Discrete Fracture Method for Simulation of Two-Phase Flow in Porous Media

By: Shayan Hoshyari
Professor: Mehrdad T. Manzari

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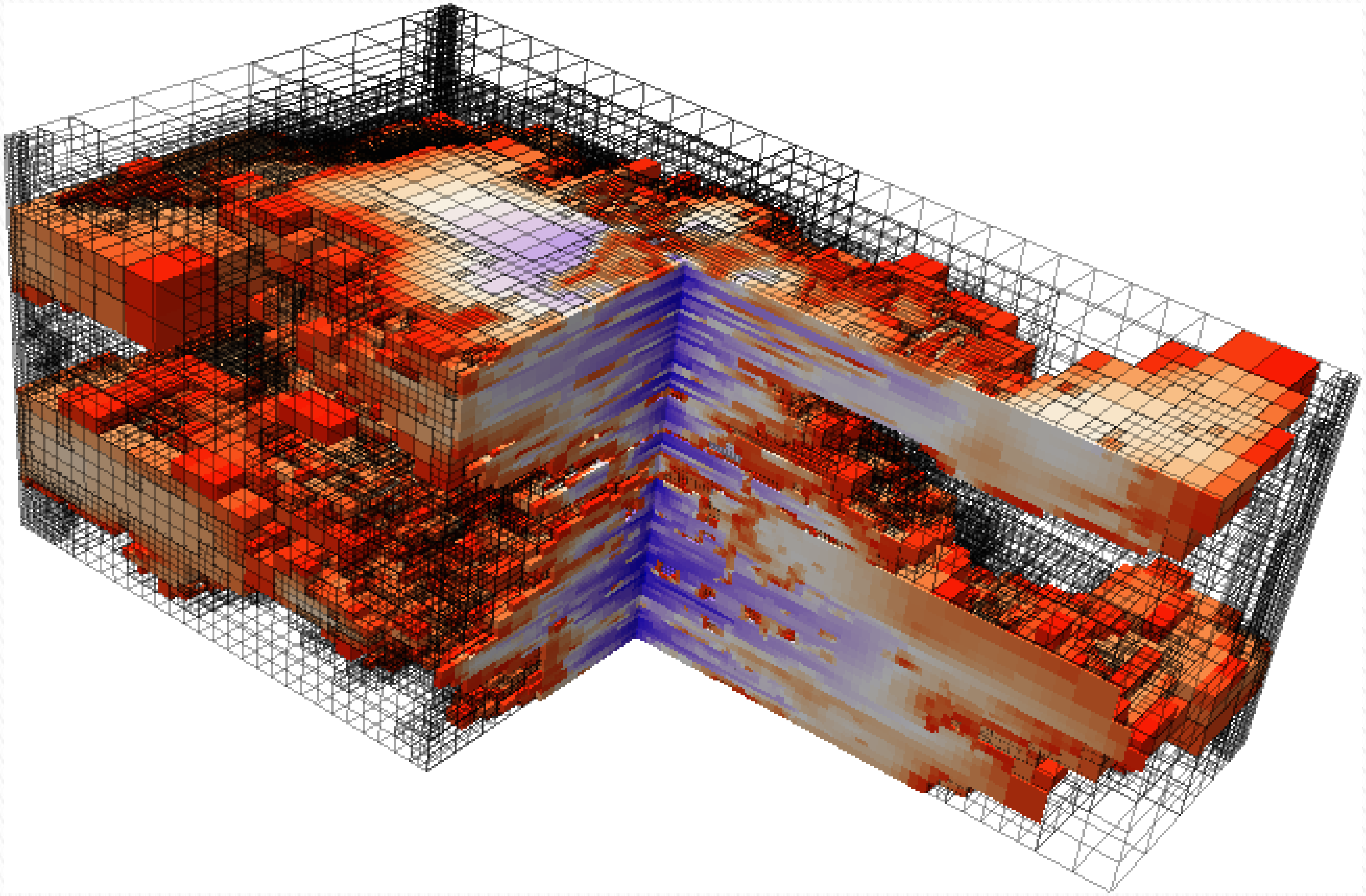
Applications of flow in PM

- Reservoir simulation:
  - Choice of EOR methods.
  - Optimizing well locations.
  - Long range planning.
  - …
  - => Enormous profit.

- Water resource management

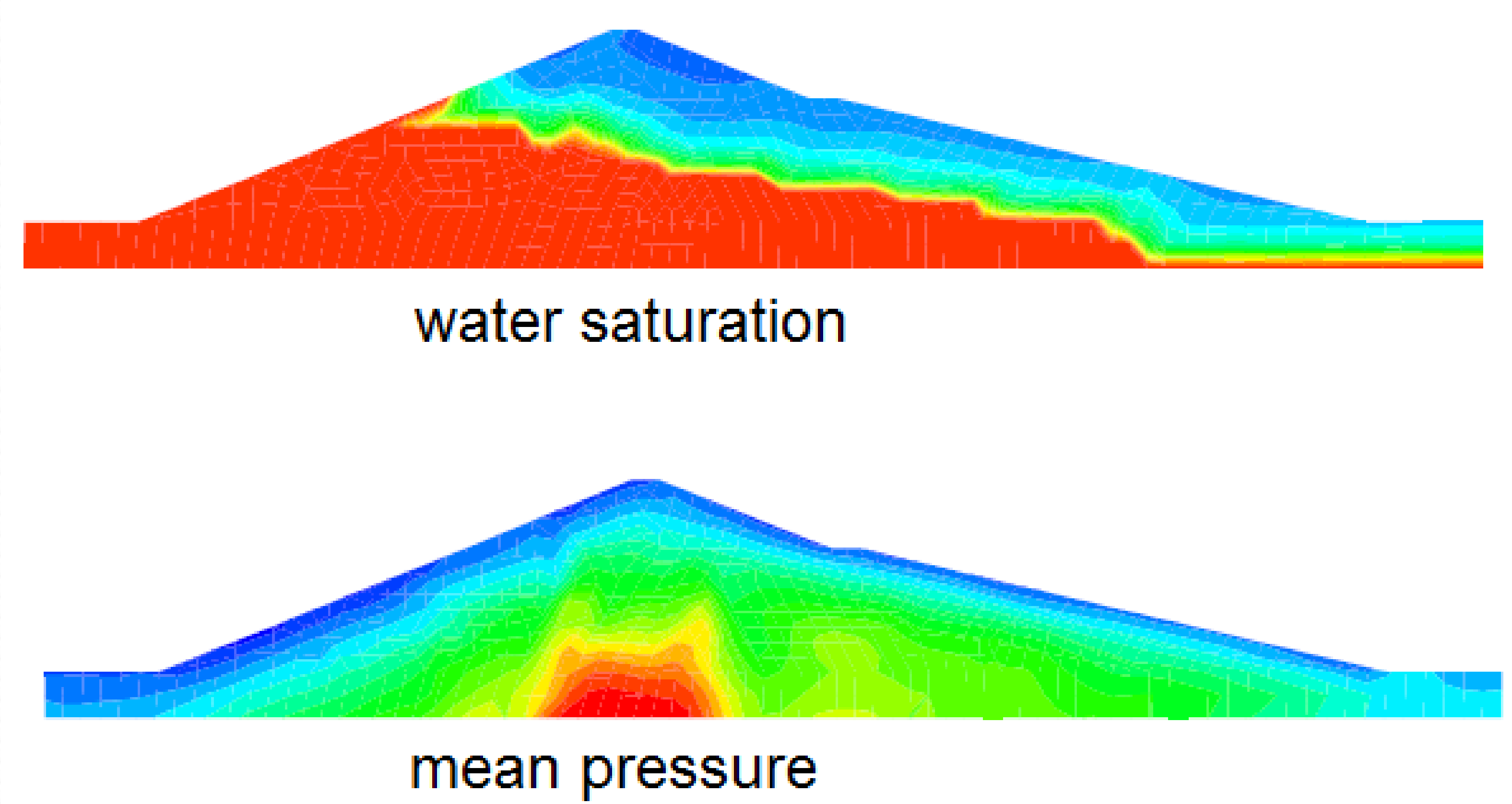
- Geotechnical engineering



Applications of flow in PM

Simulation of a five-spot injection scenario with a strongly heterogeneous domain, i.e. SPE10 benchmark problem.

(Dumux numerical library)



Applications of flow in PM

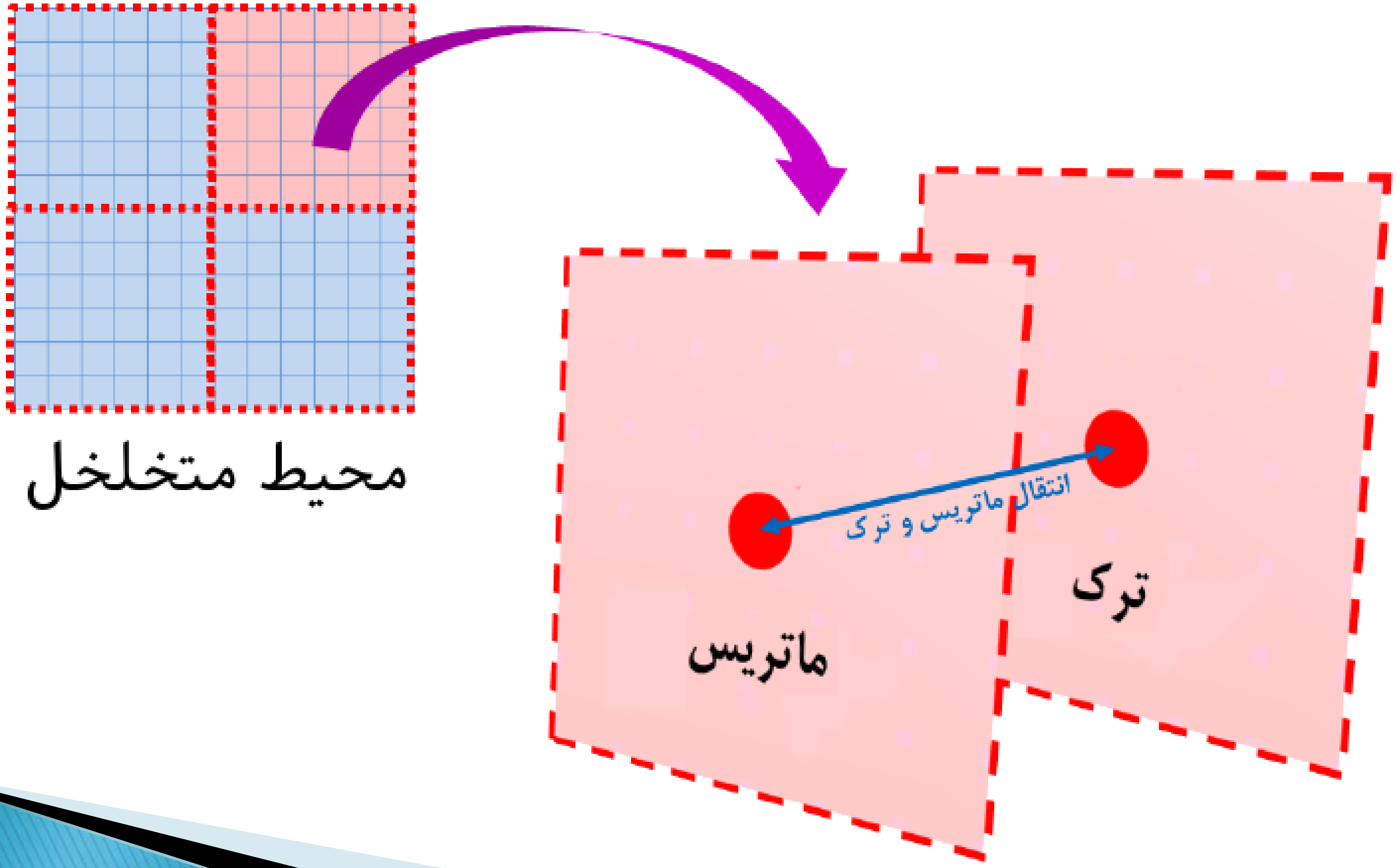
Water saturation and mean pressure in Mahabad dam, 200 seconds after the beginning of Tabas earthquake (Khoei).

Fractured Reservoirs

- 20% of world reservoirs and 30% of Middle East reservoirs are fractured (Golf-Racht).
- Fractures greatly change the behavior of the reservoir.
- The Beaver River gas reservoir in Canada 1978 (Golf-Racht):
  - Production dropped from 200 to 3 MM cf/D in 5 years.
  - Huge loss!

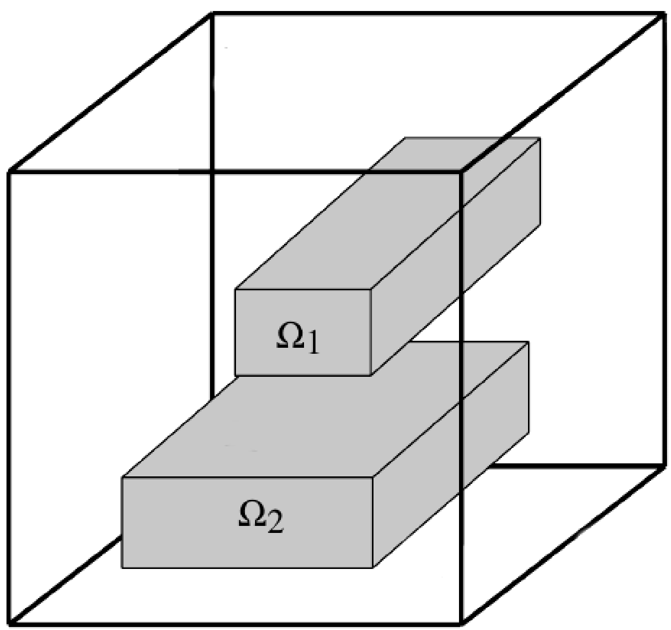
Fracture Modeling

- Dual(Multiple) Continuum Method:

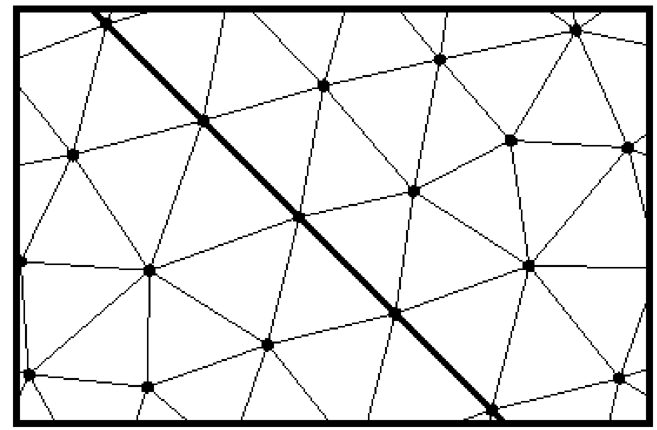


Fracture Modeling – cont.

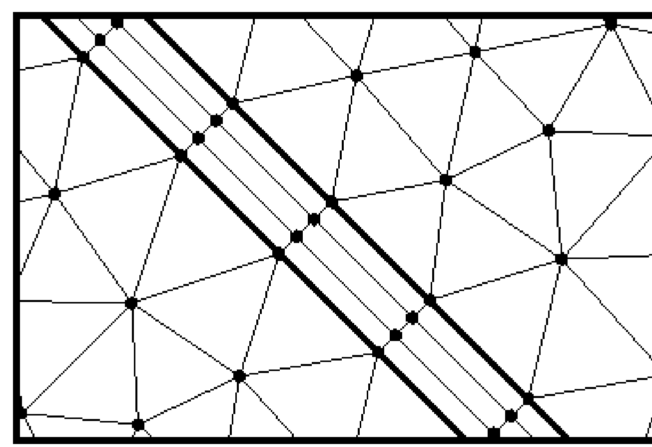
- Discrete Fracture Method:



Inhomogeneous Media
Figure from (Bastian)



Thin Fracture approximation



Thick Fracture

Discrete Fracture Method

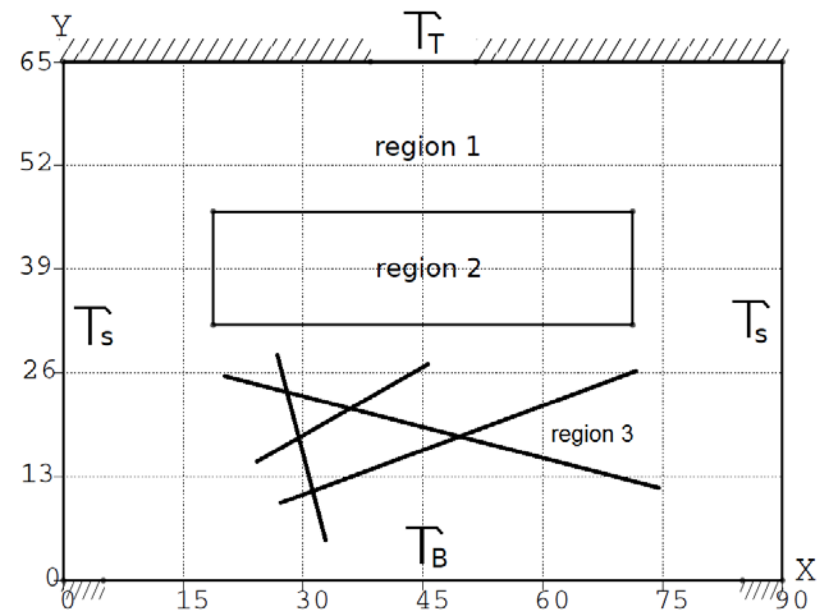
- Disadvantages:
  - Too much detail required.
  - Computationally expensive.
  - Difficult to model too many fractures.
- Advantages:
  - Perfectly models separate large fractures.
  - Can help creating new and more accurate transfer function models for dual continuum models, using <u>numerical solutions</u>.
  - Can be combined with dual continuum models to maximize efficiency.

Goals

- Develop a flow in porous media solver:
  - Discrete Fracture Method
  - Two-dimensional
  - Incompressible two-phase, black-oil, compositional
  - Finite volume method
  - IMPES method, implicit method, adaptive methods
  - Unstructured meshes

Mathematical Model

- Geometry
- Rock and fluid properties:
  - Permeability: K
  - Relative perm.: k_{rw}, k_{ro}
  - Porosity: ϕ
  - Density: ρ_o, ρ_w
  - Viscosity: μ_o, μ_w
  - Capillary pressure: p_c
- Boundary Conditions



Mathematical Model – cont.

- Equations:

$$\phi \frac{\partial S_w}{\partial t} - \nabla \cdot (\lambda_w \overline{\overline{K}} \nabla \Phi_w) = 0$$

$$\nabla \cdot [(\lambda_w + \lambda_o) \overline{\overline{K}} \nabla \Phi_w + \lambda_o \overline{\overline{K}} \nabla \Phi_c] = 0$$

- Unknowns:

$$\Phi_w, S_w$$

- New parameters:

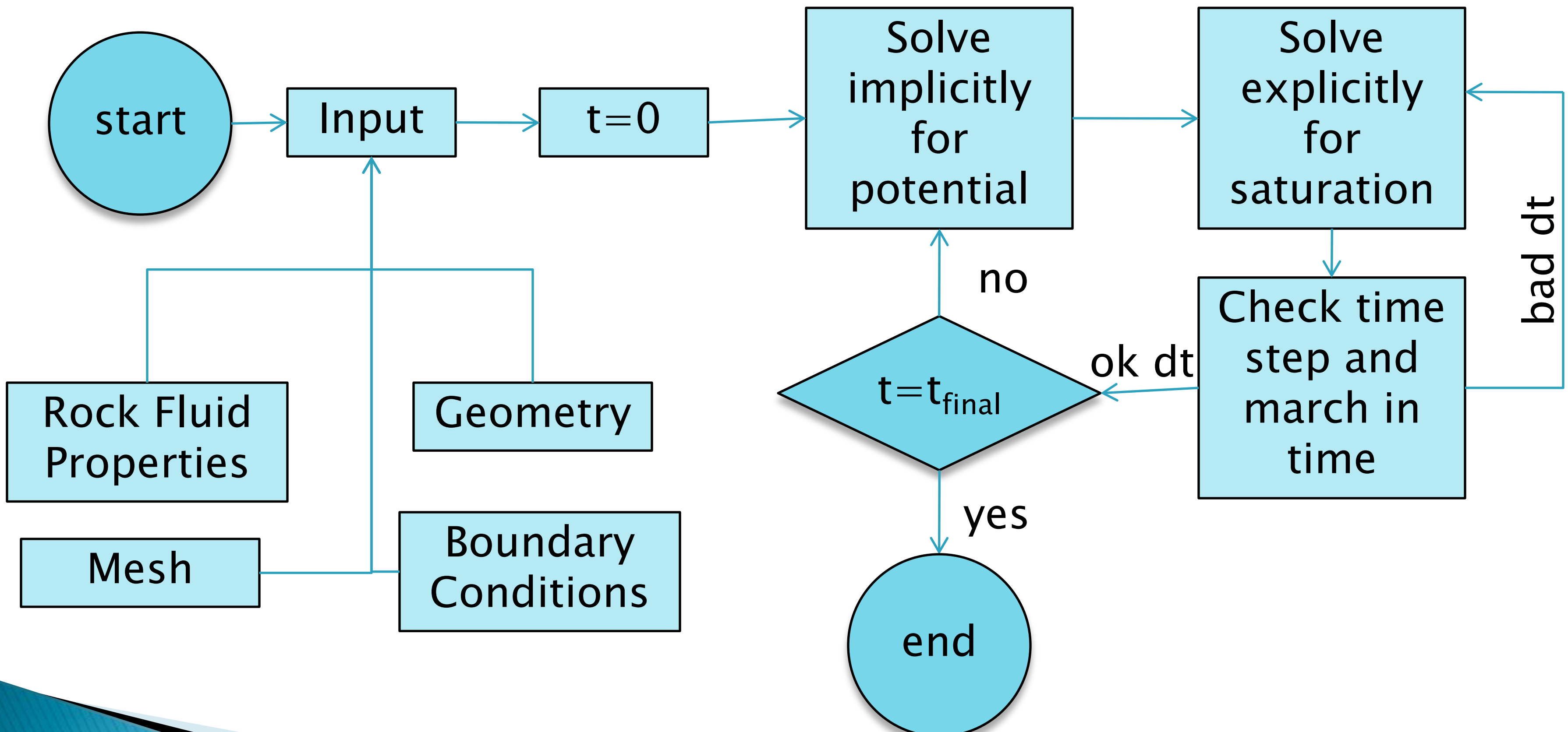
$$\mathit{\Phi}_w = p_w + \rho_w g h$$

$$\mathit{\Phi}_c = p_c(S_w) + (\rho_o \text{-} \rho_w) g h$$

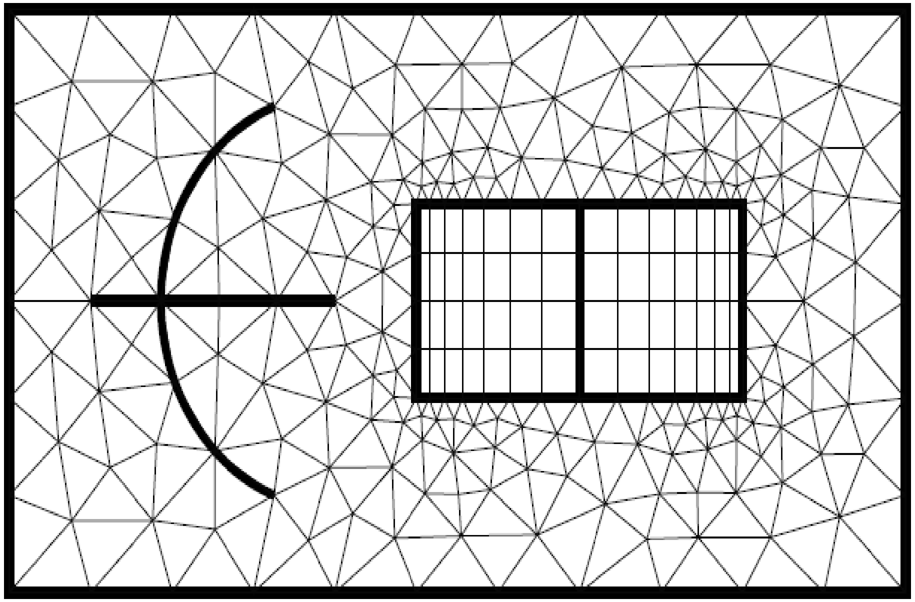
$$\lambda_\alpha = k_{r\alpha}(S_w)/\mu_\alpha \qquad \alpha = o, w$$

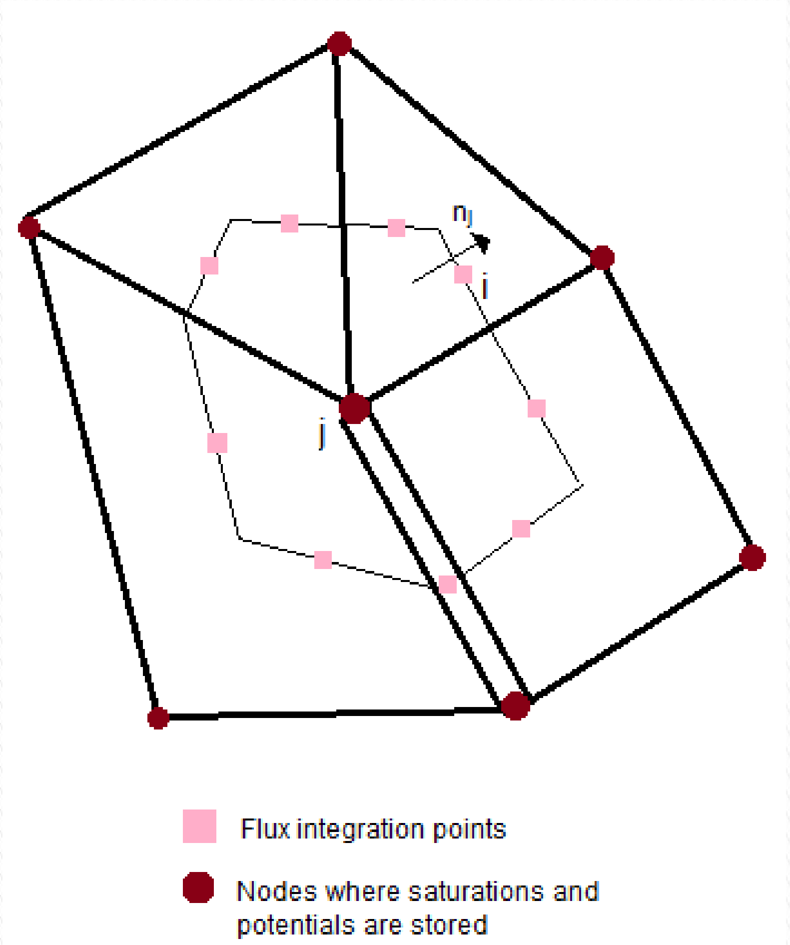
Numerical Method

- Discretization method => Finite Volume Method.



Numerical Method – cont.



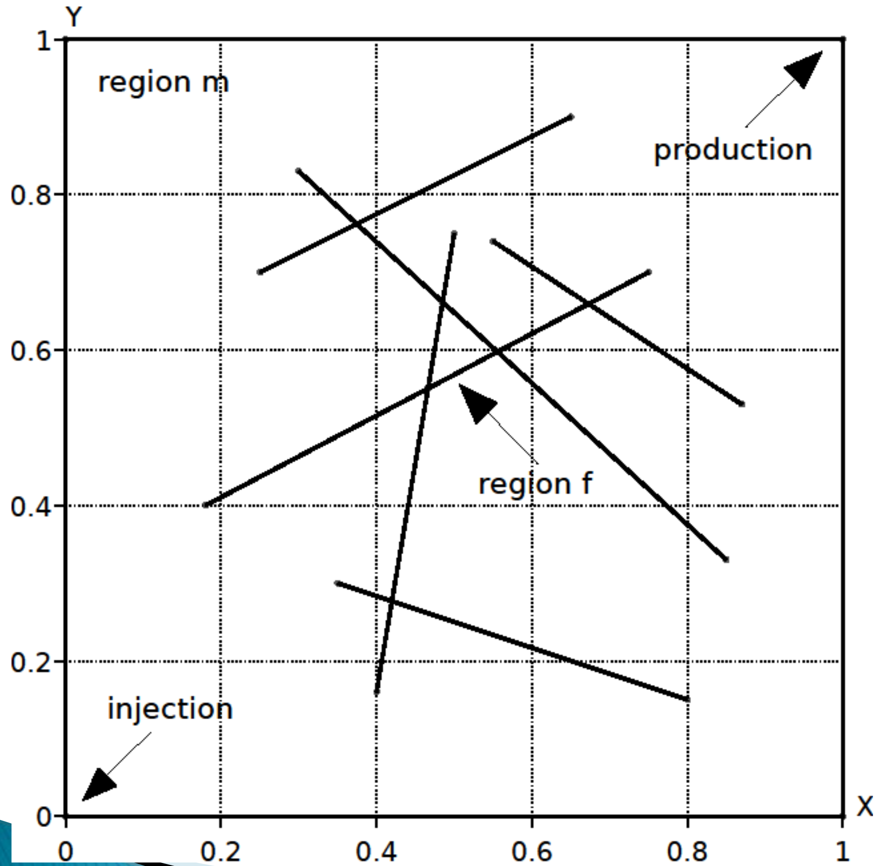


Mesh

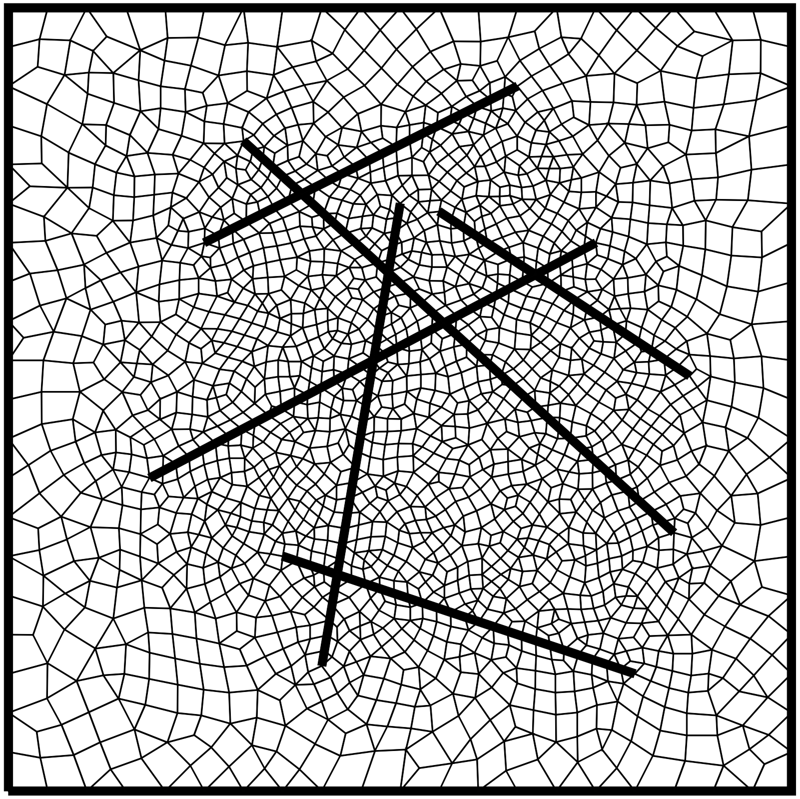
Computational Stencil

Verification Case

Geometry



Mesh



ϕ

Verification Case – cont.

- Dimensionless variables are used:

$$\tilde{x} = \frac{x}{L^*} \quad \tilde{y} = \frac{y}{L^*} \quad \tilde{h} = \frac{h}{L^*} \quad \tilde{\varphi}_\alpha = \frac{\varphi_\alpha}{P^*} \quad \tilde{t} = \frac{t}{T^*} \quad \tilde{\mathbf{K}} = \frac{\mathbf{K}}{K^*} \quad \tilde{u} = \frac{u}{u^*}$$

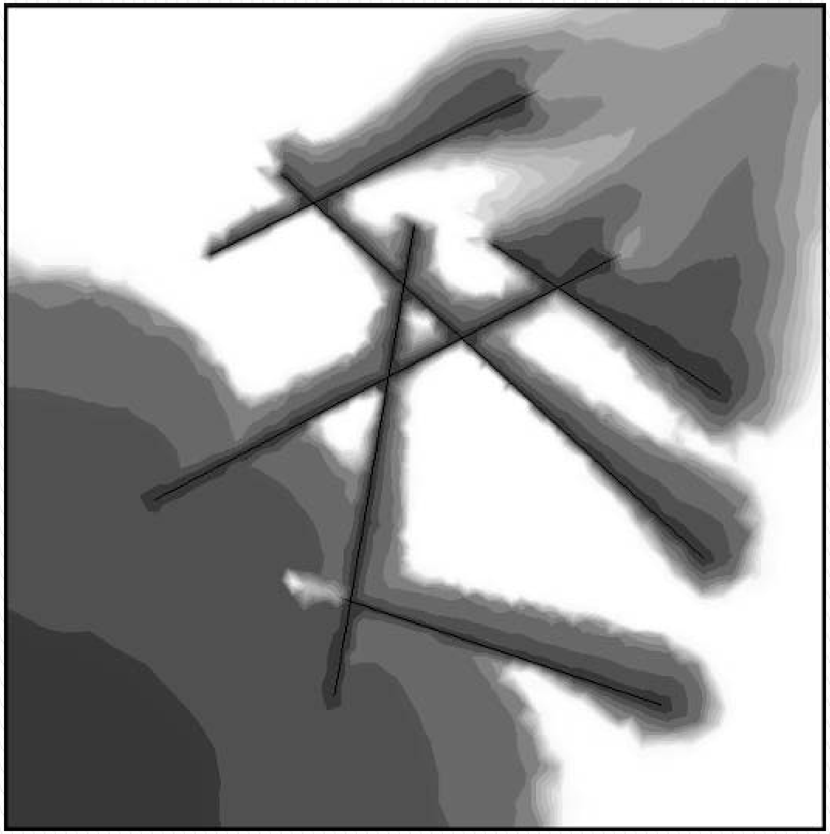
$$\mathcal{M} = \frac{\mu_o}{\mu_w} \quad \mathcal{N} = \frac{L^* \mu_w}{P^* K^*} \cdot \frac{L^*}{T^*} \quad \mathcal{P} = \frac{L^* \mu_w}{P^* K^*} \cdot u^* \quad \mathcal{G} = \frac{(\varrho_o - \varrho_w) g L^*}{P^*}$$

- Properties of rock and fluids:

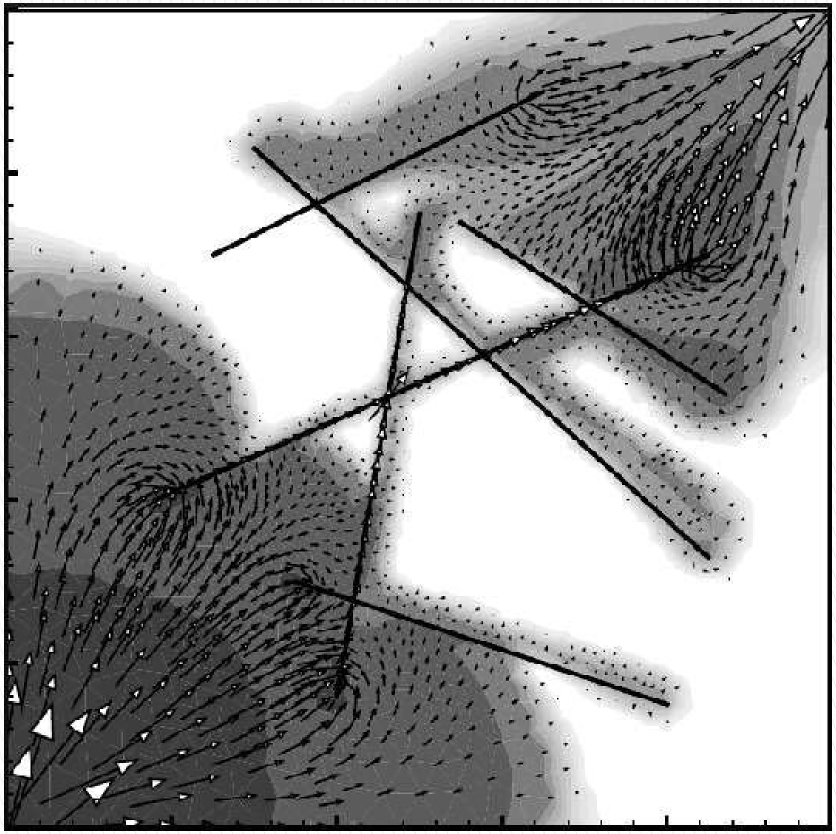
اعداد بدون بعد	ماتریس	ترک	مشخصه
M=0.45, N=P=198.2, G=-1.35	1	800000	K
جاذبه در جهت y	-0.3ln(S)	-0.04ln(S)	P_c
ضخامت ترک 4e-6	$0.2S^5$	S	k_{rw}
نرخ تزریق آب:	$0.6(1-S)^3$	1-S	k_{ro}
$q/(L^2/T)=0.02$	0.17	0.85	تخلخل

Verification Case – cont.

Water saturation profiles at 50 PV injection **no capillary pressure**



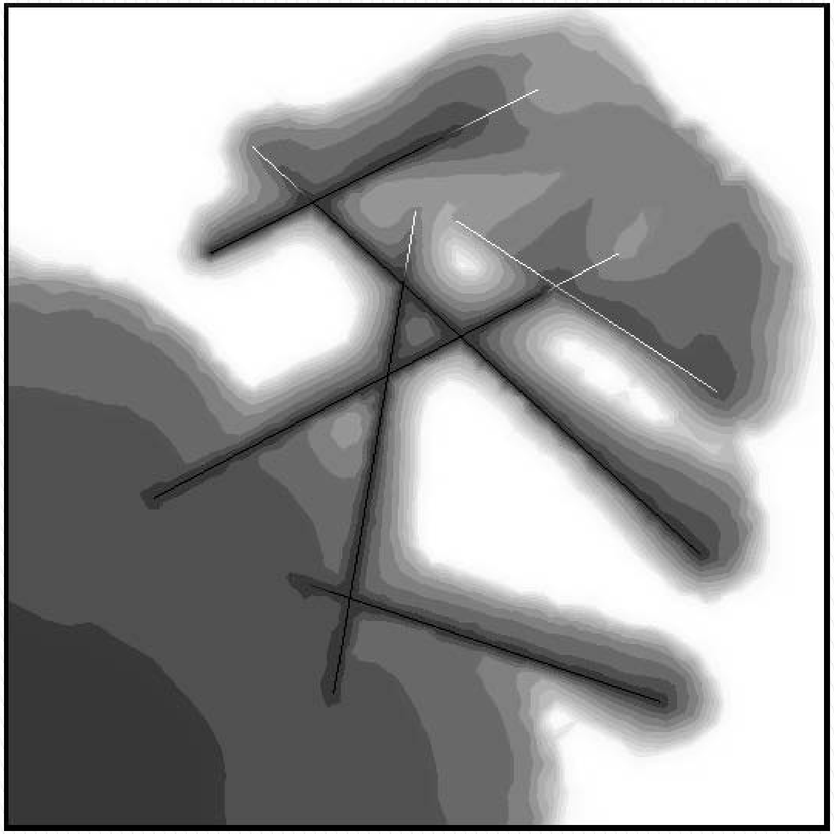
Our Method



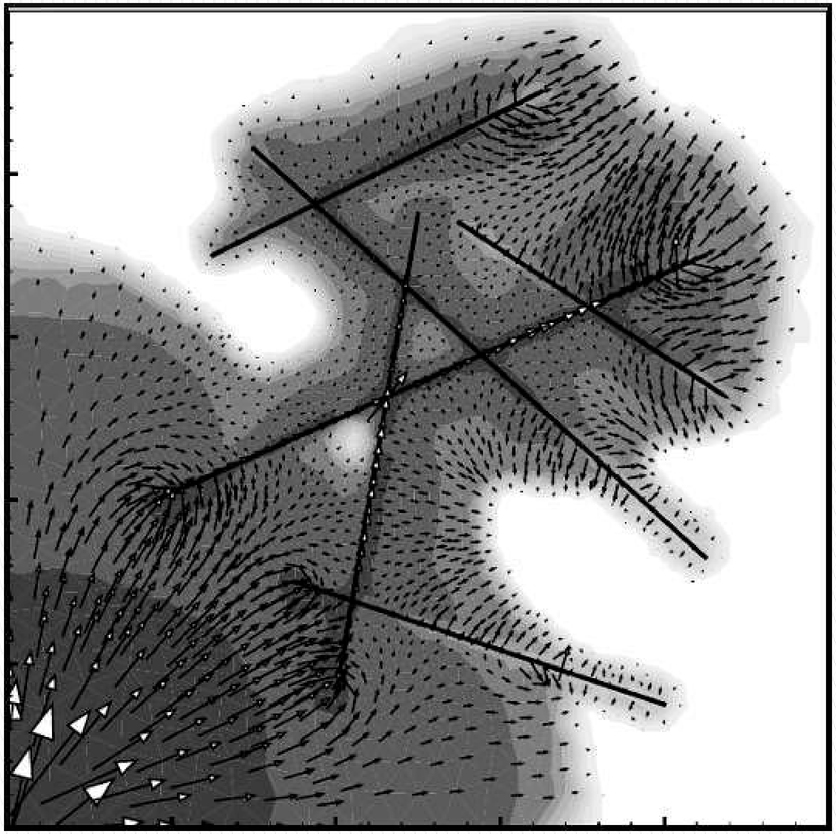
Reference (Hoteit)

Verification Case – cont.

Water saturation profiles at 50 PV injection **with capillary pressure**

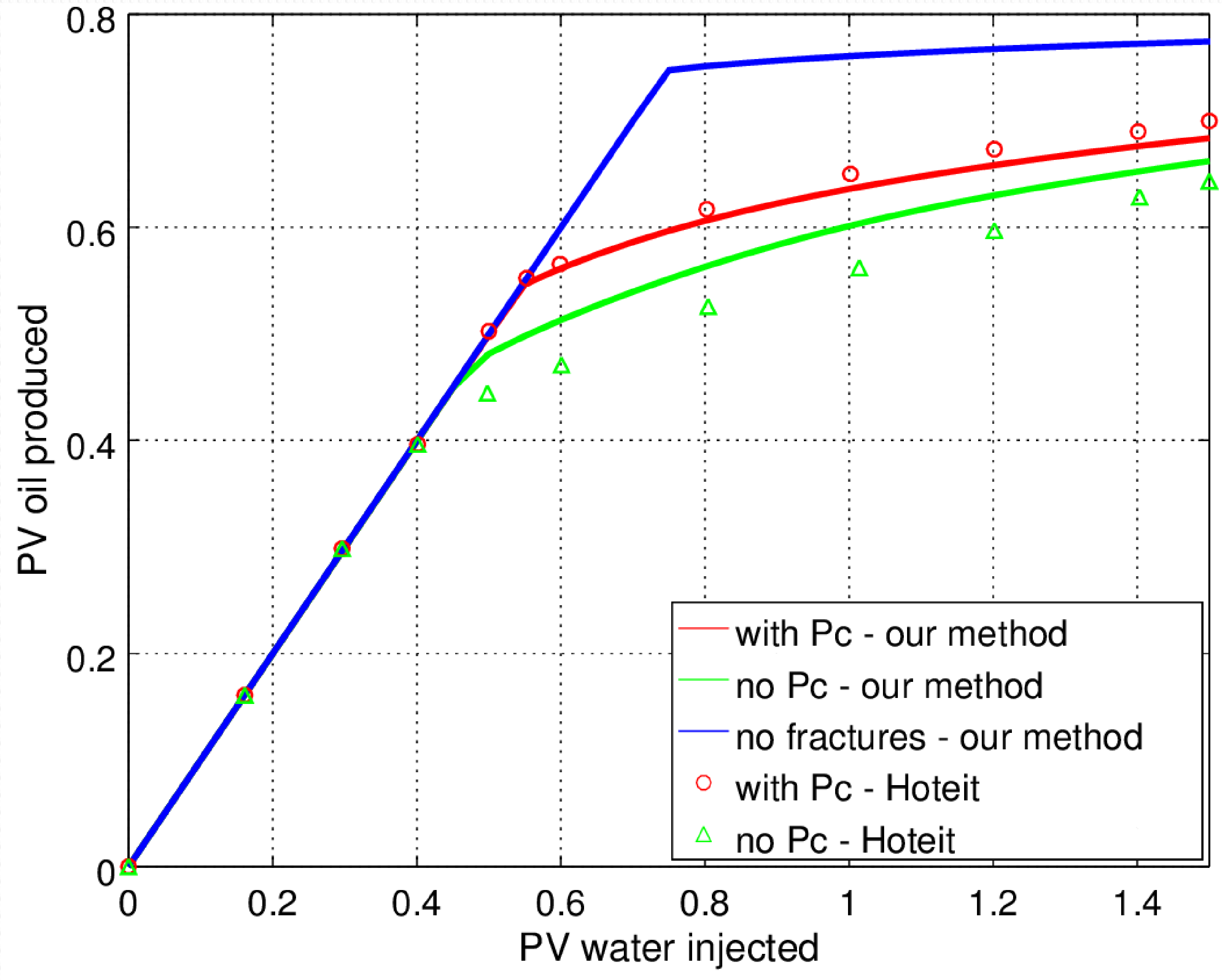


Our Method



Reference (Hoteit)

Injection – Production Curve



Future Work

- Improve the current transfer functions in dual continuum models.
- Combine the discrete solver with a dual solver.
- Investigate other numerical methods, which may produce cheaper yet more accurate results.
- More practical flow model, e.g. three-dimensional black-oil.

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