SPE 170912

Global Component Lumping for EOS Calculations

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Component Lumping – “Pseudoization”

Reduce number of components in an Equation of State (EOS) to a minimum for describing phase and volumetric behavior in a particular range of pressure-temperature-composition space for a particular engineering application.

- Reservoir simulation.
- Production “tubing” flow performance.
- Flowline networks.
- Surface processing.

EOSxx → EOSx

Component Lumping – How?

1. Start with a detailed EOSxx model – e.g. xx=15-40.
2. Choose total # of components in lumped EOSx model – e.g. x=6-9.
3. Choose which components to lump together – e.g. N_2 & C_1.
4. Choose a method to average EOS parameters – e.g. Coats.
5. Choose a composition to average EOS parameters – e.g. z_{Ri}.
6. Choose PVT calculations to validate EOSx – e.g. p_s, ρ, μ, y_i, x_i.
7. Compare EOSx versus EOSxx for same set of PVT calculations.
   - Plots & Tables.
   - Single-valued match “quality” metric – SSQ, RMS…

If results are not good enough, go back to step 2.

Component Lumping – How We Do It

1. Start with a detailed EOSxx model – e.g. XX=15-40.
2. Choose total # of components in lumped EOSx model – e.g. X=6-9.
3. Choose which components to lump together – try them “all”.
4. Choose a method to average EOS parameters – e.g. Coats.
5. Choose a composition to average EOS parameters – e.g. z_{Ri}.
6. Choose PVT calculations to validate EOSx – comprehensive.
7. Compare EOSx versus EOSxx for same set of PVT calculations.
   - Single-valued quality metric – RMS.
8. Final-pass assessment of best-RMS EOSx models.
   - MMP | Plots & Tables.

"All" Lumping Combinations

1. EOSxx to EOSx possible combinations. e.g. xx=22 | x=9

$$N_{EOSx} = \frac{N_{xx}!}{(N_{xx}-N_x)!}$$ 180,000,000,000

2. Contiguous lumping constraint (neighboring EOSxx components).

$$\mathrm{N}_{EOSx} = \frac{(\tilde{\mathrm{N}}_{\mathrm{xx}}-1)!}{(\tilde{\mathrm{N}}_{\mathrm{xx}}-\tilde{\mathrm{N}}_{\mathrm{x}})!(\tilde{\mathrm{N}}_{\mathrm{x}}-1)!}$$ 203,490

3. Algorithm to setup each scenario: Yukihiro Matsumoto (www).

4. Partial lumping not allowed – e.g. 80% C_3 in C_3C_4, 20% C_3 in C_3C_5.

5. Optional forced lumpings – e.g. N_2+C_1 , C_{30+} alone.

Comprehensive p-T-z Data Validation

1. Range of feed compositions (GORs).
2. Range of PVT types – p_s, ρ, μ, V_{ro}, y_i, x_i, …
3. Range of PVT tests – depletion, gas injection, gradient, MMP.
4. Calculated once with EOSxx.
5. Calculated for each EOSx lumped scheme.
6. Final MMP validation – i.e. long-running calculations for only select group of EOSx models.

EOSx versus EOSxx

1. RMS quality metric of EOSx vs EOSxx.

$$RMS = \bar{r} = \left[\frac{\sum_{n=1}^{N_{data}} (w_n r_n)^2}{\sum_{n=1}^{N_{data}} w_n^2} \right]^{0.5}$$

- $r_n = 100\ (d_{x,n} - d_{xx,n}) / d_{ref,n}$.
- (d_{ref}) taken as max of all d_{xx} data of a given type (e.g. oil density) in a given simulated lab test (e.g. CCE).

2. Optional MMP comparison of few EOSx models with lowest RMS.

Lumping Examples

Detailed EOSxx (xx=34) | Lumped EOSx (x=15, 9, 6)

- Peng-Robinson EOS (LBC) models.
  - EOSxx components.
    - N_2 & CO_2
    - C_1, C_2, C_3, i-C_4, n-C_4, i-C_5, n-C_5
    - C_6 C_7 C_8 ... C_{28} C_{29} and C_{30+}

- Five fluids from a isothermal gradient used in PVT calculations.
  - Lean gas condensate (OGR = 50 STB/MMscf)
  - Richer gas condensate (OGR = 100 STB/MMscf)
  - **Near- critical oil (GOR = 5000 scf/STB)***
  - Less-volatile oil (GOR = 2200 scf/STB)
  - More-volatile oil (GOR = 1000 scf/STB)

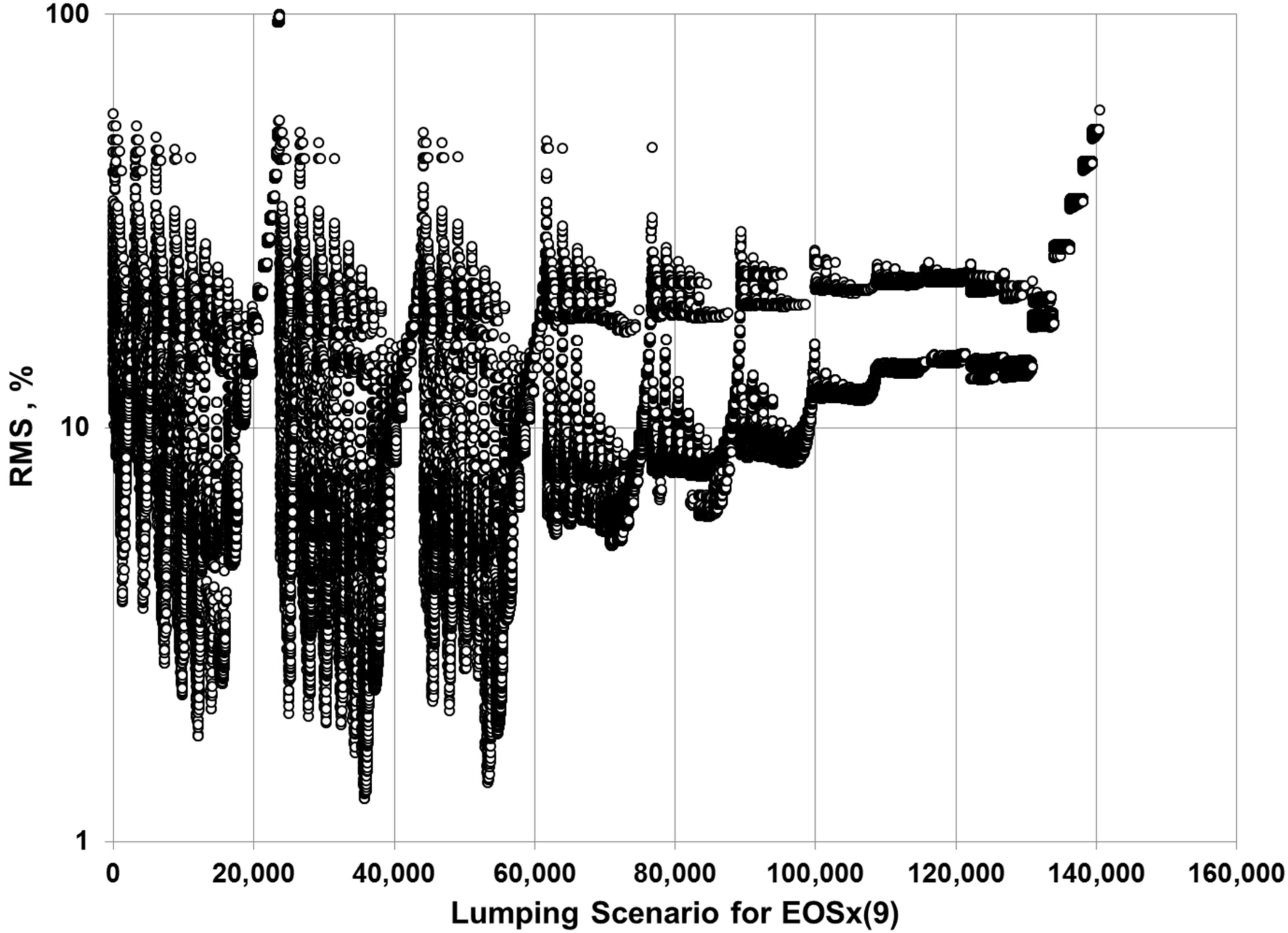
* Averaging sample.

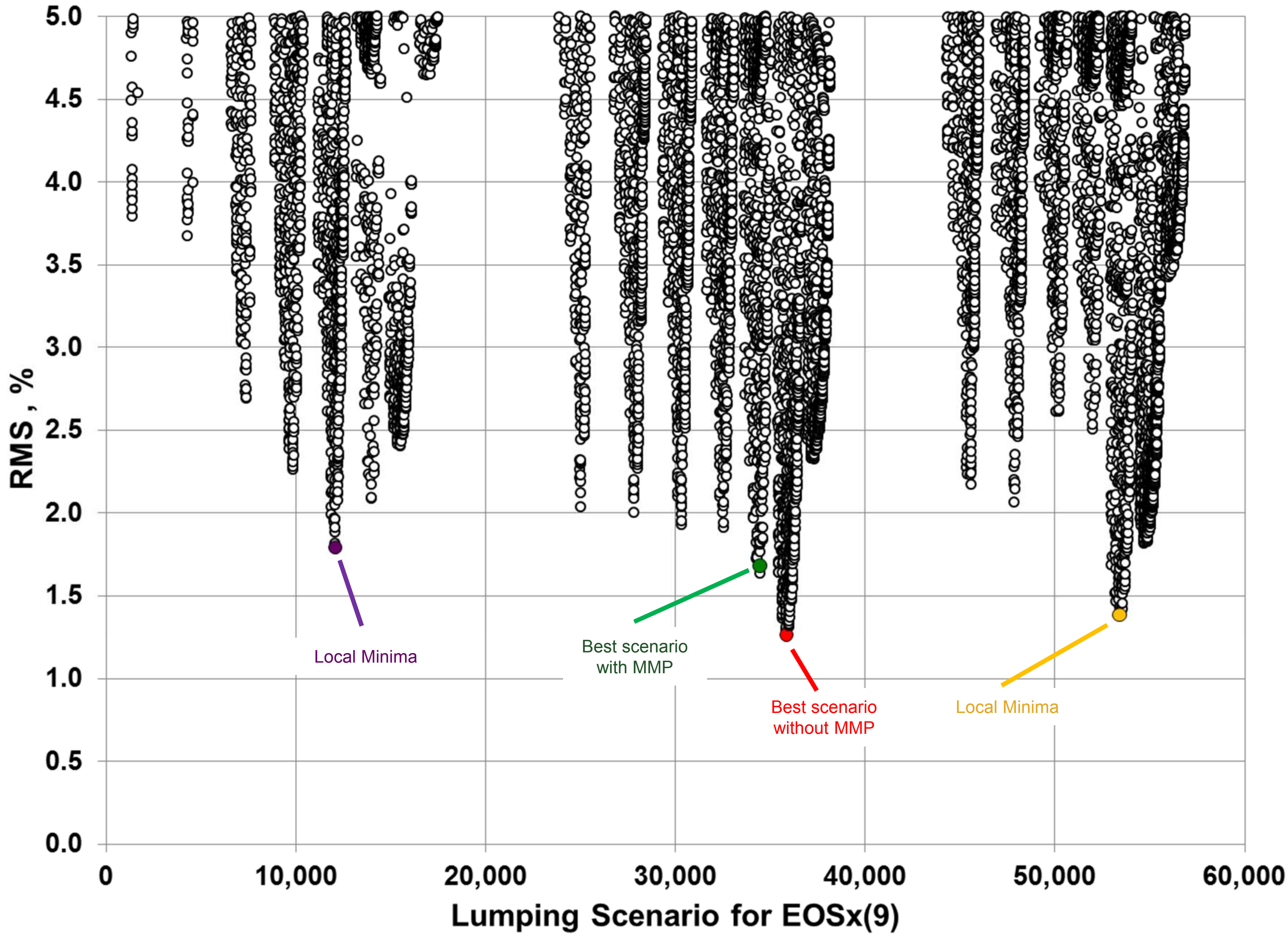
PVT Calculations & Weighting

Experimental Property	Weighting Factor
Depletion and Multi-stage Separator Tests	
Saturation Pressure	10
Liquid Volumes/Bo	3
Liquid Saturation	3
Liquid Density	2
Gas-Oil Ratio	2
Condensate-Gas Ratio	2
Relative Volume	1
Gas Specific Gravity	1
Gas Density	1
Gas Z-factor	1
Liquid API	1
Liquid Viscosity	0
Gas Viscosity	0
Swelling Experiment & CCE of Swollen Mixtures	
Saturation Pressure	3
Liquid Saturation	3
Relative Volume	1
Liquid Density	1
Gas Density	0.5
Gas Z-factor	0.5
Liquid Viscosity	0
Gas Viscosity	0
Some individual data may be weighted slightly different than the global default weighting factors given in this table. See the PhazeComp output file for exact weighting factors of data.	

Lumping Example – EOS9

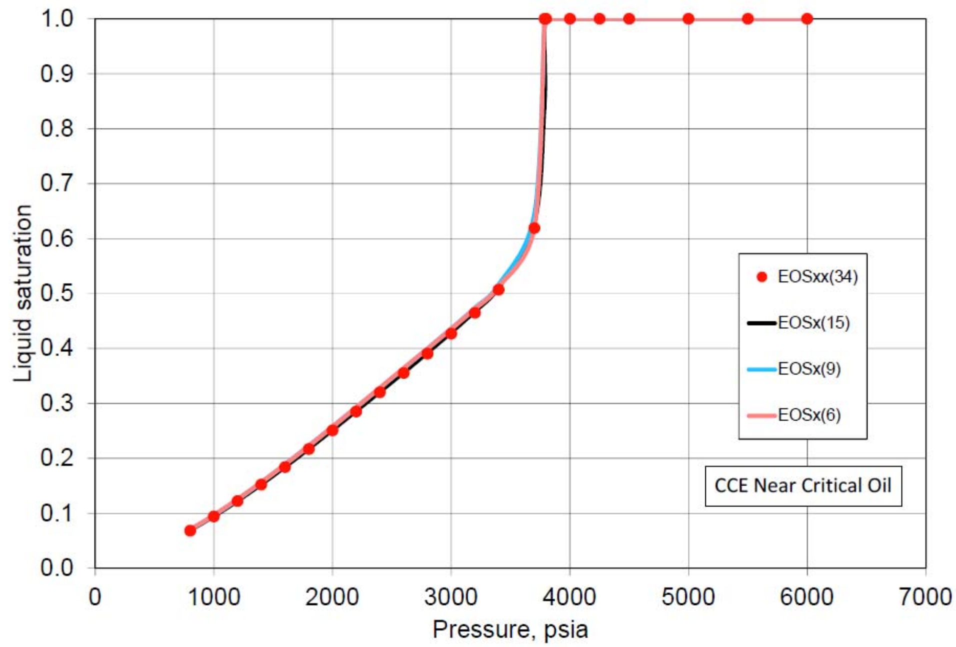
- EOS9 lumping constraints.
  - 3 single components: N_2, CO_2 and C_1
  - Lumping starts from C_2.
  - 6 Lumped components.
- 142,506 total lumping scenarios.
- All scenarios performed (without including MMP calculation).
- 500 best-RMS scenarios selected, including MMP calculation.


100
10
1
RMS , %
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
Lumping Scenario for EOSx(9)


5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
RMS , %
0
10,000
20,000
30,000
40,000
50,000
60,000
Lumping Scenario for EOSx(9)
Local Minima
Best scenario
with MMP
Best scenario
without MMP
Local Minima

	Best Five with Lowest RMS					Local Minima RMS		Best MMP
Case no.	35847	35846	35833	35832	35860	53395	12074	34458
RMS (%)	1.265	1.270	1.294	1.300	1.313	1.387	1.793	**1.683**
MMP (psia)	3583	3585	3587	3589	3582	3544	3552	**3661**
3660	-2.1%	-2.0%	-2.0%	-1.9%	-2.1%	-3.2%	-2.9%	**0.0%**
	N2	N2	N2	N2	N2	N2	N2	**N2**
	CO2	CO2	CO2	CO2	CO2	CO2	CO2	**CO2**
	C1	C1	C1	C1	C1	C1	C1	**C1**
	C2_C3	C2_C3	C2_C3	C2_C3	C2_C3	C2_I-C4	C2	**C2_C3**
	I-C4_C7	I-C4_C7	I-C4_C7	I-C4_C7	I-C4_C7	N-C4_C7	C3_N-C5	**I-C4_C6**
	C8_C10	C8_C10	C8_C10	C8_C10	C8_C10	C8_C10	C6_C10	**C7_C11**
	C11_C15	C11_C15	C11_C14	C11_C14	C11_C16	C11_C15	C11_C16	**C12_C15**
	C16_C25	C16_C24	C15_C25	C15_C24	C17_C25	C16_C23	C17_C25	**C16_C23**
	C26_C30+	C25_C30+	C26_C30+	C25_C30+	C26_C30+	C24_C30+	C26_C30+	**C24_C30+**

Near-Critical Oil



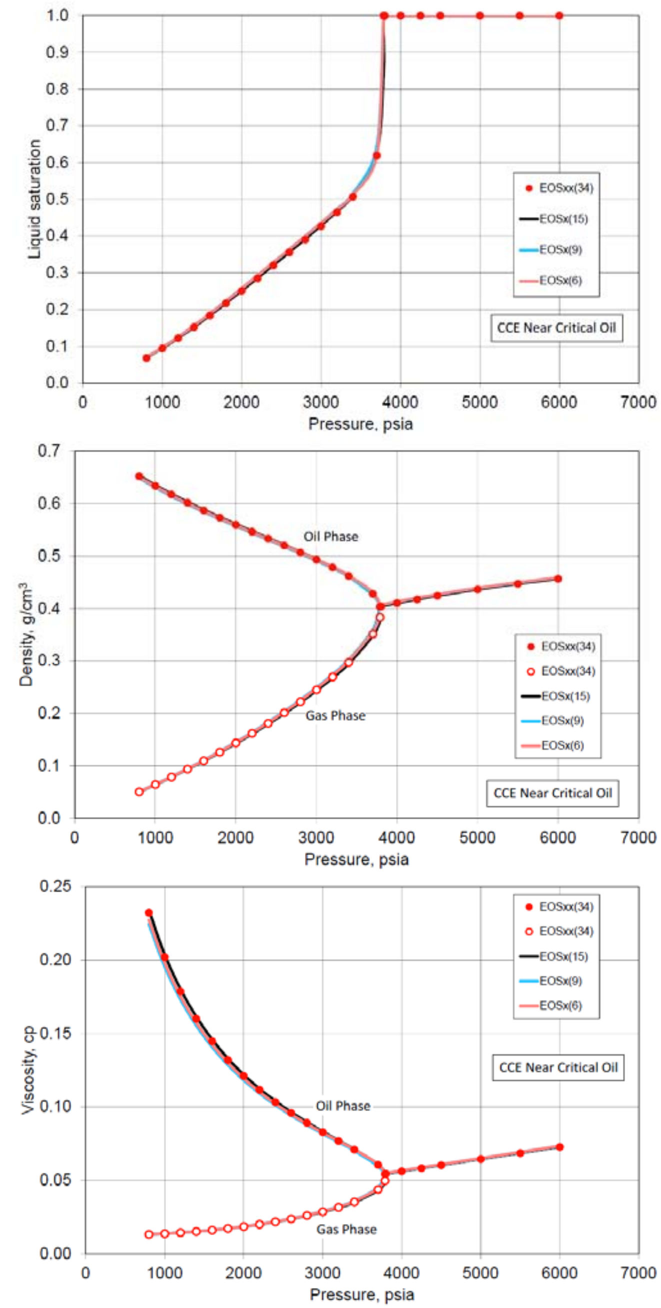
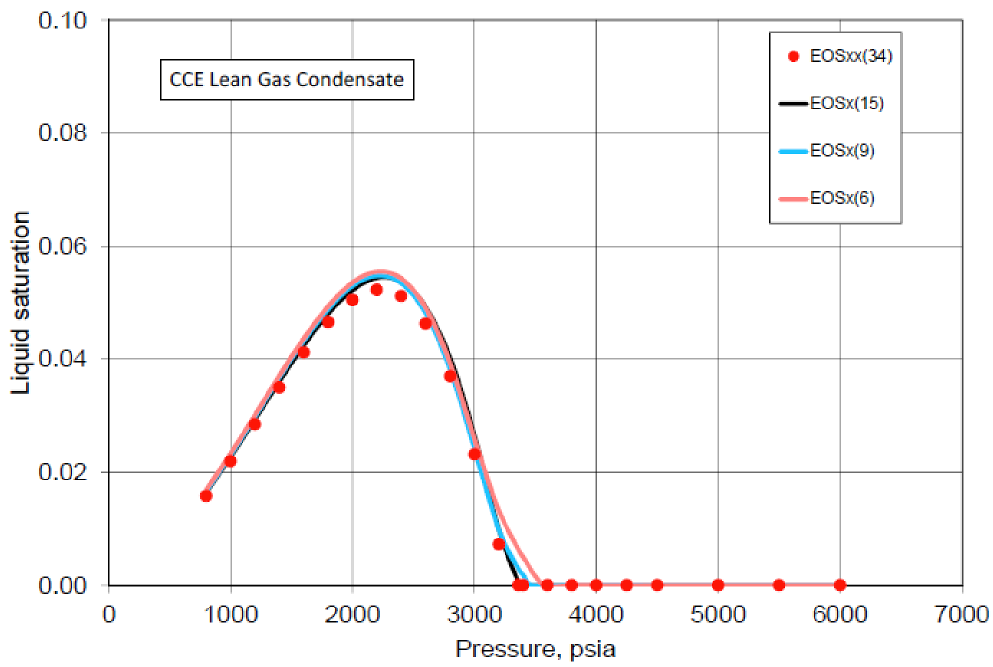


Fig. 10 – Near-Critical Oil EOS calculations.

Lean Gas Condensate



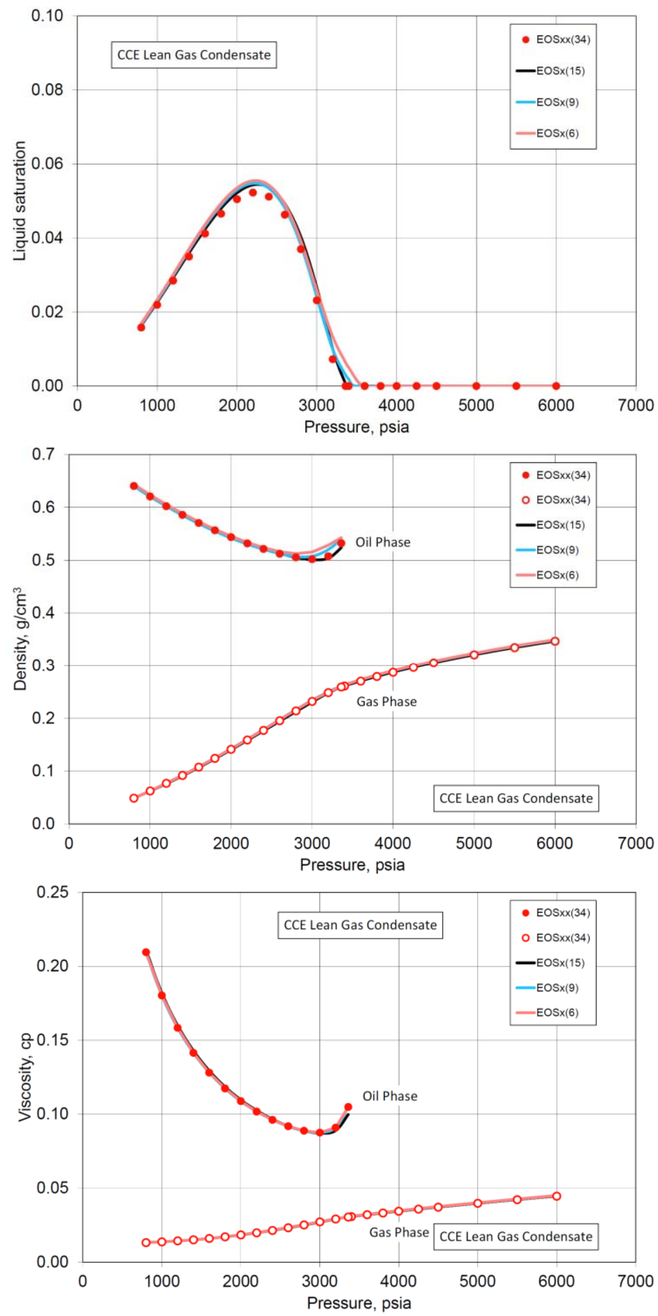


Fig. 7 – Lean Gas Condensate EOS calculations.

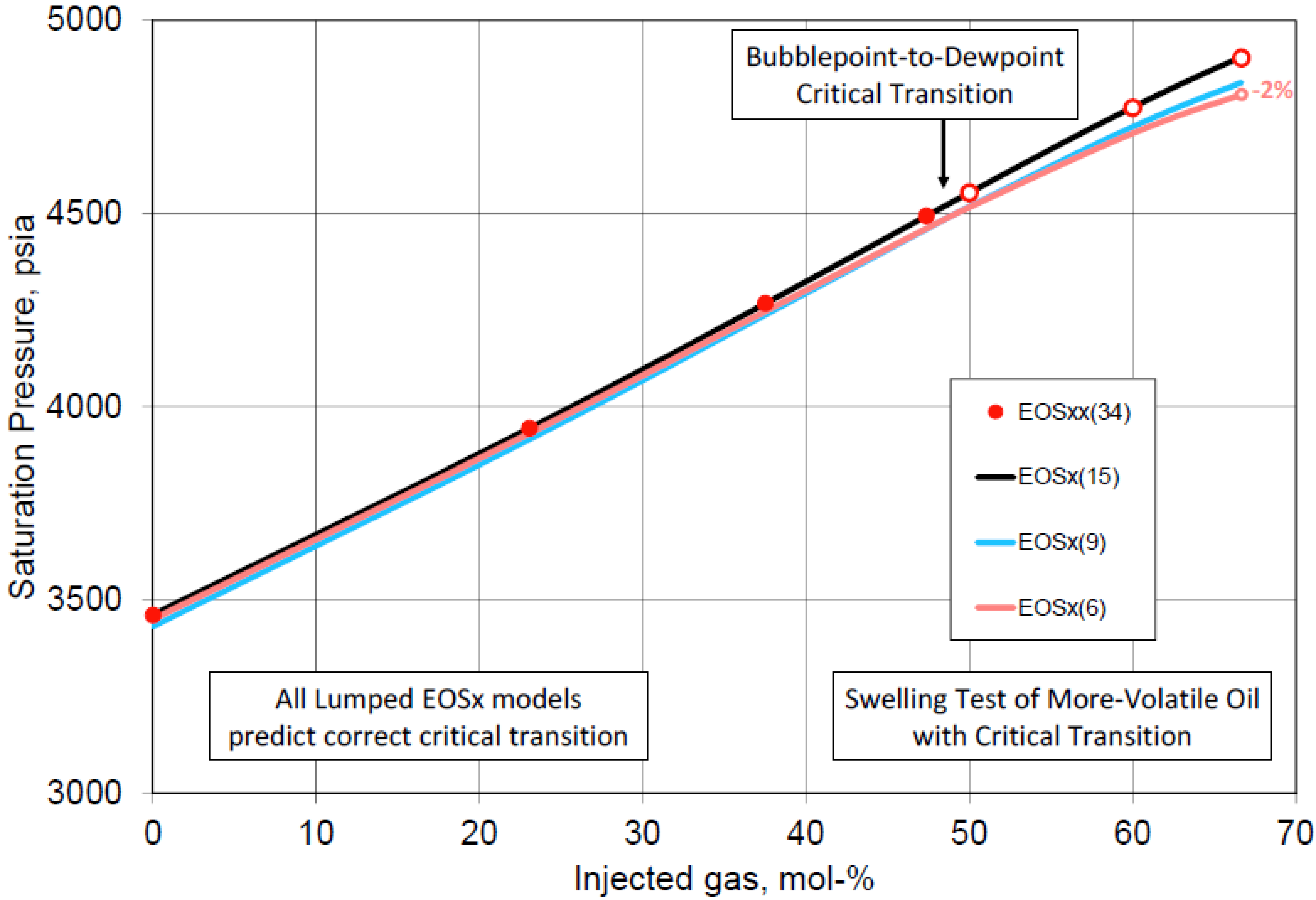


Fig. 13 – More-Volatile Oil swelling test calculations.

Conclusions

1. The lumping method is designed to describe a particular engineering discipline (reservoir, flow assurance, process facilities) for which the lumped EOSx is being applied.

   Different EOSx models may be developed for each modling discipline from same EOSxx model – ensures consitency.

2. The method uses a well-defined quantitative measure of the lumped EOSx model accuracy in terms of how well the PVT compare with the original detailed EOSxx model.

3. The lumping method makes a comprehensive search of all possible lumping scenarios with few but meaningful constraints.

Conclusions

4. The challenge in applying the proposed lumping method is

   a. Defining an appropriate set of PVT calculations for defining the quality metric for the processes being modeled with EOSx.

   b. Defining weighting factors for each data to reflect their importance to the processes being modeled with EOSx.

   c. Automated execution of all EOSx scenarios (Pipe-It) using a fast and robust EOS-based PVT program (PhazeComp).

Thank You