Fluid Properties

Hamidreza Salimi

Content

- Phase behavior
  - Five reservoir-fluid types
- Surface and subsurface volumes
- Fluid laboratory tests
- Dry gas properties

Refs: The Properties of Petroleum Fluids, McCain
Fundamentals of Reservoir Engineering, Dake
Lecture notes of Wim Swinkels

Why Fluid Properties?

- To estimate hydrocarbons in place and reserves
- To understand reservoir processes and to predict reservoir behavior
- To identify processing requirements for treatment at surface
- To identify markets

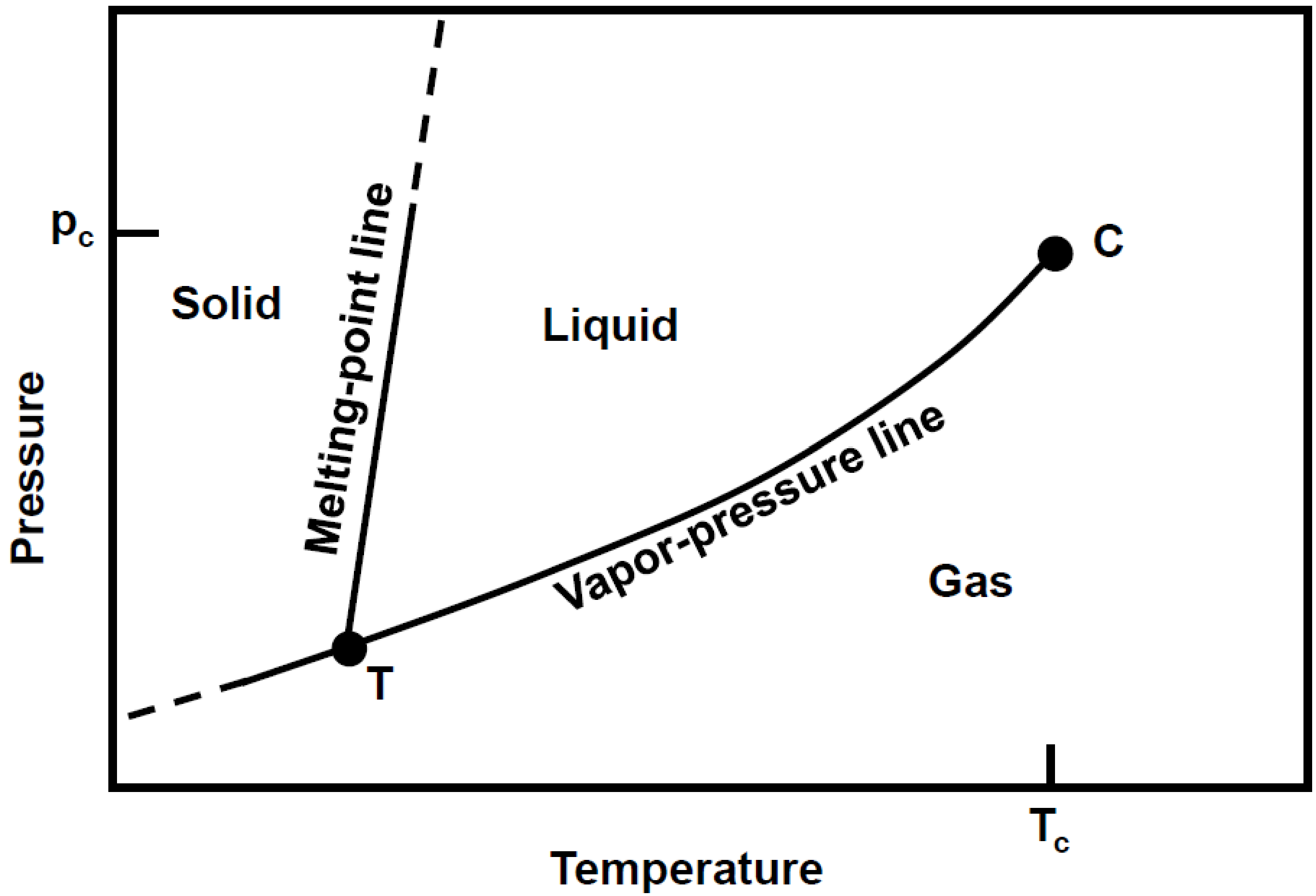
Typical Hydrocarbon Mixture Compositions

Component	Black Oil	Volatile Oil	Gas Condensate	Wet Gas	Dry Gas
C_1	48.83	64.36	72.7	86.67	95.85
C_2	2.75	7.52	10.00	7.77	2.67
C_3	1.93	4.74	6.00	2.95	0.34
C_4	1.6	4.12	2.50	1.63	0.52
C_5	1.15	2.97	1.80	0.68	0.08
C_6	1.59	1.38	0.60	0.2	0.12
C_7^+	42.15	14.91	6.40	0.1	0.42
Plus inorganics: N_2, CO_2, H_2O, H_2S					

PVT-Definitions

- Phase (state) refers to physical state of the system (gaseous, liquid, solid);
- Component refers to an individual compound regardless of the state of the system;
- Mole: gram molecular weight;
- Mole fraction: ratio of the number of moles of the component to the total number of moles in mixture;
- Weight fraction: ratio of the weight of the component to the total weight of the mixture

Phase Diagram – Pure Substance

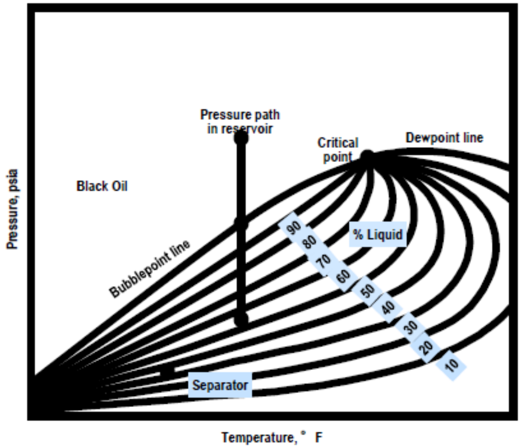


Phase Behavior - Definitions

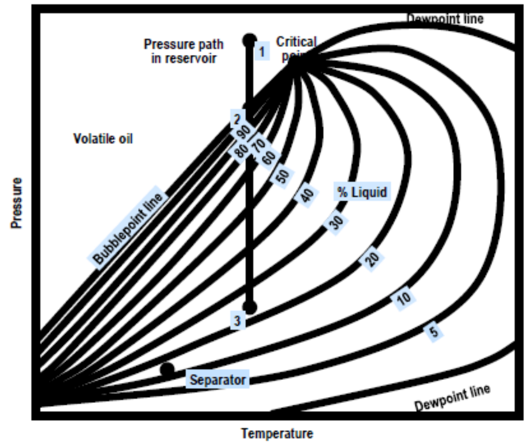
- Above critical pressure, liquid and gas cannot coexist, regardless of the temperature;
- Above critical temperature gas cannot be liquefied, regardless of the pressure;
- At triple point solid, liquid, and gas coexist under equilibrium conditions;

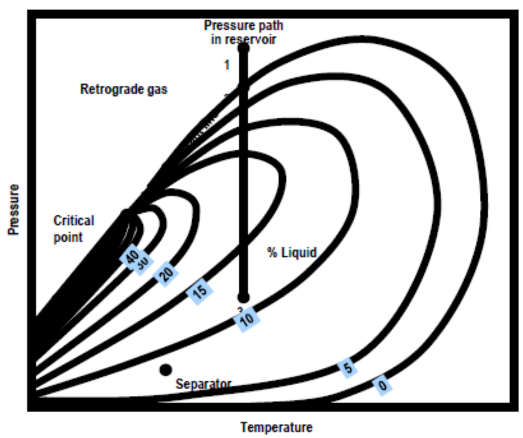
Five Reservoir Fluids

Black Oil

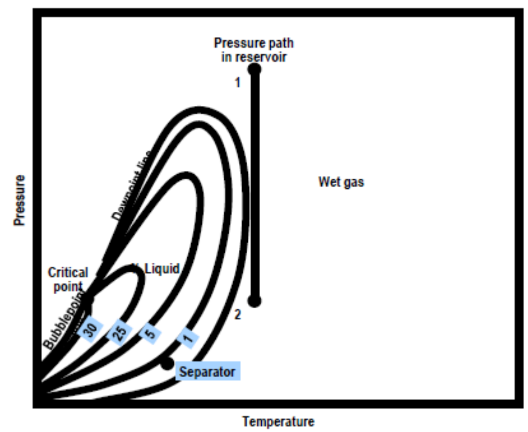


Volatile Oil

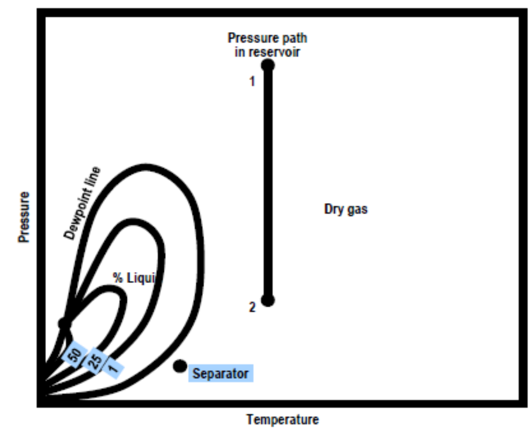




Retrograde Gas

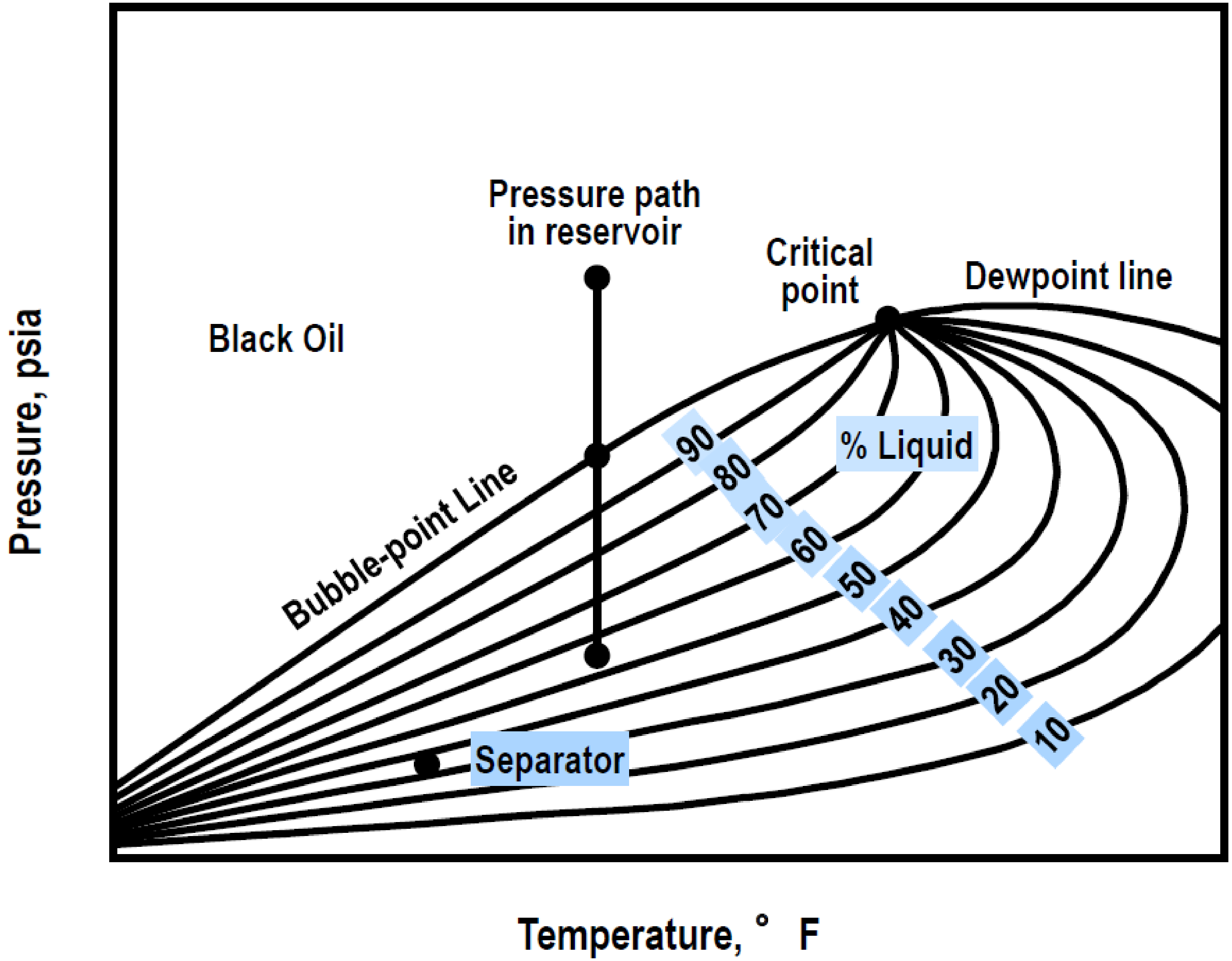


Wet Gas

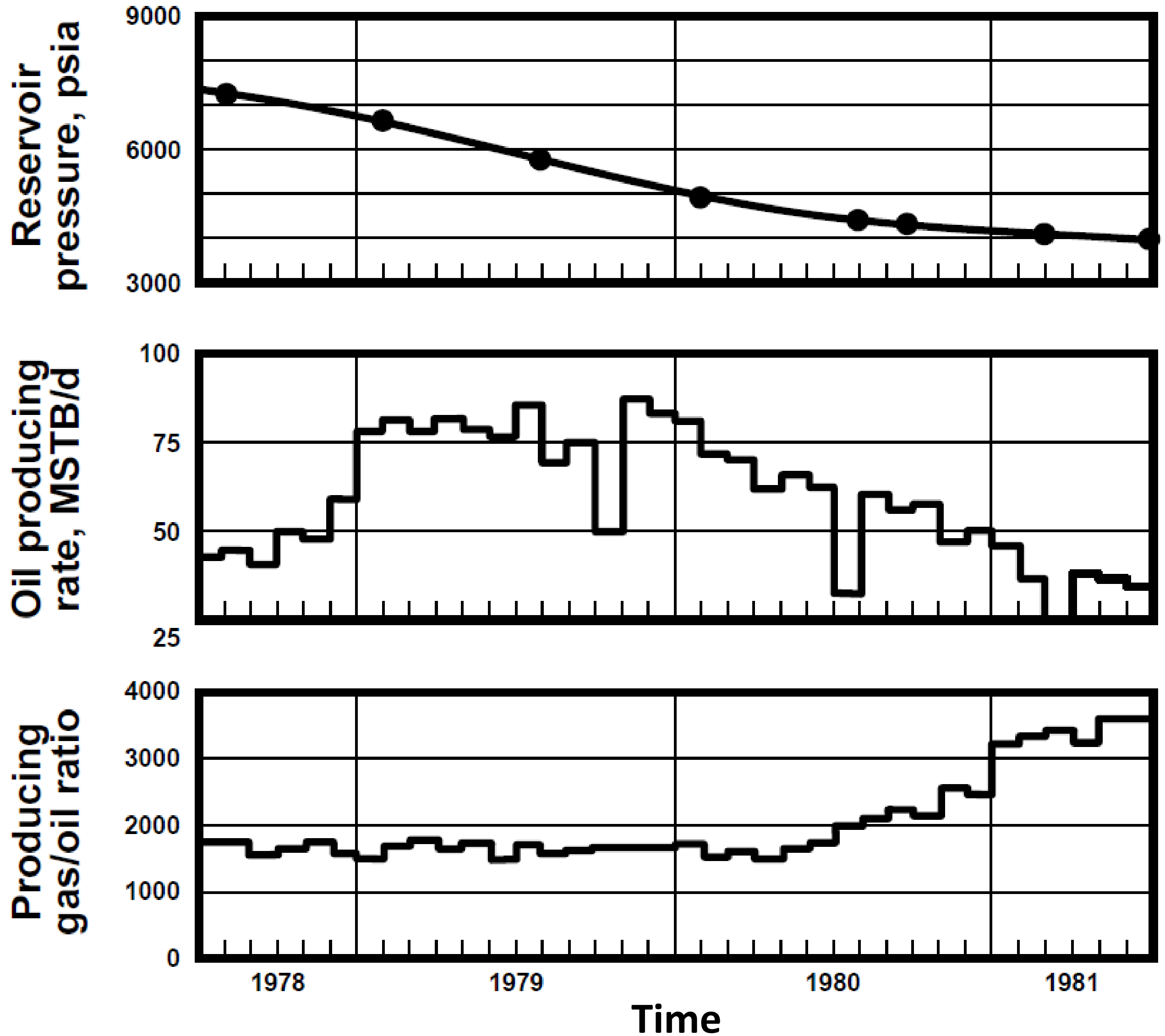


Dry Gas

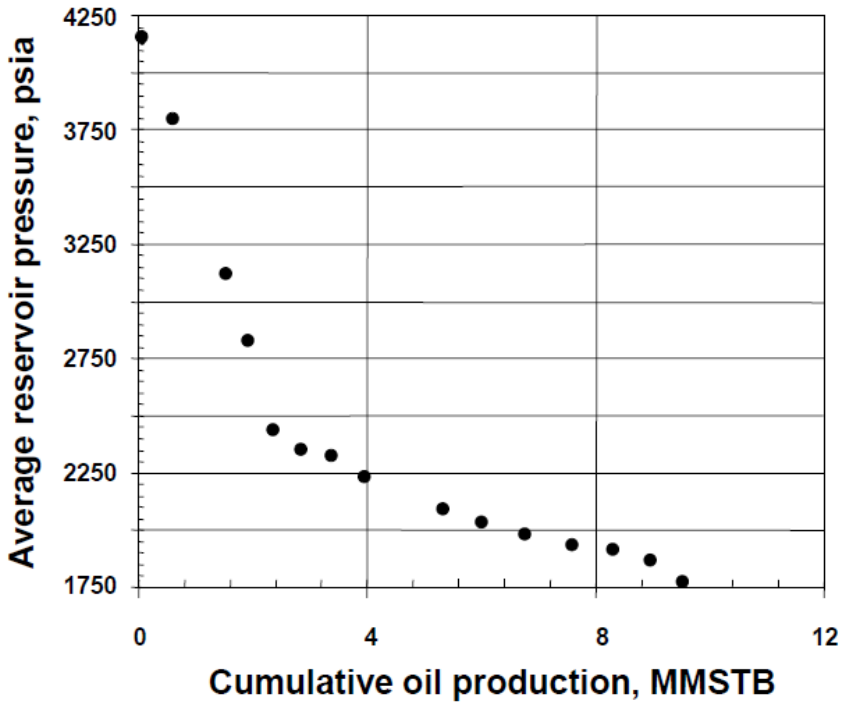
Phase Diagram – Typical Black Oil

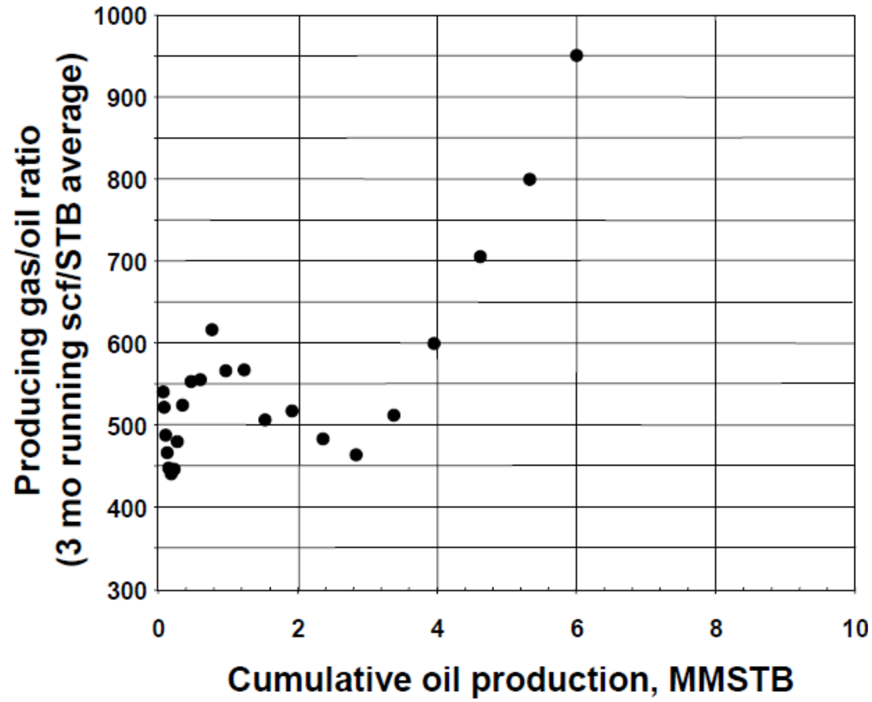


Production/Pressure History of Typical Black Oil



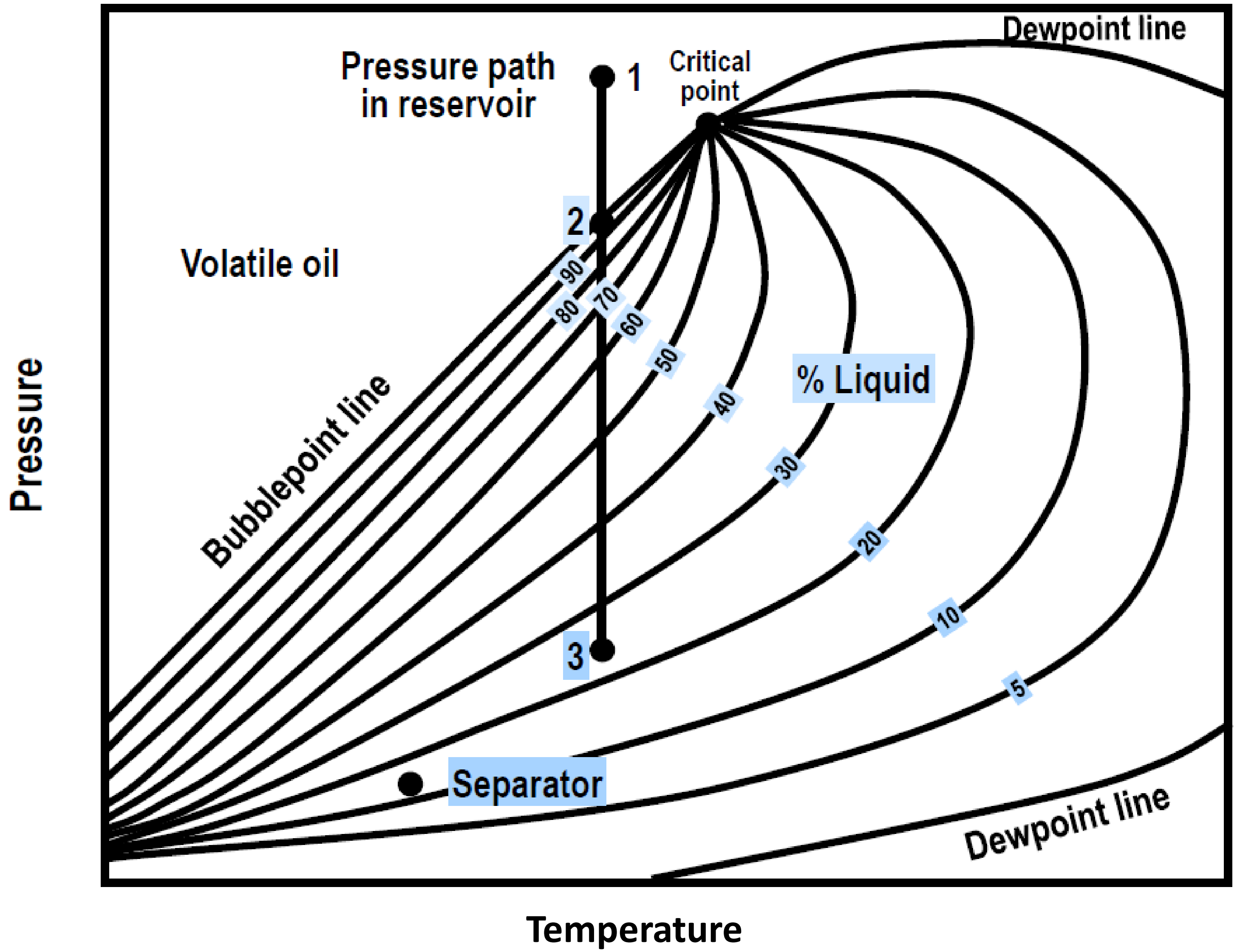
Pressure & Production History



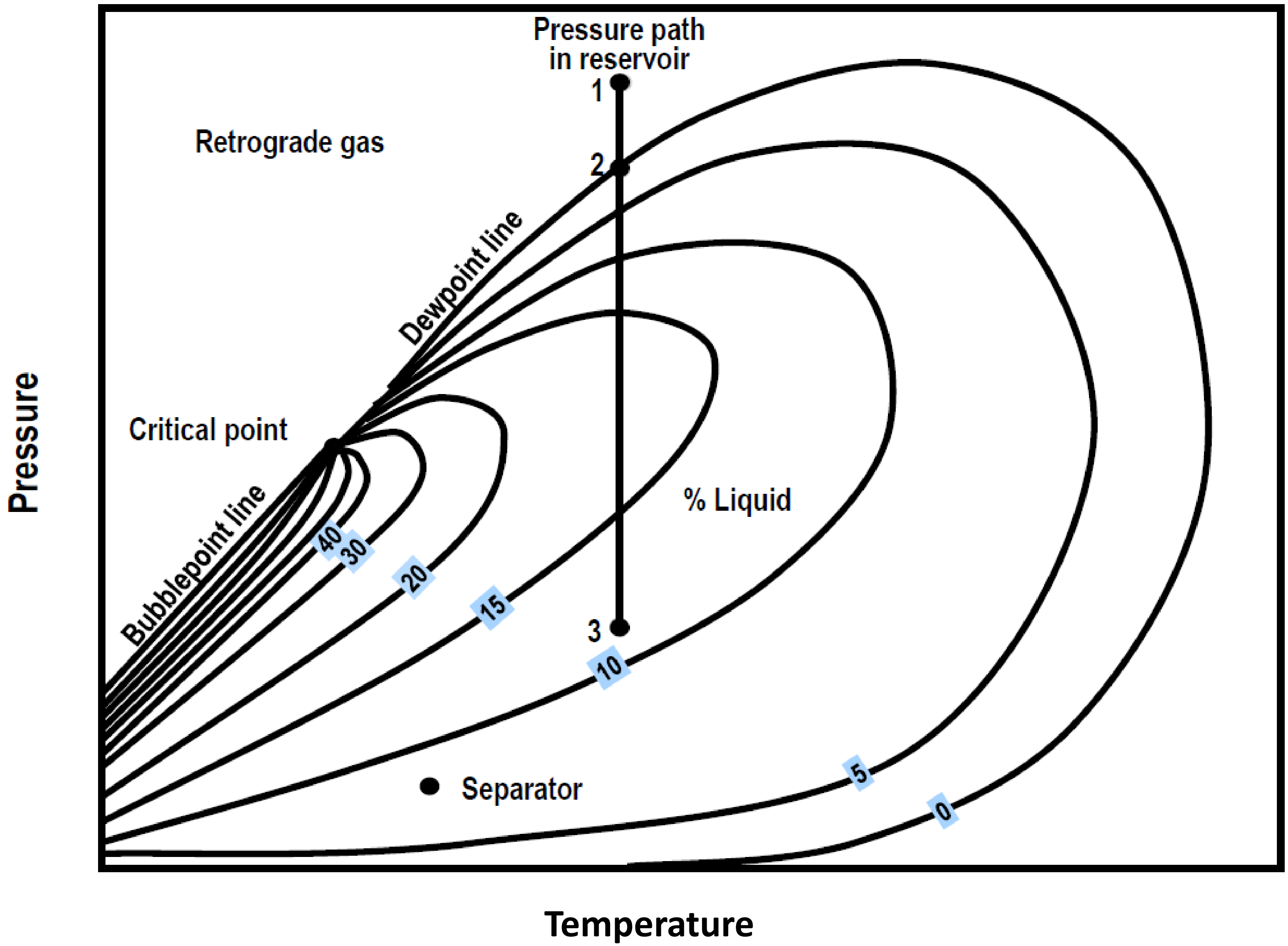


What is the bubble-point pressure?

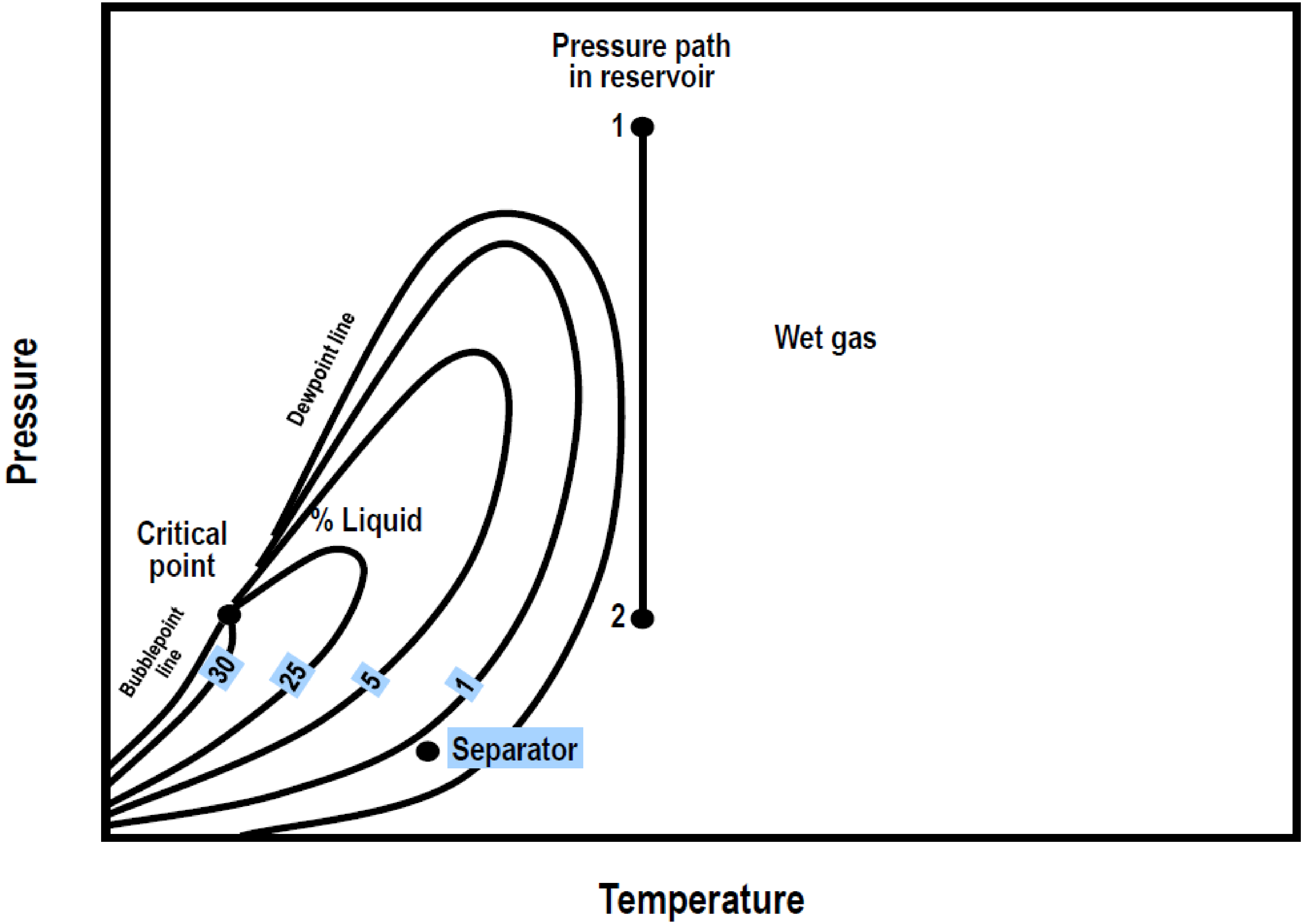
Phase Diagram of Typical Volatile Oil



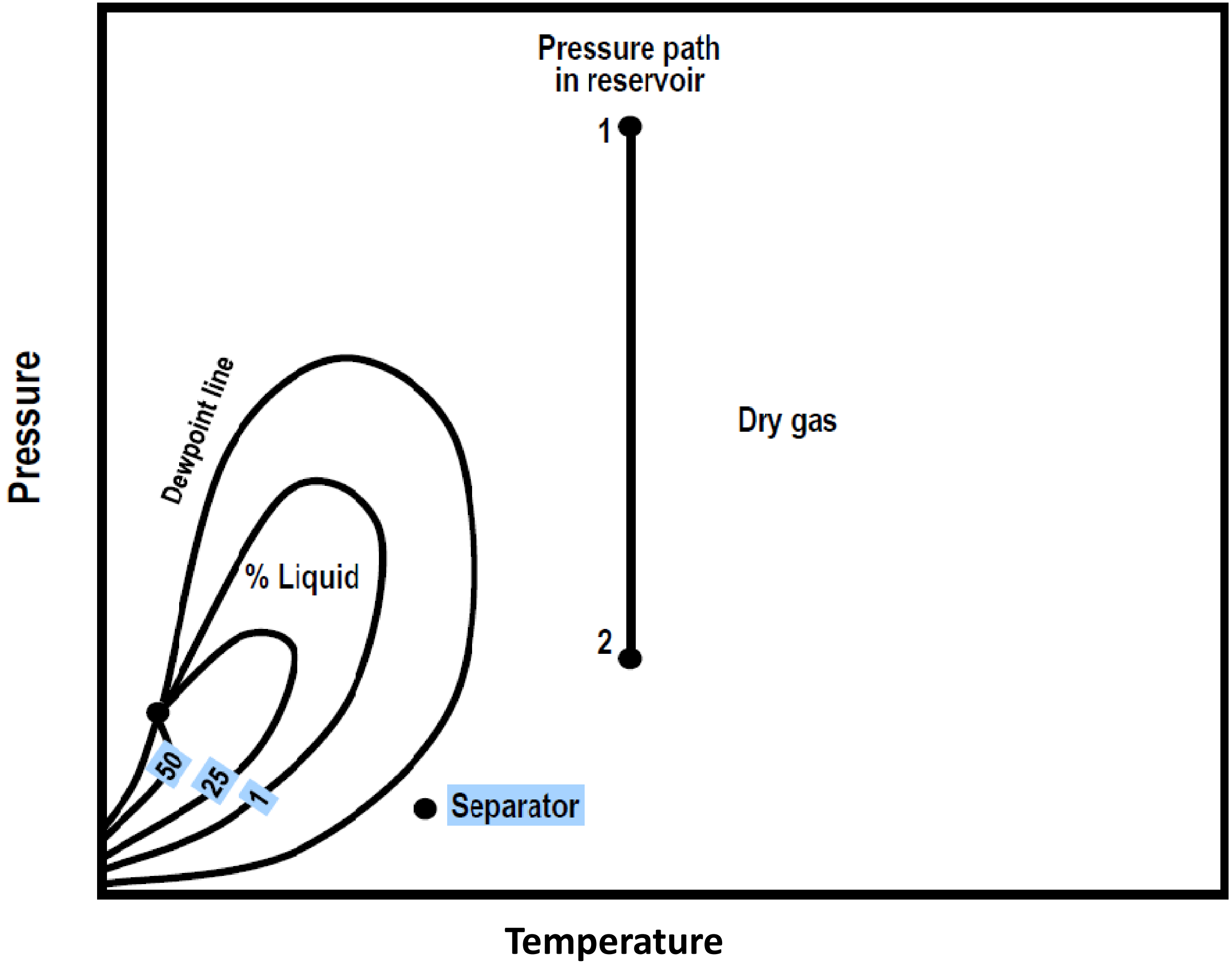
Phase Diagram of Gas Condensate



Phase Diagram of Typical Wet Gas



Phase Diagram of Typical Dry Gas



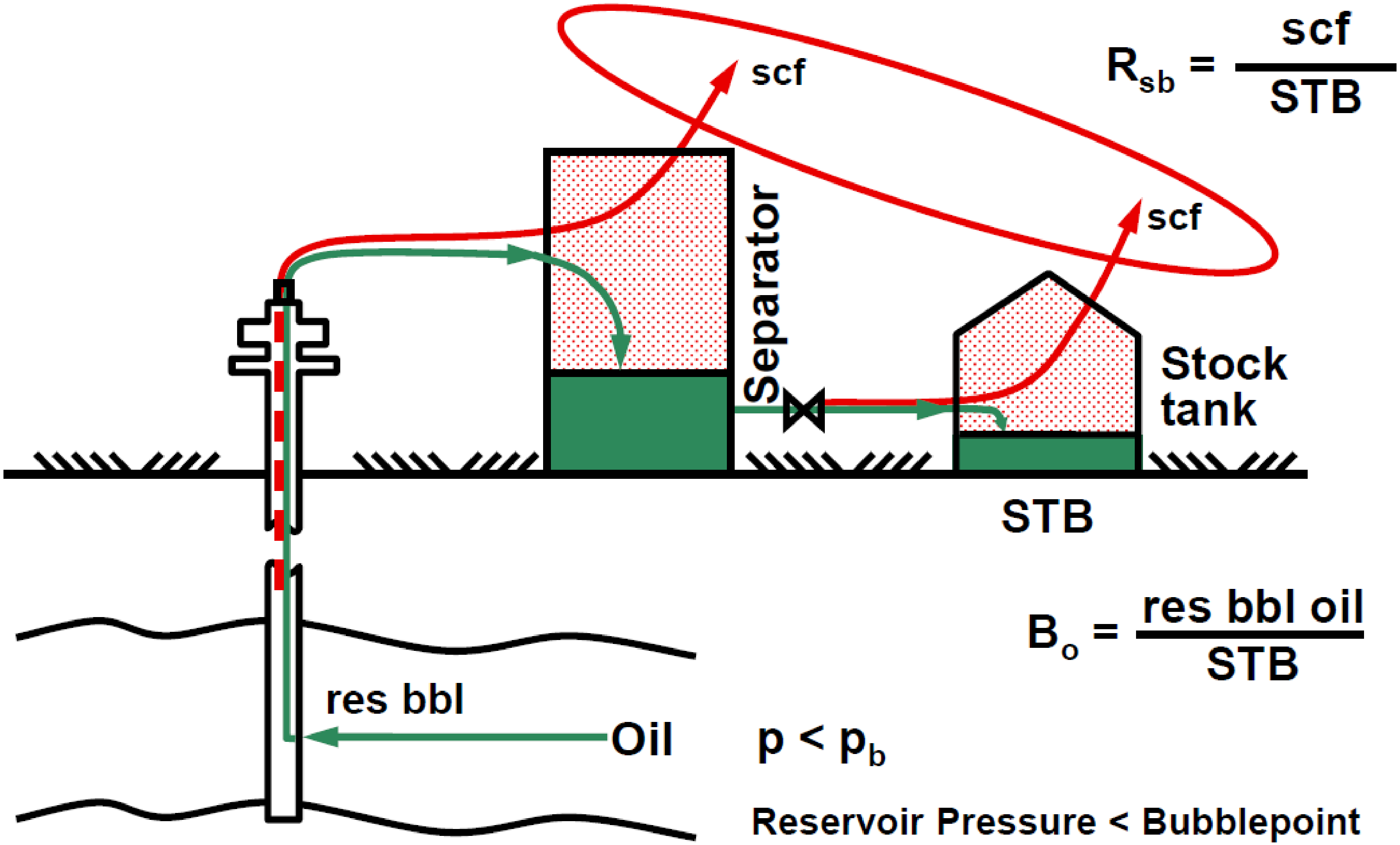
Properties of Reservoir-Fluid Systems

	Black Oil	Volatile Oil	Gas Condensate	Wet Gas	Dry Gas
GOR (m^3/m^3)	< 300	300-600	> 600	>2500	no liquid
API gravity	< 45	> 40	> 40	Up to 70	no liquid
Liquid color	Dark	medium orange	light color	water white	no liquid
C_7^+ mol%	> 20	12.5-20	4-12.5	0.7-4	< 0.7

Three Gases (Differences)

- Dry gas: gas at surface is same as gas in reservoir
- Wet gas: recombined surface gas and condensate represents gas in reservoir
- Retrograde gas: recombined surface gas and condensate represents the gas in the reservoir But not the total reservoir fluid (some retrograde condensate stays in reservoir)

Oil Production



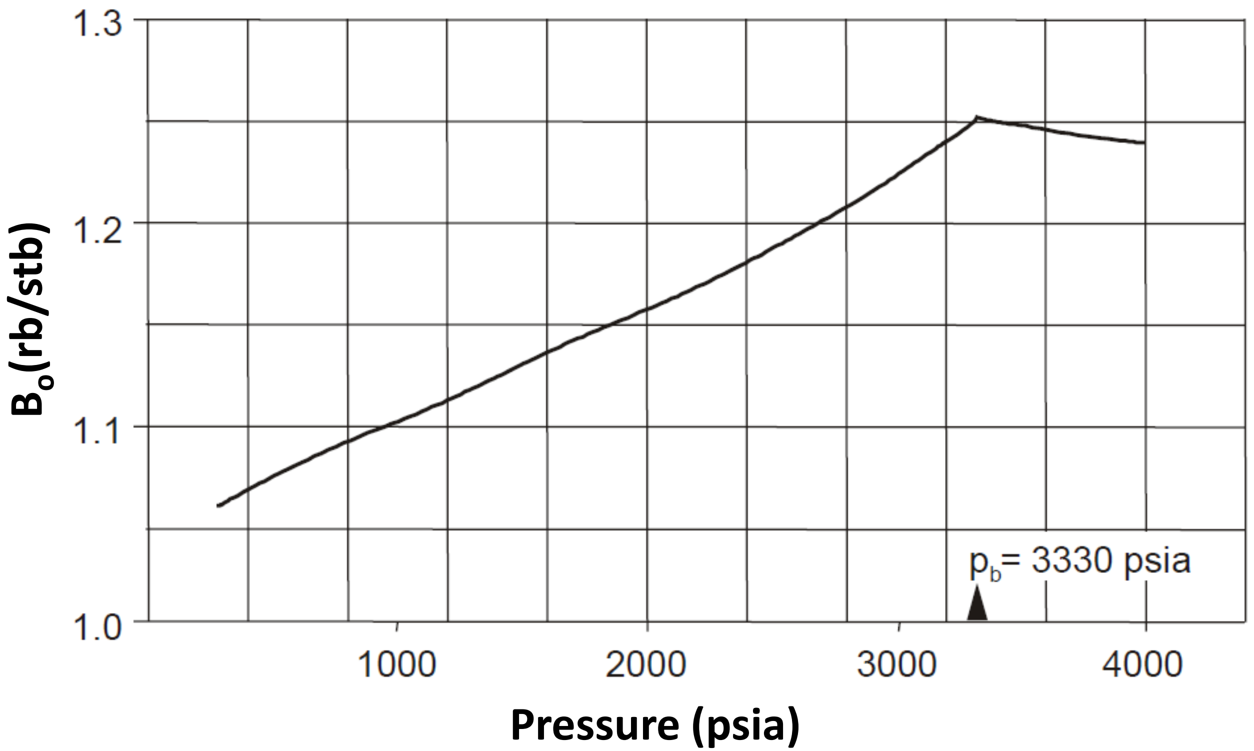
Adapted from Wim Swinkels

Oil PVT Properties

- Oil shrinks when it flows to surface:
  - Oil Formation Volume Factor, FVF or B_o : reservoir volume / stock tank volume
  - expressed in rb/stb or in m^3/m^3.
- Gas comes out of solution
  - GOR or R_s
  - Expressed in scf/stb or in m^3/m^3.
- The tank oil ends up with a gravity
  - Specific gravity or API gravity
- Oil properties in the reservoir change
  - Density
  - Viscosity
- Oil is compressible
  - Oil compressibility
  - Expressed in psi^{-1}

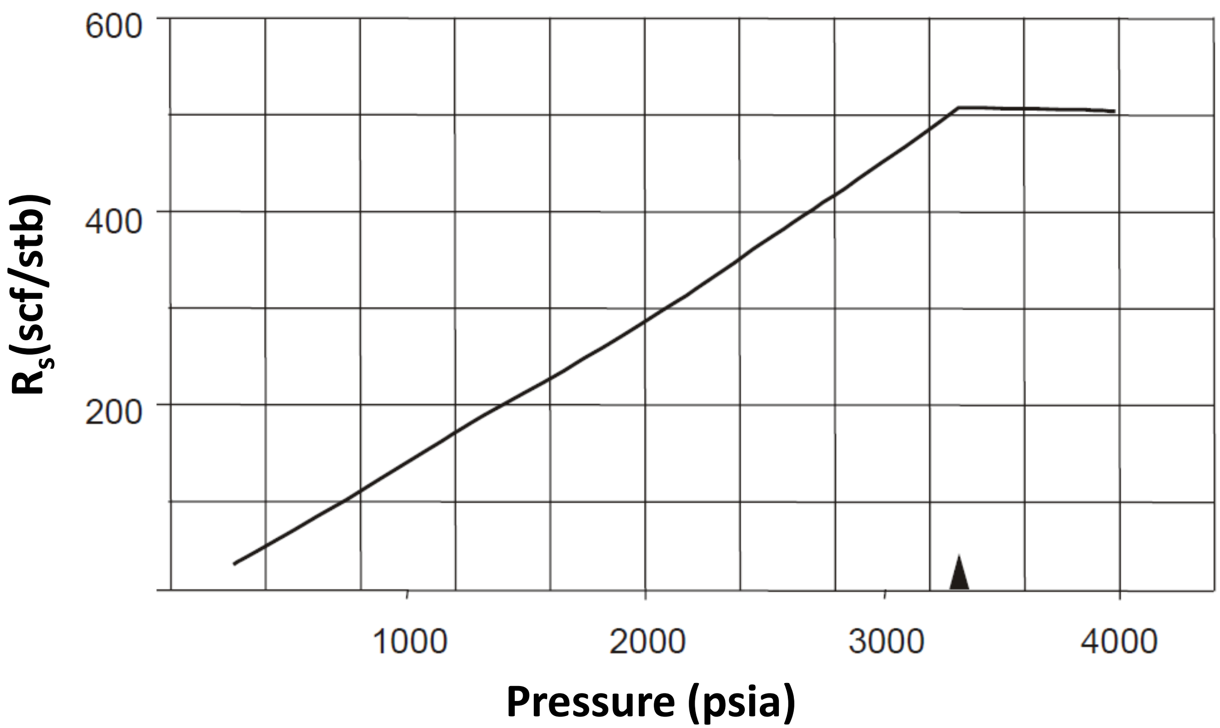
Oil-Formation-Volume Factor

- Definition: volume of reservoir oil at reservoir conditions required to produce one standard volume of stock tank oil
  - Units - res bbl/STB
  - Symbol - B_o



Solution Gas/Oil Ratio (R_s)

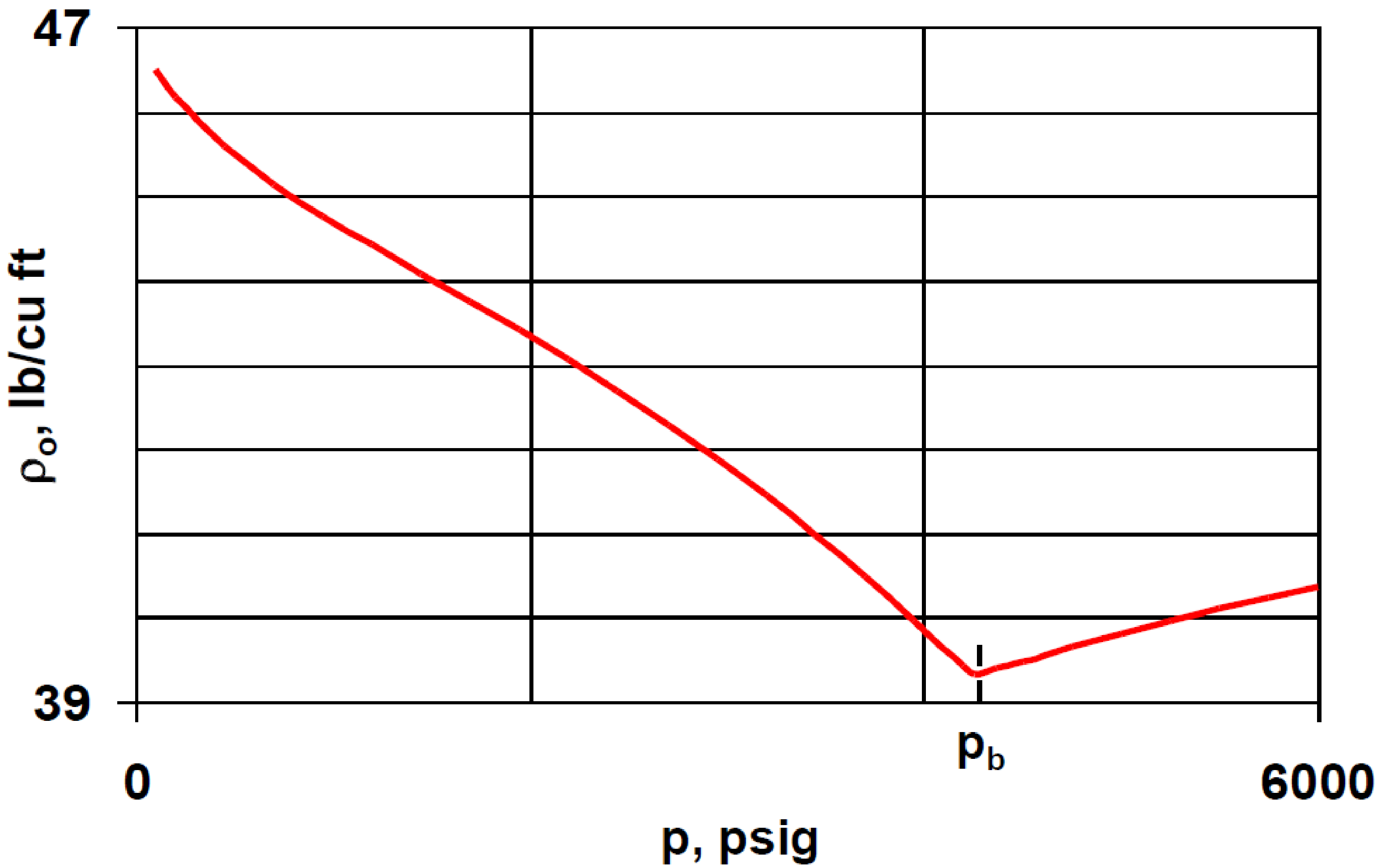
- Definition: volume of gas which comes out of the oil as it moves from reservoir temperature and pressure to standard temperature and pressure
  - Units - cubic feet of total surface gas at standard conditions per barrel of stock-tank oil at standard conditions, scf/stb



Specific Gravity of Oil

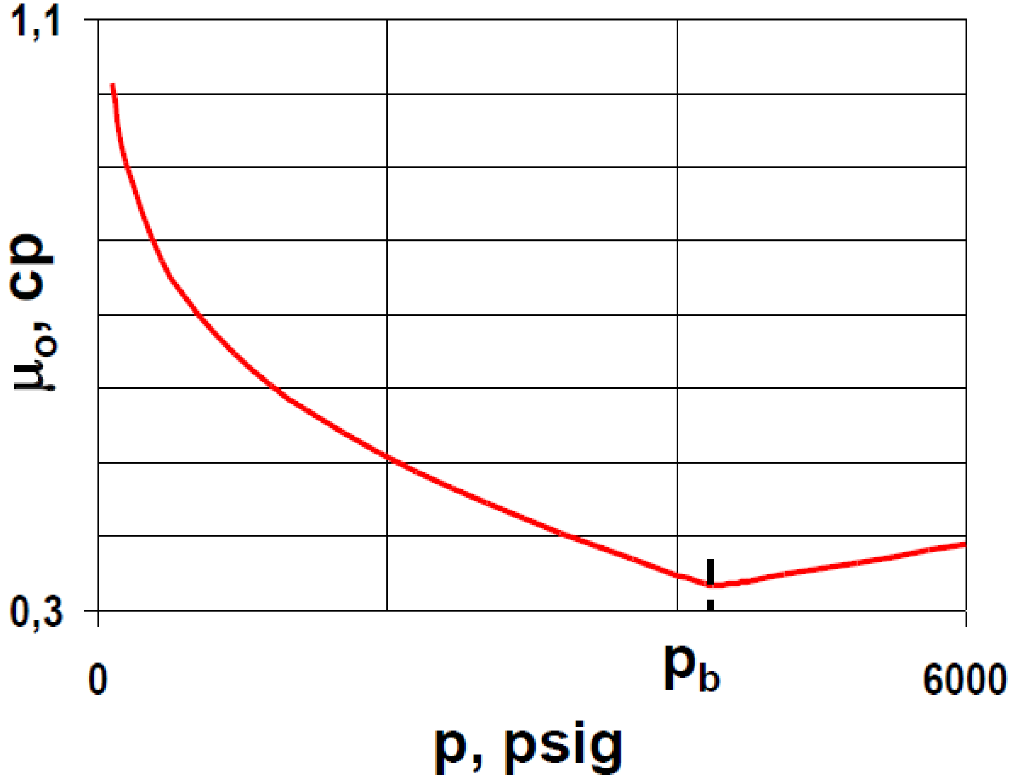
- Specific gravity: $\gamma_o = \frac{\rho_o}{\rho_w}$
- Both densities measured at same temperature and pressure
  - Usually 60^{o}F and atmospheric pressure
- API gravity: $API = \frac{141.5}{\gamma_o} - 131.5$

Density of Oil in Reservoir



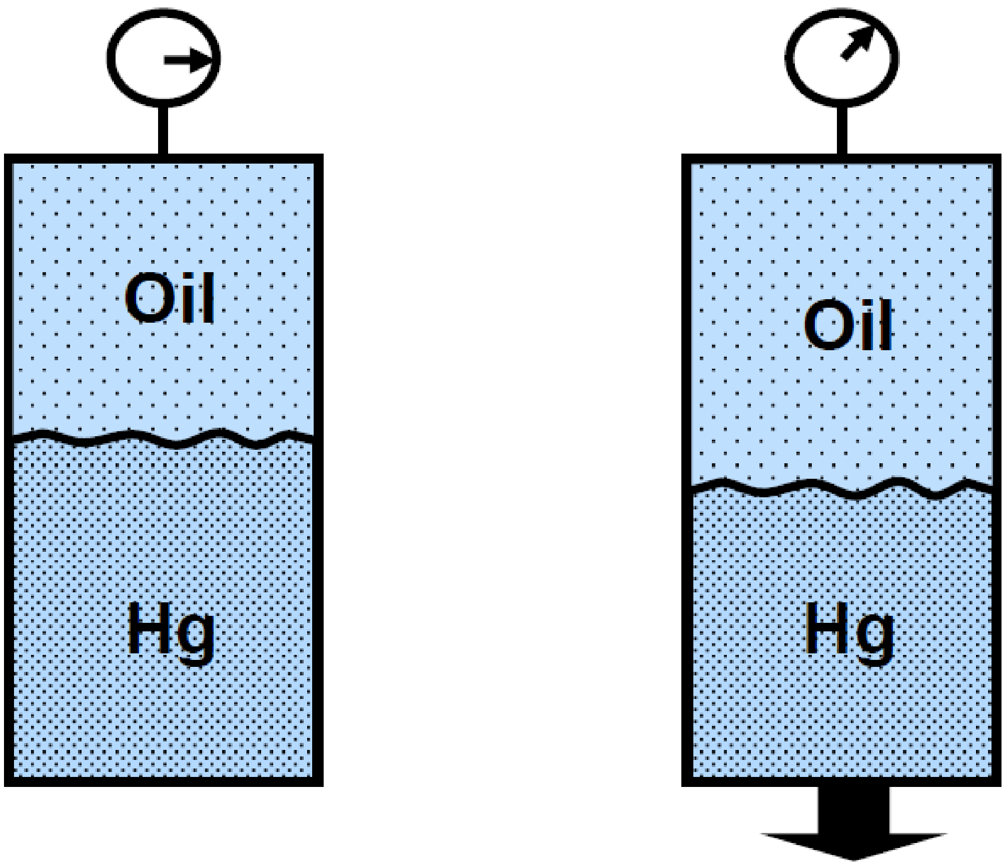
Oil Viscosity

- Definition: the resistance to flow,
  - i.e., large values = low flow rates
  - Units: centipoise = mPa s



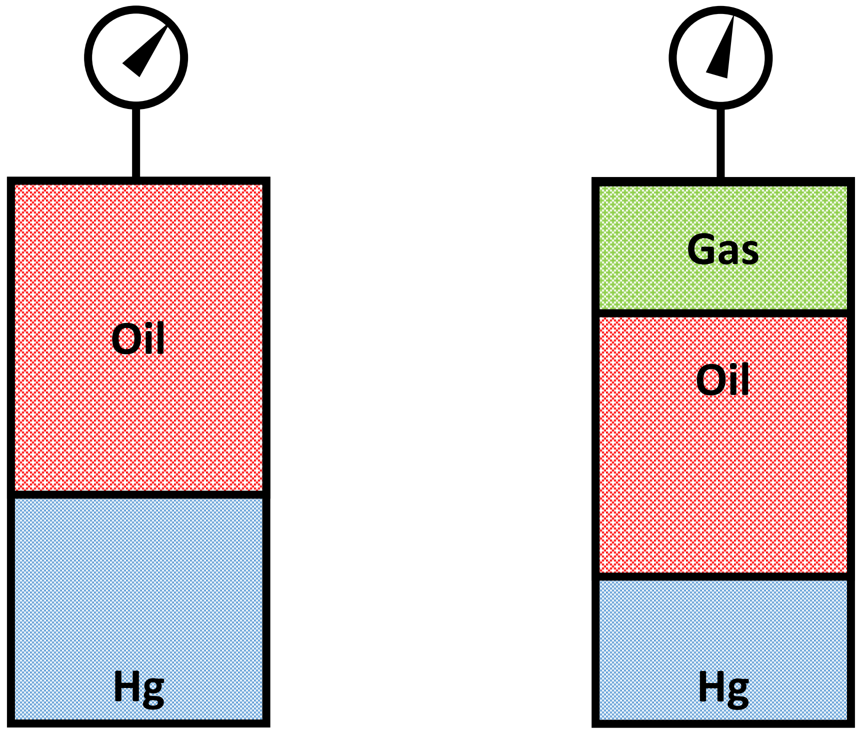
Oil Compressibility – $P > P_b$

- Definition: $c_o = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$ or $c_o = -\frac{1}{B_o}\left(\frac{\partial B_o}{\partial P}\right)_T$

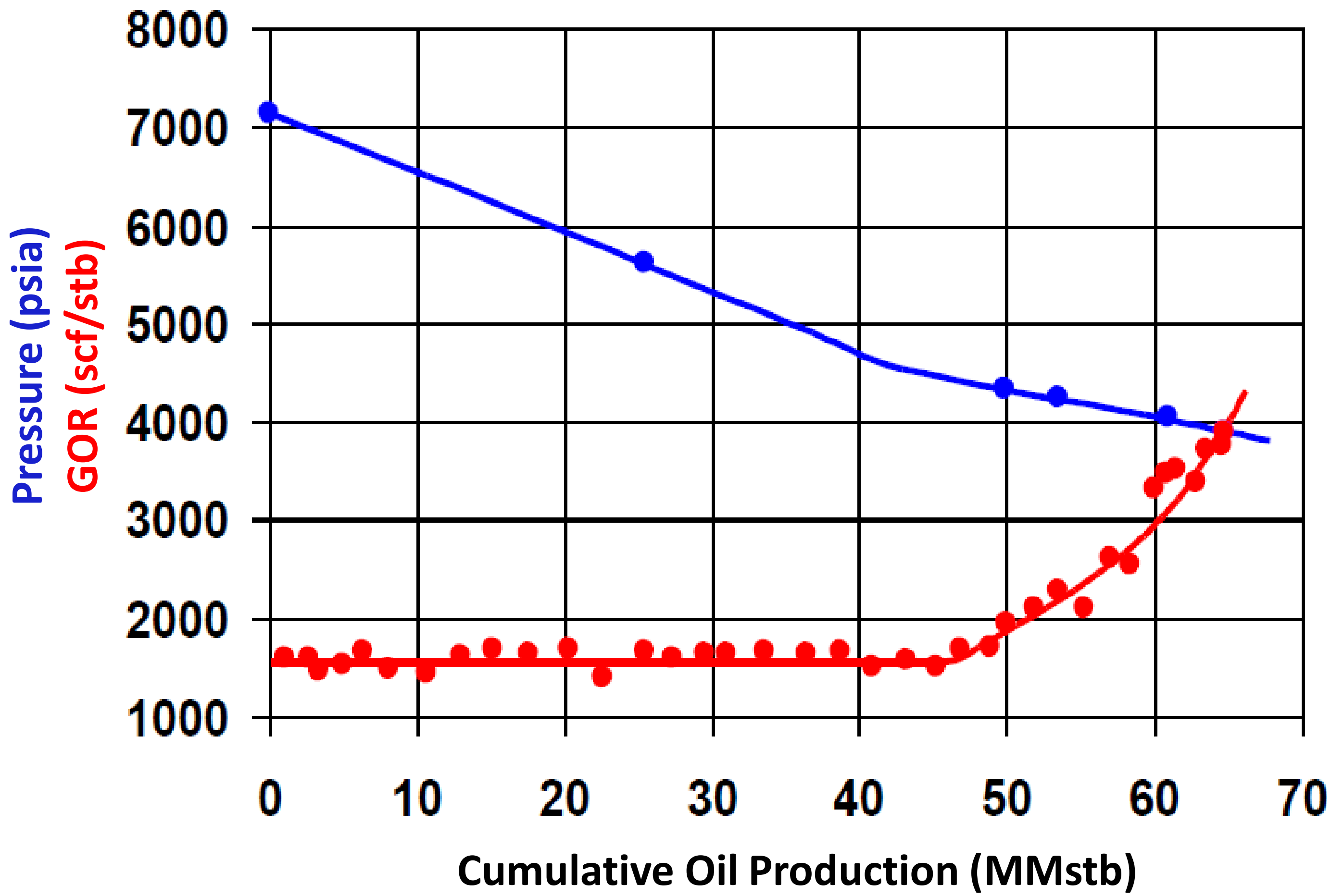


Oil Compressibility – $P < P_b$

- Definition: $c_o = -\frac{1}{B_o}\left(\frac{\partial B_o}{\partial P}\right)_T + \frac{B_g}{B_o}\left(\frac{\partial R_s}{\partial P}\right)_T$



Production/Pressure History of Typical Black Oil



What is solution GOR?
What is bubble-point pressure?

Laboratory Fluid Tests

- Fluid sampling
- Laboratory tests

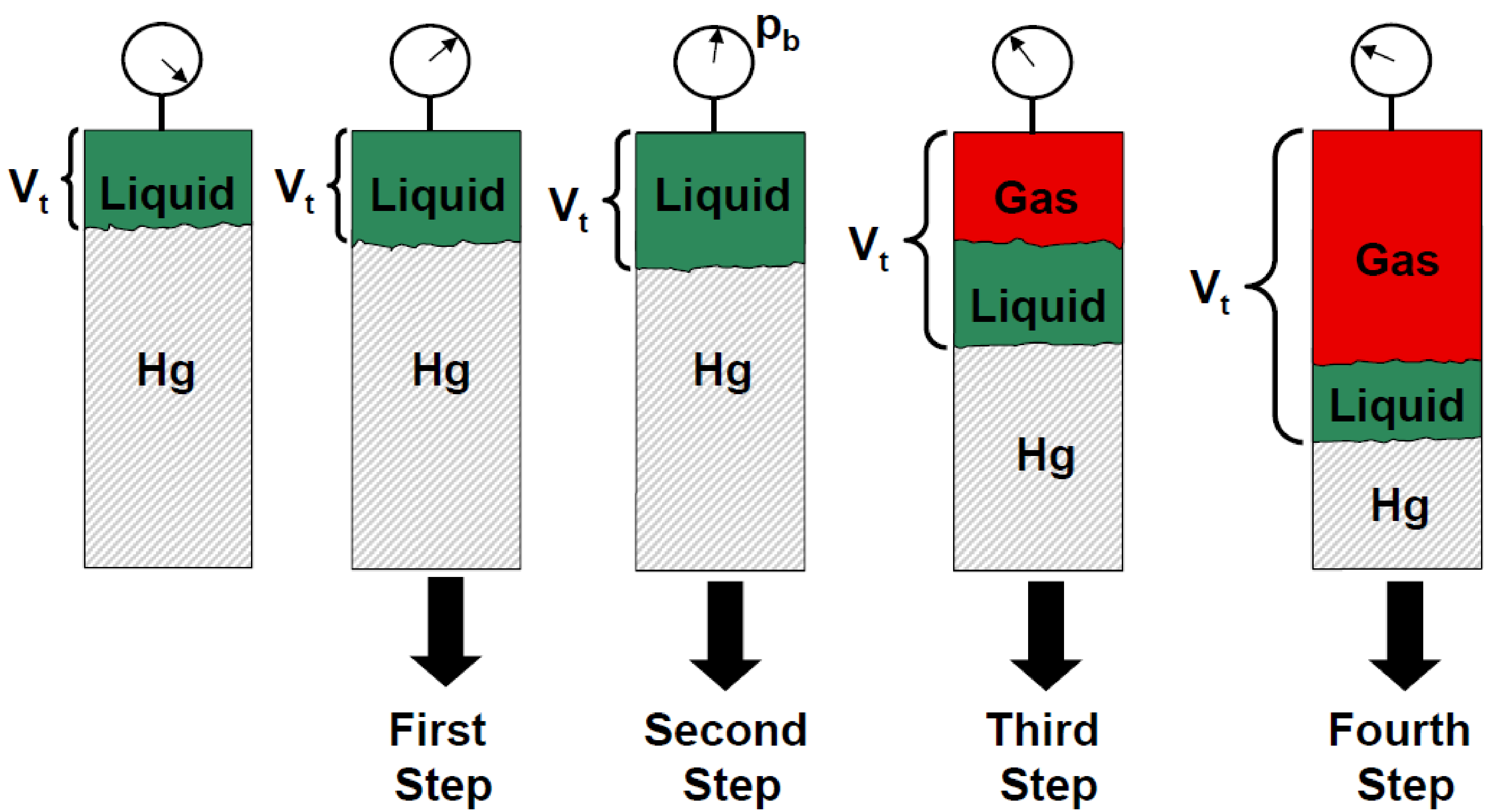
Fluid Sampling

- Surface sampling or recombination sampling
  - + Large volumes can be obtained
  - – Sample at separator outlet
  - – Recombination of gas and oil required
  - – Careful surface conditioning and stabilization required
- Subsurface sampling
  - + Sampling at reservoir conditions
  - – Expensive, wireline entry required
  - – Small volumes

Laboratory Tests

- Five major procedures are
  - Composition measurement
  - Flash vaporization
  - Differential vaporization
  - Separator tests
  - Oil viscosity measurement
- Test should simulate the reservoir process and surface facility treatment

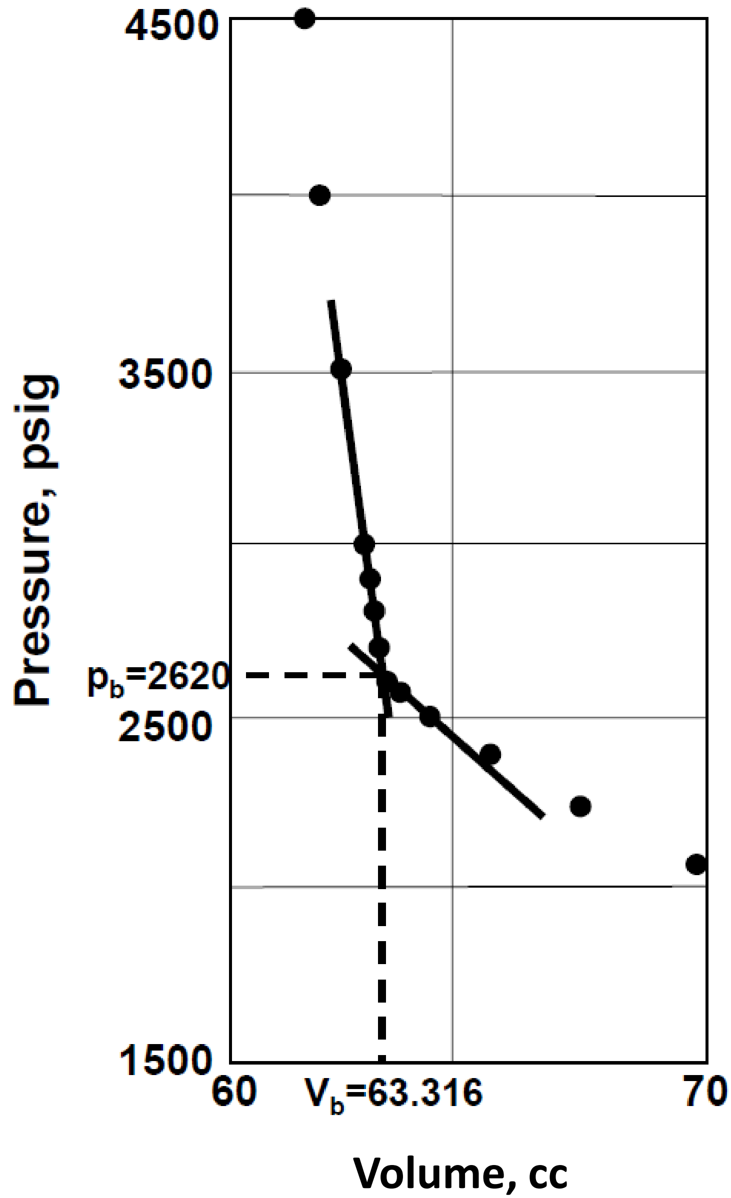
Flash Vaporization Procedure



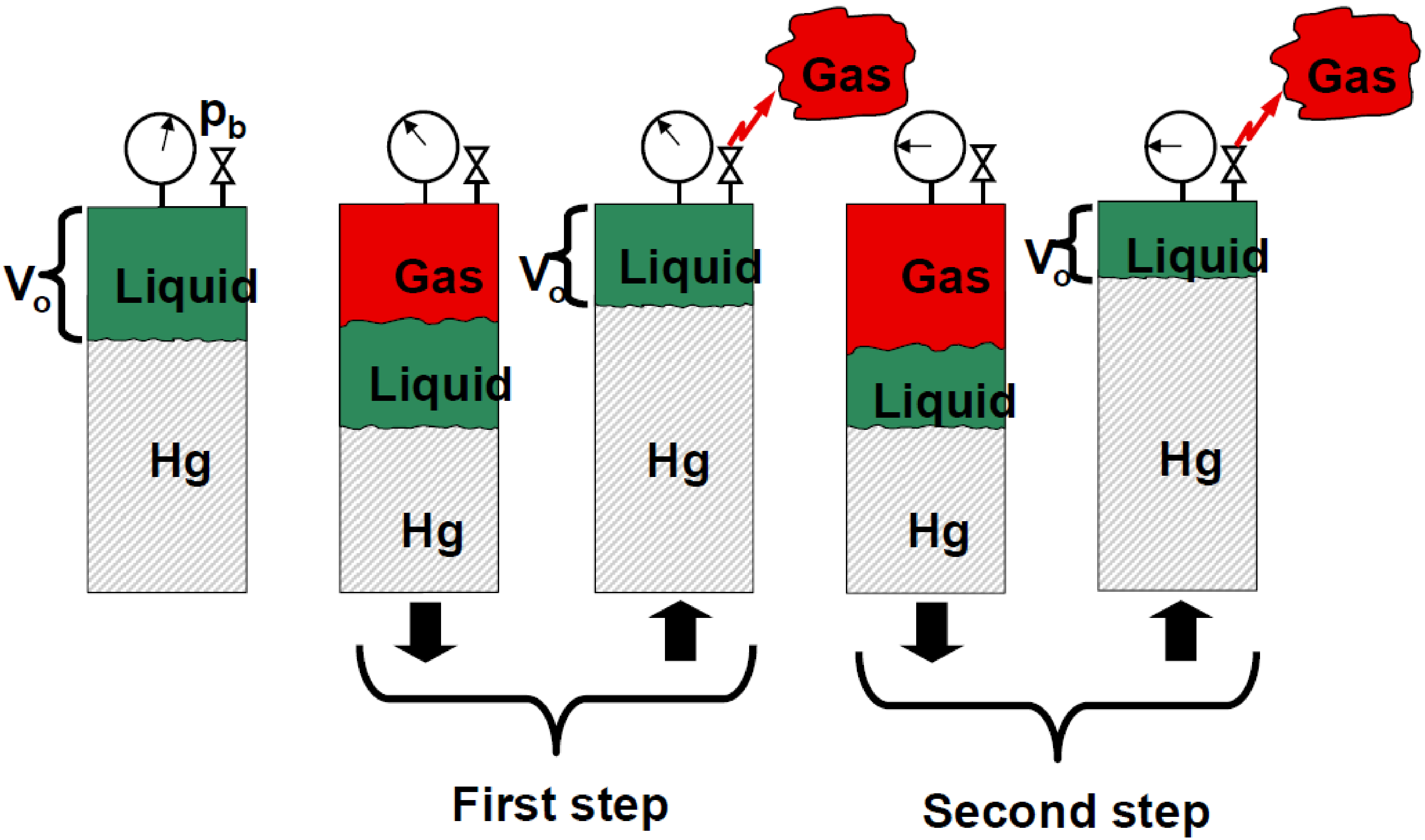
Data From Flash Vaporization

Pressure (psig)	Total Volume, V_t, (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
1477	86.224
1292	95.050
1040	112.715
830	136.908
640	174.201
472	235.700

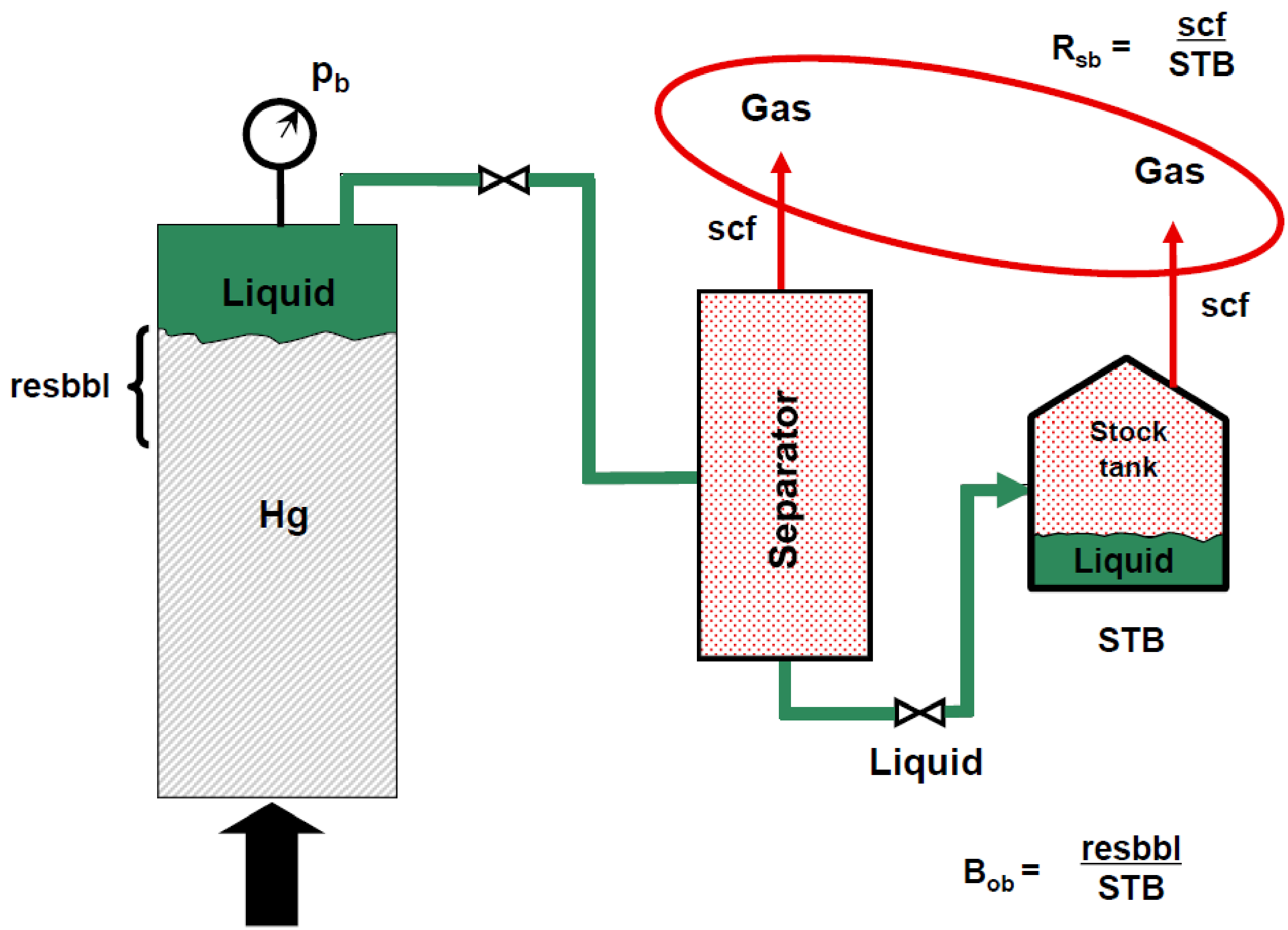
Determination of Bubble-Point Pressure From Flash Vaporization



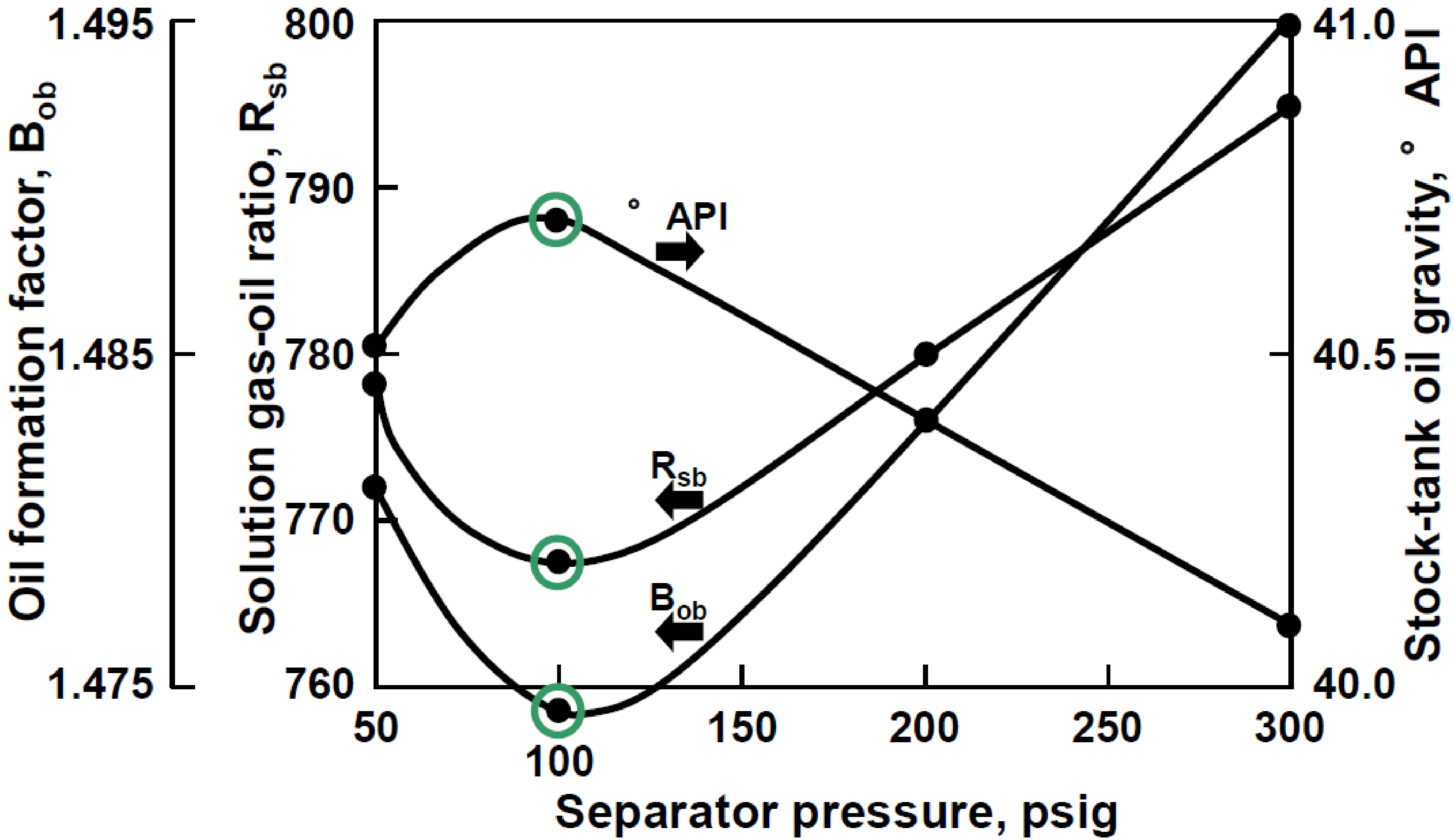
Differential Vaporization Procedure



Laboratory Separator Test



Example Separator Test Results



Gas PVT Properties

- Gas expands when it is brought to surface:
  - Gas Expansion factor E
  - expressed in Mscf/rb or in m^3/m^3
  - Gas FVF or B_g: reservoir volume / surface volume
  - expressed in rb/mscf or in m^3/m^3
- Condensate drops out
  - CGR or r_s
  - Expressed in stb/Mscf or in m^3/m^3.
- PVT properties of gas can be described by the real gas equation of state
  - Expansion factor
  - Specific gravity
  - Density
  - Gas compressibility – gas is very compressible
- Viscosity needs measurements or correlations

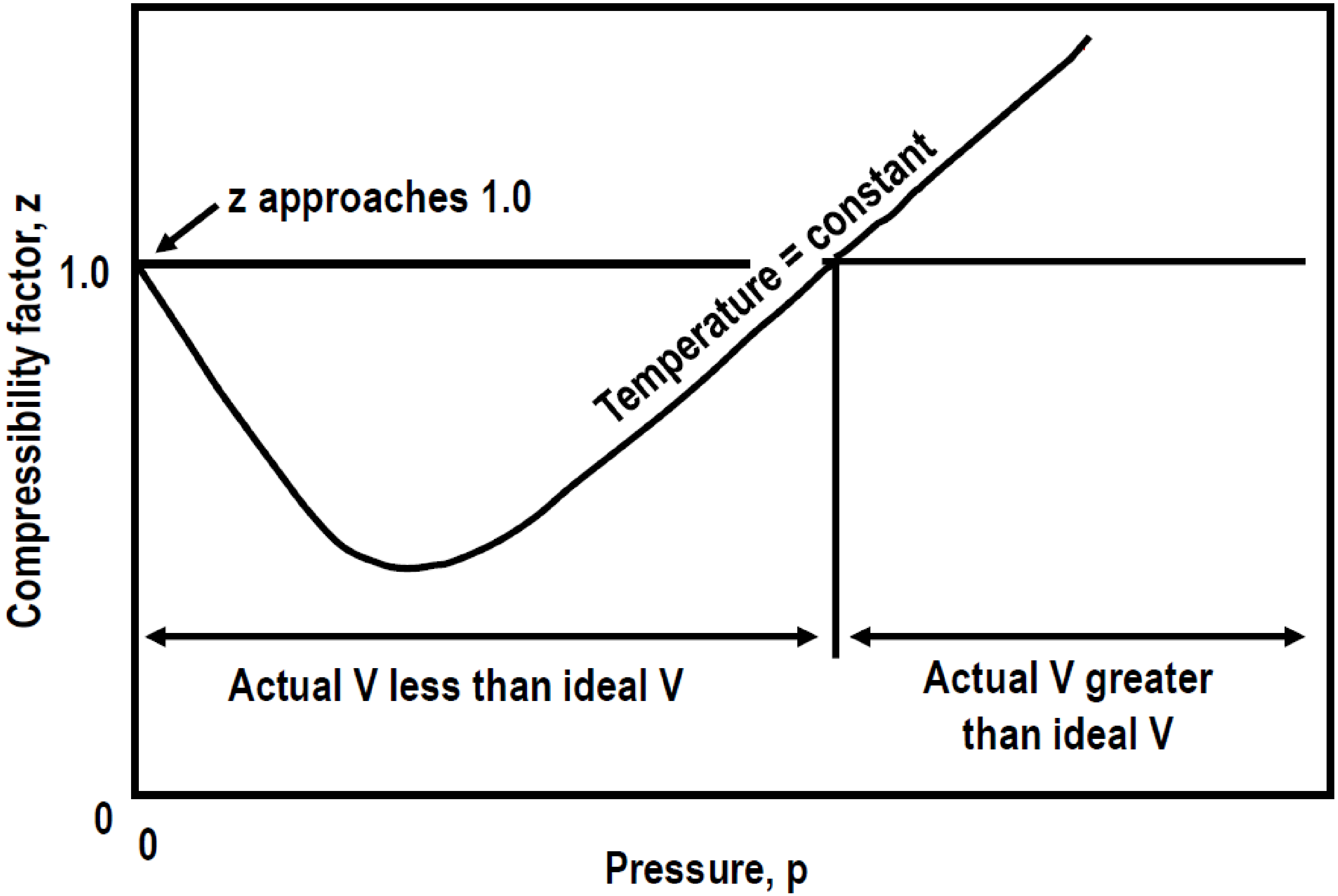
Real Gas Equation of State

$$PV = zRT$$

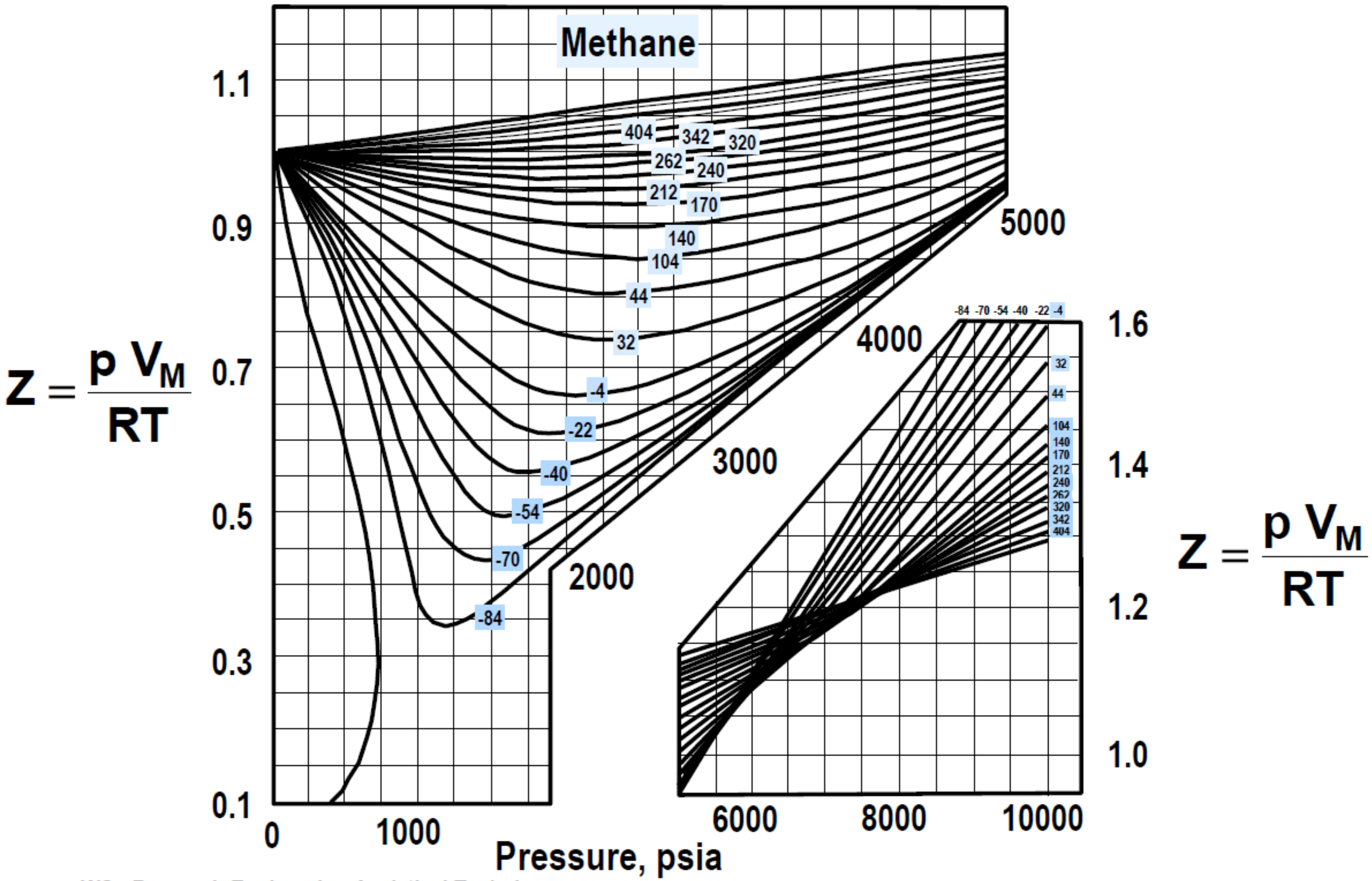
P = pressure, *V* = volume, *z* = gas deviation factor (compressibility factor), *R* = universal gas constant, *T* = absolute temperature

- *z* factor accounts for deviation from ideal gas
  - Volume occupied by molecules is significant compared to volume of gas
  - Attractive or repulsive forces between molecules
  - Collisions between molecules are not perfectly elastic
- Definition: $z = \frac{V_{real}}{V_{ideal}}$
  - *z* is thus 1 for ideal gases

Typical Shape of *z* Factor



Z-Factors For Methane

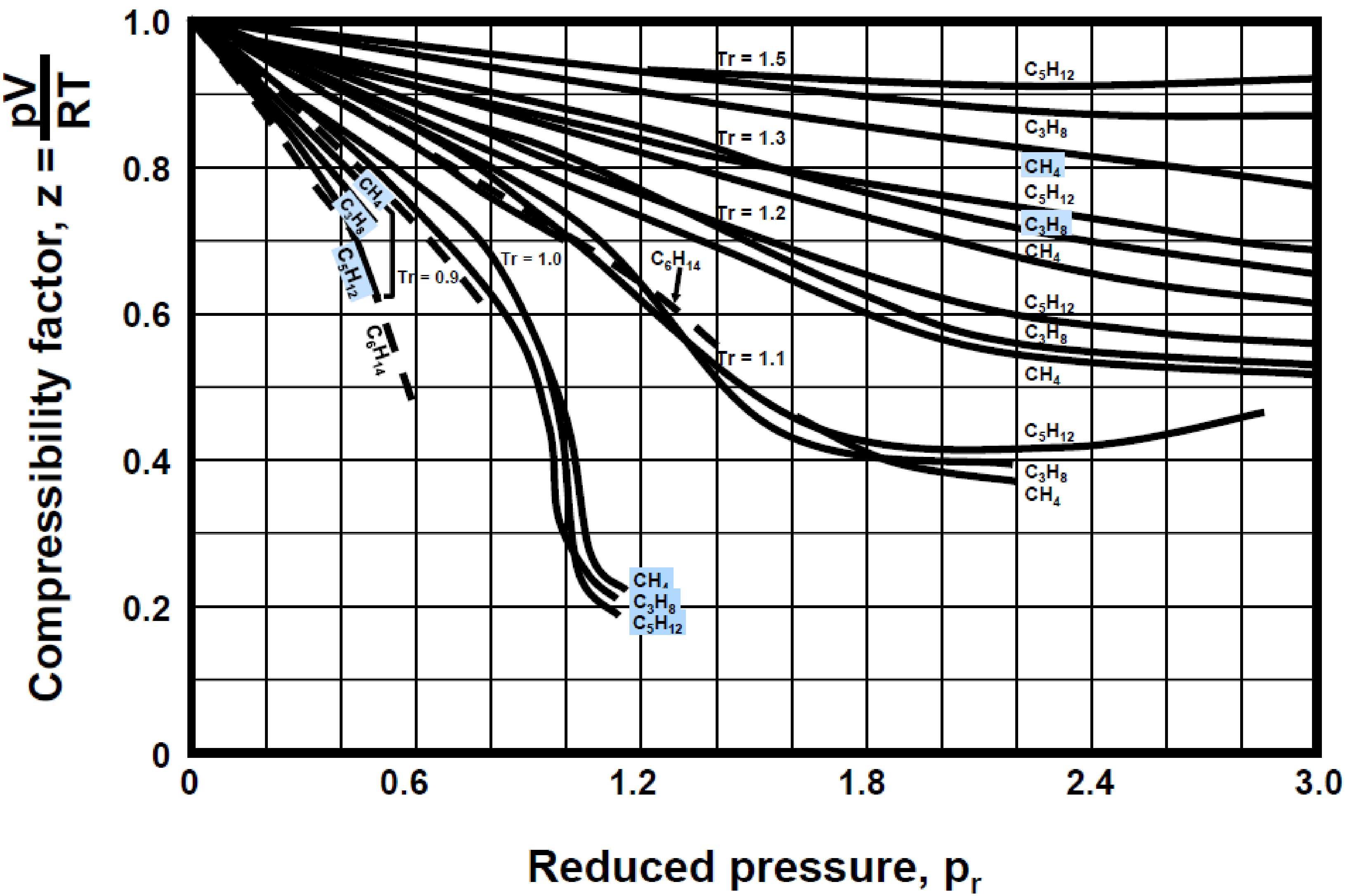


Reduced Pressure and Temperature

$$P_r = \frac{P}{P_c}$$

$$T_r = \frac{T}{T_c}\frac{K}{K} or \frac{R}{R}$$

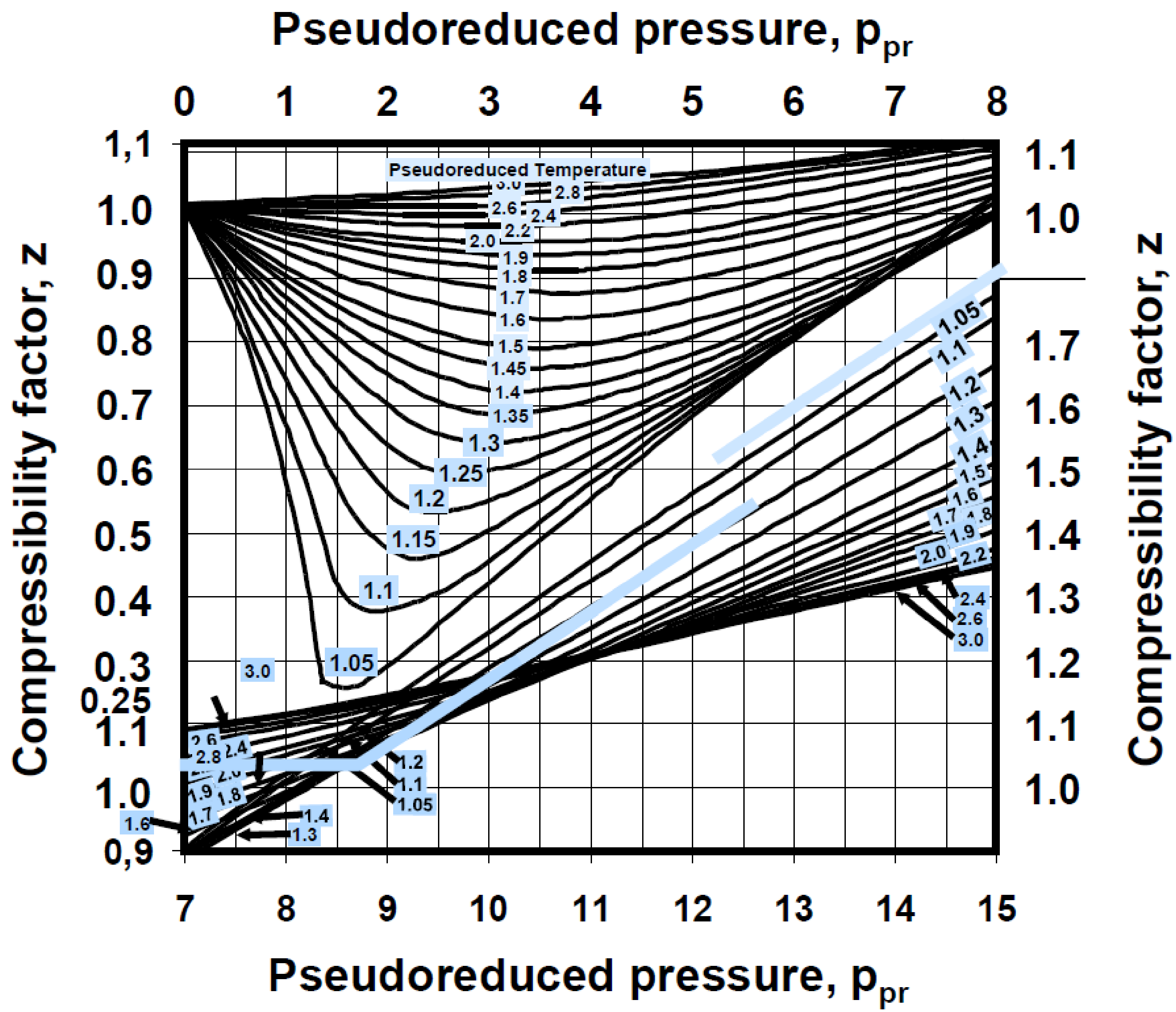
Z-Factors at Reduced P and T, single Components



What About Gas Mixtures (Multicomponent)

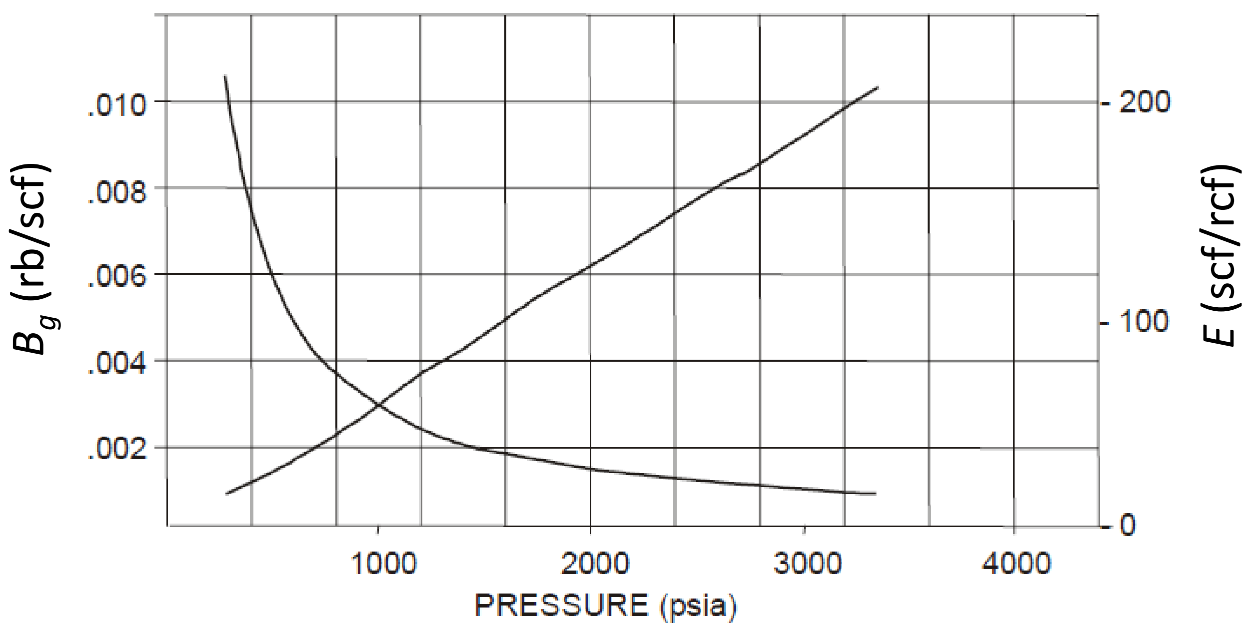
- Critical temperature and critical pressure not readily available
- Define pseudocritical temperature and pseudocritical pressure, P_{pc} and T_{pc}
  - Kay's rules: $T_{pc} = \sum y_i T_{ci}$, $P_{pc} = \sum y_i P_{ci}$
  - Correlate *z*-factor with $T_{pr} = \frac{T}{T_{pc}}$, $P_{pr} = \frac{P}{P_{pc}}$

z-Factors for Naturally Occurring Gas Mixtures



Gas-Expansion Factor

- Definition: volume of gas at surface standard conditions from production of one volume of gas at reservoir conditions
- Symbol E $\quad E = \dfrac{V_{SC}}{V_R}$ or $E = \dfrac{T_{sc}}{P_{sc}} \dfrac{P}{zT}$
  - Units: m^3/m^3 or Mscf/rb
- Shrinkage factor $B_g = \dfrac{1}{E} = \dfrac{V_R}{V_{sc}}$
  - Units: m^3/m^3 or rb/Mscf



Specific Gravity of Gas

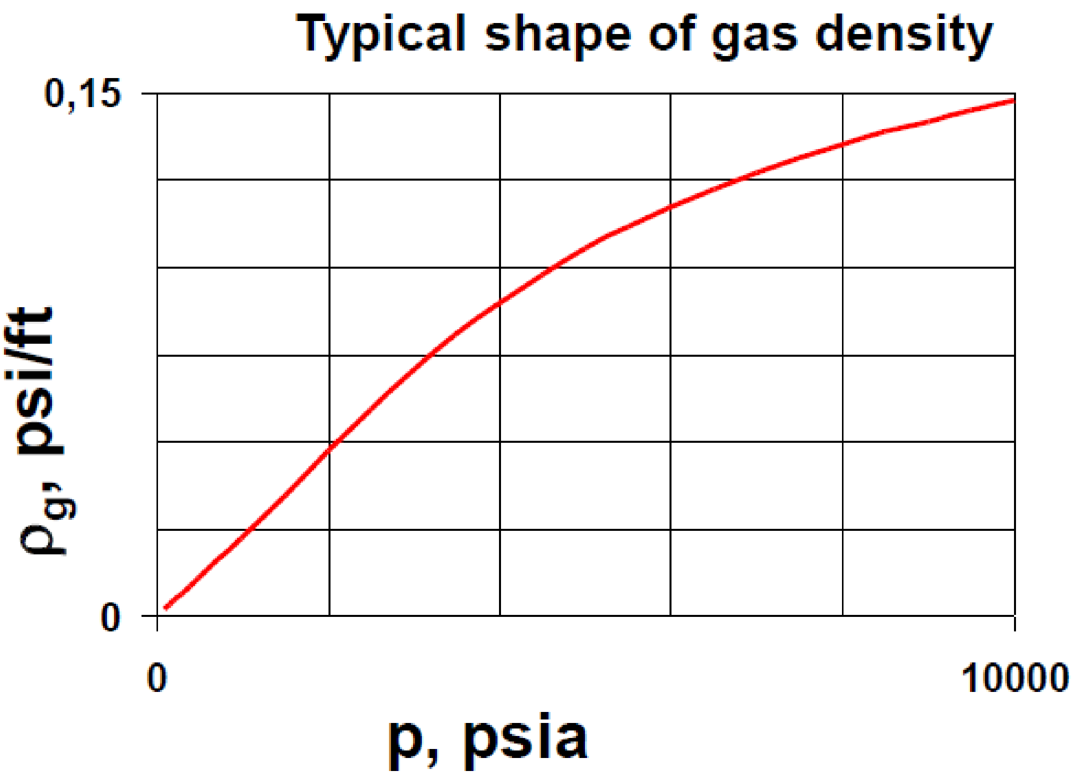
$$\gamma_g = \frac{\rho_g}{\rho_{air}}$$

- Both densities measured at the same temperature and pressure, usually 60^{o}F and atmospheric pressure
- Sometimes called γ_g (air = 1)

$$\gamma_g = \frac{\rho_g}{\rho_{air}} = \frac{\frac{PM_g}{RT}}{\frac{PM_{air}}{RT}} = \frac{M_g}{29}$$

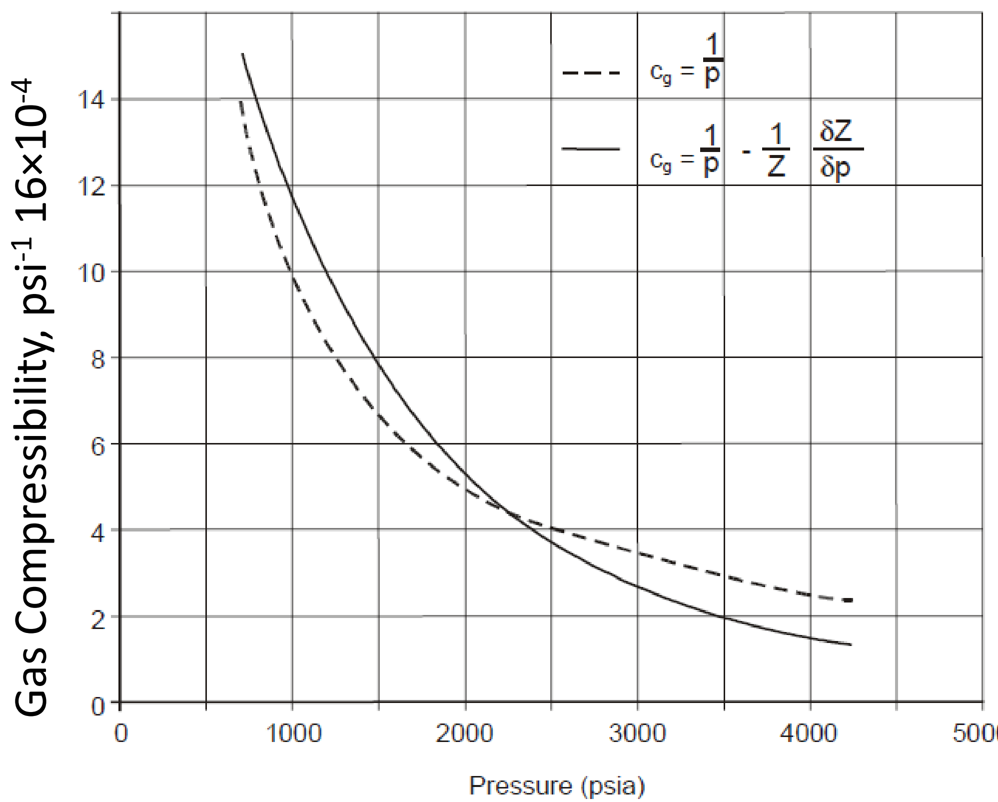
Gas Density

- Equation $\rho_g = \frac{PM}{zRT}$
  - Units: gr/cm^3, lb/cu ft



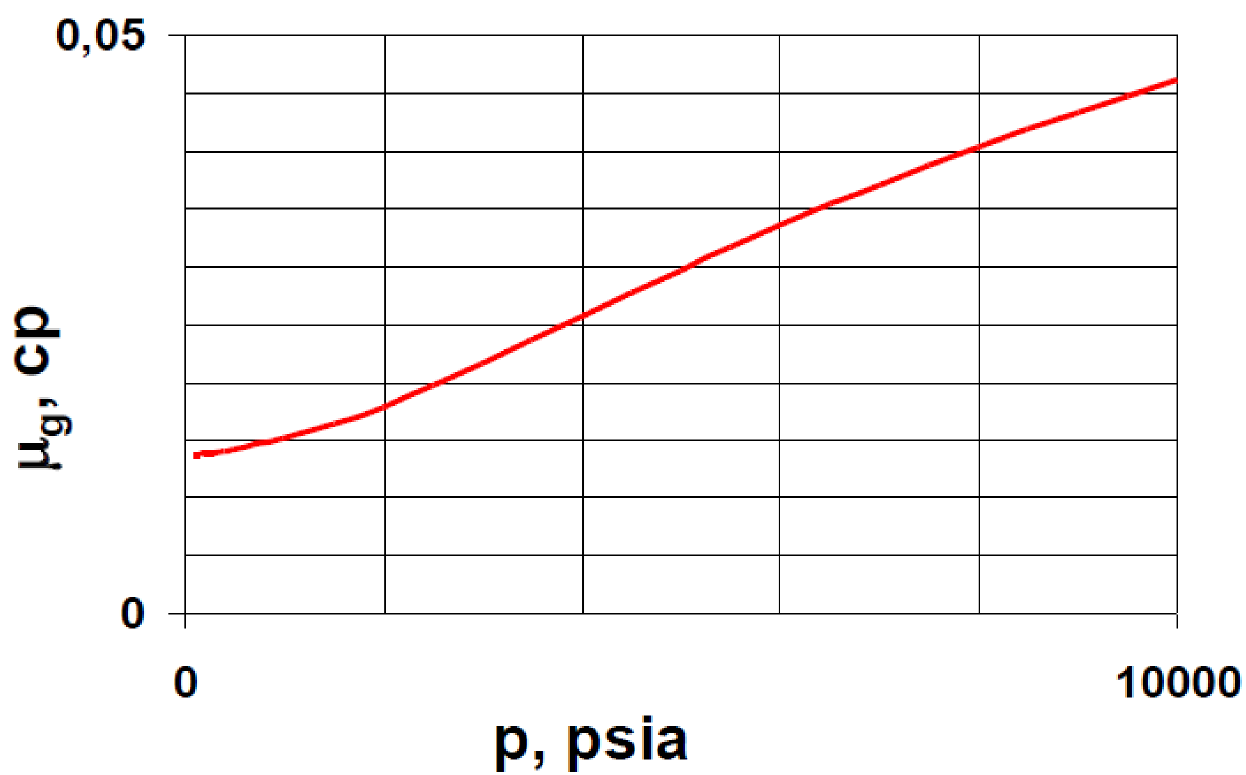
Gas Compressibility

- Gas is very compressible
- Definition: $c_g = -\frac{1}{V}\left(\frac{\partial V}{\partial P}\right)_T$
- Ideal Gas: $c_g = \frac{1}{P}$
- Real Gas: $c_g = \frac{1}{P} - \frac{1}{z}\left(\frac{\partial z}{\partial P}\right)_T$



Gas Viscosity

- Definition: the resistance to flow exerted by a fluid, i.e., large values = low flow rate
  - Units - centipoise or centistoke



Summary of Gas Properties

$$\rho_g = \frac{PM_g}{zRT}, \qquad M_g = 29\gamma_g$$

$$B_g = \frac{P_{sc}}{T_{sc}}\frac{zT}{P}$$

$$\mu_g = \mathrm{f}\left(M_g, \rho_g, T\right)$$

$$c_g = \mathrm{f}\left(\rho_g, z, P, T\right)$$

- Thus the only gas property required to enter all gas property correlations is either gas composition or gas specific gravity.