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Heat flow's propagation within porous media as a function of saturation degree: analogical and numerical modeling and geophysical imaging

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Determining the thermal characteristics of geologic media has numerous applications for low enthalpy geothermal systems design and monitoring. Despite the interest in the topic, there appears to be a scarcity of experimental data in this respect, most of the thermal properties evaluations being based on numerical simulations and back analysis. Therefore analogical and numerical modeling of heat flows in a on proper designed thermal box are presented here. In a box full of a known porous medium under constant moisture conditions, a thermal flow is generated with a single heat source and monitored using 4 temperature sensors located, at definite distances from the source. Two distinct materials have been analyzed in order to evaluate changes in heat flow propagation due to differences in porosity and grain size distribution. Tests performed under different saturation degrees and under induced water fluxes have been moreover analyzed to evaluate the effect of moisture content on the heat propagation and the relative amounts of conductive and convective phenomena into each medium. Cumulative tests on the finer medium have been also performed in order to evaluate the heat storage capacity of the material. Furthermore, during the experiments, the variation of electric resistivity as function of time and temperature has been also performed with indirect geophysical measurements at the laboratory scale to provide an indirect verification of the propagation.
Analogical data processing confirms that the heat induced propagates faster from dry to saturated conditions but is less dependent on intermediate water contents. A stronger increase in the heat propagation velocity has been obtained introducing a water flow effect, observing also a dependence on the grain size distribution. Data have been moreover used for a quantitative determination of thermal properties by the use of empirical derived laws. Numerical simulations performed with OpenGeoSys code reached a good agreement with experimental data, enabling to determine and validate, with back-analysis processes, the thermal properties of the tested porous media. In respect to the geophysical controls, a good agreement between increasing temperature and decreasing resistivity and vice versa has been found.
Coupling laboratory measurements with resistivity indirect surveys and numerical modeling seems to have good potential as real site monitoring tools. This can bring to a reliable and accurate thermal properties assessment of in-situ soils, in order to design correctly borehole heat exchangers and underground thermal heat storage systems.