Contribution ID: **696** Type: **Oral Presentation**

Thermal properties of unconsolidated sediments and borehole back fill materials for ground source thermal energy systems

Monday, 22 May 2023 12:05 (15 minutes)

The performance of Ground source heat pump systems (GSHP), and heat losses along well bores of high-temperature aquifer thermal energy storage systems (HT-ATES) and geothermal wells is strongly affected by conductive properties[1,2].

The anticipated growth of the geothermal and HT-ATES in line with global potential of geothermal energy production of between 125 and 1793 EJ/yr [3] augments to the relevance of in-depth understanding of conductive properties. Apart from heat losses affecting performance, shallow groundwater used for drinking water could be affected by the heat transfer[4,5]. This can result in (bio)chemical changes in the water composition[5,6]. This could potentially reduce the amount of suitable drinking water reserves for future use. In addition, too much heat loss in the cold subsurface could yield a risk of the formation of thermal plumes, which could in turn compromise the production of neighboring geothermal wells in urban areas[7].
Uncertainties in the thermal conductivity of an aquifer can affect the efficiency estimations of a single HT-ATES doublet. Using DoubletCalc[8], it was determined that this especially plays a role during the initial three loading cycles with a difference of up to 3.5% in efficiency. Others have shown even larger impacts, where an increase of 12.5% of the thermal conductivity reduces the total aquifer technical potential with 25–33%, while decreasing by 12.5% results in a 29–49% increase[3].

Understanding and being able to measure and predict the thermal properties both on the centimeter- and meter scale is challenging. Experimental determination is typically on the millimeter scale, most numerical simulations use solid rock-, oil and gas- and construction industry values and well thermal response tests lumpsum many different sediment types into one value.

A semi-automated setup was developed based on the needle-probe method to create an experimentally based understanding of the influence of different interrelated physical properties of unconsolidated sediments on the thermal properties of such sediments. Through a series of experiments, the impact of several sediment configurations have been investigated. Sediments were selected with various amounts of complexity in the composition or layers or layered orientation. For parameter isolation and model calibration, the impact of grain size, shape, porosity and water content was determined using amorphous soda-lime glass.

A numerical model with a radial symmetric finite volume formulation was used to determine the various thermal properties of the sediment sample, using an ensemble smoother with multiple data assimilation (ES-MDA) to inverse fit the model to the experimental data.

The combined experimental-numerical approach provides a reliable and reproducible method for determining the thermal properties of unconsolidated sediments and porous media in general and a means to determine the validity of the numerical model calculations. In oncoming research projects, the experimentally validated results will provide the input for upscaling and validation in a real life ground source heat pump setup.

Participation

In-Person

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Session Classification: MS17

Track Classification: (MS17) Thermal Processes, Thermal Coupling and Thermal Properties of Porous Media: modeling and experiments at different scales