Geophysical Research Abstracts
Vol. 21, EGU2019-15619, 2019
EGU General Assembly 2019

Laboratory Experiments on Thermal Retardation and Local-Thermal-non-Equilibrium Effects on Heat Transport under Conditions of a Highly Conductive Aquifer

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Near surface geothermal energy systems play a significant role in the aim of increasing the share of renewable energy, particularly in Germany. However, to ensure sustainable usage of hydrogeothermal systems, information about heat transport parameters, especially on thermal and hydrodynamic parameters is crucial. Furthermore, the prediction of thermally affected zones in the aquifer is a key parameter in the impact assessment of these geothermal systems. When open loop systems for near surface geothermal applications are considered, the propagation of the temperature peak in the aquifer can be very important for administrative regulations and for evaluating interference between systems. The thermal retardation factor can be used to predict thermal velocity and to determine thermal and hydrodynamic parameters, i.e. heat capacity and mean groundwater velocity. In southern Germany, the highly conductive, Quaternary aquifer in the Munich Gravel Plain is intensively used for geothermal heating and cooling, and was investigated for its geothermal potential in the GePo and GeoPot project. The aim of this study was to evaluate the applicability of the thermal retardation factor in highly conductive aquifers for determining hydrodynamic and thermal parameters, and predicting temperature peak velocities. In addition, we analyzed the validity of the local-thermal-equilibrium (LTE) approach and the influence of local-thermal-non-equilibrium (LTNE) effects on thermal retardation in conditions of a highly conductive aquifer. Laboratory experiments were conducted to evaluate the deviations between expected thermal retardation and effective thermal retardation for different flow velocities. Besides, the effect of LTNE on thermal dispersion and thermal retardation was investigated. In a series of column experiments filled with gravel, the temperature development of the fluid and solid under different flow conditions was studied. Gravel was used to simulate conditions of a highly conductive aquifer. Hydro¬dynamic flow conditions such as dispersion and water flow velocities were characterized by additional solute tracer tests.

The results show that the thermal peak velocity can significantly differ from the thermal peak velocity predicted by the thermal retardation factor in groundwater systems showing flow velocities of up to around 10 m/d. The results further indicate that advective heat transport is dominant over thermal dispersion at high flow velocities. Under these conditions, the thermal retardation factor can be used to determine the involved quantities like flow velocity and heat capacity. In contrast, at low flow velocities the thermal breakthrough time can be overestimated, if the thermal retardation factor is used in the thermal impact assessment.