Unconventional Reservoir Engineering Project

Colorado School of Mines

May 3, 2013

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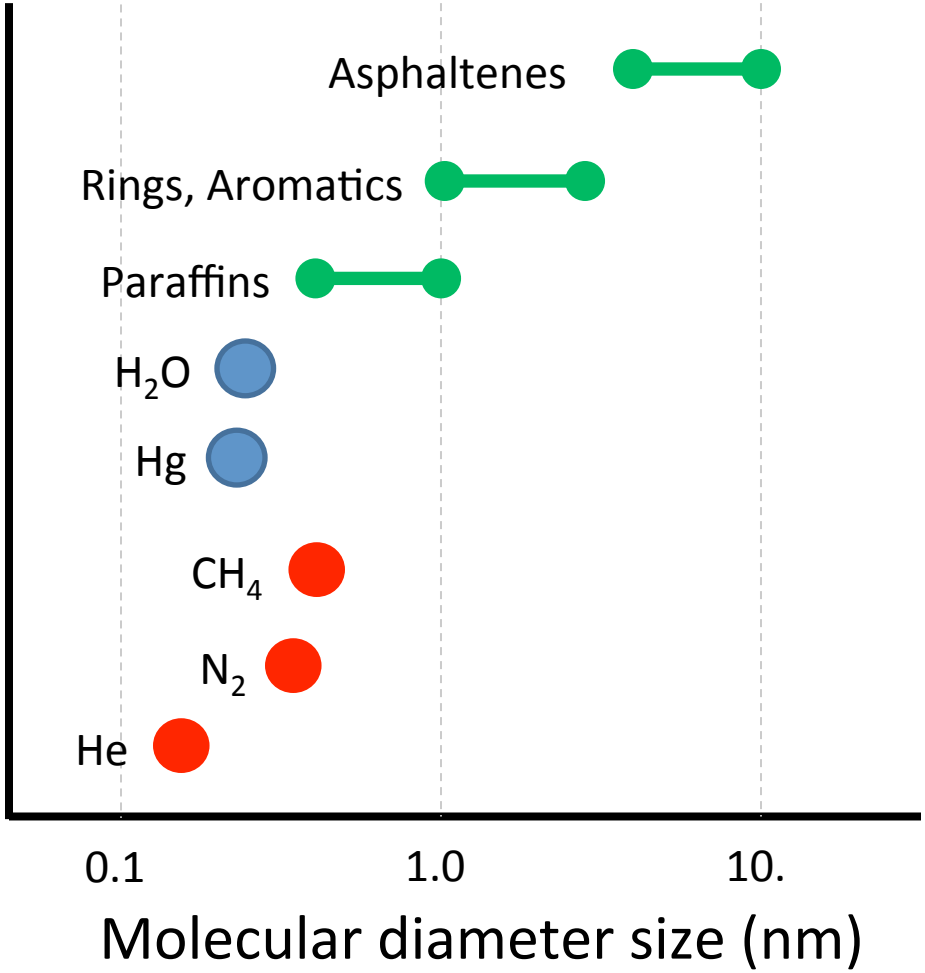
NITEC Research Topics

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

In this presentation,

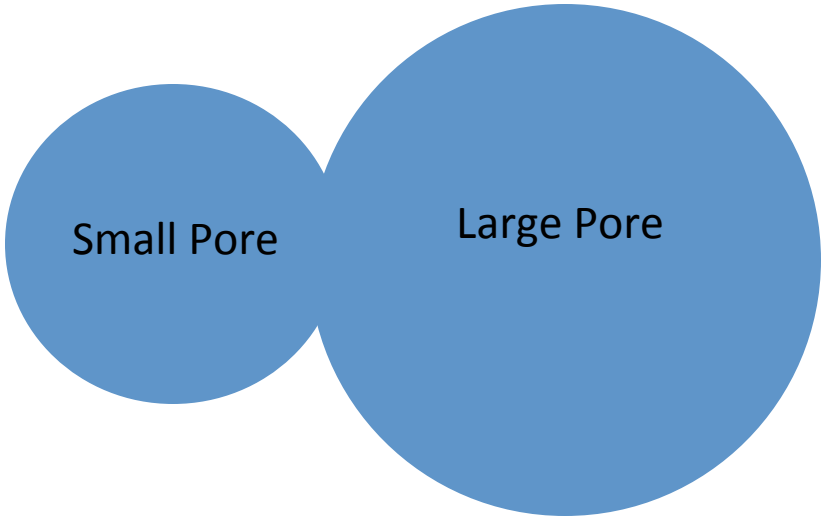
- items that are colored in green show completed work as of May 1, 2013
- Items that are colored in black reflect future work

Pore Size Related Issues



Modified from Nelson (2009)

Pore Size Related Issues

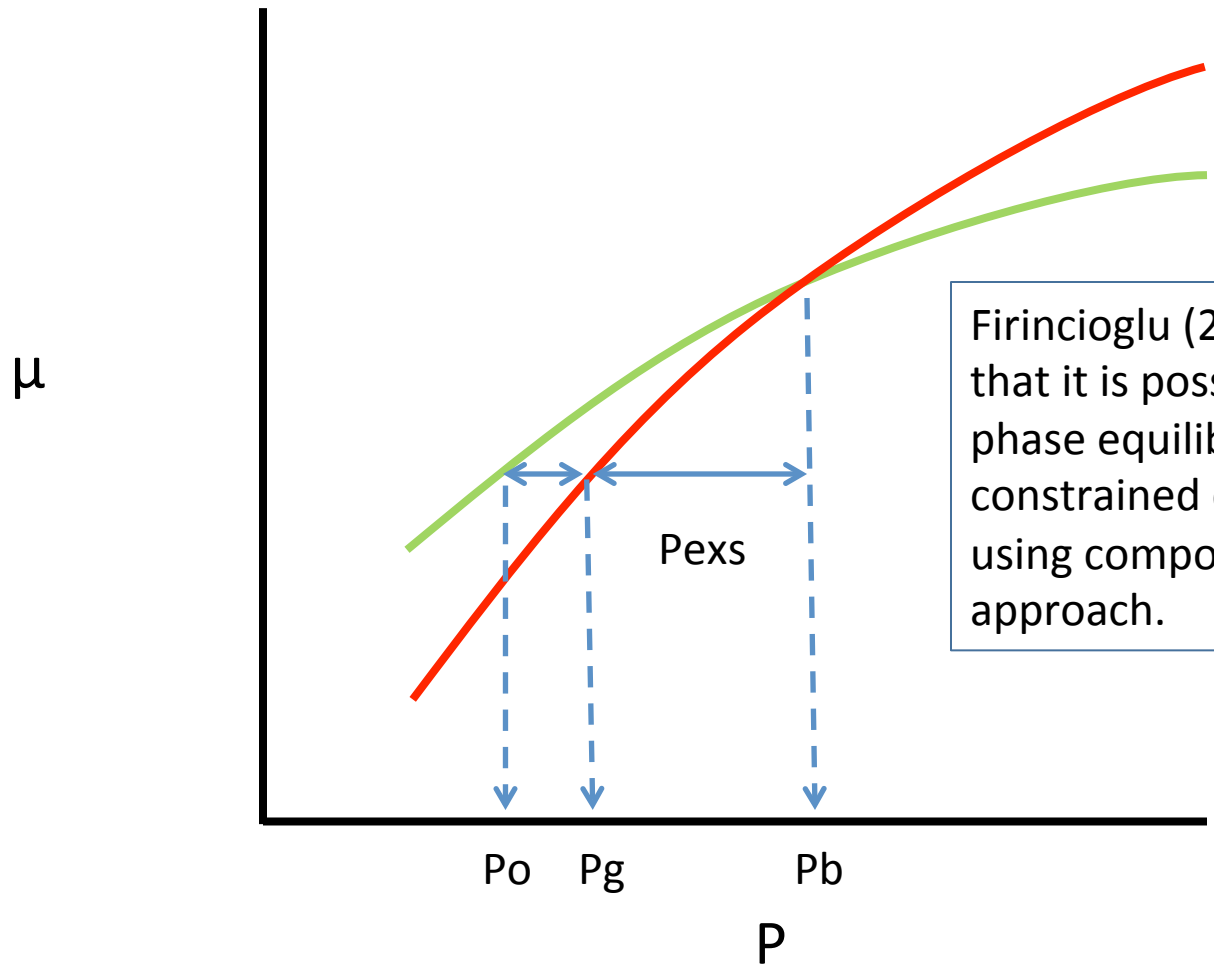


Smaller Molecules	Larger Molecules
Lower IFT	Higher IFT
Higher GOR	Lower GOR
Lower Pressure	Higher Pressure
Higher Surface Forces	Lower Surface Forces
Higher Capillary Pressure	Lower Capillary Pressure
Excessive Pc Suppression?	Excessive Pc Suppression?

Pore Size Related Issues

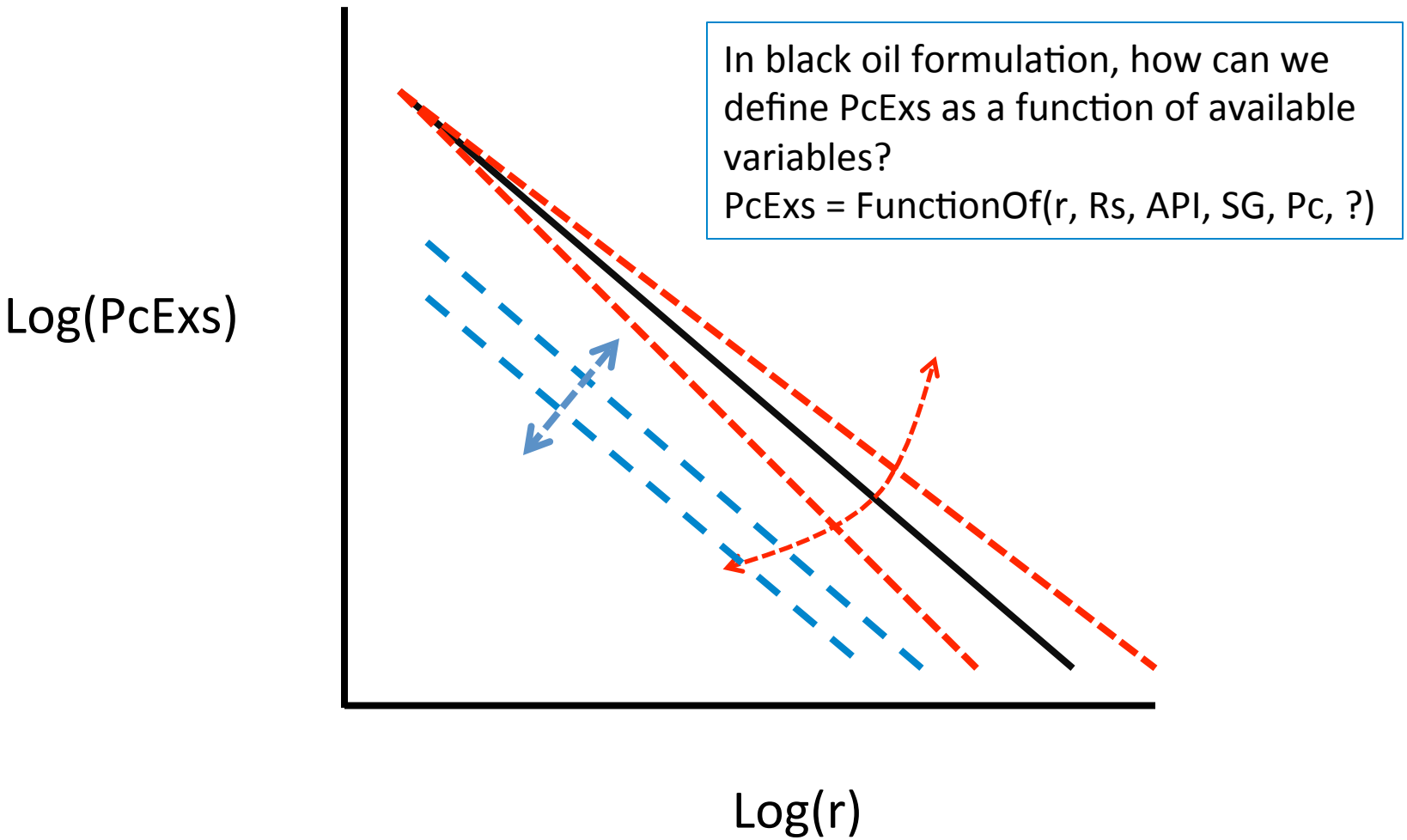
- Compositional Variation due to Nano-filtration
  - Laboratory work will commence shortly
- Chemical and Physical Equilibrium
  - Modeling work will commence concurrently
- Diffusion and Osmotic Pressure
  - Diffusion code has been implemented in extended black oil simulator (COZSim) for single-, dual-, and n-porosity formulation
  - Osmotic pressure will be included after the laboratory and modeling work

Constrained Thermodynamics



Firincioglu (2012) has shown that it is possible to solve for phase equilibrium in constrained environments using compositional approach.

Excess Suppression



Hydrodynamic Equilibrium

- Excess Capillary Pressure as a function of ?
  - Described by Firincioglu for Compositional Formulation
  - Developed by Firincioglu for Black Oil Formulation as a function of Rs and Pc
    - (PcExc+Pc) / Pc = functionOf(Rs)

Hydrodynamic Equilibrium

- COZSim Enhancements
  - Updated Initialization Code (static)
    - Calculate Phase Densities and Phase Pressures
    - Calculate Capillary Pressures
    - Estimate Rs (for multi-phase conditions)
    - PcExc = f(Pc,Rs)
    - Bulk Pressure = Pgas + PcExc
    - Iterate until convergence for multi-phase conditions

Hydrodynamic Equilibrium

- COZSim Enhancements
  - Updated Simulation Code (dynamic)
    - Assume Pc and Rs (or obtain from previous solution)
    - Estimate PcExc and calculate pBulk
    - Perform VLE at pBulk
    - Calculate phase properties at phase pressures
    - Calculate saturations and Pcs from saturations
    - Correct Pcs for IFT and integrate (dynamic pseudo)
    - Iterate until convergence in Pc and Rs

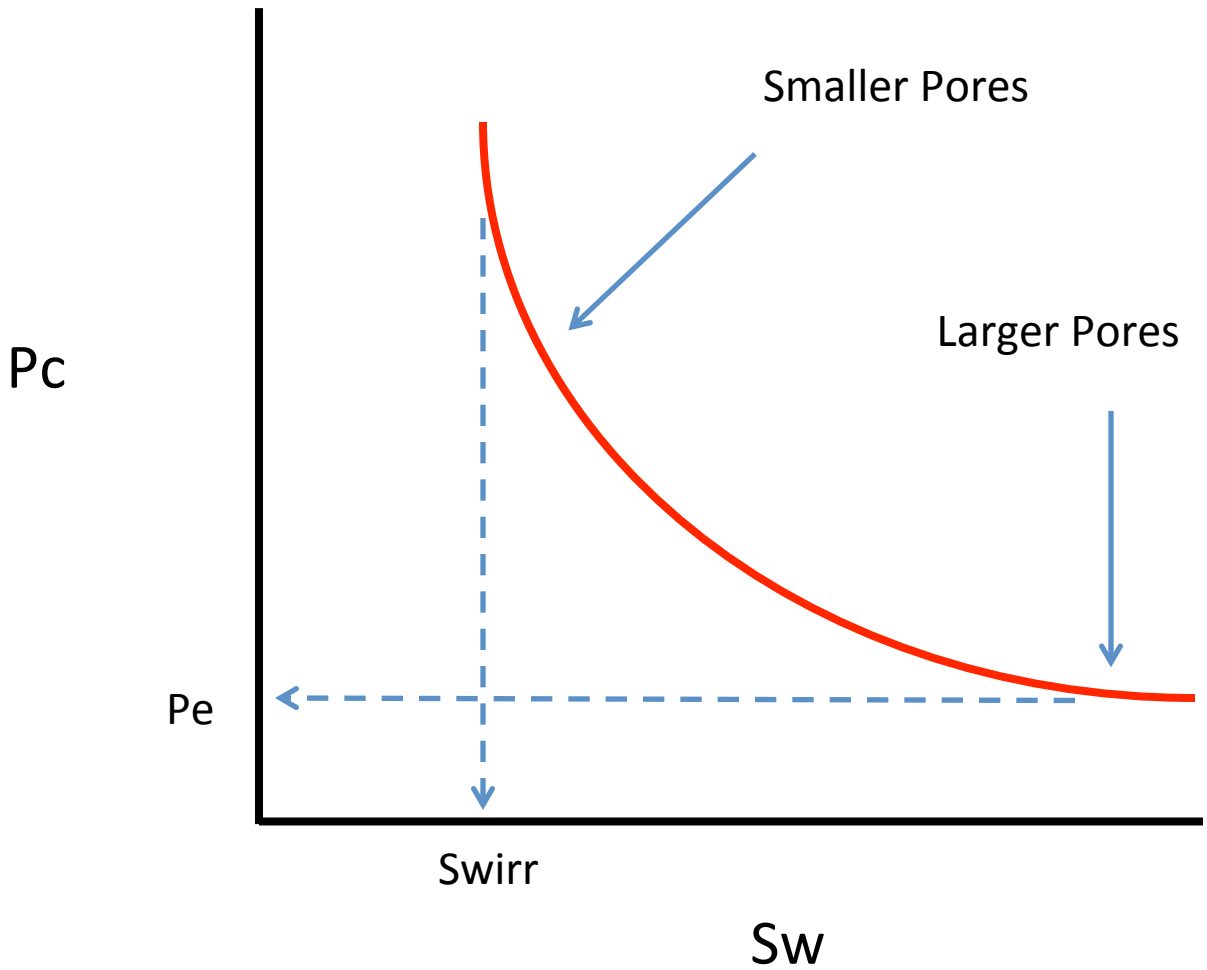
Hydrodynamic Equilibrium

- COZSim Enhancements
  - Other items
    - Dynamic and Static pseudo-Pc (Quandelle)
    - Parachor correlations from Black Oil data
    - Dynamic Interfacial Tension correction for Pc
    - Molecular Diffusion (not tested)

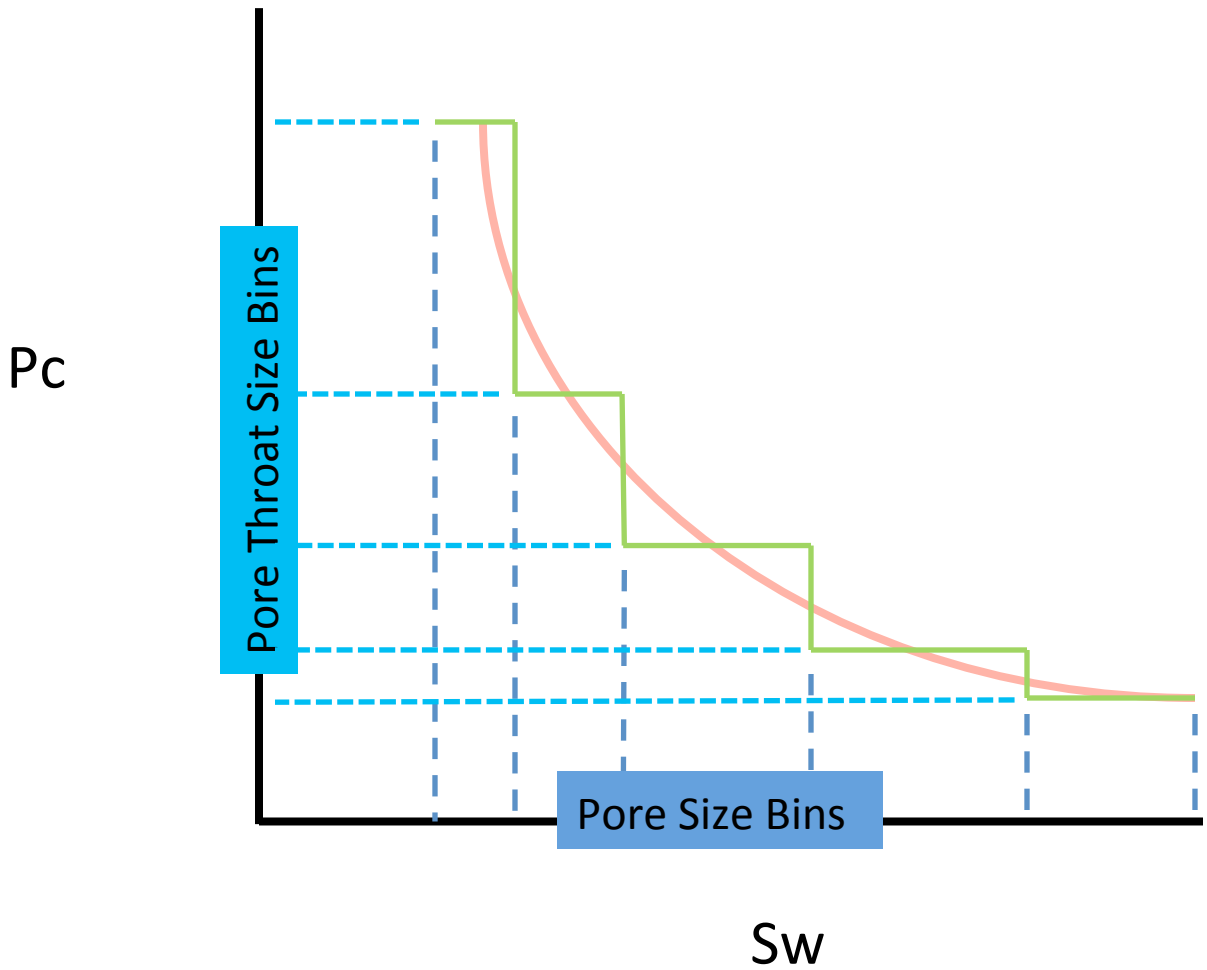
Hydrodynamic Equilibrium

- COZView (Pre-Post Processor) Enhancements
  - Simplified simulation model building for single-porosity cases
  - Post-processing of new arrays

Characteristic Pc Curve



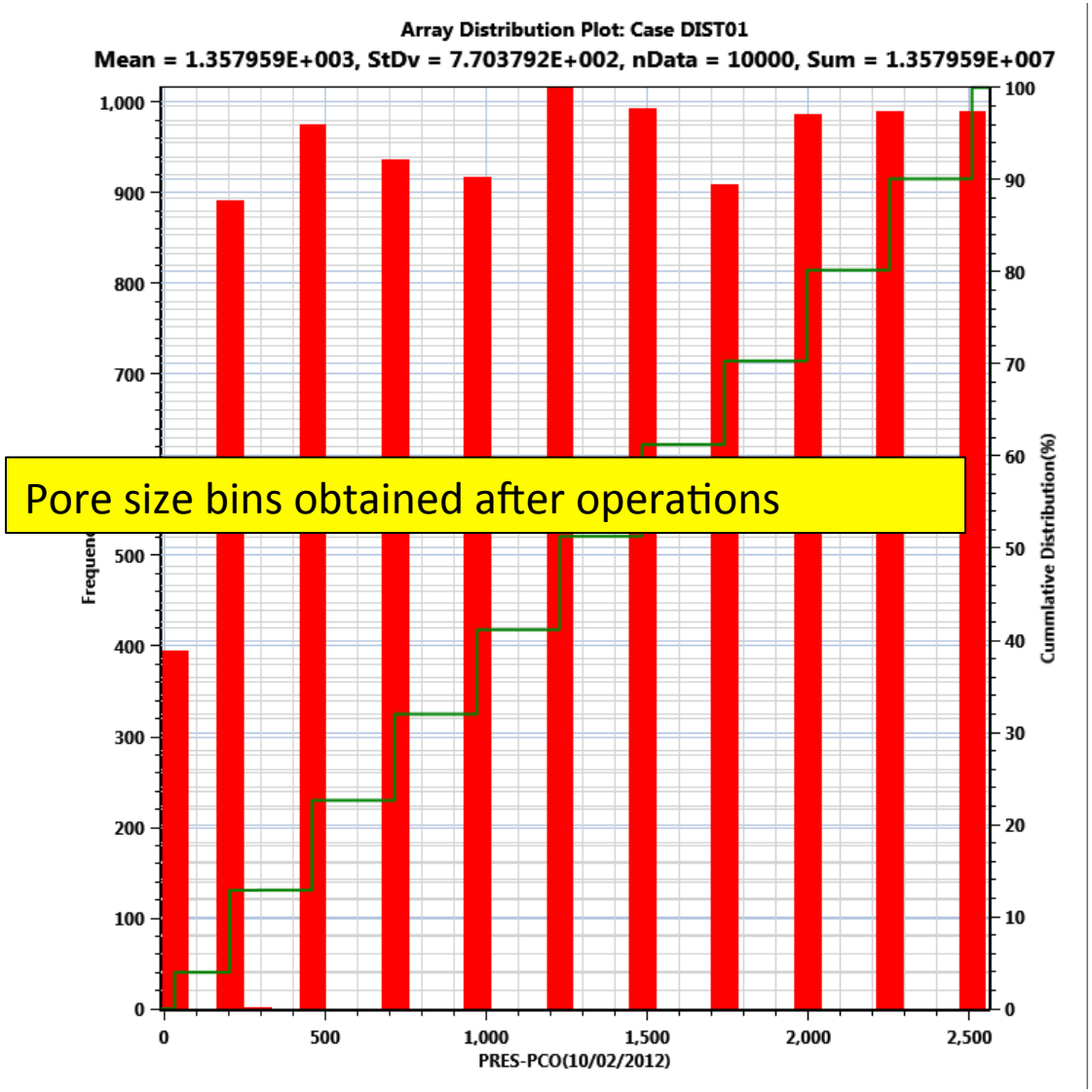
Discretized Pc Curve



Simulation Examples

```
!
POROSITY
10000*0.10                                  ! set average porosity
!
! for repeatability, set the seed to a value
SETSEED  5000
!
! initialize pore size bin array
USERDEFINED01
10000*5.5
!
! Perturbation to distribute between 0.5 and 10.5
USERDEFINED01  EQUALS   PERTURB     5.0    LINEAR
!
! get to nearest integer
USERDEFINED01  EQUALS   NINT    USERDEFINED01
!
! Now, we have a pore size bin array from 1 to 10 (integers)
!
```

Simulation Examples

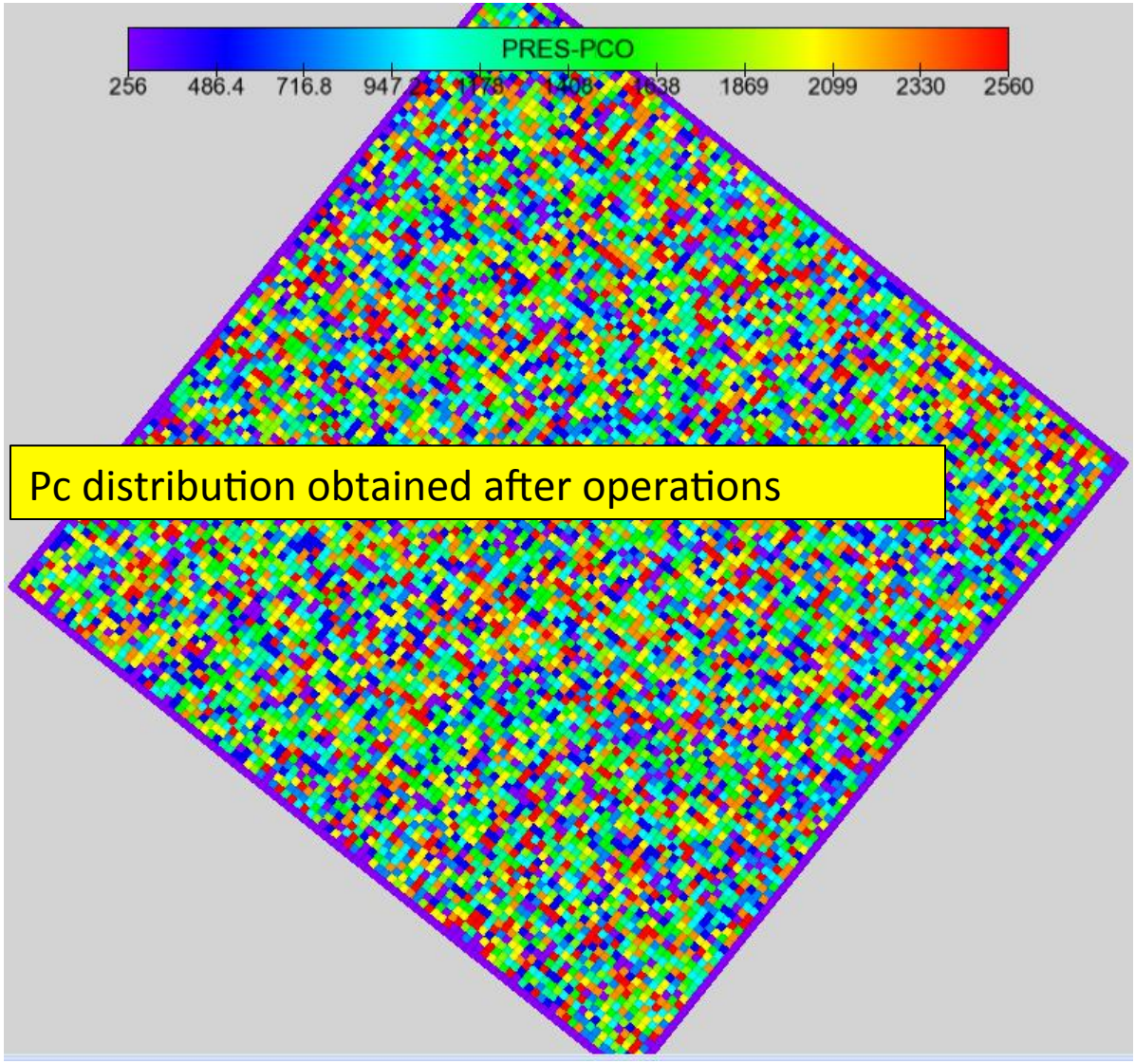


Pore size bins obtained after operations

Simulation Examples

```
!
! initialize pore size array
USERDEFINED02
10000*1.0
!
! set the pore size for each bin
USERDEFINED02  EQUALS   DIVIDEBY   USERDEFINED01
! Now, we have a normalized pore size array between 0.1 and 1.0
!
! initialize PcMult array to be Pe
PCMULTGO
10000*256.0
!
! finalize multiplier
PCMULTGO  EQUALS   DIVIDEBY   USERDEFINED02
!
! Now, we have Pc (or PcMult) for each block
!
```

Simulation Examples

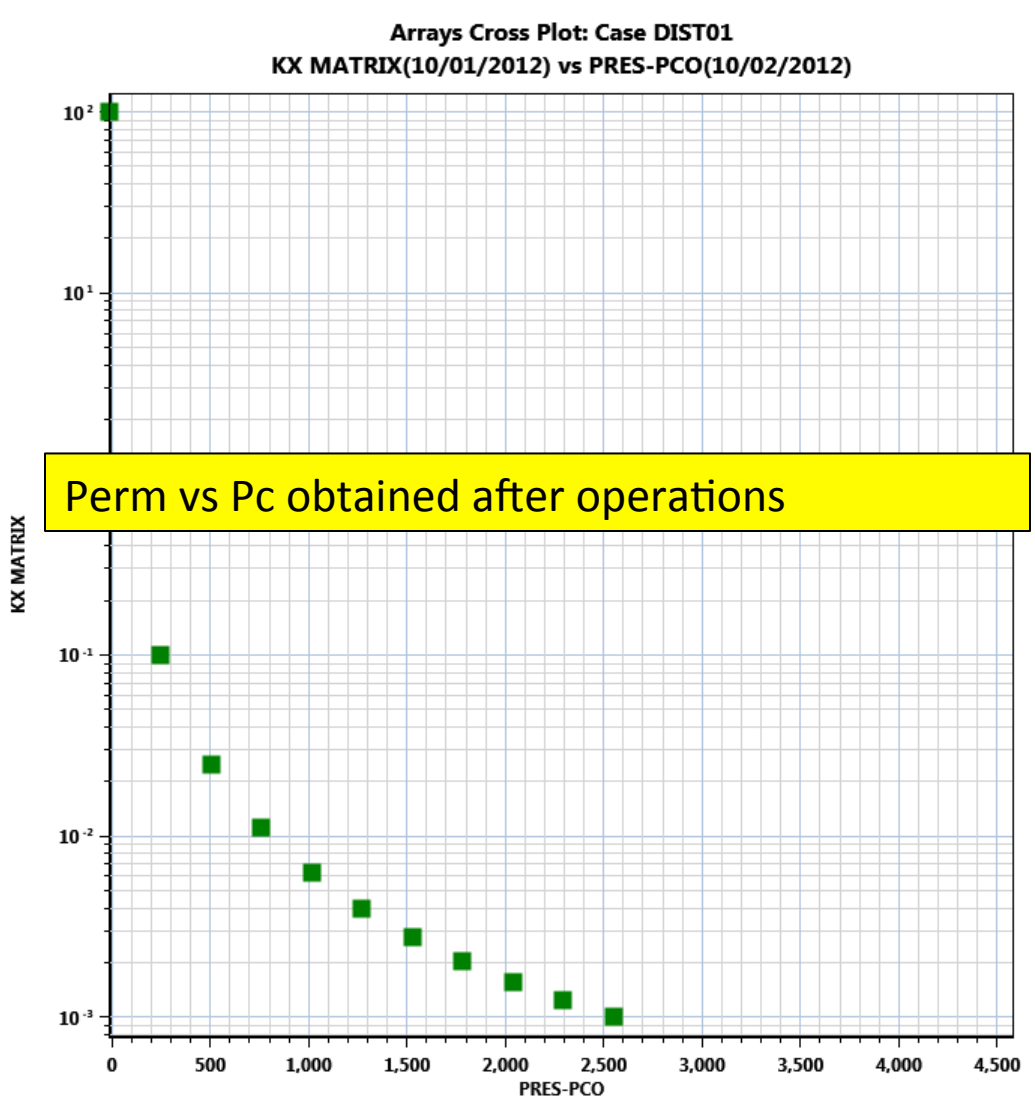


Pc distribution obtained after operations

Simulation Examples

```
!
! initialize X permeability array
PERMEABILITY-X
10000*0.100
!
! Set permeability proportional to pore size (squared)
PERMEABILITY-X  EQUALS   TIMES   USERDEFINED02
PERMEABILITY-X  EQUALS   TIMES   USERDEFINED02
!
! initialize remaining permeability arrays
PERMEABILITY-Y
10000*1
PERMEABILITY-Z
10000*1
!
! set equal to KX
PERMEABILITY-Y  EQUALS   PERMEABILITY-X
PERMEABILITY-Z  EQUALS   PERMEABILITY-X
!
! Now, we have permeability for each block
!
```

Simulation Examples



Perm vs Pc obtained after operations

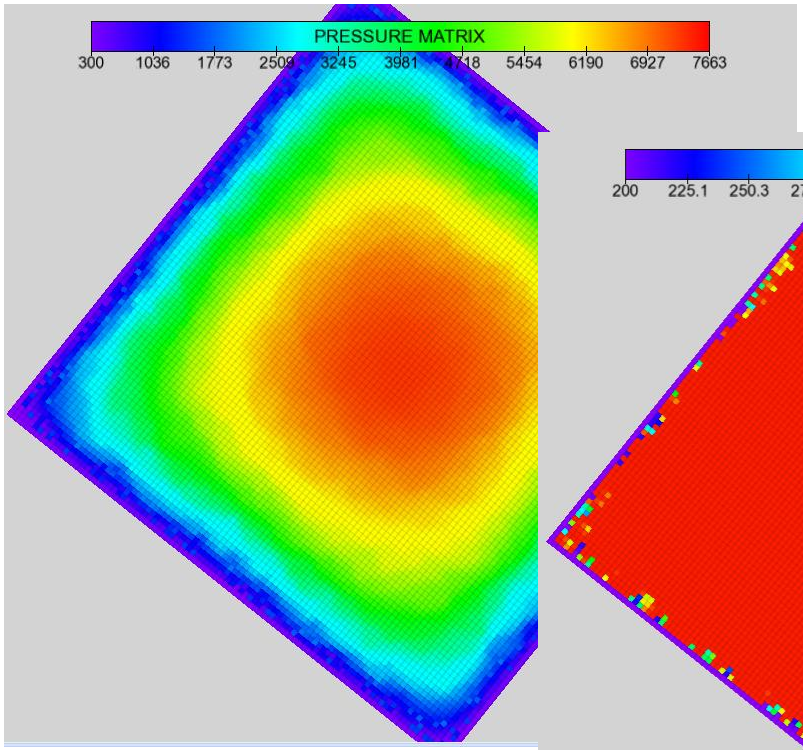
Simulation Examples

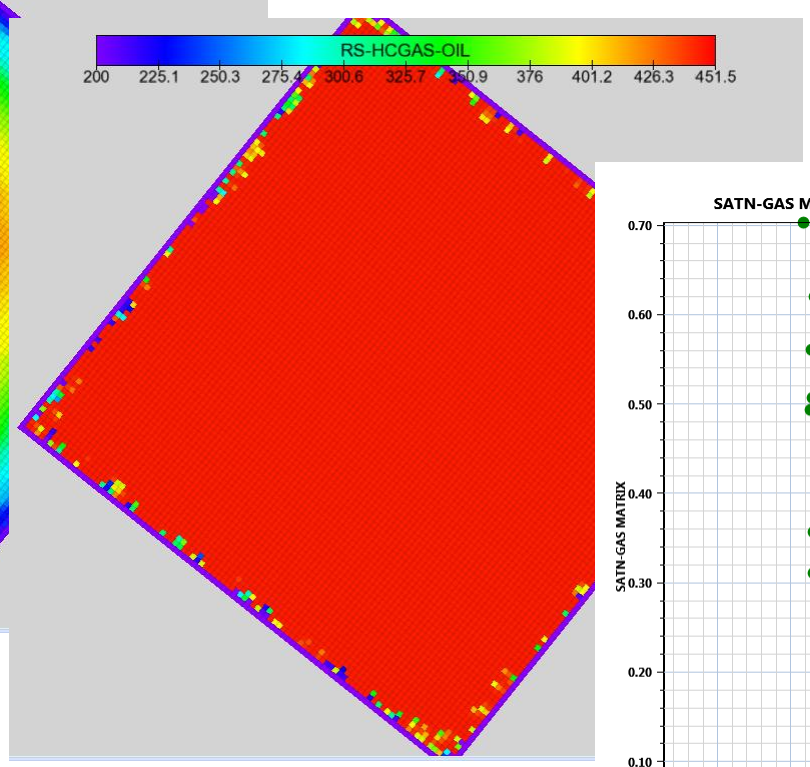
```
!
! initialize water film thickness array (half of 0.1 - which is the minimum of USERDEFINED02)
USERDEFINED03
10000*0.05
!
USERDEFINED03  EQUALS  TIMES      -1.0
USERDEFINED03  EQUALS  PLUS       USERDEFINED02
USERDEFINED03  EQUALS  DIVIDEBY   USERDEFINED02
USERDEFINED03  EQUALS  POWER      3.0
!
! swcrit update
SWCRIT EQUALS    1.0
SWCRIT EQUALS  MINUS   USERDEFINED03
!
! avoid illogical values
IF SWCRIT GT  0.95
      SWCRIT EQUALS 0.95
ENDIF
!
SWCONN  EQUALS   SWCRIT
!
```

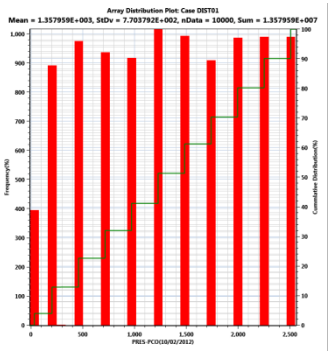
Simulation Examples

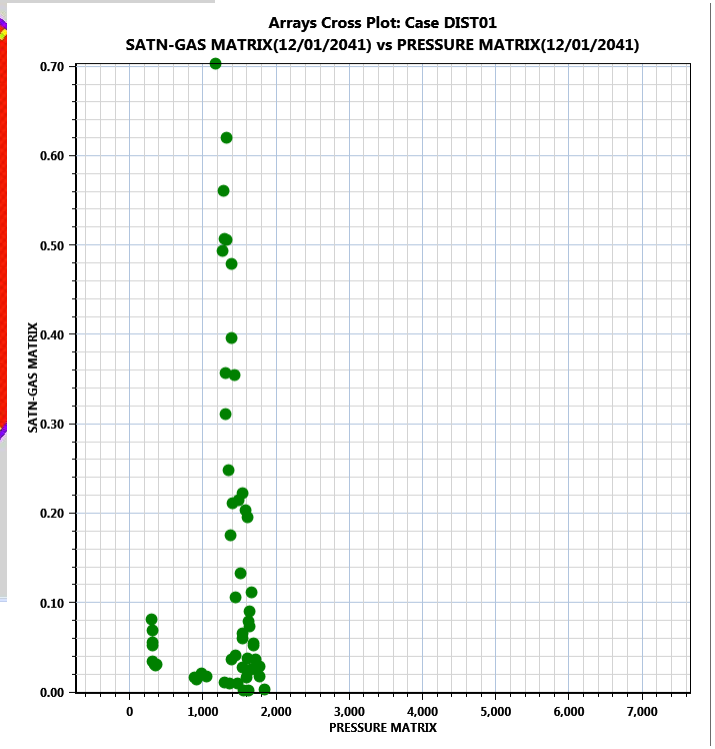
```
!
USE-EXCESSPC 1                                  ! to turn on excess pressure calculation
!
! MODIFY THE FRACTURES
!
BOX-SETUP
1 100 1 1 1 1
PERMEABILITY-X  EQUALS 100      !00
PERMEABILITY-Y  EQUALS 100      !00
SWCRIT          EQUALS 0.02
SORW            EQUALS 0.02
SORG            EQUALS 0.02
SGR             EQUALS 0.02
SWCONN           EQUALS 0.02
SLCONN          EQUALS 0.04
BOX-CLEAR
!
BOX-SETUP
1 100 1 1 1 1
PCMULTGO        EQUALS TIMES 0.0
POROSITY        EQUALS TIMES 0.25
COMPRESS-PV     EQUALS TIMES 10.0
COMPRESS-KX     EQUALS TIMES 10.0
COMPRESS-KY     EQUALS TIMES 10.0
COMPRESS-KZ     EQUALS TIMES 10.0
BOX-CLEAR
!
```

Simulation Examples

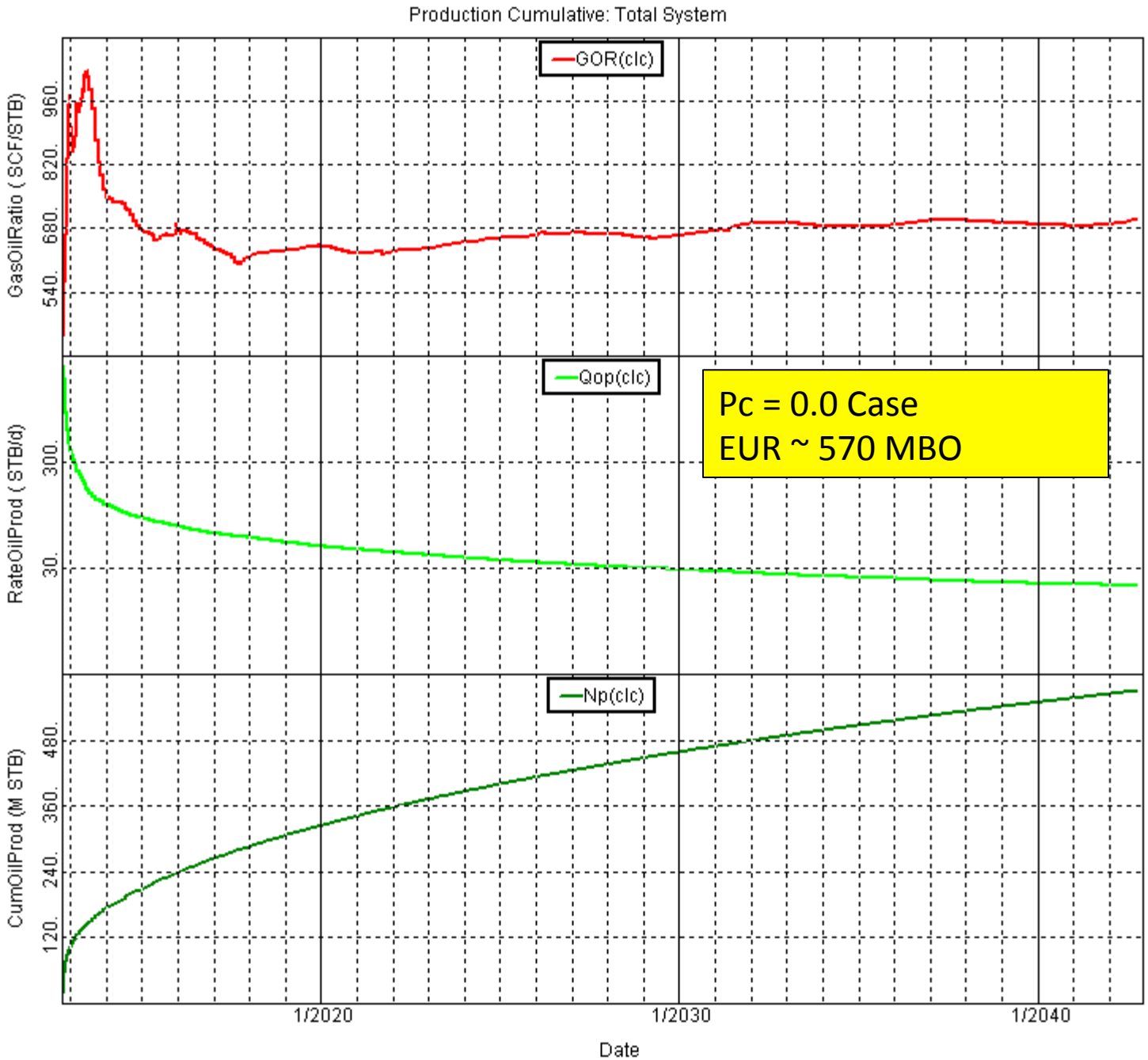


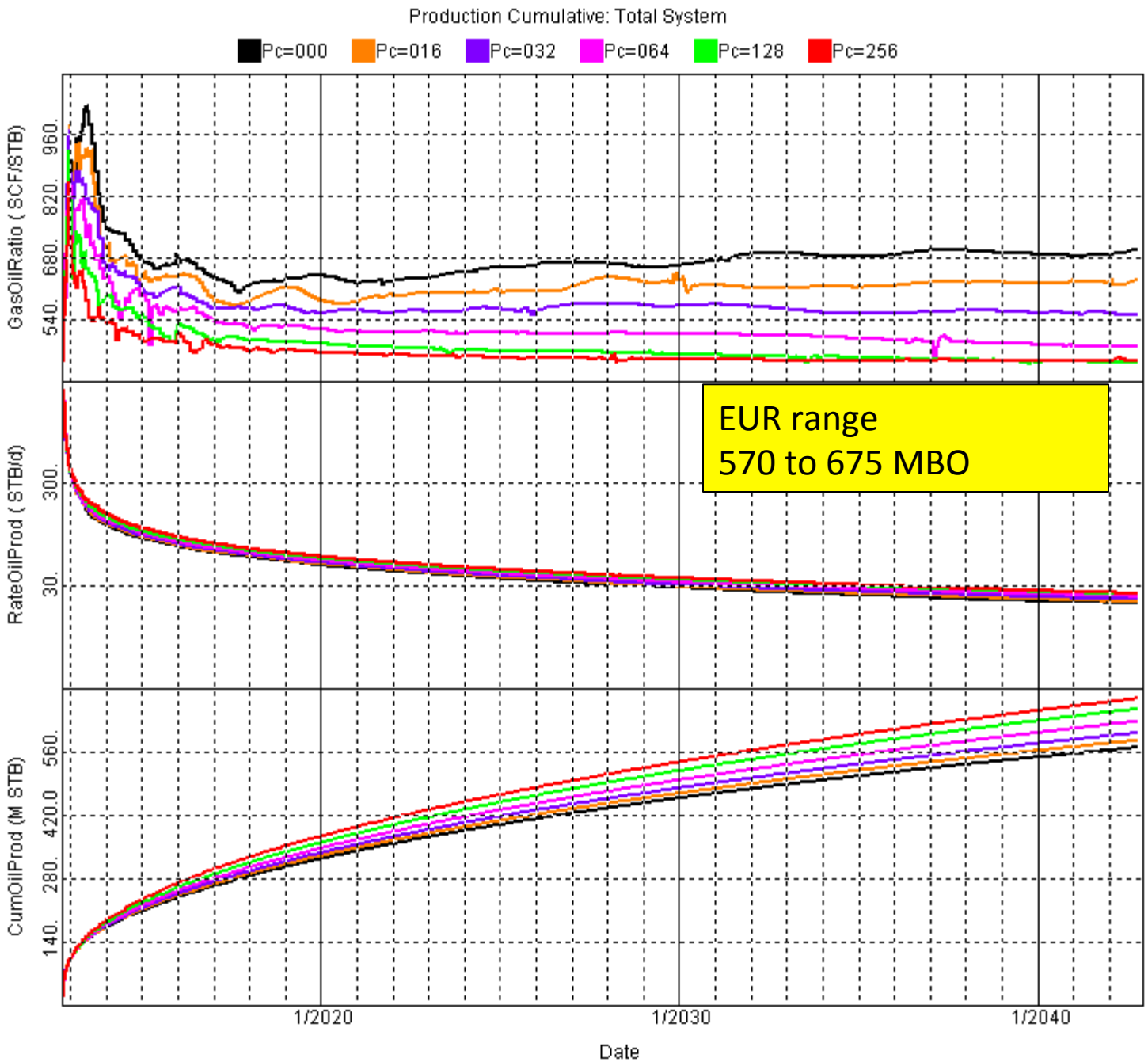


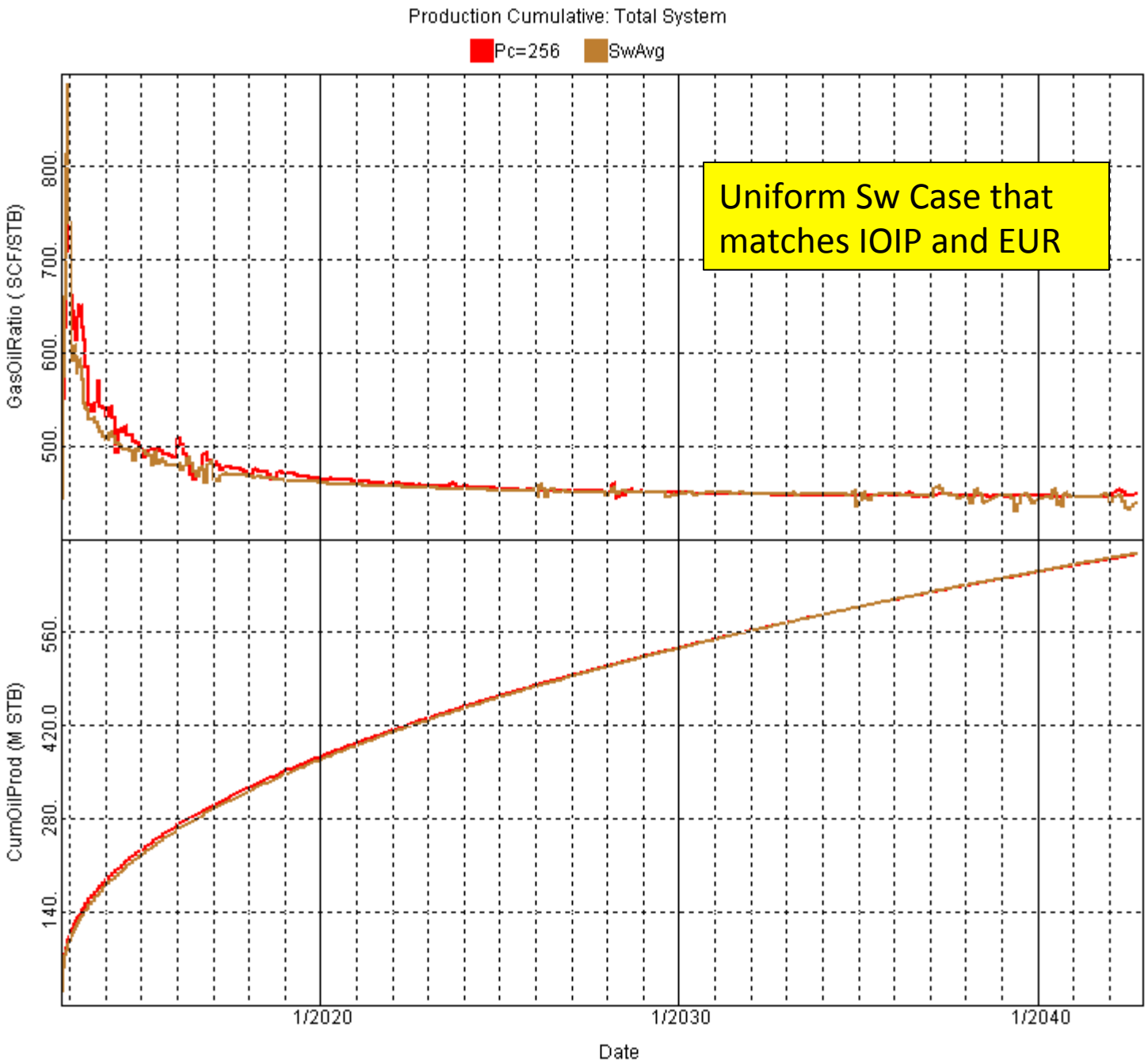


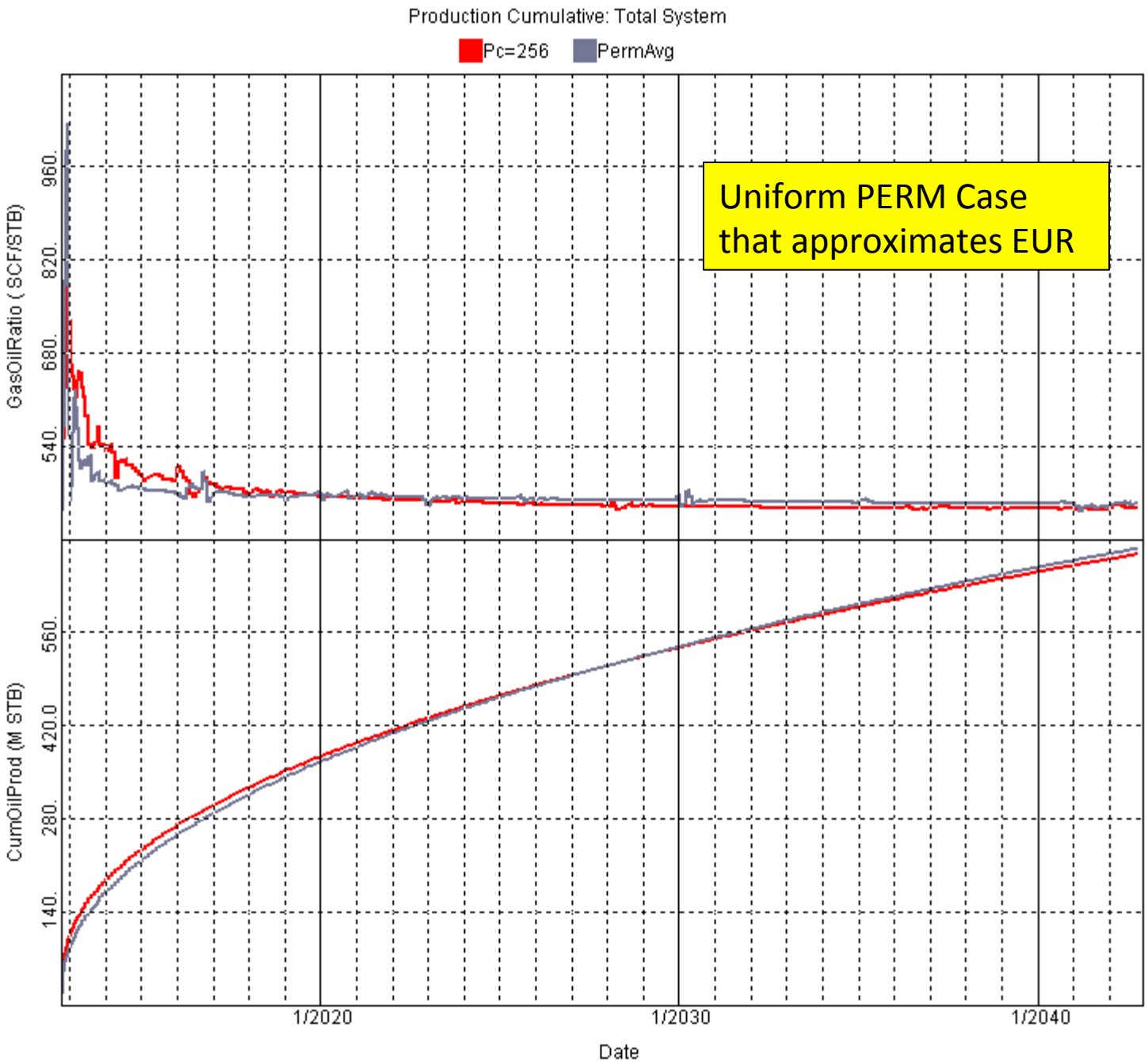


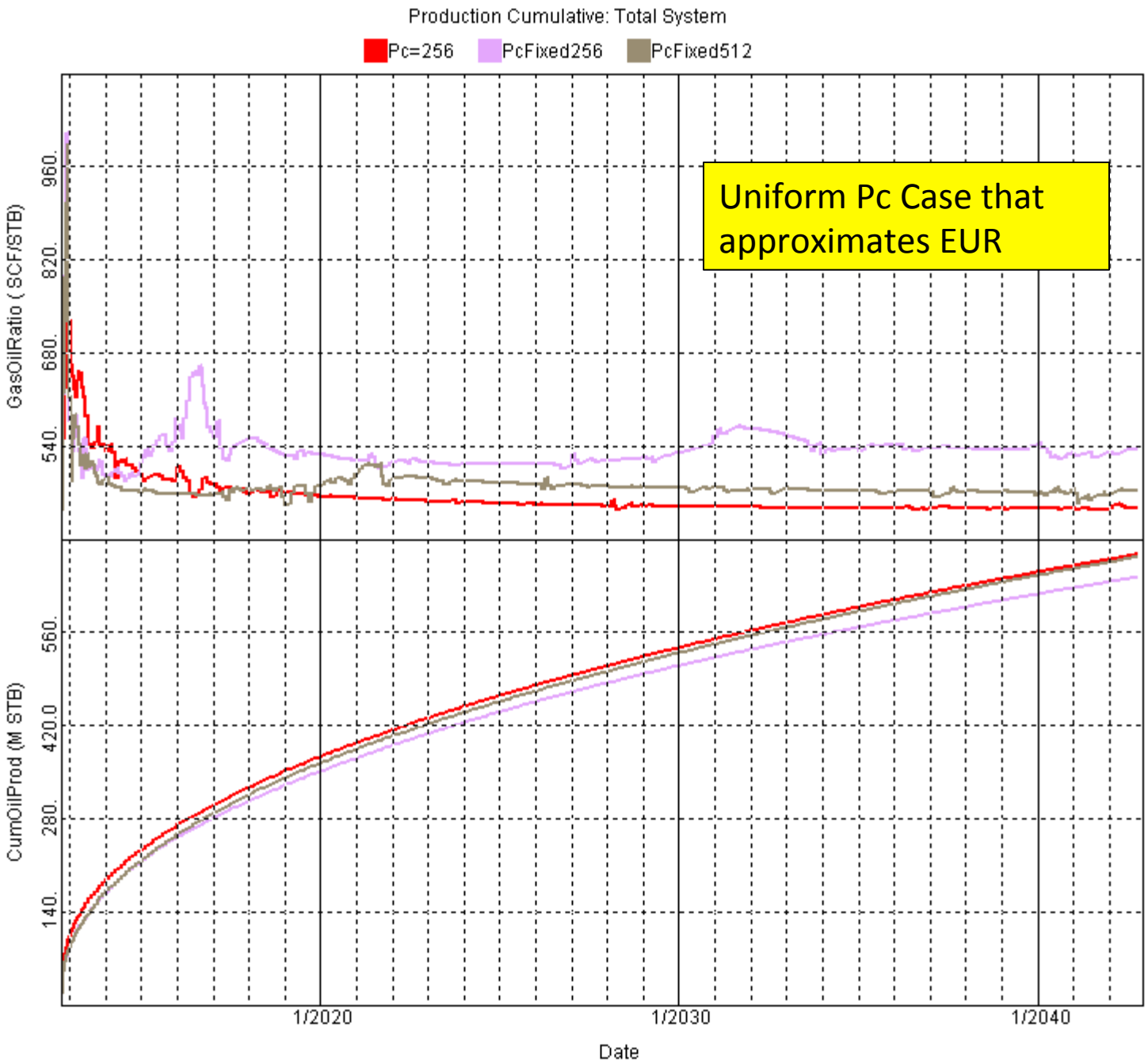
Pe=256 case after 30 years production

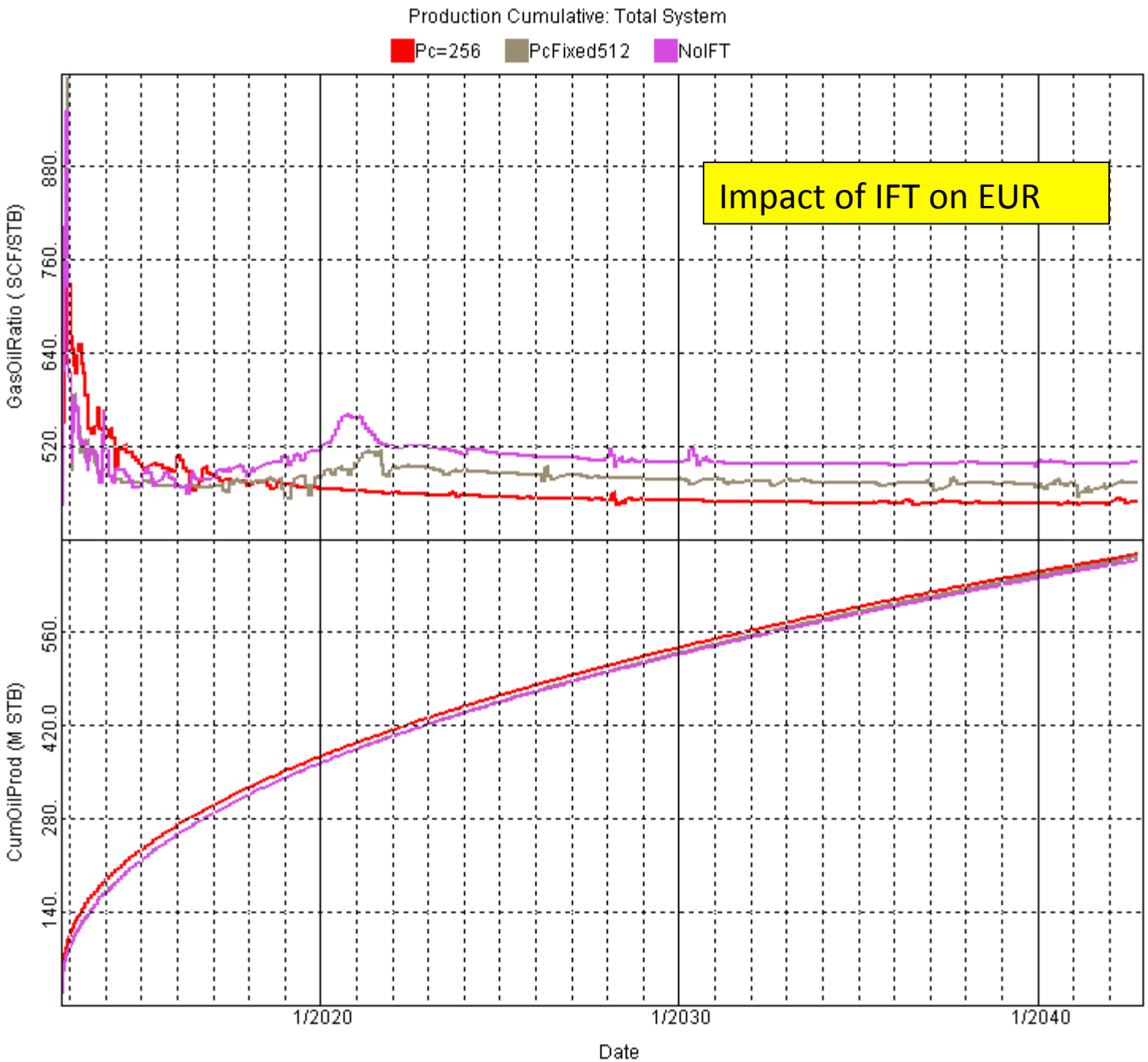

Production Cumulative: Total System
GOR(clc)
GasOilRatio (SCF/STB)
960.
820.
680.
540.
Qop(clc)
RateOilProd (STB/d)
300.
30.
Pc = 0.0 Case
EUR ~ 570 MBO
Np(clc)
CumOilProd (M STB)
480.
360.
240.
120.
1/2020
1/2030
1/2040
Date

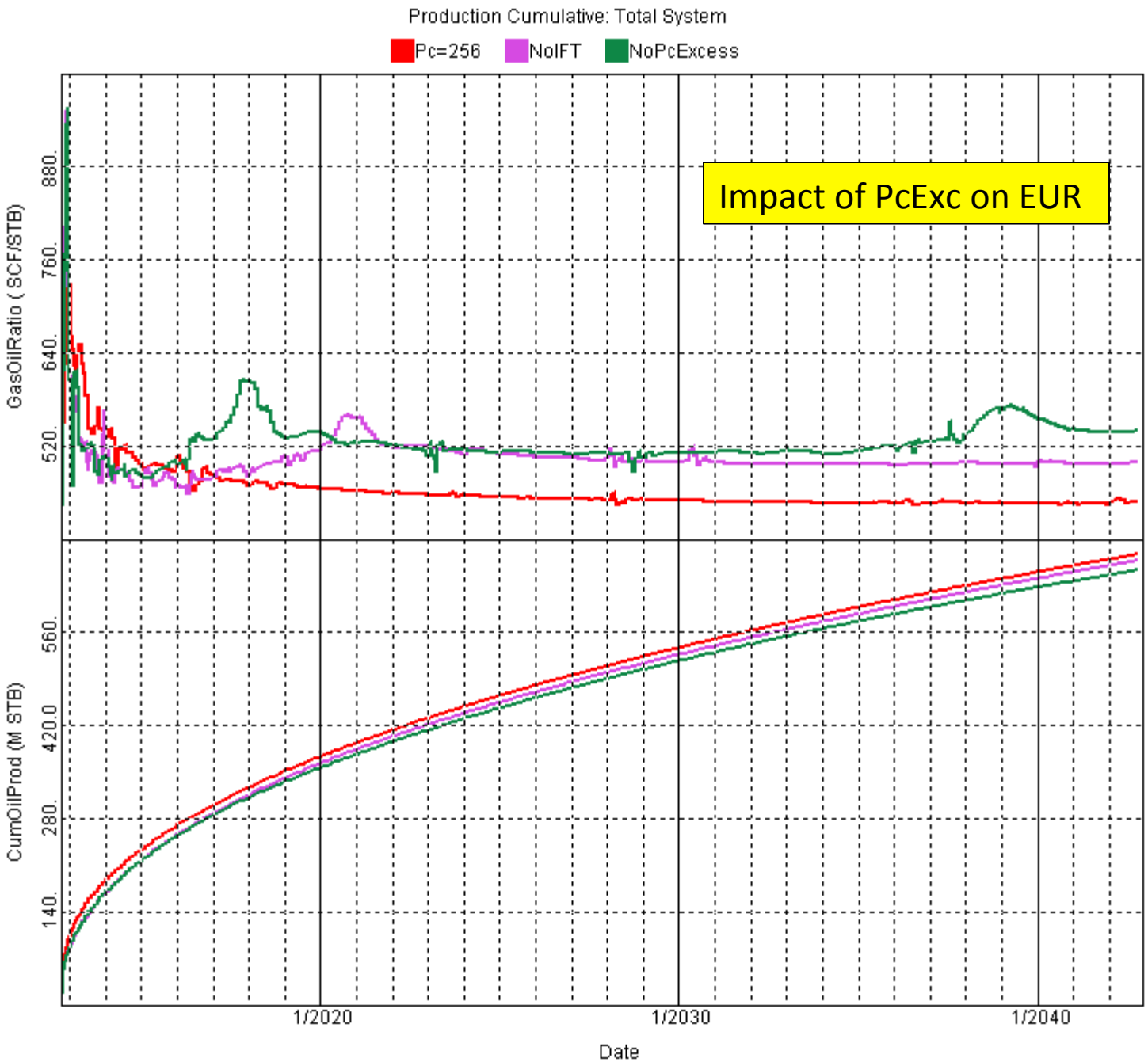

Production Cumulative: Total System
Pc=000
Pc=016
Pc=032
Pc=064
Pc=128
Pc=256
GasOilRatio (SCF/STB)
960.
820.
680.
540.
RateOilProd (STB/d)
300.
30.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date
EUR range
570 to 675 MBO

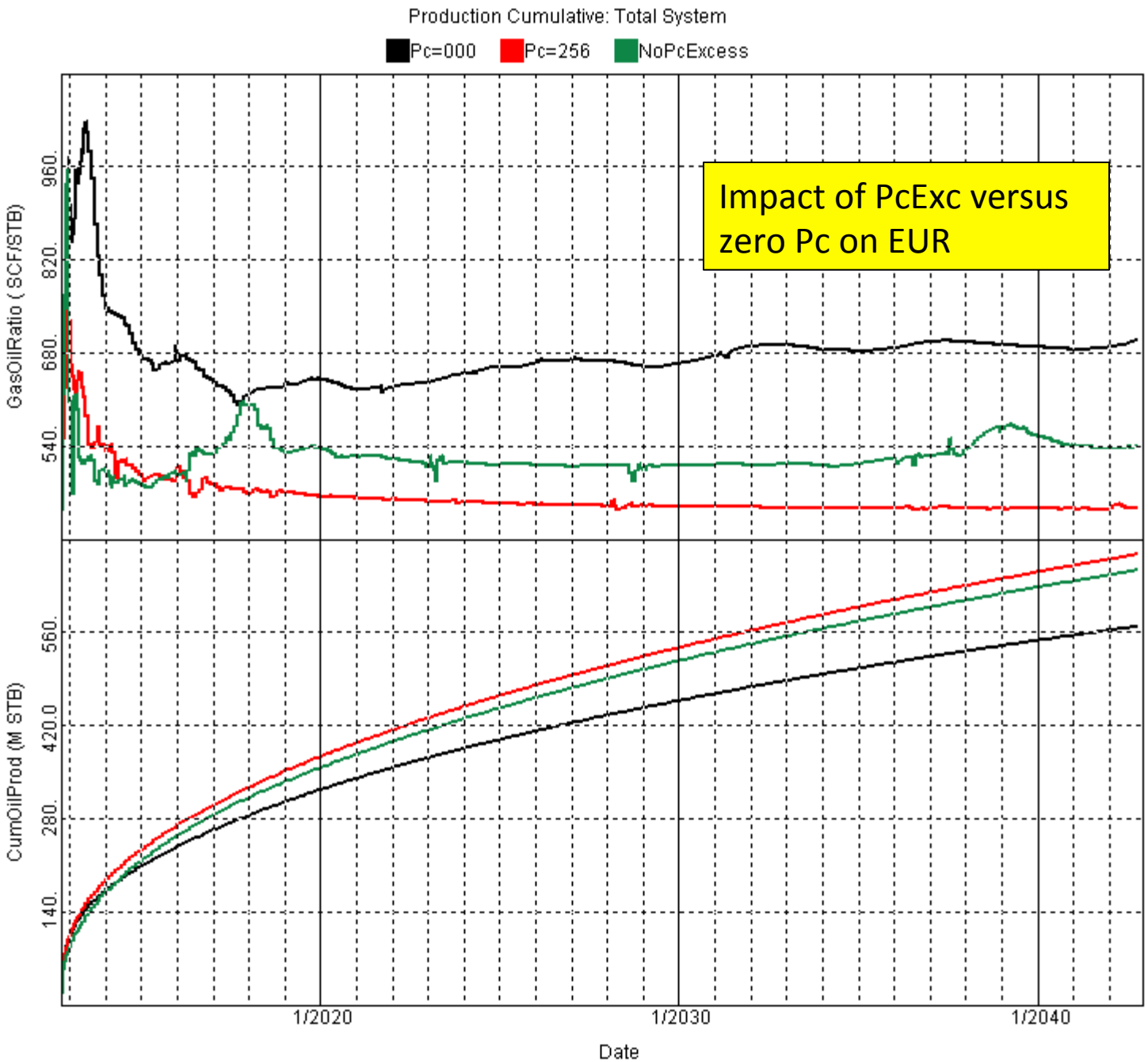

Production Cumulative: Total System
Pc=256
SwAvg
GasOilRatio (SCF/STB)
800.
700.
600.
500.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date
Uniform Sw Case that matches IOIP and EUR


Production Cumulative: Total System
Pc=256
PermAvg
Uniform PERM Case
that approximates EUR
GasOilRatio (SCF/STB)
960.
820.
680.
540.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date

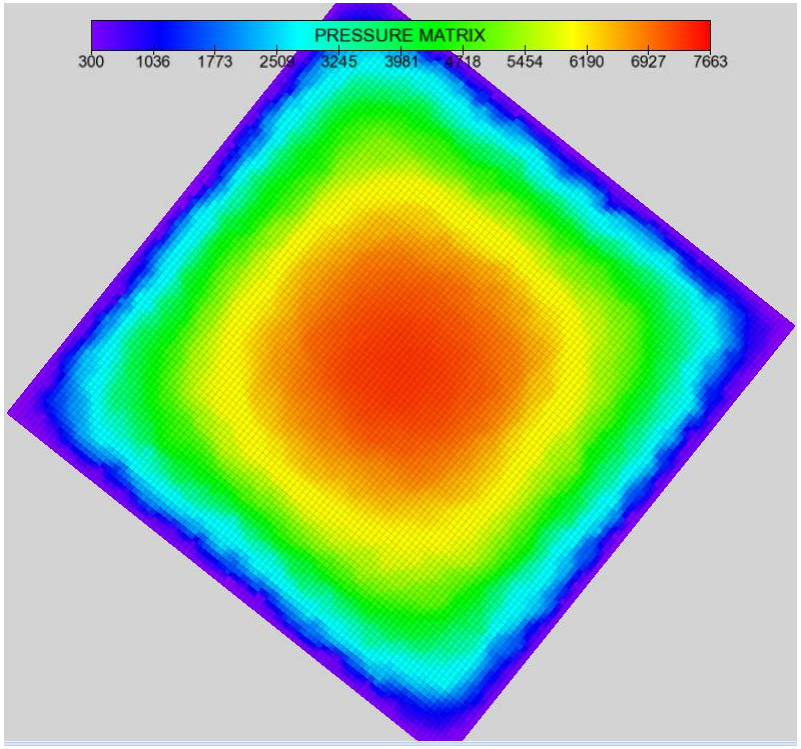

Production Cumulative: Total System
Pc=256
PcFixed256
PcFixed512
Uniform Pc Case that approximates EUR
GasOilRatio (SCF/STB)
960.
820.
680.
540.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date


Production Cumulative: Total System
Pc=256
PcFixed512
NoIFT
Impact of IFT on EUR
GasOilRatio (SCF/STB)
880.
760.
640.
520.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date

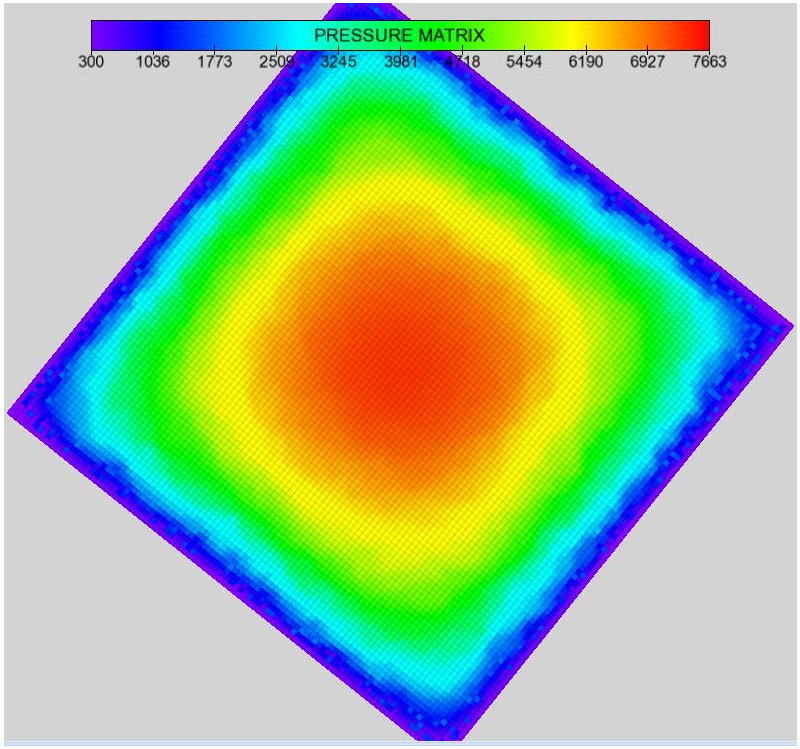

Production Cumulative: Total System
Pc=256
NoIFT
NoPcExcess
Impact of PcExc on EUR
GasOilRatio (SCF/STB)
880.
760.
640.
520.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date


Production Cumulative: Total System
Pc=000
Pc=256
NoPcExcess
Impact of PcExc versus zero Pc on EUR
GasOilRatio (SCF/STB)
960.
820.
680.
540.
CumOilProd (M STB)
560.
420.0
280.
140.
1/2020
1/2030
1/2040
Date

Simulation Examples

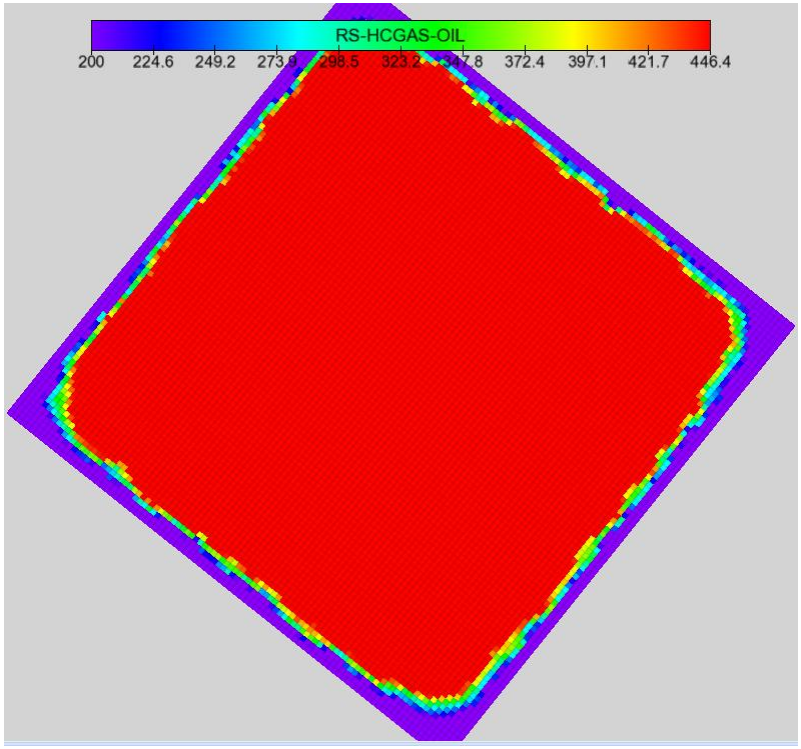


Pc=0.0 case after 30 years production

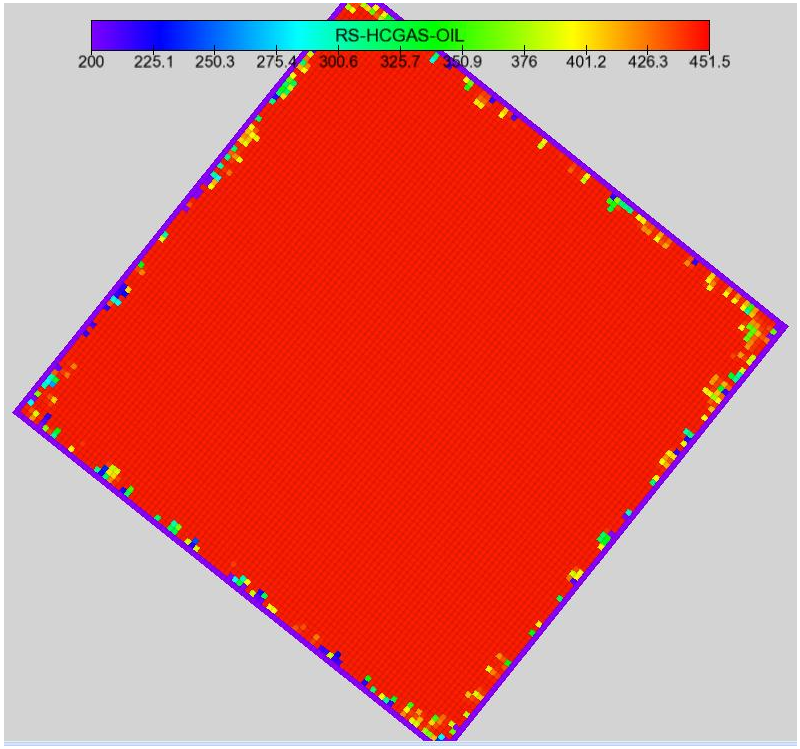


Pe=256 case after 30 years production

Simulation Examples



Pc=0.0 case after 30 years production



Pe=256 case after 30 years production

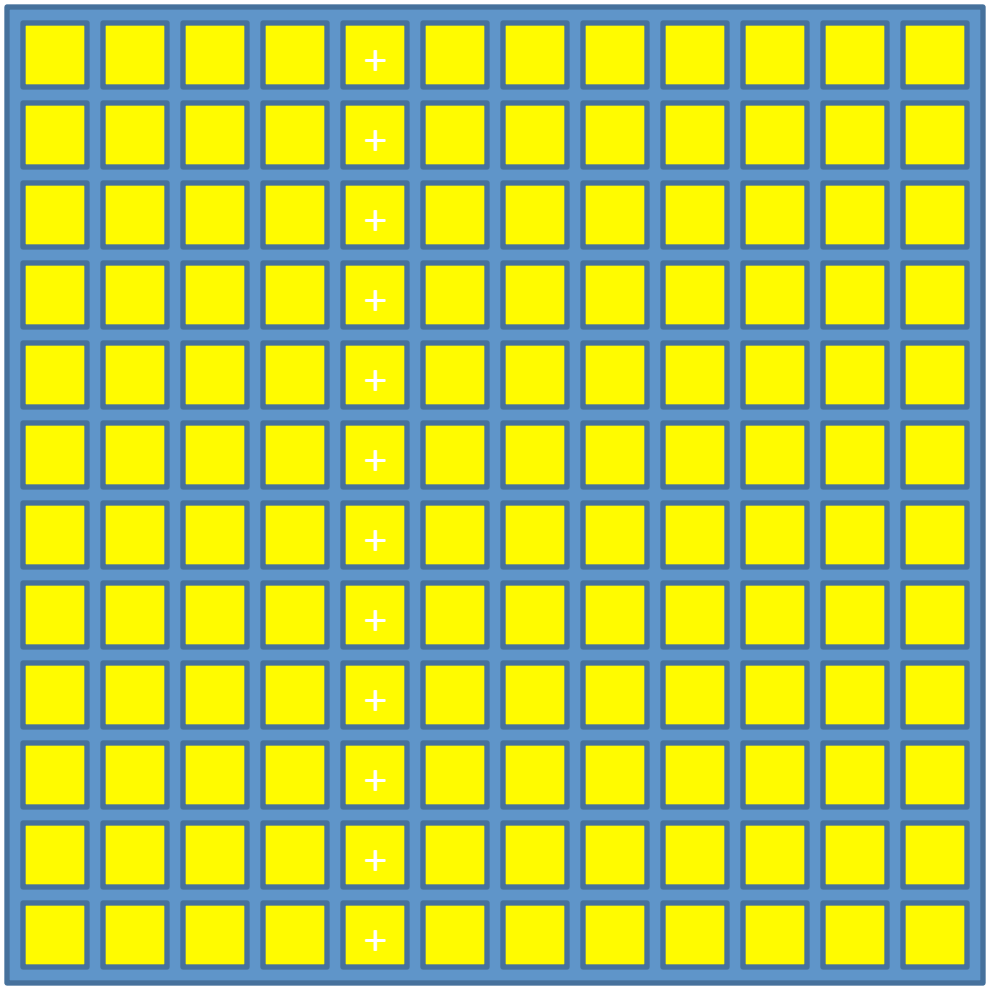
n-Porosity Simulator

- COZSim Enhancements
  - Memory allocation, new arrays
  - Dual-Porosity formulation (not tested)
  - n-Porosity formulation (not tested)
  - Automated pore size bin creation based on Pc
  - Connectivity map of pore size bins

n-Porosity Simulator

- COZView Enhancements
  - Simplified simulation model building for dual-, and n-Porosity models
  - Memory allocation, database issues for dual-porosity models
  - Post-processing for dual-Porosity models (not tested)
  - Memory allocation, database issues for n-Porosity models
  - Post-processing for n-Porosity models

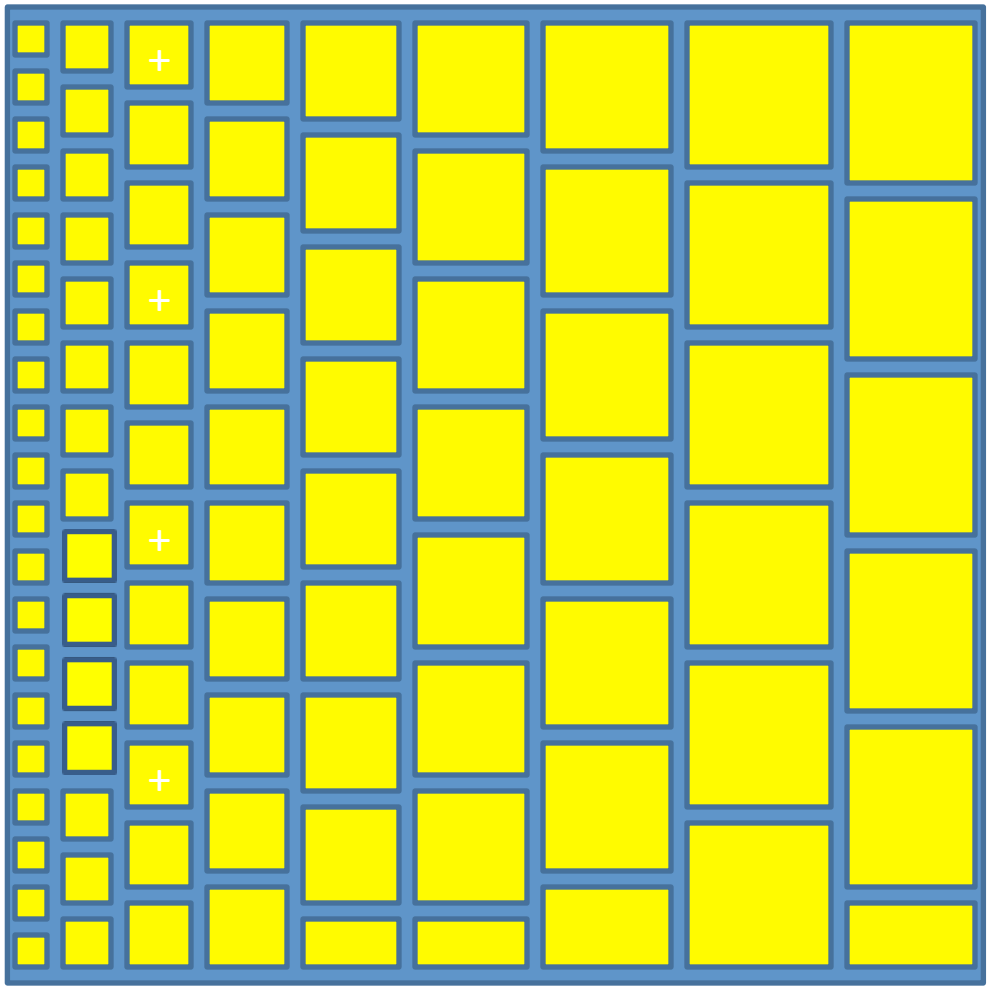
Dual-Porosity Systems



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.

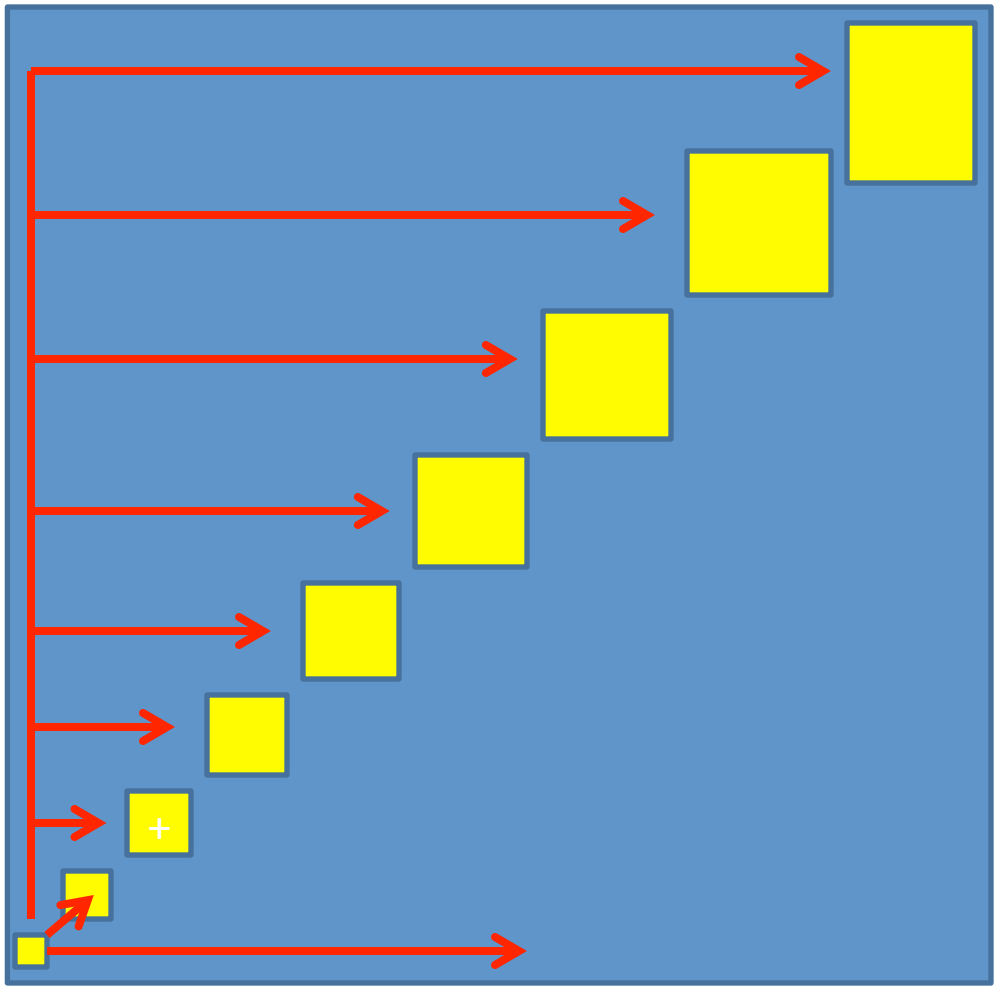
Multiple-Porosity Systems



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

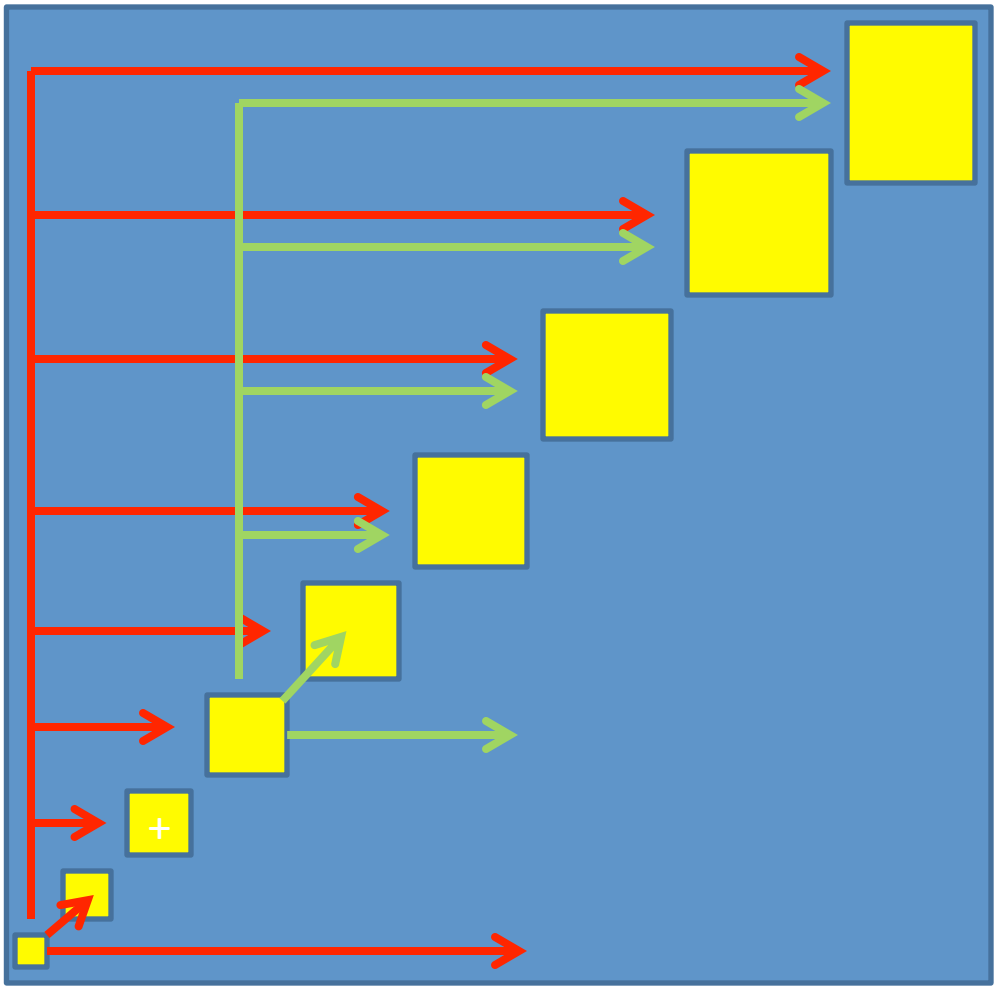
We should have many matrix blocks that represent small pores and few matrix blocks that represent large pores.

Numerical Solution



The new distribution will require the smallest pores to be connected to all of the larger pores, as well as to the natural fractures (or to the largest pores that dominate the flow).

Numerical Solution



Same connectivity logic applies to all of the intermediate pore sizes.

Unconventional Reservoir Engineering Project

Colorado School of Mines

May 3, 2013

Thank You