Research Summary

Bubble Point Suppression in Unconventional Liquids Rich Reservoirs and Its Impact on Oil Production

Tuba Firincioglu, NITEC LLC

Motivation of the Research

Conventional PVT studies do not consider the thermodynamics of confinement

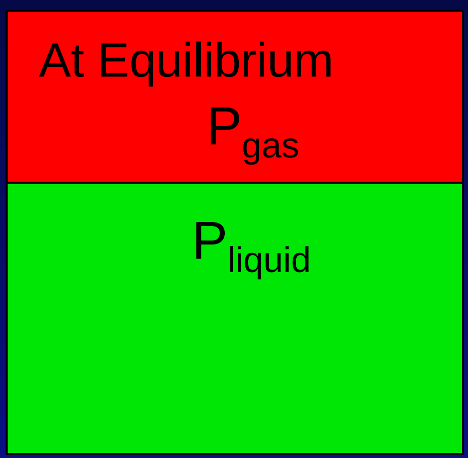
Improve modeling and prediction capabilities of unconventional reservoirs through a better understanding of confined fluid phase behavior.

Motivation of the Research

PVT cell vs. pore-confinement

PVT Cell (Bulk)

The interface is flat

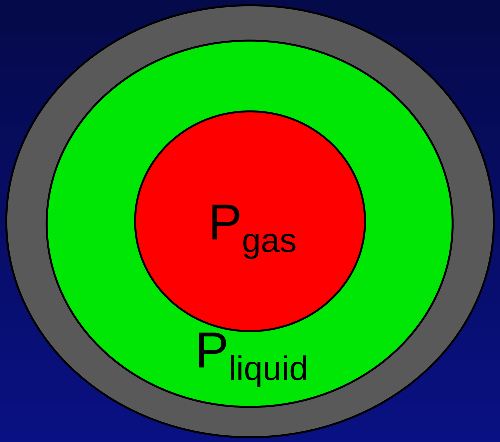


$$p_{gas} = p_{liquid} = p_b$$

Gas phase appears at bubble-point pressure

Confined Environment

The interface is curved



$$p_{gas} - p_{liquid} = p_c + \Pi$$

$$p_{gas} \neq p_{liquid} \quad \Rightarrow \quad p_b = ?$$

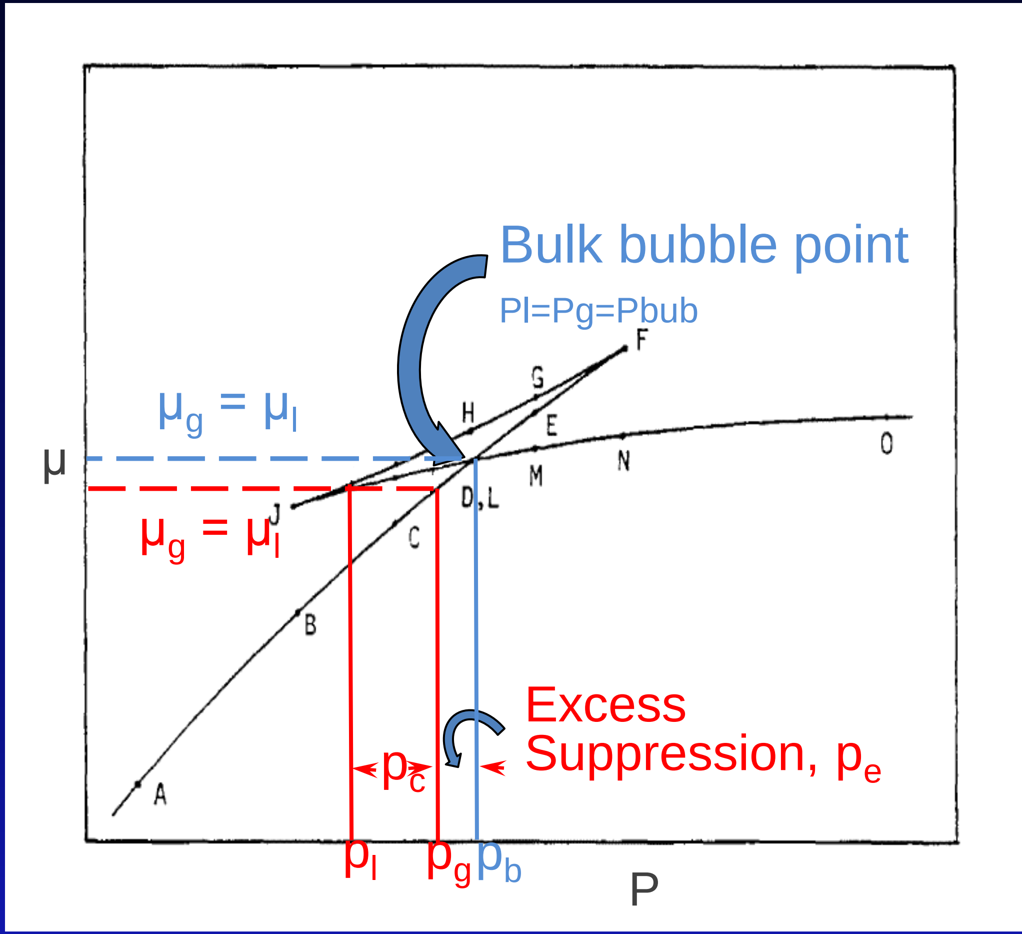
Motivation of the Research

Example: Phase equilibrium and excess suppression for a pure component

$$p_b(PVT) = p_{liquid} + p_c + \Pi + p_e$$

p_c and , may be available

p_e, to be determined from VLE



Modified from Udell, 1982

Conducted Research

In this research:

- Impact of confinement on phase behavior was investigated
  - Bubble point suppression and P_e was quantified using VLE for HC mixtures
- a correlation has been developed for P_e vs. R_s
- the impact of confined phase behavior on flow has been demonstrated by black-oil simulation

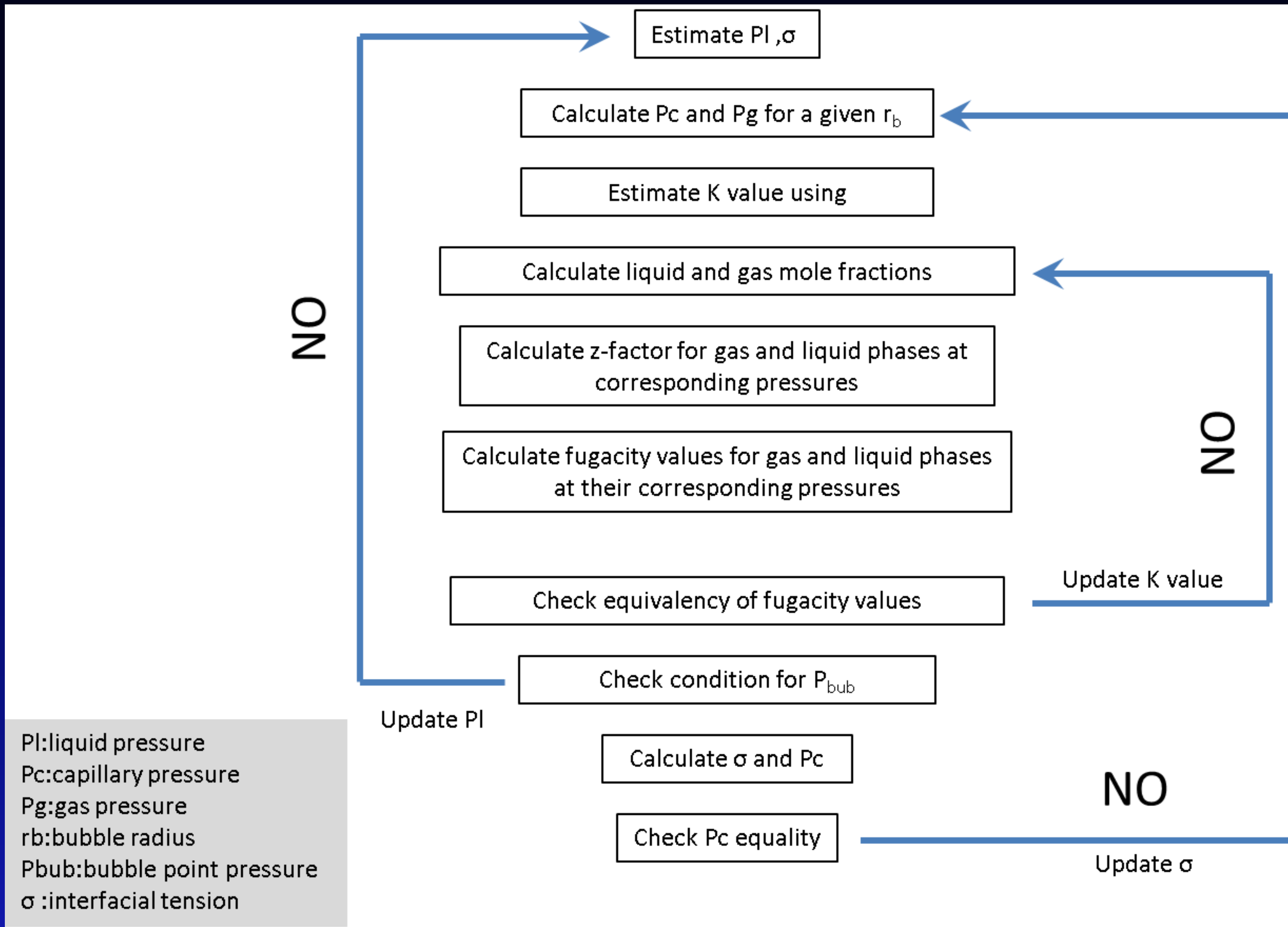
Outline

- Confined PVT Modeling Approach and Results
- Correlation for Excess Suppression
- Demonstration of the Impact on Flow Using a Black Oil Simulator
- Conclusions
- Recommendations for Future Work

Modeling Approach

- VLE was solved for two pressures (P_l and P_g) for the two phases
- Capillary K value (K_c) definition is used
- PR EOS was utilized
- EOS parameters for three fluid samples that were determined through regression to lab measurements were input

Modeling Approach – Flow Diagram



Application and Results

Three unconventional-reservoir samples

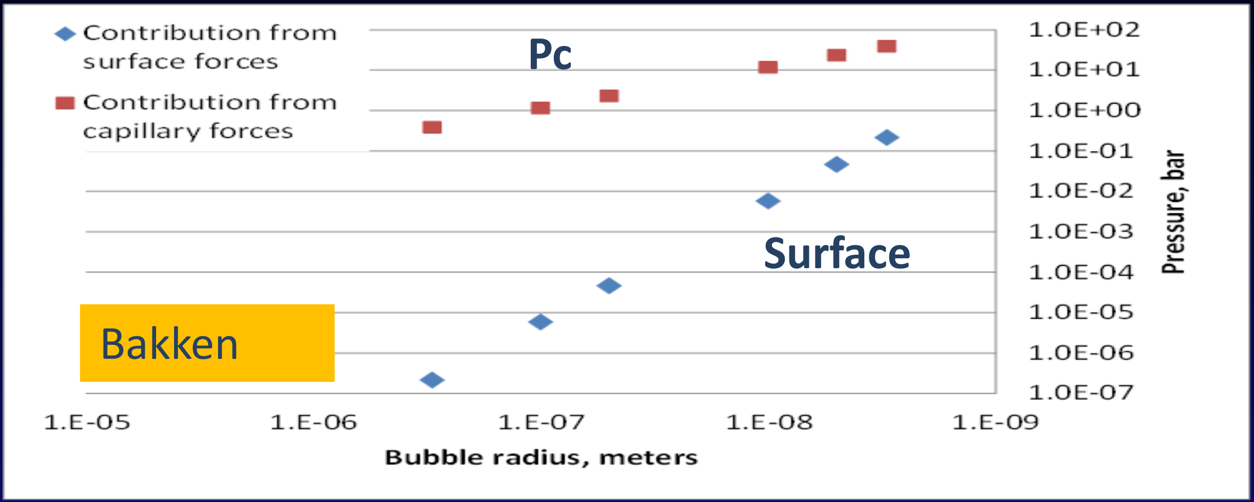
Sample 1: Monterey
Sample 2: Bakken
Sample 3: Eagle Ford

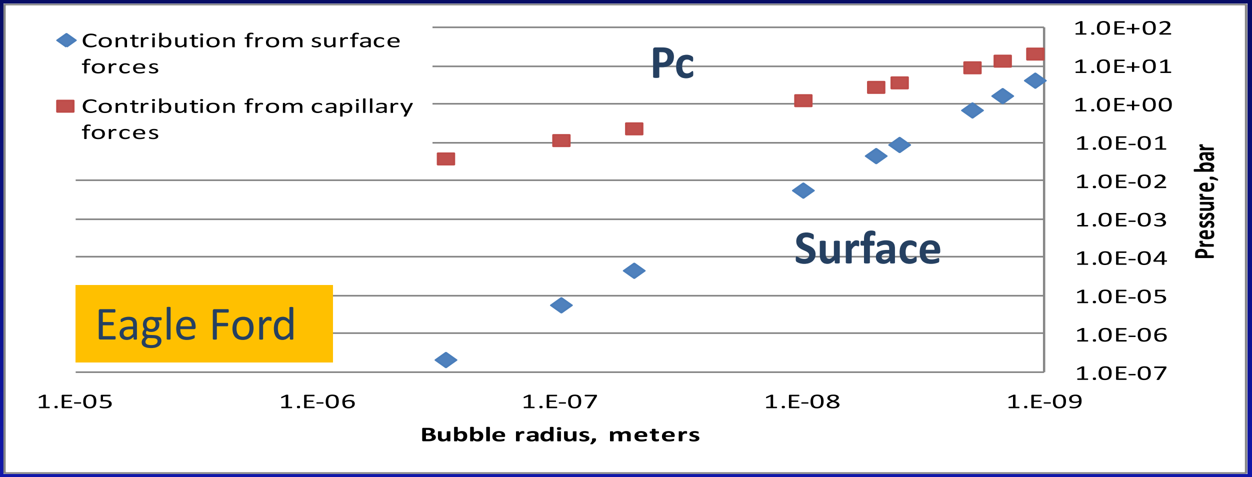
Application and Results

Investigated:

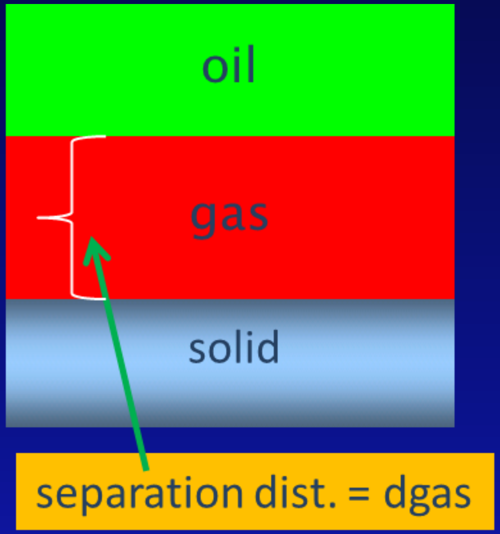
- Contribution of Surface Forces
- Confined Bubble Point Pressure
- Relationship between bubble and pore size
- Changes in Gas Composition at P_{bubble}
- Impact on Formation Volume Factor

Application and Results – Impact of Surface Forces



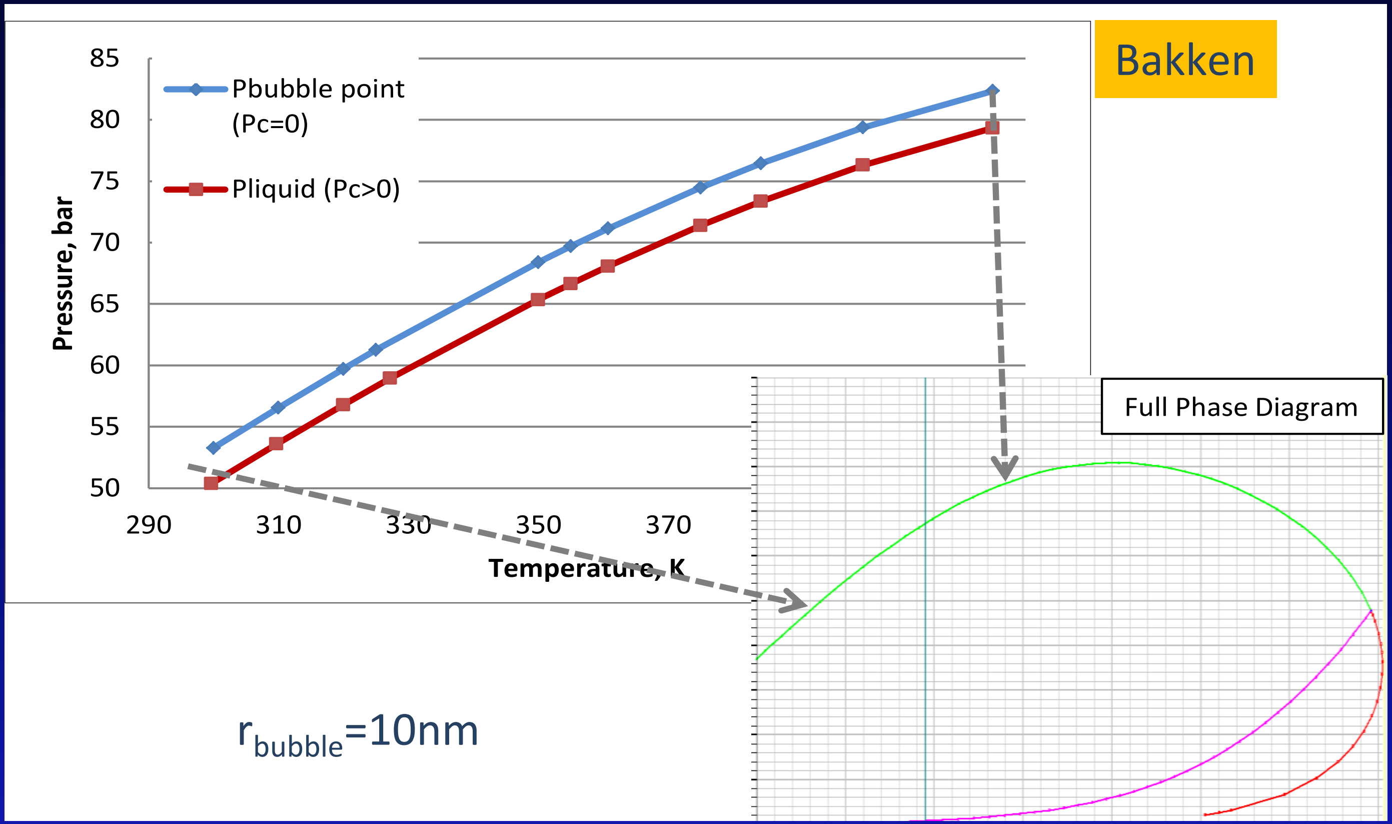


$$P_g - P_l = \frac{2\sigma}{r} + \Pi$$

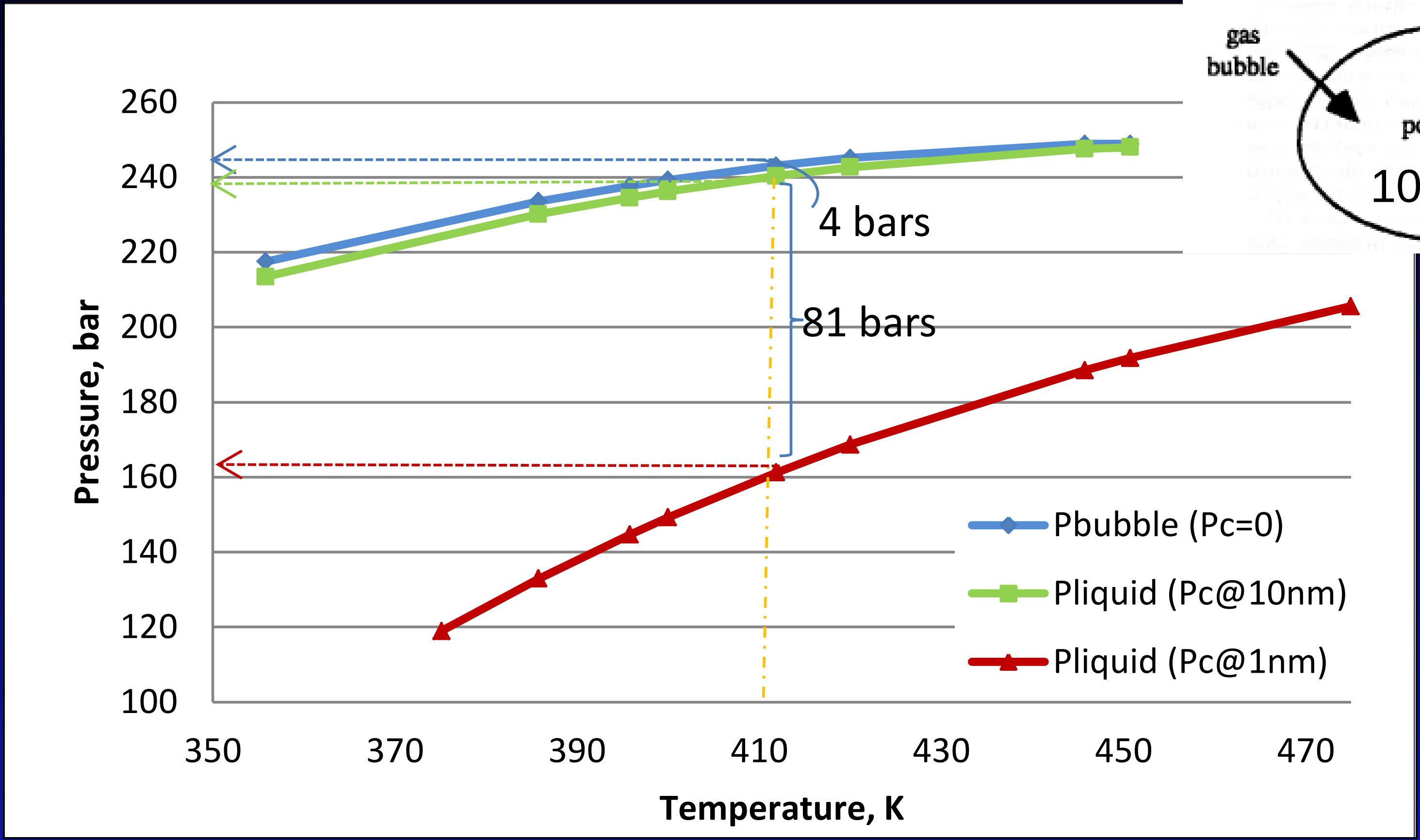


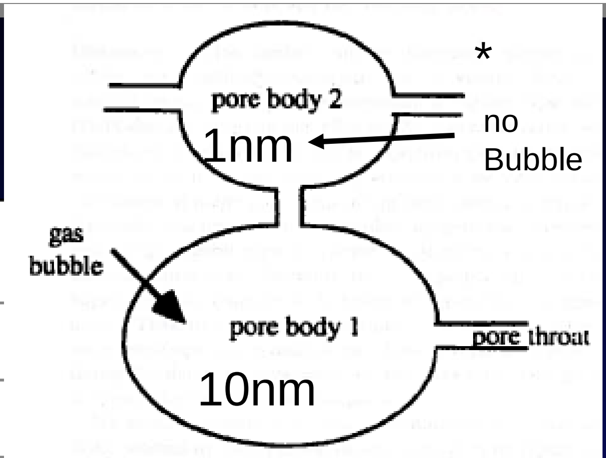
Application and Results – Bubble Point Suppression

Phase Diagram Shift / Bubble point suppression



Application and Results – Bubble Point Suppression

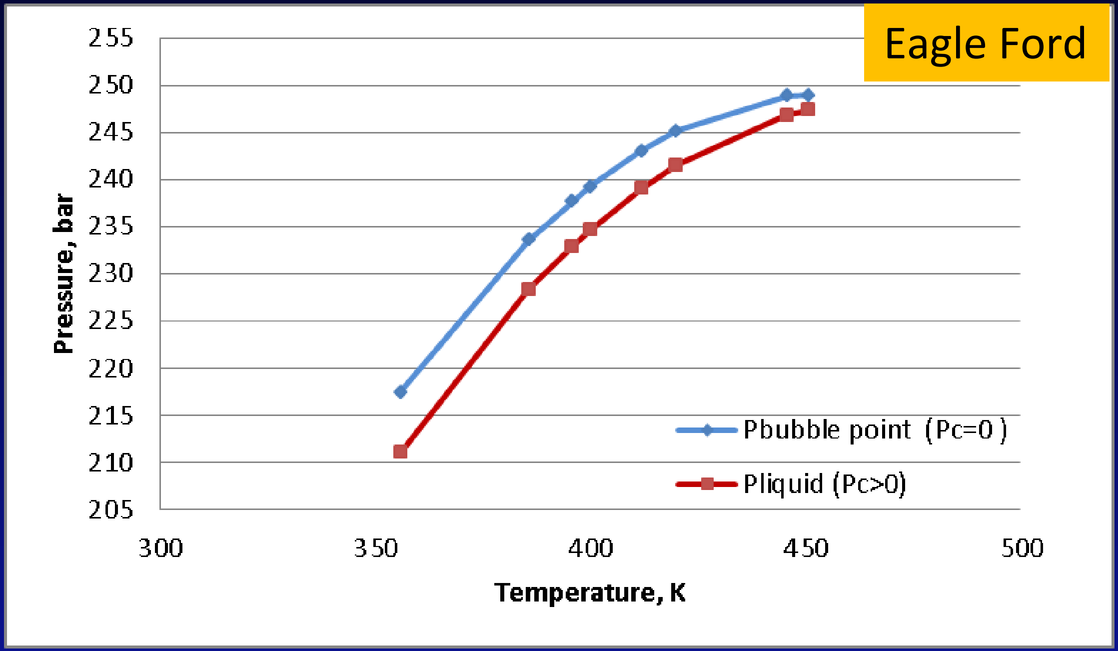




*(Mod from Kamath and Boyer, 1995)

Application and Results – Bubble Point Suppression

Phase Diagram Shift . Suppression decreases as the critical point is approached.



$$P_g - P_l = \frac{2\sigma}{r}$$

r_{bubble}=10nm

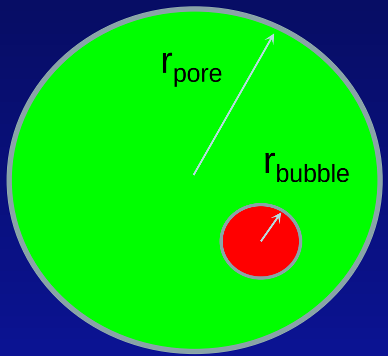
Application and Results – Pore size vs. bubble size

Oil Volume in Equilibrium with the First Gas Bubble
Possible pore sizes…

One approach is to assume that the gas bubble occupies the entire pore space

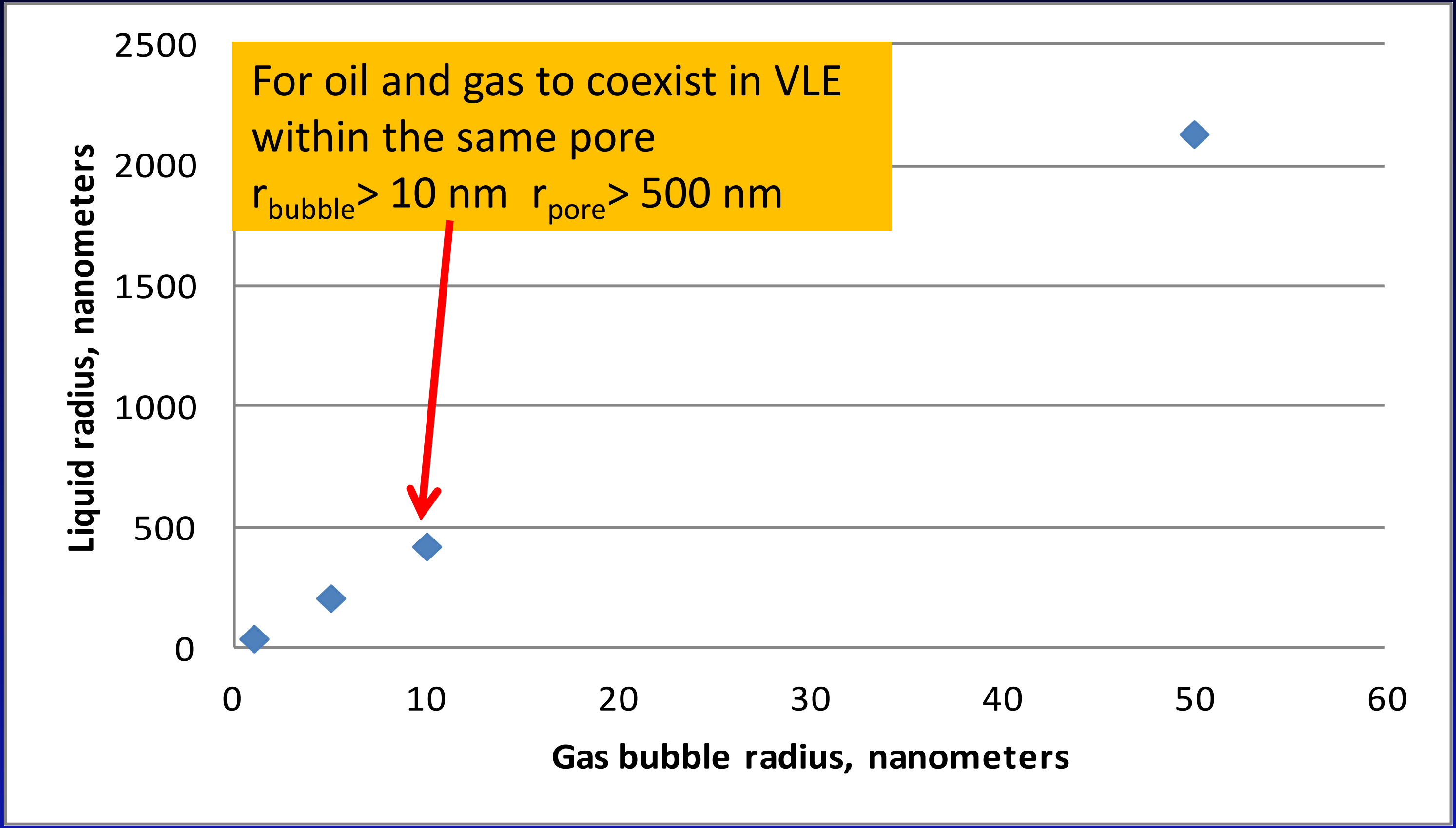
$r_{bubble} = r_{pore}$

We investigate the gas bubble being in equilibrium with the oil that occupies the rest of the pore



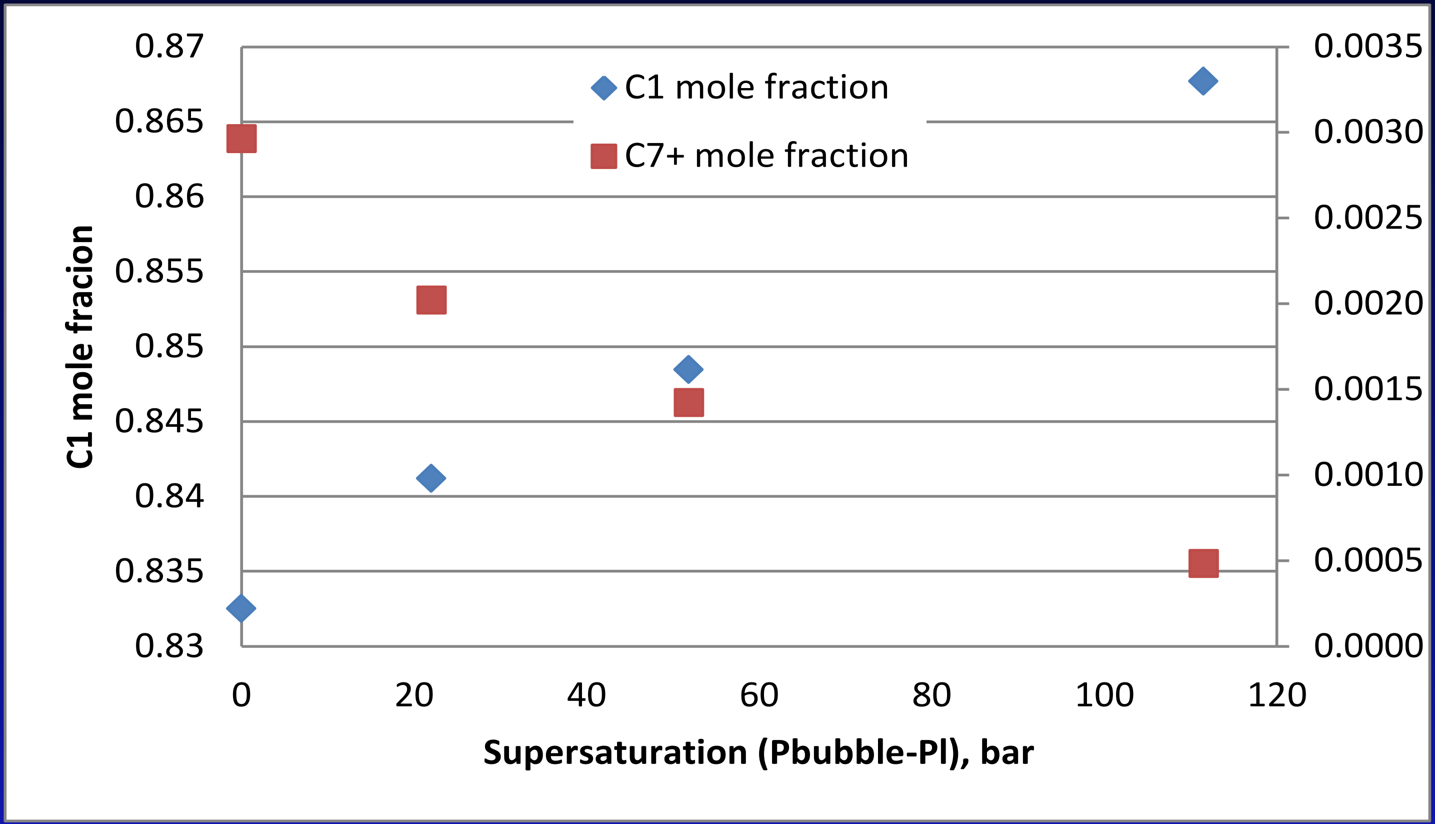
At bubble point gas bubble is infinitesimal

Application and Results – Pore size vs. bubble size



Application and Results – Gas composition at P_{bub}

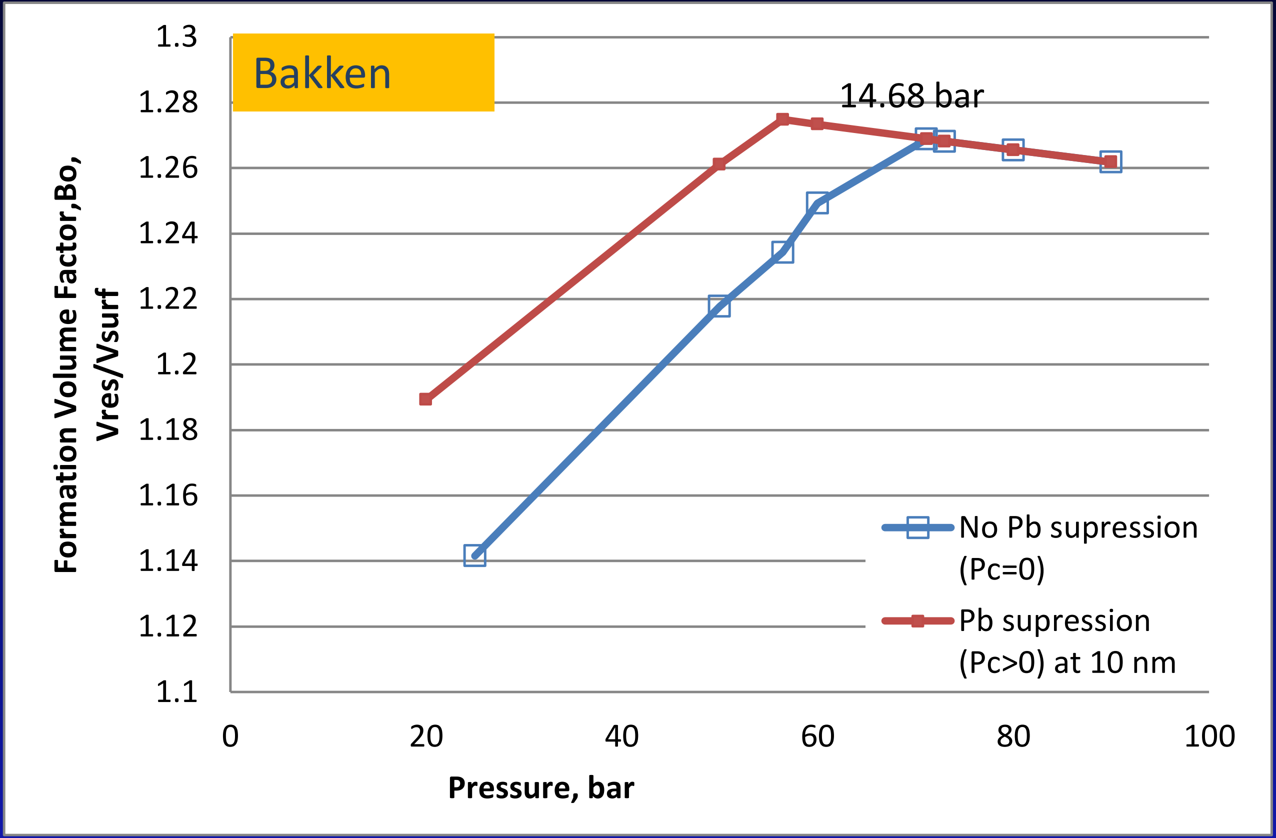
The gaseous phase contains lighter components as the bubble-point suppression increases.



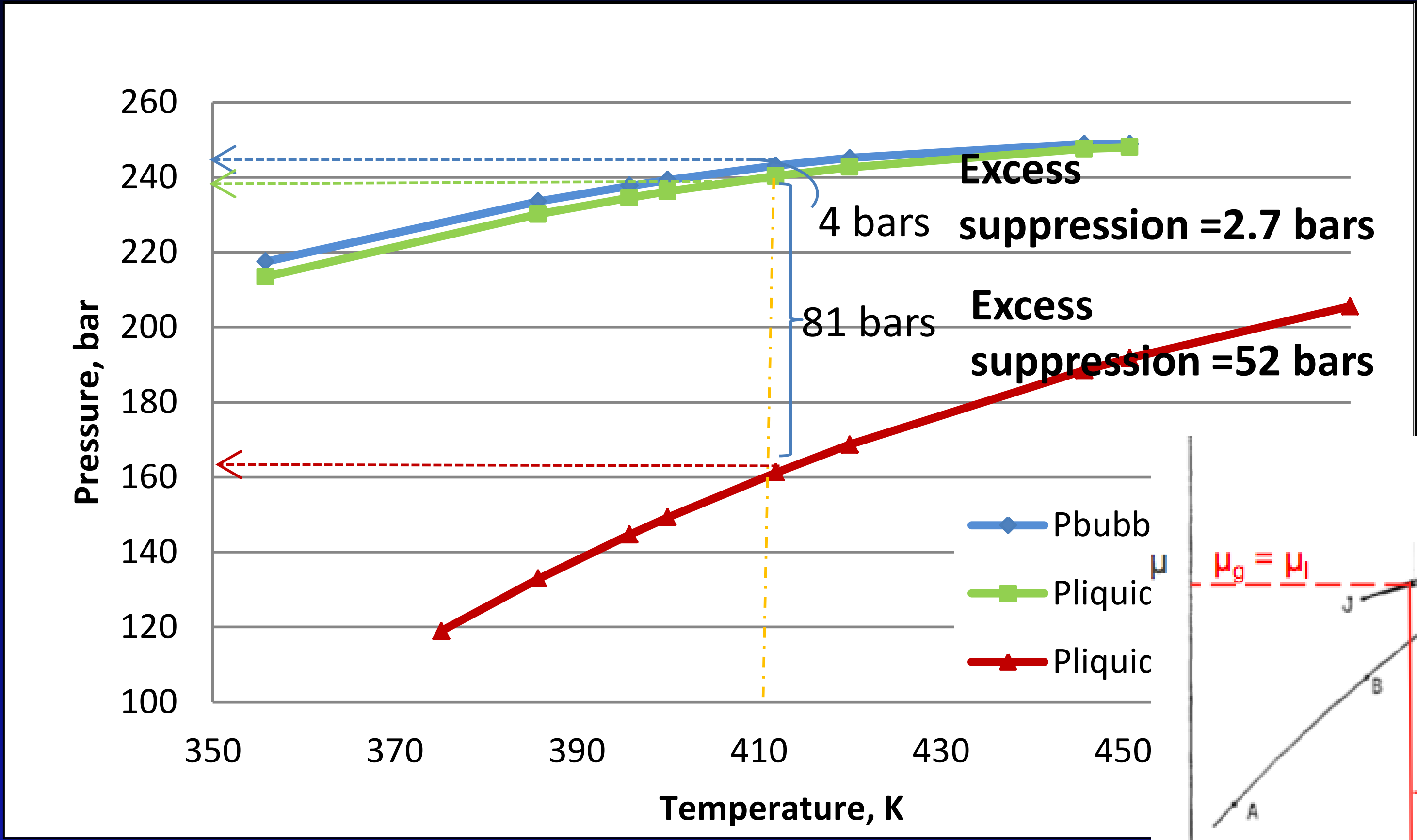
Possible impact on gas growth and diffusion

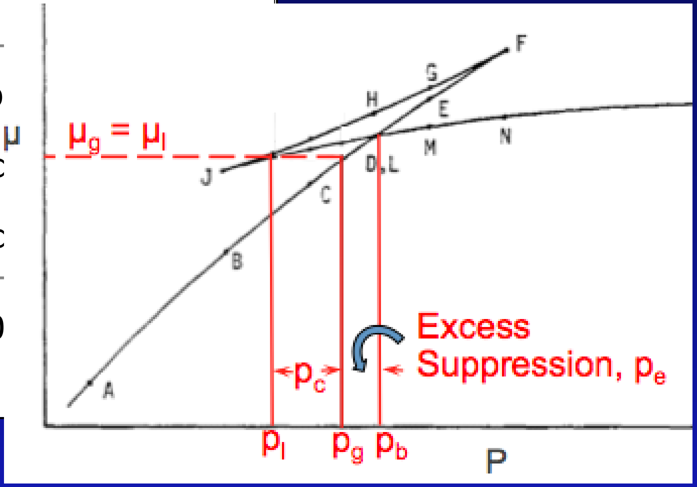
Application and Results – Formation volume factor

Undersaturated portion of the curve is extended



Application and Results – Excess suppression





Correlation for Excess Suppression

- One of the objectives of this research was to formulate the findings in a form that can be integrated into appropriate numerical simulators.
- Black oil formulation which is most commonly used in oil reservoirs was selected for this purpose

Correlation for Excess Suppression

Total Suppression = $P_c + P_{excess}$

Excess suppression needs to be input to the black oil simulator

Must be correlated to the bulk black oil properties (measured or calculated)

Correlation for Excess Suppression

The bulk and confined properties of the three samples used in the analysis were calculated for a series of bulk saturation pressures (i.e. compositions)

Bulk Properties					Confined Properties					
Psat, bar	MW	Bo, Vres/Vsurf	oil surface density, gr-mol/cm3	Rs, cm3/cm3	Pliq (Psat), bar	Pgas, bar	r, cm	ift, dynes/cm	Pc, bar	Excess supression, bar
70	124.60406	1.266311	0.734729	62.33742	62.6333	68.4687	2.00E-06	5.8355	5.8354	1.5313
70	124.60406	1.266311	0.734729	62.33742	60.1706	67.9617	1.50E-06	5.8435	7.7911	2.0383
70	124.60406	1.266311	0.734729	62.33742	55.2371	66.9527	1.00E-06	5.8581	11.7156	3.0473
70	124.60406	1.266311	0.734729	62.33742	40.4154	63.9751	5.00E-07	5.8904	23.5597	6.0249
70	124.60406	1.266311	0.734729	62.33742	20.7639	60.1409	3.00E-07	5.9066	39.3771	9.8591
65	126.8538	1.254800	0.734509	58.56951	57.4140	63.5149	2.00E-06	6.1010	6.1009	1.4851

Correlation for Excess Suppression

Composition drives the capillary pressure and the excess suppression

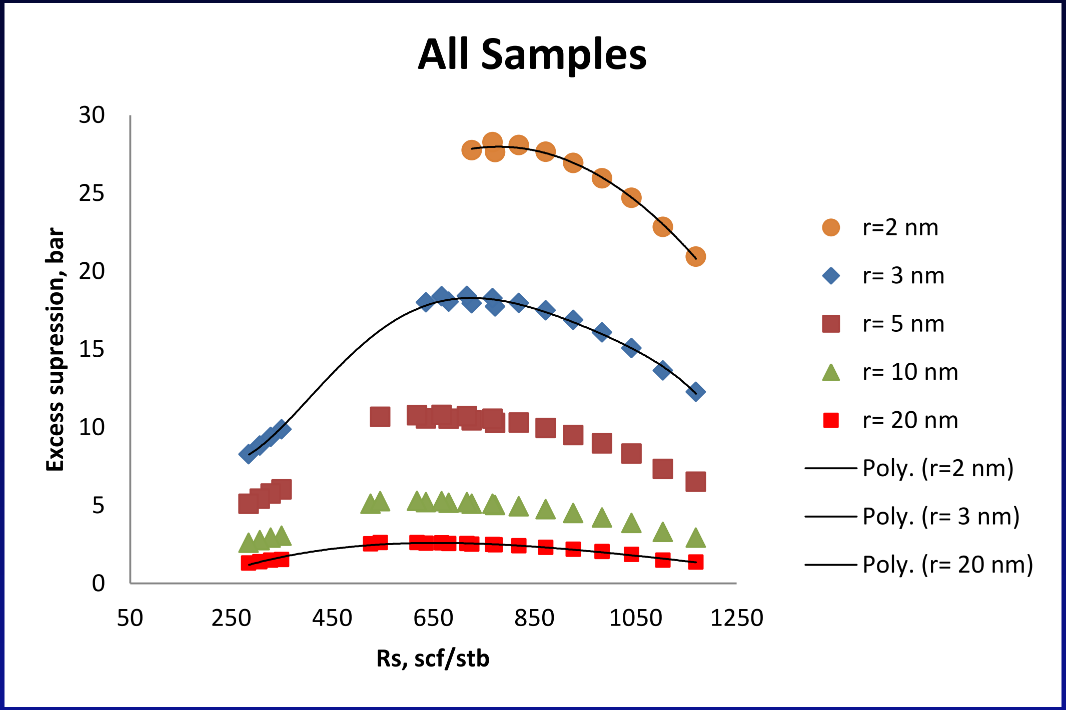
Properties that represent the composition was correlated to excess suppression

MW for compositional formulation
R_s for black oil formulation

Only R_s relationships will be demonstrated in this presentation.

Correlation for Excess Suppression

Absolute value of excess suppression

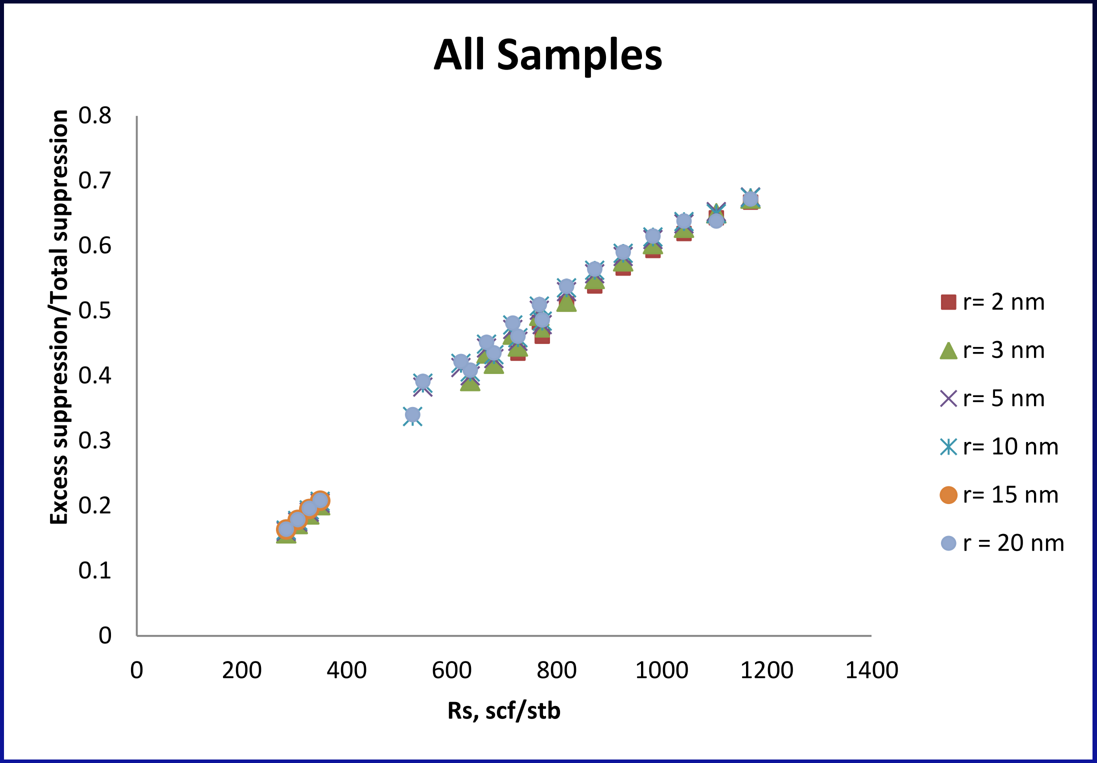


Decreases as a function of radius
Same trend for all the radii
Peaks at Rs=650 and then reduces

Total suppression levels are different for different compositions; ***normalization is necessary***

Correlation for Excess Suppression

Excess suppression ratio = Excess/total (Pc+excess)

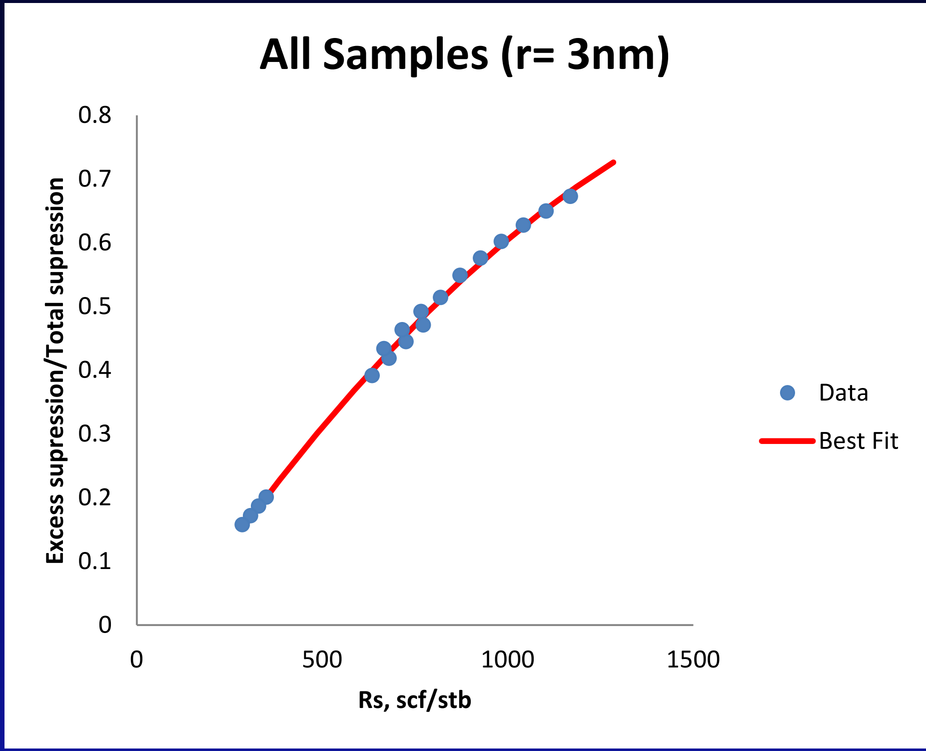


Very good trend for all the samples and radii

A single correlation suffice

Correlation for Excess Suppression

Excess suppression ratio



$$\frac{Excess\ Suppr.}{Total\ Suppr.} = 2.1x10^{-7}R_s + 0.0009R_s - 0.1022$$

The correlation is very good for the data evaluated.

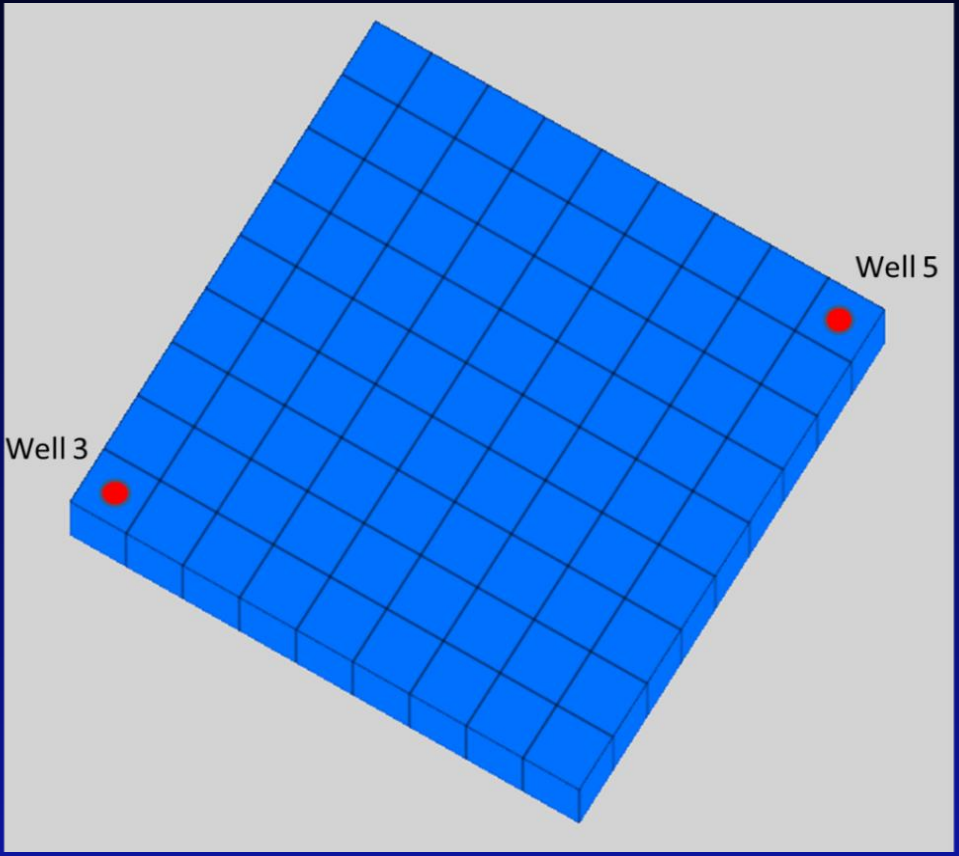
Impact on Flow

- A third party simulator (COZSim) was used to evaluate the impact of confined fluid behavior on flow.
- COZSim evaluates the oil and gas PVT properties at the corresponding pressures
- The formulation was extended to include the excess suppression correlation generated as part of this study

Impact on Flow

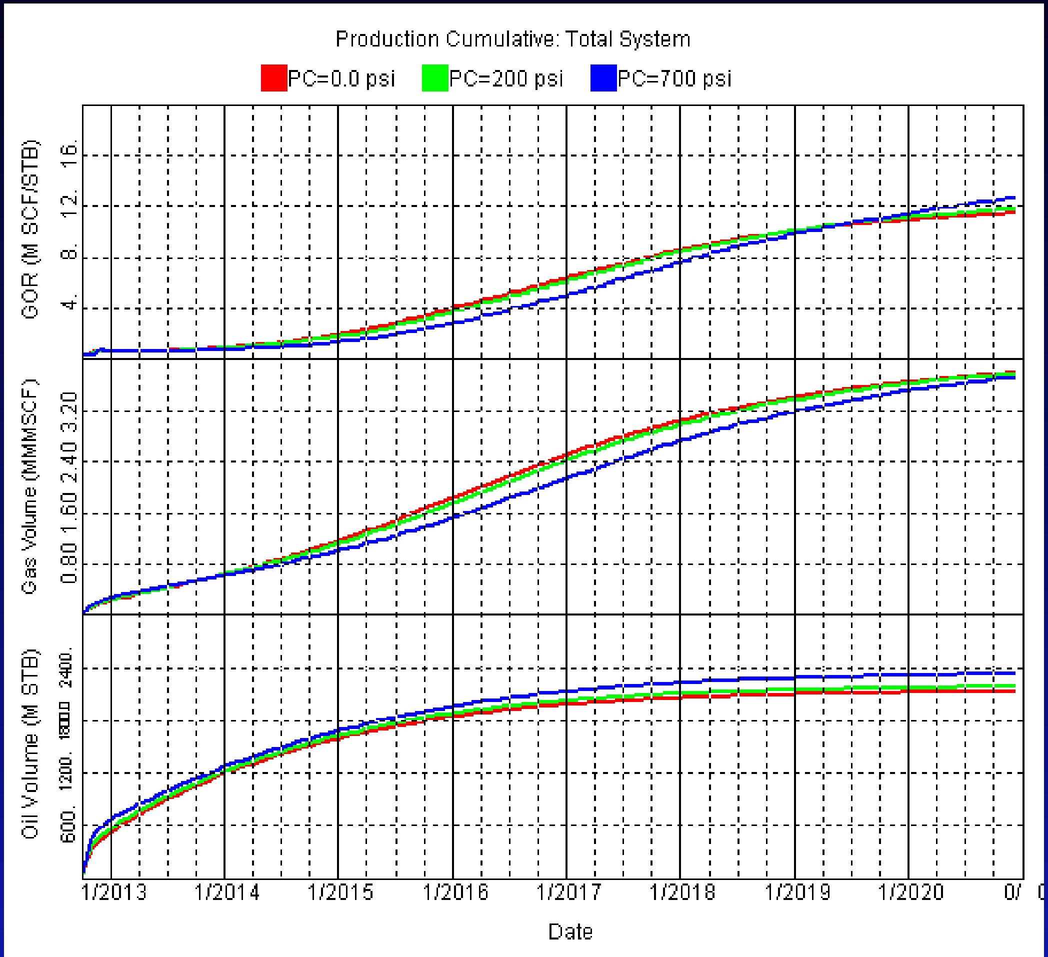
- Conceptual simulation datasets were generated and ran with and without the confinement impact.
- Oil is initially undersaturated.
- Constant Pcog was specified for each grid block (No curve)

Impact on Flow – Uniform Pcog

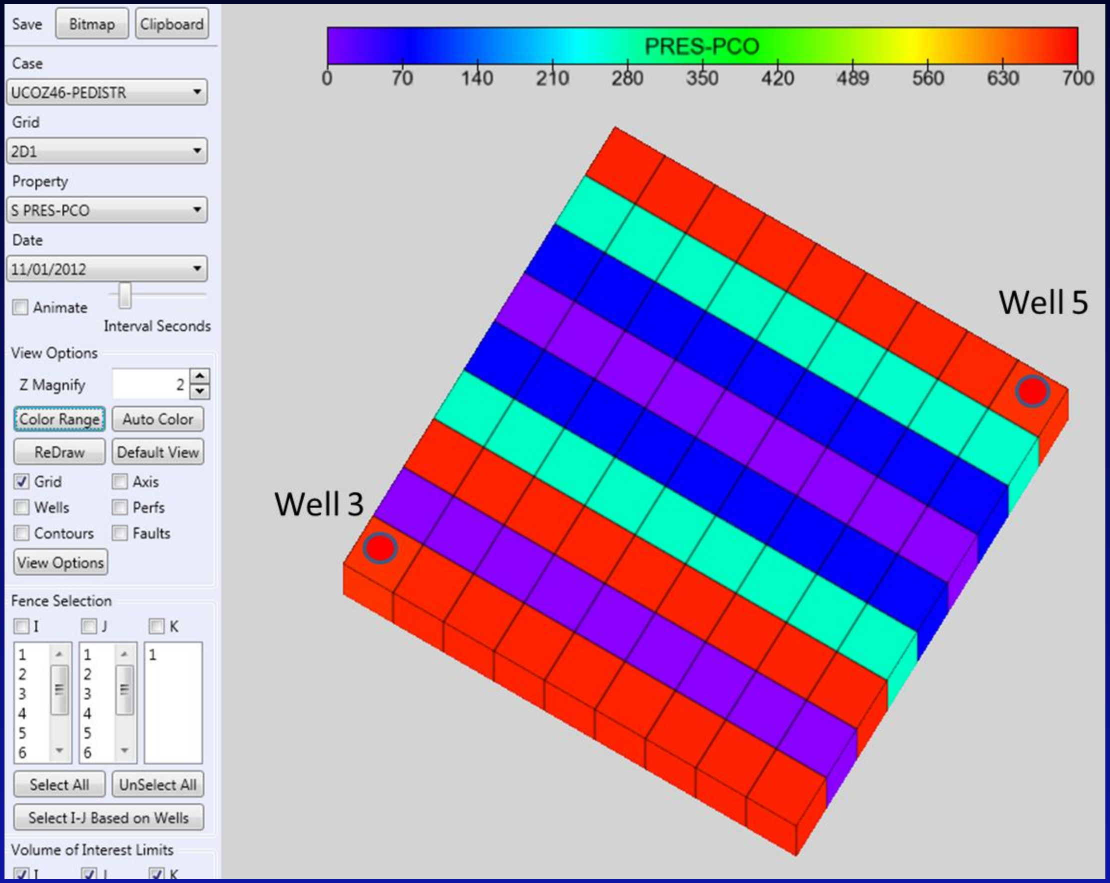


Grid: 9x9x1
100ft

Impact on Flow – Uniform Pcgo



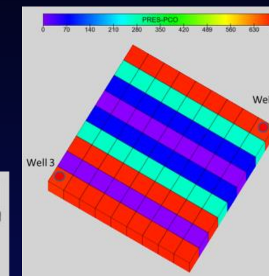
Impact on Flow – Simple distribution of Pcgo



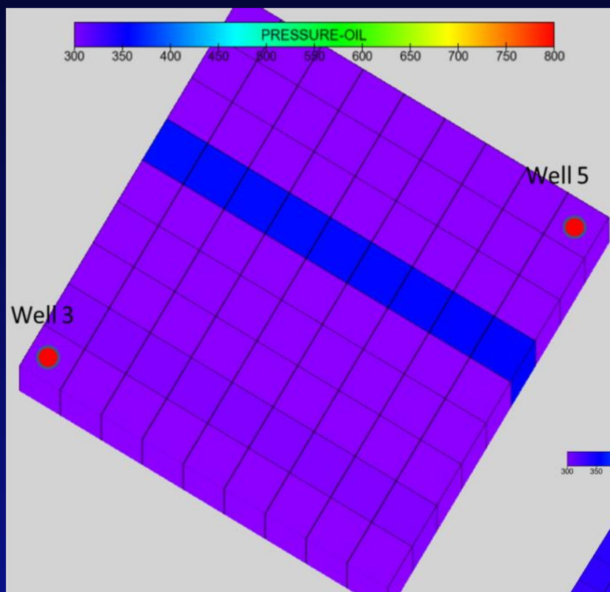
Grid=9x9x1
100ft

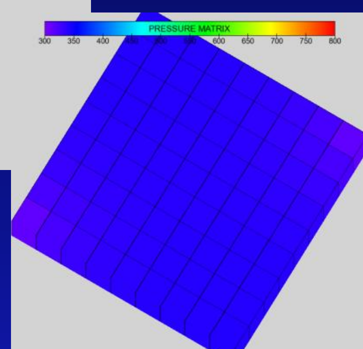
Uniform properties except Pcog

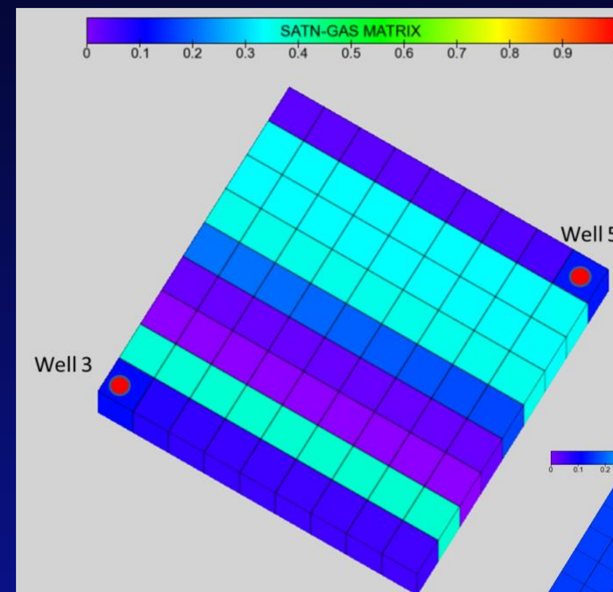
Impact on Flow – Simple distribution of Pcgo

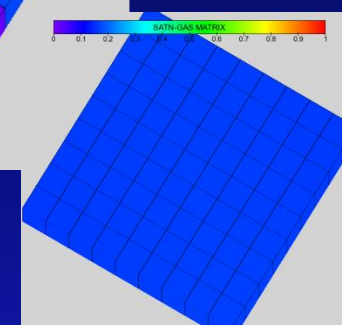


Same pressure different gas saturation levels





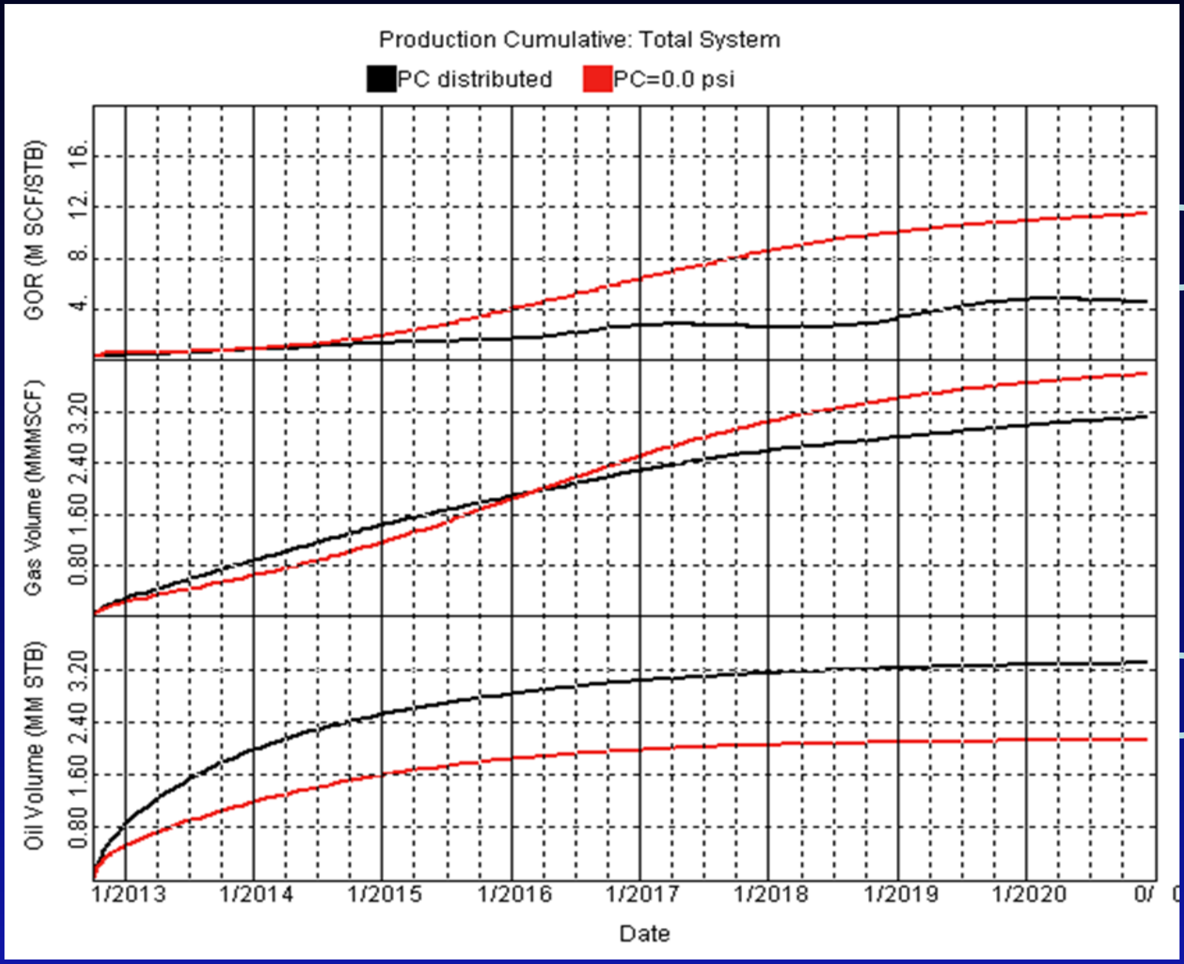




Conventional (Pc=0.0)

Conventional (Pc=0.0)

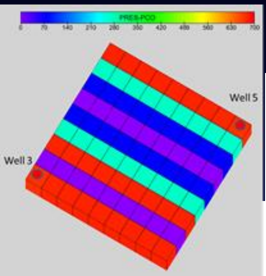
Impact on Flow – Simple distribution of Pcgo



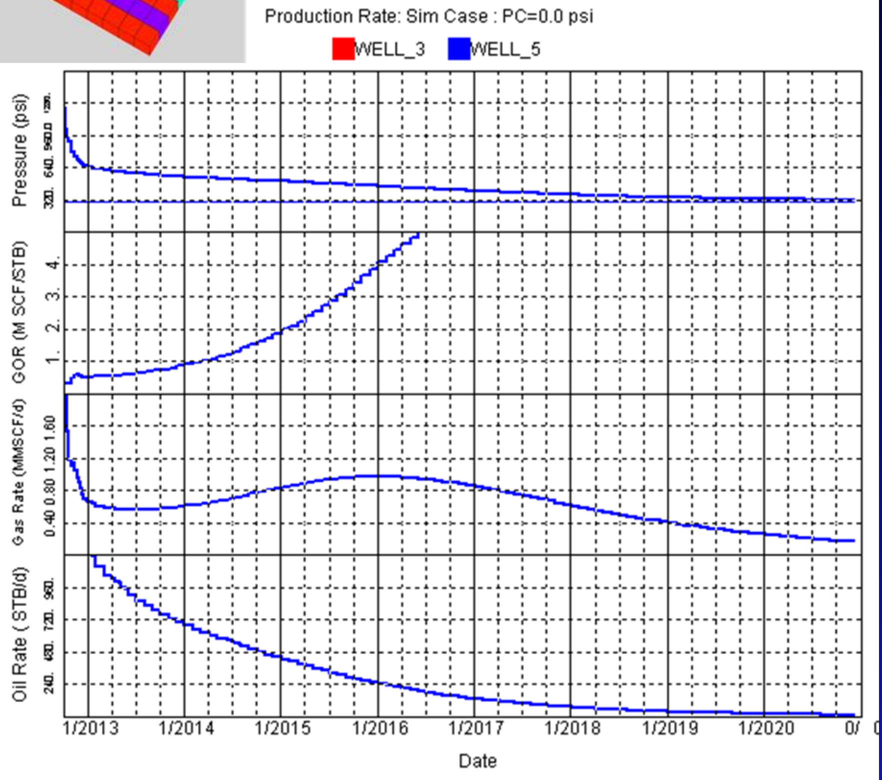
Lower GOR due to suppression

Extra oil production due to lower GOR

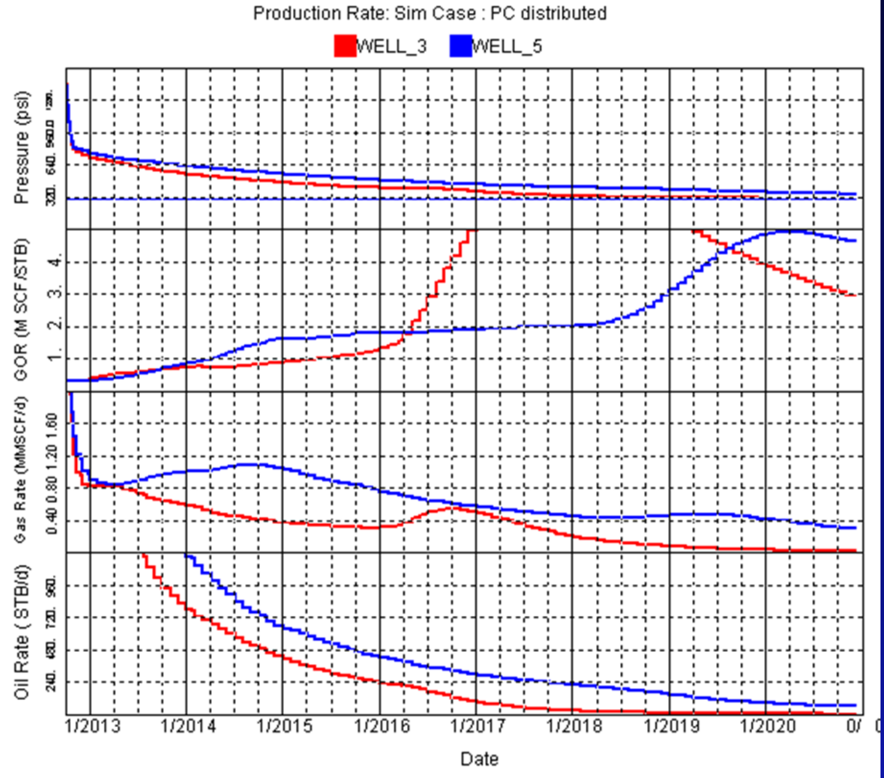
Impact on Flow – Simple distribution of Pcgo



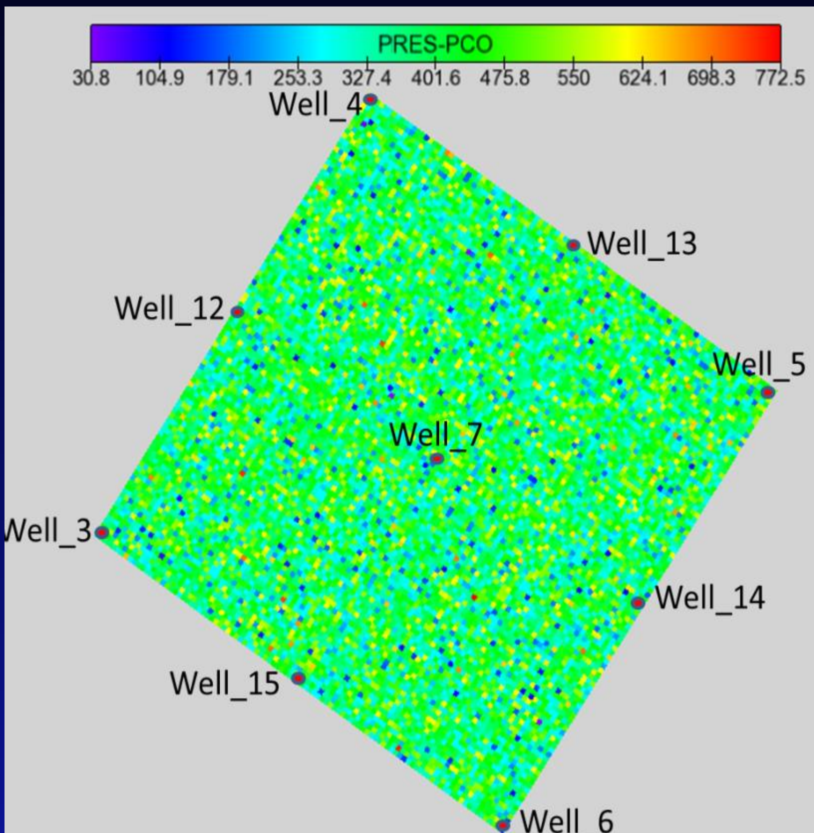
Conventional PVT ($p_c = 0$)
Well responses identical

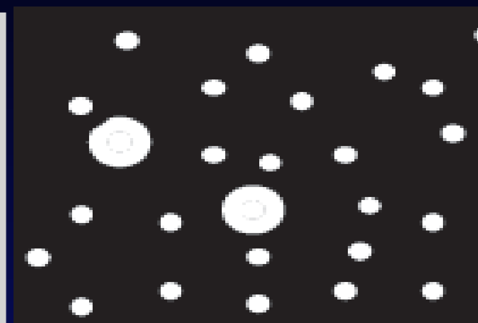


Confined PVT ($p_c > 0$)
Well responses differ based on the surrounding suppression distribution

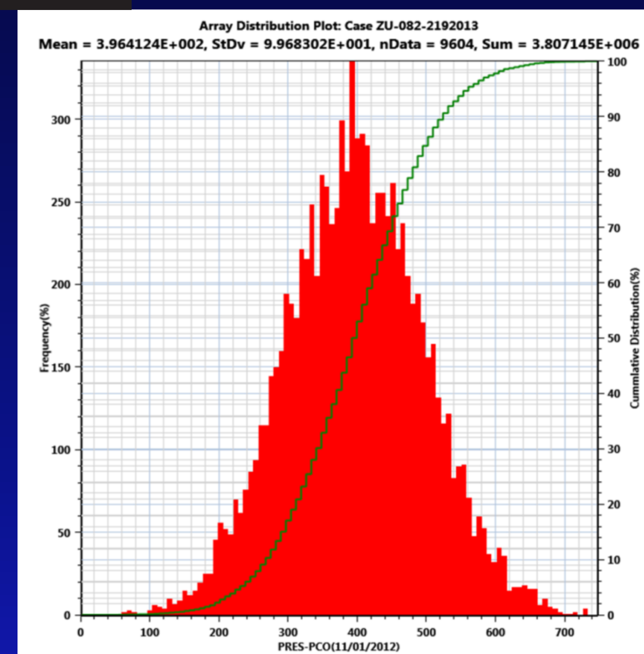


Impact on Flow – Random distribution of Pcgo





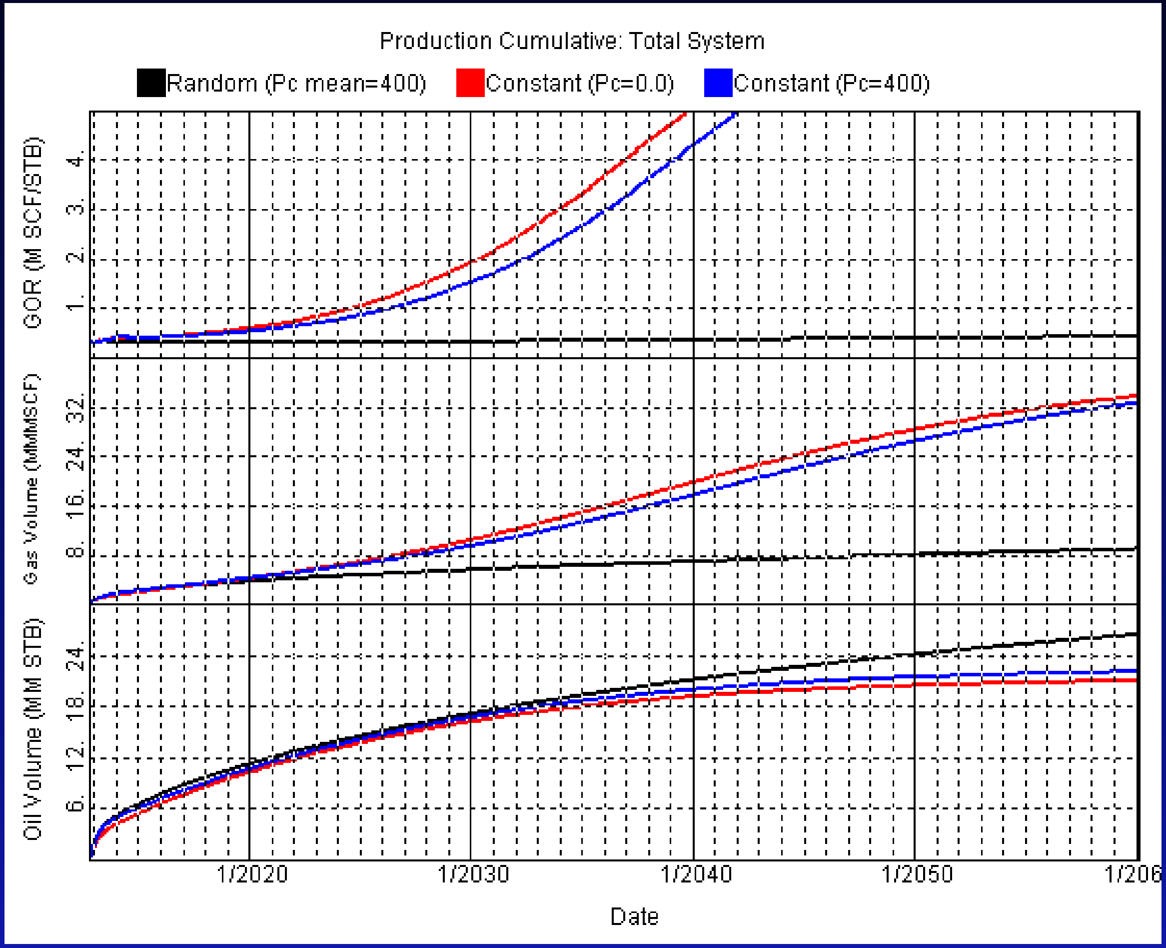
Mean = 400



Grid: 100x100x1

100ft

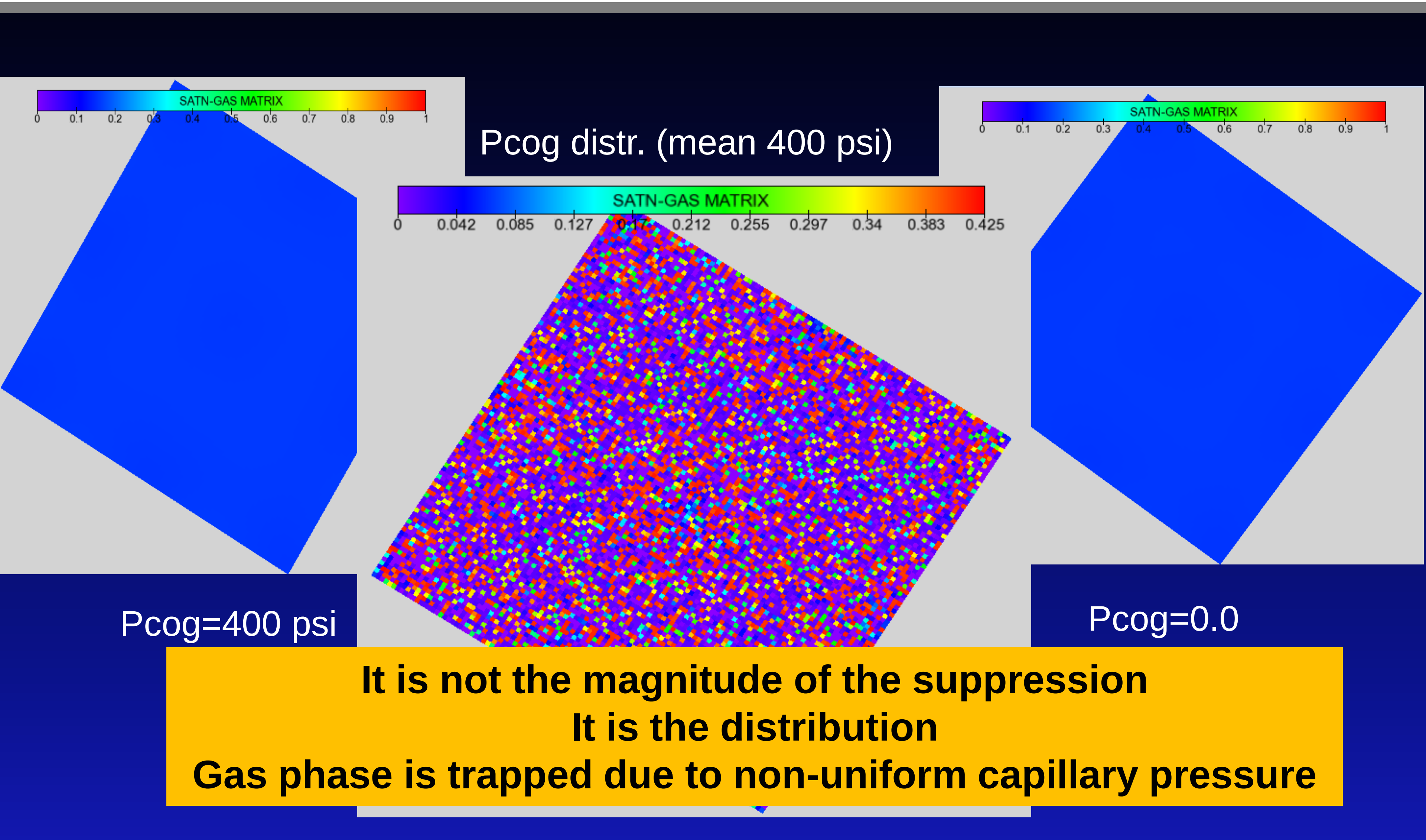
Impact on Flow – Random distribution of Pcgo



GOR behaviors of uniform and no suppression are similar

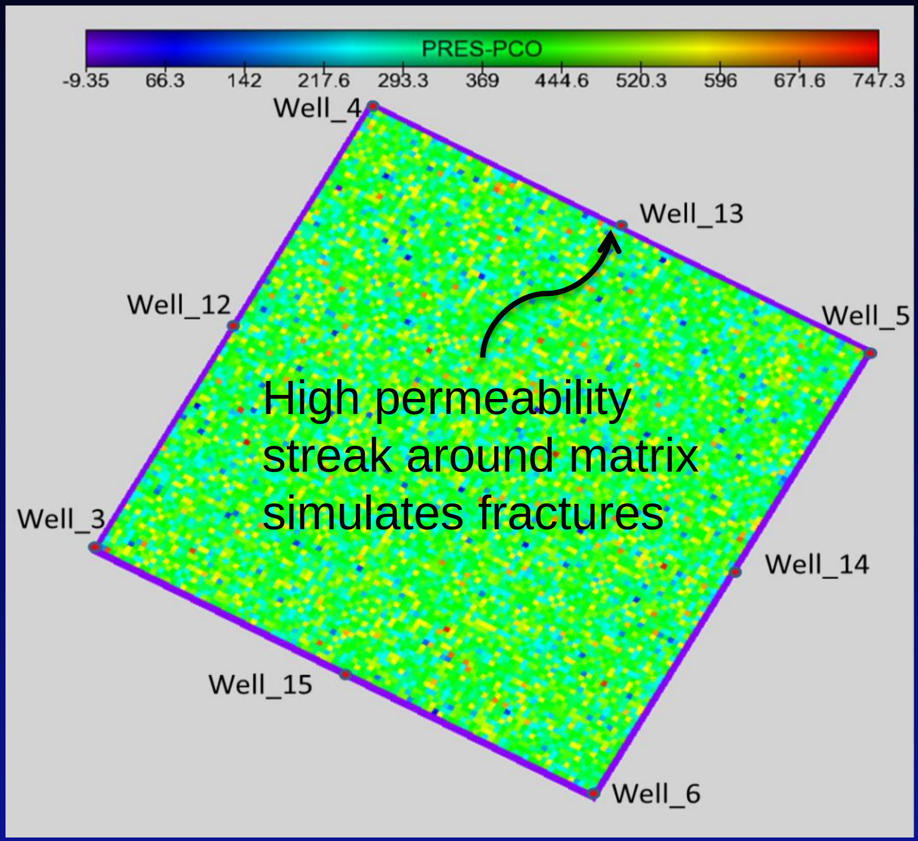
Distributed suppression creates significant deviation from the other cases

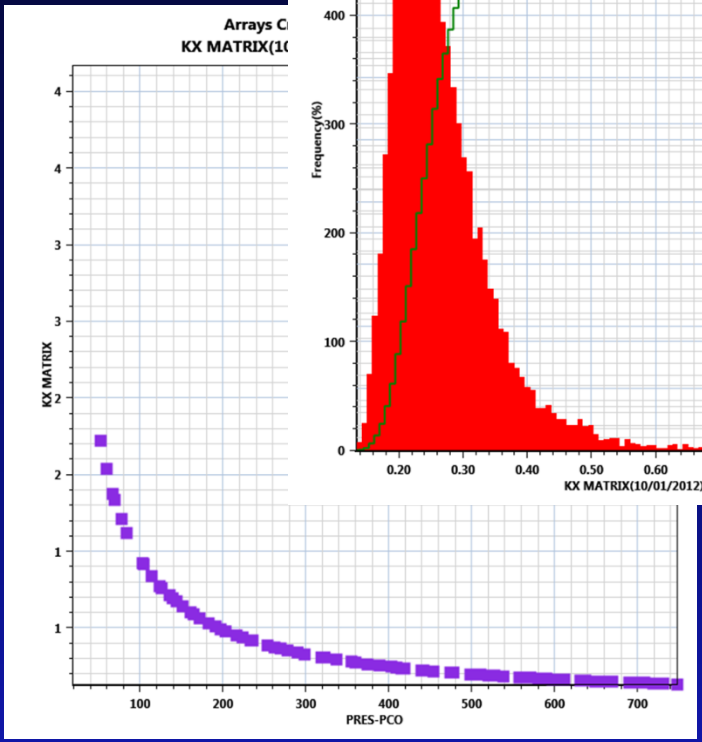
Impact on Flow – Random distribution of Pcgo

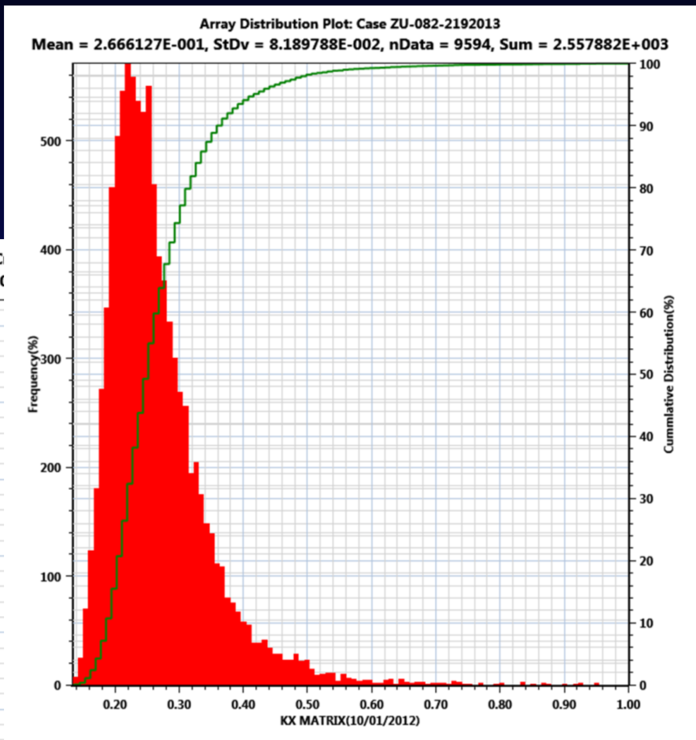


It is not the magnitude of the suppression
It is the distribution
Gas phase is trapped due to non-uniform capillary pressure

Impact on Flow – Random Pcgo and perm. with frac.



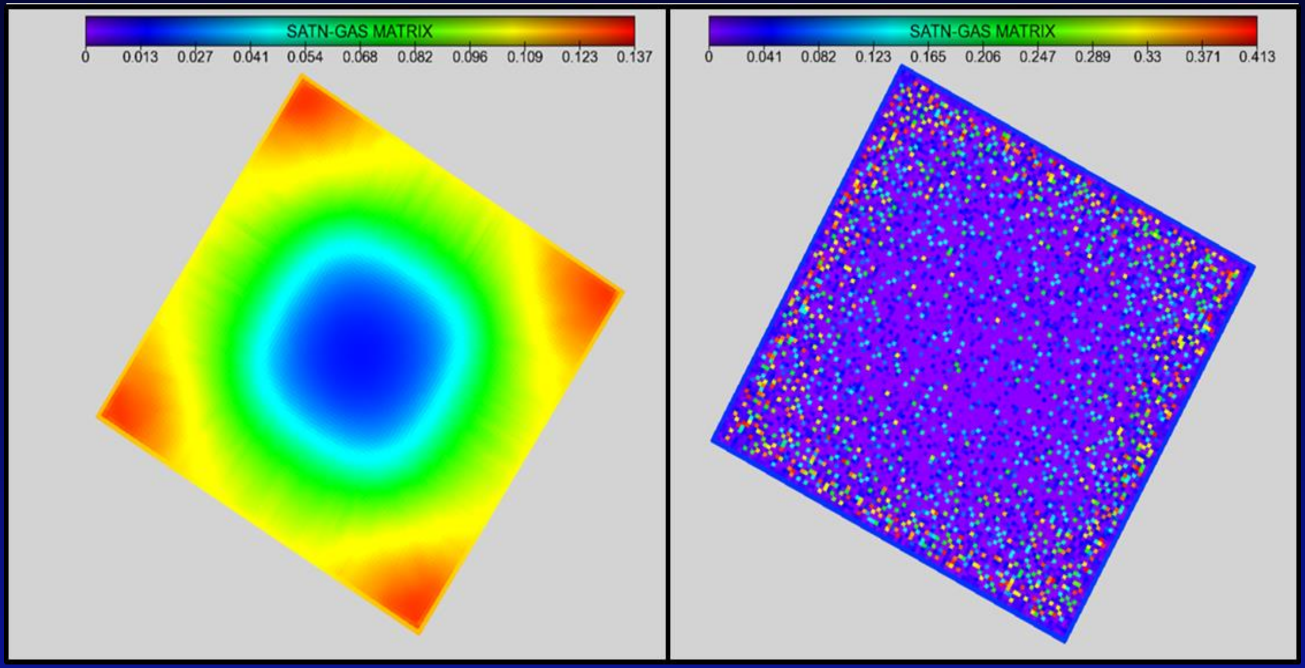




Impact on Flow – Random Pcgo and perm. with frac.

Gas Saturation Distributions

Conventional PVT (Pcog=0.0)   Confined PVT (Pcog>0.0)



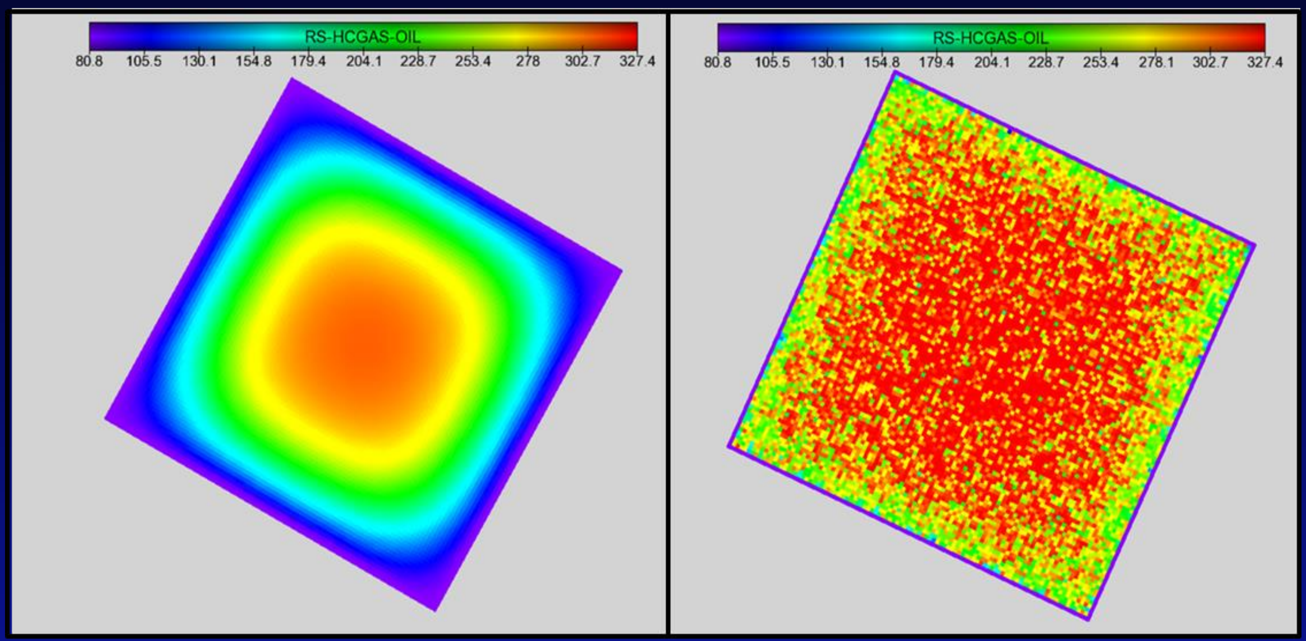
Gas saturation follows the pressure profile

Gas saturation is distributed as a function of not only pressure but non-uniform suppression also

Impact on Flow – Random Pcgo and perm. with frac.

Solution Gas-Oil Ratio Distributions

Conventional PVT (Pcog=0.0)   Confined PVT (Pcog>0.0)



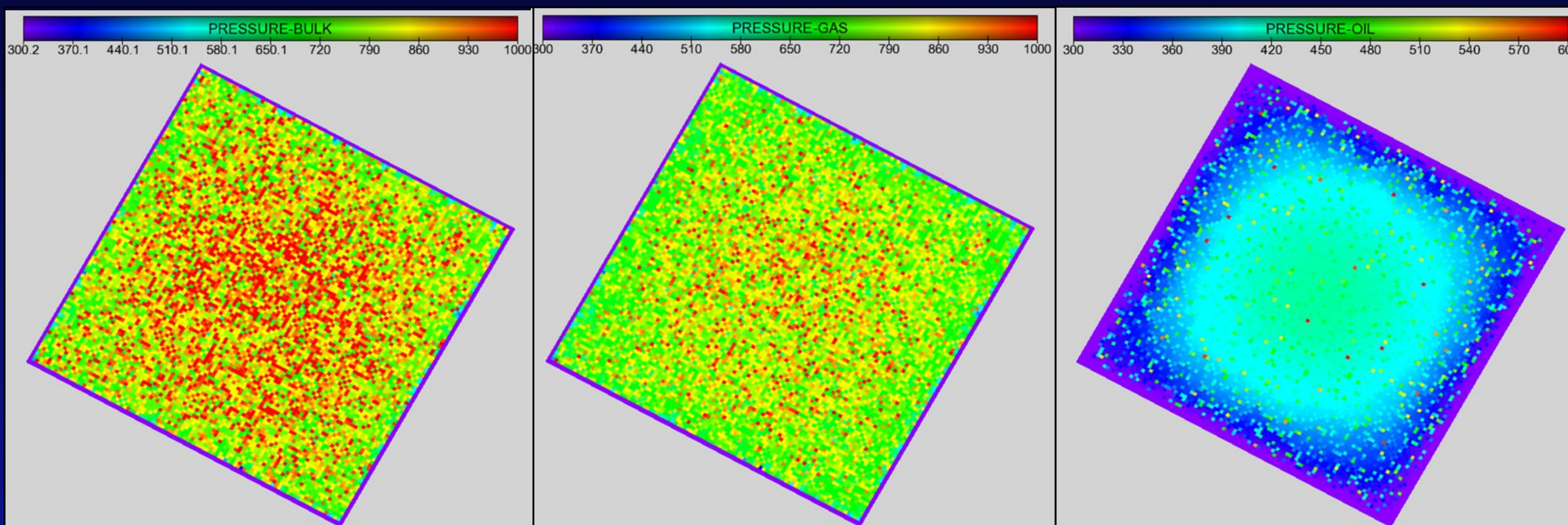
Rs follows the pressure profile

Rs is distributed as a function of not only pressure but non-uniform suppression also

Impact on Flow – Random Pcgo and perm. with frac.

Distribution of Three Pressures Used in the Simulator

Pbulk=Pgas+Pexcess   Pgas=Poil+Pc   Poil



Conclusions

- In confinement the bubble-point pressure is suppressed and the excessive suppression amount is a function of the capillary pressure and fluid composition.
- For the particular examples considered in this study, the contribution of the surface forces was small. However, the trends indicate the possibility of surface forces becoming significant.

Conclusions

- The pore size may constraint the gas formation in a confined environment.
- Due to suppression equilibrium gas composition is different.
- For a confined fluid, the undersaturated portion of B_o must be extended to lower pressure values.

Conclusions

- Excess suppression ratio can be correlated to R_s which is a convenient input into a black oil simulator

- Confined phase behavior changes the flow profile in the reservoir. The difference manifests itself as reduction in GOR and distribution of gas saturation

Conclusions

- The way the Pcog (level of suppression) is distributed impacts the gas saturation
- Gas saturation builds up in the grid blocks with low suppression that are surrounded by the blocks with high suppression.
- The well GOR profiles are also impacted by the level of suppression and its distribution around them.

Conclusions

- The impact of confinement on dew point pressure should be investigated
- The impact of including other surface forces besides van der Waals forces in phase calculations should be investigated.
- Actual rock and fluid properties used for surface force calculations should be measured.
- The excess suppression correlation should be tested and verified for other fluid samples.

Conclusions

- Sensitivity tests should be performed
  - Different mean and standard deviation of Pcog distribution to evaluate impact of suppression and capillary pressure.
  - Different R_s oils
  - Different distribution functions
- Ways of measuring confined fluid properties should be investigated

Questions?

Thank you!!