Temperature and Pressure Control for Compressed Underground Hydrogen Storage

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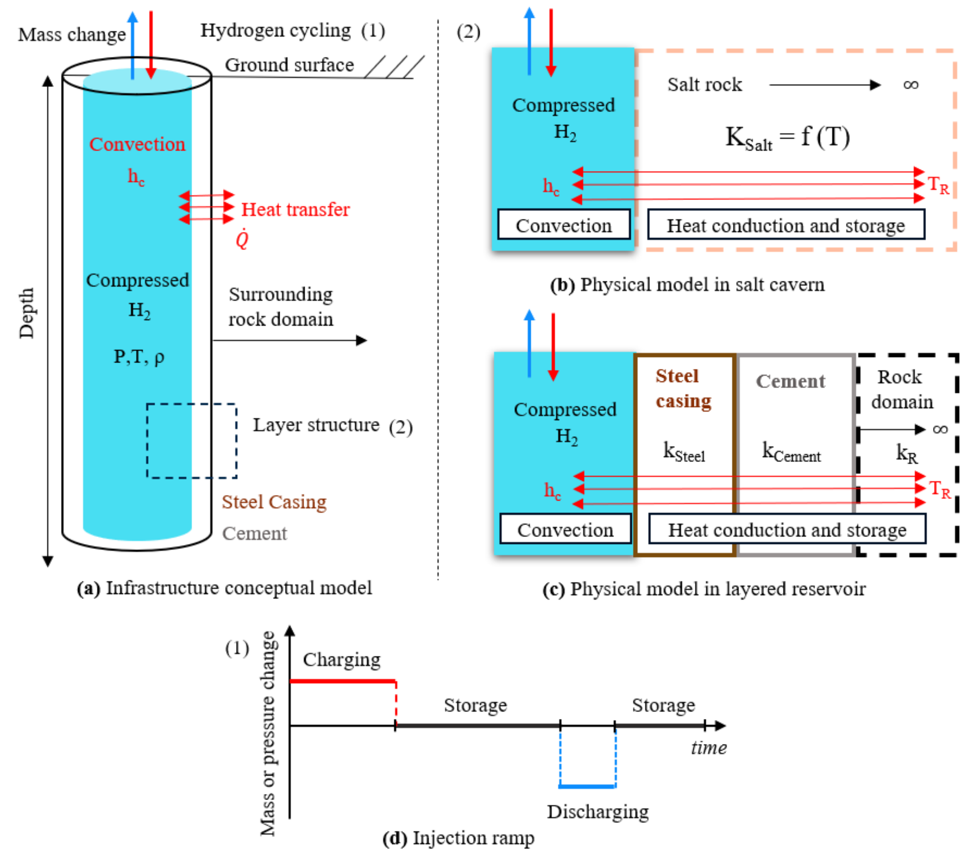
Summary

Compressed hydrogen storage, an energy-efficient alternative to liquefaction, is gaining prominence, with salt caverns being the leading solution due to scalability and cost effectiveness in projects across the United States, Europe, and China. However, in the absence of salt formations, the use of underground reservoirs like rock caverns, mining shafts, and cased boreholes is emerging as a viable alternative. Ensuring effective temperature control is essential for maintaining the integrity and maximizing hydrogen density in both storage methods. Periodic temperature changes can significantly impact the mechanical properties of salt rock, leading to alterations in stress distribution and to increased risk of salt cavern instability. Drilled reservoirs face volume constraints, resulting in short, high-pressure cycles with important temperature peaks. The objective of this presentation is to highlight the importance of temperature and pressure modeling and offer a validated numerical model along with an open-access code for simulating heat exchange and predicting the thermodynamic response in operation cycles of underground hydrogen storage in both salt cavern and layered reservoirs. The validation encompasses analytical solutions, experimental data, and existing cylindrical models. Results show that effective management of injection and extraction rate is crucial to limit temperature peaks in larger radius reservoirs where heat transfer is less efficient. As for short storage cycles, analysis indicates limited penetration depth of the thermal perturbation, underscoring the importance of simulating heat transfer across multiple layers, especially in restrictive media like cement.

Graphical Abstract



Theory / Method / Workflow

The approach involves adapting and enhancing the Kushnir et al. (2012) model (developed for compressed air energy storage), specifically by integrating variations in thermal conductivity throughout the mesh, having a thermal conductivity in function of temperature for salt, offering flexibility in handling both density and pressure injection ramps, and incorporating a proven hydrogen compressibility model, thereby eliminating the reliance on databases. The validation encompasses analytical solutions and existing cylindrical models. A sensitivity analysis on the temperature peak during storage cycles was also conducted.

Novel/Additive Information

The primary contribution lies in the public distribution of a validated code capable of simulating heat transfer in operation of underground hydrogen storage within a computing time of under 5 seconds. This effective tool is proving highly valuable in the design and operation phases of both salt caverns and excavated reservoirs and is a powerful resource for optimizing these processes.

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