Equilibrium Assumptions in Multiphase Flow Revisited

International Research Training Group nupus

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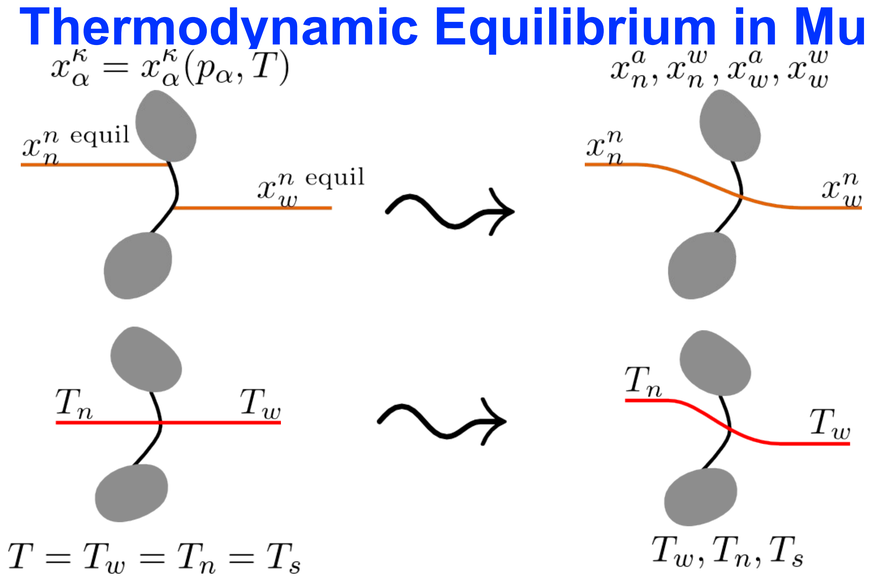
Motivation

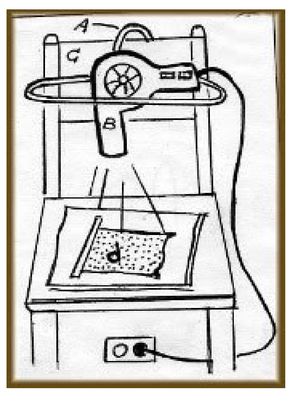
Thermodynamic Equilibrium in Multiphase Flow



Modelling Non-Equilibrium

- Limits of *thermodynamic equilibrium assumption*
  → confidence in existing models
- Being able to model situation of clear non-equilibrium
  → extending range of applicability

Thin Porous media / High Flow Velocities



High Temperature Gradients

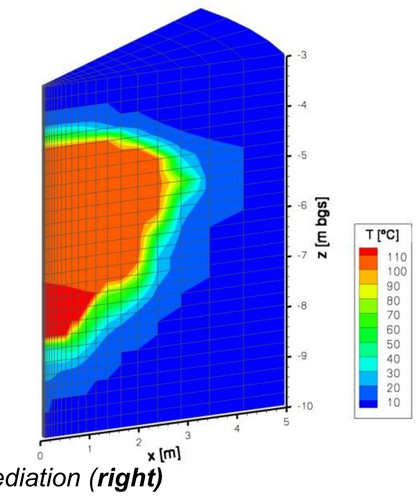


*Figure 1: Drying of paper (**left**) thermally enhanced remediation (**right**)*

Current Work

Energy Balance Equations

$$\frac{\partial(\phi \varrho_w S_w u_w)}{\partial t} + \nabla\cdot\left(\varrho_w \mathbf{v}_w h_w + \sum_\kappa \mathbf{j}_w^\kappa h_w^\kappa\right) - \nabla\cdot(\phi S_w \lambda_w \nabla T_w) =$$
$$+ \text{Nu(Re, Pr)} a_{wn} \frac{\overline{\lambda}_{wn}}{L}(T_n - T_w) + \text{Nu(Re, Pr)} a_{ws} \frac{\overline{\lambda}_{ws}}{L}(T_s - T_w)$$
$$+ \sum_\kappa q_{\kappa\rightsquigarrow w} h_{\text{origin}}^\kappa + q_w^{\text{energy}}$$

$$\frac{\partial(\phi \varrho_n S_n u_n)}{\partial t} + \nabla\cdot\left(\varrho_n \mathbf{v}_n h_n + \sum_\kappa \mathbf{j}_n^\kappa h_n^\kappa\right) - \nabla\cdot(\phi S_n \lambda_n \nabla T_n) =$$
$$- \text{Nu(Re, Pr)} a_{wn} \frac{\overline{\lambda}_{wn}}{L}(T_n - T_w) + \text{Nu(Re, Pr)} a_{ns} \frac{\overline{\lambda}_{ns}}{L}(T_s - T_n)$$
$$+ \sum_\kappa q_{\kappa\rightsquigarrow w} h_{\text{origin}}^\kappa + q_n^{\text{energy}}$$

$$\frac{\partial((1-\phi)\varrho_s c T_s)}{\partial t} - \nabla\cdot((1-\phi)\lambda_s \nabla T_s) =$$
$$- \text{Nu(Re, Pr)} a_{ws} \frac{\overline{\lambda}_{ws}}{L}(T_s - T_w) - \text{Nu(Re, Pr)} a_{ns} \frac{\overline{\lambda}_{ns}}{L}(T_s - T_n) + q_s^{\text{energy}}$$

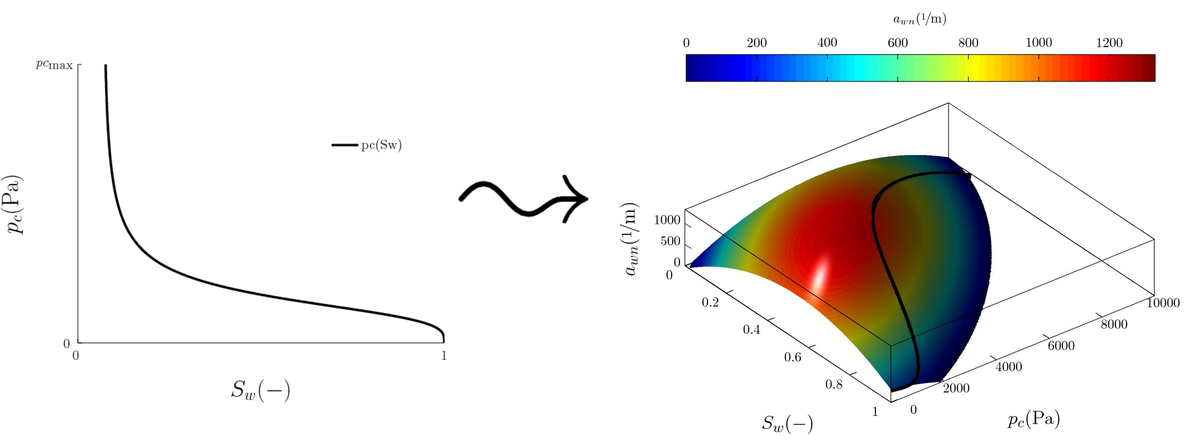


*Figure 2: Capillary pressure - saturation relationship (**left**), capillary pressure - saturation - interfacial area relationship (**right**)*

Results

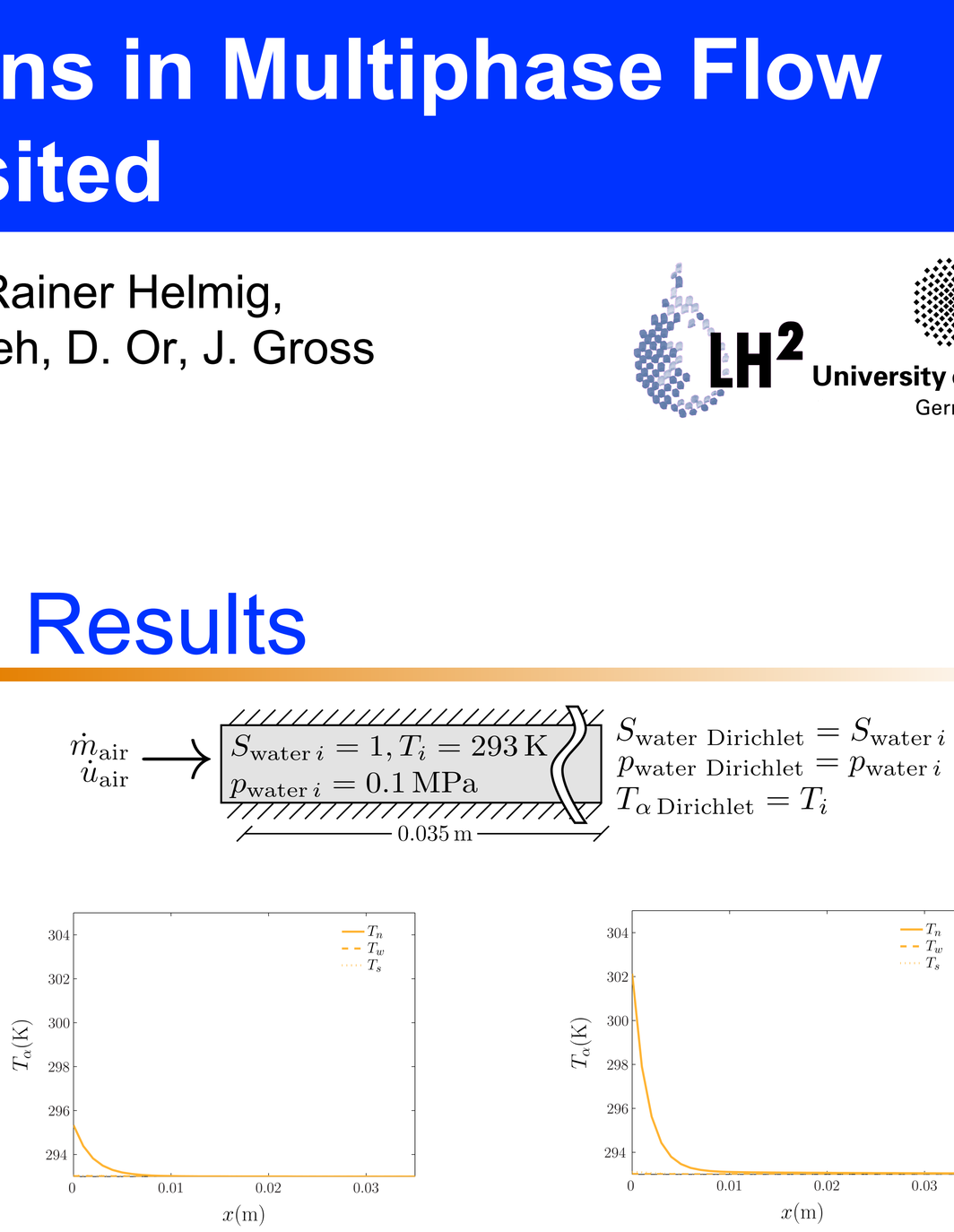


*Figure 3: Scetch of the simulation setup (**top**), Temperature distributions for slow (**middle, left**) and fast (**middle, right**) injection, Reynolds number on boundary versus temperature difference (**bottom**)*

Future Work

Micro Model Experiment

- Invasion process in Micro Model
- Temperature distribution via Infrared Camera
- Calibration / validation of the model

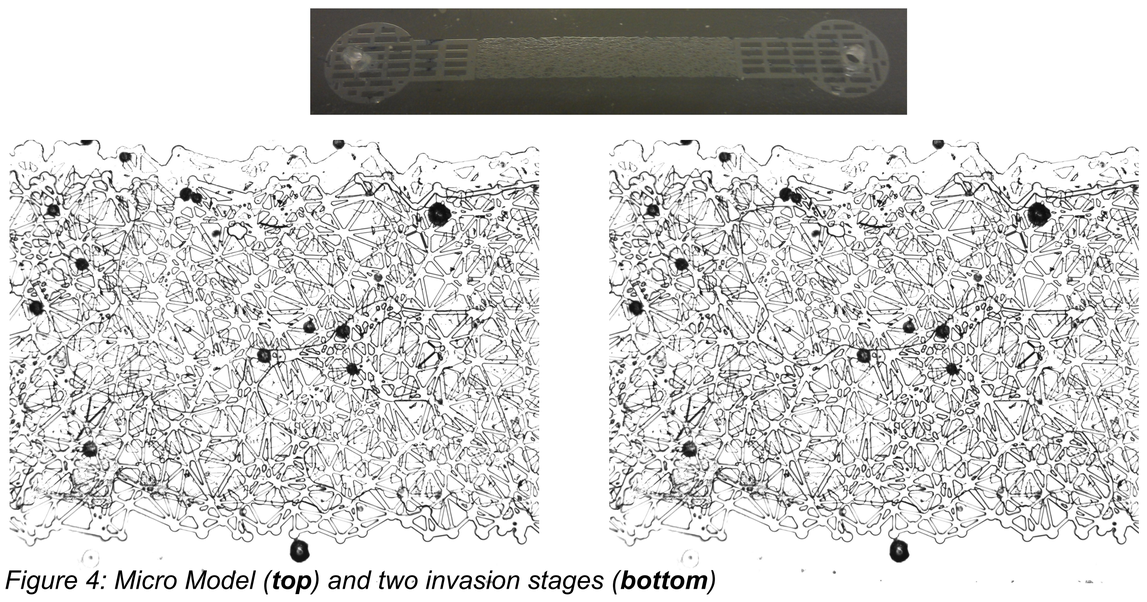


*Figure 4: Micro Model (**top**) and two invasion stages (**bottom**)*

Scenarios

- Up to now rather academic examples have been simulated.
- Ideas for more realistic setting welcomed!

Sensitivity Analysis

- Many new parameters are in the model
- How to find out which one needs most attention?

Indicators

- It would be nice to know when a model is leaving it's range of validity
- As little limitations / assumptions should go into the development of theses indicators

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