CUSP West

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PREMIER COREX

The Advantages of Unsteady-State Relative Permeability for CCUS

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What is relative permeability (Krel) and why is it important?

- Krel is the permeability of rock to one fluid in the presence of another immiscible fluid, relative to the absolute liquid permeability of the rock. These vary as fluid sat changes.
- Relative permeability strongly affects CO_2 injectivity, plume migration, and AoR.
- Lab measurement of Krel is included in the EPA guidance for Class VI well site characterization.
- Should be conducted at reservoir temp and pressure using super-critical CO_2.
- Two primary methods; Steady-state and Unsteady-state

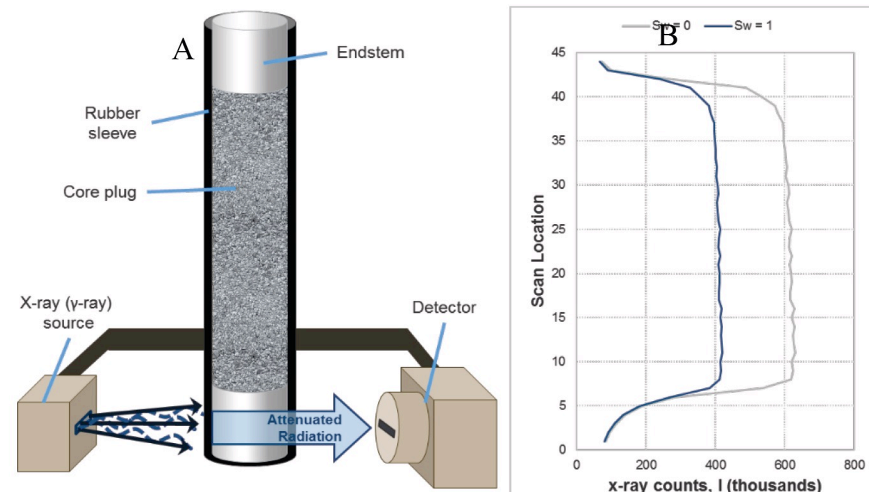
Steady-State Relative Permeability

Basic procedure

- Assemble composite sample (multiple short plugs end to end)
- Saturate – formation water
- Brine permeability
- Increase T & P to required test conditions
- Brine permeability
- Replace brine with carbonated brine
- Brine permeability
- Simultaneous injection of scCO2 & Water
- Controlled fractional flow, multi-rate
- X-ray scanning to show capillary end effects

Often requires high flow rates and differential pressures.

In-situ saturation monitoring (ISSM) with X-ray scanner

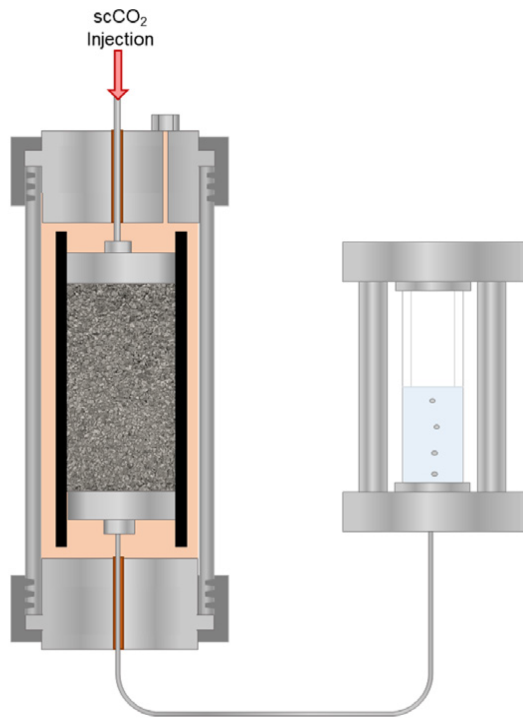


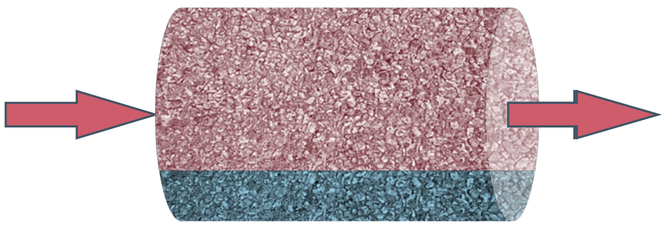
Unsteady-State Relative Permeability

Basic procedure

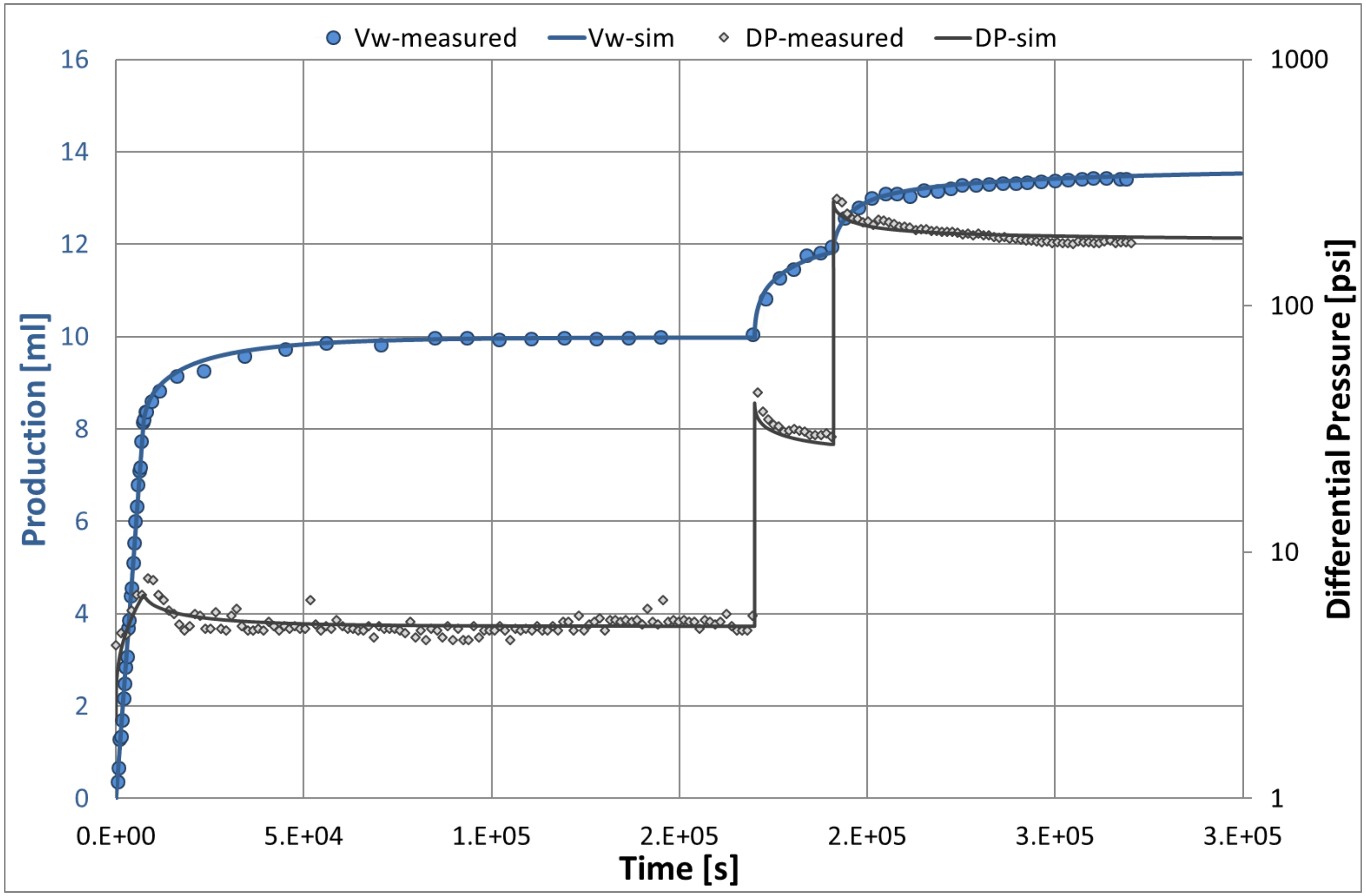
- Saturate – formation water
- Brine permeability
- Increase T & P to required test conditions
- Brine permeability
- Replace brine with carbonated brine
- Brine permeability
- Begin initial injection - equilibrated CO2
  - at reservoir equivalent advancement rate
- Bumpflood 1
- Bumpflood 2
- Bumpflood 3

Multi-rate Unsteady State



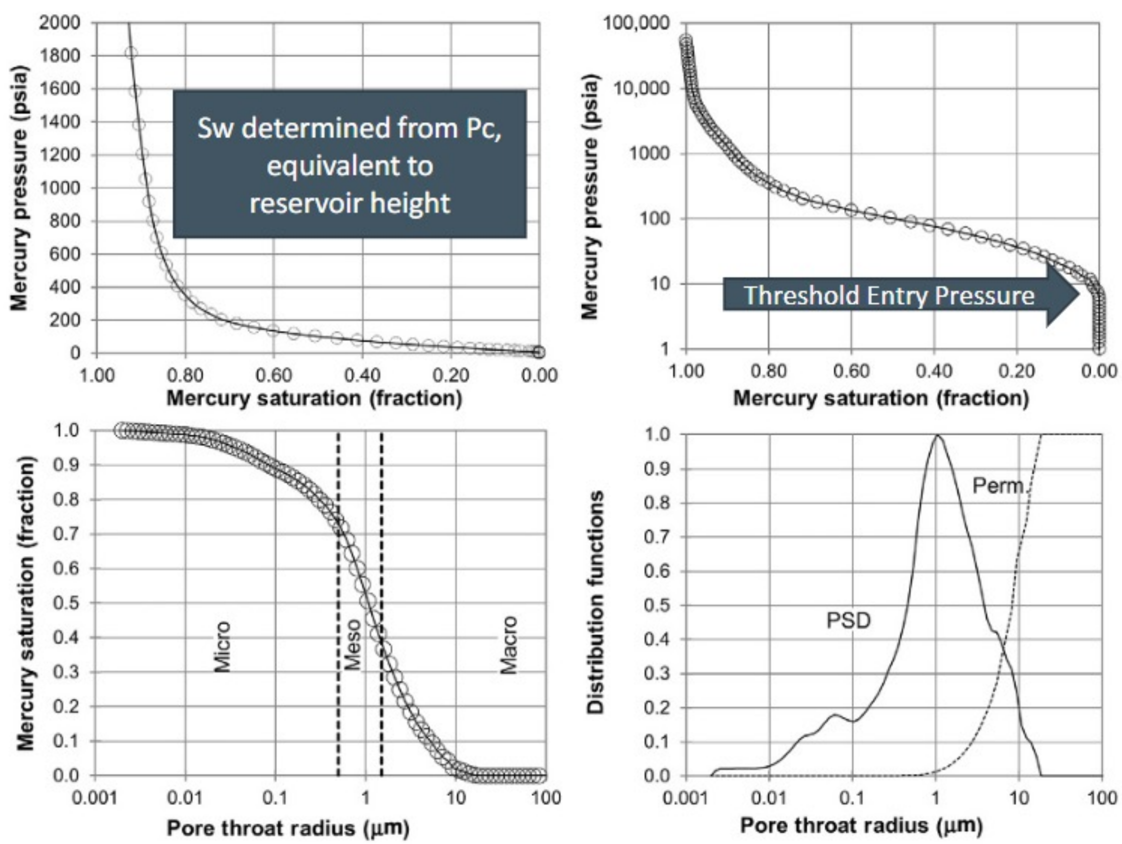


Multi-rate unsteady-state water production data



Capillary pressure conversion (air-Hg to scCO2-brine)

MICP- mercury injection capillary pressure

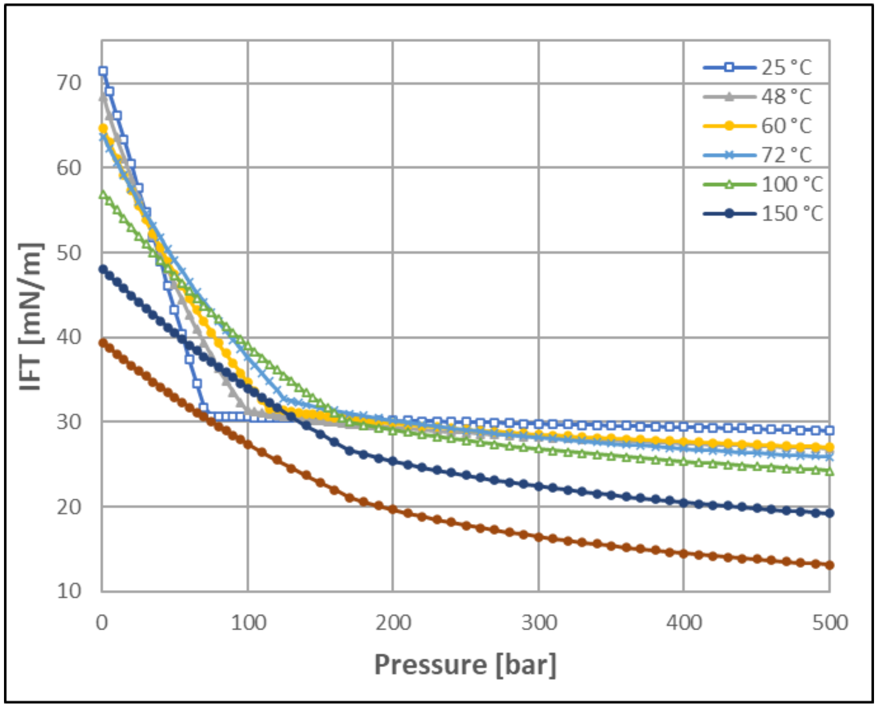


- MICP is quick, cheap and reliable method to obtain drainage capillary pressure estimate
- Very useful for input to pre-simulations to estimate possible test outcomes and optimise test parameters
- Requires correction for fluid pair
  - Young-Laplace equation

$$Pc_{CB} = Pc_{AHg}\,\frac{(\sigma\ cos\theta)_{CB}}{(\sigma\ cos\theta)_{AHg}}$$

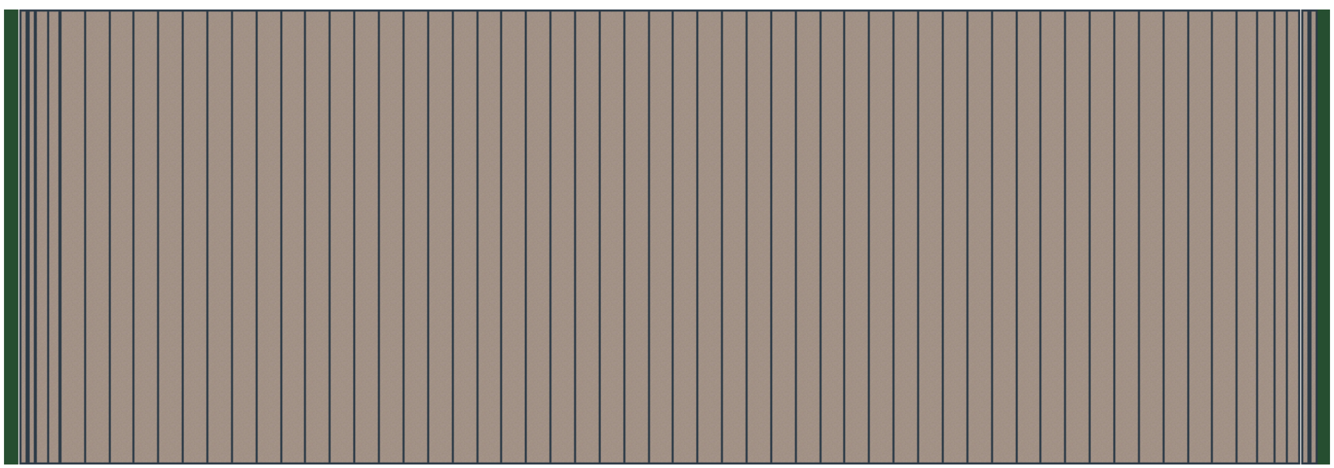
Capillary pressure conversion (air-Hg to scCO2-brine)

- CO_2-brine IFT and contact angle are changing with pressure and temperature
- These are measured prior to running relative perm tests



Reservoir simulation for core floods

- Finite element numerical code
- 30 – 200 grid blocks
- Input fluid viscosities, capillary pressure, surface tension, contact angle at test conditions
- Refines model towards inlet/outlet
  - Finer scale description of capillary end effects



Reservoir simulation software for core floods

SCA2016-006 – Benchmark Analysis – Good comparison

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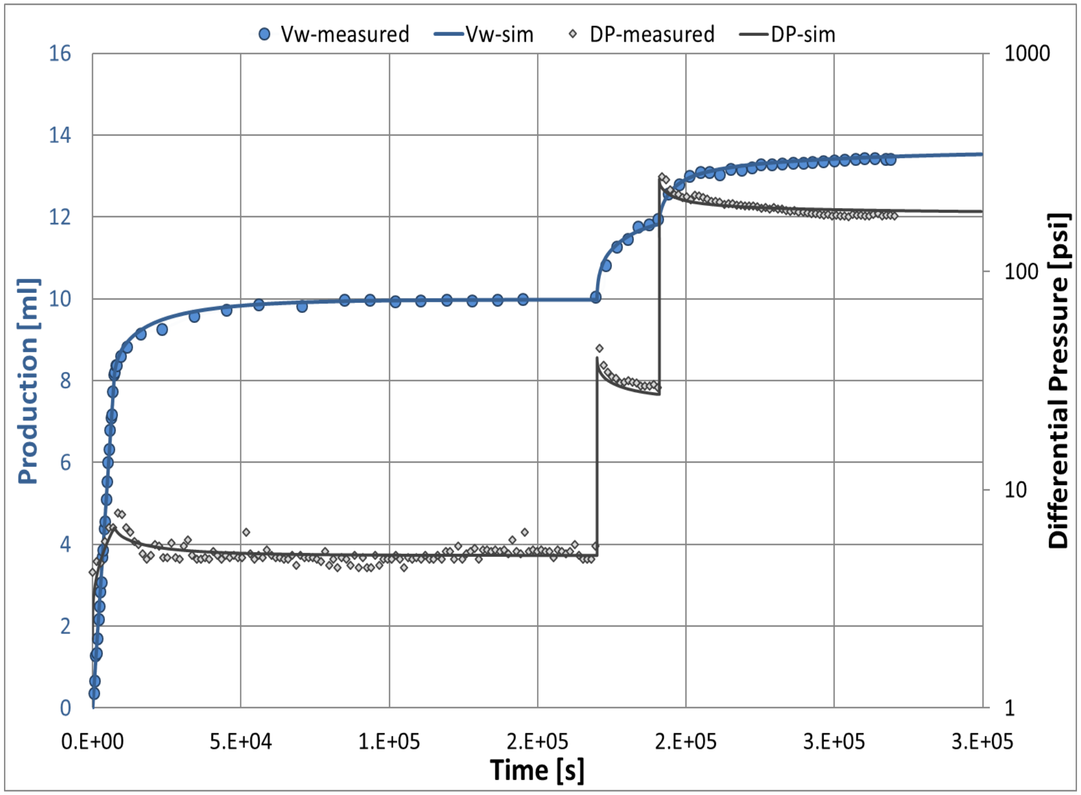
CYDAR

SENDRA

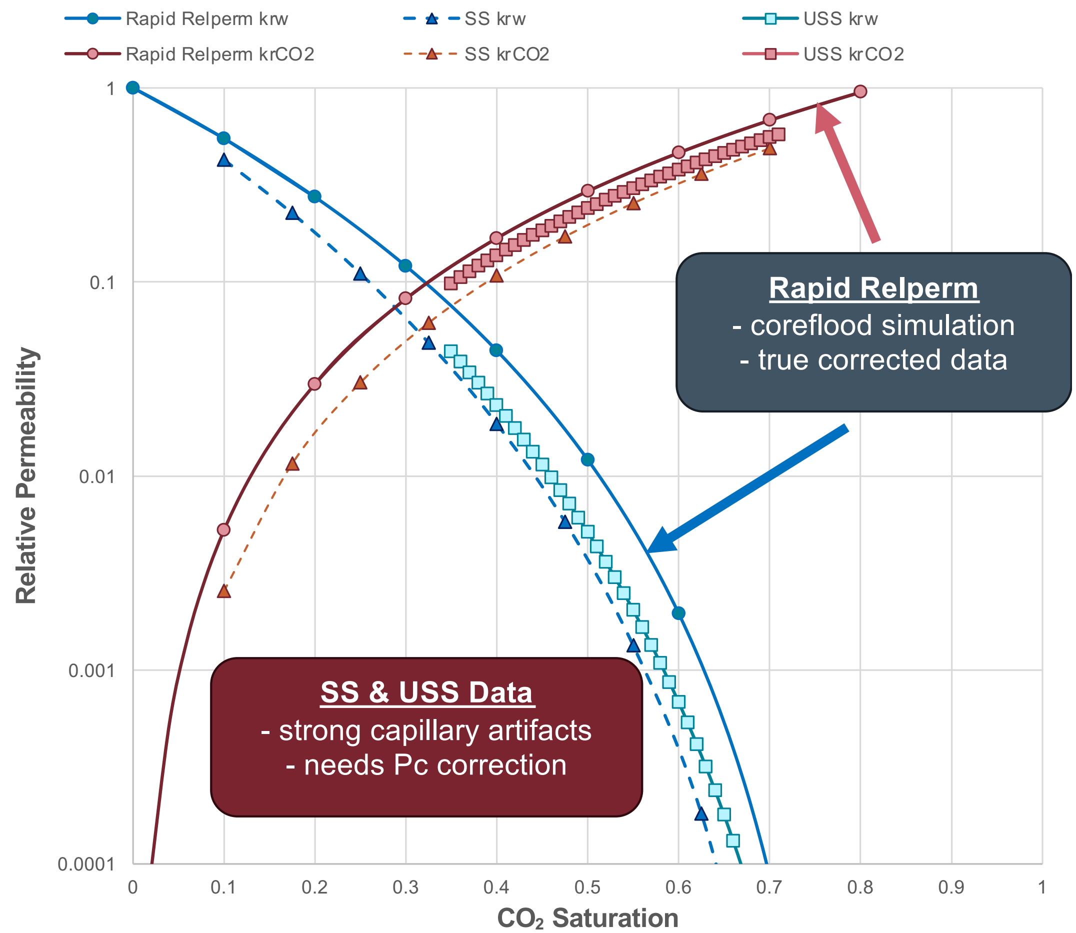
Coreflood Simulation- Multi-rate Unsteady State

- Simulation uses capillary pressure + production data vs time
- History match to laboratory production data
  - Volumes vs time
  - Differential pressure vs time
  - Bumpflood volumes and pressures vs time



Coreflood Simulation: capillary-pressure corrected relative perm curves

- SS and USS data points are both incorrect due to capillary end effects
- Core flood simulator corrects data for both
- Corrected USS curves closely follow trend and shape of pre-breakthrough SS data



Multi-rate Unsteady State Tests

- Advantages
  - Appropriate Buckley-Leverett flow, corrected for cap end effects.
  - Similar injection rates as in the actual reservoir
  - Faster testing (less expensive and/or more samples)
  - Shorter samples (easier to obtain from whole core)
  - No X-ray based saturation scans
  - Reduced potential for clay and fines migration issues
    - lower flow rates and throughput compared to SS
- Disadvantages
  - Capillary boundary effects must be corrected using simulation
  - Only post-breakthrough data are used for relative perm calculations
    - However, injection of lower viscosity, non-wetting phase ($scCO_2$) → early breakthrough and larger saturation range described
    - And multiple rates (bump-floods) increase the saturation range measured

Final thoughts

- Relative permeability is a critical input to CCUS system performance models and EPA Class VI well permit evaluations.
- Tests should be conducted at in-situ reservoir conditions using representative injection-zone samples.
- Laboratory systems with super-critical CO2 capability are complex and costly to build and operate.
- Steady-state relative perm systems with X-ray/gamma scanners are especially challenging.
- Multi-rate unsteady-state systems are less complex, faster, and less costly.
- Shorter sample lengths for USS are readily available from 4" dia whole core.
- EPA guidelines do not favor either SS or USS methodology.
- EPA guidelines do suggest "a number of core samples should be analyzed to capture heterogeneity".
- Less costly tests can be run on more samples.

Thank you.

Any Questions?

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Relative Permeability and Capillary Pressure Tables
Saturations and kr values are fractions. The pressure unit (Table PC (J-function)) is NOT used if Leverett-J is "on". Make sure that Scw and Sor are consistent across the Tables!

Fractional Flow Time Table
Specify time (and unit) since start of experiment and water flow fraction fw (between 0 and 1).

Sw	Krw
0.15	0.0
0.18	3.00E-05
0.25	1.00E-03
0.5	0.05
0.72	0.2
0.8	0.3

Empty table

Sw	Kro
0.15	0.7
0.2	0.47
0.3	0.1
0.62	1.00E-03
0.72	2.00E-05
0.8	0.0

Empty table

Sw	Pc (or J function)
0.15	1
0.18	0.0
0.2	-0.1
0.75	-0.15
0.8	-1

bar

Empty table

Time	Fw
0.0	0.0
2.	.05
6	.1
10	.3
14	.5
18	.7
24	.9
29	.95
34	1.

hour

Empty table

Simulator Control Data

Flow rate total:	1.	cm3/minute
End of Experiment:	58	hour
Start Time Step:	.1	s
Max change Saturation:	.02	(Fraction)
Max change Pressure:	.1	bar
Max Time Step:	1000	hour
Max Time Step Increment:	1.2	(Factor)
Current date:	4/8/2021 22:41	
Project name:		

Submit your project or go to next project.
Your input will be stored and is available in your account link under "Your Free Experiments" .
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