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Influence of Local Thermal Non-Equilibrium (LTNE) Processes in Saturated Porous Media and Coupled Systems

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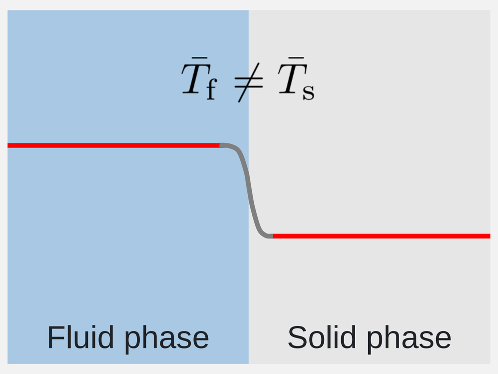
Motivation

What is LTNE?

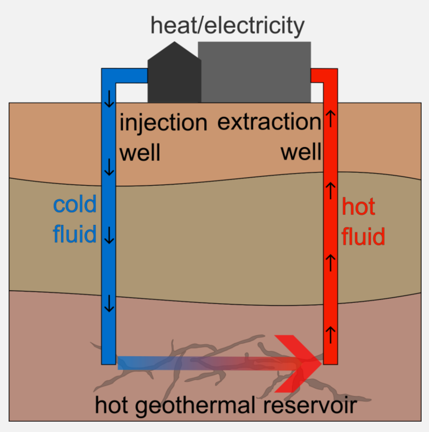


- No instantaneous heat transfer
  → Different temperatures for different phases

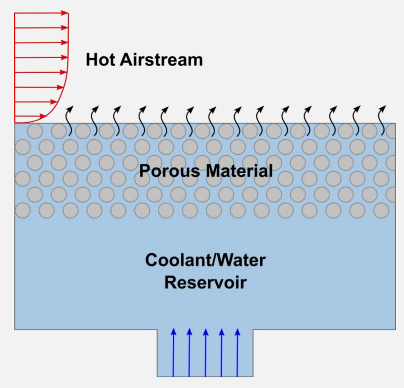
Why LTNE?
Assumption of instantaneous heat transfer not always applicable

Investigate LTNE processes in porous-medium and coupled free-flow systems across pore and REV scales.

Applications



Geothermal system



Self-pumping transpiration cooling

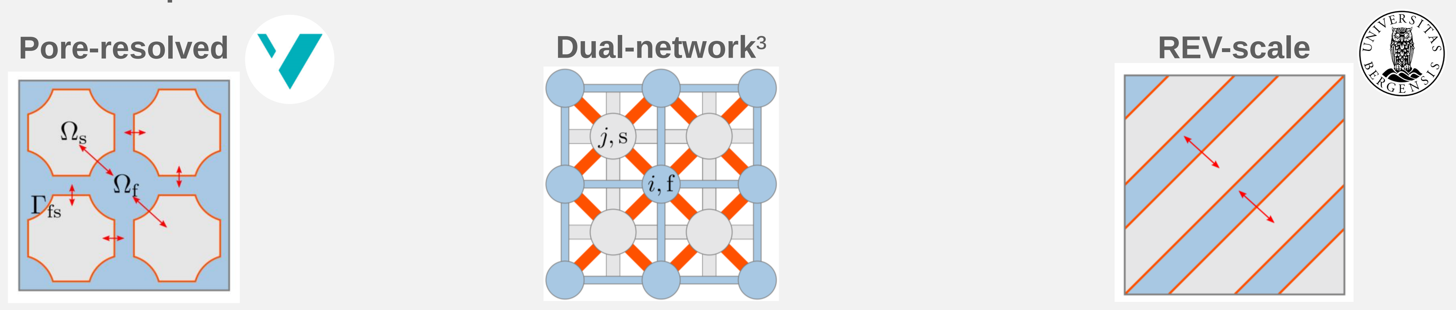
Model Comparison[1,2]

Study objective

- Systematic comparisons of LTNE models remain limited
  → Evaluate consistency between & influence of different models

Models

- Saturated porous medium

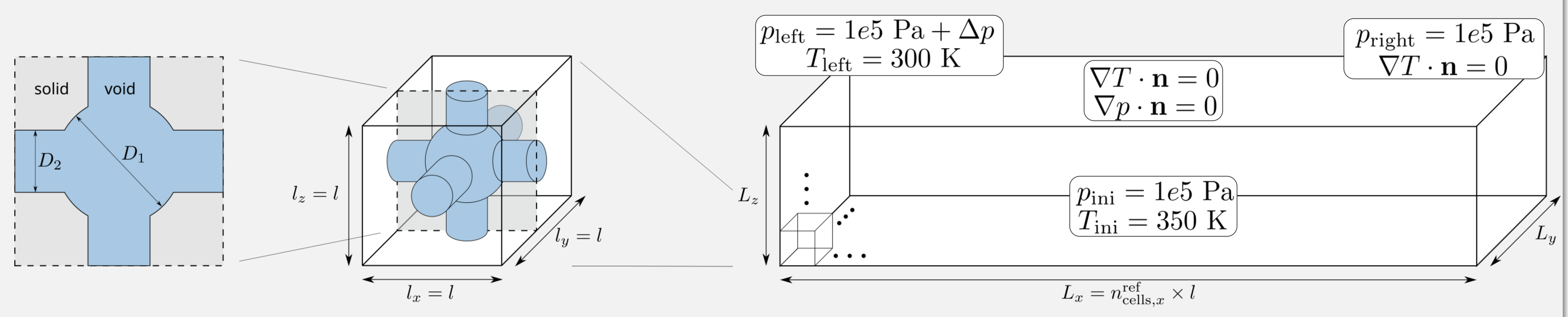


Pore-resolved	Dual-network[3]	REV-scale
Flux continuity & T-jump	Energy exchange term	Energy exchange term
$\lambda_f \nabla T_f \cdot \mathbf{n} = \lambda_s \nabla T_s \cdot \mathbf{n}$ $\lambda_f \nabla T_f \cdot \mathbf{n} = h(T_s - T_f)$	$Q_{i,f\to j,s} = t_{i,f\to j,s}(T_{i,f} - T_{j,s})$ $t_{i,f\to j,s}(\lambda_f, \lambda_s, A, h)$	$q_{\text{cond},s\to f} = \lambda_{\text{eff},I} a_{fs} (\overline{T}_s - \overline{T}_f)$ → Effective parameters needed $(\lambda_f^{\text{eff}}, \lambda_s^{\text{eff}}, \lambda_I a_{fs}, \ldots)$ e.g. Homogenization, Nuske[5], Nakayama[4], …

Upscaling

Setup

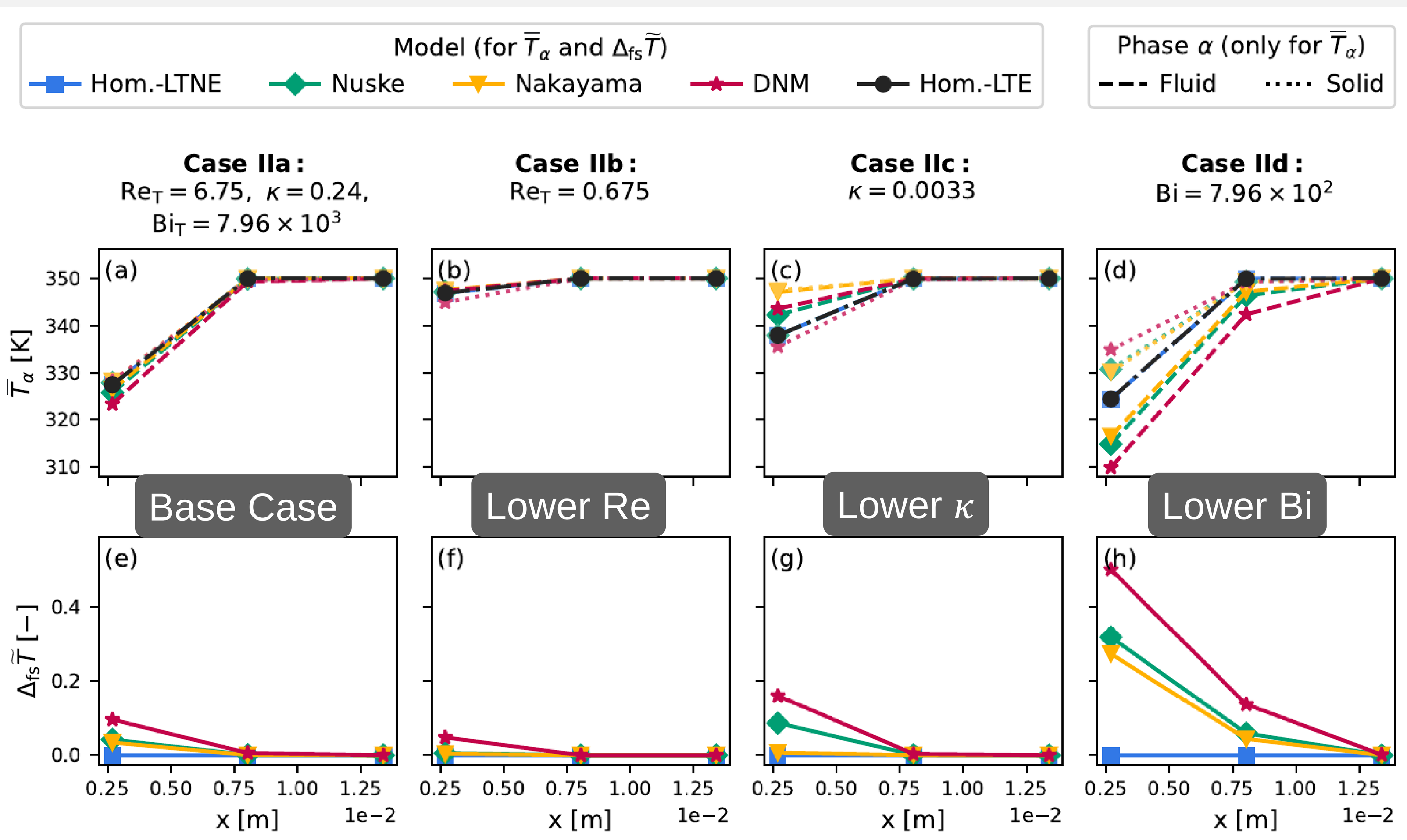
- Cooling of a warmer, porous channel (isotropic, homogeneous)



Cut-through of reference cell — Reference cell — Domain with initial and boundary conditions (45x4x4 reference cells)

Results

- REV-scale temperatures (averaged for 15x4x4 ref. cells): $\overline{T}_\alpha$
- Non-dimensional temperature difference: $\Delta_{fs}\widetilde{T} = \left|\frac{\overline{T}_f - \overline{T}_s}{T_{\text{left},f} - T_{\text{ini},f}}\right|$
- Investigation in terms of different non-dimensional numbers:
  $\text{Re}_T = \frac{v_{x,T} L_T}{\nu_f}$, $\kappa = \frac{\lambda_f}{\lambda_s}$, $\text{Bi}_T = \frac{h L_T^2 a_{fs}}{\lambda_f}$



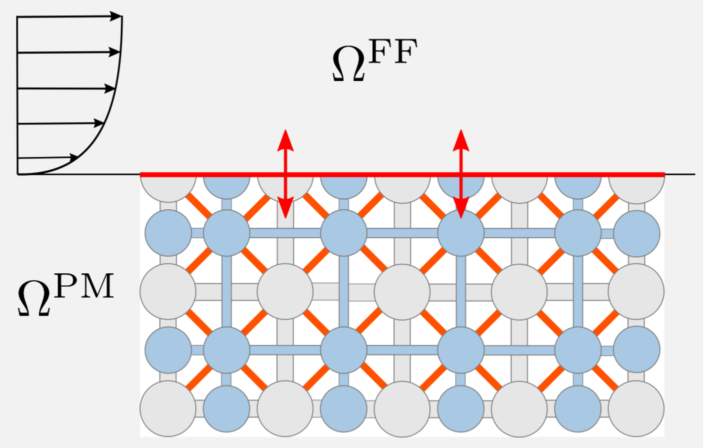
→ Differences in LTNE due to different orders of exchange term
→ Larger LTNE for **higher Re & lower Bi** number

Coupled Free-Flow Porous-Medium

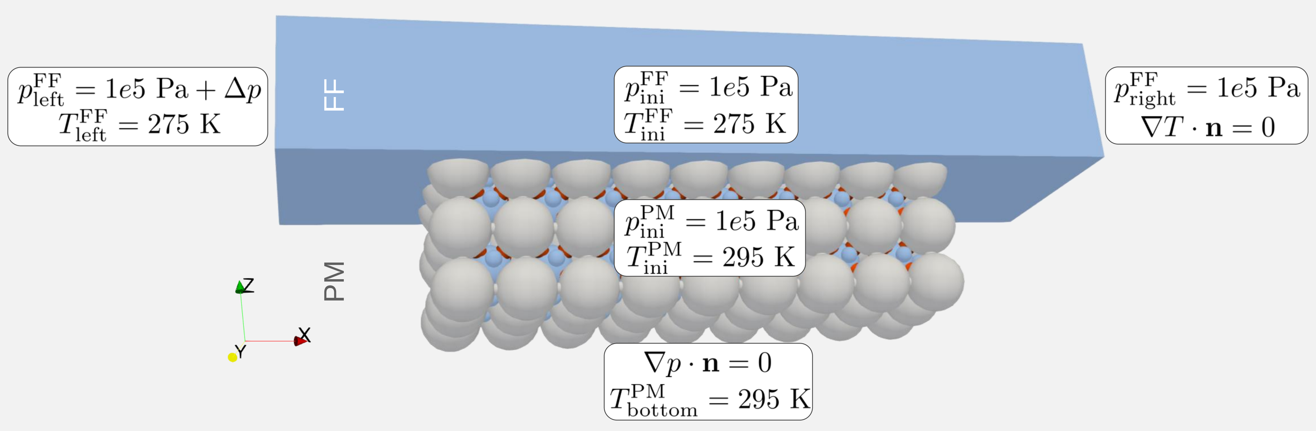
Energy coupling conditions
(dual network – free flow)

- Flux & Temperature continuity

$T^{FF} = T^{PM,p}$
$q^{FF}_{\text{cond.}+\text{conv.}} = q^{PM,p}_{\text{cond.}+\text{conv.}}$
$T^{FF} = T^{PM,s}$
$q^{FF}_{\text{cond.}} = q^{PM,s}_{\text{cond.}}$

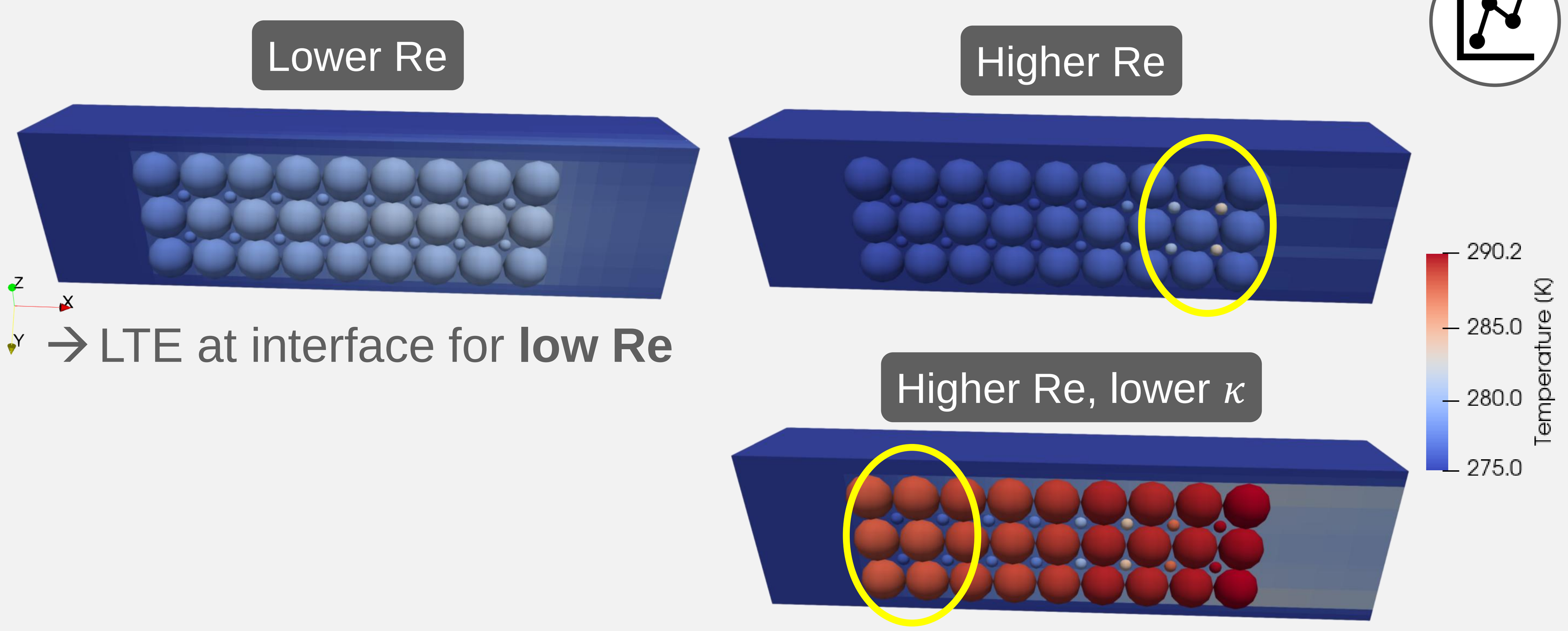


Setup



Domain with initial and boundary conditions (everywhere else: insulating, no-flow)

Results



→ LTE at interface for **low Re**

→ Larger fluid-solid temperature difference for **higher Re & lower κ**

Conclusion & Outlook

- LTE holds for conditions in natural porous media (low Re, moderate conductivity ratios, high Bi)
- LTNE becomes more relevant for **larger Re & lower Bi**
- Results are model dependent → **Benchmark studies needed**
- LTNE likely to occur at **FF-PM interface for high Re & low κ**

- **Coupled** dual network – free flow model:
  → Including temperature jump at FF – PM interface
- Extending dual-network model for **multi-phase flow**

References

[1] Kostelecky, A. M. et al. ***Comparison study*** *for Local Thermal Non-Equilibrium […] model concepts […].* TiPM, 2026.
[2] Kostelecky, A. M. et al. ***Comparison study*** *[…]: Investigation of convection including conduction.* TiPM, submitted.
[3] Koch, T. et al. *A **(dual) network model** for heat transfer in porous media,[…].* Transport in porous media, 2021
[4] Nuske, P. et al. *Modeling two-phase flow […] with **local thermal non-equilibrium** on the **Darcy** scale.* IJHMT, 2015
[5] Nakayama, A. et al., *A **two-energy equation model** for conduction and convection in porous media*, IJHMT, 2001

Preprint (Ref [1])

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