Geophysical Research Abstracts
Vol. 15, EGU2013-3187, 2013
EGU General Assembly 2013

From dry to saturated thermal conductivity: mixing-model correction charts and new conversion equations for sedimentary rocks

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The thermal conductivity (TC) of a rock is, in collaboration with the temperature gradient, the basic parameter to determine the heat flow from the Earth interior. Moreover, it forms the input into models targeted on temperature prognoses for geothermal reservoirs at those depths not yet reached by boreholes. Thus, rock TC is paramount in geothermal exploration and site selection.

Most commonly, TC of a rock is determined in the laboratory on samples that are either dry or water-saturated. Because sample saturation is time-consuming, it is desirable, especially if large numbers of samples need to be assessed, to develop an approach that quickly and reliably converts dry-measured bulk TC into the respective saturated value without applying the saturation procedure. Different petrophysical models can be deployed to calculate the matrix TC of a rock from the bulk TC and vice versa, if the effective porosity is known (e.g., from well logging data) and the TC of the saturation fluid (e.g., gas, oil, water) is considered.

We have studied for a large suite of different sedimentary rocks the performance of two-component (rock matrix, porosity) models that are widely used in geothermics (arithmetic mean, geometric mean, harmonic mean, Hashin and Shtrikman mean, and effective medium theory mean). The data set consisted of 1147 TC data from three different sedimentary basins (North German Basin, Molasse Basin, Mesozoic platform sediments of the northern Sinai Microplate in Israel). Four lithotypes (sandstone, mudstone, limestone, dolomite) were studied exhibiting bulk TC in the range between 1.0 and 6.5 W/(mK). The quality of fit between measured (laboratory) and calculated bulk TC values was studied separately for the influence of lithotype, saturation fluid (water and isooctane), and rock anisotropy (parallel and perpendicular to bedding).

The geometric mean model displays the best correspondence between calculated and measured bulk TC, however, the relation is not satisfying. To improve the fit of the models, correction equations are calculated based on the statistical data. In addition, the application of correction equations allows a significant improvement of the accuracy of bulk TC data calculated. However, the "corrected" geometric mean constitutes the only model universally applicable to different types of sedimentary rocks and, thus, is recommended for the calculation of bulk TC. Finally, the statistical analysis also resulted in lithotype-specific conversion equations, which permit a calculation of the water-saturated bulk TC from dry-measured TC and porosity (e.g., well-log-derived porosity). This approach has the advantage that the saturated bulk TC could be calculated readily without application of any mixing model. The expected errors with this approach are in the range between 5 and 10 % (Fuchs et al., 2013).