EOS – Applications – Bubble point – Algorithm

1. Provide an **estimate of the bubble point** pressure

2. Estimate the **K-factors**

$$K_i = \frac{p_{ci}}{p} e^{\left[5.37(1+\omega_i)\left(1-\frac{T_{ci}}{T}\right)\right]}$$

3. Estimate **vapor phase composition**

$$y_i^{j+1} = z_i K_i^j$$

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EOS – Applications – Bubble point – Algorithm – Cont.

4. Calculate the **vapor and liquid phase fugacity coefficients**. The liquid composition equals the feed composition.

$$\overset{v}{\Rightarrow} \ln \phi_i^v = \frac{b_i(Z^v - 1)}{b_m} - \ln(Z^v - B) - \frac{A}{2\sqrt{2}B}\left[\frac{2\psi_i}{(a\alpha)_m} - \frac{b_i}{b_m}\right] \ln\left[\frac{Z^v + (1 + \sqrt{2}B)}{Z^v + (1 - \sqrt{2}B)}\right]$$

5. Calculate **new K-factors**.

$$\ln K_i = \ln \phi_i^L - \ln \phi_i^V$$

EOS – Applications – Bubble point – Algorithm – Cont.

6. **Evaluate:**

$$F = \sum_{i=1}^{N} Z_i K_i - 1$$

7. **Evaluate:**

$$\frac{dF}{dP} = \sum_{i=1}^{N} Z_i K_i \left(\frac{\partial \ln \phi_i^L}{\partial p} - \frac{\partial \ln \phi_i^V}{\partial p} \right)$$

EOS – Applications – Bubble point – Algorithm – Cont.

6. New p:

$$p^{j+1} = p^j - \frac{F^j}{\frac{dF^j}{dp}}$$

EOS – Applications – SIMULATING OF LABORATORY PVT DATA

To use an **EOS-based compositional model** in a **full-field simulation study**, it is essential the selected equation of state is **capable of achieving** a **satisfactory match between EOS results and all the available PVT test data**. It should be pointed out that an **equation of state generally is not predictive** without **tuning its parameters to match the relevant experimental data**.

CCE Test

Constant Compositional Expansion (CCE) tests are conventionally performed on **all types of reservoir fluids** to obtain a **better understanding** of the *pressure-volume relationship* of these hydrocarbon systems.

- ◦ **Saturation pressure**

- ◦ **Oil density at and above bubble point**

- ◦ **Y-function**

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CCE Test – Experimental Procedure 1

The experimental procedure involves **placing a hydrocarbon fluid sample** in a **visual PVT cell** at **reservoir temperature** that is held **constant during the experiment**.

To **ensure** that the hydrocarbon sample *exits in a single phase*, the **sample is pressurized** to a **much higher pressure** than the **initial reservoir pressure**.

CCE Test – Experimental Procedure 2

The **pressure is reduced isothermally** in steps by **removing mercury from the PVT cell** and the

total hydrocarbon volume "Vt" is measured at each pressure.

The combination of **successive reductions in the pressure** and the **measurement of total fluid**

volume "Vt" are **performed at a CCE**; that is, _no gas or liquid is removed from the PVT cell_ at

any time throughout the experiment.

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CCE Test – Experimental Procedure 3
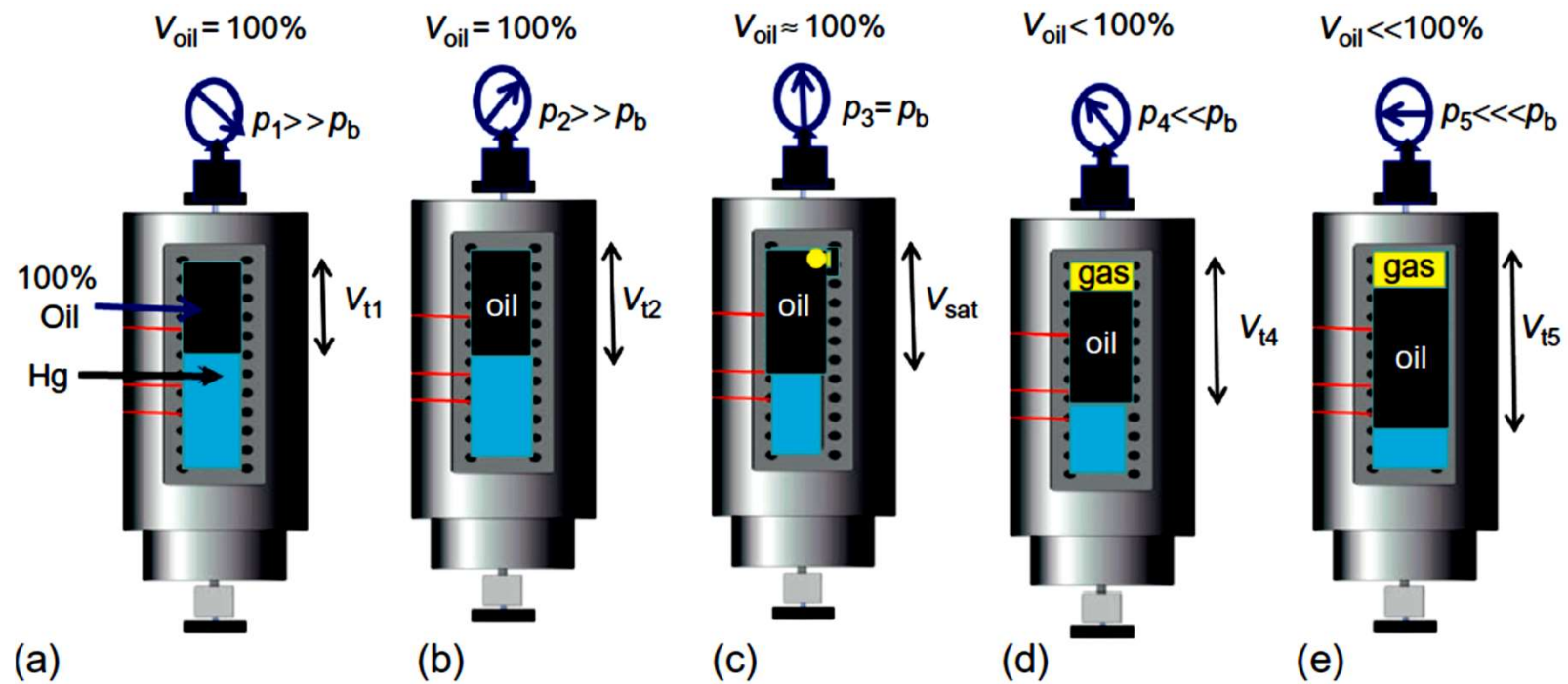
CCE Test – Experimental Procedure 4

The **saturation pressure** value is identified by **visual inspection** and by the **point of discontinuity**
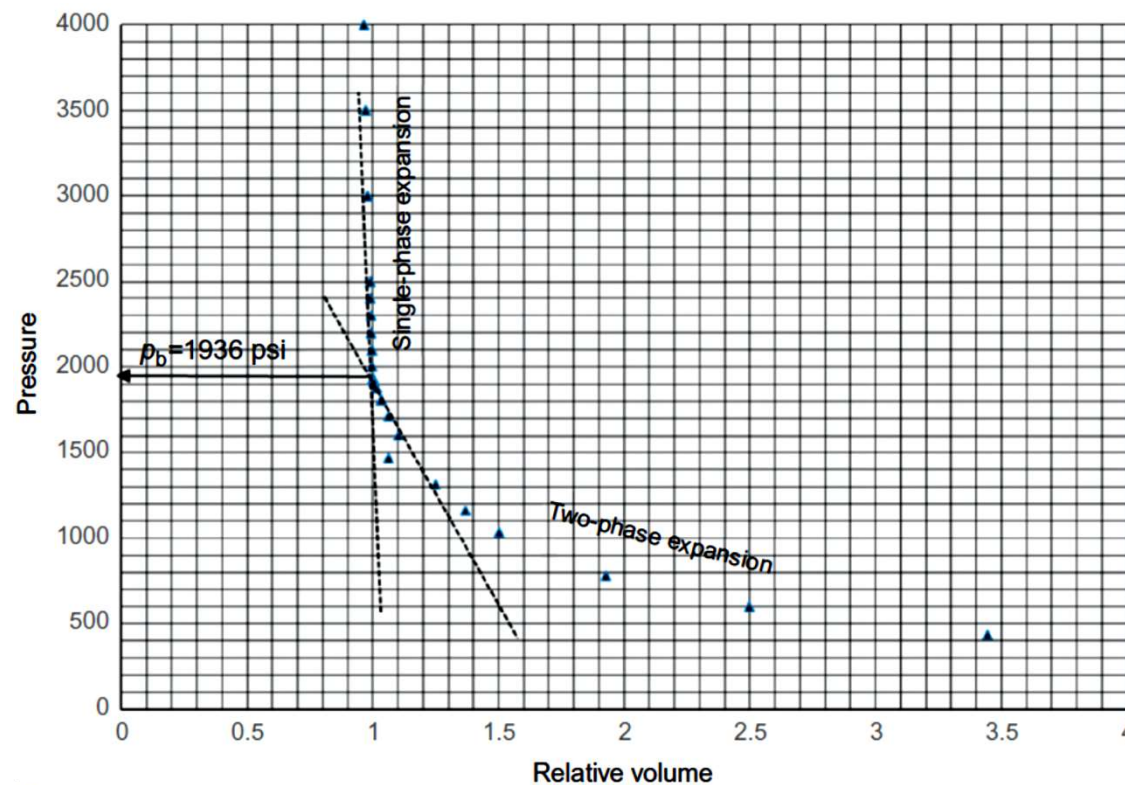
on the plot "pressure-volume" curve.

$$V_{rel} = \frac{V_t}{V_{sat}}$$

V_{rel} = relative volume
V_t = total hydrocarbon volume
V_{sat} = volume at the saturation pressure

CCE Test – Experimental Procedure 5

p	Rel Vol
6500	0.9371
6000	0.9422
5500	0.9475
5000	0.9532
4500	0.9592
4000	0.9657
3500	0.9728
3000	0.9805
2500	0.989
2400	0.9909
2300	0.9927
2200	0.9947
2100	0.9966
2000	0.9987
1936	1
1930	1.0014
1928	1.0018
1923	1.003
1918	1.0042
1911	1.0058
1878	1.0139
1808	1.0324
1709	1.0625
1600	1.1018
1467	1.0611
1313	1.2504
1161	1.3694
1035	1.502
782	1.9283
600	2.496
437	3.4464

CCE Test – Experimental Procedure 6

The instantaneous **isothermal compressibility coefficient** of **any substance** is defined as the **rate of change in volume with respect to pressure per unit volume at a constant temperature**.
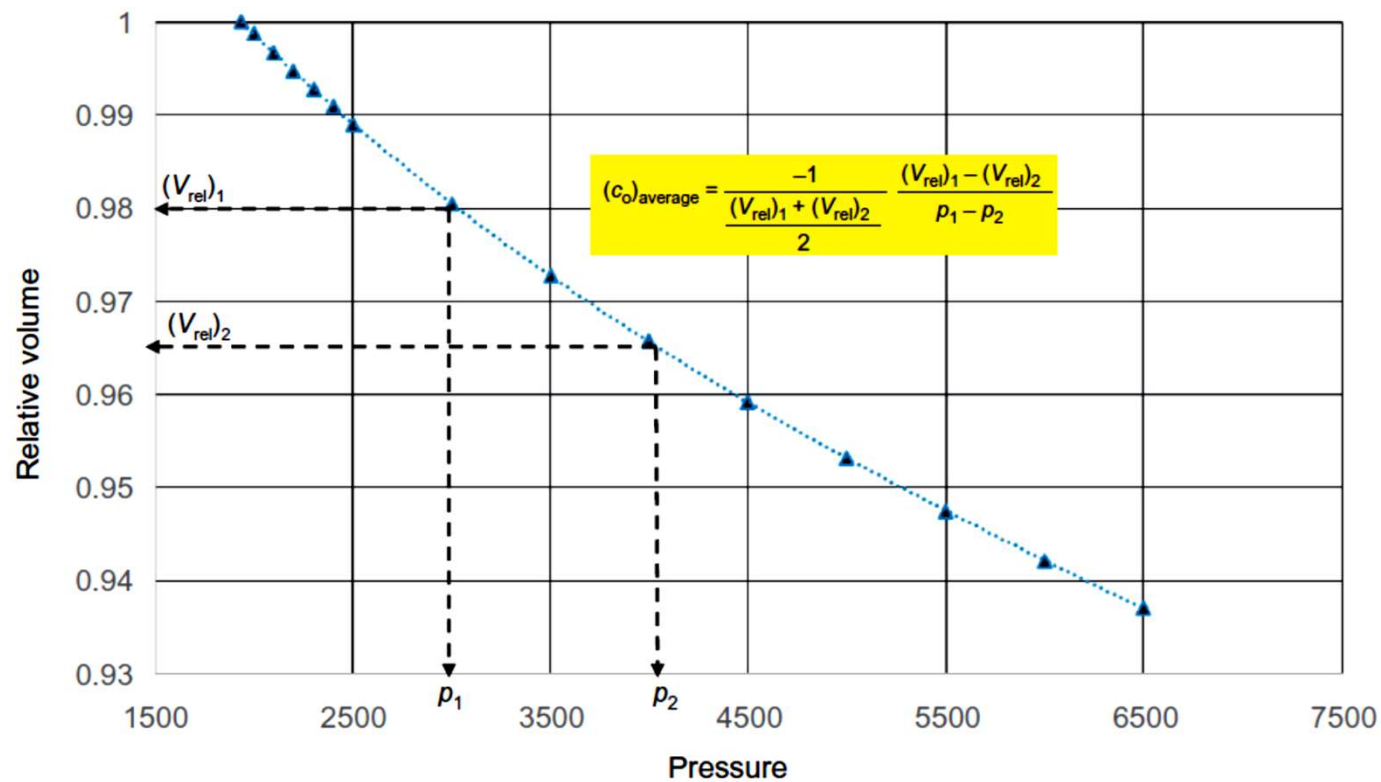
$$c = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$

$$c_o = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$

$$c_o = \frac{-1}{(V/V_{\text{sat}})}\frac{\partial(V/V_{\text{sat}})}{\partial p}$$

$$c_o = \frac{-1}{V_{\text{rel}}}\frac{\partial V_{\text{rel}}}{\partial p}$$

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CCE Test – Experimental Procedure 7

$$(c_o)_{average} = \frac{-1}{\dfrac{(V_{rel})_1 + (V_{rel})_2}{2}} \cdot \frac{(V_{rel})_1 - (V_{rel})_2}{p_1 - p_2}$$

CCE Test – Experimental Procedure 8

The relative volume data frequently **require smoothing to correct for laboratory inaccuracies** in measuring the total hydrocarbon volume, particularly **below the saturation pressure** and also **at lower pressures**.

A **dimensionless compressibility function**, commonly called the **Y-function**, is used to **smooth the values of the relative volume "Vrel" below the saturation pressure**.

$$Y = \frac{p_{\text{sat}} - p}{p(V_{\text{rel}} - 1)}$$

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CCE Test – EOS Simulation – 1

Step 1:

Given the **total composition of the hydrocarbon system, Zi,** and **saturation pressure** (Pb for oil systems), **calculate the total volume occupied by 1 mol of the system**. **This volume corresponds to the reference volume Vsat** (volume at the saturation pressure). Mathematically, the volume is calculated from the relationship:

$$V_{sat} = \frac{(1)ZRT}{p_{sat}}$$

V_{sat} = volume of saturation pressure, ft^3/mol
p_{sat} = saturation pressure (dew point or bubble point pressure), psia
T = system temperature, °R
Z = compressibility factor, Z^L or Z^v depending on the type of system

CCE Test – EOS Simulation – 2

Step 2:

The pressure is **increased in steps above the saturation pressure**, where the single phase still exists. At each pressure, the compressibility factor, Z, is calculated.

$$V = \frac{(1)ZRT}{p} \qquad \Longrightarrow \qquad V_{rel} = \frac{V}{V_{sat}}$$

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CCE Test – EOS Simulation – 3

Step 3:

The pressure is then **reduced in steps below the saturation pressure Psat. The equilibrium ratios are calculated and flash calculations are performed at each pressure level.** The volumes of the liquid and gas phases can then be calculated from the expressions.

$$V_L = \frac{(1)(n_L)Z^L RT}{p}$$

$$V_g = \frac{(1)(n_v)Z^v RT}{p}$$

$$V_t = V_L + V_g$$

$$\text{Relative total volume} = \frac{V_t}{V_{sat}}$$

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