UNIVERSITY OF TRIPOLI
FACULTY OF ENGINEERING
PETROLEUM DEPARTMENT

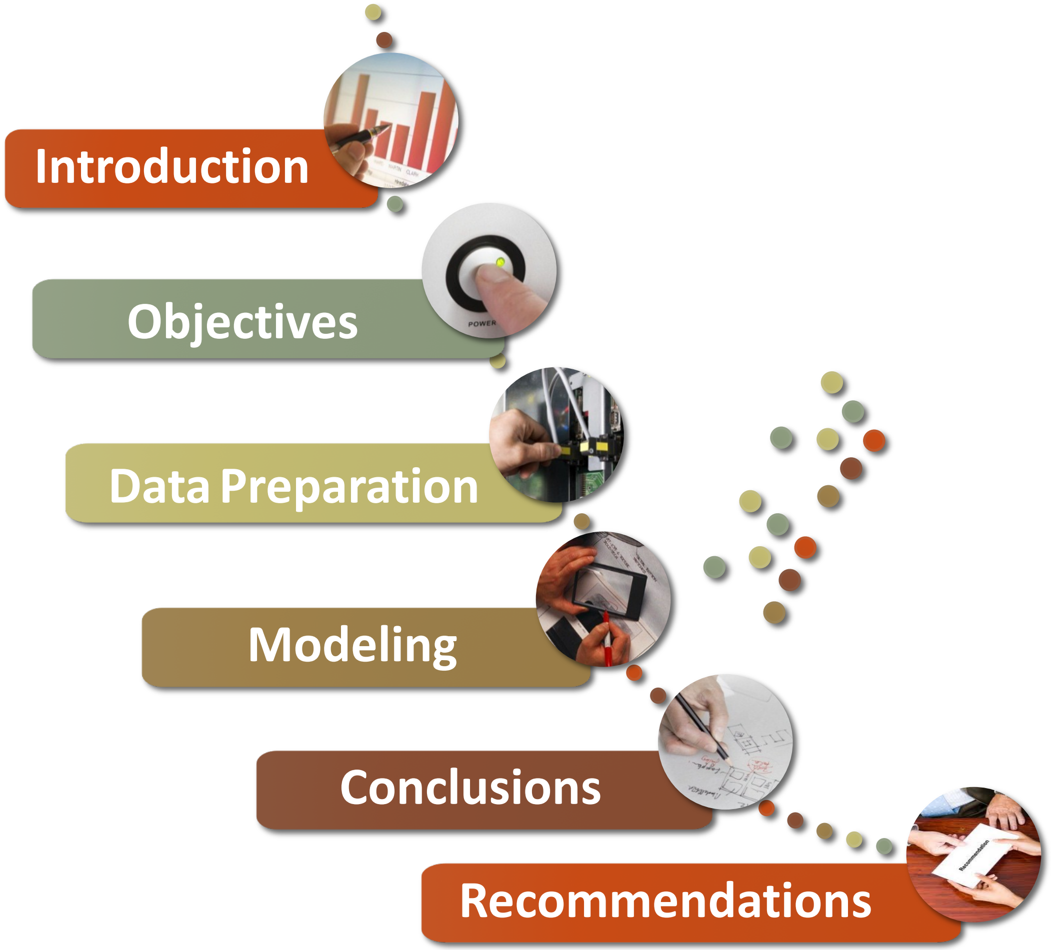
DYNAMIC VALIDATION OF AMAL PHASE BEHAVIOR FOR EOR APPLICATIONS

PREPARED BY:

ABDUALGHAFFAR.E.BEZAN AHMED.I.ABUFARWA MOHAMED.M.ELNECA'A

SUPERVISED BY: Dr. MOHSEN MOHAMED KHAZAM

Contents



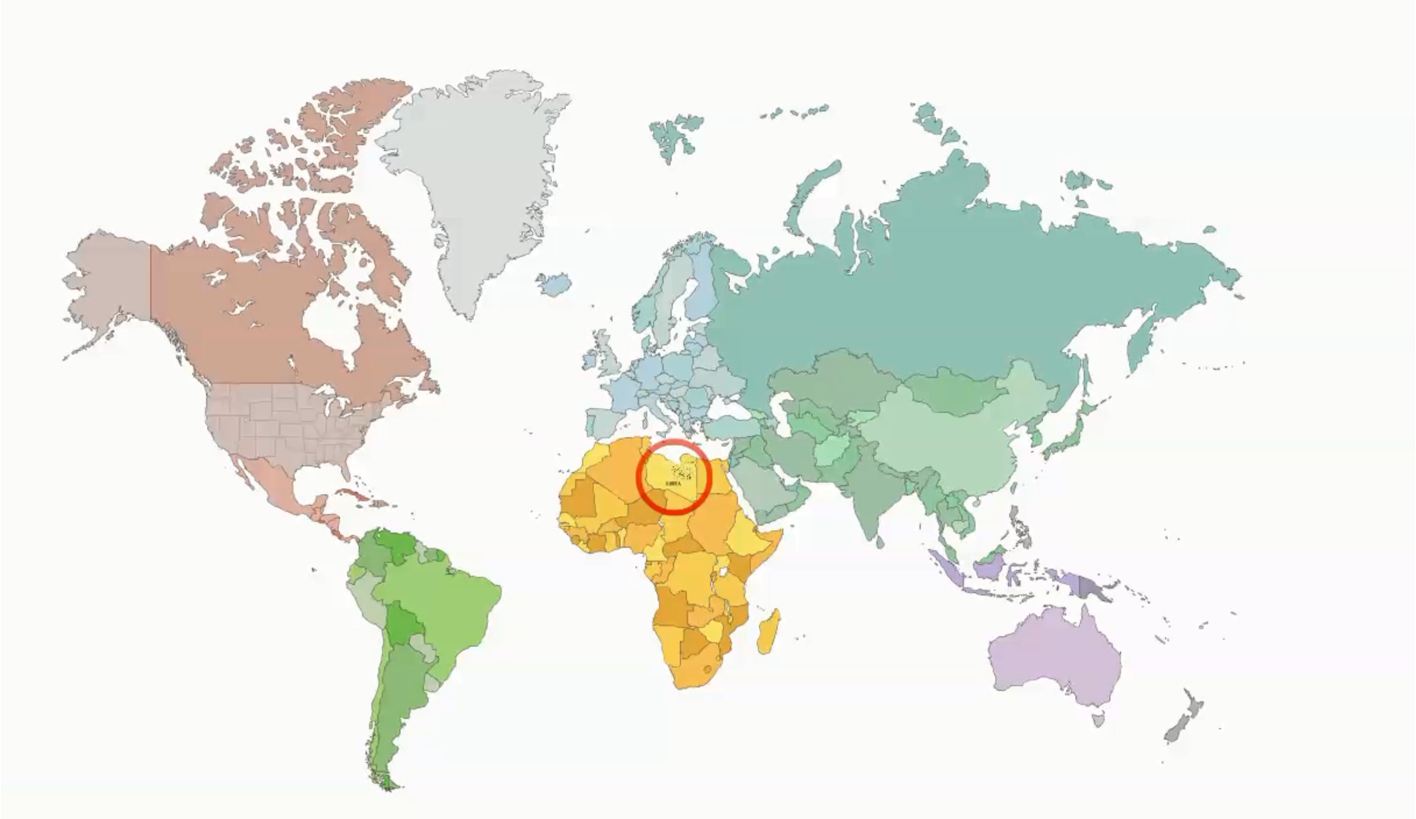
Modeling

1. Phase Behavior and EOS Tuning of The Selected PVT Sample.
2. Relative Permeability.
3. Slim Tube Modeling.

Introduction

- **Amal Field Location**
- Reservoir Fluid Type
- Laboratory Analysis of Reservoir Fluids
- EOS Overview
- Miscibility Concept

Amal Field Location Map



Introduction

- Amal Field Location
- **Reservoir Fluid Type**
- Laboratory Analysis of Reservoir Fluids
- EOS Overview
- Miscibility Concept

Amal Fluid Specifications

Comp.	MOL %
CO_2	0.5
N_2	1.35
C1	25.62
C2	6.67
C3	6.8
I-C4	1.44
n-C4	4.65
I-C5	1.81
n-C5	2.61
C6	4.62
C7+	43.93

Oil gravity=34.7° API

GOR = 410 SCF/STB

B_o = 1.356 rbbl/STB

P_i = 4690 psig

$P_{current}$ = 2719 psig

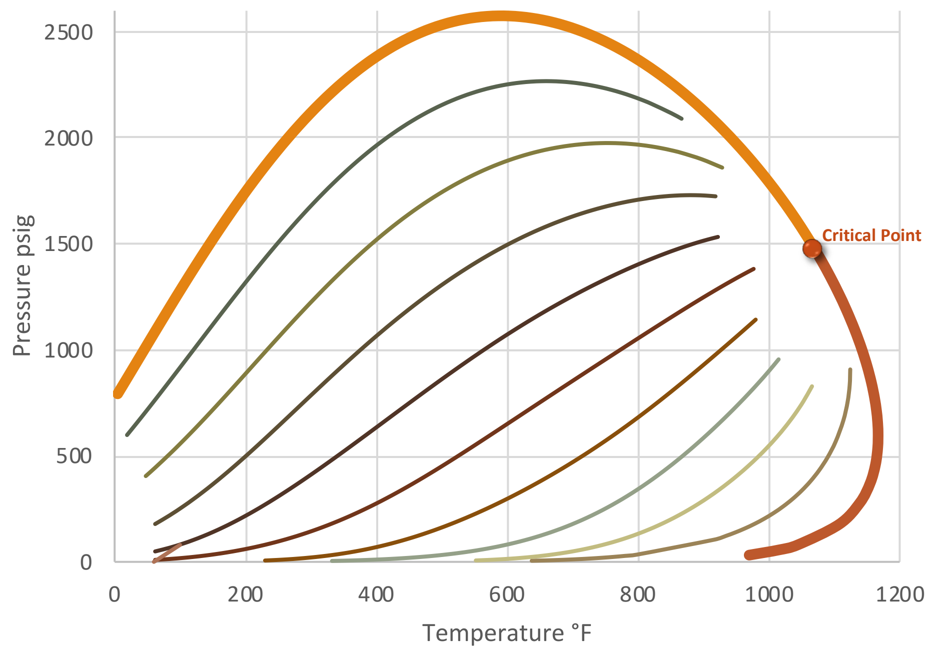
P_b=1852 psig

T_{res}= 229° F

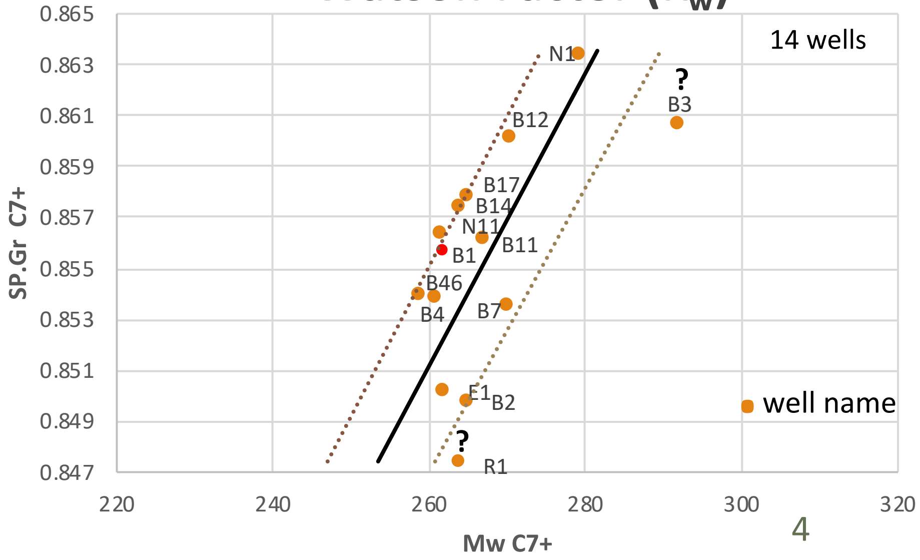
K_w=12.15

Black oil
Low-shrinkage crude oil
Naphthenic

Phase Diagram



Watson Factor (K_w)

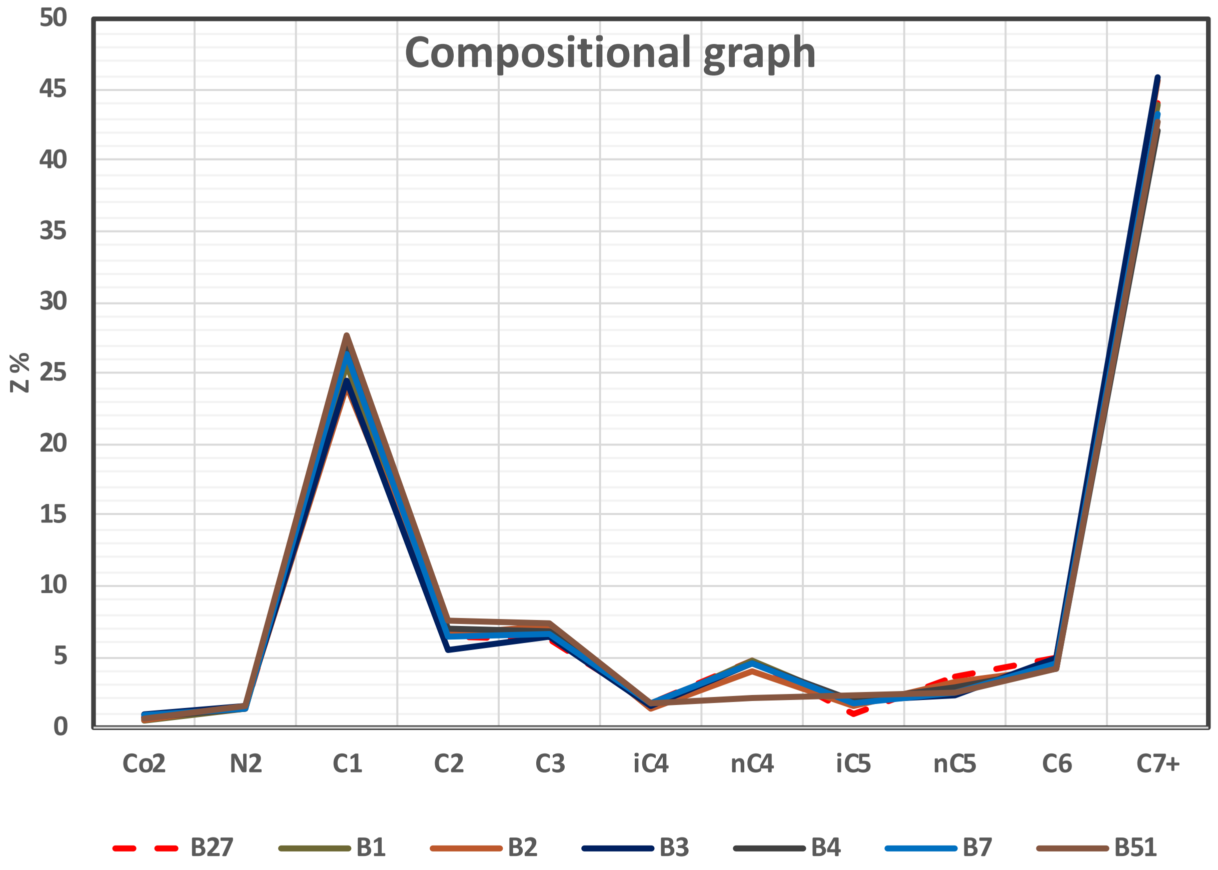


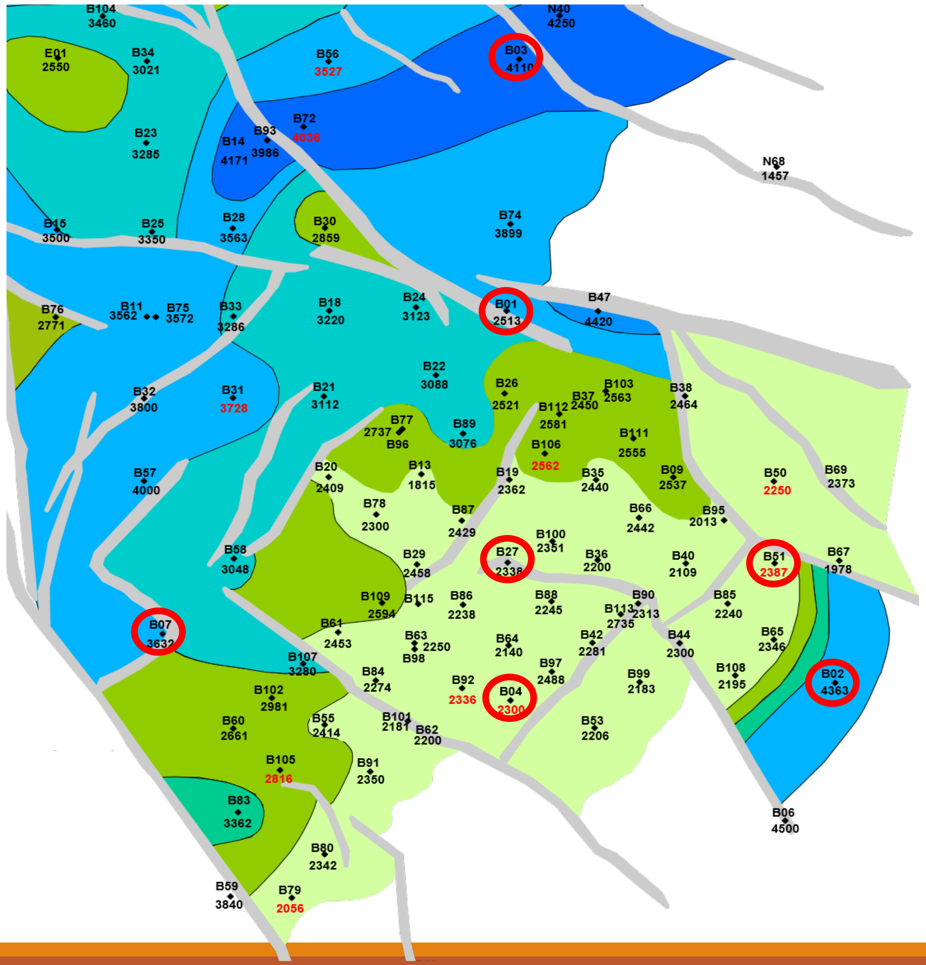
Objectives

The main objective of this study is to dynamically validate the Amal phase behavior model using CO_2 as injection solvent for EOR applications.

- **PVT Screening and Assessment**
  - ✓ Collect all the Amal available PVT data (14 samples).
  - ✓ Analyze and assess the PVT properties arealy and vertically.
  - ✓ Select the most representative PVT sample to model.
- **Phase Behavior Modelling**
  - ✓ Select and adjust the most commonly used EOS’s (PR3 and SRK3) to model the Amal fluid behavior.
  - ✓ Use conventional and special PVT data for tuning purpose.
  - ✓ Examine the extended and lumped compositional models using the splitting and lumping techniques. adopted in the industry (e.g. Whitson approach).
- **Slim Tube Modelling**
  - ✓ Build and characterize a slim tube model using 1D E300 model with optimum number of grids.
  - ✓ Use measured data to back calculate the base relative permeability curves (BL & JR techniques).
  - ✓ Conduct sensitivity analyses to evaluate and minimize any other dynamic flow effects.
  - ✓ Simulate CO2 injection at different pressures with the concept of interfacial forces (IFT change) and its impact on relative permeability shapes.
  - ✓ CO2 MMP determination.

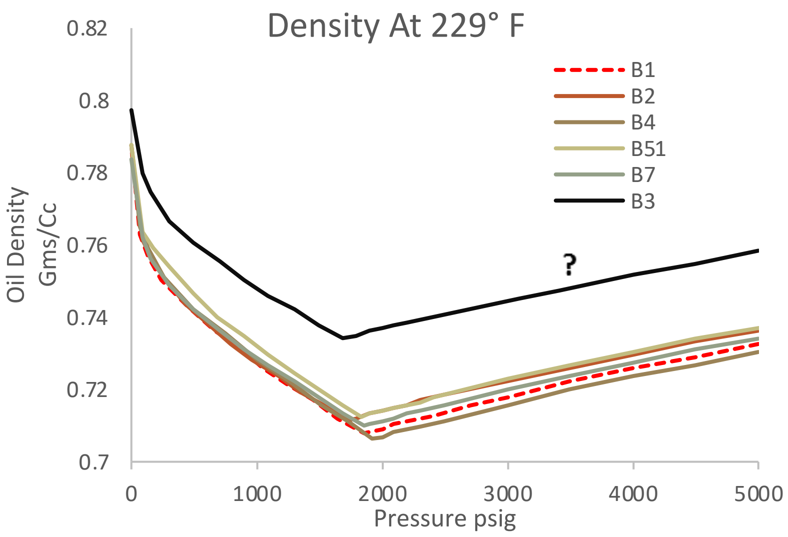
Comparison and Assessment of PVT Data

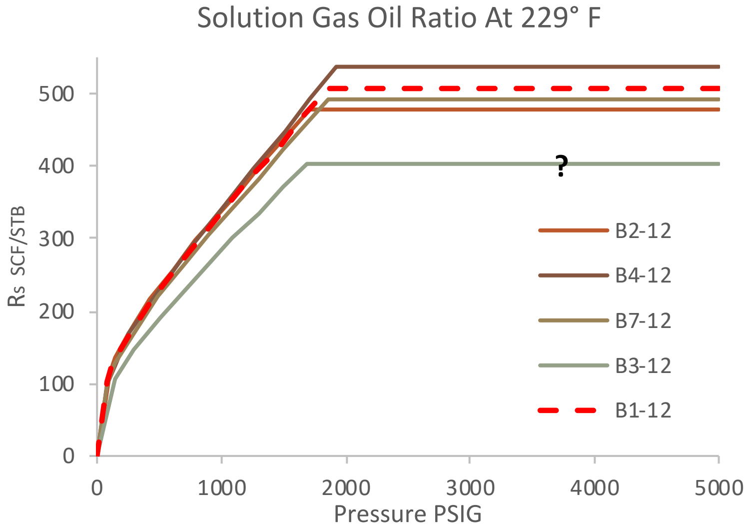


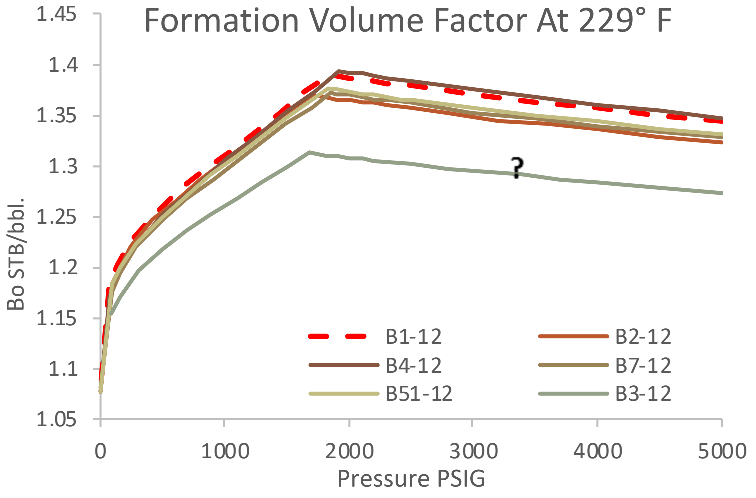


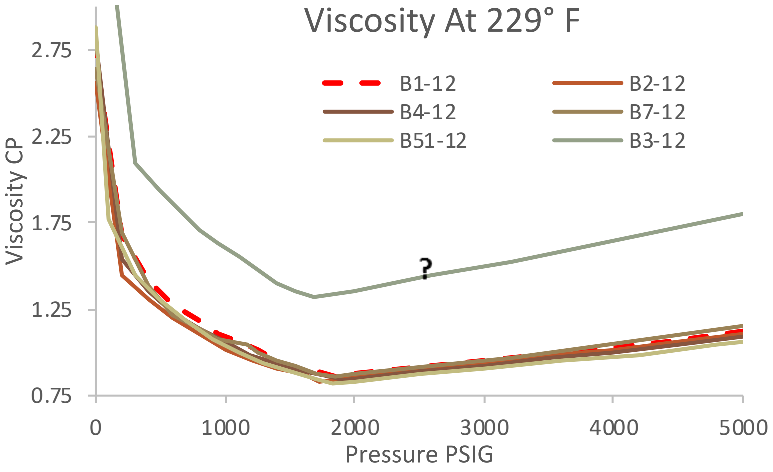
Comparison and Assessment of PVT Data

Areal Analysis

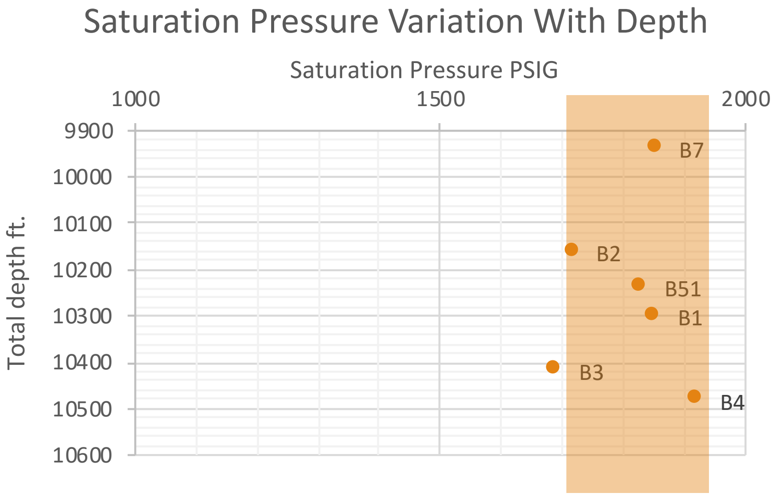


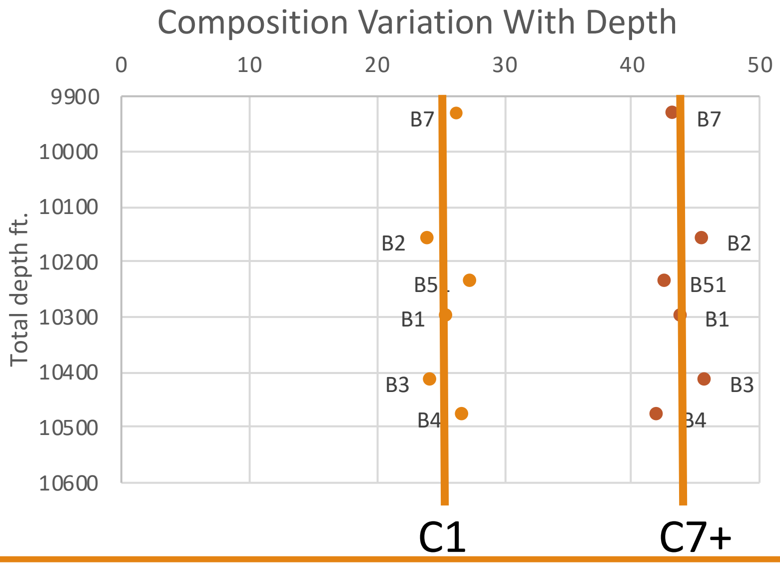






Vertical Analysis





Phase Behavior and EOS Modeling

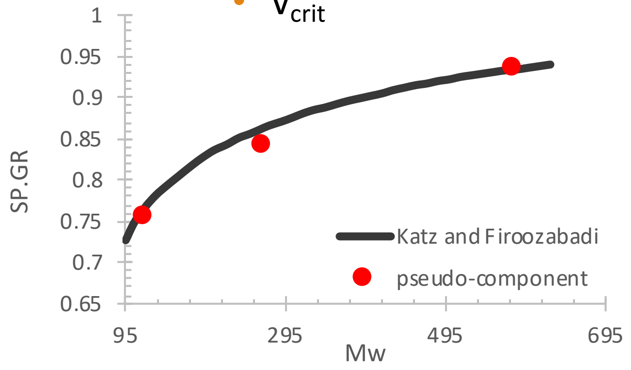
PVTi Package

PR3 EOS was applied to simulate Amal phase behavior using:

- ✓ **Conventional PVT tests**
  - ✓Constant-composition expansion.
  - ✓Differential liberation.
  - ✓Separator tests.
  - ✓Viscosity tests
- ✓**Special PVT tests**
  - ✓Swelling test.
  - ✓Slim tube experiments-MMP.

Splitting & Regression

- **C7+ Characterization/splitting using**
  - Whitson Gamma-Distribution Model.
    - Three pseudo-components.
- **Critical Properties and Acentric Factors**
  - Kesler-Lee Correlation
  - Edmister Correlation
- **Regression Techniques**
  - Careful selection of weight factors for different experiments
  - Regression variables within acceptable limits
- **Regression variables**
  - T_{crit}, P_{crit}, S_{shift}, BIC
  - V_{crit}



Comp.	mol %	MW
CO2	0.5	
N2	1.35	
C1	25.62	
C2	6.67	
C3	6.8	
IC4	1.44	
NC4	4.65	
IC5	4.62	
NC5	2.61	
C6	1.81	
FRC1	16.927	119.59
FRC2	19.721	266.82
FRC3	7.2816	580

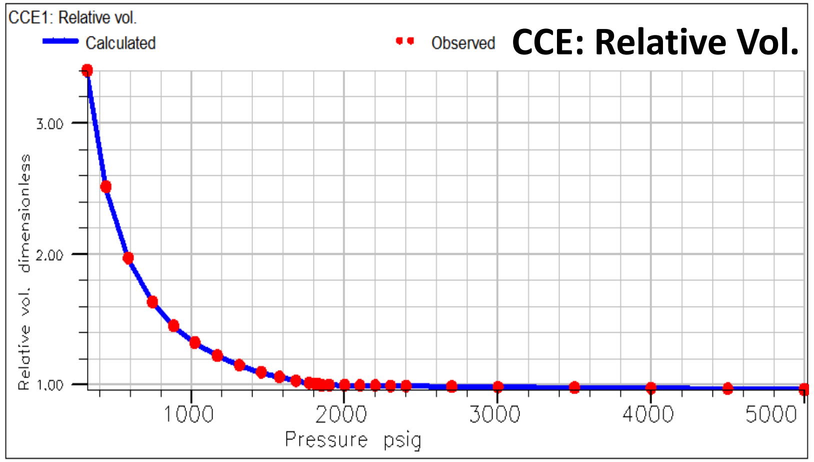
Grouping & Regressing

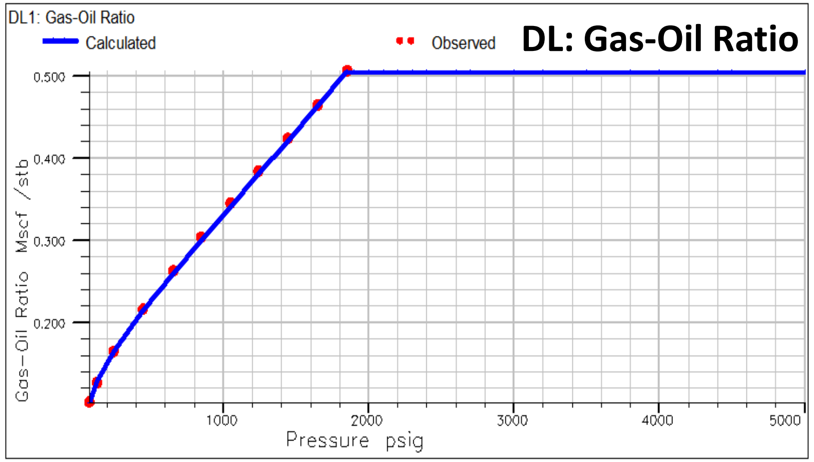
- **Grouping technique**
  - Mole Fraction

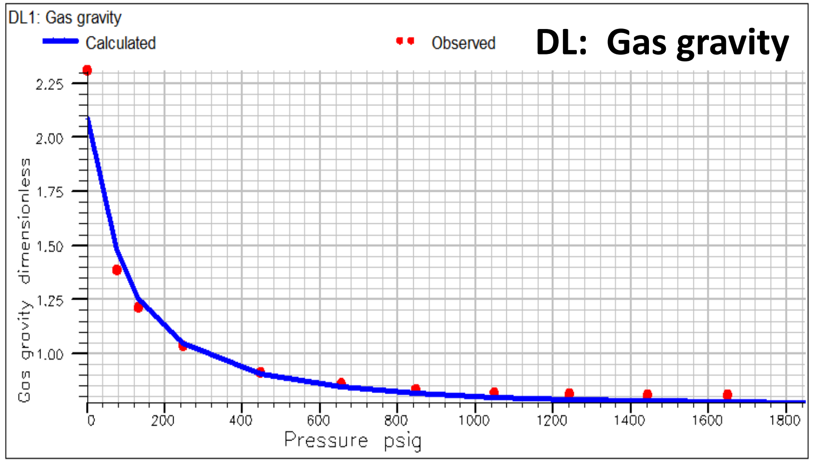
Comp.	Z%	Mw
CO2	0.5	0.1629
N2C1	26.97	16.642
C2	6.67	1.4847
C3C4	12.89	50.724
C5C6	9.04	74.523
FRC1	16.927	119.59
FRC2	19.721	266.82
FRC3	7.2816	580

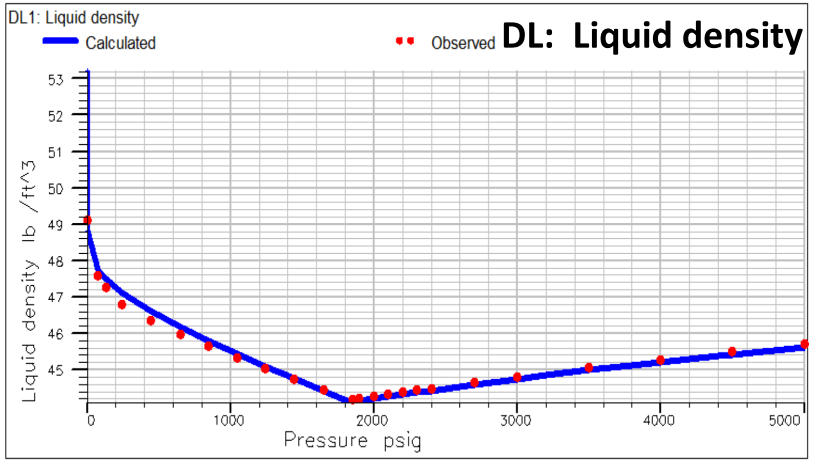
- **Regression Technique**
  - Critical properties (P_{crit}, T_{crit})
  - Critical Volume (V_{crit})
  - Binary interaction coefficient (BIC)

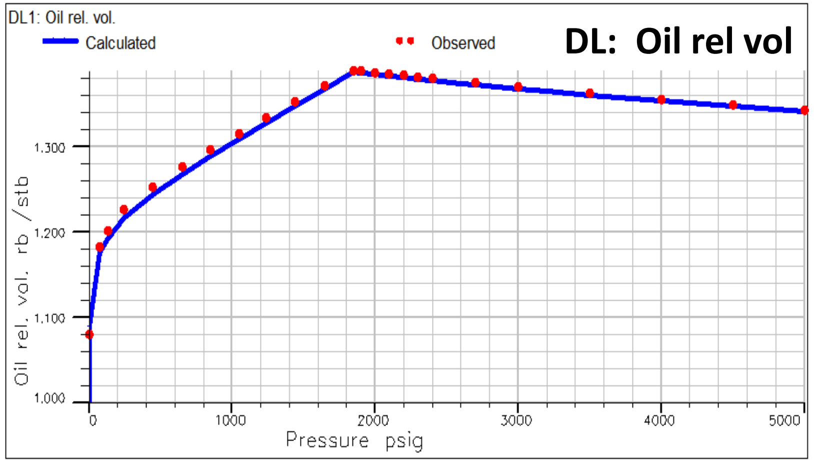
Simulation of Conventional PVT Tests – Lumped Model

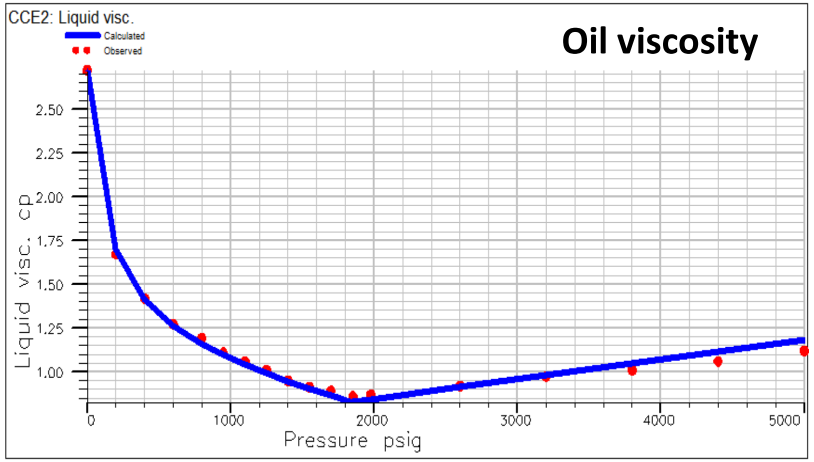




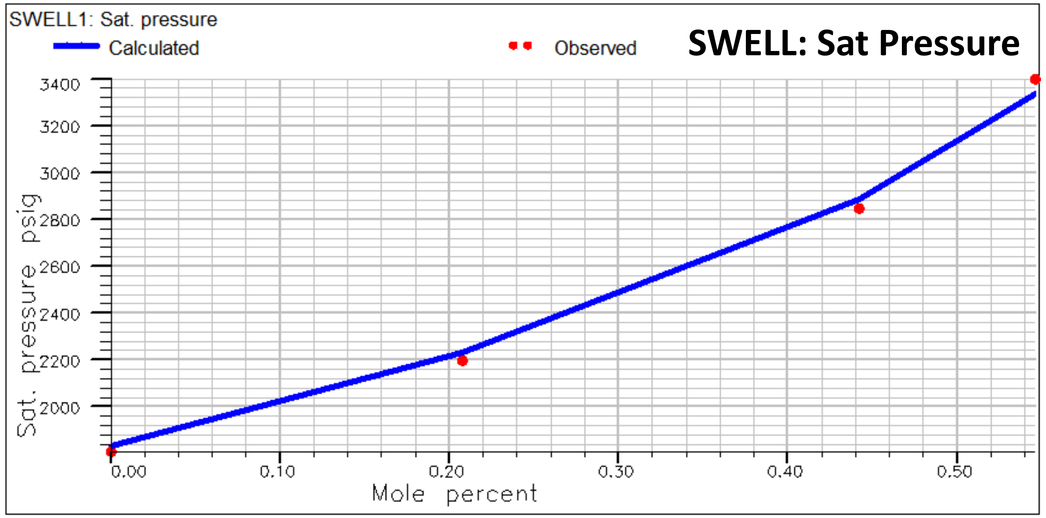


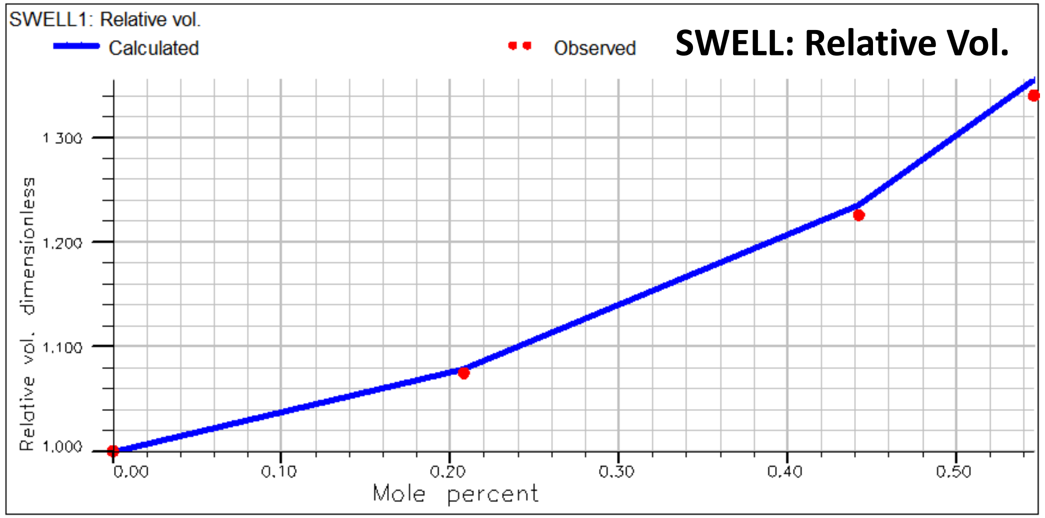






Simulation of Special PVT Test – Lumped Model





Base Relative Permeability Curves

Applying lab data from the immiscible experiment At 2000 Psia (IFT = 5 Dyne/Cm)

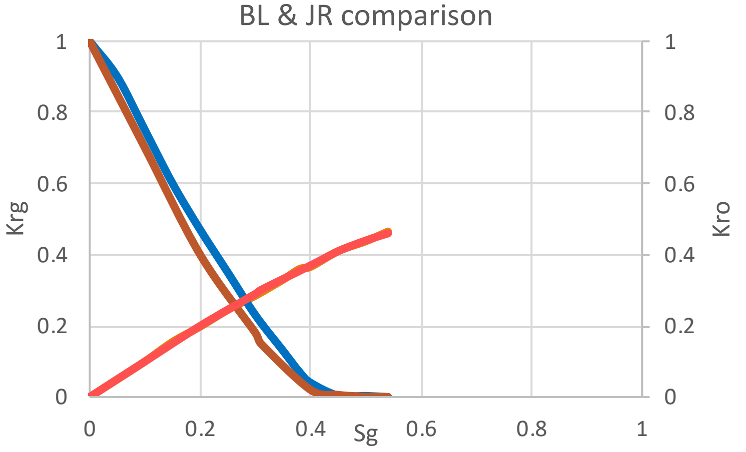
Bardon and Longeron Method

$$Kr_g = \Delta p_g \left(\frac{f_g}{\Delta p - t \frac{d(\Delta p)}{dt}} \right)$$

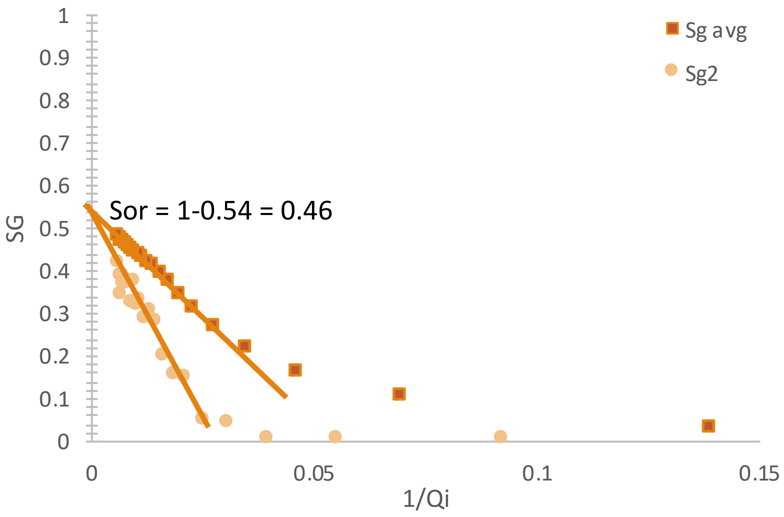
$$Kr_O = \Delta p_O \left(\frac{f_O}{\Delta p - t \frac{d(\Delta p)}{dt}} \right)$$

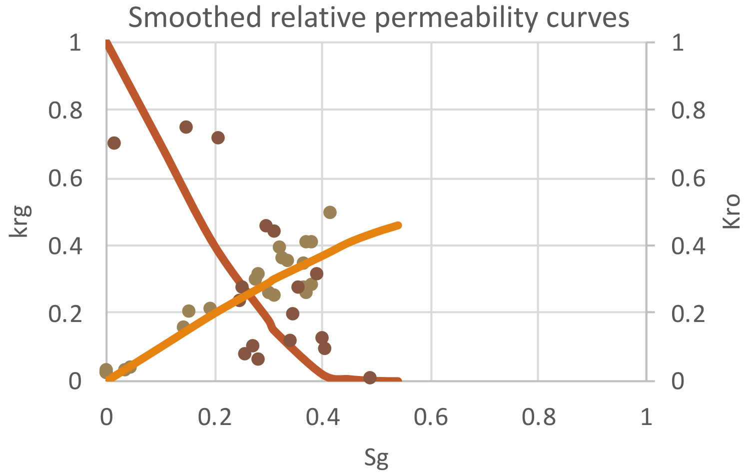
Jones and Roszelle Method

$Kr_O = \mu_O f_{O2}/\mu e_2$ $\quad K_{rg} = \mu_g f_{g2}/\mu_{e2}$

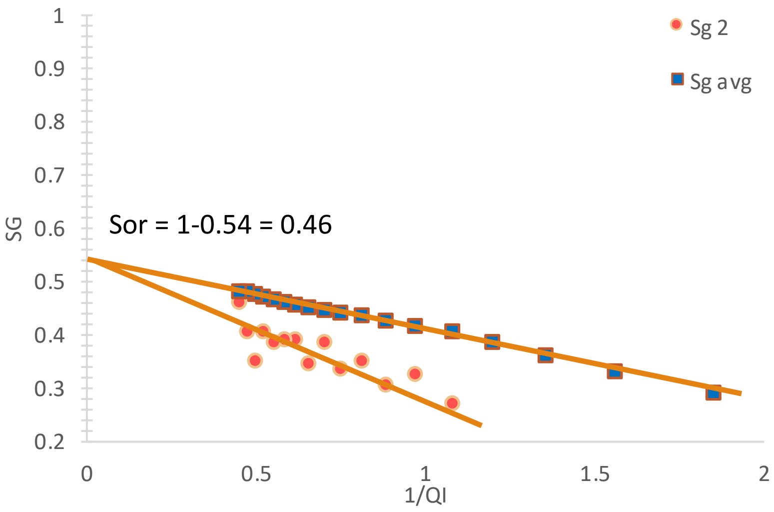


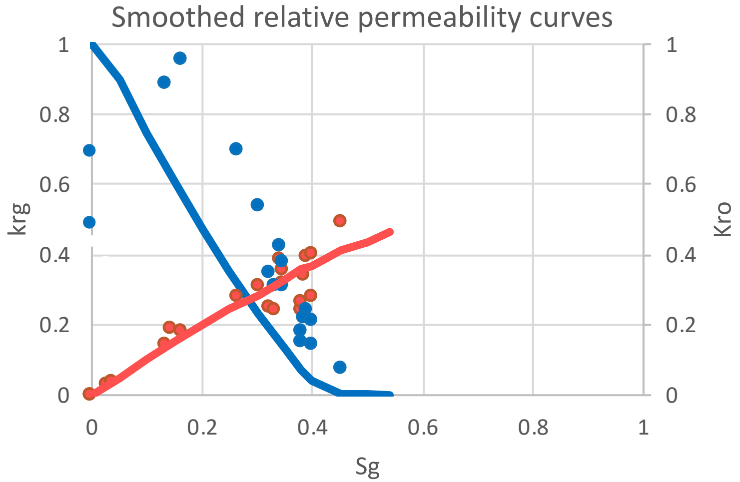
Bardon and Longeron Method





Jones and Roszelle Method





Relative Permeability – Using Analytical Correlations

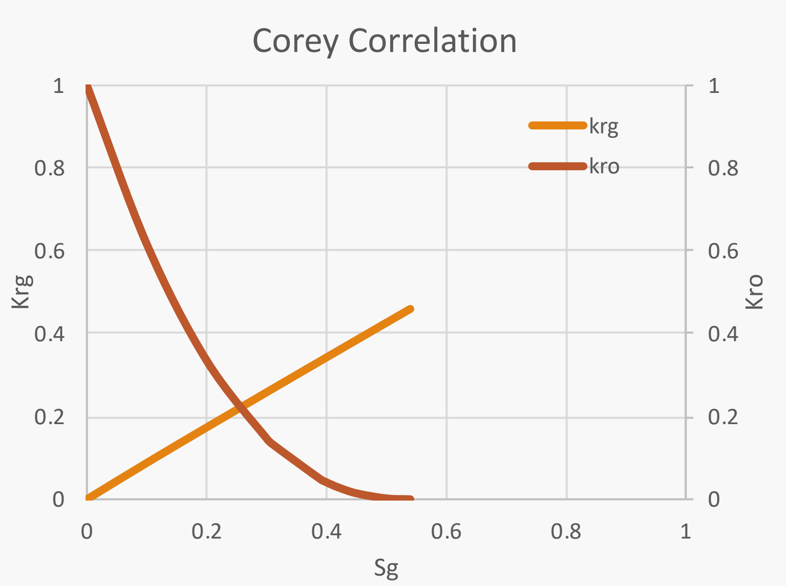
Analytical correlations can be applied to calculate the base relative perm (using simulation model with trail & error) if no enough measured data are available to back calculate the base relative perm.

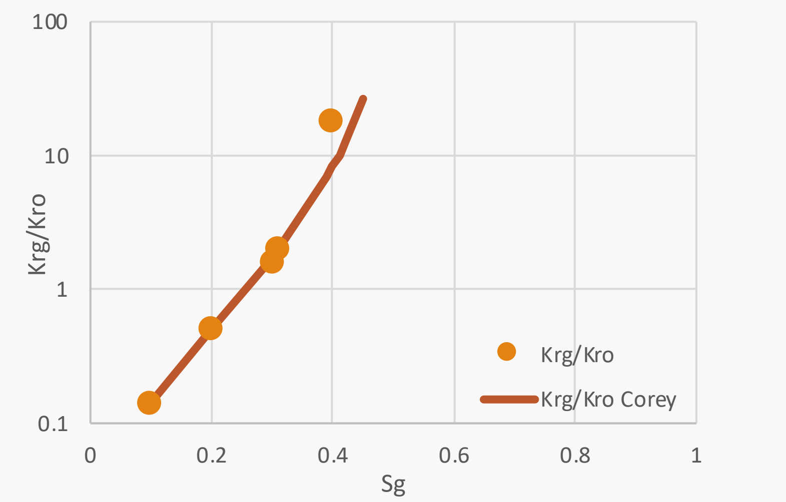
- **Corey correlation (1954) oil-gas system**

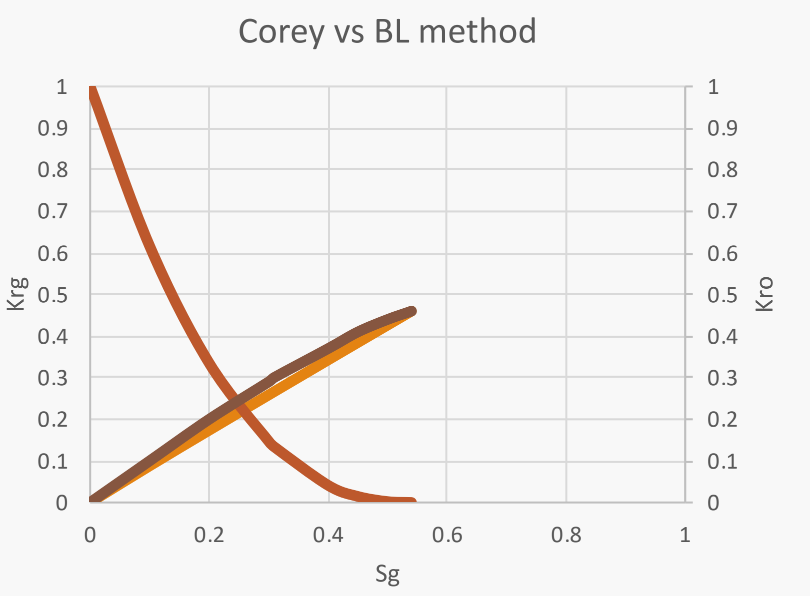
$$k_{rg} = krg_{\,max}\left(\frac{S_g - Sgc}{1 - Swc - Sgc - Sor}\right)^{Ng}$$

$$k_{ro} = kro_{\,max}\left(\frac{1 - Swc - Sor - Sg}{1 - Swc - Sgc - Sor}\right)^{No}$$

Krg_{max} =	0.46	Sg_c =	0	Ng =	0.98
Kro_{max} =	1	(So_r) =	0.46	No=	2.363





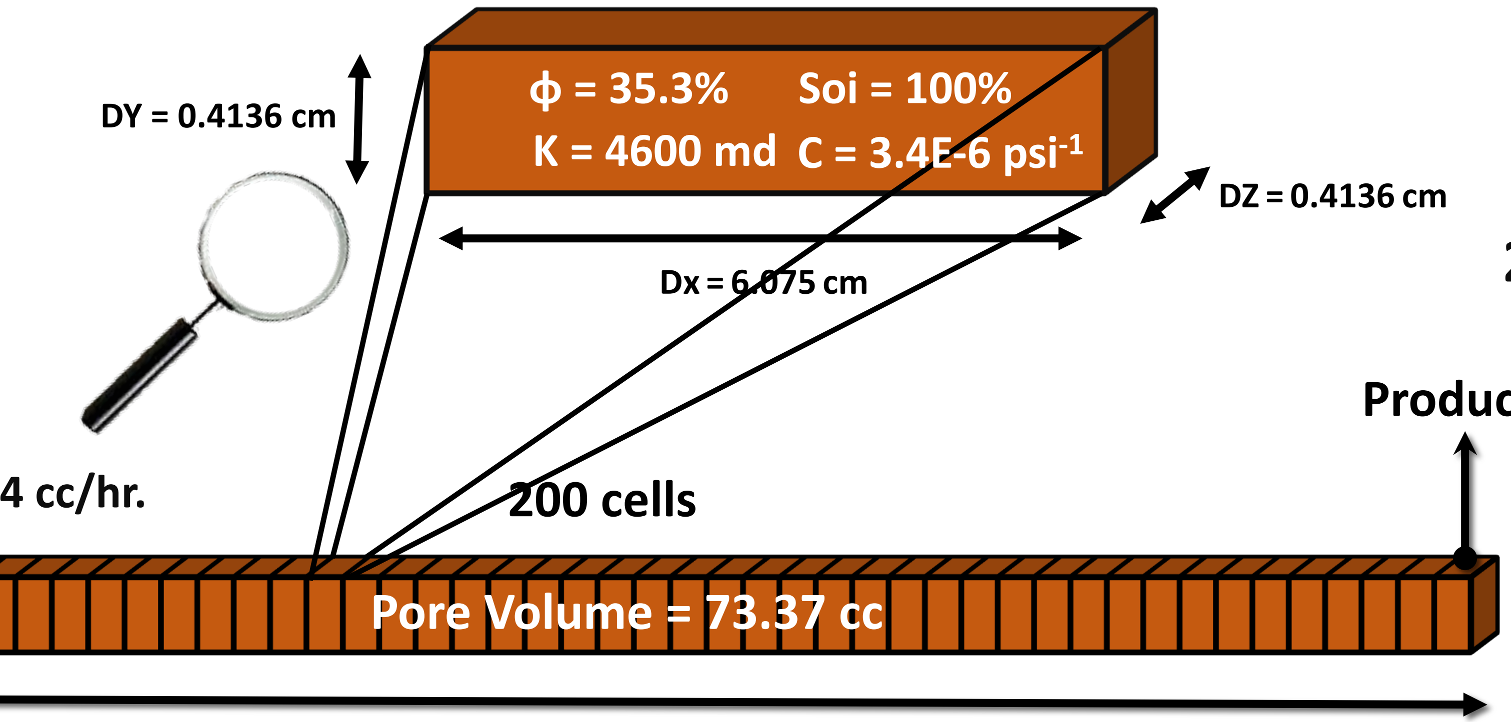


Slim Tube Experiments - Simulation Model

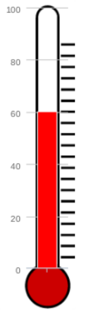
- The Slim Tube horizontal model was built using Eclipse E300
  - 3PR EOS
  - Rel.Perm curves

Exp.	Pressure Psia
1st	2000
2nd	3000
3th	3600
4th	4000

23 hr..



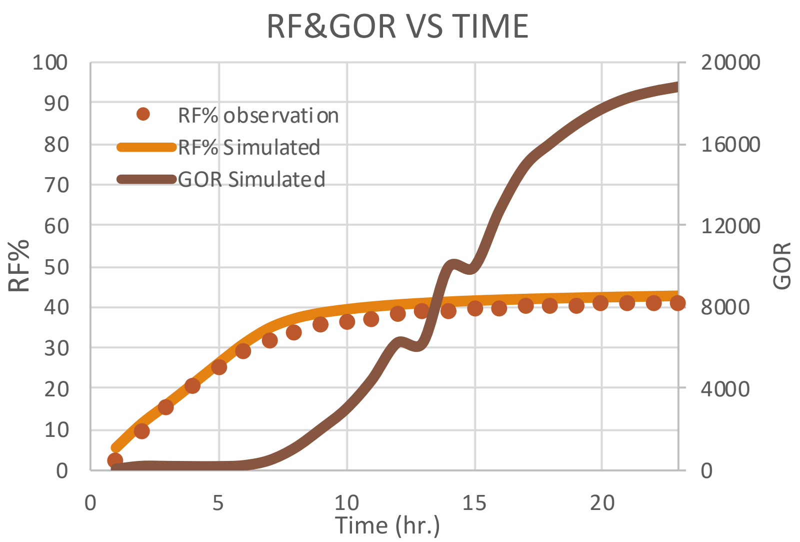
Reservoir Temperature

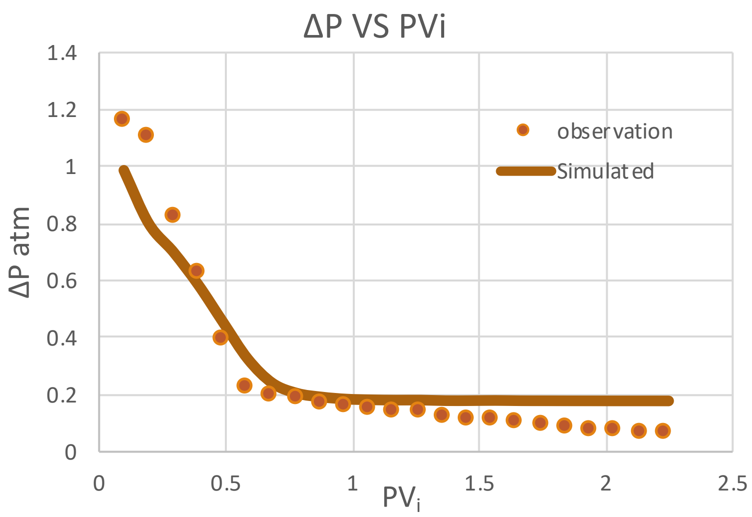


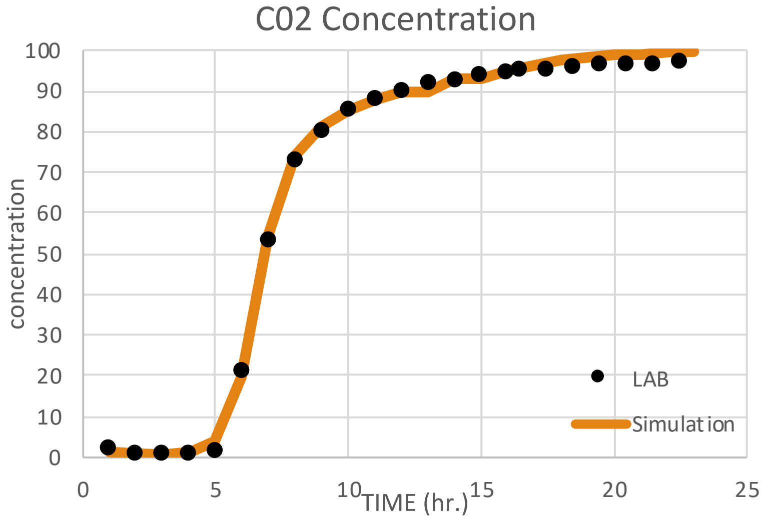
225⁰ F

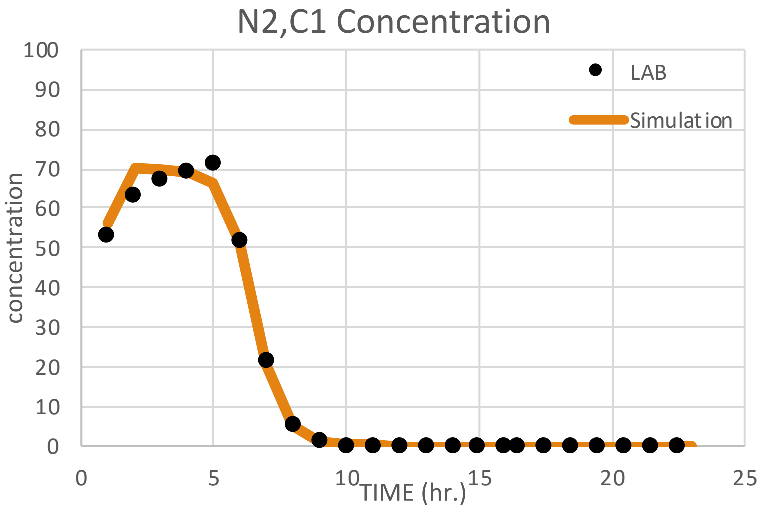
Slim Tube Model Results – Lumped Compositional Model

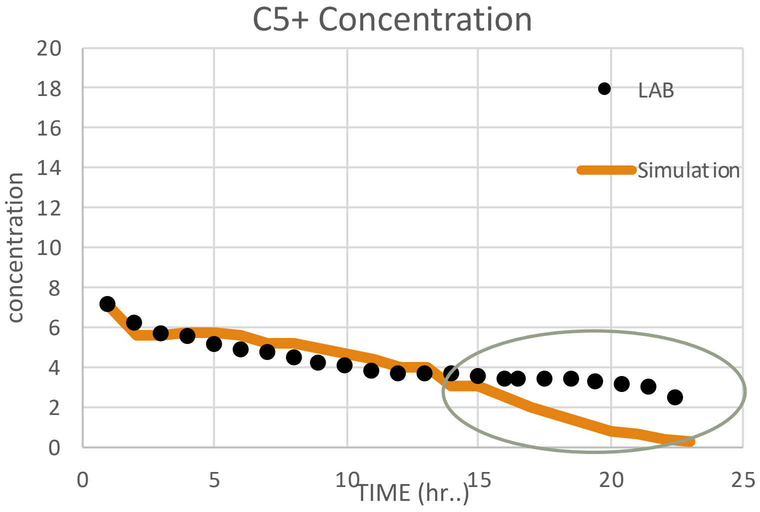
- 1st experiment at P =2000 psia (immiscible case)
- Overall match is good with some exceptions at the late C5+ concentration after the B.T.
- Perfect simulation of CO2 concentration with time.
- Measured RF at the end of experiment is 41.5% (predicted is 42.8 %)











Modeling Concept of Other Slim Tube Experiments

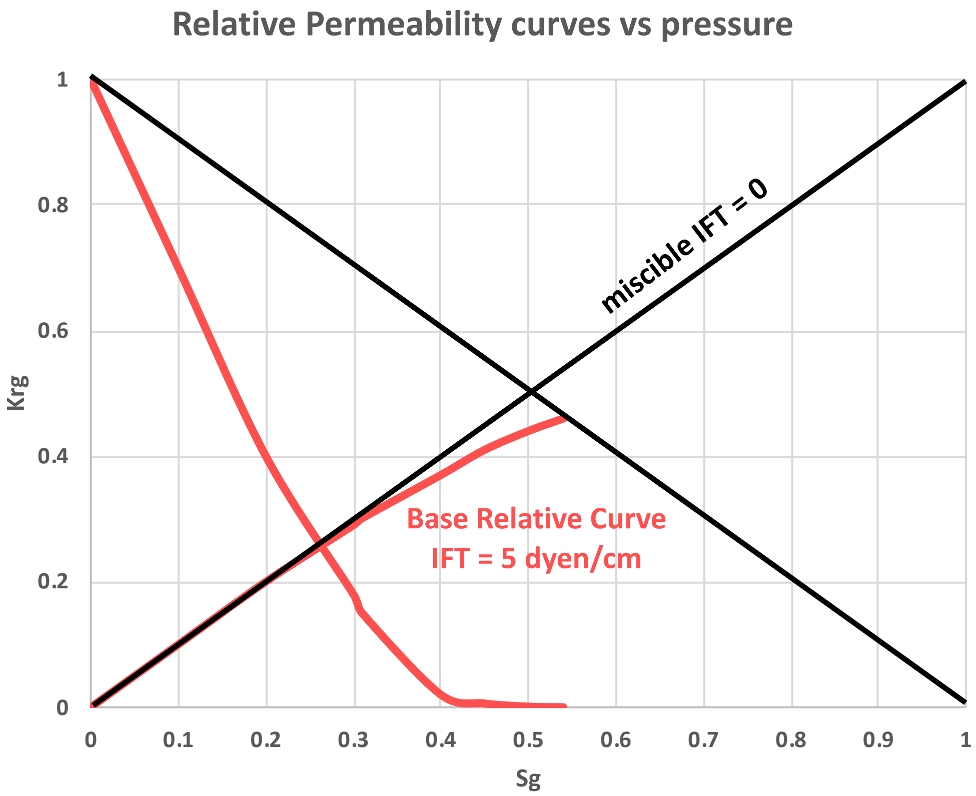
Once the good match on the immiscible experiment at 2000 psia was achieved and all the adverse flow factors have been taking into consideration, then the miscibility mechanism of other slim tube experiments at higher pressures were simulated with the IFT change with the relative permeability curves concept using the following equation.

$$K_{ro} = FK_{ro}^{imm} + (1 - F)K_{ro}^{mis}$$

$$K_{rg} = FK_{rg}^{imm} + (1 - F)K_{rg}^{mis}$$

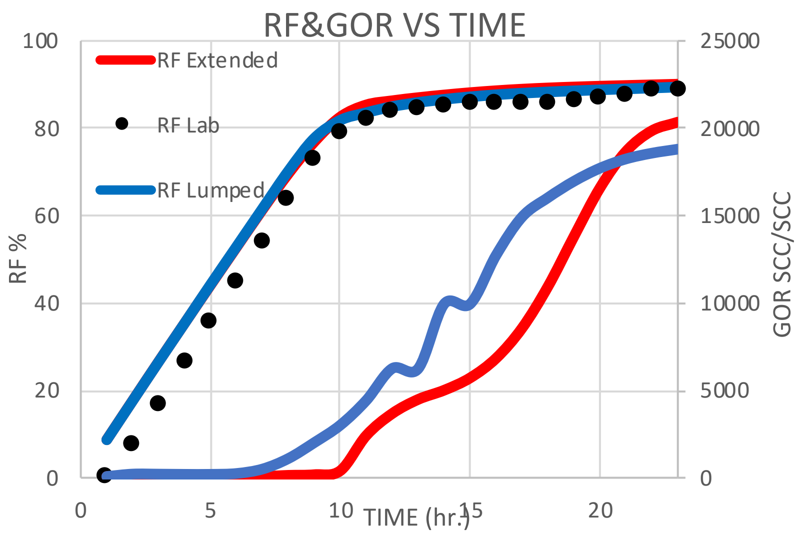
$$F = \left(\frac{\sigma}{\sigma_0}\right)^N$$

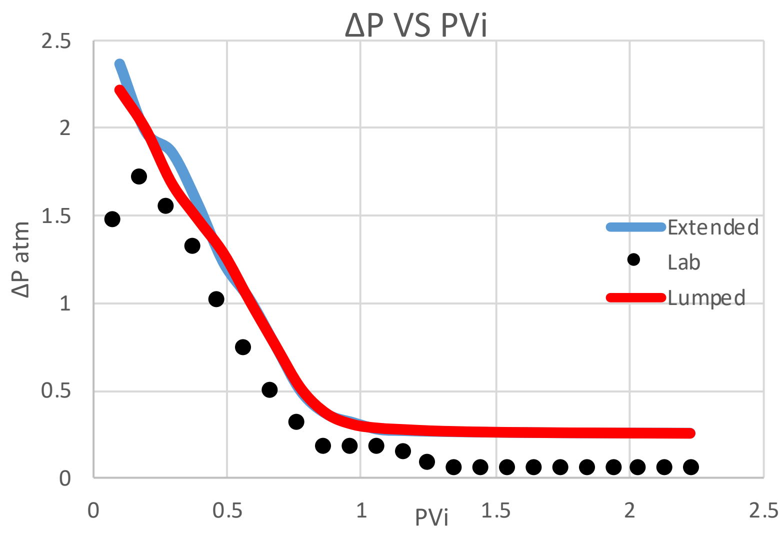
N = 0.32 σ_0= 5 dyen/cm

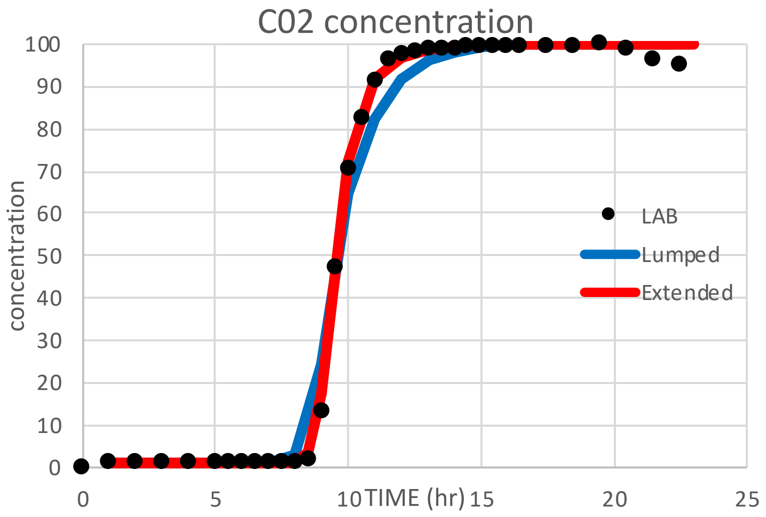


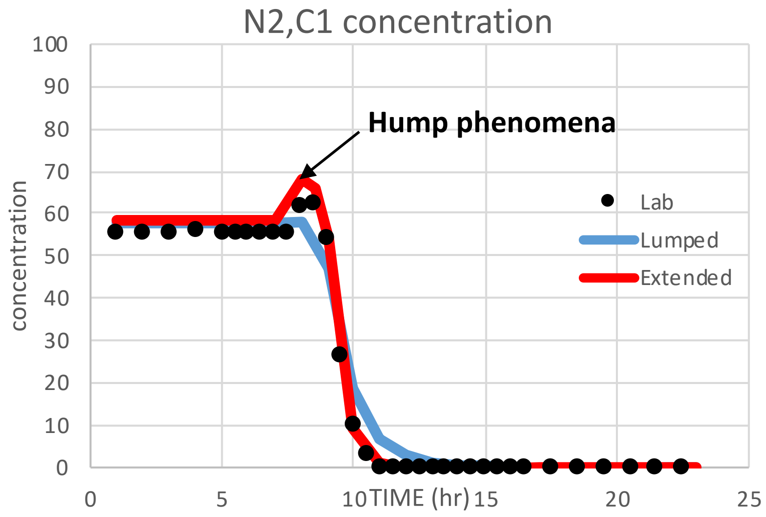
Slim Tube Model Results – Extended Vs Lumped Compositional Model

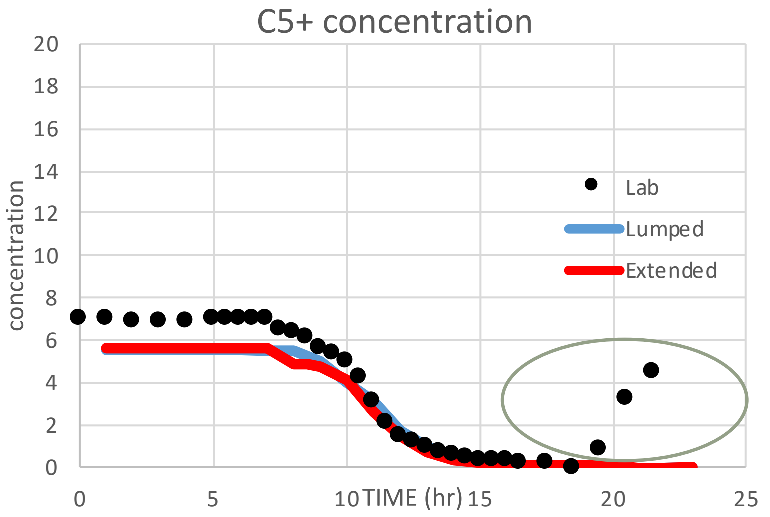
- 2nd experiment at P =3000 psia (near miscible case)
- Overall match is quite good with some exceptions at the last few C5+ concentration measurements (likely measurement errors).
- Better simulation of the hump phenomenon with the extended compositional model .
- Measured RF at the end of experiment is 89% (predicted is 90 %)









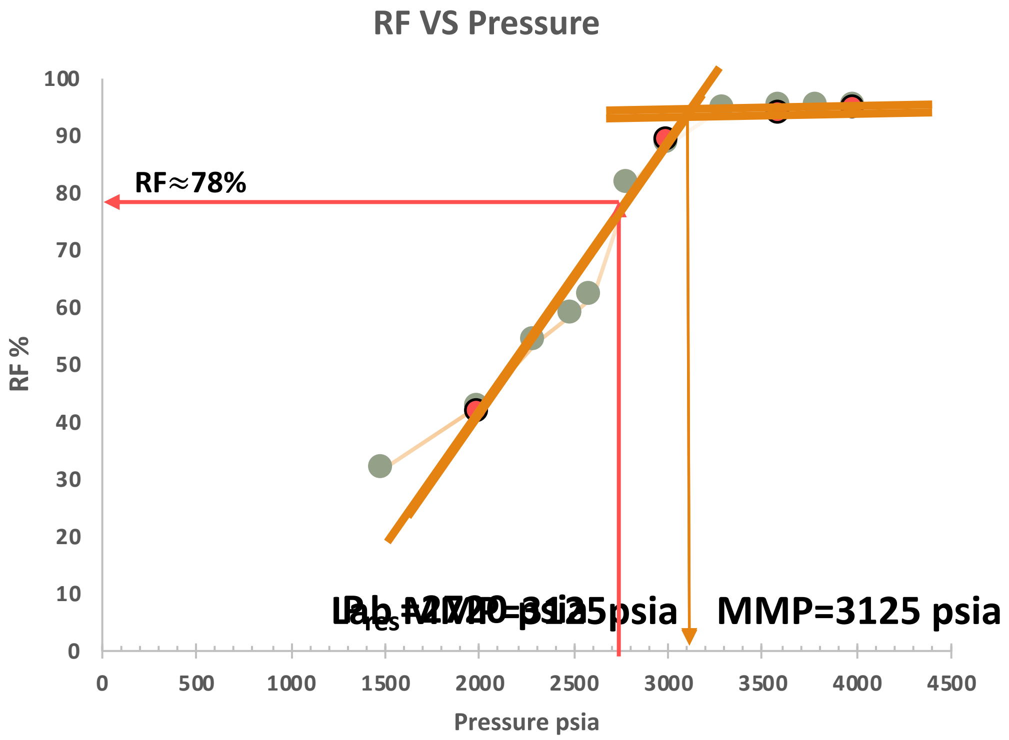


Minimum Miscibility Pressure (MMP)

- The measured lab MMP is 3125 psia

- The Predicted MMP using 1D-model is exactly aligned with the measured figure (3125 psia)

- Different runs were conducted to simulate slim tube experiments at different pressures and an “S“ shape trend was pictured which is aligned with many literature findings.



Conclusions

- ☑ Perfect match was achieved for Amal conventional and special PVT experiments using both PR3 and SRK3 with the extended and Lumped compositional models (13 and 8 components, respectively).
- ☑ Match of only the conventional PVT data will not be enough to simulate the slim tube experiments. Therefore, it is essential to match both the conventional and special tests for EOR simulation studies.
- ☑ The relative permeabilities at higher pressure experiments are sensitive to IFT values, especially at low IFT value. These were simulated by the change of relative permeability with IFT (i.e. the base relative perm curves will approach to straight lines as the IFT approaches to zero).
- ☑ The measured produced gas C5+ concentration, especially at the end of some experiments, was dramatically deviated from the predicted data raising some doubts on the measurements.
- ☑ The hump phenomena before B.T. time was better simulated with the extended compositional model compared to the lumped model. This highlights the favorability of extended compositional model in future EOR simulation studies.
- ☑ Perfect match of all slim tube experiments from immiscible to miscible conditions (2000, 3000, 3600 and 4000 psia) was achieved indicating the validity and reliability of Amal phase behavior model.
- ☑ The multiple contact MMP pressure of Amal field, using CO_2 as injection solvent, is around 3125 psia based on measured and predicted results.

Recommendations

The following areas for future researches are recommended, utilizing the Amal phase behavior model developed in this study:

- Simulate and study the EOR core flood experiments conducted on Amal field, such as:
  - ✓Investigate and assess the impact of core heterogeneity, viscous fingering and gravity overrides on CO2 injections
  - ✓identify optimum CO2 slug size and sweep displacement efficiency
  - ✓Investigate and assess the optimum WAG process for Amal field
- Conduct EOR sector model simulation studies
- Conduct EOR pilot study on area of Amal field that is representing the average field properties.

Thank You for Listening

Thank You for Your Time

SPE -182793-MS