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Thermo-hydro-mechanical modeling and analysis of cement-based energy storages for small-scale dwellings

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One of the common technologies for balancing the energy demand and supply in district heating, domestic hot water production, thermal power plants and thermal process industries in general is thermal energy storage. Thermal energy storage, in particular sensible heat storage as compared to latent heat storage and thermo-chemical storage, has recently gained much interest in the renewable energy storage sector due to its comparatively low cost and technical development. Sensible heat storages work on the principle of storing thermal energy by raising or lowering the temperature of liquid (commonly water) or solid media, and do not involve material phase change or conversion of thermal energy by chemical reactions or adsorption processes as in latent heat and thermo-chemical storages, respectively.

In this study, the coupled thermo-hydro-mechanical behaviour of a cement-based thermal energy storage system for domestic applications has been modeled in both saturated as well as unsaturated conditions using the Finite Element method along with an extensive experimental analysis program for parameter detection. For this purpose, a prototype model is used with three well-known thermal energy storage materials, and the temperature and heat distribution of the system were investigated under specific thermo-hydro-mechanical conditions. Thermal energy samples with controlled water to solids ratio and stored in water for up to 28 days were used for the experimental program. The determination of parameters included: thermal conductivity, specific heat capacity and linear coefficient of thermal expansion (CTE) using a transient line-source measurement technique as well as a steady-state thermal conductivity and expansion meter; mechanical strength parameters such as uni-axial strength, young's modulus of elasticity, poisson's ratio and shear parameters using uniaxial, oedometer and triaxial tests; and hydraulic properties such as hydraulic permeability or conductivity under controlled stress and temperature conditions using a specialised hydraulic permeability meter.

Keywords: thermal energy storage; cement-based storage; coupled T-H-M material properties, FE method