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Interpreting experimental Local Thermal Non-Equilibrium (LTNE) effects using a two-phase numerical heat transport model

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Modeling heat transport in porous media is a key focus in engineering and earth sciences, with applications ranging from using heat as a tracer to determine hydrogeological properties to modeling decay heat from nuclear waste repository in aquifers, and simulating geothermal systems. Most models assume local thermal equilibrium (LTE), where multi-phase media are averaged into a single phase to simplify mathematical equations. However, the validity of this assumption is often uncertain. Incorporating local thermal non-equilibrium (LTNE) effects, which describe separate thermal behaviors for fluid and solid phases with an interphase heat exchange term, provides a physically more realistic representation.

We therefore investigated LTNE effects observed in laboratory experiments involving heated water flowing through a column with glass spheres of varying sizes, using a fully coupled two-phase heat transport model developed in the Multiphysics Object-Oriented Simulation Environment (MOOSE). The study emphasizes the role of non-uniform flow effects, which complicate the interpretation of LTNE phenomena from experimental measurements. The model reveals that LTNE effects result from the interplay of transport processes, including heat transfer between fluid and solid phases, and are strongly influenced by flow velocity, grain size, and non-uniform flow conditions. Accounting for non-uniform flow in the model however accurately reproduces the observed temperature difference between fluid and solid phases.

These results highlight that grain-scale LTNE effects stem from the combined influence of phase-specific thermal properties, heat transfer, and flow field heterogeneity. The findings deepen our understanding of heat transport dynamics in porous media and offer valuable insights for improved modeling of applications in hydrogeology, geothermal energy, and nuclear water management.