (PCM) within a novel shell-tube TES device through numerical simulation. The research examines the influence of inlet velocity and tube arrangement on solidification time, thermal power, and system utilization rates. Five hypotheses are tested, addressing the correlation between velocity and heat release power, the impact of tube configurations, and efficiency improvements from design modifications. Results indicate an inverse relationship between velocity and solidification time but a reduction in utilization rate. A nonlinear relationship is observed between velocity and thermal power, with an initial positive trend followed by diminishing returns. The five-row PCM arrangement outperforms the triple-row design, demonstrating enhanced heat transfer efficiency. Moreover, strategic design modifications yield notable efficiency improvements. While these findings provide valuable insights for optimizing TES performance, future experimental studies are recommended to validate the simulation results and explore broader operational parameters.

1. Introduction

This section explains the importance of high-temperature thermal energy storage (TES) technologies in the face of supply-demand imbalances in energy supply and shows the promise of aluminum-silicon phase change materials (PCMs) in such applications. The main research question focuses on how design and operational parameters affect the heat release process in a novel shell-tube heat storage device. The sub-research questions that guide the analysis are five in number: how inlet velocity affects heat release, the effect of tube arrangement on performance, the correlation between velocity and thermal release power, the comparative performance of triple-row versus five-row PCM arrangements, and the overall efficiency improvement by design modifications. It utilized a quantitative method that focused on the relationship of independent variables: inlet velocity, tube arrangement to dependent variables, such as the time of solidification, the power of thermal release, and utilization rate. The paper begins with a literature review, continues to explain methods, present the results, and finally concludes the implications and future directions of the research.

2. Literature Review

This section critically assesses existing work on heat release processes in TES devices along five main avenues derived from the introductory sub-questions: Inlet velocity dependence of heat release, Role of tube arrangement for device performance, Velocity dependence and thermal power relationships, Comparing different arrangements of PCMs, and Improvements in efficiency based on design variations. These inquiries reveal existing gaps in research and propose hypotheses derived from variable dependencies.

2.1 Heat Release Effect of Inlet Velocity

The initial studies looked into the basic principles of inlet velocity in heat transfer, showing that it does indeed affect the time of solidification without really analyzing the utilization rates. Later research built upon these findings by including variable velocity conditions, showing intricate interaction patterns. However, even with such developments, the velocity's dual impact on power correlation is still not well understood. Hypothesis 1: Inlet velocity is inversely proportional to the time of solidification but reduces the overall utilization rate of the device.

