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EGU General Assembly

Discontinuous low order pressure formulation in CVFE method for simulating flow and transport in highly heterogeneous porous media

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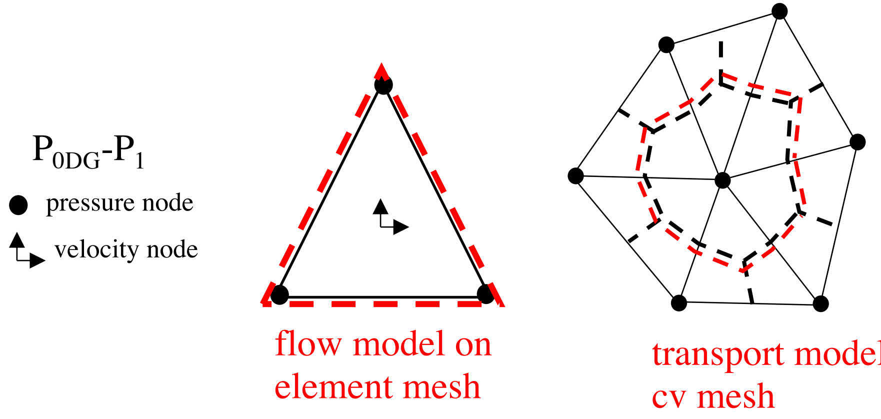
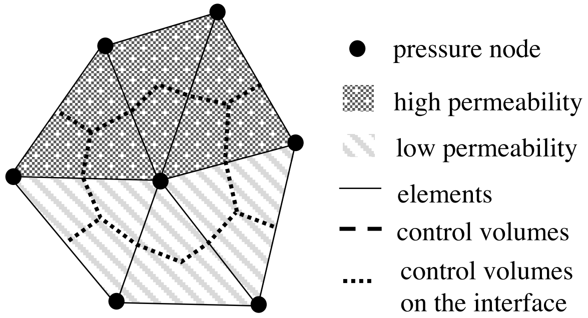
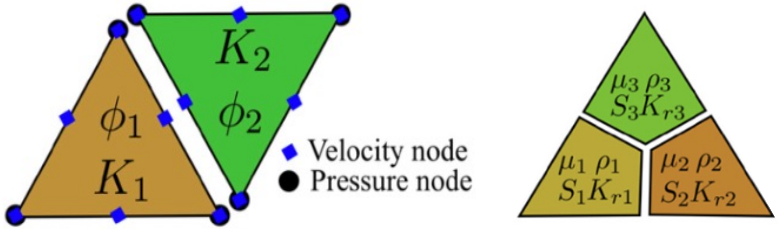
Motivation

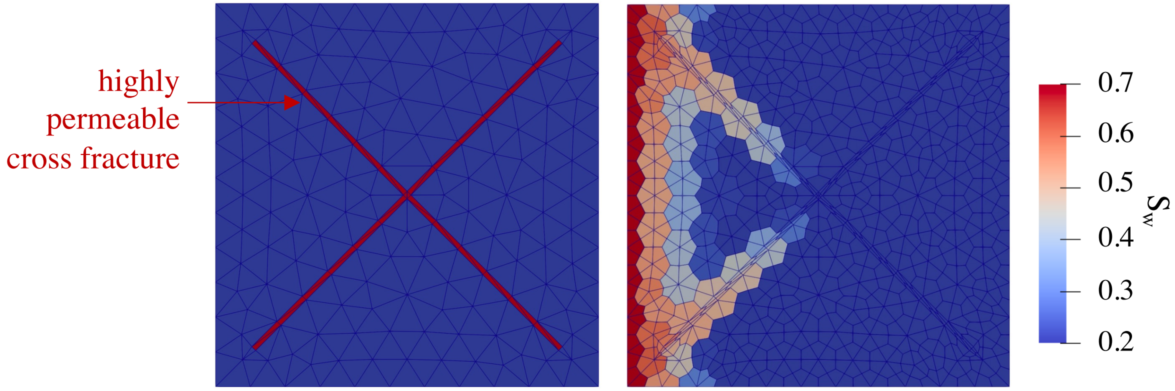


- CVFE method to capture flexible geometry
- Continuous CV discretization span element interfaces smears solution
- Discontinuous methods are computationally costly





High order discontinuous method [1]



[1] Salinas, P., Pavlidis, D., Xie, Z., Osman, H., Pain, C., Jackson, M., 2018. A discontinuous control volume finite element method for multi-phase flow in heterogeneous porous media. Journal of Computational Physics .

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Multiphase flow and transport model

- Darcy's law

$$\mathbf{v_t} = -\lambda_t \mathbf{K} \nabla p + \mathbf{f}$$

where

$$\lambda_t = \frac{k_{r,w}(S_w)}{\mu_w} + \frac{k_{r,nw}(S_w)}{\mu_{nw}}$$

- Continuity equation

$$\nabla \cdot \mathbf{v_t} = q_t$$

- Mass conservation

$$\phi \frac{\partial S_w}{\partial t} + \nabla \cdot (f_w \mathbf{v_t}) = q_w$$

s.t.

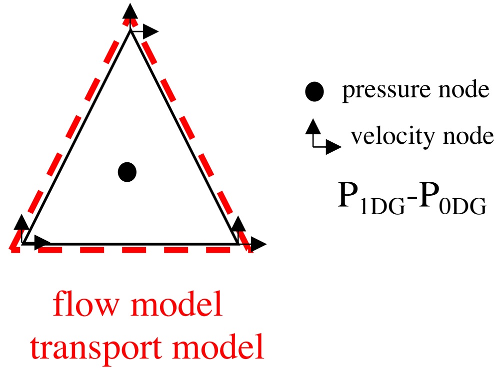
$$S_w + S_{nw} = 1.$$

fractional flow

$$f_w = \frac{\lambda_w}{\lambda_t}$$

Proposed (P_{1DG}-P_{0DG}) approach

- one to one element-control volume mapping for consistent discretization
- Flux continuity between elements/CV is applied in discretization
- Locally and globally mass conservative
- Discretized force balance equation $\boldsymbol{A}\, v_t + \boldsymbol{B}\, p = b_1$



vanish; jump term

$$\sum_{\Omega_e \in \Omega} \sum_{j=1}^{N_v} \int_{\Omega_e} \mathbf{\Phi_i} v_{t,j} \mathbf{\Phi_j} d\Omega_e + \sum_{\Omega_e \in \Omega} \sum_{k=1}^{N_p} \int_{\Omega_e} \lambda_t \mathbf{K} \mathbf{\Phi_i} p_k \nabla \Psi_k d\Omega_e + \sum_{\Gamma_e \in \Gamma} \sum_{k=1}^{N_p} \oint_{\Gamma_e} \lambda_t \mathbf{K}_h \mathbf{n}. \Big(\mathbf{\Phi_i} \Psi_k (p_k - \tilde{p}_k) \Big) d\Gamma_e = \mathbf{0},$$

Harmonic permeability

- Discretized continuity equation $\boldsymbol{C}\, v_t = b_2$

fluxes

$$\sum_{\Gamma_e \in \Omega} \sum_{j=1}^{N_v} \int_{\Gamma_e} \Psi_i \mathbf{n}.\mathbf{\Phi_j} \tilde{\mathbf{v}}_{\mathbf{t},\mathbf{j}} d\Gamma_e - \sum_{\Omega_e \in \Omega} \int_{\Omega_e} \Psi_i q_t d\Omega_e = \mathbf{0}$$

permeability-weighted harmonic average velocity

- IMPES-based scheme to solve for flow and transport

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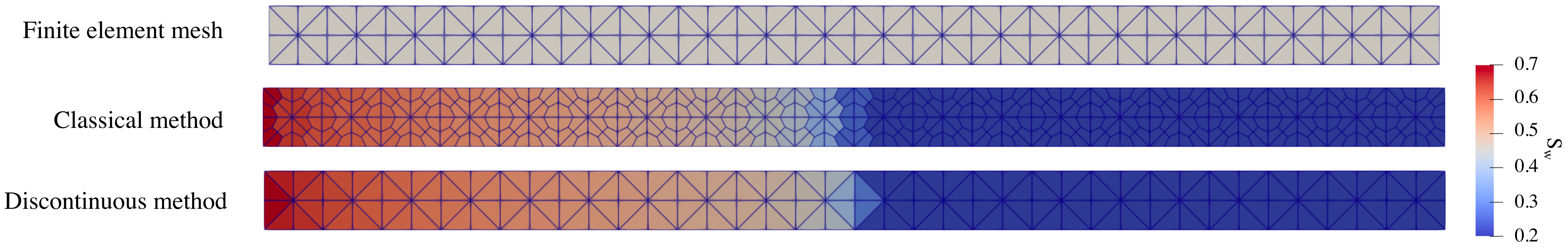
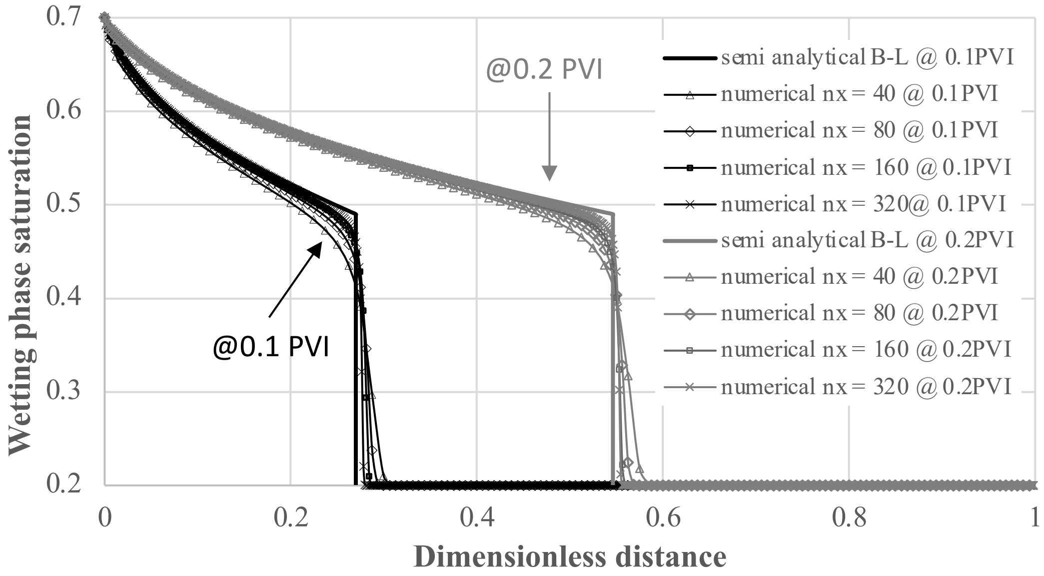
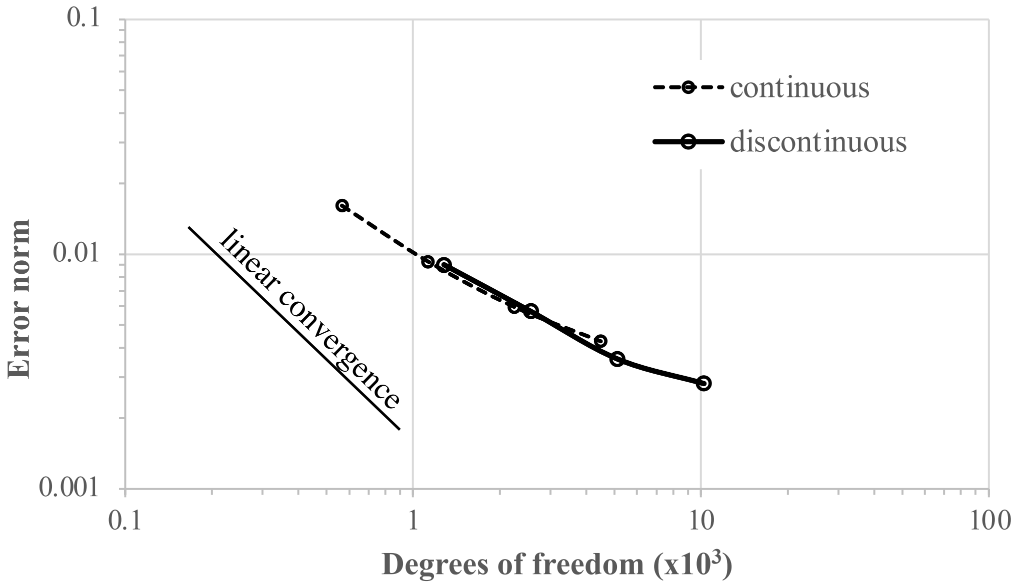
Buckley-Leverett validation







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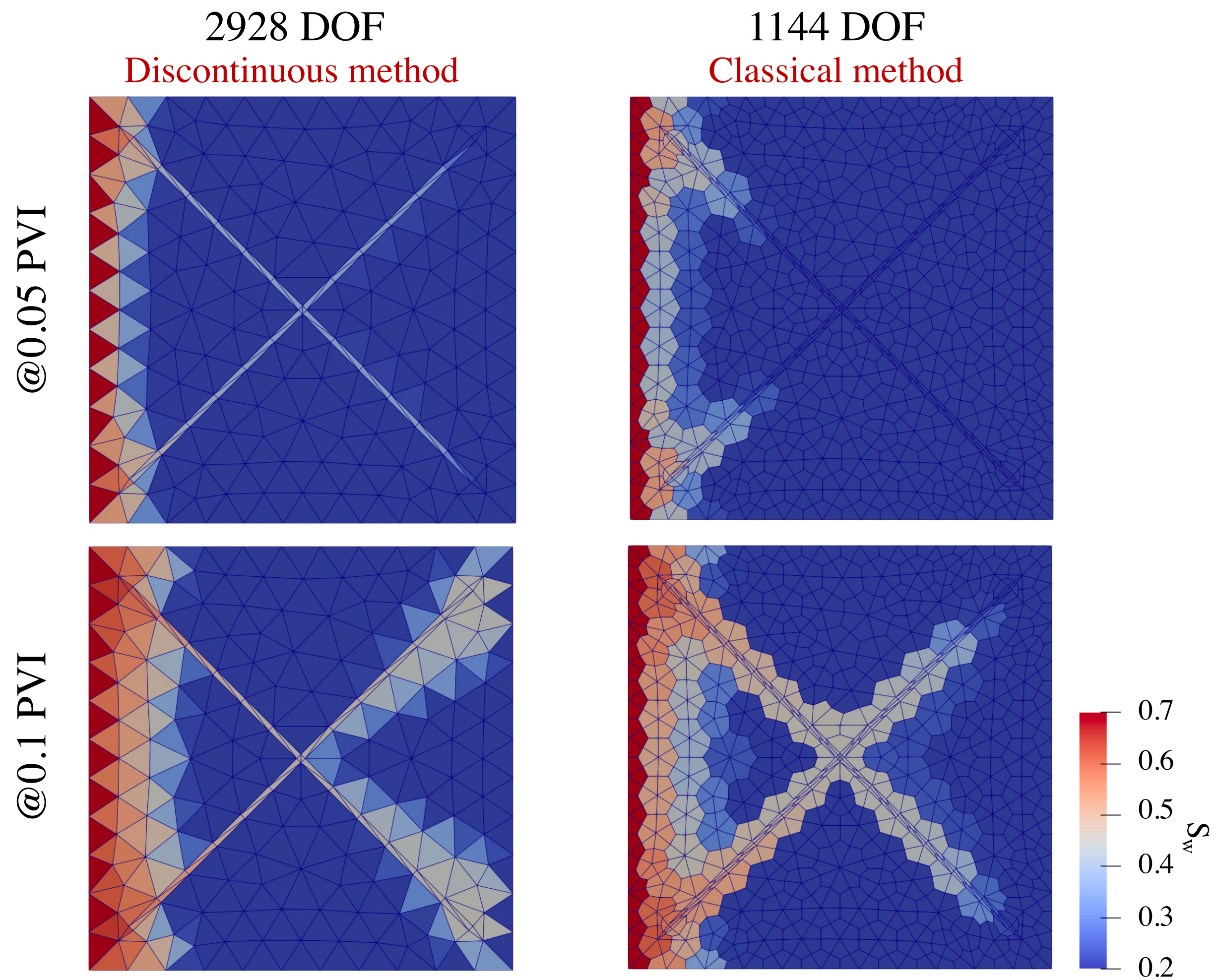
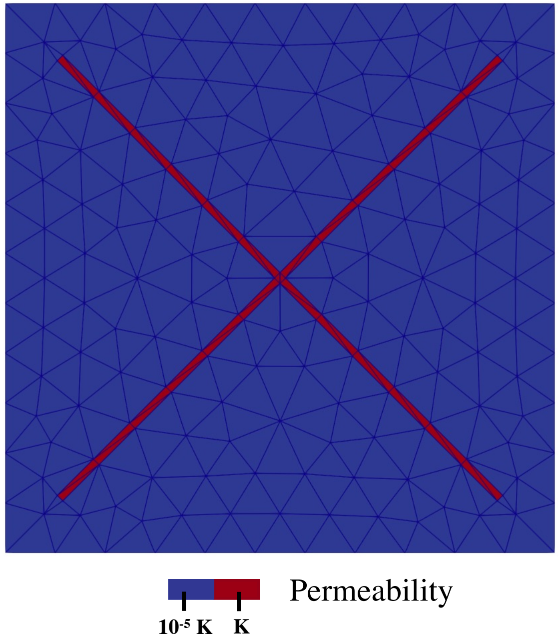
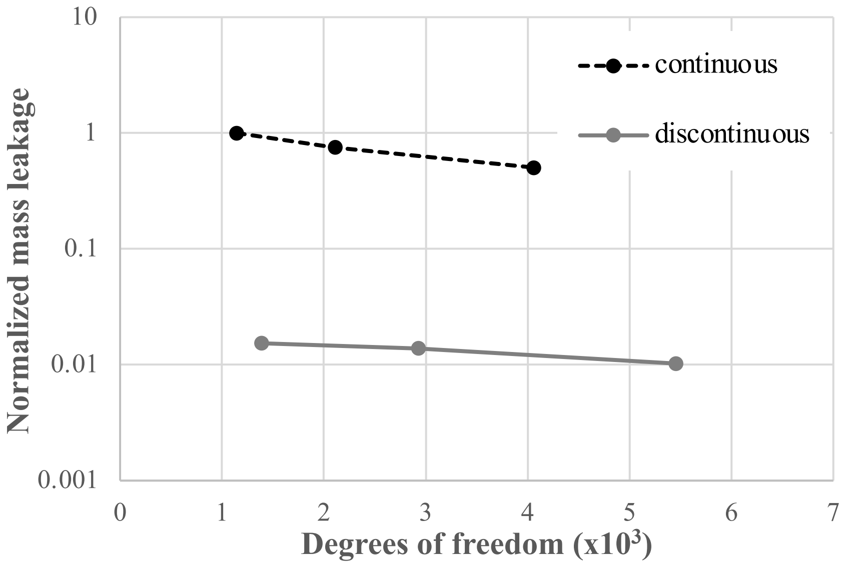
Numerical example 1: cross fracture







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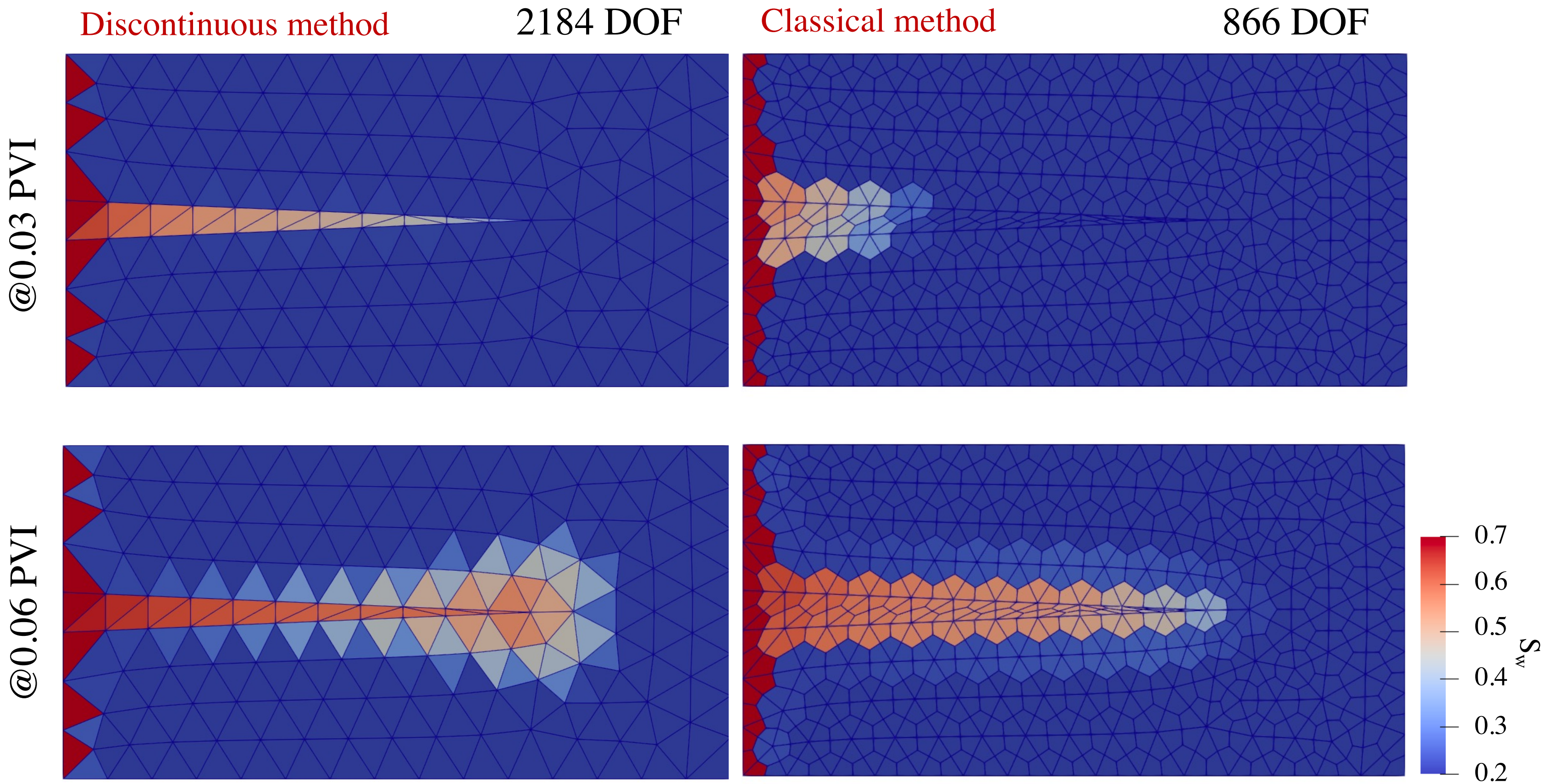
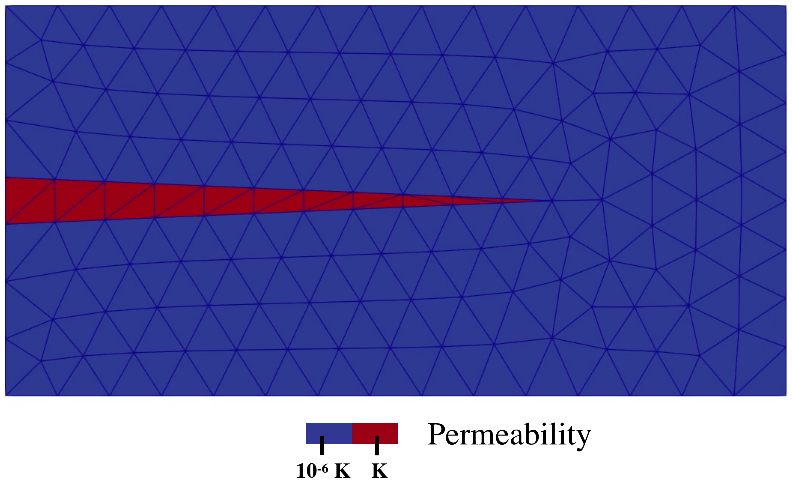
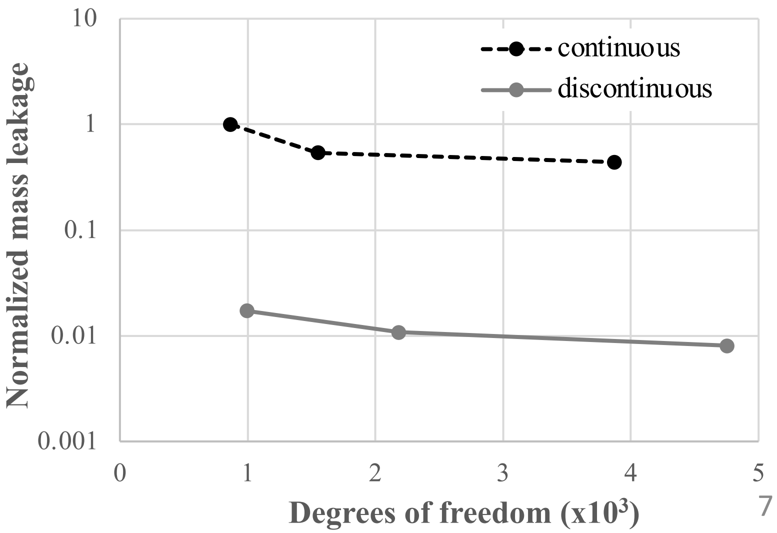
Numerical example 2: wedge pinch out







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Conclusions

The proposed method

- Significantly outperforms the accuracy of classical CVFE method to preserve sharp saturation interfaces
- Consistent, stable, and numerically convergent
- Locally and globally mass conservative
- Requires less degrees of freedom than other discontinuous methods and yields similar results

Thank you!