The thermal properties of the subsurface – key parameters for geothermal energy utilization

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Summary

Often the investigation of petrophysical properties is far behind the capabilities of sophisticated modelling techniques applied in basin and geothermal modelling and for which these data serve as an input. Therefore, more in-depth investigations especially of thermal properties are requested. We evaluate different methods and devices for measuring rock thermal properties including thermal conductivity and thermal diffusivity and will compare the results to assure a high quality of these important key parameters.

Introduction

The determination of reliable in-situ rock thermal properties is a pre-requisite for an enhanced geothermal site characterization. Under conductive and steady-state conditions, heat flow is calculated by the product of thermal conductivity and the thermal gradient according to the Fourier Law. If transient processes are to be considered, for example during production of geothermal plants, heat capacity and thermal diffusivity governs the transfer of heat. This means that to successfully describe the temperature field and its changes, further thermo-hydraulic parameters need to be known like thermal diffusivity, heat capacity, density, porosity, permeability and pore content (fluid properties). Together with undisturbed rock temperatures, heat flow can be determined and the thermal field evaluated. Due to the lack of sufficient subsurface thermal data, modellers often need to fall back to textbook values for main lithologies.

In-depth analysis of thermal conductivity determined on cores of the Northeast German Basin and elsewhere show that a wide range of thermal conductivity do apply for one singular formation or a specific lithotype (e.g. Norden & Förster, 2006; Schütz et al., 2011). Thus, more effort is needed in the investigation of the real rock properties and their relation to the geological setting including e.g. the rock mineralogy, facies distribution, and burial depth. To take scale effects into account, the laboratory-determined point data should be upscaled to the formation scale by using borehole logging data. Furthermore, the thermal and hydraulic model parameterization should include facies studies for a better description of the lateral distribution pattern.

Methods

In order to investigate these parameters, a test suite of different core samples are measured for porosity, thermal diffusivity, density, and thermal conductivity, using different apparatuses. The comparison study will help to classify the errors to be expected from the applied measurement technique. Porosity and density could be determined by weighting of the sample under water-saturated and dry conditions following the Archimedes principle or by using industry standard poroperm (He) devices. To measure thermal conductivity and thermal diffusivity under laboratory conditions, several devices will be tested and compared (Fig. 1). Data obtained from these measurements need to be corrected for in-situ pressure and temperature. Based on lithological well-log analysis, the measured data could be upscaled to representative reservoir or formation thermal properties which will contribute to the parameterization of geothermal models. In this study we will concentrate on comparison of thermal conductivity, thermal diffusivity and heat capacity extending on studies like Pribnow (1994) and Popov et al. (1999).

Examples

First results for the determination of thermal diffusivity show that this parameter is much more sensitive to the applied measurement technique and sample preparation than it is the case for the determination of thermal conductivity. The availability of good standard reference materials is important.

Figure 1 Devices used for laboratory measurements of thermal conductivity and thermal diffusivity. a) TCS-apparatus (Popov et al., 1983), b) line source (Blackwell, 1954; Bording et al., 2012), c) C-Therm TCI, a modified transient plane source apparatus after Gustafsson et al. (1979), d) modified transient divided bar (Nielsen et al., 2008).

Conclusions

Reliable laboratory data of thermal conductivity and thermal diffusivity form a base input for thermal modelling and for the calibration of well-log approaches for the estimation of rock thermal properties. A comparison of different standard laboratory measuring techniques provides valuable information on the accuracy by which direct measurements can be carried out. Further steps include investigations of pressure and temperature dependencies upon the rock thermal properties.

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