

Tishk International University
Engineering Faculty
Petroleum and Mining Department



Petroleum Reservoir Engineering I

Lecture 9: Volumetric Method (Gas Reservoirs)

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Content:

- ❑ Gas Reservoirs
 - Retrograde Gas-Condensate
 - Near-Critical Gas-Condensate
 - Wet Gas
 - Dry Gas
- ❑ Gas Formation Volume Factor (B_g)
- ❑ Gas Expansion Factor (E_g)
- ❑ Volumetric Method
- ❑ Volumetric Method Equation
- ❑ Volumetric Method Application

Gas Reservoir

- Reservoirs containing only free gas are termed gas reservoir.
- Such a reservoir contains a mixture of hydrocarbons, which exists wholly in the gaseous state.
- The mixture may be a *dry, wet, or condensate* gas, depending on the composition of the gas, along with the pressure and temperature at which the accumulation exists.

Gas Reservoir

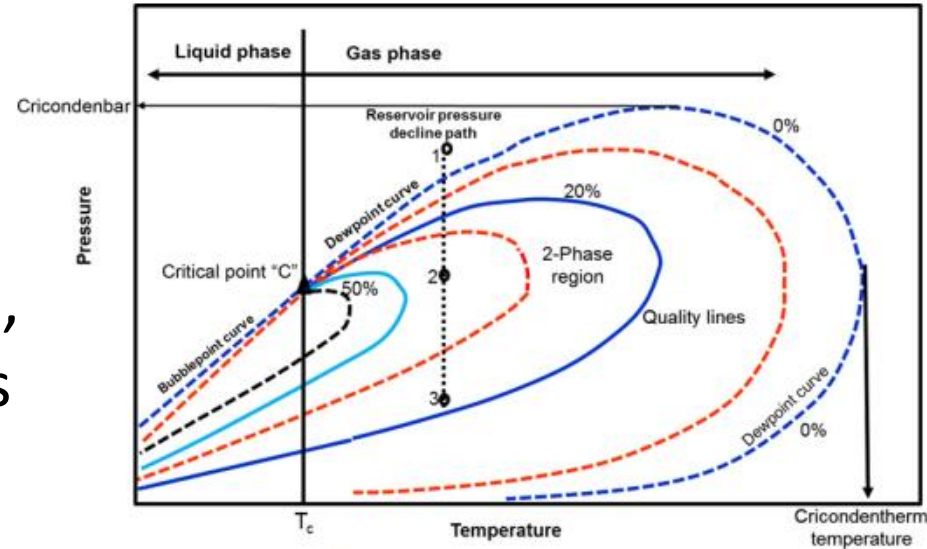
- **Gas Reservoirs:** If the reservoir temperature T_{res} is greater than the critical temperature T_c of the hydrocarbon fluid, the reservoir is considered as a gas reservoir.
- Based on the phase diagram and prevailing reservoir conditions, natural gases can be classified into four categories:
 1. Retrograde gas-condensate
 2. Near-Critical gas-condensate
 3. Wet gas
 4. Dry gas

1. Retrograde Gas-Condensate

- **Retrograde:** reverting to an earlier condition.
- **Condensate:** to change or make something change from a gas to a Liquid
- **Retrograde Gas-Condensate:** If the reservoir temperature T_{res} lies between the critical temperature T_c and cricondentherm T_{ct} of the reservoir fluid. The retrograde gas-condensate reservoir is a unique type of hydrocarbon accumulation.
- The special thermodynamic behavior of the reservoir fluid is the controlling factor in the development and the depletion process of the reservoir

1. Retrograde Gas-Condensate

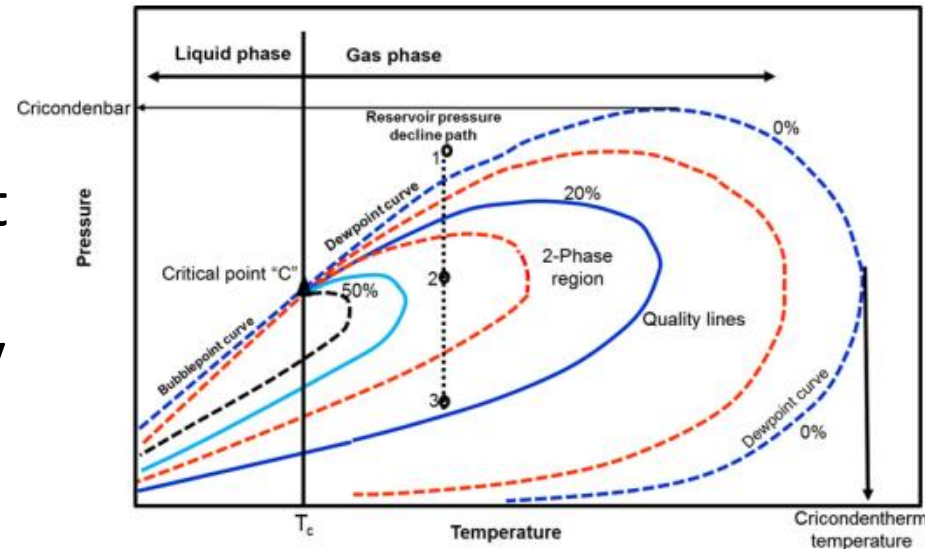
- **Point 1:** Initial condition of a retrograde gas- condensate reservoir. Because the reservoir pressure is above the upper dew-point pressure, the hydrocarbon system exists as a single phase (i.e., vapor phase) in the reservoir.



A typical phase diagram for a retrograde system.

1. Retrograde Gas-Condensate

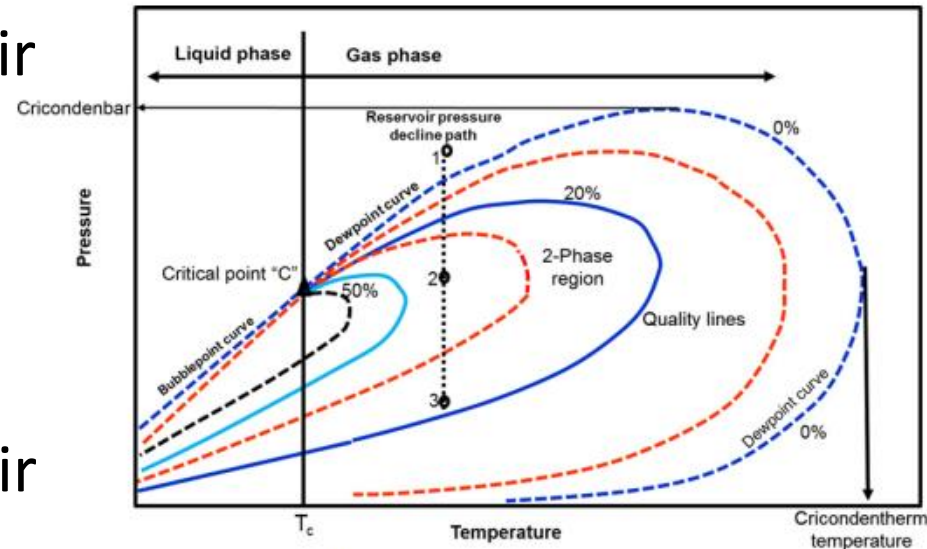
- **Point 2:** As the reservoir pressure declines isothermally during production from the initial pressure (Point 1) to the upper dew-point pressure (Point 2), the attraction between the molecules of the light and heavy components causes them to move farther apart. As a result, the attraction between the heavy component molecules becomes more effective; Thus, liquid begins to condense.



A typical phase diagram for a retrograde system.

1. Retrograde Gas-Condensate

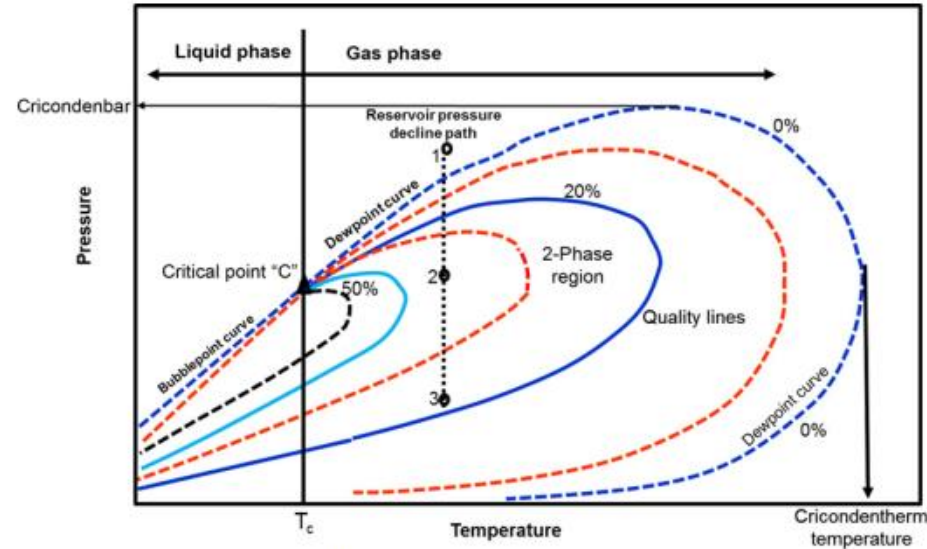
- At **point 2**, the condensate remain immobile in the reservoir since the droplets are isolated and hasn't reached the concentration where the drops are connected. The droplets remain immobile in the reservoir until it reaches the critical saturation of 10, 15, or 20%. After this concentration, the droplets are connected, and the liquid will begin to flow.



A typical phase diagram for a retrograde system.

1. Retrograde Gas-Condensate

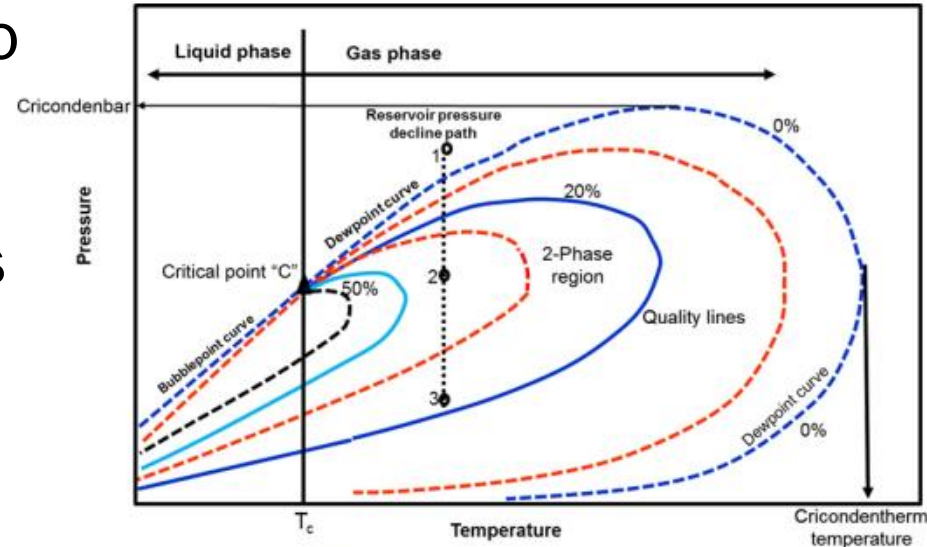
- **Point 3:** The retrograde condensation process continues with decreasing pressure until the liquid dropout reaches its maximum point at point 3.



A typical phase diagram for a retrograde system.

1. Retrograde Gas-Condensate

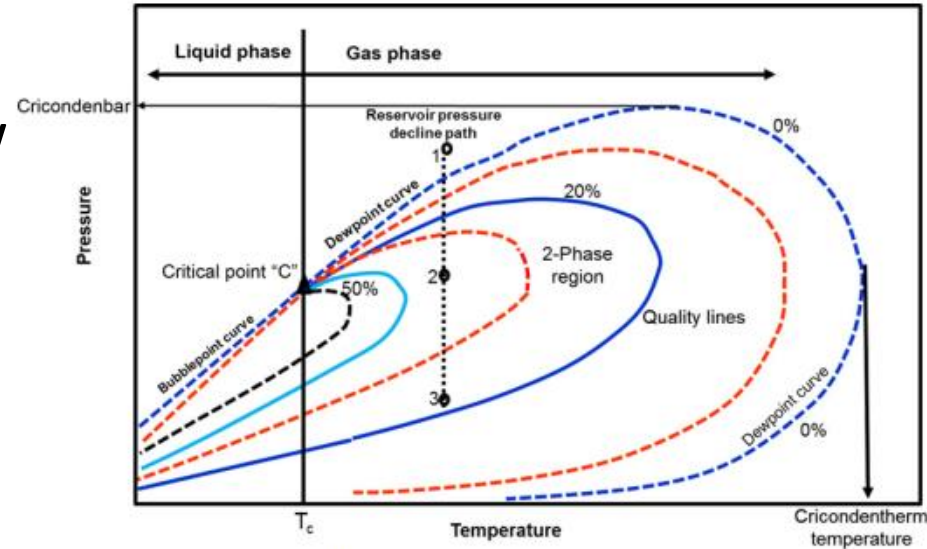
- Further reduction in pressure permits the heavy molecules to commence the normal vaporization process. This is the process whereby fewer gas molecules strike the liquid surface, which causes more molecules to leave than enter the liquid phase .



A typical phase diagram for a retrograde system.

1. Retrograde Gas-Condensate

- The vaporization process continues until the reservoir pressure reaches the lower dew point pressure. At this point, all the liquid is vaporized because the system is essentially all vapors at the lower dewpoint.

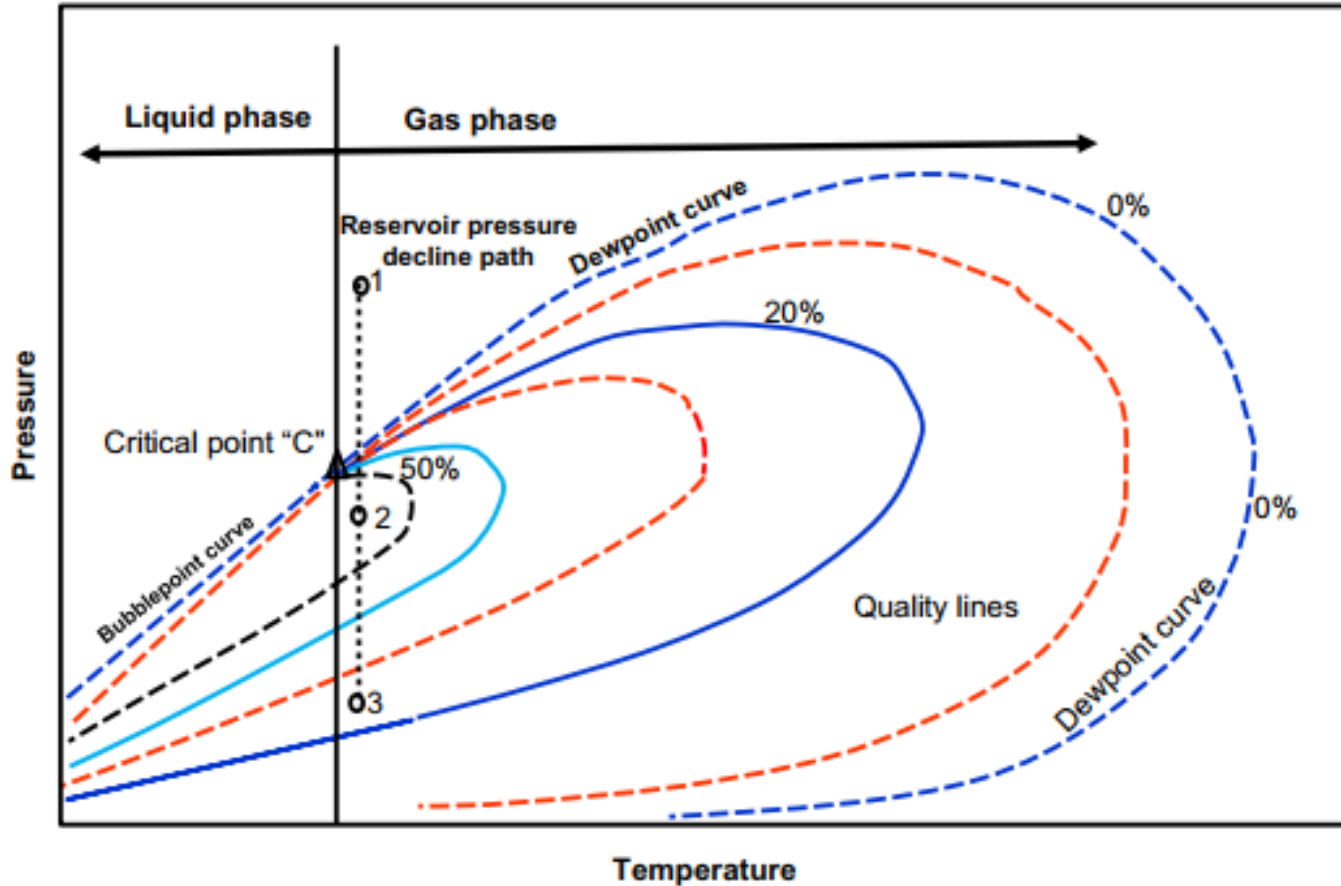


A typical phase diagram for a retrograde system.

2. Near-Critical Gas-Condensate

- If the reservoir temperature is near the critical temperature, the hydrocarbon mixture is classified as a near critical gas-condensate.
- Because all quality lines converge at the critical point, a rapid liquid buildup will immediately occur below the dew point as the pressure reduced (Point 2)
- At the point where the liquid ceases to build up and begins to shrink again, the reservoir goes from the retrograde region to a normal vaporization region.

2. Near-Critical Gas-Condensate

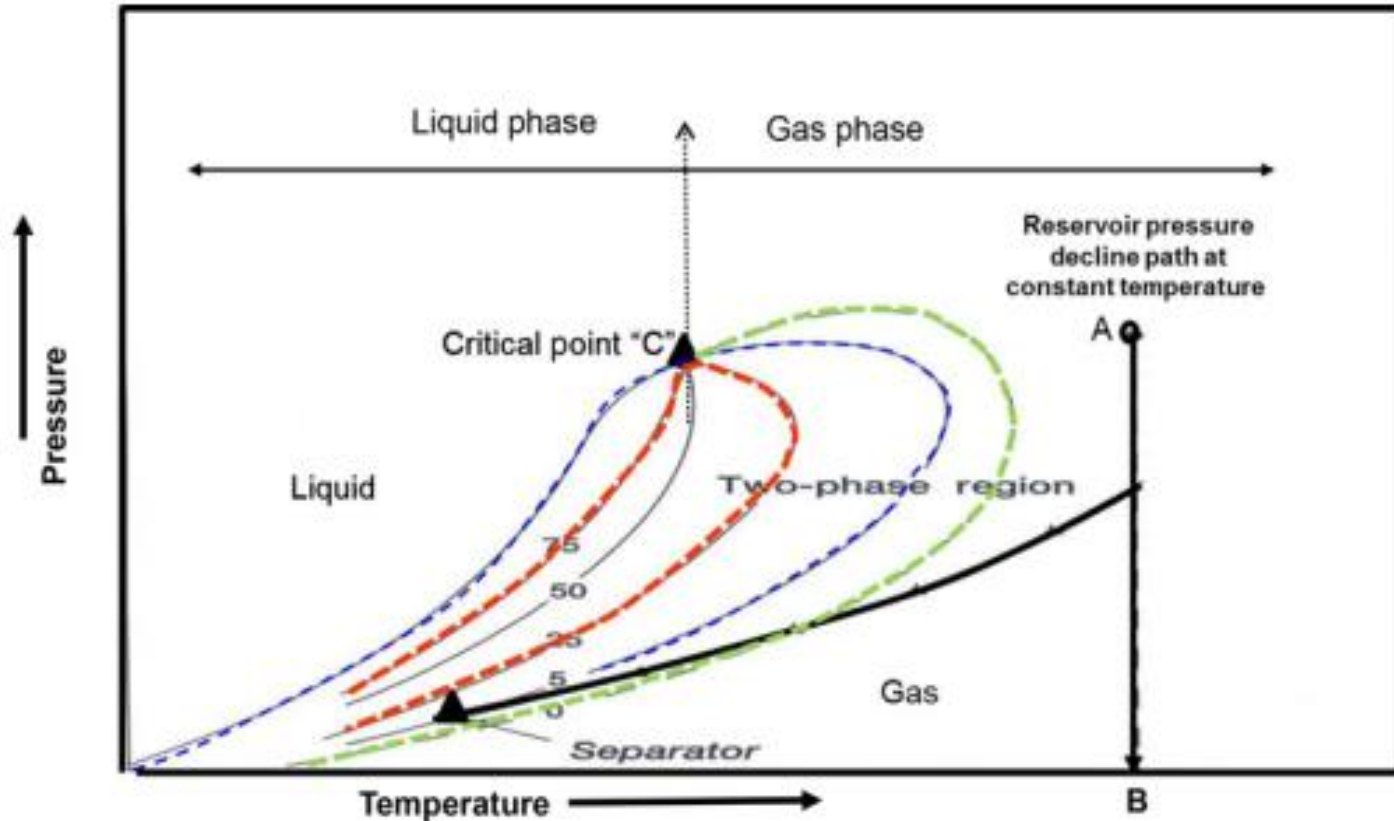


A typical phase diagram for a near-critical gas condensate reservoir.

3. Wet Gas

- The reservoir temperature is above the cricondenthem of the hydrocarbon mixture.
- Since the reservoir temperature exceeds the cricondenthem of the hydrocarbon system, the reservoir fluid will always remain in the vapor phase region as the reservoir is depleted isothermally.
- As the produced gas flows to the surface, the pressure and temperature of the gas will decline.
- If the gas enters the two-phase region, a liquid phase will condense out of the gas and be produced from the surface separators.

3. Wet Gas

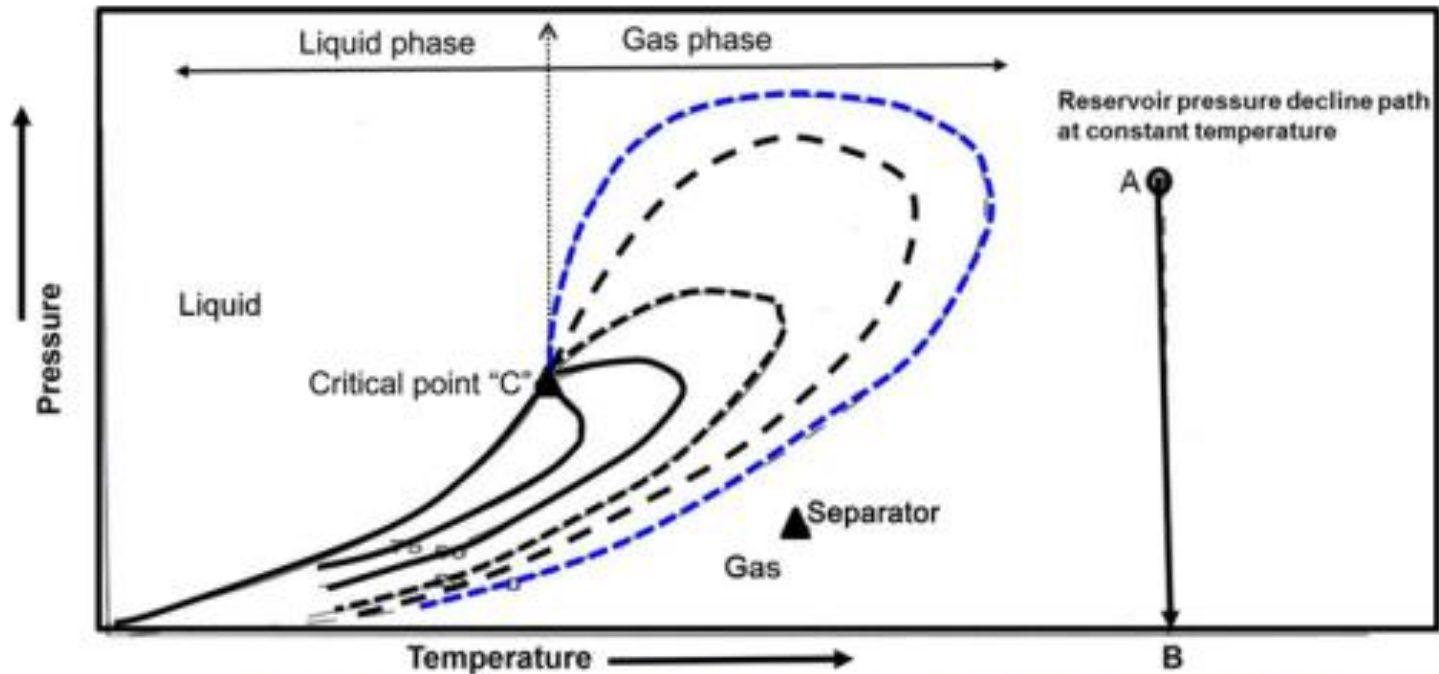


Phase diagram for a wet gas. (After Clark, N.J. Elements of Petroleum Reservoirs,

4. Dry Gas

- The hydrocarbon mixture exists as a gas both in the reservoir and in the surface facilities.
- The only liquid associated with the gas from the dry-gas reservoir is water.
- Gas-oil ratio greater than 100,000 scf/STB.

4. Dry Gas



Phase diagram for a dry gas. (After Clark, N.J. Elements of Petroleum Reservoirs, SPE, 1969).

Gas Reservoir

- Gas reservoirs may have water influx from a contiguous water-bearing portion of the formation or may be volumetric (i.e., have no water influx)
- **Volumetric Gas Reservoir:** A volumetric gas reservoir is completely enclosed by low-permeability or completely impermeable barriers and does not receive pressure support from external sources, such as an encroaching aquifer.
- **Non-volumetric Gas Reservoir:** Gas reservoirs with water influx from an aquifer are non-volumetric reservoirs and they produce under the pressure support provided by the encroaching water.

Gas Reservoir

- Most gas engineering calculations involve the use of gas formation volume factor B_g and gas expansion factor E_g .
- Gas Formation Volume Factor (B_g): is defined as the actual volume occupied by n moles of gas at a specified pressure and temperature, divided by the volume occupied by the same amount of gas at standard conditions.
- Applying the real gas equation-of-state to both conditions gives:

$$B_g = \frac{p_{sc}}{T_{sc}} \frac{zT}{p} = 0.02827 \frac{zT}{p} \dots\dots\dots(1)$$

where:

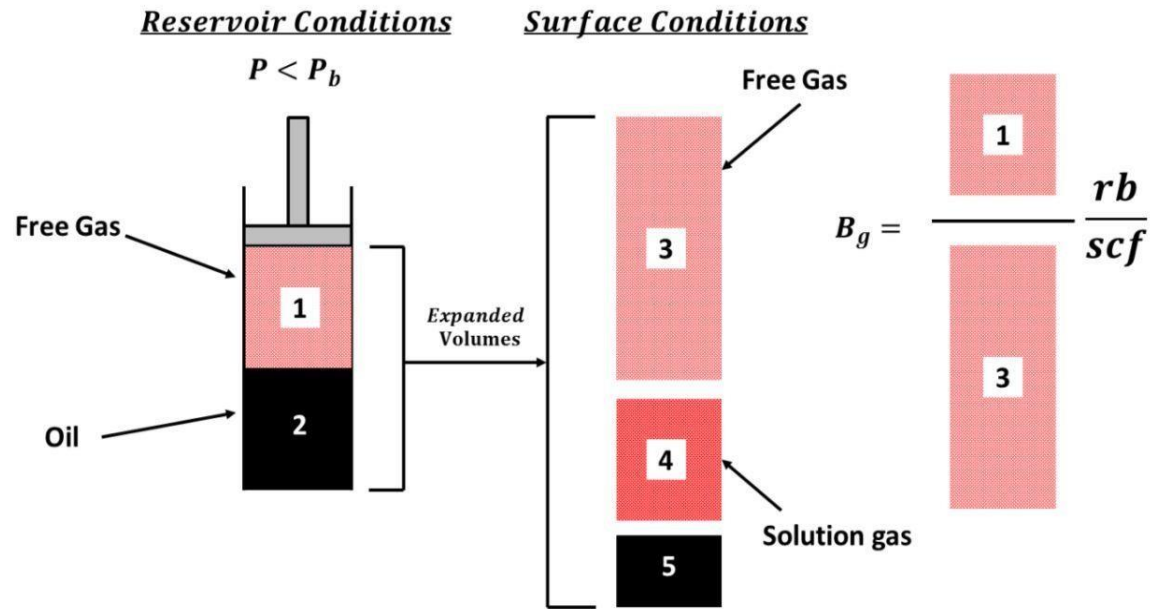
B_g = gas formation volume factor, ft³/scf

Gas Reservoir

- **Gas Formation**

Volume Factor (B_g):

is defined as the actual volume occupied by n moles of gas at a specified pressure and temperature, divided by the volume occupied by the same amount of gas at standard conditions.



Gas Reservoir

- Most gas engineering calculations involve the use of gas formation volume factor B_g and gas expansion factor E_g .
- Gas Formation Volume Factor (E_g): is simply the reciprocal of B_g
or:

$$E_g = \frac{T_{sc}}{p_{sc}} \frac{p}{zT} = 35.37 \frac{p}{zT} \dots\dots\dots(2)$$

where:

E_g = gas expansion factor, scf/ft³

Gas Reservoir

- This lecture and the next lecture presents two approaches for estimating initial gas- in-place G , gas reserves, and the gas recovery for volumetric and water-drive mechanisms:
 - Volumetric method
 - Material balance approach

Gas Reservoir

□ The Volumetric Method:

- Data used to estimate the gas-bearing reservoir include, but are not limited to:
 - Well Logs
 - Core analysis
 - Bottom-hole pressure (BHP)
 - Fluid sample information
 - Well tests

Gas Reservoir

□ The Volumetric Method:

- This data typically is used to develop various subsurface maps.
- Of these maps, structural and stratigraphic cross-sectional maps help to establish the reservoir's areal extent and to identify reservoir discontinuities, such as pinch-outs, faults, or gas-water contacts.
- Subsurface contour maps, usually drawn relative to a known or marker formation, are constructed with lines connecting points of equal elevation and therefore portray the geologic structure.

Gas Reservoir

□ The Volumetric Method:

- The volumetric equation is useful in reserve work for estimating gas-in-place at any stage of depletion.
- During the development period before reservoir limits have been accurately defined, it is convenient to calculate gas-in-place per acre-foot of bulk reservoir rock.
- Multiplication of this unit figure by the best available estimate of bulk reservoir volume then gives gas-in-place for the lease, tract, or reservoir under consideration.
- Later in the life of the reservoir, when the reservoir volume is defined, and performance data are available, volumetric calculations provide valuable checks on gas-in-place estimates obtained from material balance methods.

Gas Reservoir

□ The Volumetric Method:

The equation for calculating gas in place is:

$$G = \frac{43,560 Ah\phi(1 - S_{wi})}{B_{gi}} \dots(3)$$

where:

G = gas in place, scf

A = area of reservoir, acres

h = average reservoir thickness, ft

ϕ = porosity

S_{wi} = water saturation, and

B_{gi} = gas formation volume factor, ft³/scf

Gas Reservoir

□ The Volumetric Method:

This equation can be applied at both initial and abandonment conditions in order to calculate the recoverable gas.

$$\text{Gas produced} = \text{Initial gas} - \text{Remaining gas}$$

or

$$G_p = 43,560 Ah\phi(1 - S_{wi}) \left(\frac{1}{B_{gi}} - \frac{1}{B_{ga}} \right) \dots\dots\dots(4)$$

where B_{ga} is evaluated at abandonment pressure. Application of the volumetric method assumes that the pore volume occupied by gas is constant. If water influx is occurring, A , h , and S_w will change.

Gas Reservoir

□ The Volumetric Method:

Example

A gas reservoir has the following characteristics:

$$A = 3000 \text{ acres}$$

$$h = 30 \text{ ft}$$

$$\phi = 0.15$$

$$S_{wi} = 20\%$$

$$T = 150^\circ\text{F}$$

$$p_i = 2600 \text{ psi}$$

p	z
2600	0.82
1000	0.88
400	0.92

Calculate cumulative gas production and recovery factor at 1000 and 400 psi.

Gas Reservoir

□ The Volumetric Method:

Solution

Step 1. Calculate the reservoir pore volume P.V

$$P.V = 43,560 Ah\phi$$

$$P.V = 43,560 (3000) (30) (0.15) = 588.06 \text{ MMft}^3$$

Step 2. Calculate B_g at every given pressure by using Equation 1.

p	z	$B_g, \text{ft}^3/\text{scf}$
2600	0.82	0.0054
1000	0.88	0.0152
400	0.92	0.0397

Step 3. Calculate initial gas in place at 2600 psi

$$G = 588.06 (10^6) (1 - 0.2) / 0.0054 = 87.12 \text{ MMMscf}$$

Gas Reservoir

□ The Volumetric Method:

Step 4. Since the reservoir is assumed volumetric, calculate the remaining gas at 1000 and 400 psi.

- Remaining gas at 1000 psi

$$G_{1000 \text{ psi}} = 588.06(10^6) (1 - 0.2)/0.0152 = 30.95 \text{ MMMscf}$$

- Remaining gas at 400 psi

$$G_{400 \text{ psi}} = 588.06(10^6) (1 - 0.2)/0.0397 = 11.95 \text{ MMMscf}$$

Gas Reservoir

□ The Volumetric Method:

Step 5. Calculate cumulative gas production G_p and the recovery factor RF at 1000 and 400 psi.

○ At 1000 psi:

$$G_p = (87.12 - 30.95) \times 10^9 = 56.17 \text{ MMM scf}$$

$$\text{RF} = \frac{56.17 \times 10^9}{87.12 \times 10^9} = 64.5\%$$

Gas Reservoir

□ The Volumetric Method:

Step 5. Calculate cumulative gas production G_p and the recovery factor RF at 1000 and 400 psi.

- At 1000 psi:

$$G_p = (87.12 - 30.95) \times 10^9 = 56.17 \text{ MMM scf}$$

$$\text{RF} = \frac{56.17 \times 10^9}{87.12 \times 10^9} = 64.5\%$$

- At 400 psi:

$$G_p = (87.12 - 11.95) \times 10^9 = 75.17 \text{ MMMscf}$$

$$\text{RF} = \frac{75.17 \times 10^9}{87.12 \times 10^9} = 86.3\%$$

Gas Reservoir

□ The Volumetric Method:

- Recovery factor: The recoverable amount of hydrocarbon initially in place, normally expressed as a percentage. The recovery factor is a function of the displacement mechanism.
- The recovery factors for volumetric gas reservoirs will range from 80% to 90%. If a strong water drive is present, trapping of residual gas at higher pressures can reduce the recovery factor substantially, to the range of 50% to 80%..