

Reservoir Engineering II

Laboratory Analysis of Reservoir Fluids

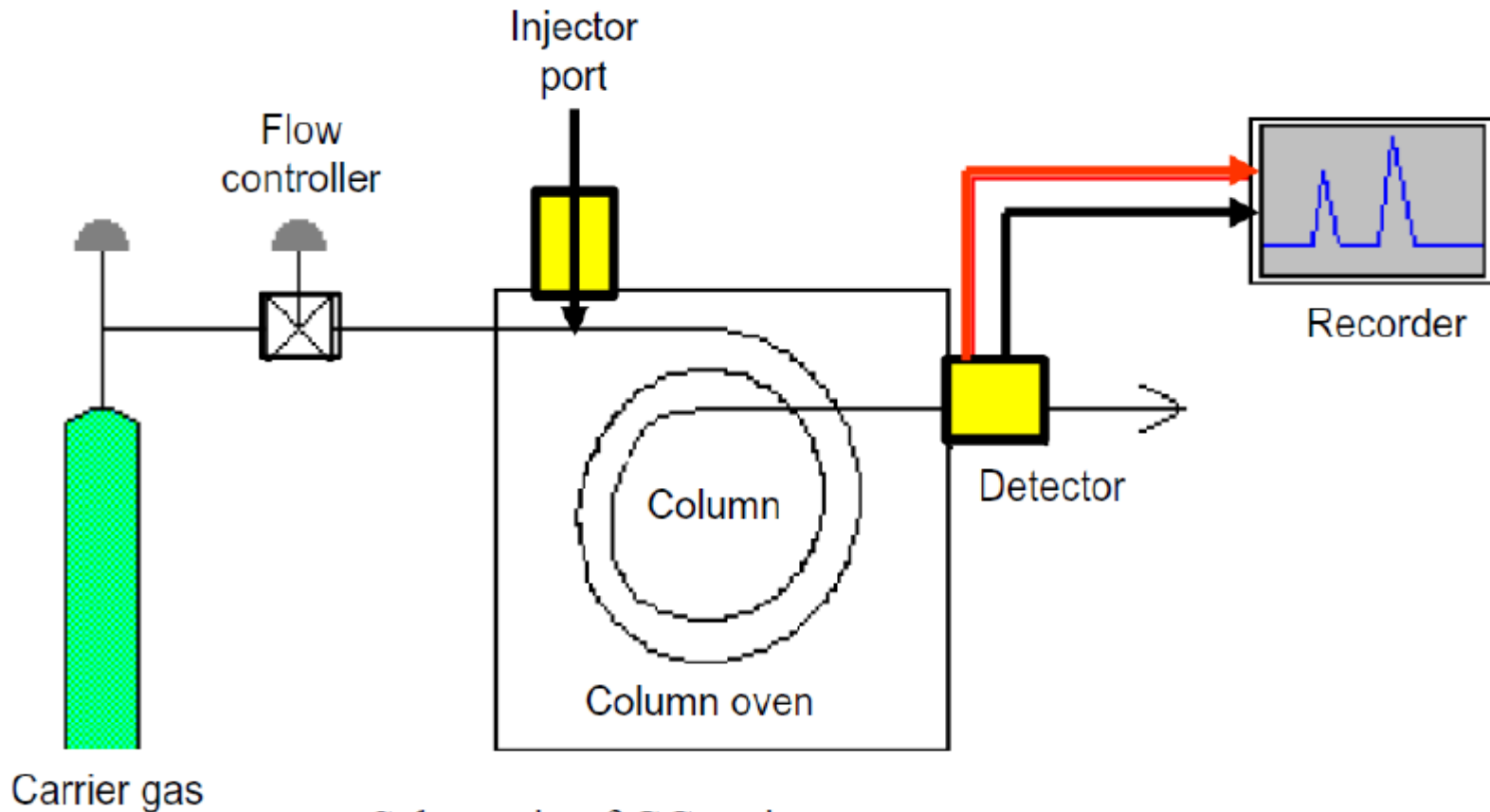
By

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Composition of the Reservoir Fluid

- Compositional analysis generally refers to the measurement of the distribution of hydrocarbons and other components present in oil and gas samples.
- Gas chromatography (GC) is the technique for separating and identifying components of hydrocarbon mixtures.
- It is desirable to obtain a fluid sample as early in the life of a field as possible so that the sample closely approximates the original reservoir fluid.

Composition of the Reservoir Fluid



Schematic of GC main components.

Constant-Composition Expansion Tests (CCE)

- Equilibrium tests are conventionally performed on reservoir fluids to obtain a better understanding of the pressure-volume relationship of these hydrocarbon systems.
- This test can also be referred to by different names, including equilibrium test, pressure-volume relations, constant mass expansion, flash liberation, flash vaporization, or flash expansion.

Propose Of CCE Tests

The equilibrium test is performed on crude oil systems for the purposes of determining:

- Saturation pressure.
- Relative volume “ V_{rel} ”.
- Isothermal compressibility coefficient “ C_o ” above P_b .
- Oil density “ ρ_o ” at and above P_b .
- Oil FVF “ B_o ” above P_b .
- Two-phase formation factor B_t below P_b .

The Experimental Procedure Of CCE Tests

The experimental procedure involves:

1- placing a hydrocarbon fluid sample in a visual PVT cell at reservoir temperature that is held constant during the experiment.

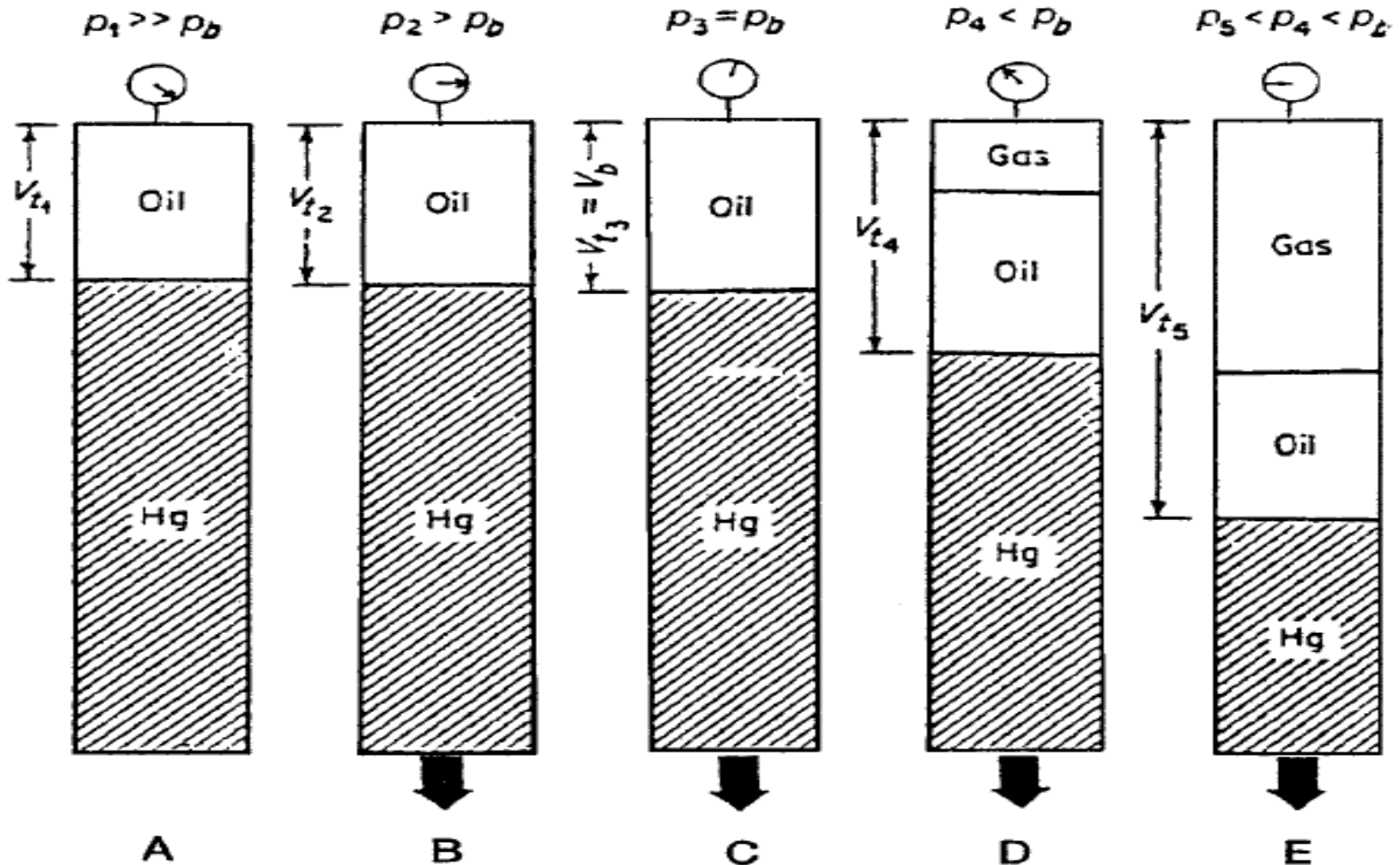
2- To ensure that the hydrocarbon sample exits in a single phase, the sample is pressurized to a much higher pressure than the initial reservoir pressure.

The Experimental Procedure Of CCE Tests

3- The pressure is reduced isothermally in steps by removing mercury from the PVT cell and the total hydrocarbon volume “ V_t ” is measured at each pressure.

4- This test is performed at a equilibrium; that is, no gas or liquid is removed from the PVT cell at any time throughout the experiment.

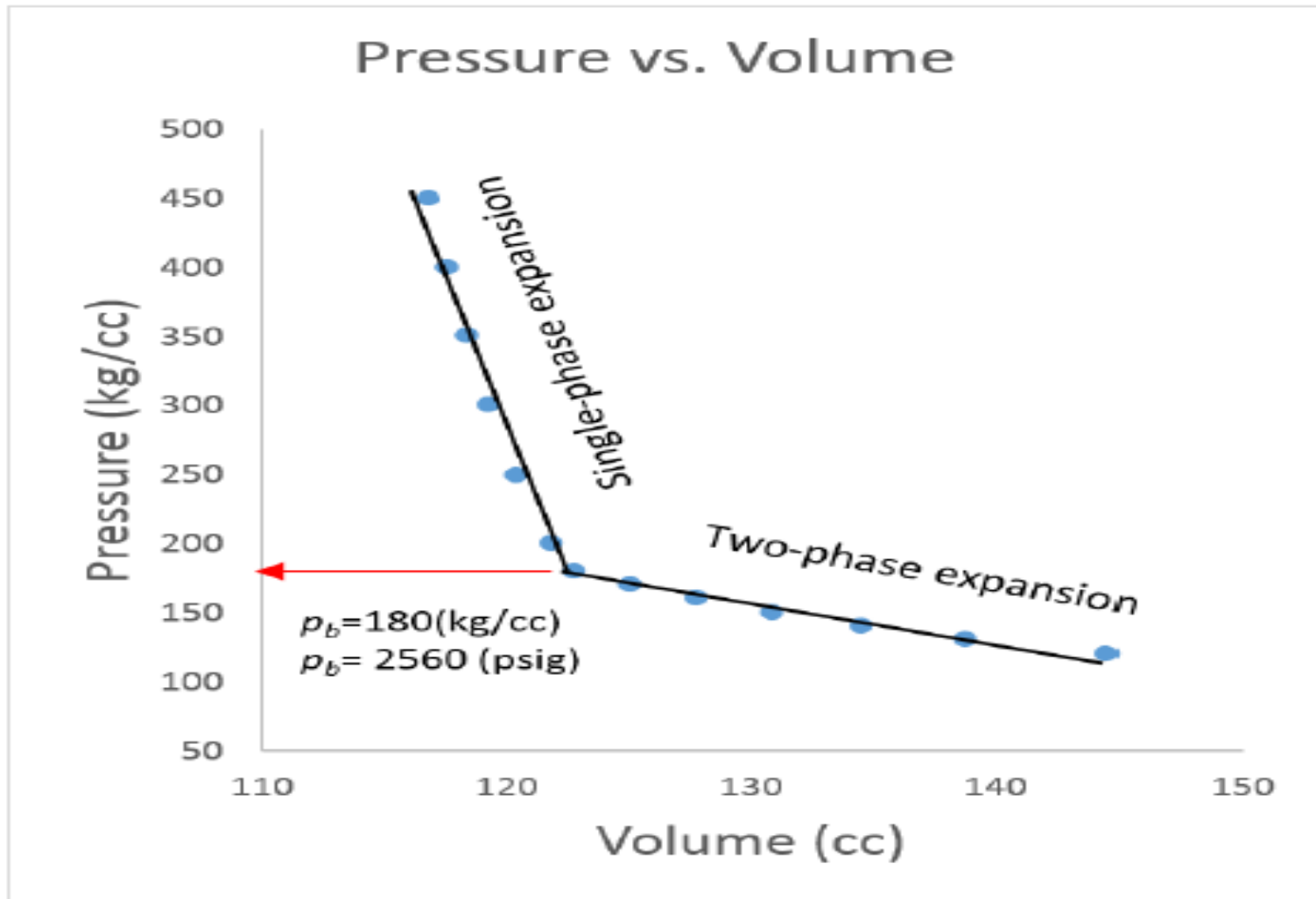
The Experimental Procedure Of CCE Tests



Saturation Pressure Estimation

- As the pressure approaches the saturation pressure, the total volume continuously increases due to the expansion of the single-phase crude oil.
- Reaching the bubble point pressure marks the appearance and start of liberation of the solution gas.
- The saturation pressure value is identified by visual inspection and by the point of discontinuity on the plot “pressure-volume” curve.
- The saturation pressure and corresponding volume are recorded and designated as “ P_{sat} ” and “ V_{sat} ”, respectively.

Saturation Pressure Estimation



Saturation Pressure Estimation

- It should be pointed out the change in the slope is related to the fluid compressibility resulting from the transition from the single phase to the two-phase state.
- In the single liquid phase region, the liquid compressibility is relatively small resulting in a steep decline in the pressure with a small increase in the liquid volume.
- As the pressure approaches the bubble point pressure and initiation of liberation solution gas, the evolved gas is characterized by a high compressibility that causes less reduction in the pressure resulting in a sharp break in the slope between the single- and two-phase regions.

Relative Volume Estimation

- The volume at the saturation pressure “ V_{sat} ” is used as a reference volume and the total volume “ V_t ” as a function of pressure is reported relative to V_{sat} as a ratio of “ V_t/V_{sat} .”
- This volume is termed the relative volume and is expressed mathematically by the following equation:

$$V_{rel} = \frac{V_t}{V_{sat}} \dots(1)$$

where: V_{rel} = relative volume.

V_t = total hydrocarbon volume.

V_{sat} = volume at the saturation pressure

Oil Density From The CCE Test

- The density is determined directly from mass “m” of the fluid sample and fluid volume “V” measurements.
- Designated ρ_{sat} for the fluid density at the saturation pressure, it can be calculated from:

$$\rho_{sat} = \frac{m}{V_{sat}} \dots\dots(2)$$

- Above the bubble point pressure, the density of the oil can be calculated by using the recorded relative volume at any pressure, to give:

$$\rho = \frac{m/V_{sat}}{V_{P,T}/V_{sat}} = \frac{\rho_{sat}}{V_{rel}} \dots\dots(3)$$

Oil Density From The CCE Test

where: ρ = density at any pressure above the saturation pressure.

ρ_{sat} = density at the saturation pressure.

V_{rel} = relative volume at the pressure of interest.

$V_{p,T}$ = volume at the pressure “p” and reservoir (cell) temperature.

Isothermal Compressibility From CCE Test

The instantaneous isothermal compressibility coefficient “ c_o ” is defined by the following expression:

$$C_o = \frac{-1}{V} \frac{\Delta V}{\Delta P}$$

$$C_o = \frac{-1}{V_{rel}} \frac{\partial V_{rel}}{\partial p} \dots\dots(4-a)$$

$$C_o = \frac{-1}{(V_{rel})_2} \frac{(V_{rel})_1 - (V_{rel})_2}{P_1 - P_2} \dots\dots(4-b)$$

Constant-Composition Expansion Tests (CCE)

Example

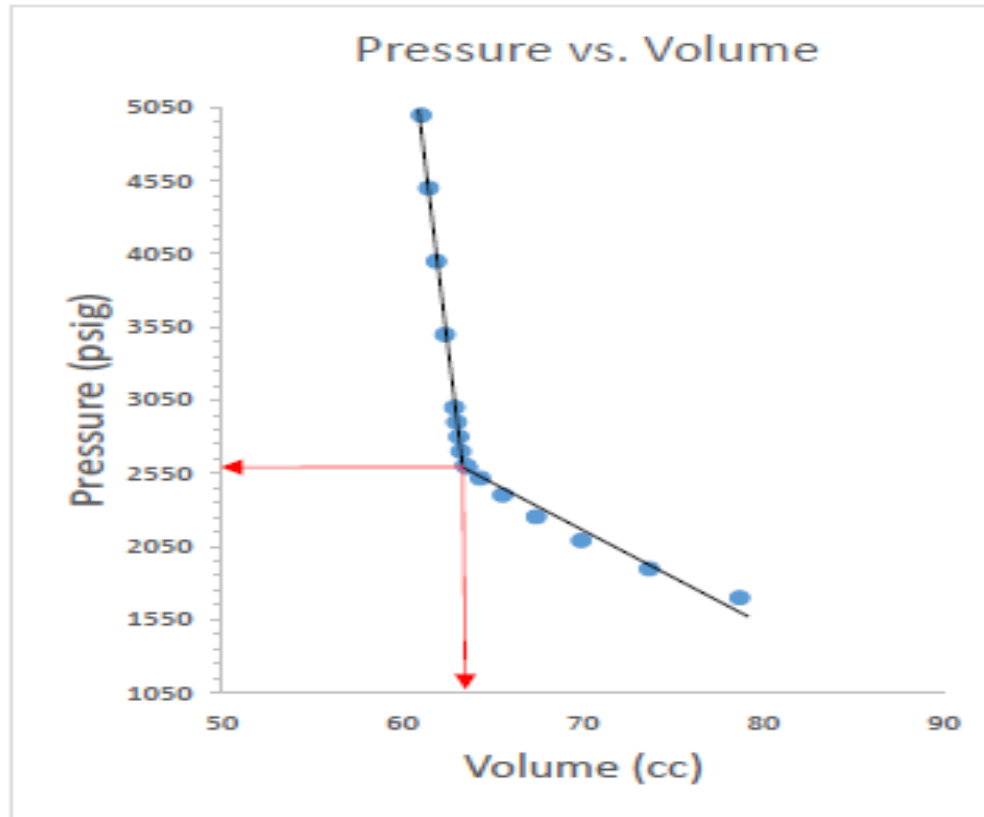
Using the following data of CCE test to:

Pressure (psig)	Total Volume (cc)
5000	61.030
4500	61.435
4000	61.866
3500	62.341
3000	62.866
2900	62.974
2800	63.088
2700	63.208
2605	63.455
2591	63.576
2516	64.291
2401	65.532
2253	67.400
2090	69.901
1897	73.655
1698	78.676

1. Find the saturation pressure.
2. Find the relative volume.
3. Calculate ρ_{sat} if $m=0.094$ lb.

Constant-Composition Expansion Tests (CCE)

1. Plot pressure vs. volume to find the saturation pressure:



From the pressure volume relationship, the saturation pressure is (2570 psig) and the saturation volume is (63.776 cc).

Constant-Composition Expansion Tests (CCE)

2. The values of relative volume are calculated:

$$V_{rel} = \frac{V_t}{V_{sat}} = \frac{V_t}{63.776}$$

the results are shown in the table below:

Pressure (psig)	Total Volume (cc)	V _{rel}
5000	61.030	0.95694305
4500	61.435	0.963293402
4000	61.866	0.97005143
3500	62.341	0.977499373
3000	62.866	0.98573131
2900	62.974	0.987424737
2800	63.088	0.989212243
2700	63.208	0.991093828
2605	63.455	0.994966759
2591	63.576	0.996864024
2570	63.776	1
2516	64.291	1.008075138
2401	65.532	1.027533869
2253	67.400	1.056823884
2090	69.901	1.096039262
1897	73.655	1.15490153
1698	78.676	1.233630206

3. $V_{sat} = 63.776 \text{ cc}$

$$\rho_{sat} = \frac{m}{V_{sat}} = \frac{0.094 \text{ lb}}{63.776 \text{ cc} (35.516 \times 10^{-6}) \frac{\text{cu ft}}{\text{cc}}} = 41.78 \text{ lb/cu ft}$$

Constant-Composition Expansion Tests (CCE)

Example

Using Figure 3 to evaluate c_o at 3,000 psi.

Solution

- Draw a tangent line to the curve and determine the slope.

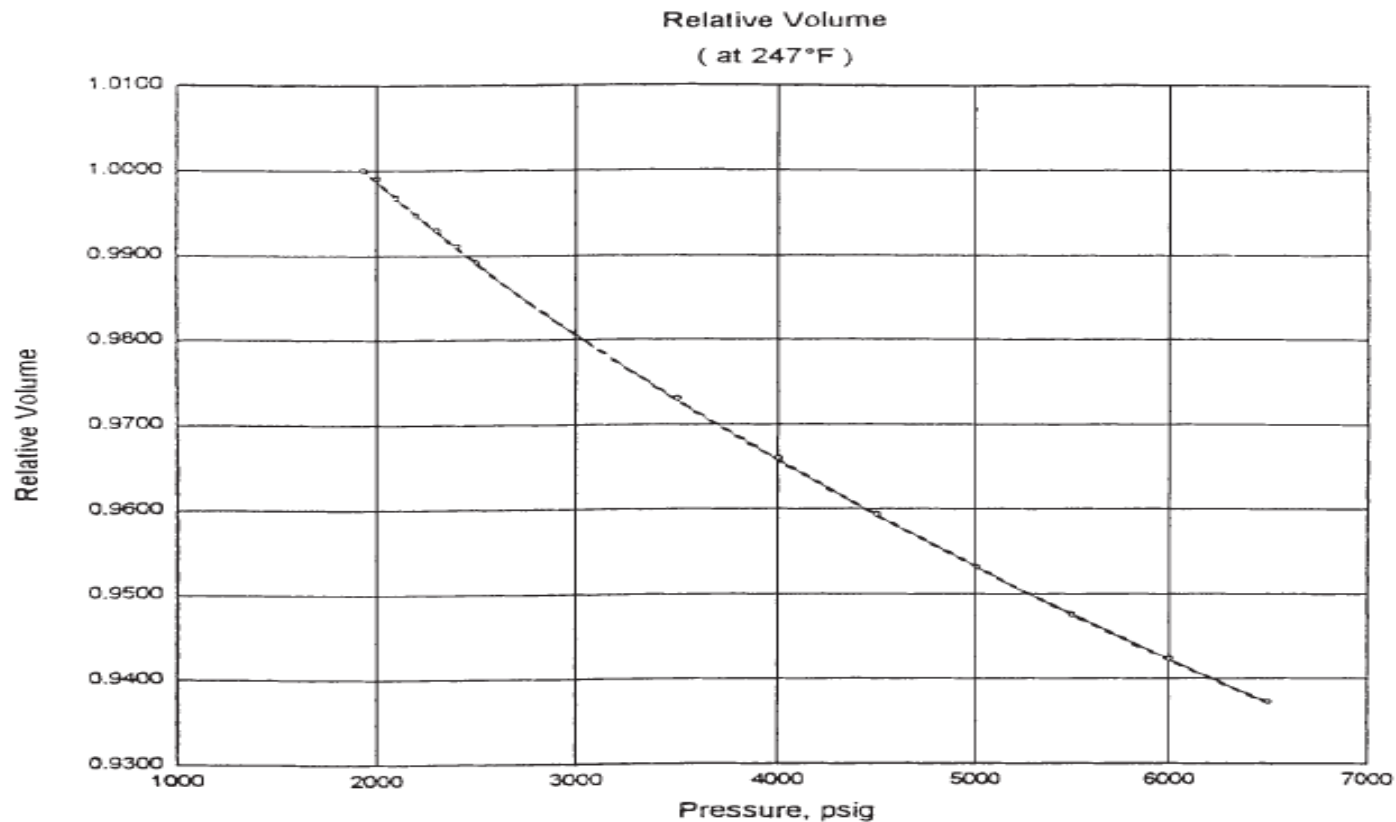
$$\partial V_{\text{rel}}/\partial p = -14.92 \times 10^{-6}$$

- Apply Equation(4-a) to give

$$c_o = \left(\frac{-1}{0.98} \right) (-14.92 \times 10^{-6}) = 15.23 \times 10^{-6} \text{ psi}^{-1}$$

Constant-Composition Expansion Tests (CCE)

Figure (3)



Differential Liberation Test (DL)

The DL process is summarized in the following steps:

- 1- A crude oil sample is placed in a visual PVT cell at its bubble point pressure (estimated from CCE) and reservoir temperature.
- 2- The cell pressure is reduced in stages, usually 10–15 pressure increments, from the saturation pressure to atmospheric pressure.
- 3- The liberated gas at each pressure stage is allowed to reach equilibrium with the cell remaining oil.
- 4- The volume of the two phases (ie, remaining oil volume “ V_L ” and liberated gas volume “ V_{gas} ”) are measured and recorded at each pressure level.

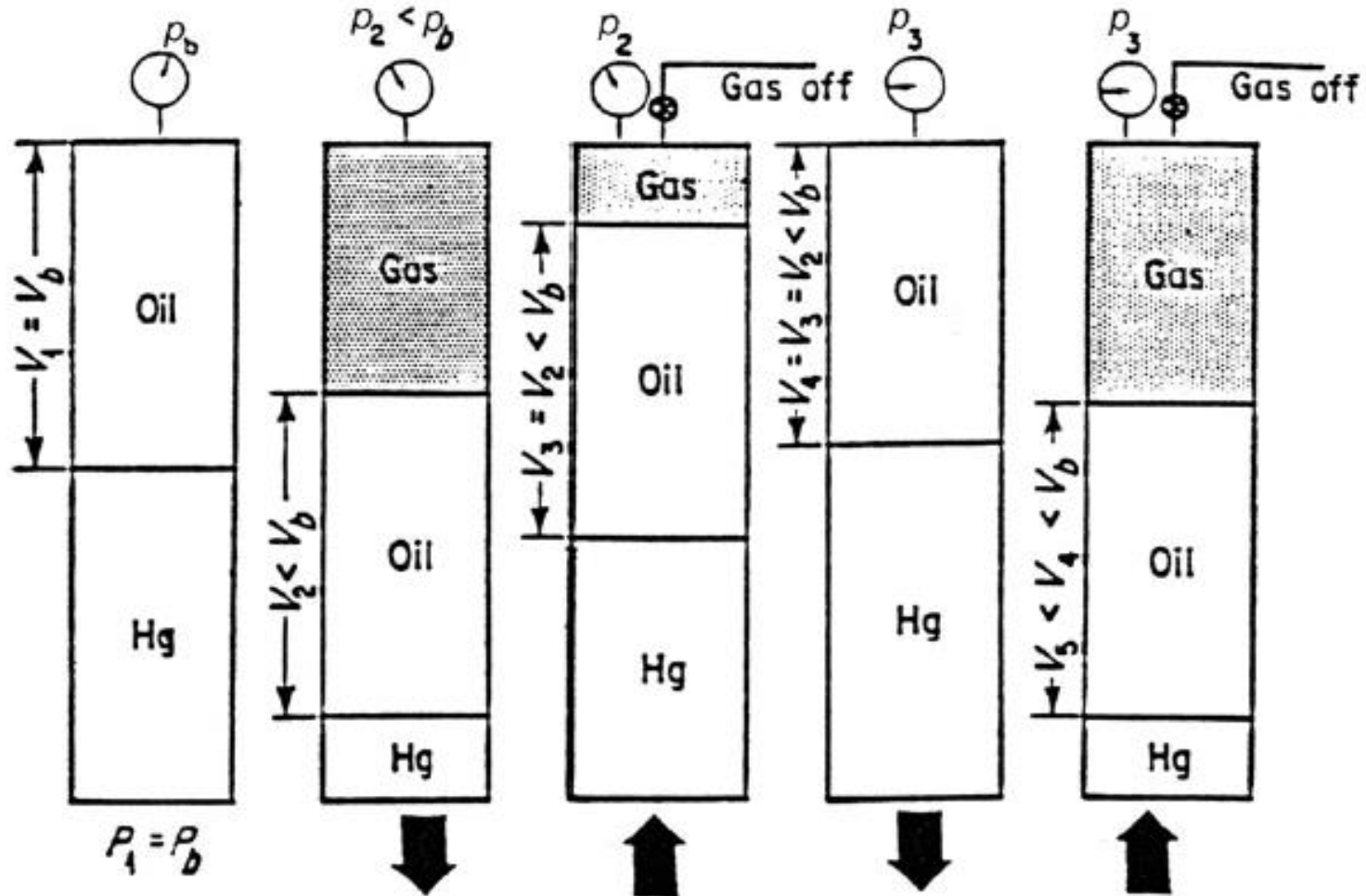
Differential Liberation Test (DL)

5- The liberated gas is then displaced at constant cell pressure (by the injection of mercury) to a metering device (e.g., gasometer) and the measured volume is corrected to SC and designated to as “ $(V_{\text{gas}})_{\text{sc}}$ ”.

6- The above depletion process is repeated at constant reservoir temperature until a pressure close to atmospheric pressure is reached.

7- At the last stage, the volume of the residual oil is first measured at last cell conditions, then corrected to SC (ie, 14.7 psia and 60°F), and designated as “ V_{Lsc} ”.

Differential Liberation Test (DL)



Nomenclatures Of Hydrocarbon Volume Measurements

The following nomenclatures are used to describe the various hydrocarbon volume measurements associated with each pressure-depletion stage during the DL experiment:

P = cell pressure.

T = cell temperature.

V_t = total combined volume of the liberated gas and remaining oil at P & T .

V_L = remaining oil volume at P & T .

V_{Lsc} = remaining oil volume at P_{sc} & T_{sc} .

V_{gas} = liberated gas volume at P & T .

$(V_{gas})_{sc}$ = liberated gas volume at P_{sc} & T_{sc} .

Differential Liberation Test (DL)

- It should be noted that the remaining oil at each depletion stage is subjected to continual compositional changes as it becomes progressively richer in the heavier components.
- The main difference between CCE and DL is that:
 1. The liberated gas is removed from the cell in each pressure decline stage in DL test while no gas or liquid is removed from the PVT cell at any time throughout the CCE test.
 2. DL characterized by a varying composition of the total hydrocarbon system; whereas the total system composition is kept unchanged during the equilibrium test.

The Experimental Data Obtained From The DL Test

- The differential oil FVF “ B_{od} ”.
- The differential gas solubility; that is, solution GOR, “ R_{sd} ”.
- Gas FVF “ B_g ” in ft³/scf.
- Gas compressibility factor “ Z ”.
- Total FVF “ B_{td} ”.
- Composition of the liberated gas.
- Gas specific gravity.
- Density of the remaining oil as a function of pressure

The Experimental Data Obtained From The DL Test

Differential Gas Solubility “ R_{sd} ”:

- The gas solubility at any pressure is defined as the volume of gas that is dissolved (remaining) in solution at the pressure per stock-tank barrel of the corrected residual oil.
- Mathematically, the differential solution GOR, R_{sd} , is calculated by dividing the volume of gas remaining (dissolved) in solution at the specified pressure by the residual oil volume.

$$R_{sd} = \frac{\text{volume of remaining solution gas}}{\text{volume of residual oil}} \quad \dots(5)$$

$$R_{sd} = \frac{\text{vol. of total gas removed} - \text{vol. of gas removed till the cell wanted}}{\text{vol. of residual oil}}$$

The Experimental Data Obtained From The DL Test

Differential Oil FVFs “B_{od}”:

- The differential oil FVFs, B_{od} (commonly called the relative oil volume factors), are calculated at all pressure levels by dividing the recorded oil volumes, V_L, by the volume of residual oil, V_{Lsc}:

$$B_{od} = \frac{\text{volume of oil at any } (p, T)}{\text{volume of residual oil (at } p_{sc}, T_{sc})} = \frac{V_L}{V_{Lsc}} \quad \text{.....(6)}$$

The Experimental Data Obtained From The DL Test

Gas Deviation Factor “Z”:

- Using the volume of the free gas at any pressure and the corresponding volume at SC, the gas deviation factor can be calculated by applying the following equation:

$$B_g = \frac{V_R}{V_{sc}} = \frac{Z T_R}{P_R} \bigg/ \frac{T_{sc}}{P_{sc}} \quad \Rightarrow \quad Z = \frac{V_R P_R T_{sc}}{V_{sc} P_{sc} T_R} \quad \text{.....(7)}$$

The Experimental Data Obtained From The DL Test

Gas FVF “ B_g ”:

- The gas FVF is the defined ratio of the volume “ $(V_{gas})_{p,T}$ ” occupied by n moles of gas at a specified pressure and temperature to the volume “ $(V_{gas})_{sc}$ ” occupied by the same number of moles (i.e., n moles) at SC. Mathematically, this is defined by

$$B_g = \frac{(V_{gas})_{p,T}}{(V_{gas})_{sc}} = \frac{0.02827 ZT}{p}; ft^3/scf \quad \text{.....(8)}$$

The Experimental Data Obtained From The DL Test

Differential gas oil ratio at the bubble point pressure “ R_{sdb} ”:

- R_{sdb} value is constant in all steps of calculations.

$$R_{sdb} = \frac{\text{vol. of total gas removed}}{\text{vol. of residual oil}} \quad \text{.....(9)}$$

The Experimental Data Obtained From The DL Test

Total FVF “ B_{td} ” From DL Test:

- The two-phase (total) FVF from DL test is determined by applying the definition of this property as expressed mathematically by:

$$B_{td} = B_{od} + (R_{sdb} - R_{sd})B_g \quad \text{.....(10)}$$