Modeling of Non-equilibrium Effects in the Gravity Driven Countercurrent Imbibition

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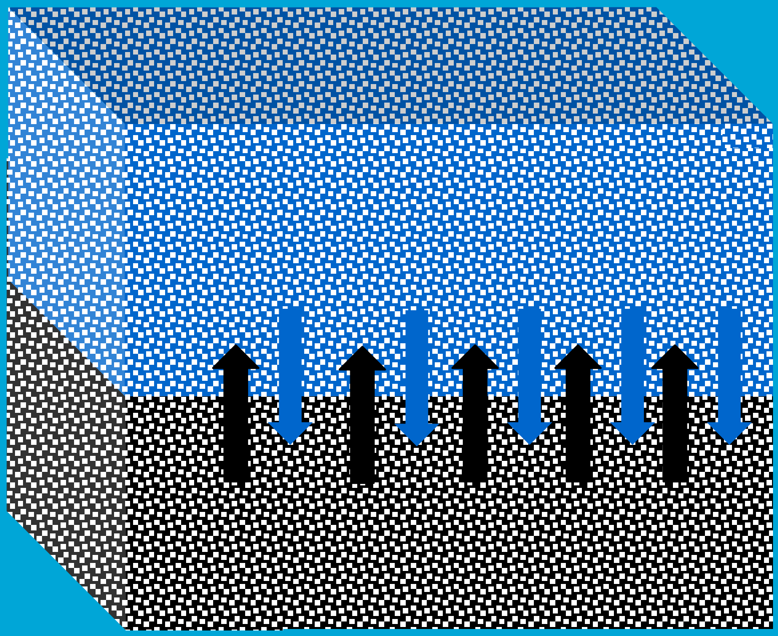
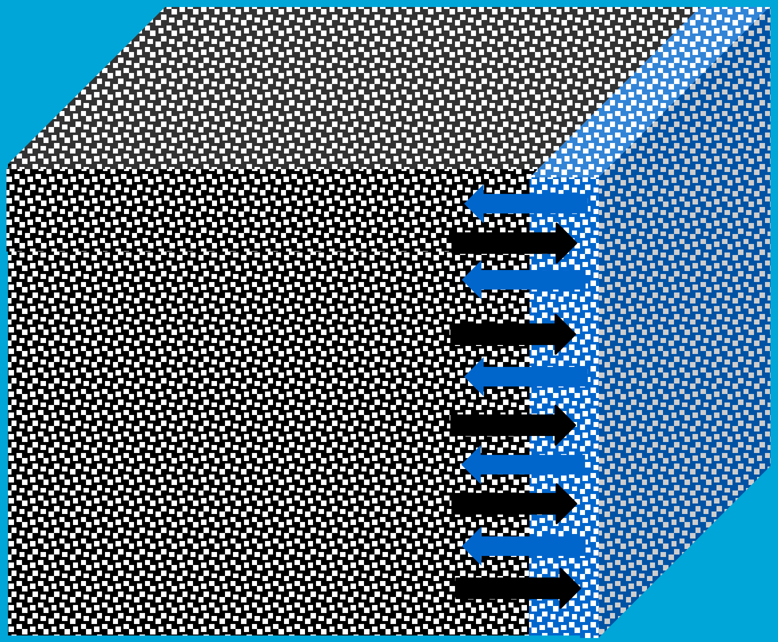
Introduction

- Countercurrent flow is a important mechanism in Fractured oil Reservoirs and secondary migration into reservoirs



Migration



Enhanced oil recovery in FR

Oil Water

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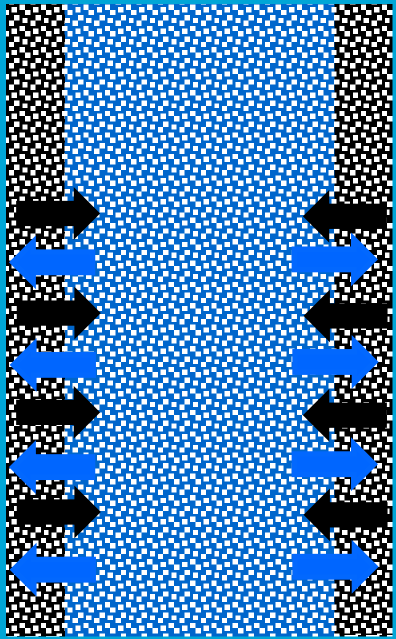
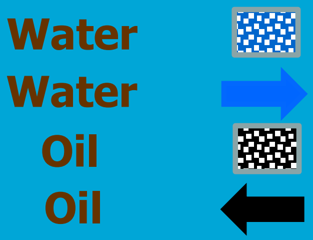
Introduction

- Conventional theories for multiphase immiscible fluid flow in porous media are established based on instantaneous equilibrium of phases.
- After displacement phases are not redistributed instantaneously.
- A non-equilibrium approach for capillary imbibition was developed by Barenblatt et al. (2003)





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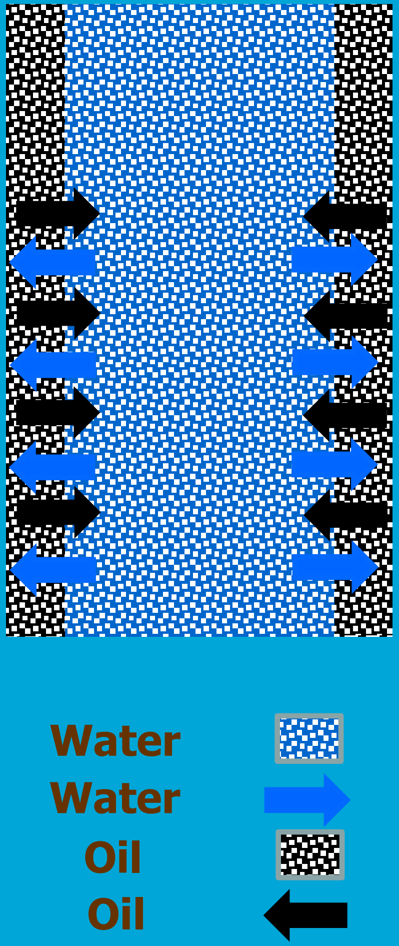
Barenblatt proposed

- The same constitutive relations (rel-perm + capillary pressure), but now with a dynamic saturation

$$\eta_w(z,t) = S_w(z,t) + \tau \frac{\partial S_w(z,t)}{\partial t}$$

instead of the static saturation S_w

- Example application for modeling of a gravity dominated fluid flow problem in porous media



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Mathematical Model; classical description with stationary saturation

$$a^2 \frac{\partial}{\partial z}\left(f_w(S_w(z,t))\ k_{ro}(S_w(z,t)) \frac{\partial J(S_w(z,t))}{\partial z} \right) - b^2 \frac{\partial}{\partial z}\left(f_w(S_w(z,t))\ k_{ro}(S_w(z,t)) \right) = -\frac{\partial S_w(z,t)}{\partial t}$$

$$a^2 = \frac{\sigma}{\mu_o}\sqrt{\frac{k}{\varphi}} \qquad b^2 = \frac{\Delta\rho g k}{\varphi \mu_o}$$

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Mathematical Model; non-equilibrium Model, effective water saturation, η_w

Nonlinear system of equations: time dependent model

$$\frac{\partial \eta_w(z,t)}{\partial t} + a^2 \frac{\partial}{\partial z}\left(\frac{\partial \phi(\eta_w(z,t))}{\partial z} + \tau \frac{\partial \phi(\eta_w(z,t))}{\partial t}\right)$$
$$-b^2\left(\frac{\partial \psi(\eta_w(z,t))}{\partial z} + \tau \frac{\partial \psi(\eta_w(z,t))}{\partial t}\right) = 0$$

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Mathematical Model

Initial condition:

nonlinear system of equations: stationary model

$$\eta_w{}^0(z) + \tau \frac{\partial}{\partial z} \left(a^2 \phi(\eta_w{}^0(z)) - b^2 \psi(\eta_w{}^0(z))\right) = S_w{}^0(z)$$

$$\phi(\eta_w(z,t)) = \int_0^{\eta_w(z,t)} f_w(u)\ k_{ro}(u) J'(u)$$

$$\psi(\eta_w(z,t)) = f_w(\eta_w(z,t))\ k_{ro}(\eta_w(z,t))$$

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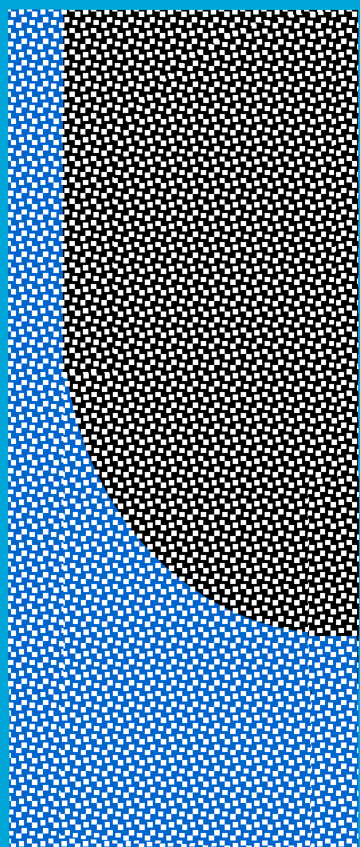
Case study:

Initial distribution of phases

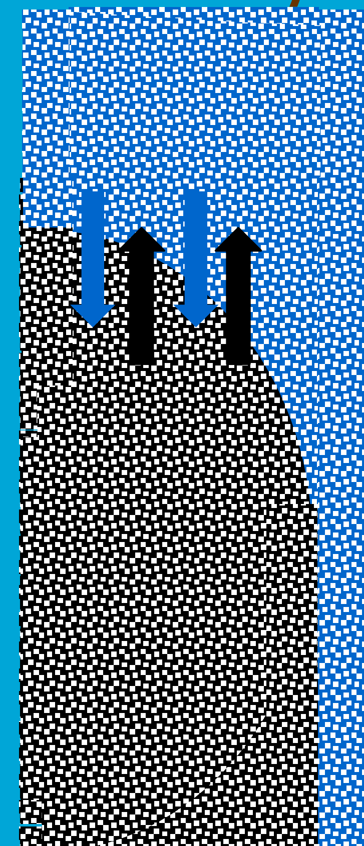


Water

Oil

A guaranteed countercurrent imbibition process

Turning the core 180 degree, vertically



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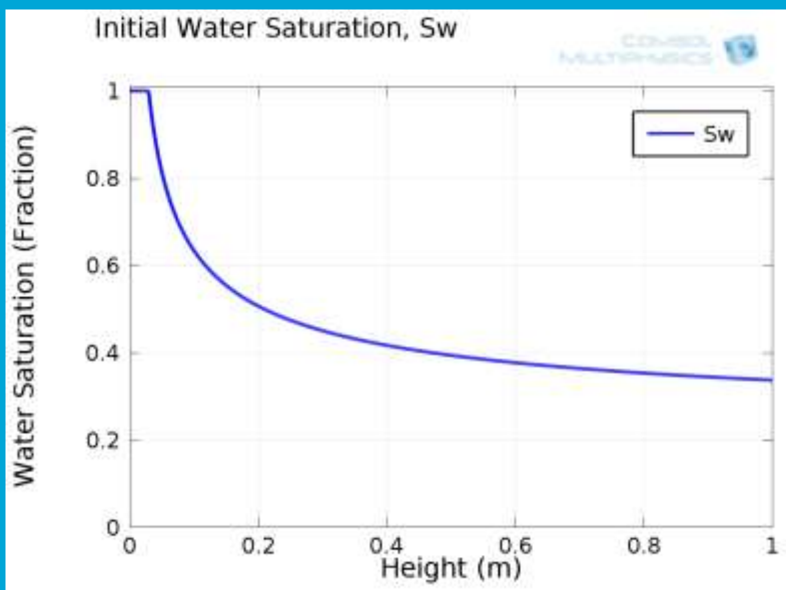
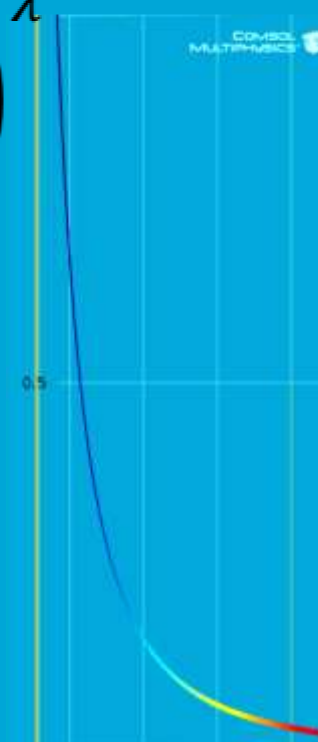
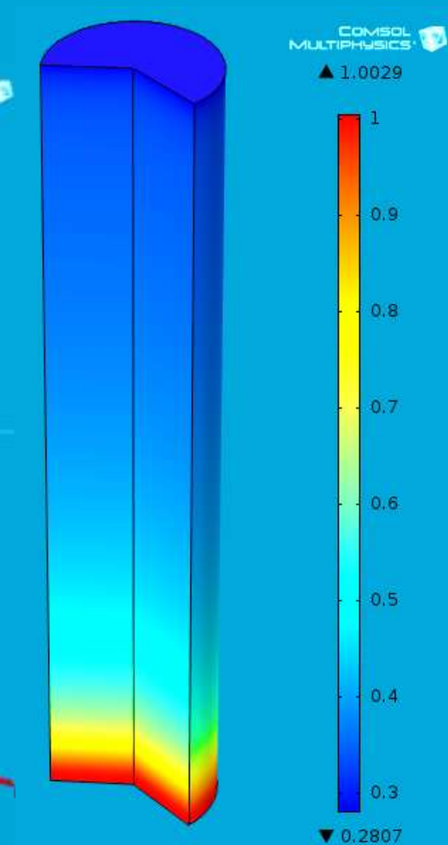
Initial distribution of static saturation, S_w

Gravity-capillary equilibrium for initial current saturation, S_w

$$S_w{}^0(z,t) = S_{wc} + \left(\frac{1}{2} - S_{wc}\right)\left(\frac{a^2}{b^2 z}\right)^{\lambda}$$

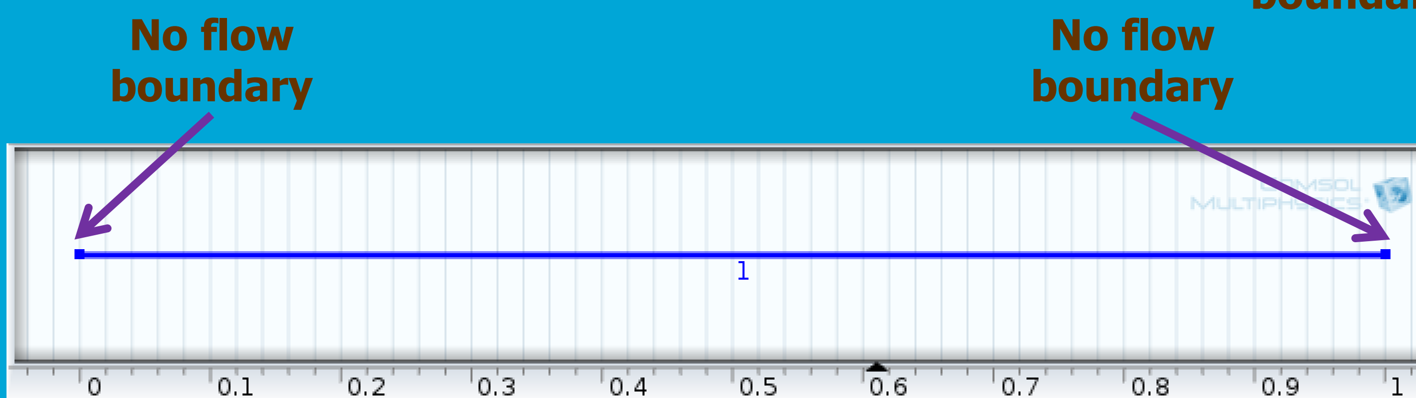


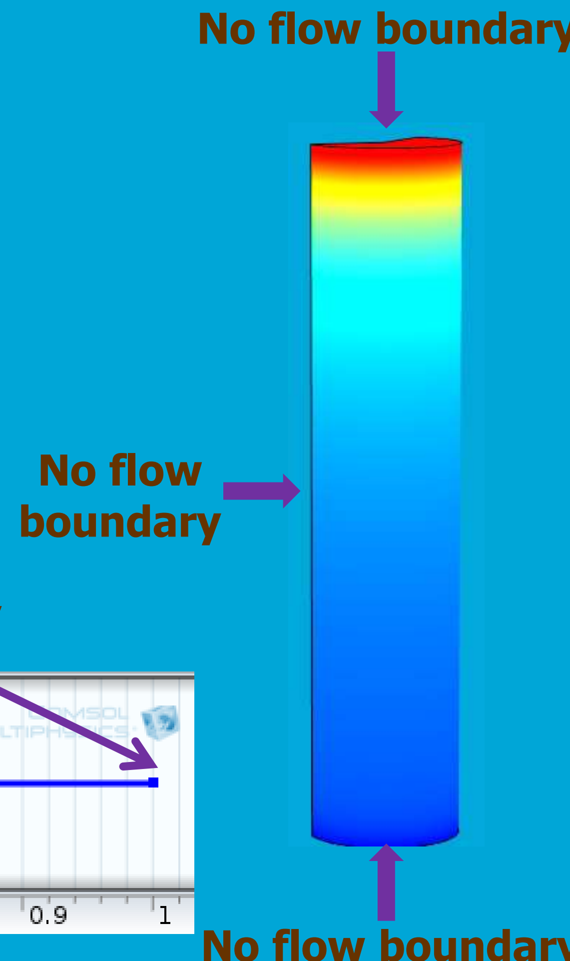




Boundary condition for effective water saturation, η_w

- No flow boundary at both ends and sides





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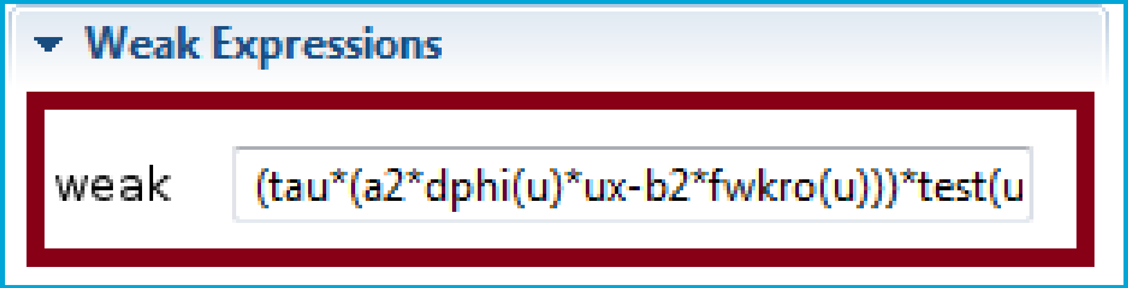
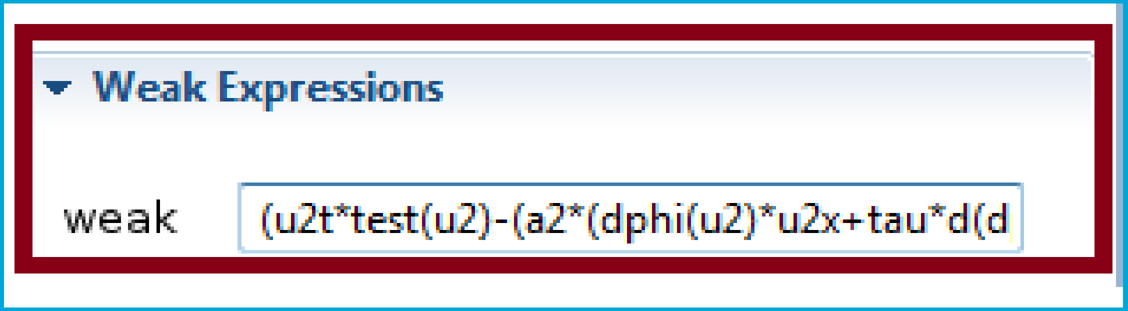
Equation-based modelling

- Weak From PDE, including a very small artificial diffusion coefficient





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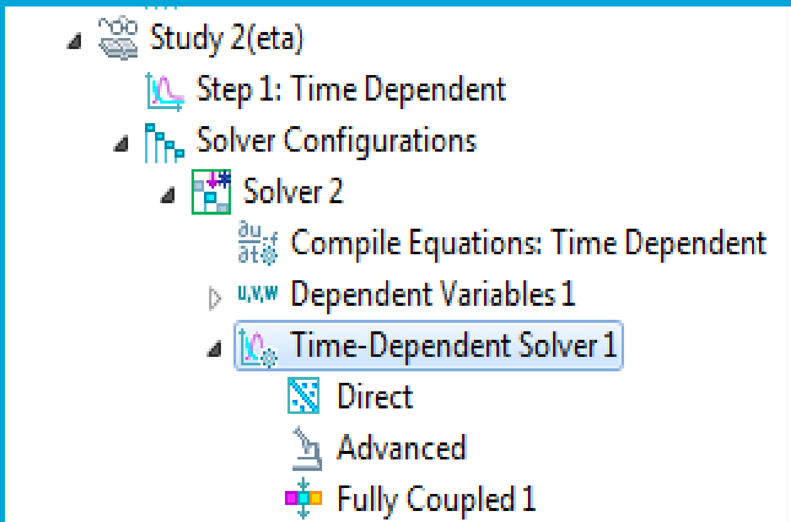
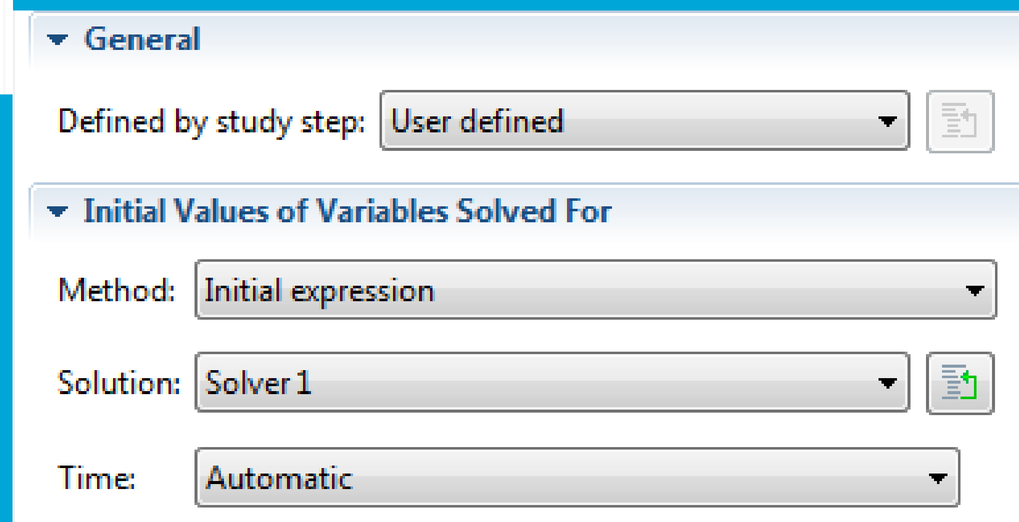
Equation-based modelling





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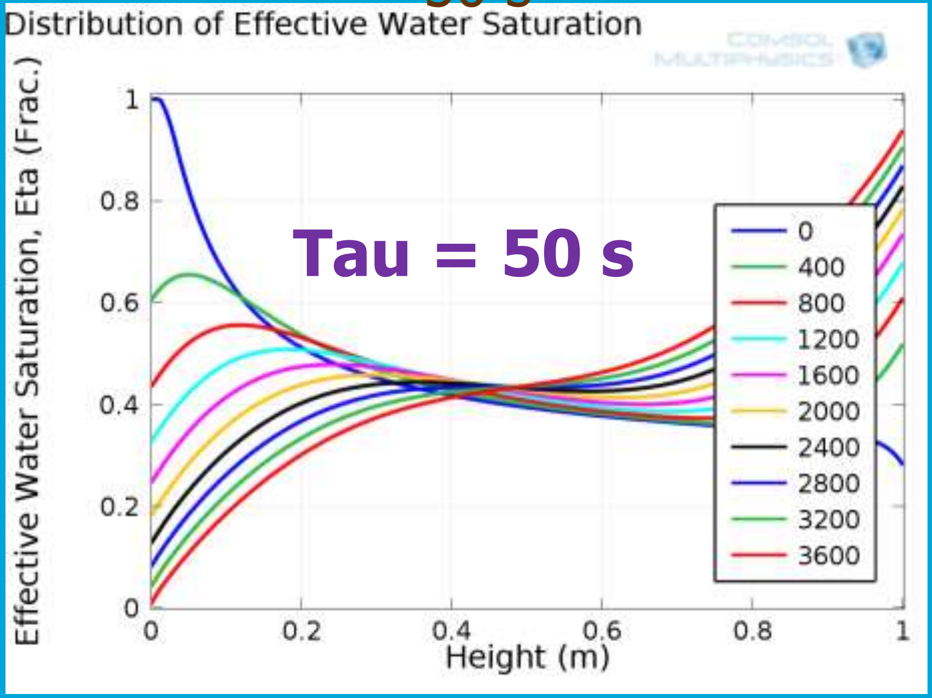
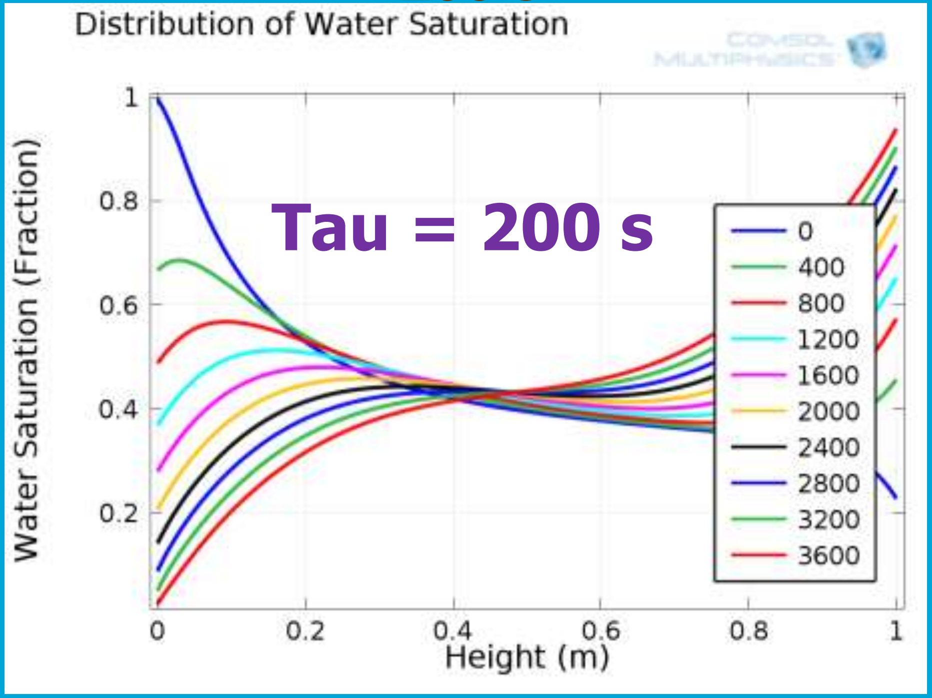
Results

Distribution of effective water saturation with relaxation time of 50 s



Distribution of effective water saturation with relaxation time of 200 s



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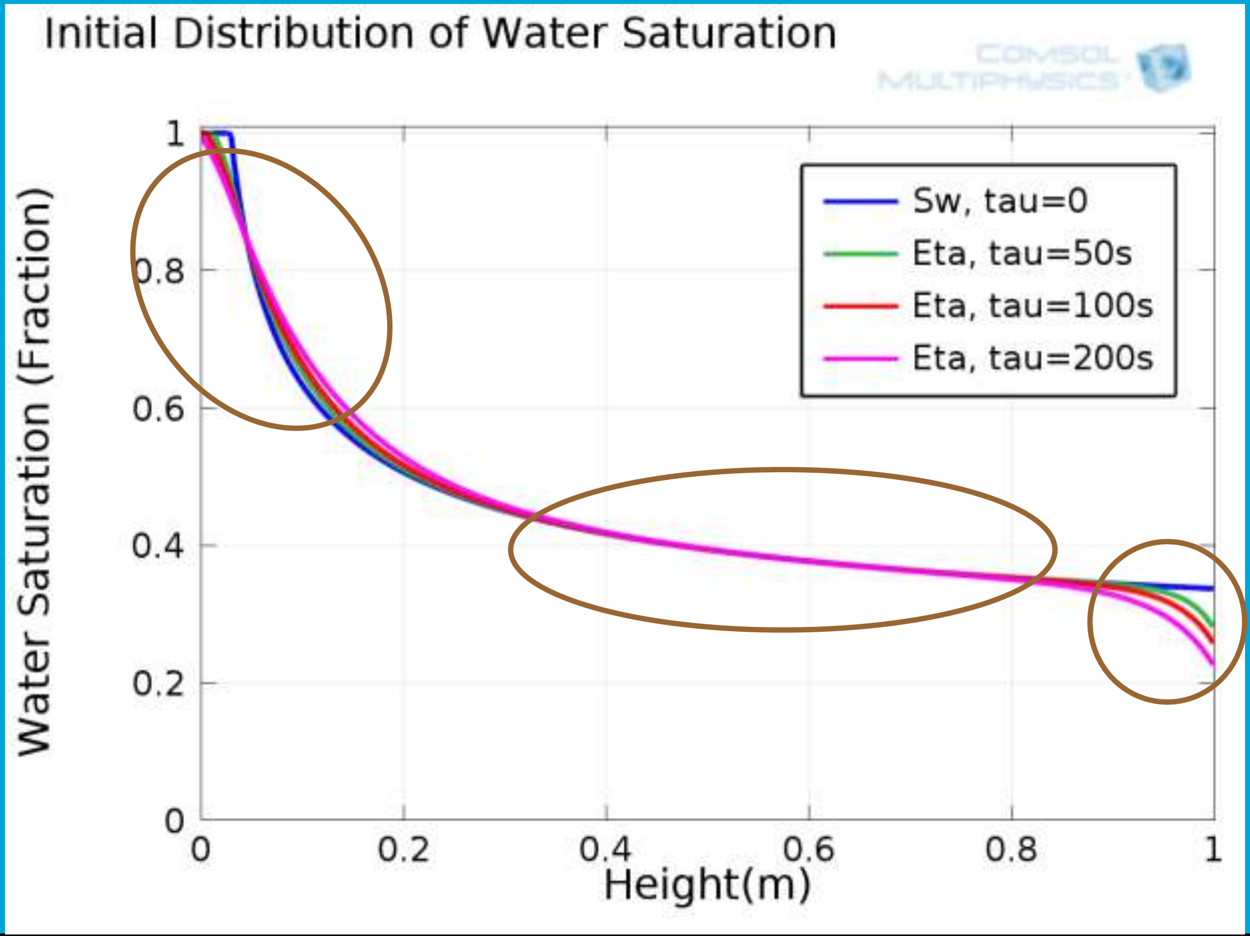
Results:
initial distribution differs for different relaxation time



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Conclusion

- The procedure can be used as a basis for quantifying recovery from fractured media

- This formulation can be used for both capillary and gravity dominated enhanced oil recovery processes like ultra-low IFT method.

- Developing a relaxation time as a function of saturation rate may improve the model.

Thanks for your attention

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