THM behaviour of a deep Eocene clay formation during heating tests

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Introduction

An experimental study on Ypresian clays – one of the potential deep formations in Belgium for the geological disposal of heat-emitting radioactive waste – was undertaken to systematically study its thermal properties and coupled hydro-mechanical response during heating tests. An accurate characterization of the thermal properties is required for assessing the near-field perturbations around disposal galleries that the sedimentary host rock formation will undergo resulting from temperature changes over hundreds to thousands of years after waste emplacement. When dealing with deep host formations – where *in situ* tests have not been performed –, laboratory tests are mandatory. Besides using well retrieved and preserved samples, strict protocols are required to restore *in situ* stresses and their initial state (suction may be induced during the release of total stresses on deep sampling).

Material and experimental setups

Ypresian clays are constituted by marine sediments deposited during the Ypresian Age (spanning the time between 56 and 47.8 Ma). Ypresian clays at Kallo (Belgium) are located between 300 and 450 m depth. The geotechnical characterization around a depth of 370 m indicates a bulk density 1.88-1.95 Mg/m^3, void ratio between 0.75 and 0.83, degree of saturation 88-95%, and initial total suction 2.0-2.7 MPa mainly associated with sample retrieval. To complement this characterisation, a set of CT scans were performed that allowed a non-destructive evaluation of sample quality (particularly, the low-density or fracture zones).

A new experimental setup – based on Romero et al. (2016) and presented in Fig. 1a – with heat flux measurement (top and bottom heat flux sensors with 4 thermocouples), three local thermocouples and adapted to apply high stresses with an insulated and rigid PEEK ring was used to directly measure the thermal conductivity. This cell ensured applying effective stresses equivalent to *in situ* conditions (vertical effective stresses around 3.7 MPa at the sampling depth of 370 m). The study was then complemented by performing heating pulse tests on a new and instrumented axisymmetric heating cell under constant volume and controlled hydraulic boundary conditions with automatic pressure / volume controllers. The cylindrical cell was equipped with thermocouples (T_i), pore water transducers (Pw_i), total stress sensors (P_i) and heater (H), as shown in Fig. 1b.

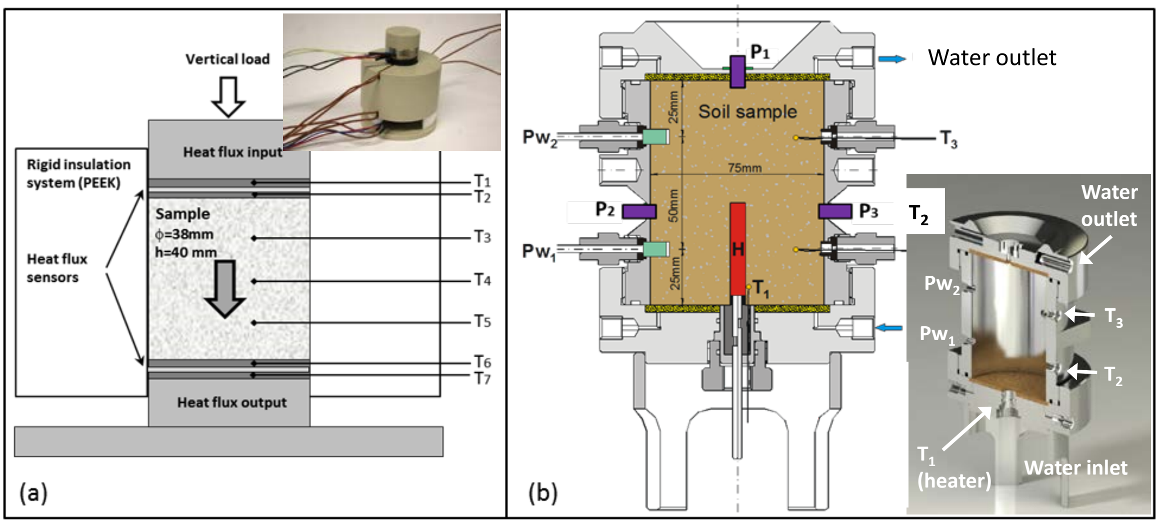

Fig 1. Scheme of thermal conductivity setup (a), and isochoric heating cell with transducers (b).

Results

Fig. 2a presents the time evolutions of temperature during one of the thermal tests, as well as the time evolutions of inflow and outflow fluxes (q_{in} and q_{out}) together with the normalised heat loss $\Delta q/q_{in}$ that tended to around 10% under steady-state conditions. Fig. 2b summarises these thermal conductivity results in terms of degrees of saturation before the thermal tests. A clear influence of the degree of saturation and anisotropic features on thermal conductivity values has been detected. The influence of degree of saturation has important implications on the protocols to follow when testing deep samples. For example, Romero *et al.* (2016) reported that thermal tests under low stress conditions were particularly sensitive when the thermal conductivity was determined along a direction orthogonal to bedding planes (opening of gaps along bedding planes and the consequent loss of full saturation of the material).

A finite element program (Code_Bright) was used to calibrate by back-analysis some thermal properties (saturated thermal conductivity and convection coefficient ruling the heat exchanged between the stainless steel cell and the external temperature). The experimental results of the isochoric heating cell under steady state conditions were used for this calibration. Best agreement between model results and experimental observations was obtained for $\lambda = 1.9$ Wm^{-1}K^{-1}, which has been plotted in Fig. 2b. The back-analysed value that involves the combined contribution of the principal components of the thermal conductivity tensor agreed well with directly measured values at high degrees of saturation. The soil specific heat under fully saturated conditions – required for the simulations – was directly measured using a new small cell. The heated cell – instrumented with thermocouples for measuring soil and cell temperatures – was immersed in a calorimeter containing a known mass of colder water until equilibrium of temperature was reached. The measured soil specific heat was between 1551 and 1695 Jkg^{-1}K^{-1}.

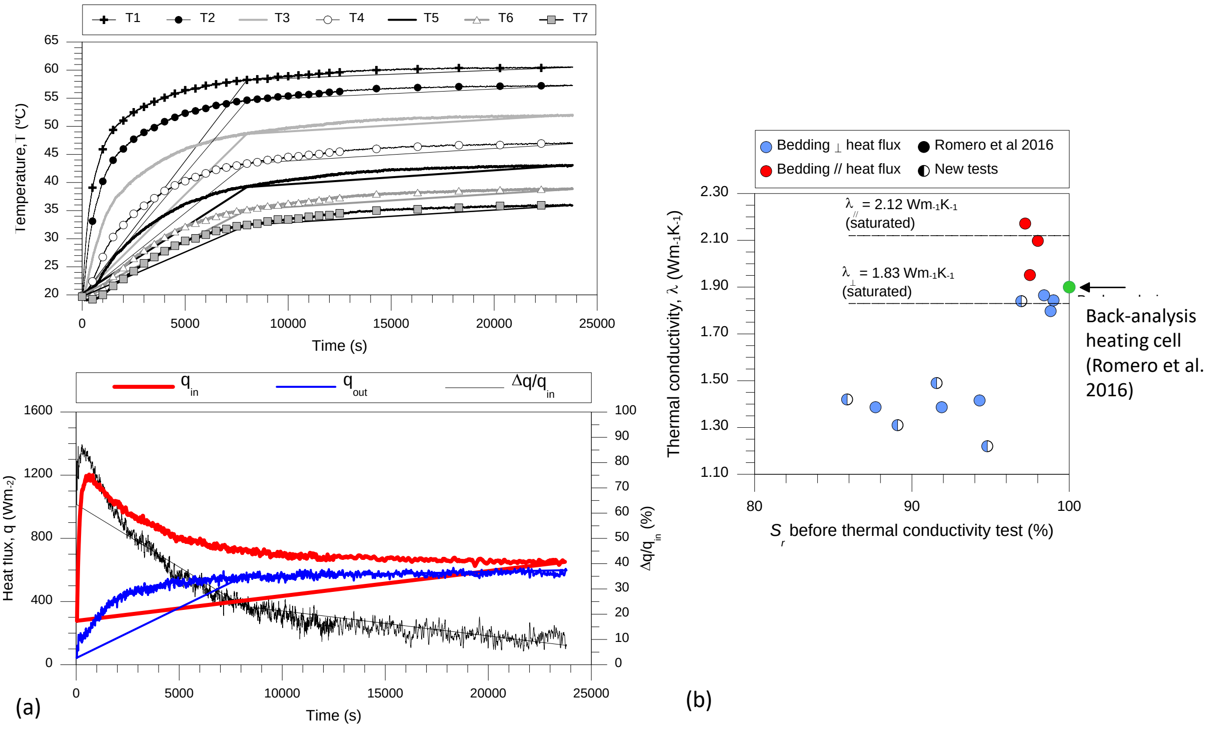

Fig 2. (a) Time evolution of temperature and heat fluxes using the thermal conductivity setup. (b) Thermal conductivity values at different initial degrees of saturation and sample orientations.

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References

Romero E., Sau N., Lima A., Van Baelen H., Sillen X. & Li X. (2016). Studying the thermal conductivity of a deep Eocene clay formation: Direct measurements vs back-analysis results. Geomechanics for Energy and the Environment. Vol 8: 62-75. https://doi.org/10.1016/j.gete.2016.10.005