Detailed Axial Symmetrical Model of Large-Scale Underground Thermal Energy Storage

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Abstract

Introduction:
Nowadays, the energy demand in buildings sector (i.e. space heating and domestic hot water) accounts for more than one-third of the total energy demand in the European countries. District heating (DH) approach has been commonly used to meet this demand as it enhances the energy efficiency and, thus, developments of these systems have grown rapidly in the last decade. One of the crucial developments is to enhance the exploitation of renewables in DH to substitute the fossil fuels; thereby, many goals are realized (e.g. less CO2 production). Yet, heat availability from renewables and buildings' heating demand vary mostly with asynchronous pattern, which is often observed due to the large variation in the outdoor temperatures between summer and winter. On another hand, the major drawback of renewables is the intermittency as they fluctuate daily, weekly and seasonally. Thus, a significant amount of heat might be lost during summer, when the buildings' heating demand is commonly minimal. Accordingly, seasonal thermal energy storage (STES) represents a good opportunity for compensating the seasonal mismatch observed between energy supply and demand.
Seasonal Thermal Energy Storage in DH Systems:
Seasonal Thermal Energy Storage (STES) appears as prominent elements for solar-assisted DH systems since they particularly can bridge the gap between solar heat abundance in summer and the space heating demand in winter. Nevertheless, STES systems are frequently seen challenging because of the large volume required for the storage. For instance, if a seasonal tank TES has a size more than 100,000 m3, and then more efforts are needed to build a freestanding tank. Accordingly, those systems are mostly buried either fully or partially under the ground forming the so-called underground TES (UTES) systems. Research has been ongoing reporting UTES performance in DH systems, UTES thermal behavior etc. Yet, it is found that there is a gap of UTES models with 40 consideration of groundwater. The importance of this consideration arises from the fact that in several countries in Europe (e.g. Austria) there are several hydro geological standards, which state on preventing the groundwater's temperature from increasing above 20°C (see figure attached). This increase in temperature is usually seen due to the long storage period and, thus, higher amount of lost heat that increases the temperature. Thus, numerical modeling approach is often used to investigate the thermal behavior and to quantify the heat lost to the ground.
Numerical Modelling:
In this work, a 3-D numerical model is developed using COMSOL Multiphysics® in which

the storage model is discretized in a finite element fashion. The model is suitable only for cylindrical geometries (e.g. truncated cones or cylinders) for the time being. There are ongoing efforts to develop the model into a parameterized model that simulates different geometries (e.g. pyramid stump). Back to the model, the impact of the soil and the groundwater on the thermal losses from the tank and the stratification can be investigate. In the tank model, it is imposed that the mass of the water flowing into/from the tank is conserved and, thus:

$\dot{m}_{in}=\dot{m}_{out}=\dot{m}$

Whereas the energy stored in a volume element can be described by the following equation:

$(\partial E(t))/\partial t=\dot{m}\cdot(h_{in} - h_{out})+(\dot{q}_z - \dot{q}_{z+dz})-UA_{side}(T(t) - T_{ground}(t))$

Results and Discussion:

The model is able to examine underground cylinderical structures (e.g. TES systems with truncated conical or circular geometries) and, therefore, it provides a thermal analysis of such systems, which makes it possible to perform optimization with regard to thermal losses. The results depict that stratification takes place inside the tank storage over time and this implies that the thermo-hydraulic behavior of the storage medium is correctly implemented. Also, the results reveal that the ground is highly influenced during the storing phase in which the surroundings temperature exceed 50°C, whereas the ground underneath the tank storage is strongly affected during charging resulting in a temperature at around 50°C. Therefore, it can be said that an amount of energy is stored in the ground and it is difficult to retain it back.

Figures used in the abstract

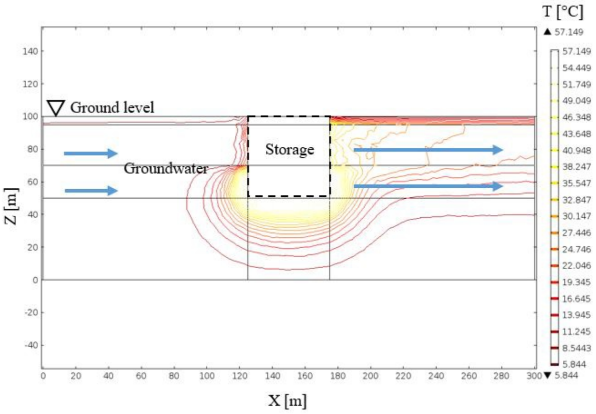

Figure 1: Temperature distribution in the ground around the storage after 10 years of simulation time.