An open-source toolbox for multiphase flow in porous media

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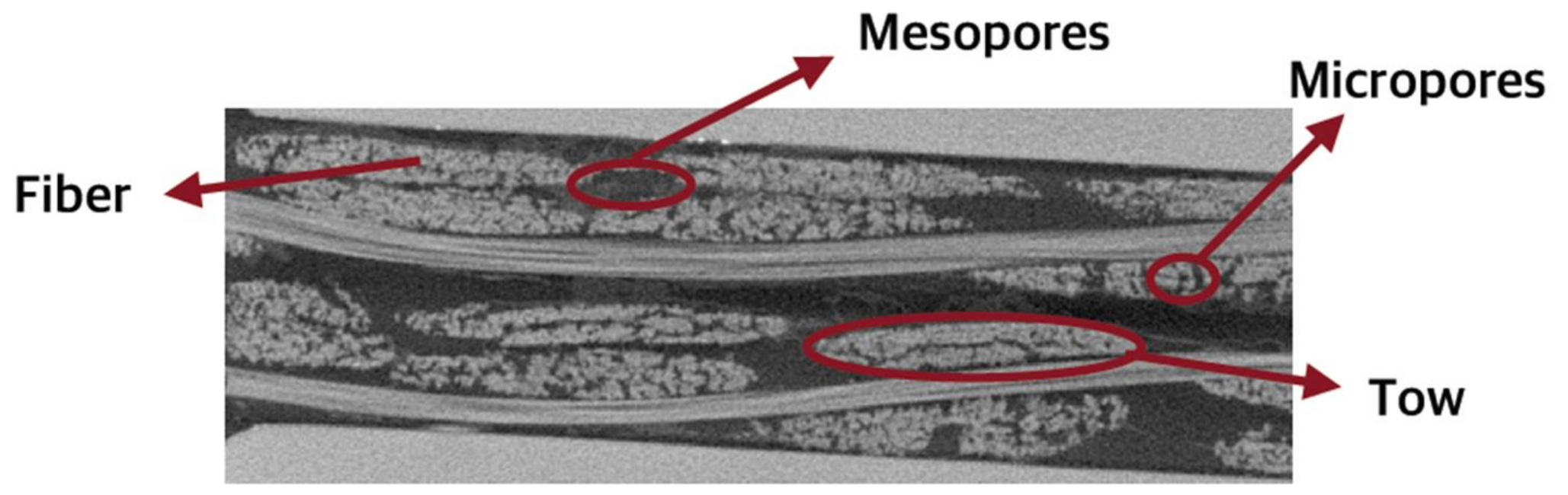
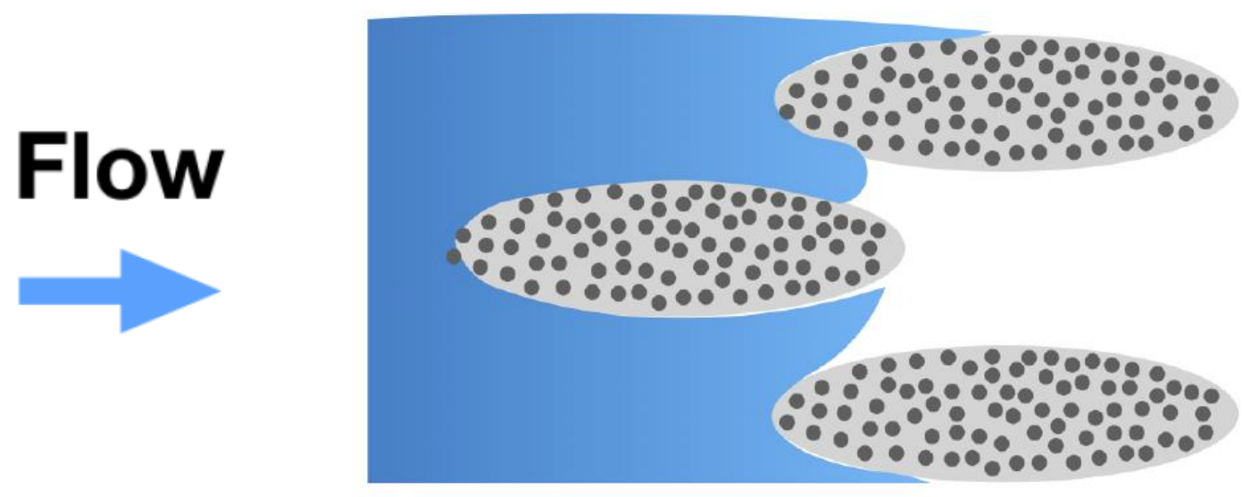
Flow in a Porous Medium





- **Liquid Composite Molding** is a generic term for a family of related processes in composite manufacturing.
- The resin flows through a fibrous reinforcement which can be considered as a **porous medium**.
- The resin impregnation of the is governed by **Darcy's law**.

Implicit pressure explicit saturation method

- Wetting phase + non-wetting phase
- Representative Elementary Volume (REV)
- Saturation S_i defining the filling rate of a phase within the pore space of a REV

$$S_i = \frac{V_i}{V_{void}}$$

- The macro-scale mass balance equation for phase i:

$$\varepsilon \frac{\partial S_i}{\partial t} + \nabla \cdot \boldsymbol{U_i} = q_i$$

- The superficial velocity of each phase is:

$$\boldsymbol{U_i} = -\frac{K_i}{\mu_i}(\nabla p_i - \rho_i g)$$

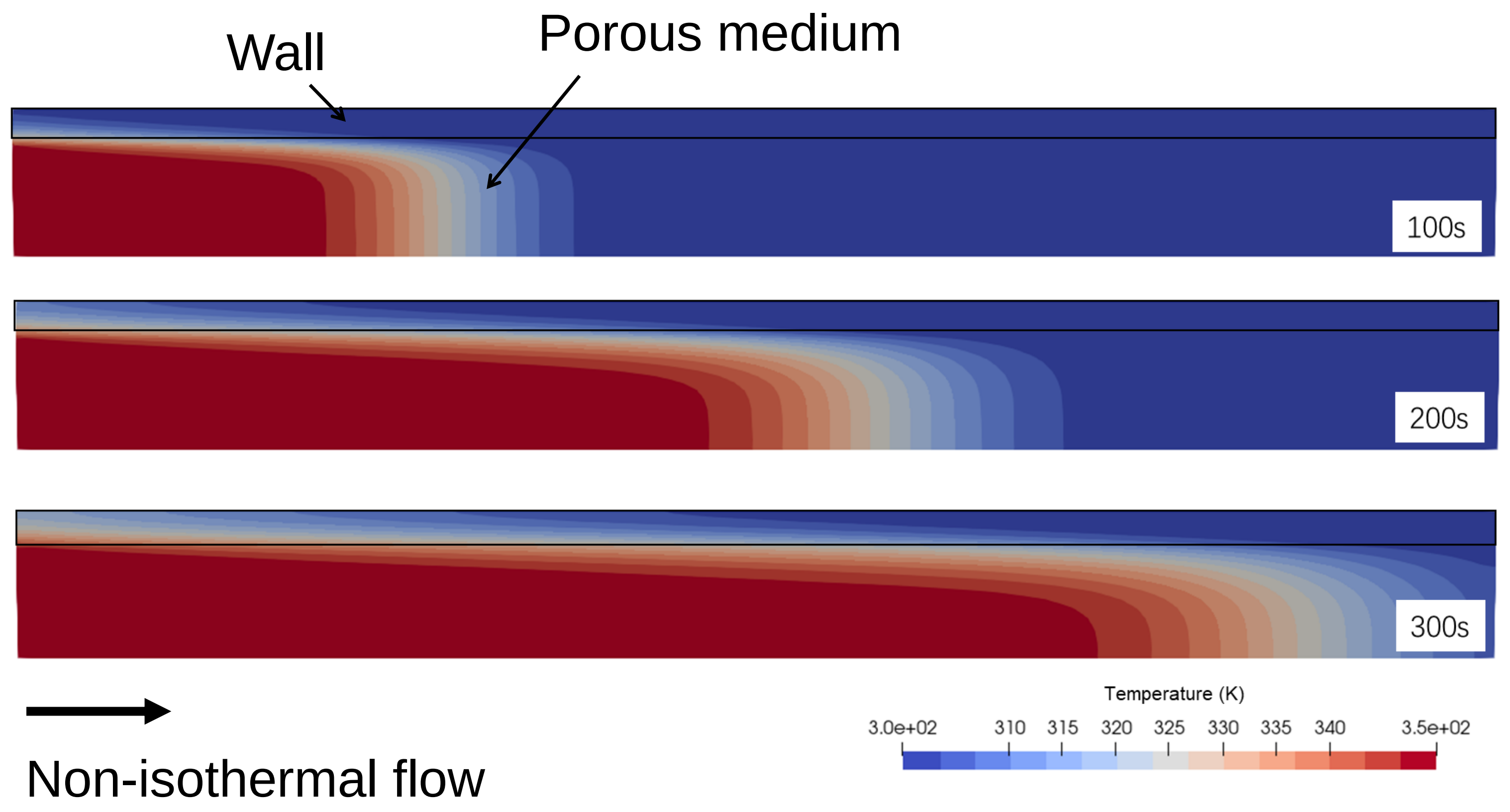
where K_i is the apparent permeability.

- Saturation S_i field is explicitly computed using the last known flux field.
- Pressure field p_i is implicitly computed.
- Originally developed in OpenFOAM [1] for **iso-thermal** flow in porous media.
- Adapted to LCM process simulations by adding curing and heat transfer features.

[1] Horgue, Pierre, et al. "An open-source toolbox for multiphase flow in porous media." Computer Physics Communications 187 (2015): 217-226.

Conjugate Heat Transfer

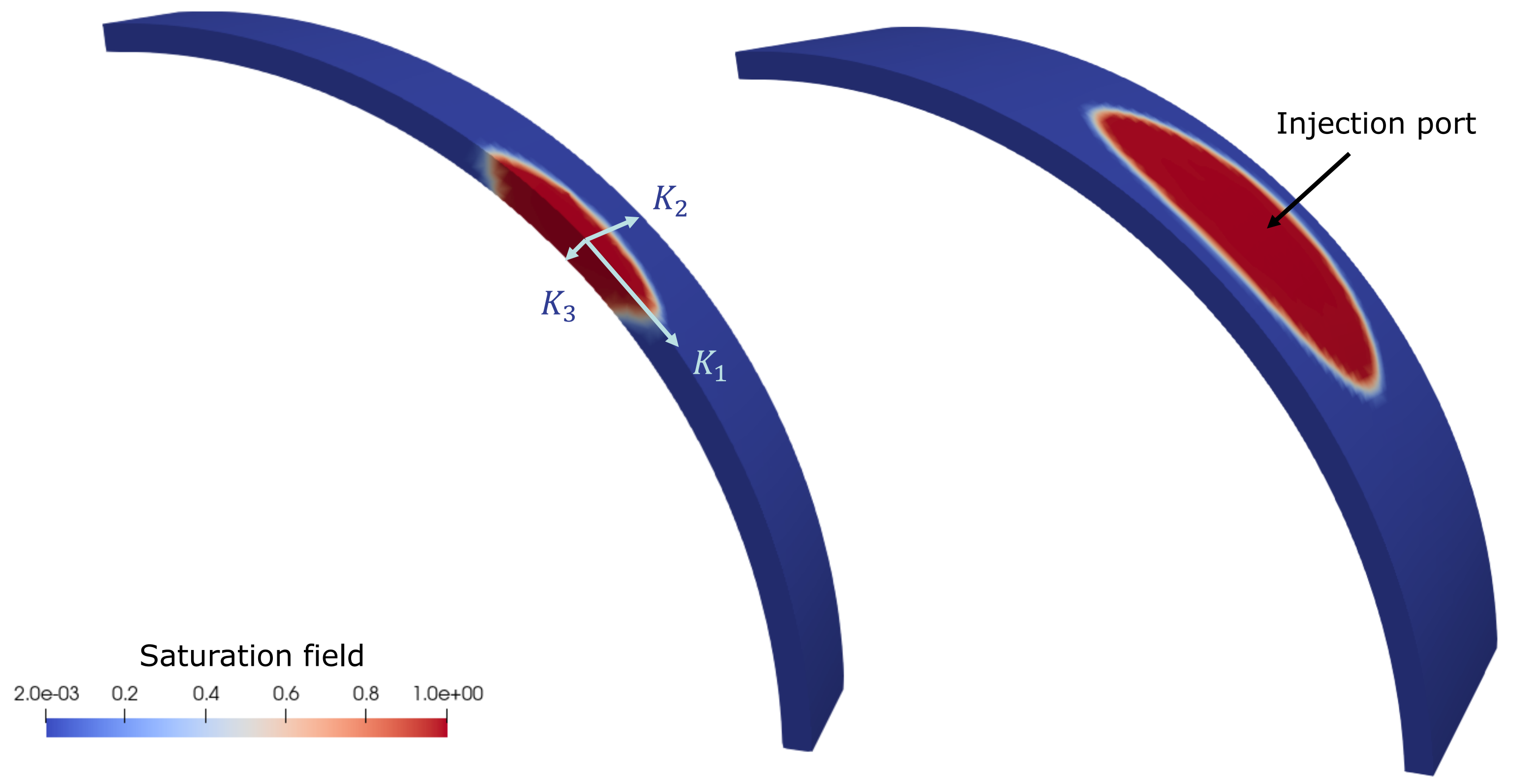
- Dirichlet-Neumann partitioning at interface:
  - Step 1: solve fluid temperature subject to Dirichlet BC.
  - Step 2: solve solid temperature subject to Neumann BC.
  - Repeat 1 and 2 until converged.



3D anisotropic preform injection

- The three permeability values are different, i.e.,$K_1 \neq K_2 \neq K_3$
- Three basic rotation matrices are used to determine the local permeabilities.

$$R_x(\theta) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \quad R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & \sin\theta \\ 0 & 1 & 0 \\ -\sin\theta & 0 & \cos\theta \end{bmatrix} \quad R_z(\theta) = \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$



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Curing Simulation

- The released energy due to curing reactions S_{cure}:

$$S_{cure} = \rho_b \Delta H_{tot} V_m \frac{d\alpha}{dt}$$

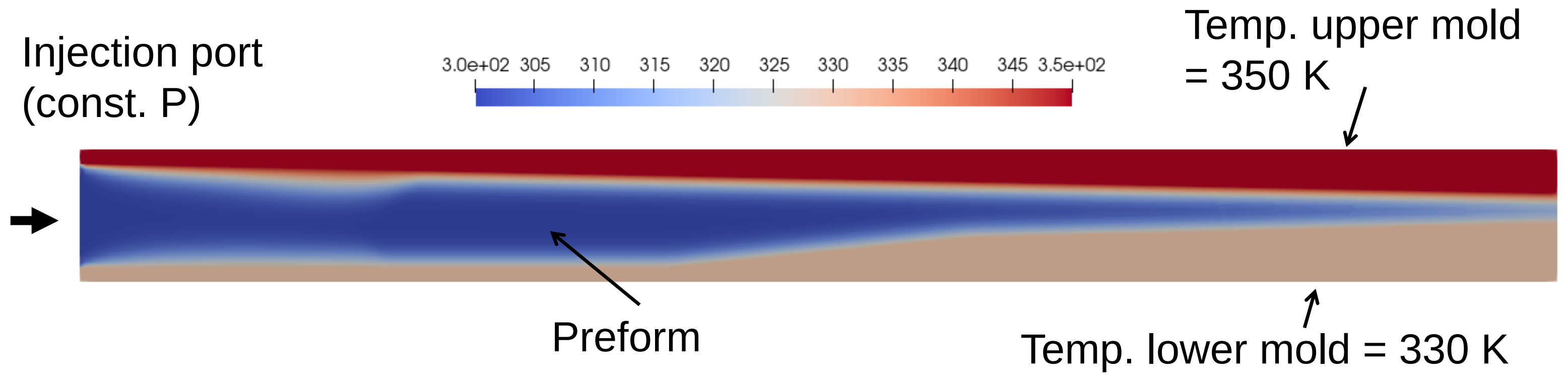
- Kamal-Sourour model is used to determine the DoC:

$$\frac{d\alpha}{dt} = K(T)\alpha^m(1-\alpha)^q$$

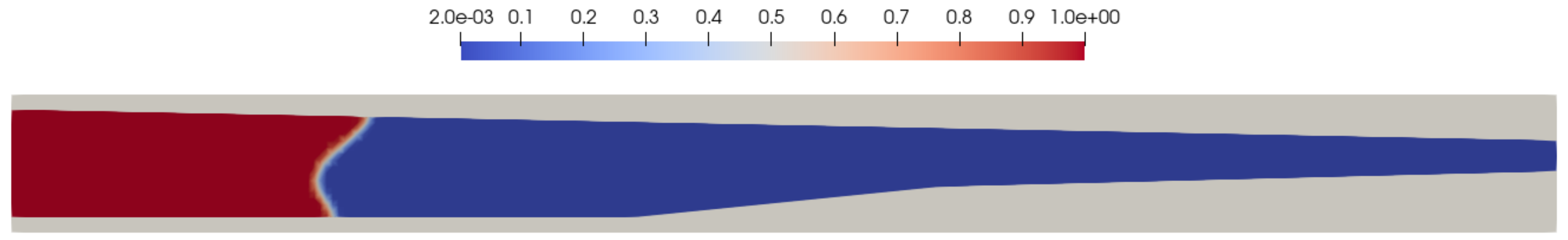
- The temperature dependent resin viscosity writes:

$$\mu = c_0 e^{\frac{c_1}{T}} \left(\frac{c_2}{c_2 - y}\right)^{c_3 + c_4\alpha}$$

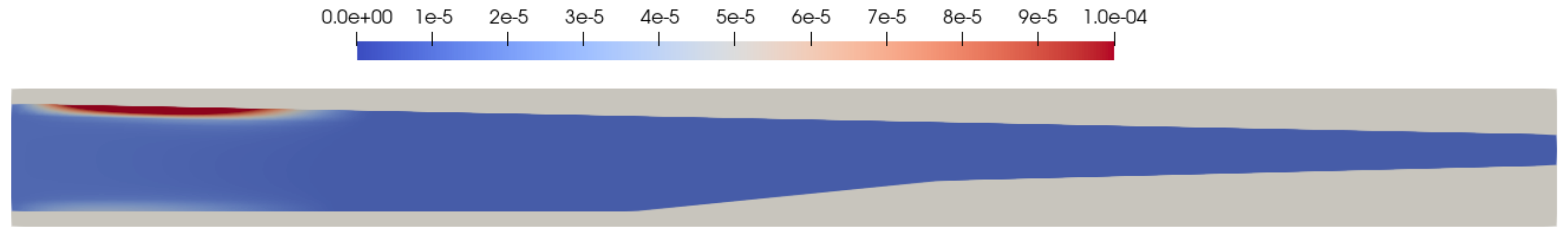
- Temperature field (K) at 100 s:



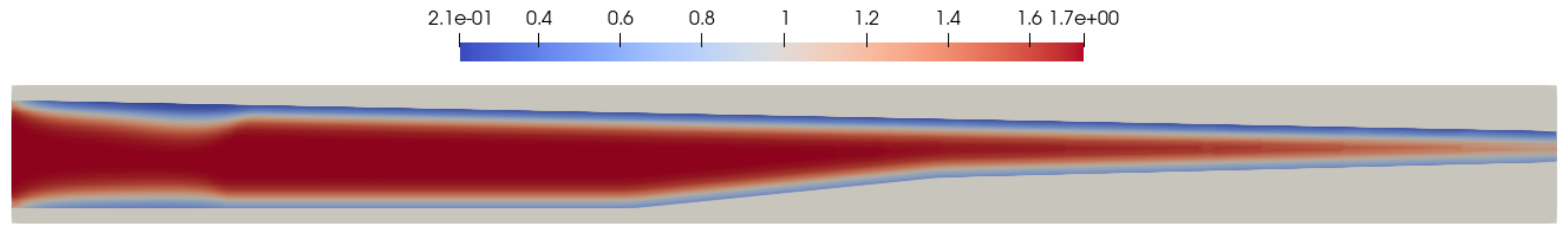
- Saturation field at 100 s:



- DoC (degree of cure) field at 100 s:



- Resin viscosity (Pa.s) field at 100 s:



Air entrapment

- Injection from a point, constant inlet velocity = 0.2m/s, length = 1 m.