Research on Stability and Tightness of Surrounding Rocks in Layered Salt Rock Hydrogen Storage Caverns under Thermo-Hydro-Mechanical Coupling

The massive consumption of fossil fuels such as coal, oil and natural gas has exacerbated the global energy crisis and contributed to greenhouse gas emissions, leading to environmental challenges such as global warming, the greenhouse effect and melting glaciers. With the proposed strategic goals of "carbon peaking" and "carbon neutrality", France and China are accelerating their energy transition. Both countries have abundant wind, solar and hydro resources. However, the intermittent, fluctuating and discontinuous nature of renewables makes it difficult to integrate them into the grid in a stable manner, leading to significant curtailment issues. It is therefore crucial to address the grid integration and utilisation of renewable energy.

Large-scale energy storage technologies have emerged to resolve these challenges. These technologies store excess electricity during low-demand periods and release it during peak demand, balancing grid loads and achieving "peak shaving and valley filling". Such technologies not only enhance grid stability but also promote the integration of renewable energy, advancing the development of green power systems and energy internet infrastructure. Current mainstream energy storage technologies include pumped hydro storage (PHES), compressed air energy storage (CAES), and underground hydrogen storage (UHS). Among these, underground hydrogen storage, due to hydrogen's high energy density, offers large-scale (gigawatt-level) and long-duration (weeks to months) storage potential, meeting the demands of grid-scale peak regulation.

China holds significant advantages in constructing underground salt cavern hydrogen storage facilities. First, the country has abundant and widely distributed salt rock resources, which align well with the distribution of renewable energy. Second, China has extensive experience in salt mining and underground cavern construction. However, Chinese salt formations are predominantly layered, characterized by thin salt layers, multiple interlayers, high impurity content, and limited total thickness. Compared to salt dome formations commonly used globally, layered salt rock poses more complex challenges for hydrogen storage, particularly regarding the sealing integrity of surrounding rocks and hydrogen permeability. Hydrogen’s small molecular size and low viscosity enable it to easily permeate through interlayers and high-permeability rock layers, leading to leakage risks. Therefore, studying hydrogen permeability characteristics, damage evolution, and seepage mechanisms in layered salt rock formations—especially the long-term sealing integrity of the entire formation—is crucial for ensuring the safety and stability of salt cavern hydrogen storage.