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Local thermal non-equilibrium (LTNE) effects revealed through porous media heat transport experiment

Haegyeong Lee[1], Manuel Gossler[2], Kai Zosseder[3], Philipp Blum[1], Peter Bayer[4], and Gabriel Rau[5]
[1]Institute of Applied Geosciences, Karlsruhe Institute of Technology, Karlsruhe, Germany
[2]SWM Services GmbH, Munich, Germany
[3]Chair of Hydrogeology, Technical University of Munich, Munich, Germany
[4]Martin Luther University of Halle-Wittenberg, Department of Applied Geology, Halle, Germany
[5]School of Environmental and Life Sciences, The University of Newcastle, Callaghan, Australia

Precise prediction of heat transport in porous media holds crucial significance in Earth Sciences for diverse applications, ranging from the design of geothermal systems to utilizing heat as a tracer in aquifers. Traditionally, the description of heat transport has been simplified by assuming local thermal equilibrium (LTE), where the temperature within the fluid and solid phases in the representative elementary volume is presumed to reach an instant equilibrium. In reality, assuming two distinct phases coupled by heat transfer across their surface area describes the complete physics and is referred to as the local thermal non-equilibrium (LTNE) model. While earlier research delved into the theoretical aspects of LTNE effects, a notable gap exists due to the absence of experimental data to elucidate the heat transport mechanism in porous aquifers containing natural grains. To address this gap and investigate LTNE on a granular scale, we conducted systematic flow-through experiments employing porous media containing glass spheres with distinct grain sizes of 5, 10, 15, 20, 25 and 30 mm. Each sphere contained a small temperature sensor for the solid temperature, accompanied by sensors in the adjacent pore space to measure the fluid temperature. Our findings revealed that the temperature difference between two phases grows with increasing grain size and flow velocity ranging from 9 to 61 m d^{-1}, thereby highlighting qualitative LTNE effects in relation to grain size and flow velocity. To further enhance our understanding, we used a numerical model to investigate the heat transfer coefficient, fitting the LTNE model to the experimental data. These simulation results indicated evidence of non-uniform flow which we included into our model to estimate its effects on heat transport. This comprehensive approach contributes valuable insights into the intricate interplay of LTNE effects, grain sizes, and flow velocity, advancing our understanding of heat transport in natural porous media.