

Thermal Analysis of a PCM based Heat Exchanger for a Thermally driven Gas Compression System



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Motivation

- Rising energy demand drives urgent need for efficient, sustainable energy storage and management solutions
- Large, largely untapped industrial waste heat potential could be reused effectively in Compressed Air Systems (CASs) to reduce electrical demand
- This work explores using Phase change material (PCM) volume expansion during melting to compress air, thereby converting waste heat into mechanical work-while improving PCM heat transfer using porous metal structures

Methodology

- Concept Framework: Integrated thermodynamic, materials, & system perspectives for PCM-based actuation application
- Design Aids (VDI 2221): Structured system into functions and solution principles; used AHP and TOPSIS to select two detailed designs
- Material Selection & Characterization: Screened PCM for thermal properties like melting point, latent heat, etc. Using effective PCM-Fiber composite properties
- Computational Modelling: Built 3D COMSOL models to simulate heat transfer and phase change
- Verification Process: Conducted energy balance checks and mesh convergence analysis for model credibility
- Thermal Performance Analysis: Simulated monitor variables like temperature evolution, phase change progression, and charge/discharge response times

Abstract

- Developed a transient 3D thermal model in COMSOL Multiphysics to investigate phase change behavior of PCM embedded in porous metal, targeting waste-heat-driven air compression
- Simulated & analyzed cylindrical heat exchanger (HEX) to assess melting/solidification dynamics, thermal enhancement from metal fibers, and sensitivity to key design and operating parameters
- Verified energy consistency and identified performance-limiting factors, establishing a modeling framework to guide future optimization of PCM-based cyclic compression systems

Results

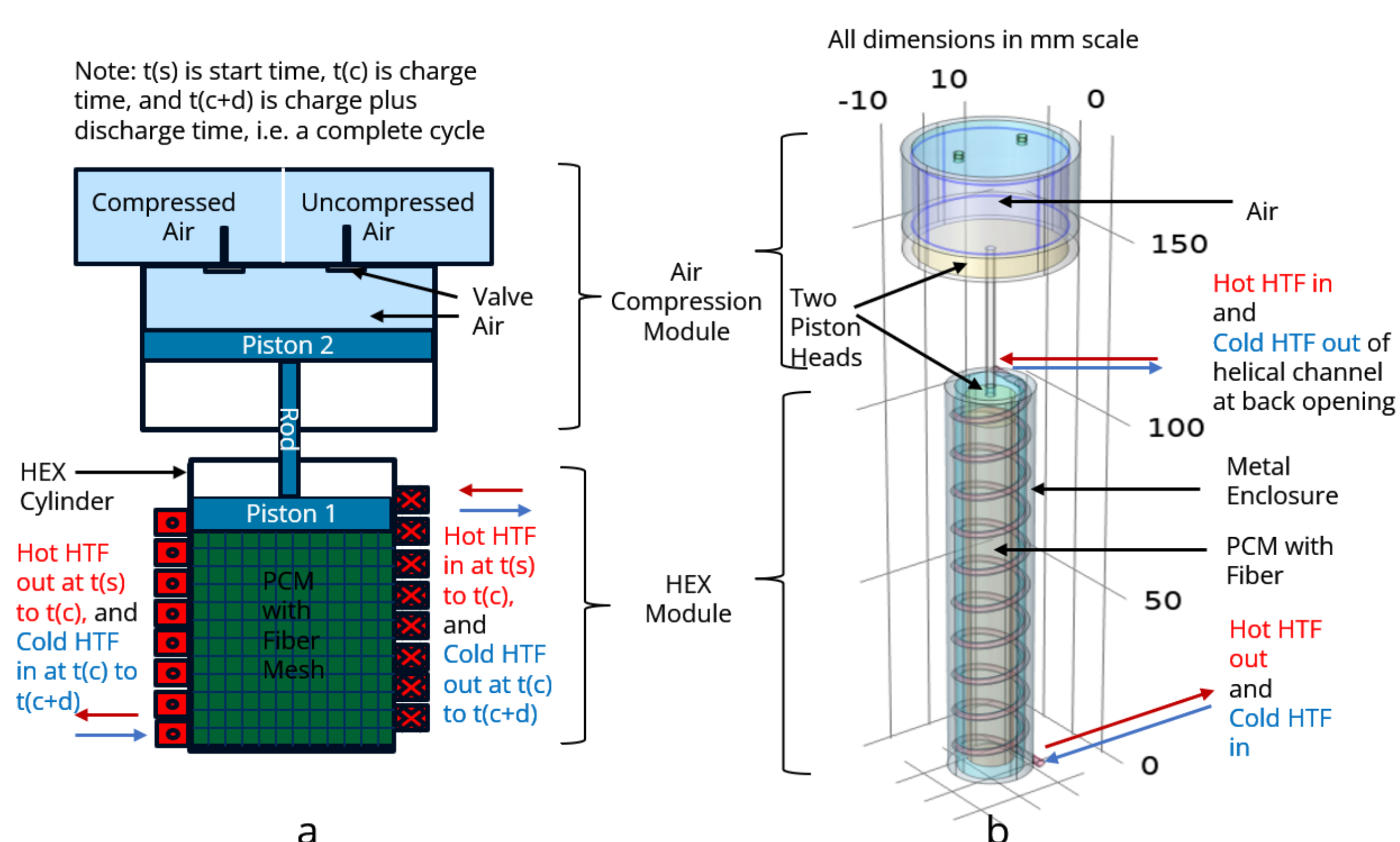
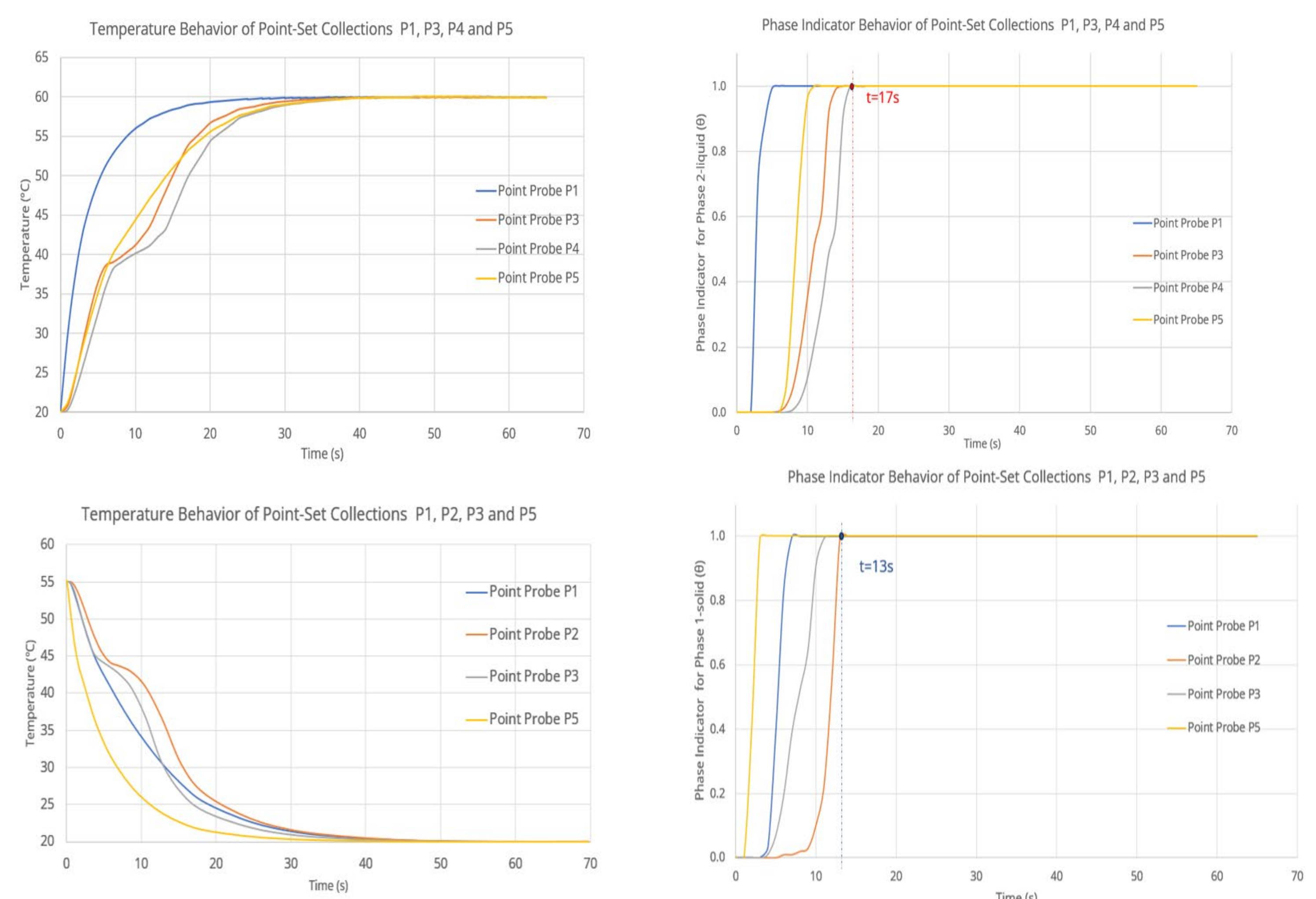


Figure: Cylinder-based HEX system a) 2D schematic b) 3D representation

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Conclusion

- Investigated PCM-based HEX for cyclic gas compression
- Developed simulation frameworks incorporating heat transfer in solids and fluids, phase change & fluid flow physics modeling
- Cylindrical model shows complete PCM melting in ~17 s and complete PCM solidification in ~13 s – a complete cycle in 30s
- Localized hotspots highlight areas for thermal optimization
- VDI 2221 method guided design selection & initial evaluation
- Parametric sensitivity is studied to draw comparisons