Unconventional Reservoir Engineering Project

Colorado School of Mines
November 14, 2014
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NITEC Research Topics

- Pore Size Related Issues
- Hydrodynamic Equilibrium In Black Oil Simulators
- Development of n-Porosity Simulator

In this presentation,

- items that are colored in green show completed work as of November 1, 2014
- Items that are colored in black reflect future work

Pore Size Related Issues

- Compositional Variation due to Nano-filtration
  - Filiz Geren, Tuba Firincioglu
- Chemical and Physical Equilibrium
  - Elham Parsa (Theoretical), Xylong Lin (Experimental)
- Diffusion and Osmotic Pressure
  - Diffusion code has been implemented
  - Osmotic pressure will be included after the laboratory and modeling work

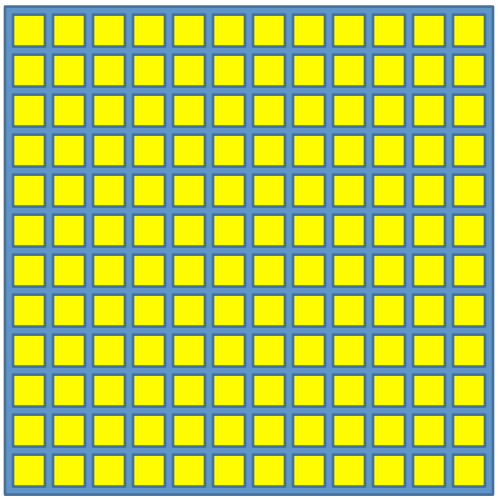
Hydrodynamic Equilibrium

- COZSim Enhancements
  - All tasks are completed
- COZView (Pre-Post Processor) Enhancements
  - Simplified simulation model building for single-porosity cases
  - Post-processing for history matching
  - Post-processing of new arrays

n-Porosity Simulator

- COZSim Enhancements
  - Dual-Porosity formulation
  - n-Porosity formulation
  - Connectivity map of pore size bins
  - Automated pore size bin creation based on Pc (ongoing, today's presentation)
- COZView Enhancements
  - Post-processing for n-Porosity models

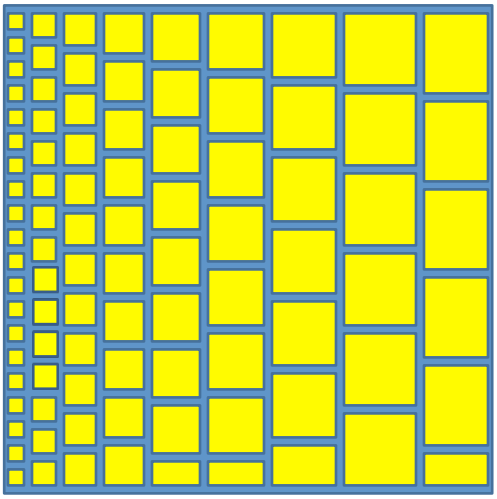
Dual-Porosity Systems



In existing simulators, dual porosity formulation assumes that ALL of the matrix can be represented as uniform blocks in continuum.

This formulation assumes that all of these uniform blocks have the same pore size distribution and pore throat size distribution, and can be represented using a single saturation value and a single capillary pressure value.

Multiple-Porosity Systems



Instead of assuming uniformly distributed matrix, what if we distribute the pores and the pore throats based on capillary pressure function?

We should have many matrix blocks that represent small pores and few matrix blocks that represent large pores.

n-Porosity Simulator

In May 2014 meeting, we introduced the concept of automated pore size bin creation.

In this (November 2014) meeting, we will discuss the concept and seek feedback. Code development will commence upon completion of this discussion.

n-Porosity Simulator

Objectives of this task:

1. Distribute the Swirr among bins
2. Develop Pc-drainage for each bin
3. Distribute Sorw among bins
4. Develop Pc-imbibition for each bin
5. Develop Kr-drainage for each bin
6. Develop Kr-imbibition for each bin
7. Calculate permeability of each bin
8. Decide on Lx, Ly, Lz for each bin
9. Distribute bulk volume to each bin

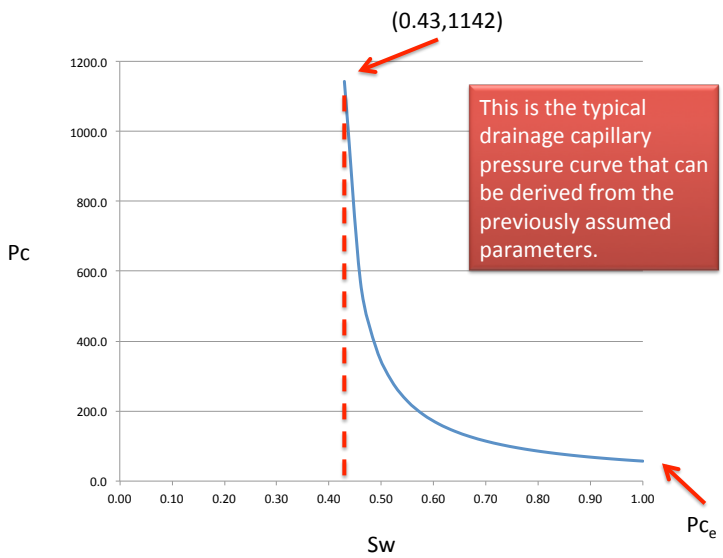
n-Porosity Simulator

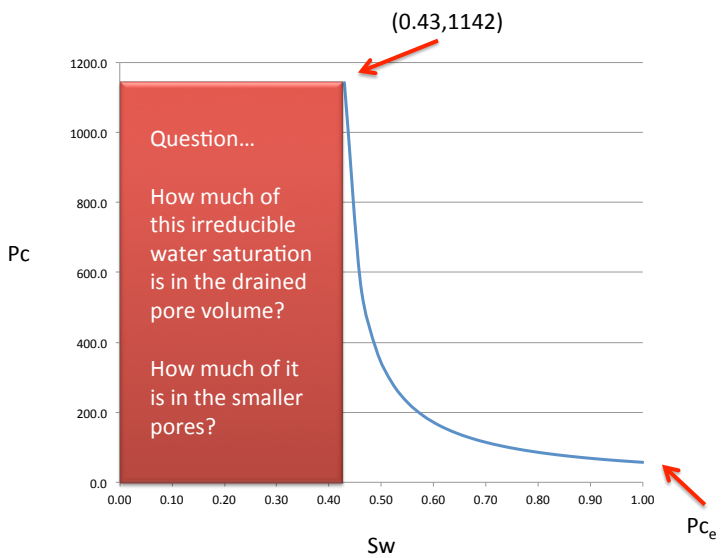
For a matrix block in a dual-porosity environment:

assume $\phi = 0.06$
using $\log k = 0.2\,\phi - 3.5$ → $k = 0.325\ \mu D$
using $Pc_e = 2.3\ k^{-0.4}$ → $Pc_e = 57.1$ psi

assume $\lambda = 1.0$
assume $Sw_{irr} = 0.40$

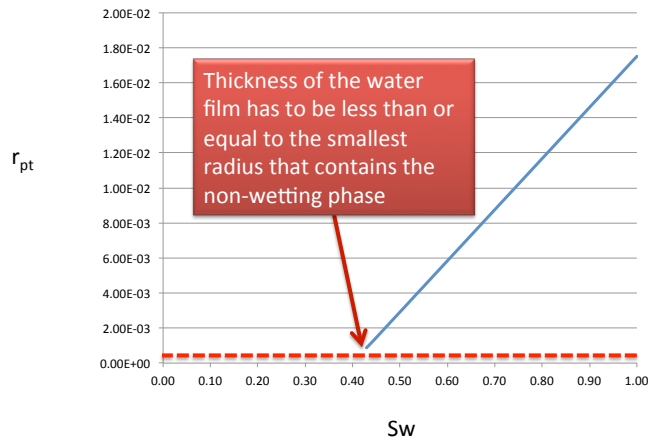
Objective is to develop Pc versus Sw
using $Pc = Pc_e\,(Sw^*)^{-1/\lambda}$
where,
$Sw^* = (Sw - Sw_{irr}) / (1 - Sw_{irr})$


(0.43,1142)
This is the typical drainage capillary pressure curve that can be derived from the previously assumed parameters.
Pc
Sw
Pc_e
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00


(0.43,1142)
Question…
How much of this irreducible water saturation is in the drained pore volume?
How much of it is in the smaller pores?
Pc
Sw
Pc_e
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

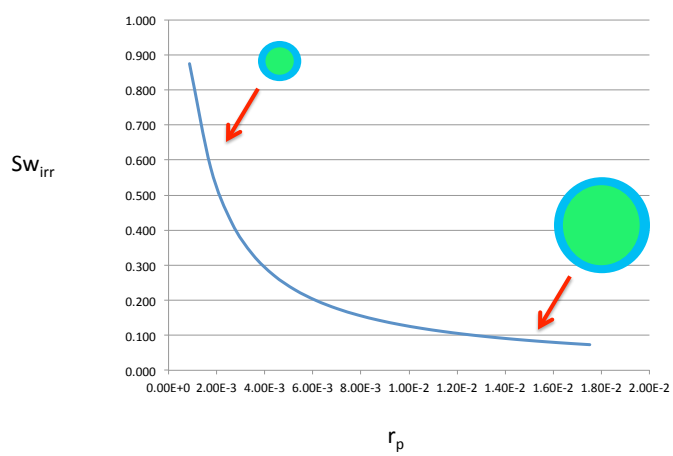
Let's convert Pc to r_{pt} and plot against Sw

r_{pt} = constant / Pc r_{pt} is pore throat radius

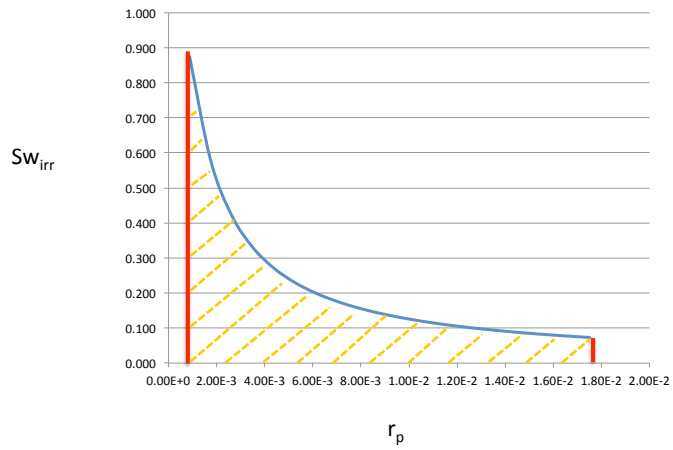


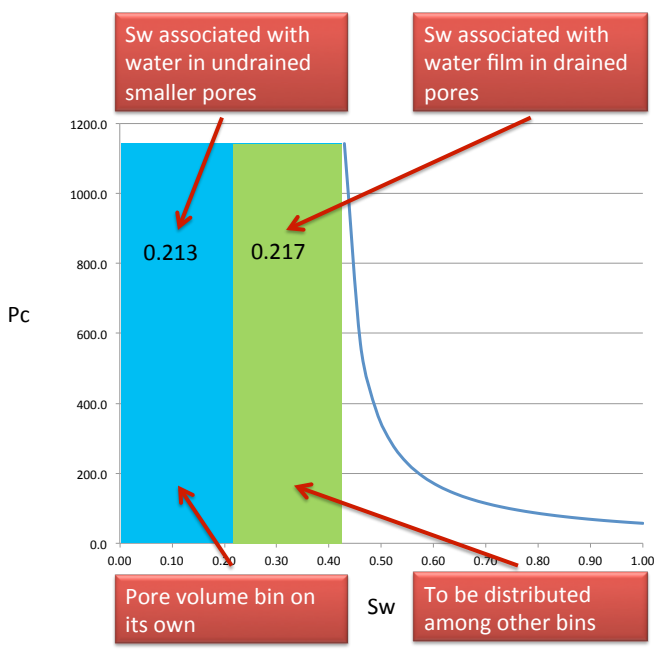
Let's convert the same information to Sw_{irr} versus r_p

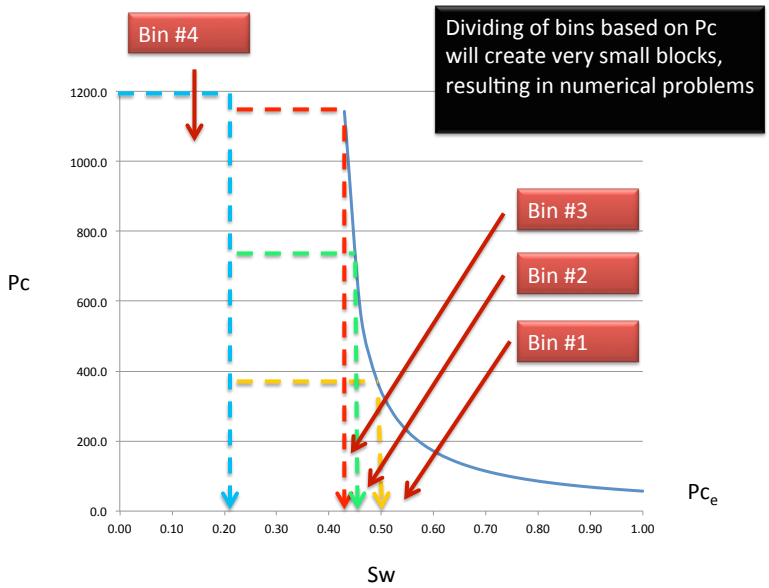
Assume r_p is proportional to r_{pt} r_p is pore radius

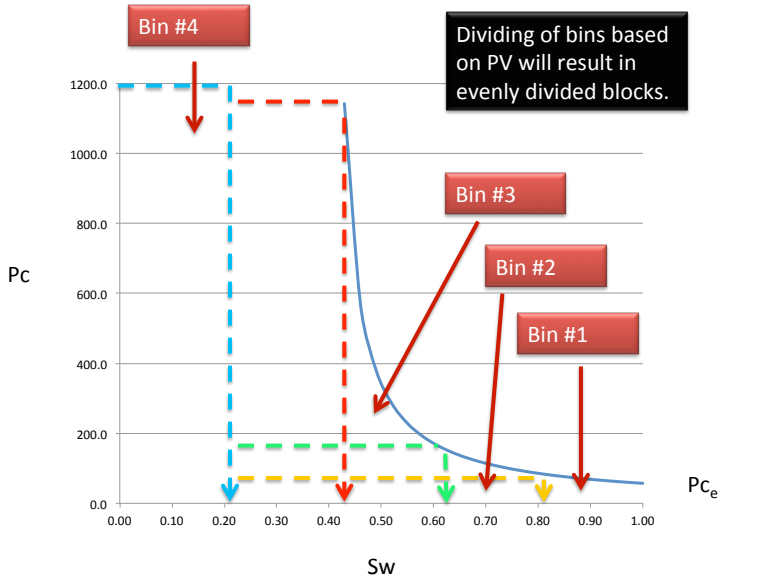


Integrating the curve yields Sw_{irr} = 0.217 (in this example)

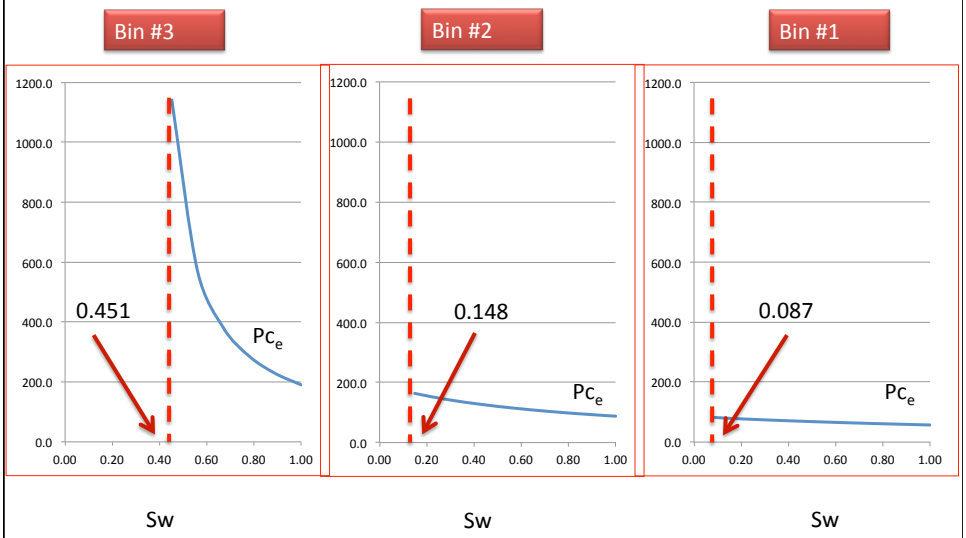





Bin #4
Dividing of bins based on Pc will create very small blocks, resulting in numerical problems
Bin #3
Bin #2
Bin #1
Pc
Pc$_e$
Sw
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00


Bin #4
Dividing of bins based on PV will result in evenly divided blocks.
Bin #3
Bin #2
Bin #1
Pc
Pc$_e$
Sw
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00

Pc curves for the first three bins
(the fourth bin is 100% water)

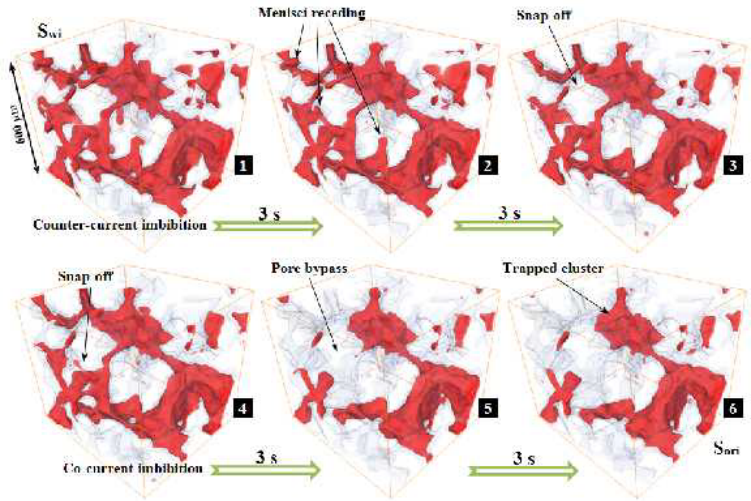


n-Porosity Simulator

Objectives of this task:

1. Divide the Swirr among bins
2. Develop Pc-drainage for each bin
3. Divide Sorw among bins
4. Develop Pc-imbibition for each bin
5. Develop Kr-drainage for each bin
6. Develop Kr-imbibition for each bin
7. Calculate permeability of each bin
8. Decide on Lx, Ly, Lz for each bin
9. Distribute bulk volume to each bin

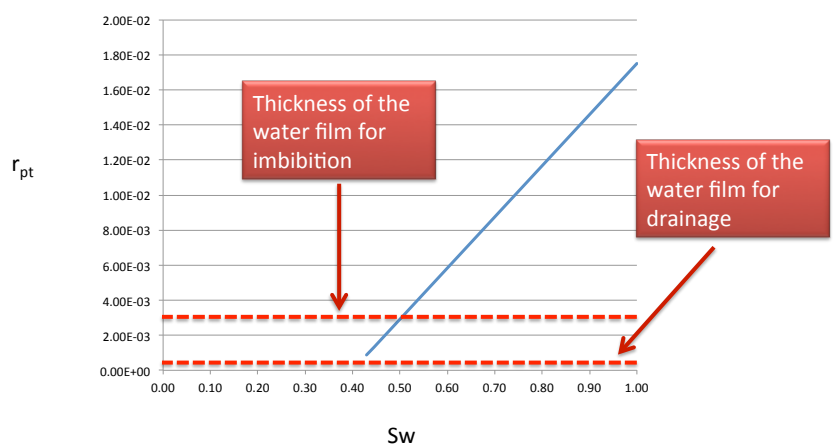
n-Porosity Simulator



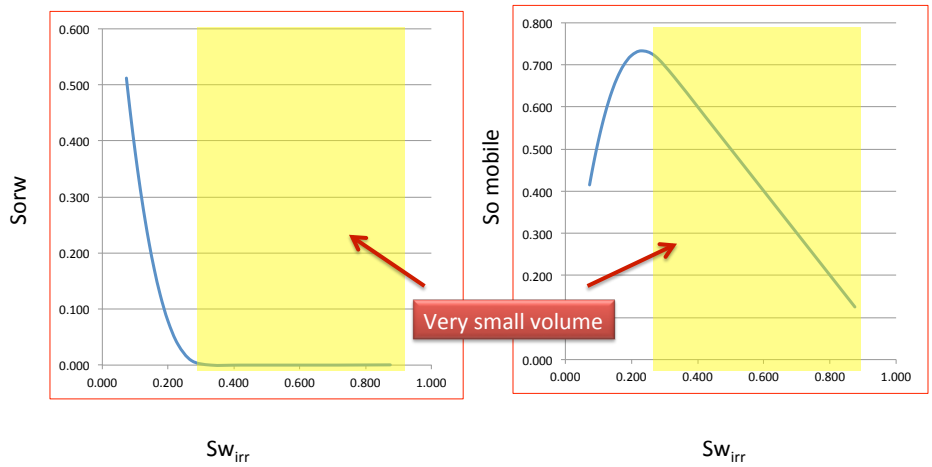
Youssef, et. al., International Symposium of the Society of Core Analysts, Avignon, France, September 2014

Consider r_{pt} versus Sw plot for imbibition

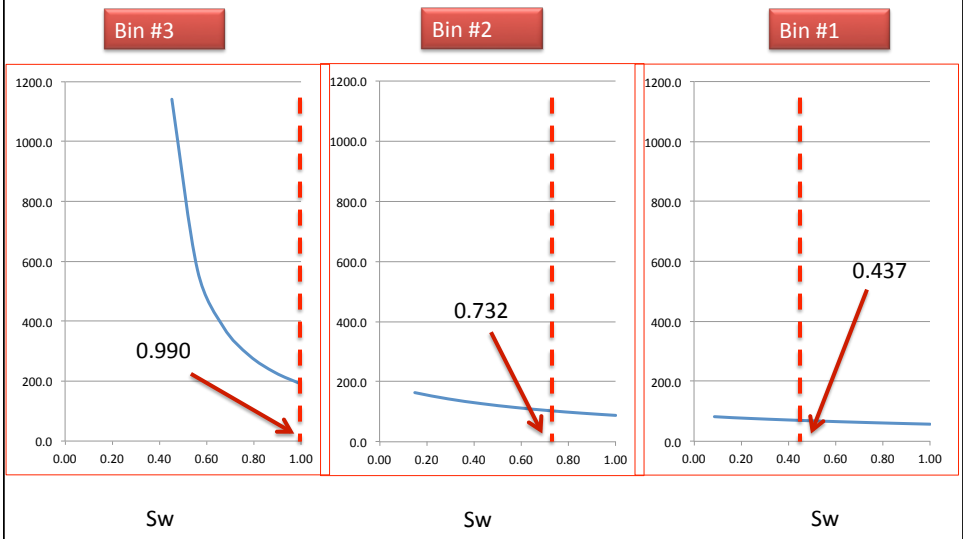
r_{pt} is pore throat radius

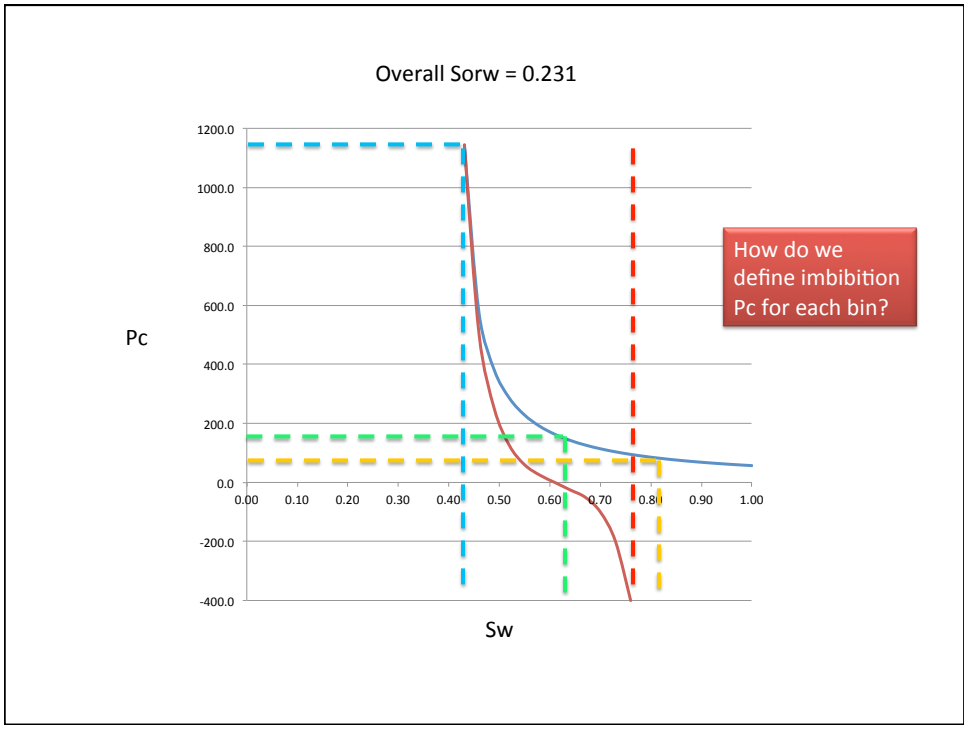


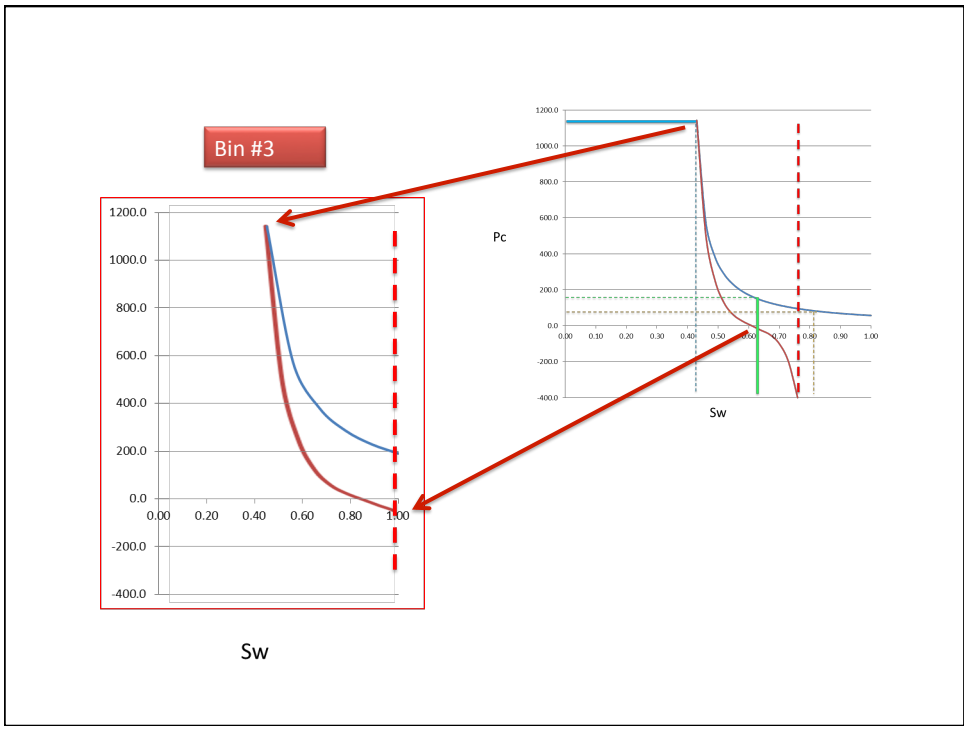
Assume that water film thickness of imbibed rock is 8 times that of the drained rock

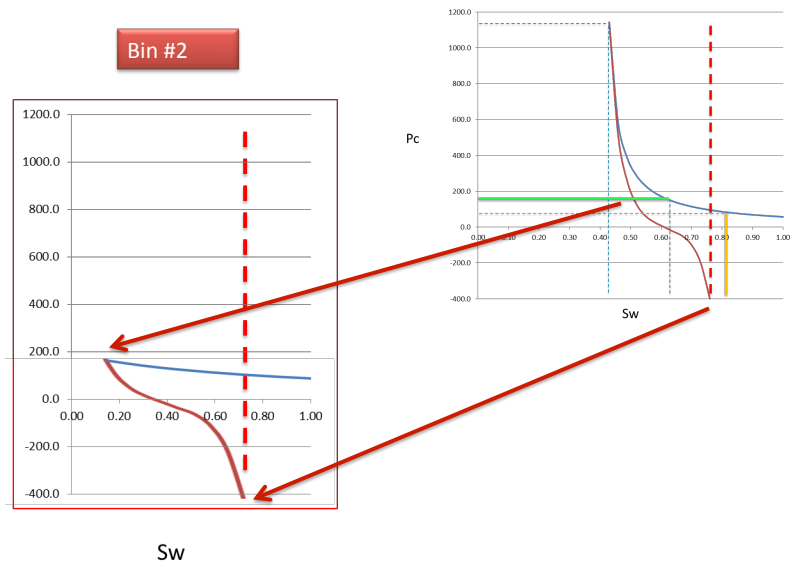


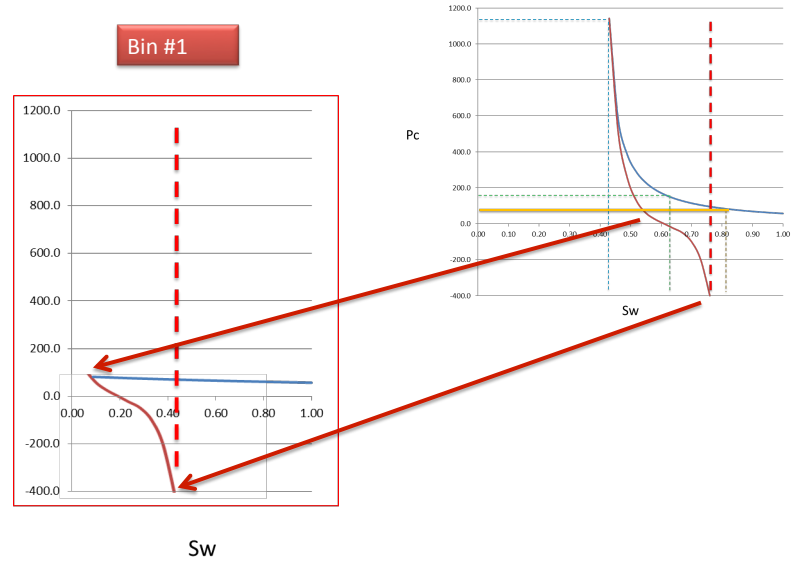
Calculated Sorw of the first three bins (overall Sorw = 0.231)

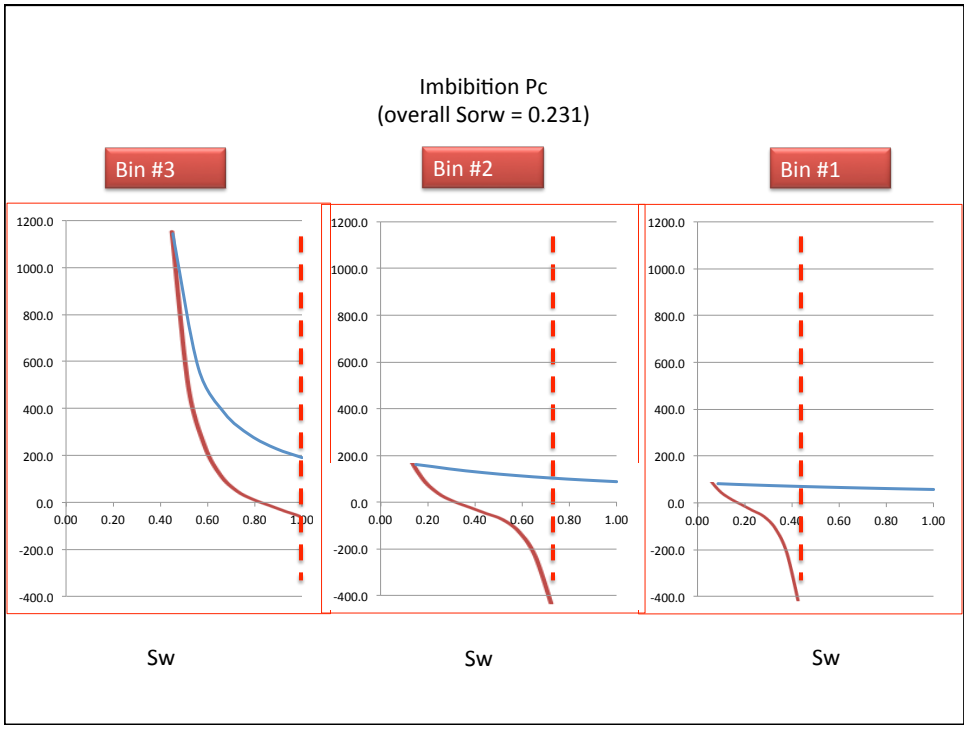



Overall Sorw = 0.231
Pc
Sw
How do we define imbibition Pc for each bin?


Bin #3
Pc
Sw
Sw


Bin #2
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
-200.0
-400.0
0.00
0.20
0.40
0.60
0.80
1.00
Sw
Pc
Sw


Bin #1
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
-200.0
-400.0
0.00
0.20
0.40
0.60
0.80
1.00
Sw
Pc
Sw



n-Porosity Simulator

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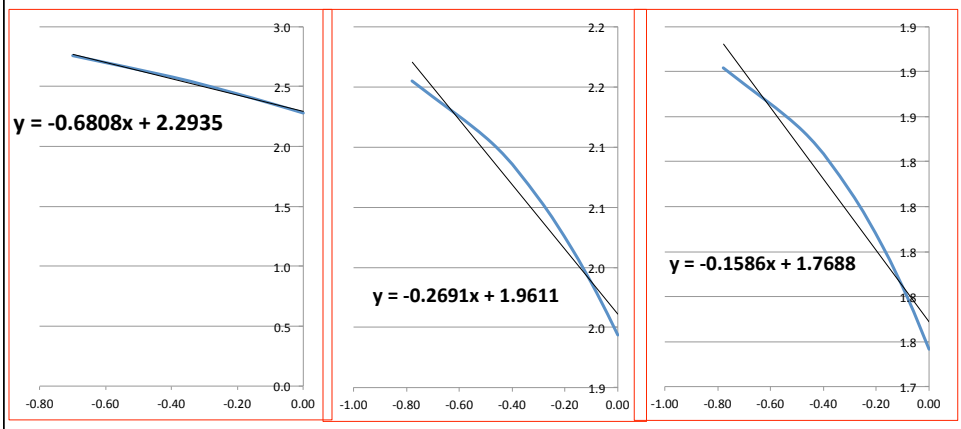
5. Develop Kr-drainage for each bin
6. Develop Kr-imbibition for each bin
7. Calculate permeability of each bin
8. Decide on Lx, Ly, Lz for each bin
9. Distribute bulk volume to each bin

Plot Log(Pc-d) versus Log(Sw*) for the three bins
Calculate pore size distribution index
Calculate Corey's Kr coefficient for wetting phase

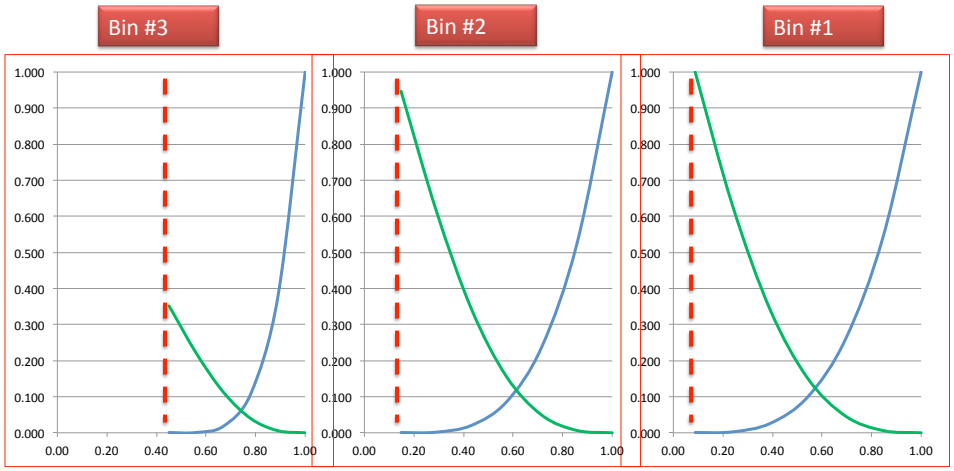


$\lambda = 1.47$
Corey $n_w = 4.36$

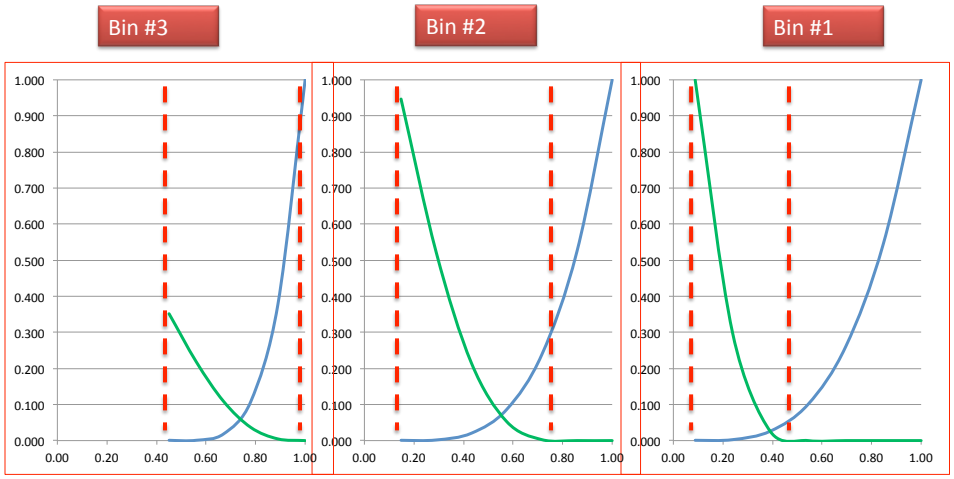
$\lambda = 3.72$
Corey $n_w = 3.54$

$\lambda = 6.31$
Corey $n_w = 3.32$

Calculate drainage Krw and Kro for each bin



Calculate imbibition Krw and Kro for each bin



n-Porosity Simulator

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9. Distribute bulk volume to each bin

$\log k = 2.225 \log r_{50} + 0.214$ Gao and Hu (2013)
Since we use arbitrary units for radius, the relationship is
$\log k = 2.225 \log r_{50} + b$
Constant "b" can be calculated from known grid block data

	K (μD)	R_{50} (10^3)	K (μD) (Gao&Hu)	Pc_e	K (μD) (Pc_e)
Grid	0.325	9.19		57.1	0.3256
Bin #1		14.9	0.9525	57.1	0.3256
Bin #2		8.76	0.2921	87.8	0.1111
Bin #3		3.06	0.0281	190.	0.0161
Bin #4		0.876	0.0017	1142.	0.0002

n-Porosity Simulator

Lx, Ly, Lz parameters of each bin:
- will be identical to that of the grid block

Bulk volume of each bin:
- will be proportional to the pore volume of each bin
- more accurate estimate will require knowledge of rock density as a function of pore size

n-Porosity Simulator

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November 14, 2014

Thank You

Location of irreducible water at end point (@Sw=0.43)