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Examining a salt-based energy storage system with an emphasis on latent heat

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1. Introduction

Renewable energy requires efficient storage to maintain grid stability. Converting low-cost electricity into heat and releasing it during peak demand is a promising approach, with molten salt storage offering improved efficiency and stability for industrial applications. Molten salt systems enhanced with phase change materials can store and release large amounts of latent heat at nearly constant temperatures, improving efficiency. To explore this potential, a semi-industrial test rig and a 3D CFD model were developed to study salt melting, crystallization, and overall energy balance under realistic operating and boundary conditions. Figure 1 illustrates the key stages of the thermal discharge process involving quantitative salt freezing. This work was created in collaboration with Emerald Horizon AG and carried out within the CALstore FFG project (Basic Programme, project numbers 903946, 913344, and 927823).

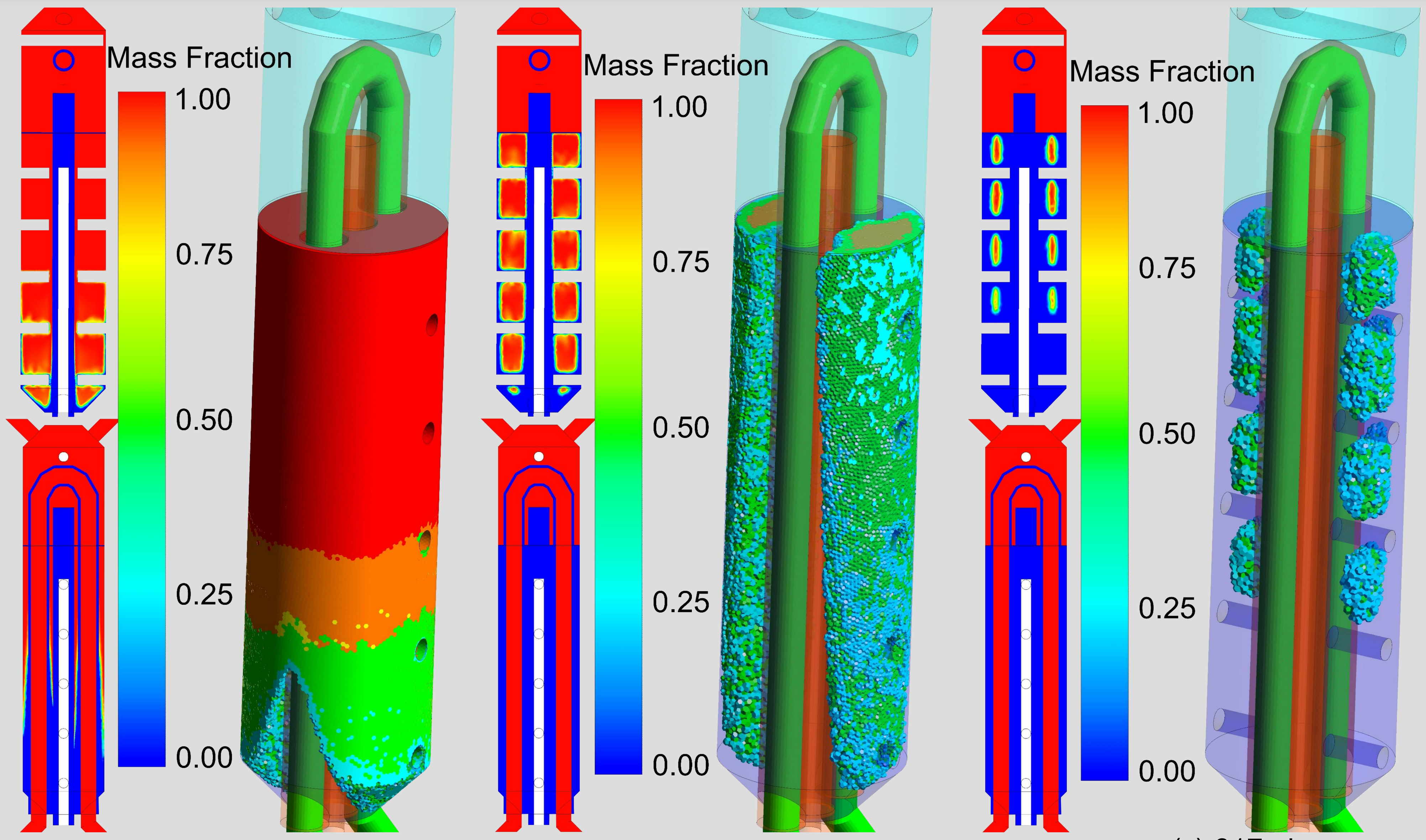

Fig.1: Mass fraction on relevant time steps during the crystallization process

2. Methods

A semi-industrial experimental test rig was designed as a vertical U-tube shell-and-tube heat exchanger filled with solar salt, where compressed air serves as the heat-transfer fluid to simulate industrial operating conditions. The true-to-scale structure of the salt tank, including the measurement points, is shown in Figure 2. Heating surfaces were dimensioned according to the VDI Heat Atlas, and the setup was instrumented with flow, pressure, and multiple thermocouple sensors to measure air and salt temperatures at various axial and radial positions. Controlled experiments were conducted under different thermal loading and extraction conditions to determine heat transfer behaviour, turbulence regimes (Re > 10000), and system energy balances. The collected spatial- and time-resolved temperature data enable detailed analysis of melting, convection, and crystallization processes within the salt tank.

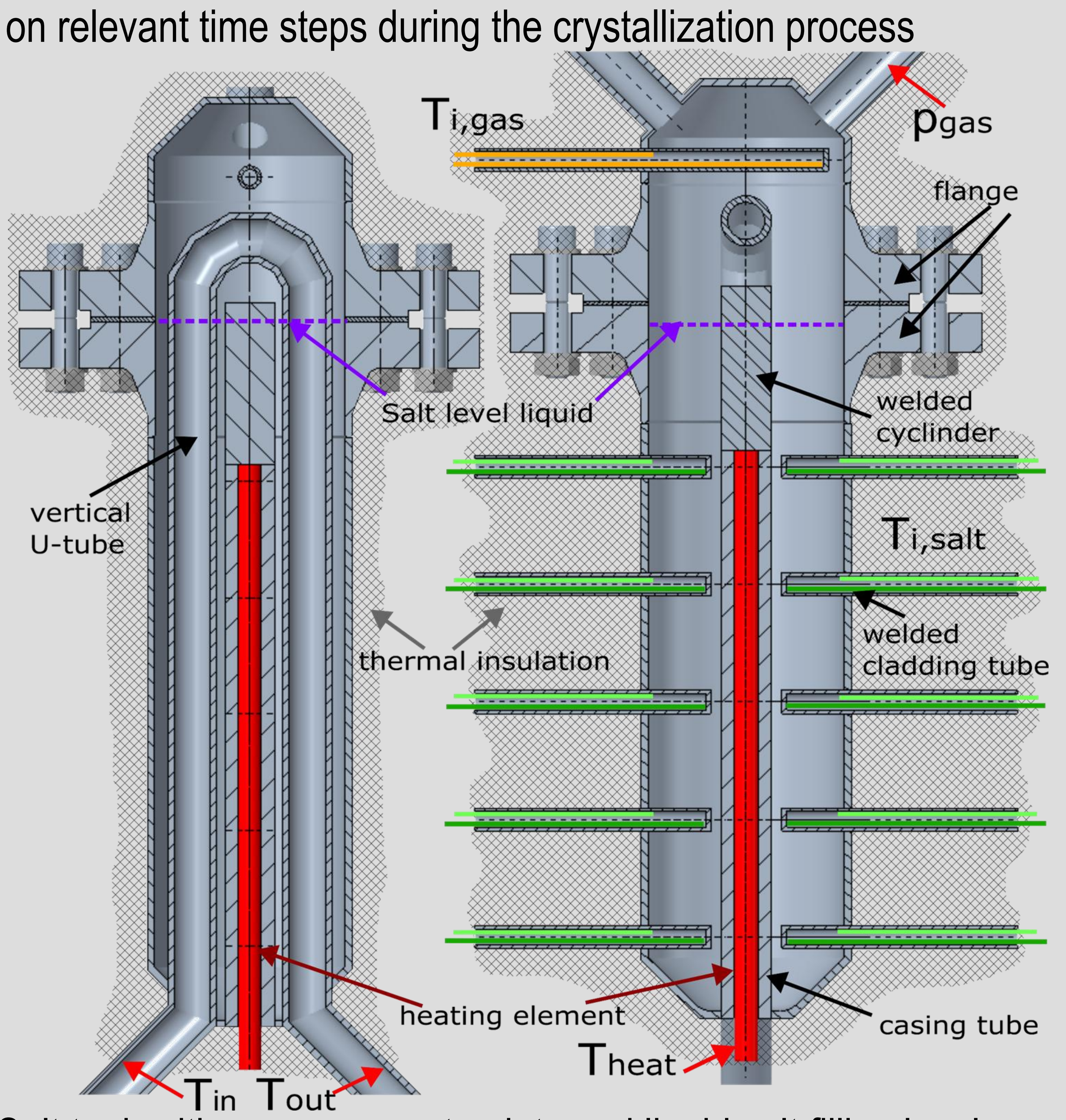

Fig.2: Salt tank with measurement points and liquid salt filling level

3. Results

The experiments successfully demonstrated the use of both sensible and latent heat in a TES (Thermal Energy Storage) based on a vertical U-tube shell-and-tube heat exchanger. Crystallization behaviour was experimentally analysed and accurately reproduced by a validated 3D transient CFD model. Air temperature deviated by only ±2%. The results show that up to 60% of the salt's latent heat can be safely utilised, corresponding to a frozen layer thickness of about 3–4 mm around the U-tube. Under optimal conditions (550°C maximum salt temperature, up to 8 bar, and 0.005–0.01 kg/s air mass flow), approximately 1300 kJ/kg of thermal energy could be extracted. The phase state of the salt is represented in Figure 3 using the mass fraction parameter, where 1 indicates liquid and zero indicates solid.

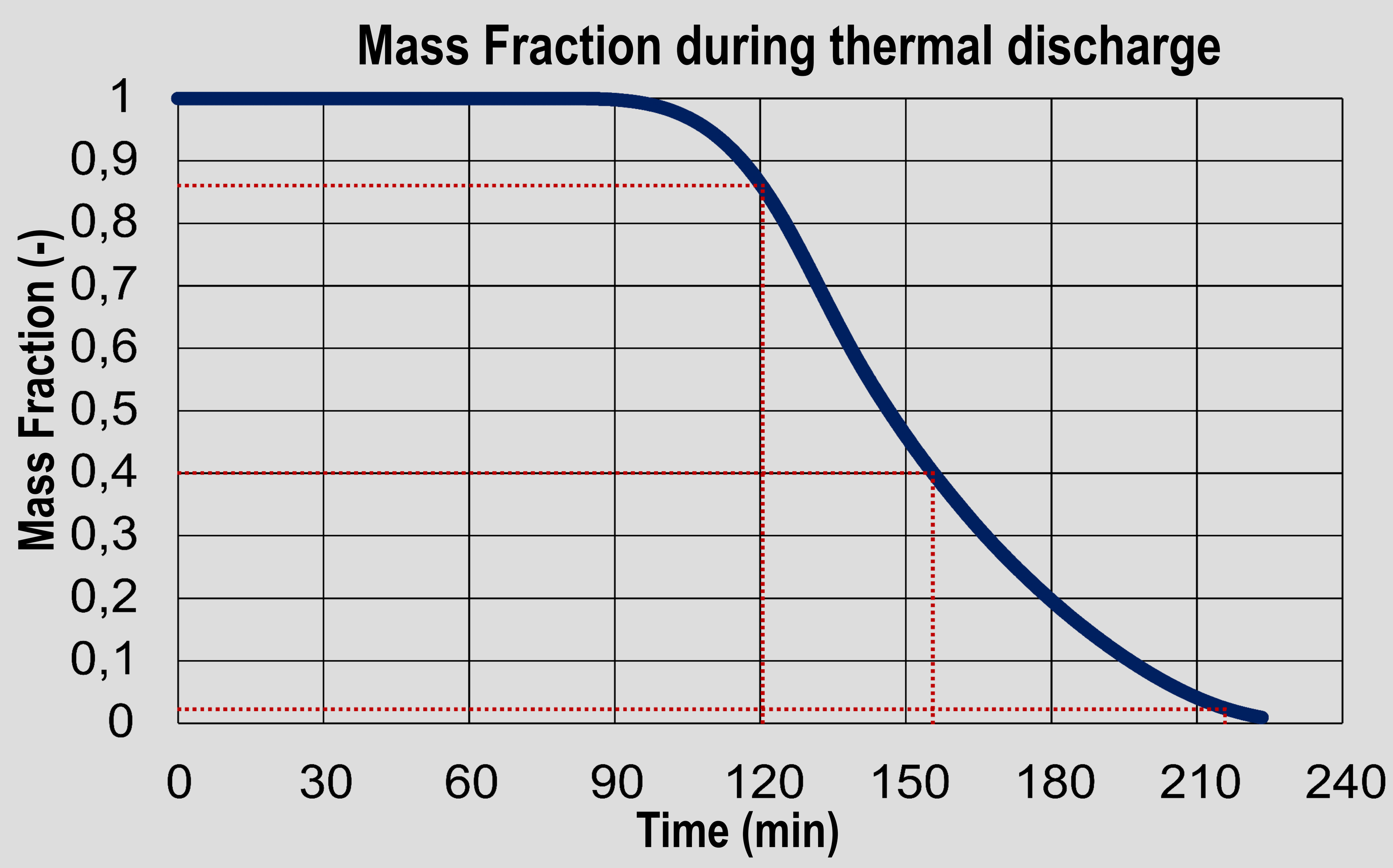

Fig.3: Mass fraction of salt domain during thermal discharge

4. Conclusion

- First to explore safe salt crystallization in TES with sensible and latent heat.
- 60% of the salt's latent heat can be used without affecting structural integrity.
- The best operating strategy maximizes the use of latent heat and heat flow.
- To obtain the maximum latent heat, extraction should be stopped at 2-3 hours.
- The data precisely identifies when and where salt crystallizes.
- Measured temperature and heat fluxes over time cover all relevant operating states.

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