Modelling Large-Scale Thermal Energy Stores

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by

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Abstract

More than 30 research and pilot seasonal thermal energy stores (TES) have been realized internationally within the last 30 years. Experience with operation of these central solar heating plants with seasonal thermal energy storage (CSHPSTES) shows that TES are technically feasible and work well. However, seasonal storage of solar thermal energy or of waste heat from heat and power cogeneration plants can only contribute significantly to substitute fossil fuels in future energy systems, if performance with respect to thermal losses and lifetime can be enhanced while construction costs can be further reduced. The aim of this work is to improve TES technology with regard to design and construction. To achieve this, models are necessary that enable the realistic representation of all relevant thermodynamic processes related to TES.

The large variety of TES makes it difficult to compare performance in relation to construction costs. Performance of TES depends on location (geological situation: rock, soil, sand, with or without ground water), construction type (tank or pit), size (from some 100 m³ to more than 10 000 m³), geometry and position (cuboid, cylinder, cone or pyramid trunk, buried or partially buried), storage medium (water, gravel/sand/soil-water, direct or indirect charging) and used material (e.g. stainless steel or polymer membrane liner).

Furthermore, TES are integrated in a heating and cooling system. Obviously, there is a great variety of system configurations and control strategies. Important aspects are e.g. number of charging cycles, maximum charging temperature, net return temperature and operation with or without heat pump and with or without additional buffer store.

All these constructional and operational characteristics as well as the boundary conditions influence the energetic and exergetic efficiency of (seasonal) TES.

Hence, for realistic comparison, system simulations are required which include all relevant parameters.

This work provides an overview of state-of-the-art seasonal thermal energy storage with the focus on tank and pit TES construction. Aspects of TES modelling are discussed. Based on modelled and measured data the effects of construction type, system configuration and boundary conditions on thermal losses of large-scale TES are identified. It is found that available coarse-structure TES models simplify the real processes such that a detailed analysis with the objective to enhance TES design is not possible.

Optimization of TES design and construction requires detailed insight in the processes related to heat and moisture transfer in the envelope of TES. The materials applied for insulation and lining are characterised and evaluated. By means of measurements and modelling of relevant material properties, i.e. sorption isotherm, thermal conductivity and permeation resistance, the processes in the envelope can be better explained, which is essential for improving TES design.

An analytical model for the thermal conductivity, developed in this work, yields good results. However, it represents a simplification of the real processes in the envelope of a TES. Hence, a model was established that accounts for coupled heat and moisture transport at elevated temperatures. Exemplarily, calculations were performed to demonstrate essential features of the model.

Outdoor laboratory experiments confirmed the transferability and relevance of the findings with regard to the influence of elevated temperature and moisture content on thermal losses. Good agreement between monitoring data and modelled thermal losses is achieved.