Geotechnical challenges for a High Temperature Energy Storage in the greater Copenhagen area (Zealand, Denmark)

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Introduction

Research and industrial interest in Denmark is gradually moving towards geothermal energy due to the ambitious emission reduction targets established for 2020. Due to the geographical location with respect to the plate tectonics (Goutorbe et al., 2011), the potential for geothermal exploitation is small compared to other countries in southern and western Europe. However, geothermal exploitation could still cover approximately 66% of the heating demand in Denmark, which represents 84% of the energy needs, despite the lower underground temperature gradient. In particular, Underground Thermal Energy Storage combined with heat production from solar energy or waste incineration provides the possibility to use deep aquifers as a buffer. Currently, seasonal shallow heat storage exchangers are being installed (Sørensen, 2016) that work below 25°C in combination with heat pumps to avoid pollution of the shallow aquifer, which is used for drinking purposes. However, to be able to combine this technology with renewable energy sources for the purpose of district heating, which is very widespread in Denmark, it is necessary to work at higher temperature ranges and at greater depth.

Geological settings and physical properties

In Zealand, the Chalk Group (Upper Cretaceous-Danian) is the uppermost lithological succession of the pre-Quaternary deposits. It is formed by carbonate skeletons of planktonic algae and other pelagic organisms, and it comprises the following formations: Copenhagen Limestone Fm. (Upper Danian), Stevens Klint Fm. and Faxe Fm. (Middle-lower Danian) and Tor Fm. (Maastrichtian) (Jakobsen et al. 2017). In the greater Copenhagen area, these carbonate sediments are the relevant reservoir for groundwater and medium depth geothermal energy. A major source of uncertainty for investors in ATES technology is the lack of geotechnical data at greater depth, as the majority of geotechnical investigations are connected to the construction of public infrastructures, where the top of the chalk (Copenhagen Limestone Fm.) is encountered. The Tor Formation in Zealand is analogue to the chalk in the Dan field (North Sea), where an extensive database has been obtained in connection with oil exploitation. However, this is found at 2km depth in the Dan field and from as shallow as the ground level until depths in excess of 1km in the grater Copenhagen area due to uplift and erosion of Zealand (Japsen, 1998).

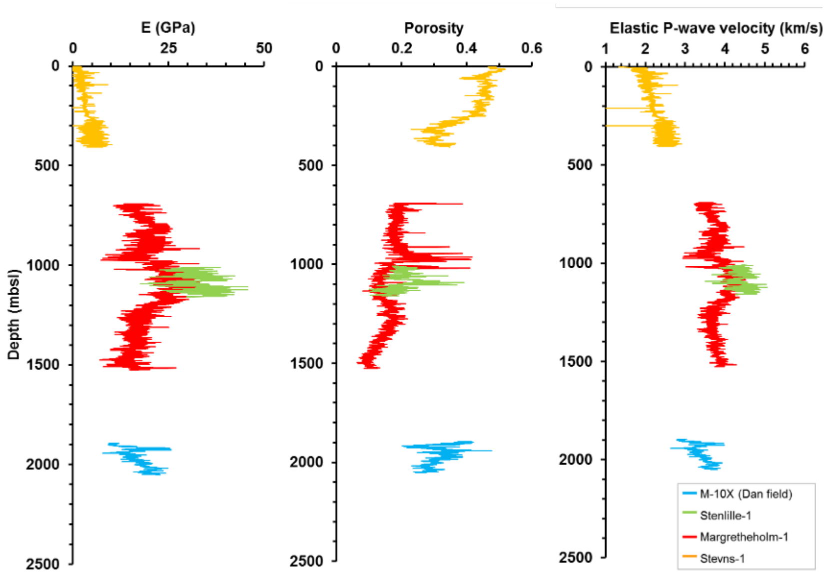

Fig. 1: Elastic and petrophysical properties of the Chalk Group in Zealand and North Sea (Dan field).

Based on the regional velocity-depth anomaly developed by Japsen (1998), the maximum effective stress is comparable to the current one in the Dan field. Upon comparison of downhole measurements, the porosity (ϕ) based on bulk density log is similar for the two locations, but the elastic modulus (E) obtained from density and P-wave velocity logs is significantly different (Fig.1). The difference in the Porosity-Elastic modulus relationship could be due to the specific temperatures experienced by the chalk during the diagenetic process at the two locations and this is expected to have an effect on the thermal conductivity measured (Paci et al., 2017).

Thermal conductivity

Field measurements of thermal conductivity λ are not yet part of standard logging campaigns and therefore predictions from other downhole parameters by means of correlations or theoretical formulations are used, mostly based on porosity ϕ (Abdulagatova et al., 2009). Given the thermal conductivity of the constituents, the Wiener bounds represent the maximum and minimum physically possible values for λ at a given porosity, as obtained by arranging the constituents in purely serial or parallel heat paths with relation to the direction of heat transfer. However, describing rock texture solely through volume fractions is incomplete and pore geometry, grain size and grain shape have also to be included in some theoretical models (Revil, 2000). In particular, emphasis should be on describing the cross sections between single pores and single solids respectively, which can be achieved linking thermal conductivity to other properties such as electrical resistivity (Revil, 2000) and elastic wave velocity (Kazatchenko et al., 2006) that indirectly relates cross sections between respectively single pores and single solids. For this reason, Orlander et al. (2017) introduced Biot's coefficient (α) derived from mineralogy, bulk density and elastic wave velocities as a measure of the solid heat transfer cross section.

$$\alpha = \frac{1-K_{frame}}{K_{min}} \quad (1)$$

This formula requires the knowledge of the mineral bulk modulus, K_{min}, whereas drained bulk modulus, K_{frame} is determined from compressional (v_p) and shear (v_s) wave propagation in dry specimens:

$$K_{frame} = M_{dry} - \frac{4}{3}G_{dry} \quad (2)$$

Orlander et al. (2017) model λ for dry and water saturated sandstones using one-dimensional heat transfer through modelling of the rock structure as three parallel heat transfer paths: solid, fluid, and solid-fluid in series and compare it to laboratory and logging data. Current research is underway measuring λ in the laboratory on samples from the Chalk Group to investigate whether the same model as proposed by Orlander et al. (2017) can be used for carbonate sediments. This would help provide a physical link for the parameters of the equation developed in the model.

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