

Transient numerical model of a latent heat thermal energy storage unit with axial organic fin geometry

Juan Camilo Toloza-Esparza*, Jorge Payá, Francisco Barceló-Ruescas

Instituto Universitario de Investigación en Ingeniería Energética (IUIIE), Universitat Politècnica de València (UPV)

*jctolesp@iie.upv.es

INTRODUCTION

This work is being performed by UPV within the frame of the European project CHASE4Heat, which aims to integrate renewable electricity into industrial process heating by combining high-temperature heat pumps (HTHP) with latent heat thermal energy storage (LHTES). This combination can improve energy efficiency and provide a more flexible heat supply from renewable energy sources. This study focuses on the dynamic modelling of a vertical LHTES unit developed by DLR. The storage consists of a finned-tube system with PCM as storage material and a heat transfer fluid flowing in two-phase flow inside the tubes. The model is implemented in Modelica using the Dymola environment and will be used to study the storage behaviour and its coupling with a HTHP.

METHODOLOGY

The transient model of the DLR LHTES was developed using a two-dimensional axial-radial discretization. The HTF is discretized along the tube axis, while heat transfer in the storage domain is considered in both axial and radial directions. The HTF model accounts for two-phase flow during condensation and evaporation and is coupled with external C/C++ libraries for thermodynamic properties and two-phase heat transfer calculations.

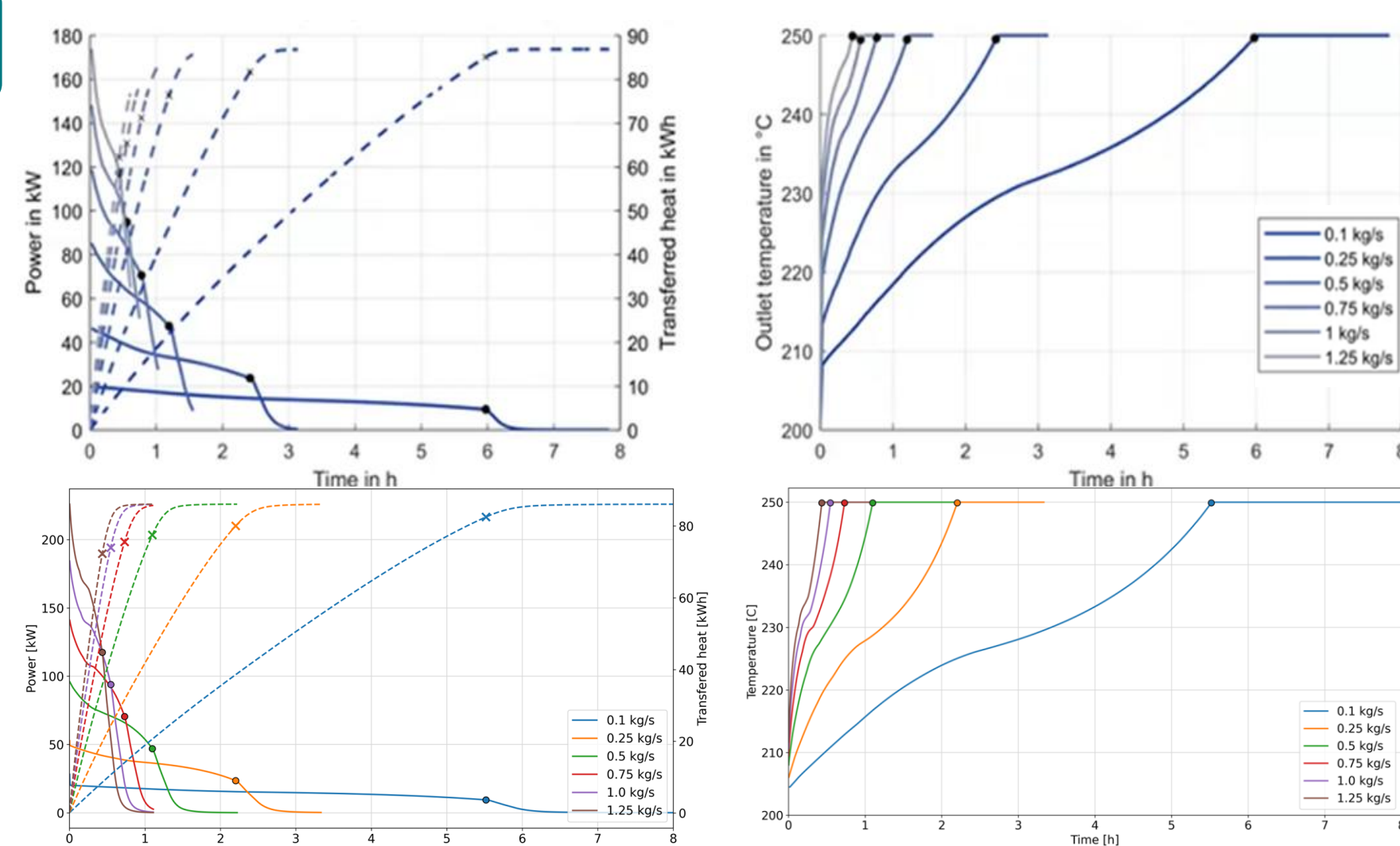
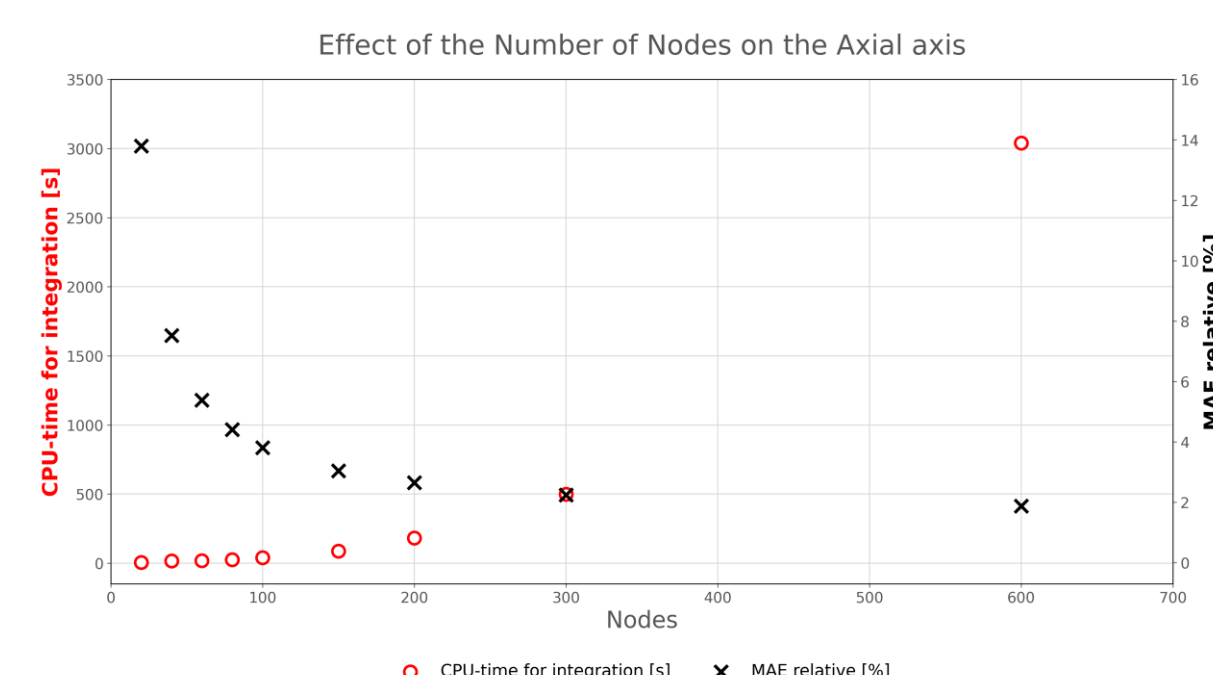
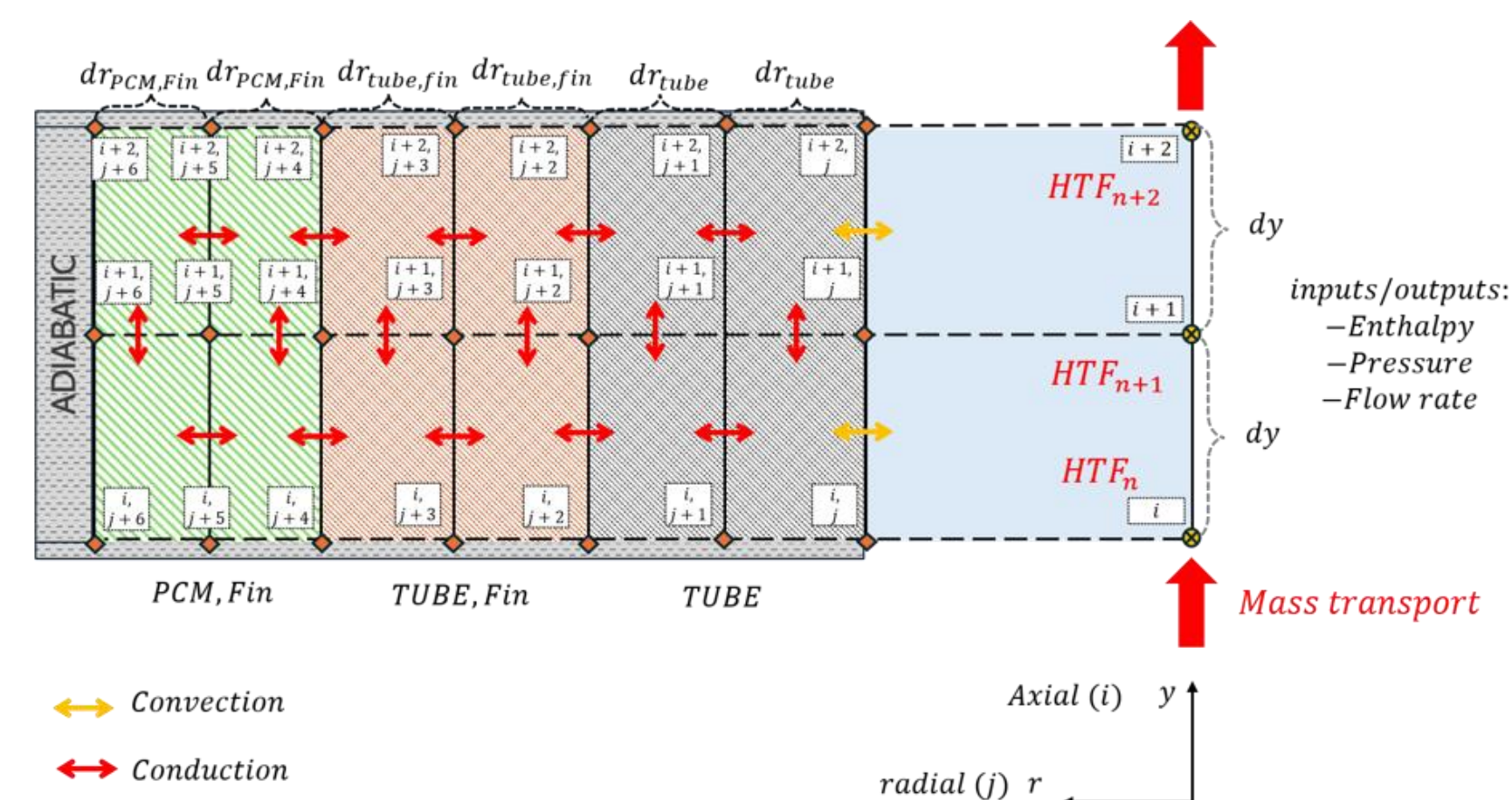
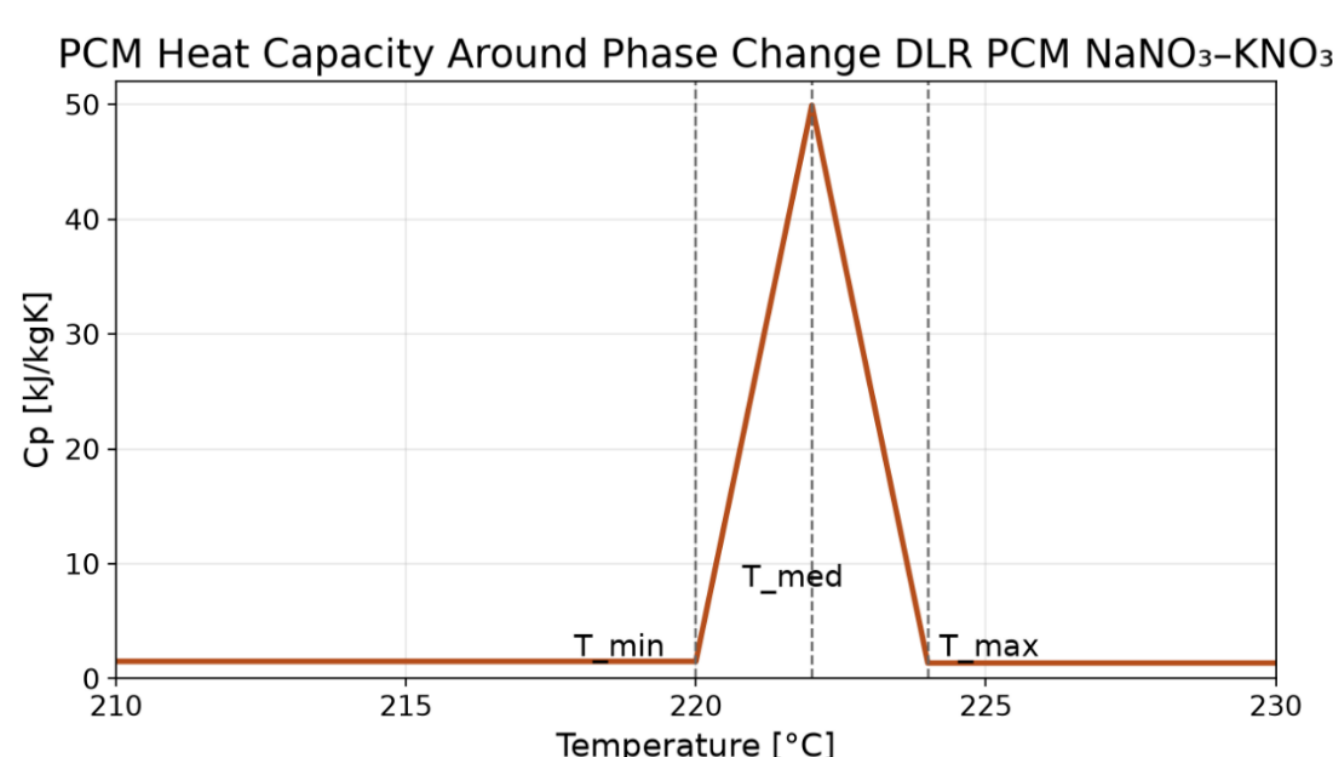
Heat conduction through the storage is solved using a finite-difference approach. The phase change is described with an enthalpy-based PCM formulation using an apparent heat capacity curve. The complex fin geometry is simplified by representing the PCM and aluminium fins as a homogenized domain with equivalent thermophysical properties, avoiding the explicit discretization of each fin. The fin efficiency has been calculated and is higher than 95%, which implies that there is no need for a more detailed calculation of the temperature profile along the fins.

The hardware used for the simulations was: Intel® Core™ i5-10400 CPU @ 2.90 GHz ,16 GB RAM, Windows 11 Enterprise 24H2, 932 GB storage

RESULTS

The model provides the time evolution of the HTF thermodynamic state, vapor quality, pressure, temperature, and heat transfer rate, together with the PCM temperature distribution, liquid fraction, and stored or extracted energy. These variables can be evaluated at different positions along the LHTES unit. The model was evaluated for charging and discharging and compared with the DLR reference model. Both models show similar results for HTF outlet temperature, thermal power, and PCM liquid fraction. The difference in the total exchanged energy is 1.11% for charging and 1.19% for discharging.

The effect of the HTF mass flow rate was also analysed. Higher mass flow rates increase the thermal power and reduce the charging time, while the total transferred energy does not increase proportionally. A nodal sensitivity analysis was performed to select the spatial discretization, considering the numerical accuracy and computational cost.



Charging comparison between the DLR model and UPV model, using water as HTF, $T_{in} = T_s = 200^\circ\text{C}$ from $T_{PCM} = 250^\circ\text{C}$ (images on the top for DLR model and at bottom for UPV)

CONCLUSIONS

The developed LHTES model offers a flexible simulation framework for analysing latent heat storage units under dynamic operating conditions. By coupling the PCM enthalpy dynamics with the HTF properties and two-phase flow calculations, the model can support the design evaluation, operating strategy analysis, and integration studies within CASHE4Heat. This provides a useful tool for reducing design uncertainty before experimental implementation.

REFERENCES

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