InterPore2026

18th Annual Meeting & Conference Courses
19-22 May 2026, Nantes France

Effect of Temperature on Matrix Acidizing in Carbonate Formations Through 3D Computational Simulation Using OpenFOAM

Caio Cézar Goes Pereira, Nathalia Almeida Braga, Lorena Cardoso Batista Aum, Raphael Gachet, and Pedro Tupã Pandava Aum
pedroaum@ufpa.br

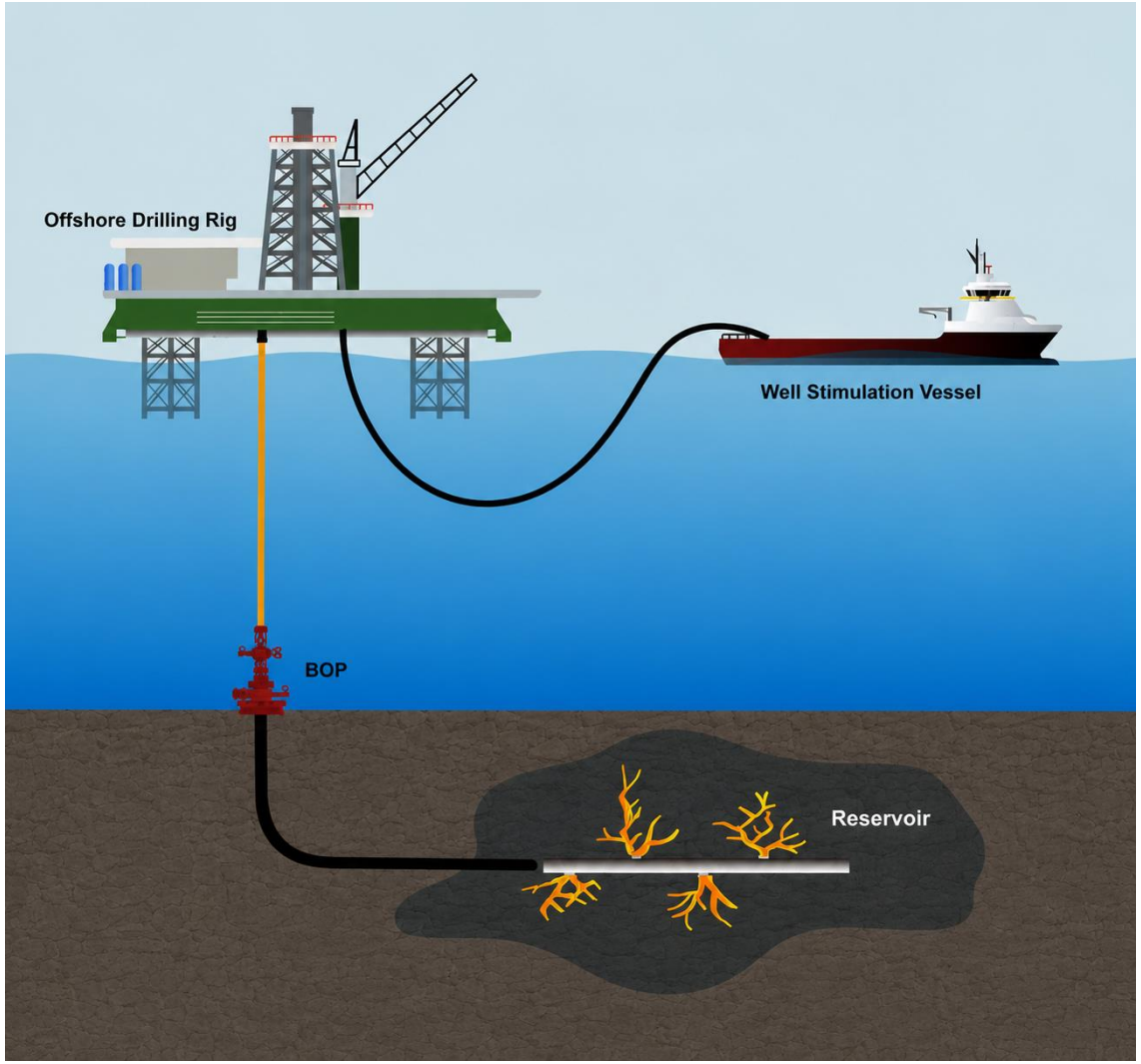
LCPETRO
Laboratório de Ciência e Engenharia de Petróleo e Energia
www.lcpetro.ufpa.br

Federal University of Pará
Energy and Petroleum Science Laboratory
May 2026

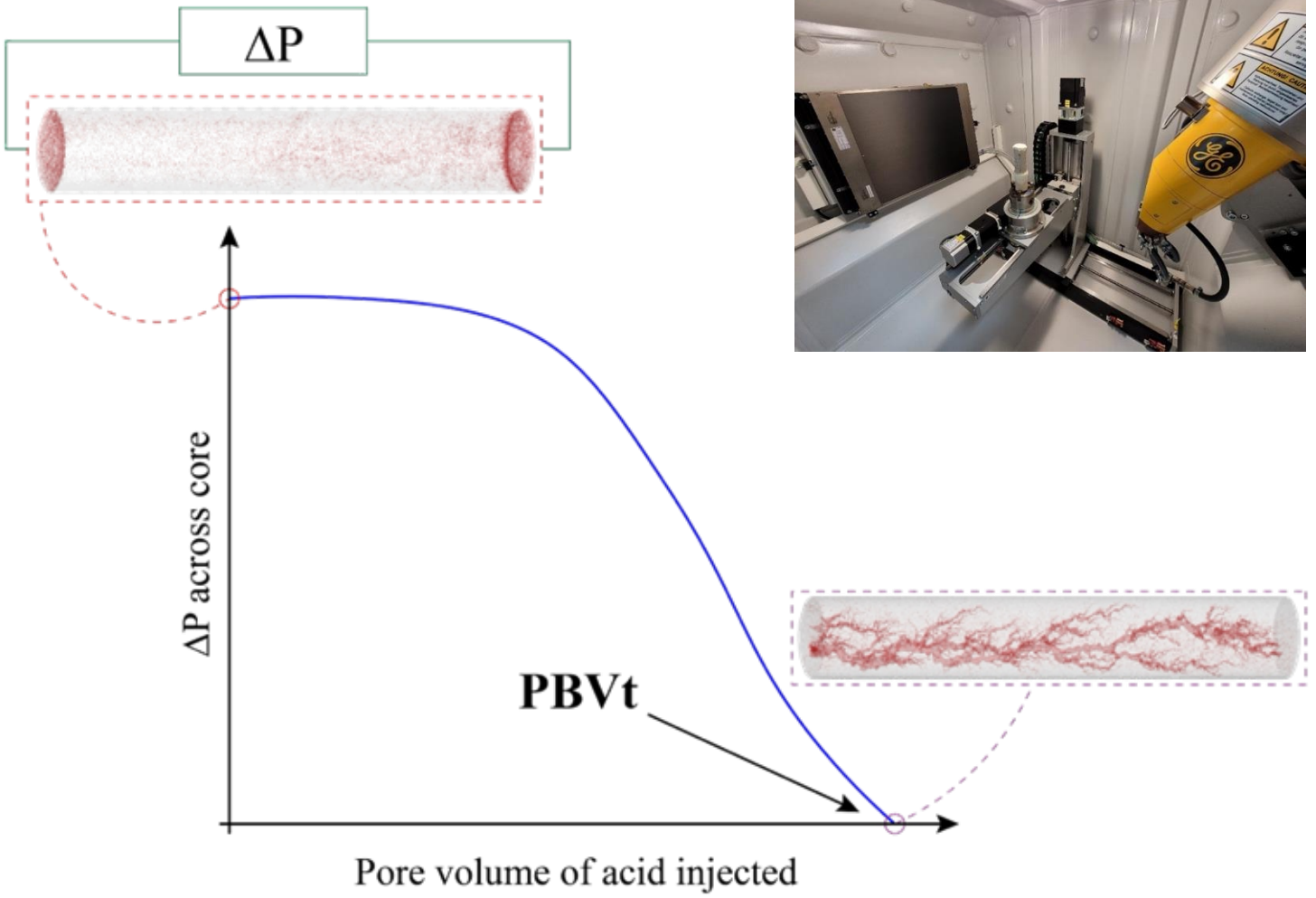
Outline

- Carbonate Acidizing
- Experiments at Laboratory Scale
- Numerical Simulation Experiments
- Objectives
- Mathematical Model
- Results
- Conclusions
- Outlooks

Carbonate Acidizing

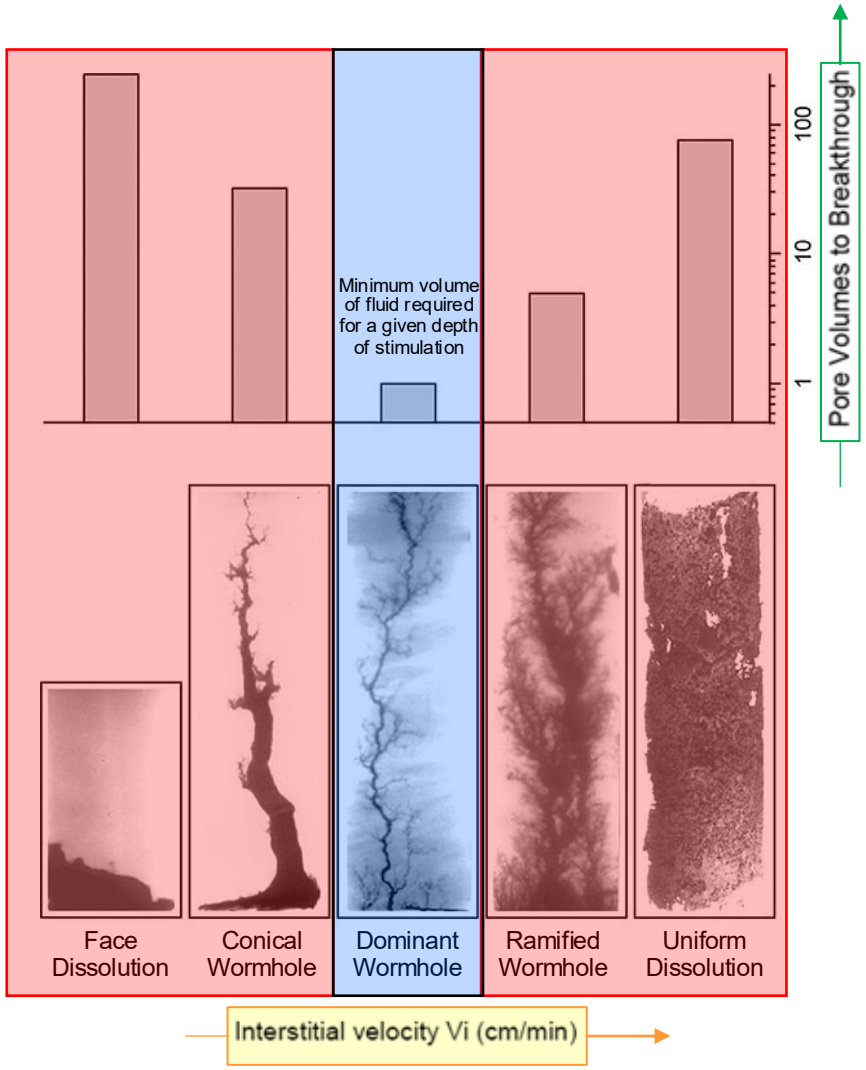


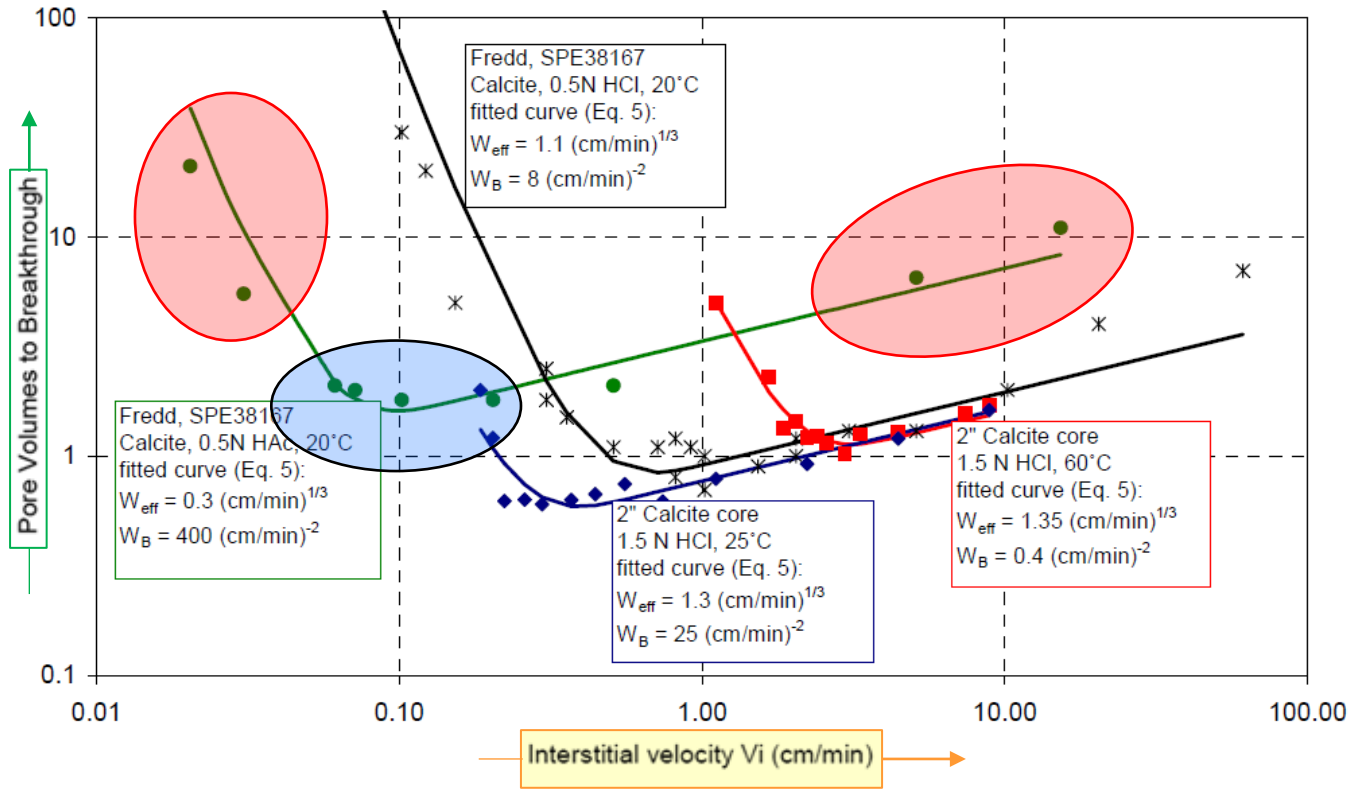
Carbonate Acidizing - Laboratory Experiments



Carbonate Acidizing - Laboratory Experiments

Objective: optimum parameters for a dominant wormhole (lowest Pore Volumes to Breakthrough - PVBt)





[*A Semiempirical Model To Calculate Wormhole Growth in Carbonate Acidizing* - M. Buijse, Shell Intl. E&P B.V., and G. Glasbergen, Halliburton - SPE 96892]

Objective

- 3-D Reactive Flow Simulation, incorpotating the effects of temperature on reaction kinectics in carbonate acidizing simulations

Mathematical Model

- **Momentum conservation**

$$\frac{1}{\varepsilon}\left(\frac{\partial \boldsymbol{u}}{\partial t}+\nabla\cdot\left(\frac{1}{\varepsilon}\boldsymbol{u}\boldsymbol{u}\right)\right)=-\frac{\nabla p}{\rho_f}+\frac{\nu}{\varepsilon}\nabla^2\boldsymbol{u}-\nu\boldsymbol{K}^{-1}\boldsymbol{u}$$

- **Mass conservation**

$$\frac{\partial \varepsilon}{\partial t}+\nabla\cdot\mathbf{u}=0$$

- **Acid concentration**

$$\frac{\partial \varepsilon C_f}{\partial t}+\nabla\cdot(\mathbf{u}C_f)=\nabla\cdot(\varepsilon\boldsymbol{D}_e\cdot\nabla C_f)-a_v\frac{k_c k_s}{k_c+k_s}C_f$$

- **Porosity correlations**

$$\frac{\boldsymbol{K}}{\boldsymbol{K}_0}=\left(\frac{\varepsilon}{\varepsilon_0}\right)^{b_1}\left[\frac{(1-\varepsilon_0)}{(1-\varepsilon)}\right]^{b_2}$$

$$\frac{r_p}{r_{p0}}=\left(\frac{\varepsilon}{\varepsilon_0}\right)^{b_3}\left[\frac{(1-\varepsilon_0)}{(1-\varepsilon)}\right]^{b_4}$$

$$\frac{a_v}{a_{v0}}=\left(\frac{\varepsilon}{\varepsilon_0}\right)^{b_5}\left[\frac{(1-\varepsilon_0)}{(1-\varepsilon)}\right]^{b_6}$$

- **Porosity evolution**

$$\frac{\partial \varepsilon}{\partial t}=\frac{a_v\alpha}{\rho_s}\frac{k_c k_s}{k_c+k_s}\rho_f C_f$$

Panga *et al.* (2005), *AIChE Journal*
Akanni *et al.* (2017), *SPE J.*, SPE-187962-PA

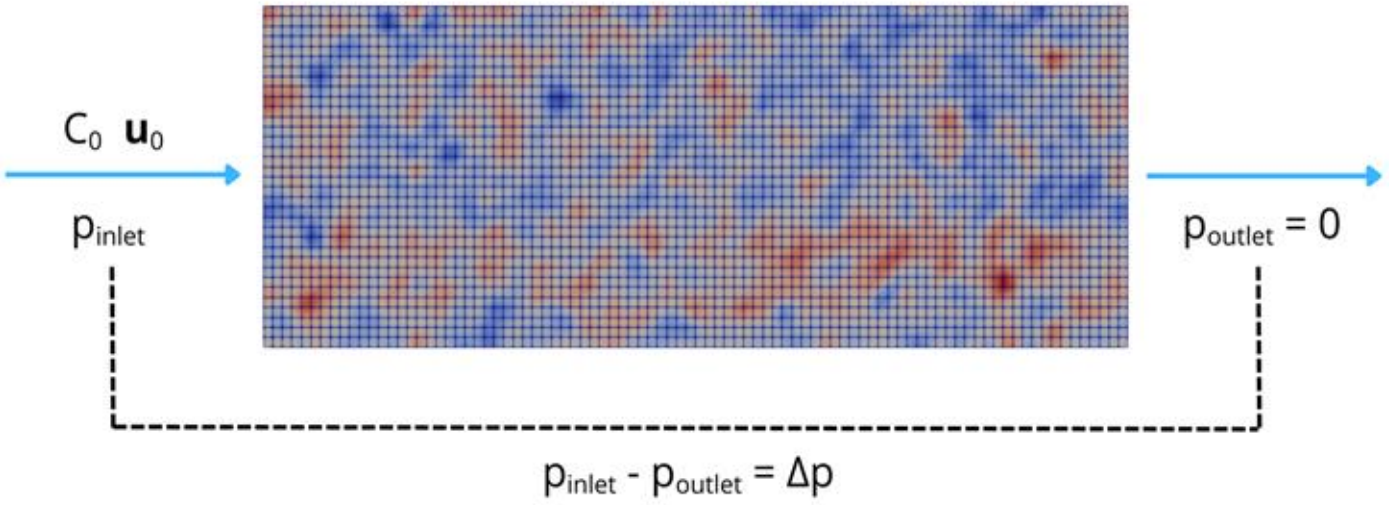
Mathematical Model

- **Reaction rate constant (ks):**

$$k_s = k_s^0 \exp\left(-\frac{\Delta E}{RT}\right)$$

- **Molecular diffusivity (Dm):**

$$D_m = D_m^0 \exp\left(-\frac{\Delta E_D}{RT}\right)$$



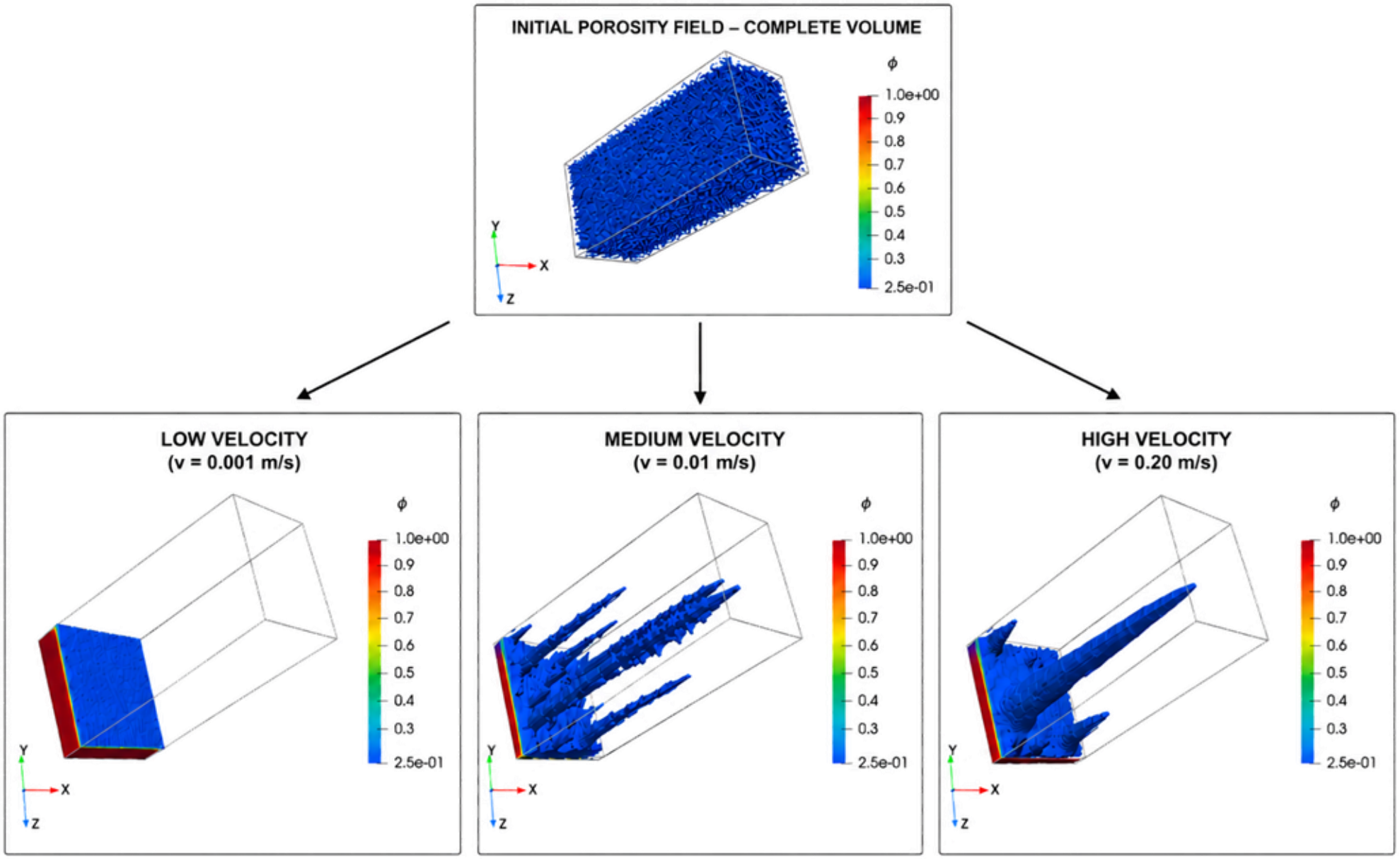
OpenFOAM®

$$\begin{cases} \boldsymbol{u} = \boldsymbol{u}_0 \quad \text{at } x = 0 \\ \nabla \boldsymbol{u} \cdot \vec{n} = 0 \quad \text{at } x = L \\ \boldsymbol{u} = \vec{0} \quad \text{on other boundaries} \\ \boldsymbol{u} = \vec{0} \quad \text{at } t = 0 \end{cases}$$

$$\begin{cases} p = 0 \quad \text{at } x = L \\ \nabla p \cdot \vec{n} = 0 \quad \text{on other boundaries} \\ p = 0 \quad \text{at } t = 0 \end{cases}$$

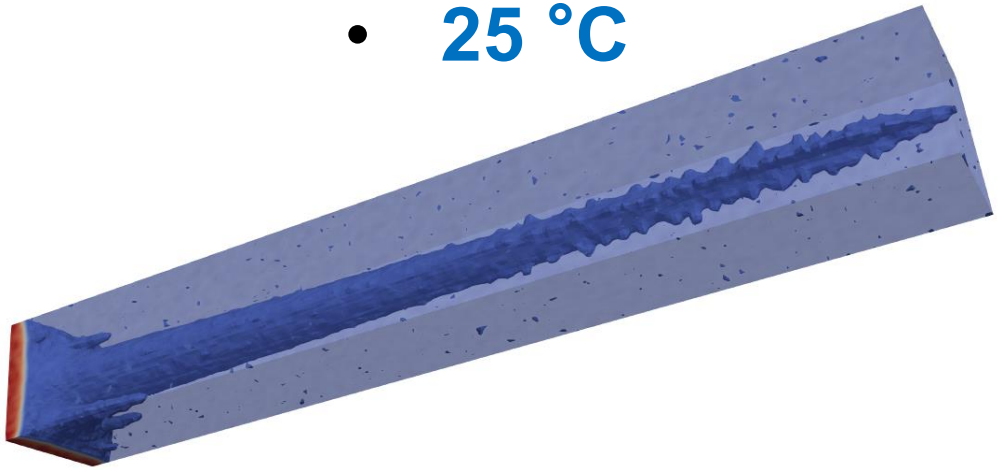
$$\begin{cases} C_f = C_0 \quad \text{at } x = 0 \\ \nabla C_f \cdot \vec{n} = 0 \quad \text{on other boundaries} \\ C_f = 0 \quad \text{at } t = 0 \end{cases}$$

Results – Reactive Flow Simulation

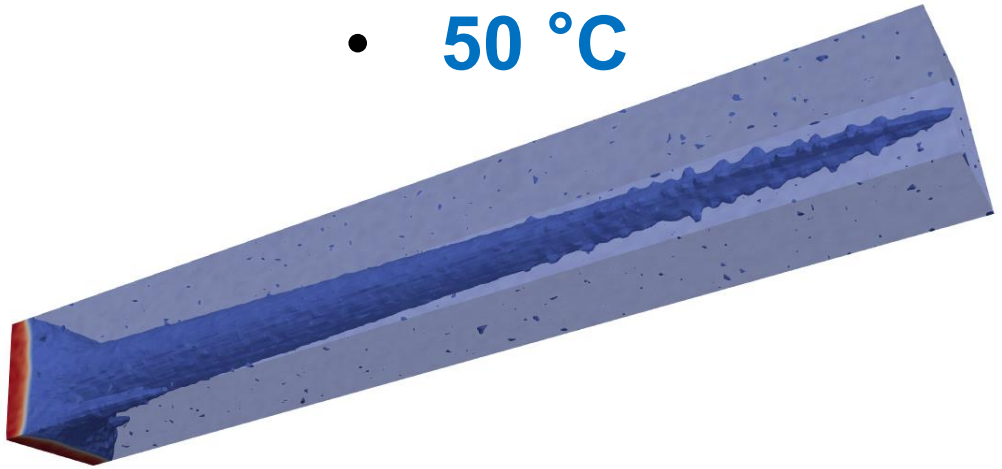


Results – low velocity (0.0001 m/s)

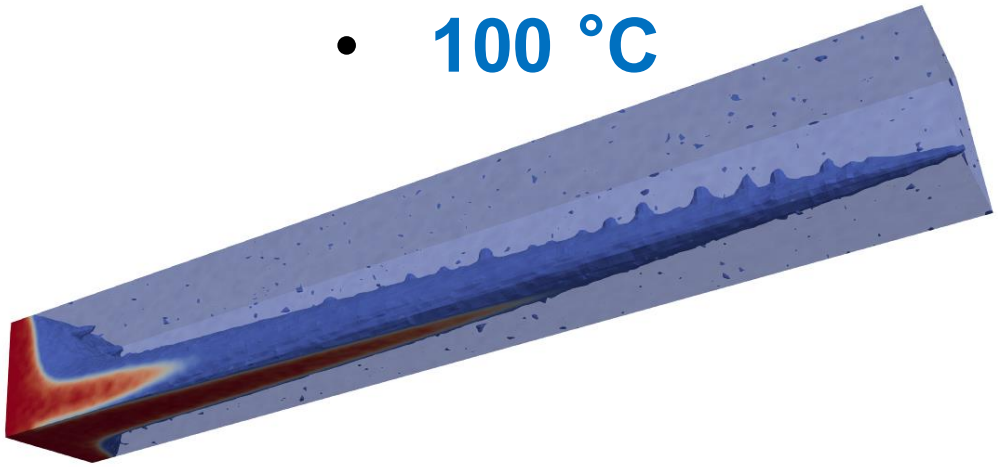
- 25 °C



- 50 °C

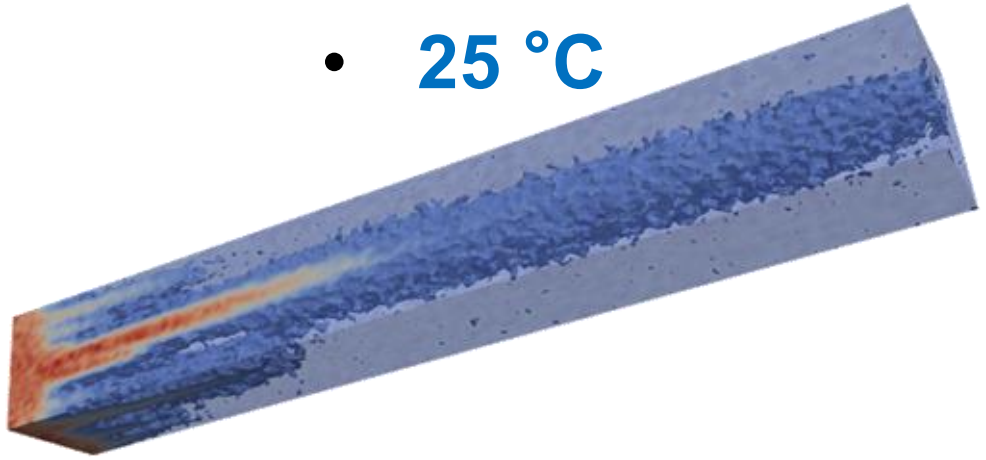


- 100 °C

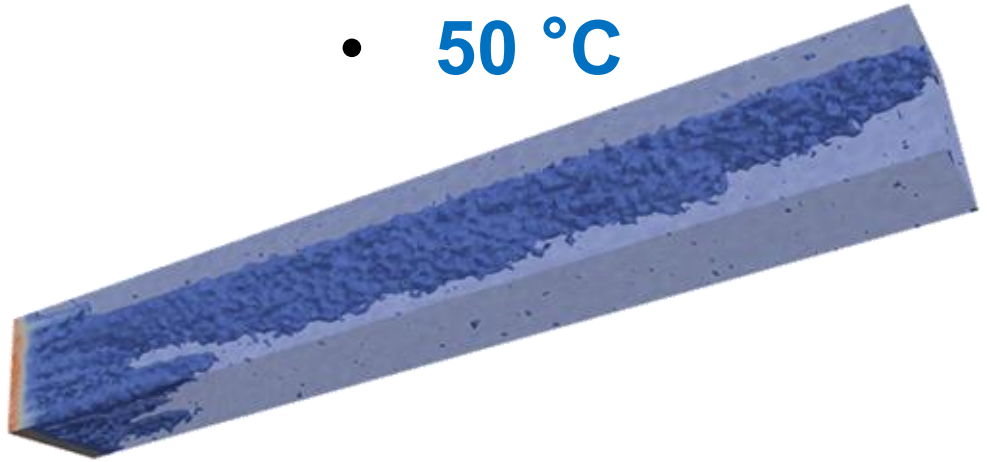


Results – Intermediate Velocity (0.01 m/s)

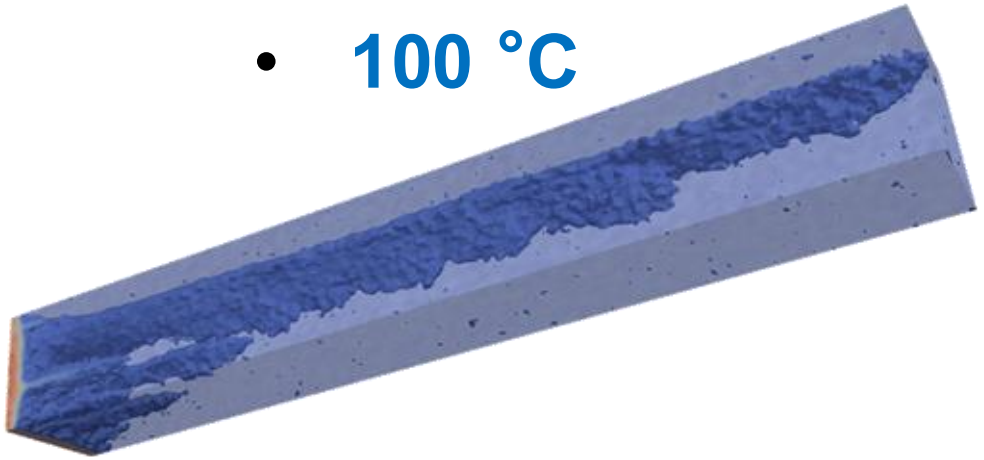
- 25 °C



- 50 °C

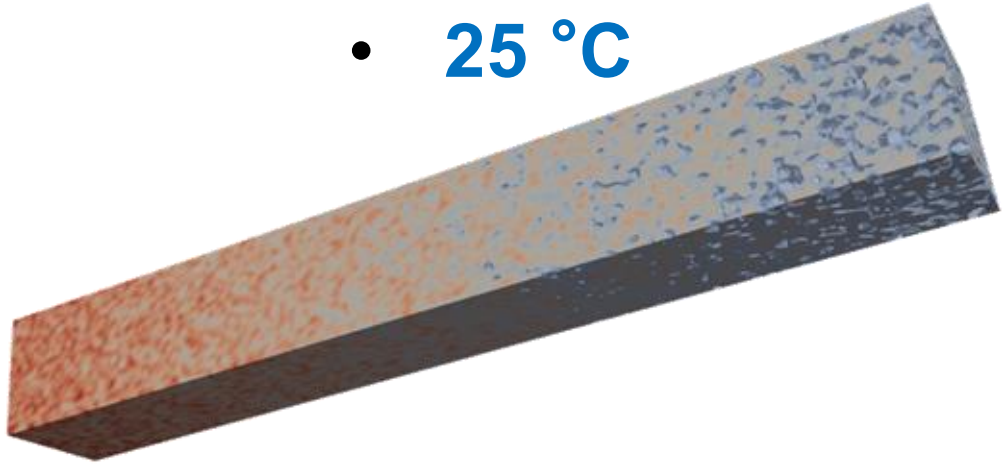


- 100 °C

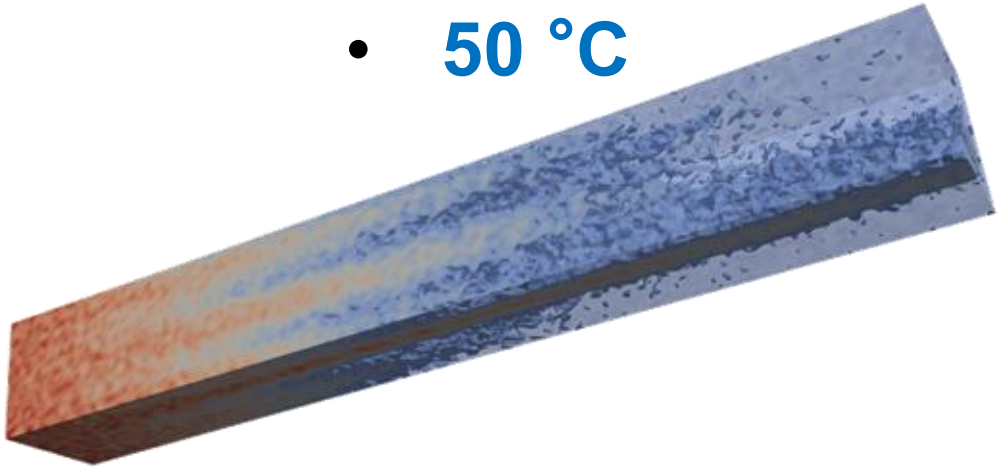


Results - high velocity (0.2 m/s)

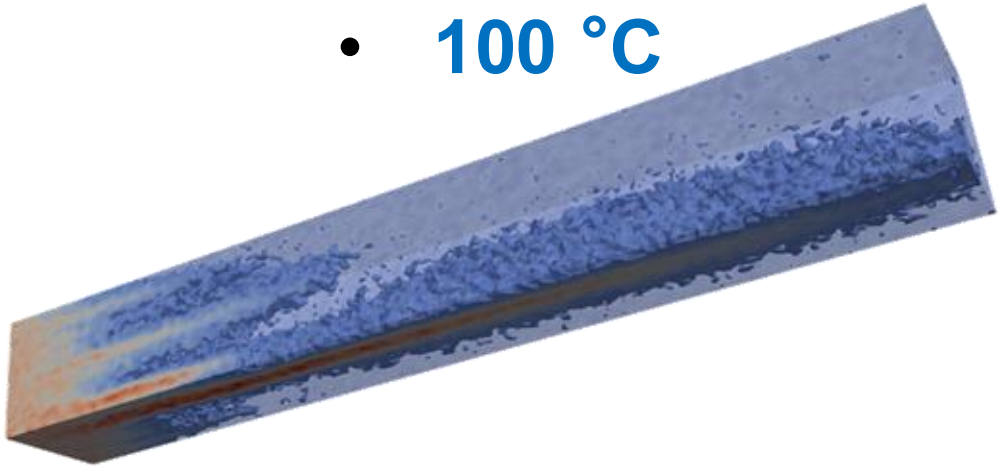
- 25 °C



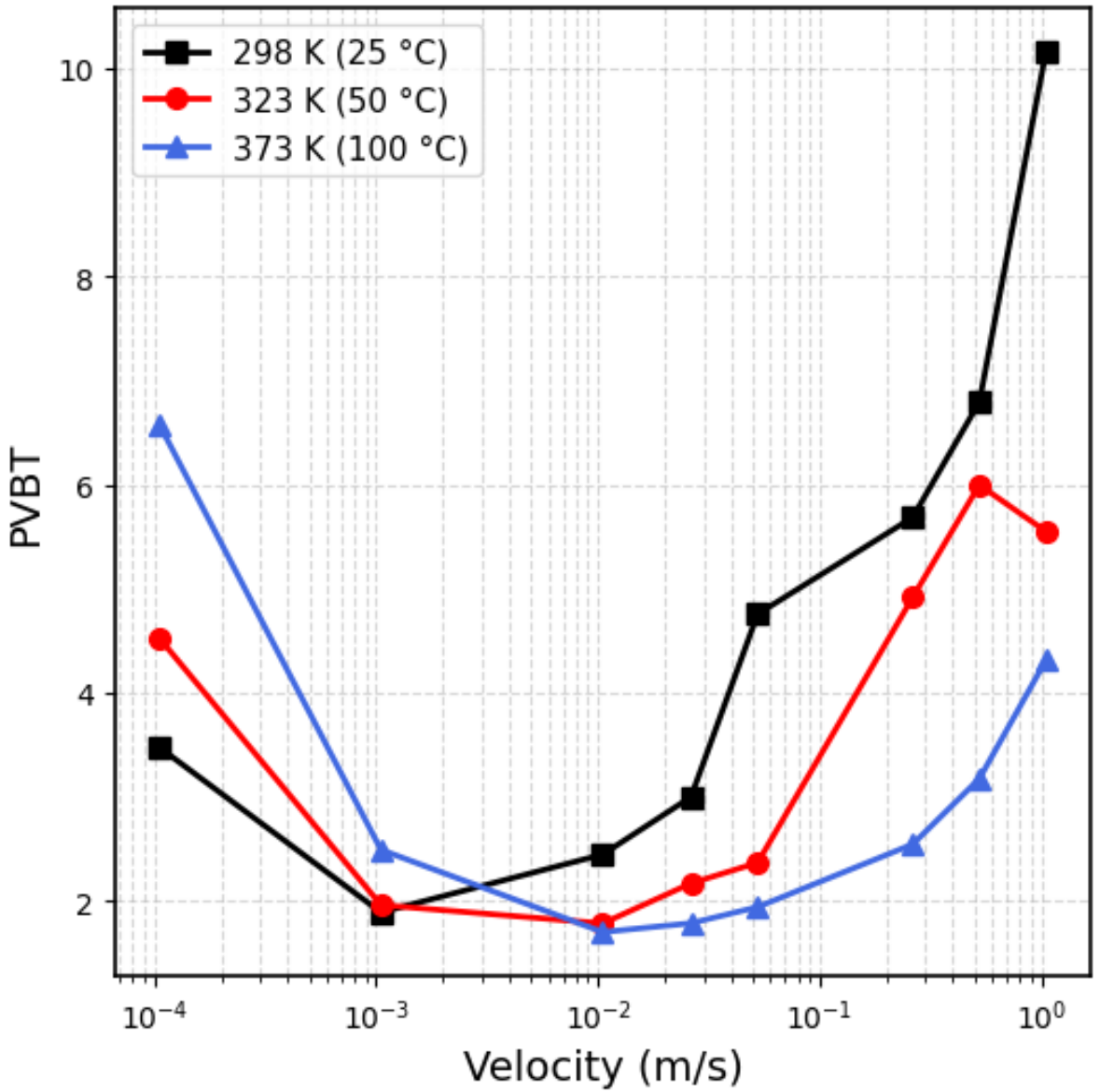
- 50 °C



- 100 °C



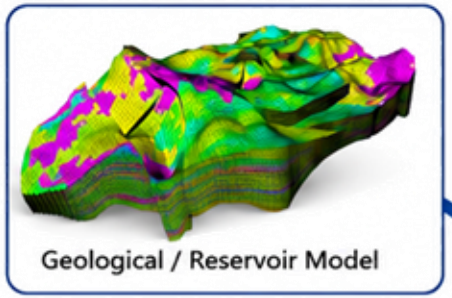
Results


298 K (25 °C)
323 K (50 °C)
373 K (100 °C)
PVBT
Velocity (m/s)
10
8
6
4
2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}

Conclusions

- Higher temperatures exhibit larger PVBT values before the optimal point is reached.
- At high flow velocities, lower temperatures lead to higher PVBT values.
- The optimal point shifts toward higher velocities as temperature increases.
- The system exhibits distinct optimal operating conditions depending on the temperature level.

Research Outlook



Geological / Reservoir Model

Characterization

- MICP, XRD, K-Φ
- CT and Micro-CT
- Fluid Rheology

Validate prediction; Software calibration with field data

Characterized representative samples

Evaluate the performance of different acid systems

Quantify efficiency and optimize acid formulations for maximum performance.

Predict the impact at Field Scale

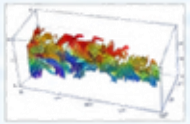
Validated models and calibrated tools enable field-scale predictions of acid performance.

Well Scale

- Optimized design
- Cost Reduction

Acid Injection Experiments

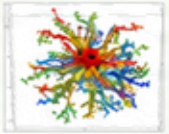
- Coreflooding
- Micro CT Imaging and Analysis



Validated model upscaling, optimization and job design

Software Calibration

- Model interactions with experimental results
- Sensitivity Analysis



Dissolution patterns; Optimum injection rate

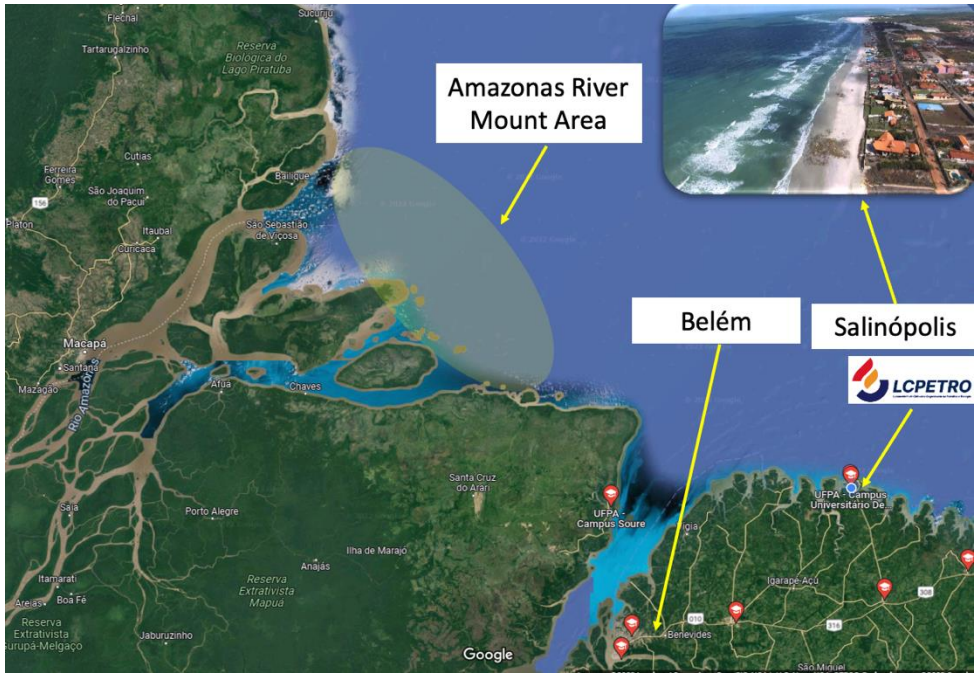
With Pre-Salt data

Improve model reliability and applicability using field data from Pre-Salt reservoirs.

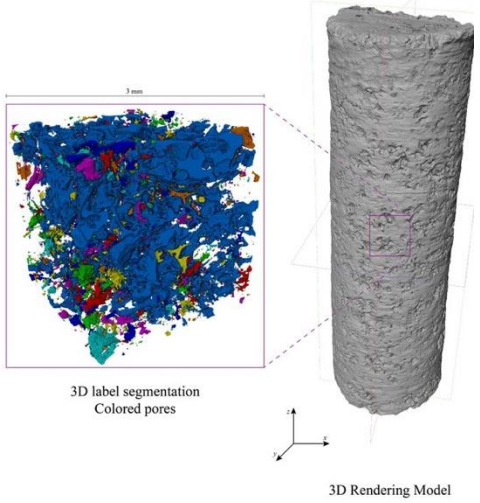
PETROBRAS TotalEnergies

LCPETRO

Energy and Petroleum Science Laboratory



Research group focused on reactive and non reactive **flow in porous media – experimental and numerical simulation**



www.lcpetro.ufpa.br

Acknowledgments and Support