Al-Ayen University

College of Petroleum Engineering

Reservoir Engineering II

Lecturer: Dr. Mohammed Idrees Al-Mossawy

Lecture 1: Introduction

Outlines

- Syllabus of Reservoir Engineering II
- Review for Important Topics of Reservoir Engineering I
  - Classification of Reservoirs and Reservoir Fluids
  - Properties of Natural Gases
  - Properties of Crude Oil Systems
  - Properties of Reservoir Water
  - PVT Lab Tests
  - Porosity
  - Permeability
  - Averaging Absolute Permeabilities
  - Wettability
  - Capillary Pressure of Reservoir Rocks
  - Relative Permeability Curves for a Water-Oil System

Syllabus of Reservoir Engineering II

Petroleum Reservoir Engineering II:

Fundamental concepts; oil reservoirs: depletion drive; gas cap drive, water drive, gravity drainage reservoir, combination drive reservoirs; pressure maintenance; secondary recovery; gas reservoirs; gas condensate reservoirs; miscellaneous subjects.

Review for Important Topics of Reservoir Engineering I

Classification of Reservoirs and Reservoir Fluids

Depending on components (light or heavy), density (°API), Gas Oil Ratio (GOR), reservoir pressure and temperature, reservoir fluids are classified into five categories:

1. **Dry gas**
2. **Wet gas**
3. **Retrograde condensate gas**
4. **Light oil (volatile oil)**
5. **Heavy oil (black oil)**

Heavy components,
higher specific gravity
lower API, lower GOR

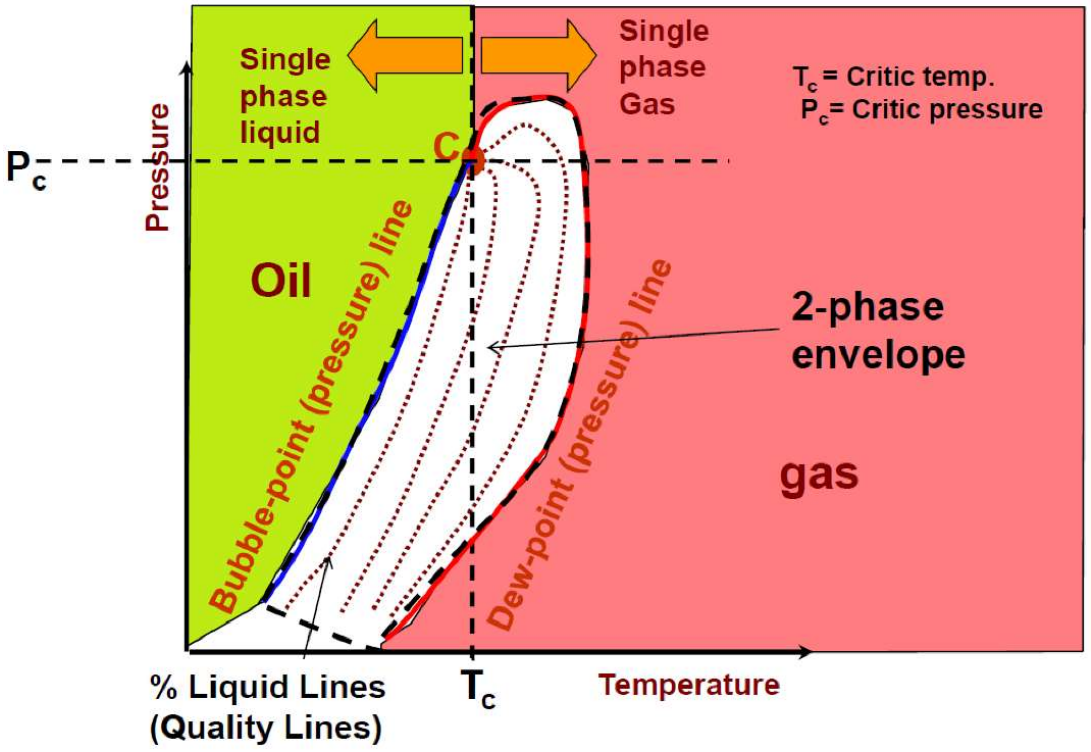
$$\text{API gravity} = \frac{141.5}{\text{SG}} - 131.5$$

45° 30° 20°

Review for Important Topics of Reservoir Engineering I

Classification of Reservoirs and Reservoir Fluids

Pressure-Temperature Diagram

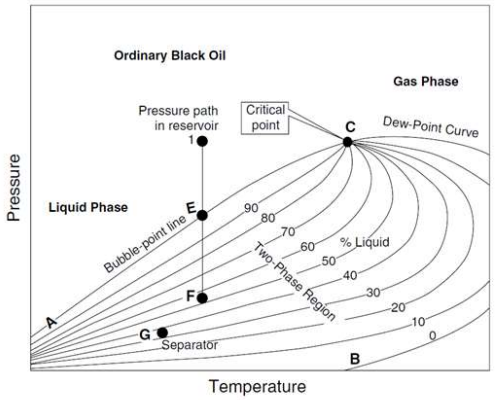


Review for Important Topics of Reservoir Engineering I

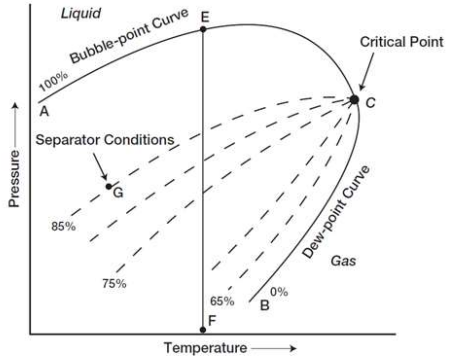
Classification of Reservoirs and Reservoir Fluids

Oil Reservoirs

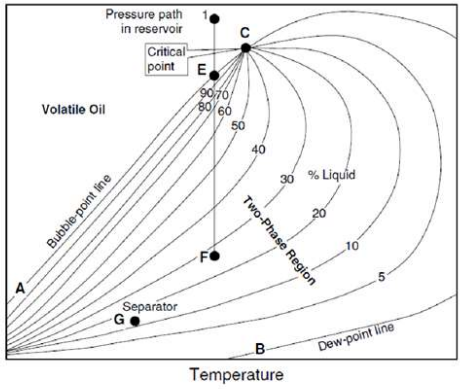
- Under-Saturated oil reservoir (Pri>Pb, and Tr<Tc)
- Saturated oil reservoir (Pri<= Pb, and Tr<Tc)
- Gas-cap or two phase reservoir (Pri < Pb, and Tr<Tc)



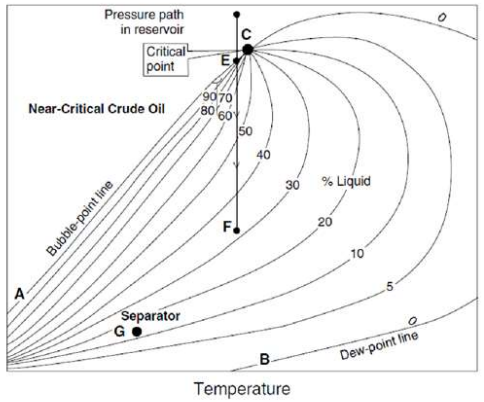
Ordinary Black Oil



Low-Shrinkage Oil



Volatile (High Shrinkage) Oil

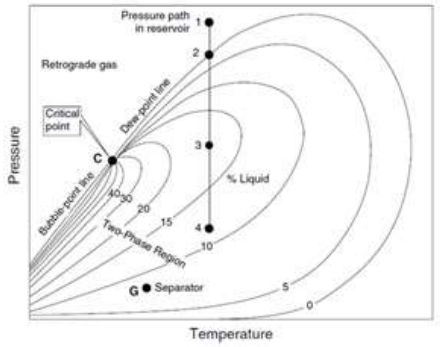


Near-Critical Crude Oil

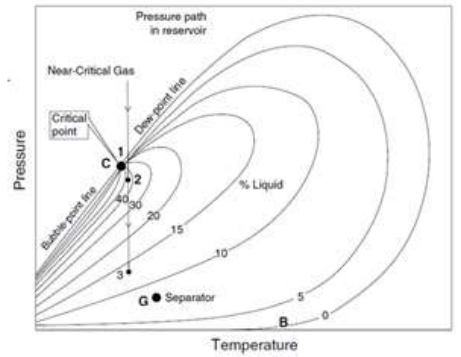
Review for Important Topics of Reservoir Engineering I

Classification of Reservoirs and Reservoir Fluids

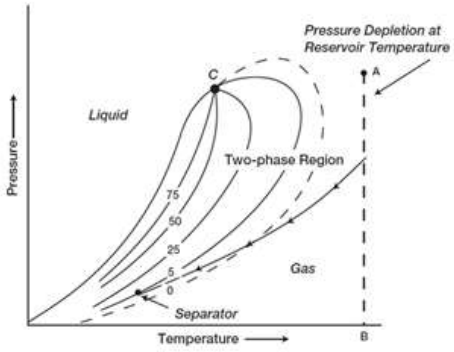
Gas Reservoirs



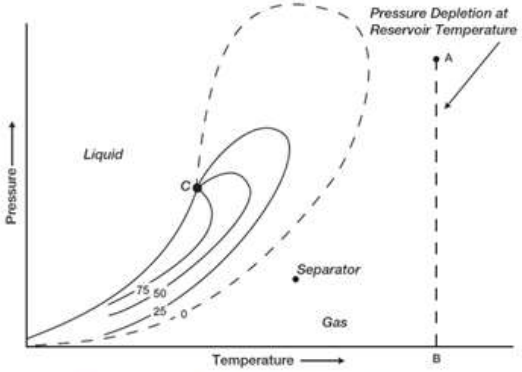
Retrograde gas-condensate (Tc<Tr<Tcricond)



Near-critical gas-condensate (Tri~Tc)



Wet gas (Tri>Tcricond)



Dry gas (Tri>Tcricond)

Review for Important Topics of Reservoir Engineering I

Properties of Natural Gases

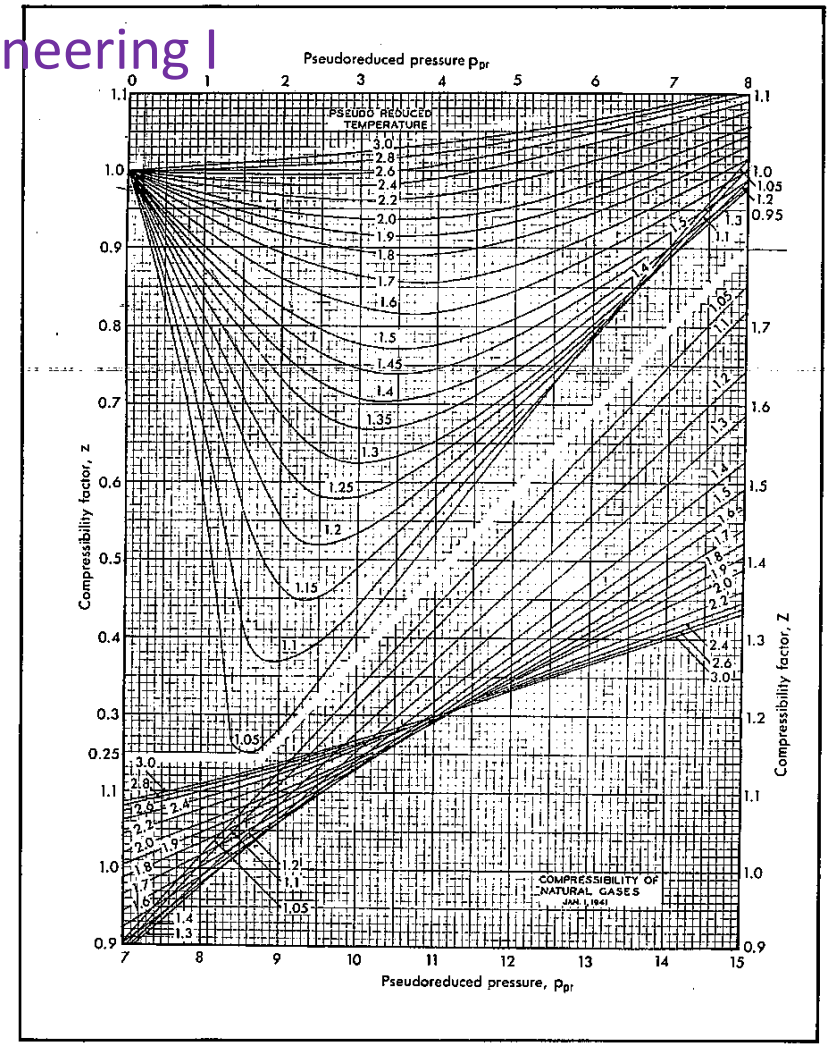
$$pV = nRT \quad \longleftrightarrow \quad \textit{Ideal Gas Law}$$

$$pV = znRT \quad \longleftrightarrow \quad \textit{Real Gas Law}$$

$$p_{pc} = \sum_{i=1} y_i \, p_{ci} \qquad T_{pc} = \sum_{i=1} y_i \, T_{ci}$$

$$p_{pr} = \frac{p}{p_{pc}} \qquad T_{pr} = \frac{T}{T_{pc}}$$

$$M_a = \sum_{i=1} y_i \, M_i$$



Compressibility factors of natural gases. (Standing and Katz, *Trans.*, AIME, *146*, 140. Copyright 1942 SPE-AIME).

Review for Important Topics of Reservoir Engineering I

Properties of Natural Gases

$$c_g = -\frac{1}{V}\left(\frac{\partial V}{\partial p}\right)_T$$ ⟷ *Isothermal Gas Compressibility*

$$c_g = \frac{1}{p} - \frac{1}{z}\left(\frac{\partial z}{\partial p}\right)_T$$ ⟷ *For Real Gases*

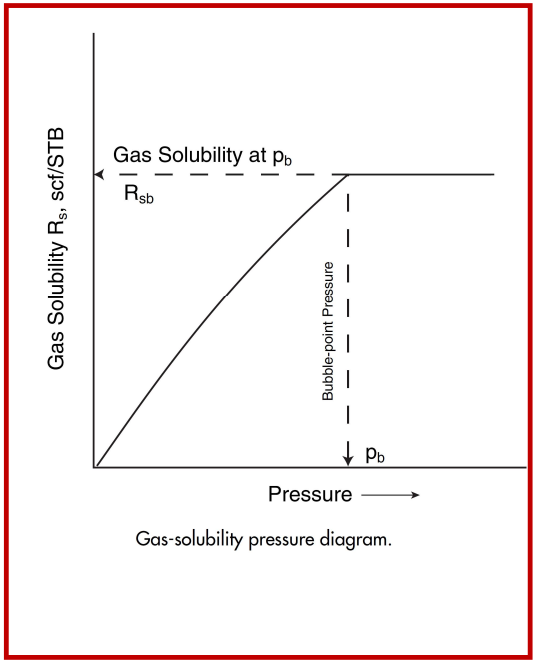
$$c_g = \frac{1}{p}$$ ⟷ *For Ideal Gases*

$$B_g = \frac{V_{p,T}}{V_{sc}}$$ ⟷ *Gas Formation Volume Factor*

$$B_g = 0.02827\frac{zT}{p}$$ ⟷ *Gas Formation Volume Factor*

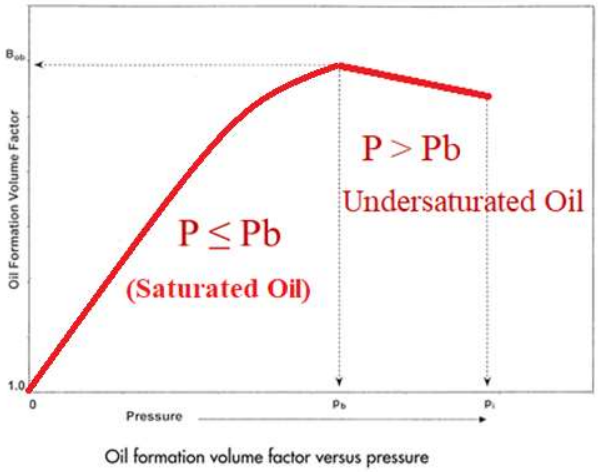
Review for Important Topics of Reservoir Engineering I

Properties of Crude Oil Systems



Gas Solubility

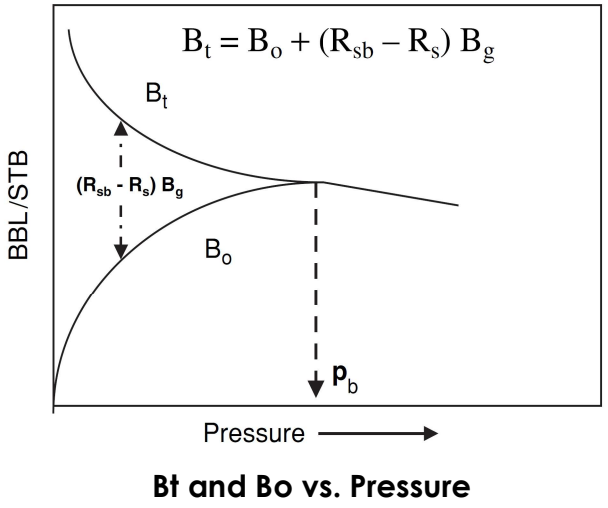
$$B_o = \frac{(V_o)_{p,T}}{(V_o)_{sc}}$$



Oil Formation Volume Factor

$$B_t = \frac{(V_o)_{p,T} + (V_g)_{p,T}}{(V_o)_{sc}}$$

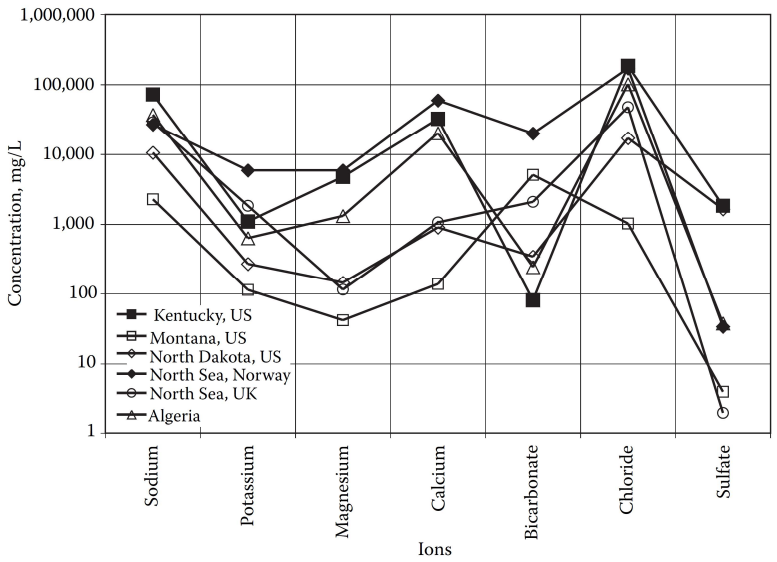
$$B_t = B_o + (R_{sb} - R_s)\, B_g$$



Total Formation Volume Factor

Review for Important Topics of Reservoir Engineering I

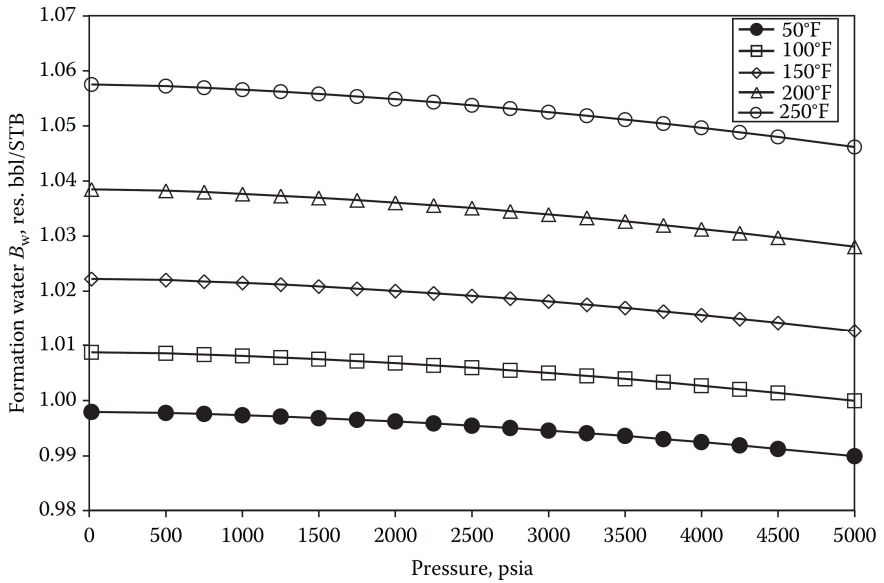
Properties of Reservoir Water



Ionic concentration of various formation waters of oil fields from various parts of the world.

Compositional Characteristics of Formation Water

$$B_w = \frac{V_{wR}}{V_{wsc}} = \frac{\rho_{wsc}}{\rho_{wR}}$$

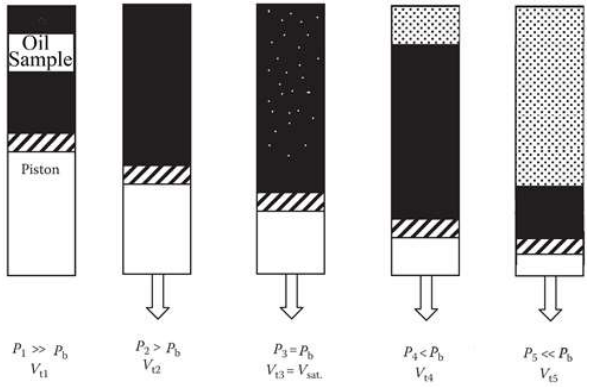


Formation volume factor of formation water, as a function of pressure and temperature.

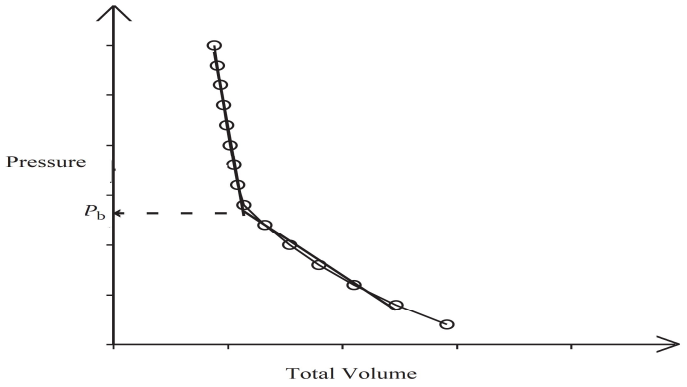
Formation Volume Factor of Formation Water

Review for Important Topics of Reservoir Engineering I

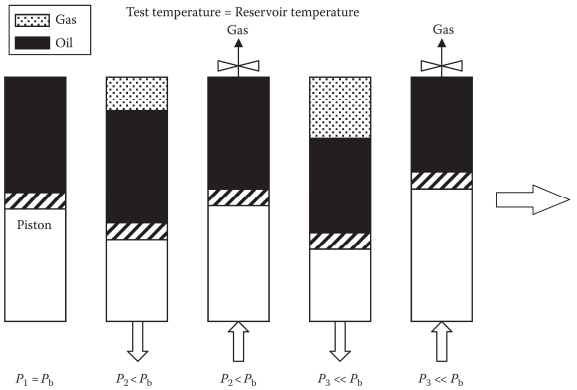
PVT Lab Tests



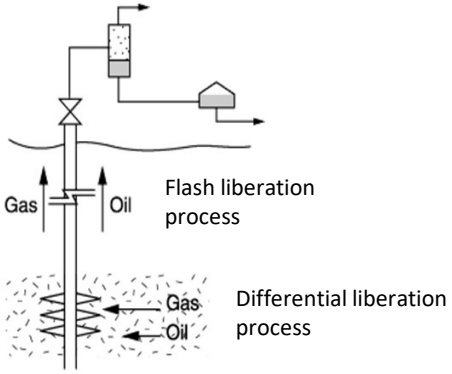
Schematic representation of a CCE test for a black oil sample

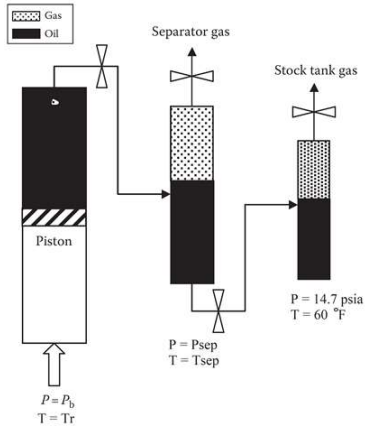


PV relationship for a black oil system



Schematic representation of a differential liberation test on an oil sample.





Schematic representation of a separator test on an oil sample

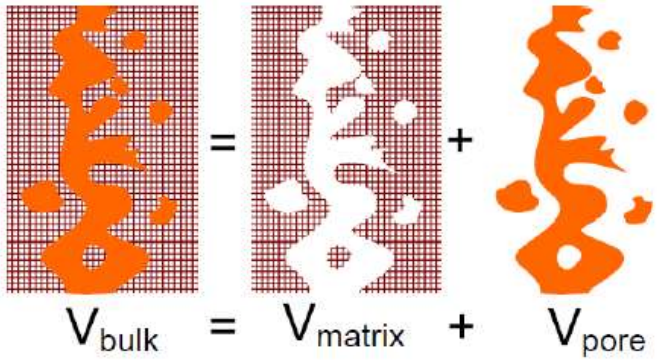
- Three main parameters are usually determined from separator tests:
  - The bubble-point oil formation volume factor, as measured by flash liberation.
  - The bubble-point solution gas-oil ratio as measured by flash liberation.
  - The specific gravity of the stock tank oil.

Review for Important Topics of Reservoir Engineering I

Porosity

$$\phi = \frac{\text{pore volume}}{\text{bulk volume}}$$

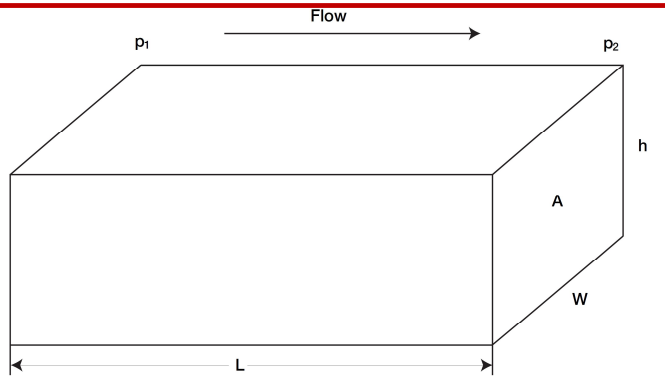
- Negligible 0-5 %
- Poor 5-10%
- Fare 10-15%
- Good 15-20%
- Very Good 20-25%



$$\varphi = \frac{V_p}{V_b} = \frac{V_b - V_m}{V_b} = 1 - \frac{V_m}{V_b}$$

Review for Important Topics of Reservoir Engineering I

Permeability

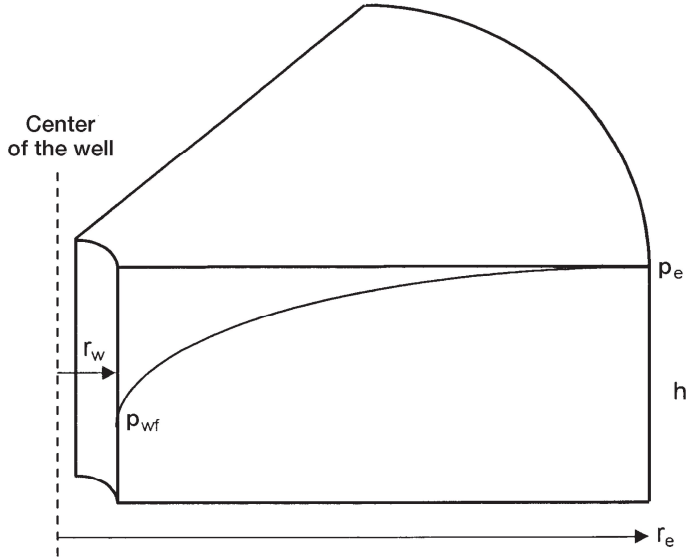


Darcy's Law for Linear Flow of Incompressible Fluids

$$q = \frac{kA\,(p_1 - p_2)}{\mu\, L}$$

Darcy's Law for Linear Flow of Gases

$$Q_{gsc} = \frac{k\,A\,(p_1^2 - p_2^2)}{2\,\mu_g\, L\, p_b}$$

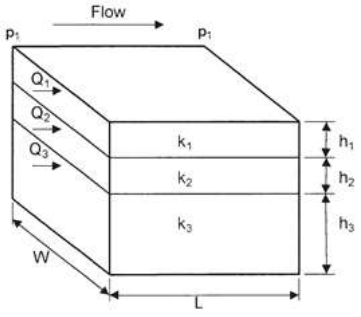


Darcy's Law for Radial Flow of Incompressible Fluids

$$q = \frac{2\,\pi\, kh\,(p_e - p_{wf})}{\mu\, \ln(r_e/r_w)}$$

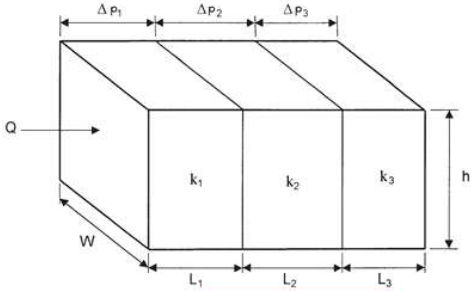
Review for Important Topics of Reservoir Engineering I

Averaging Absolute Permeabilities



$$k_{avg} = \frac{k_1 h_1 + k_2 h_2 + k_3 h_3}{h_t} = \frac{\sum_{j=1}^{n} k_j h_j}{\sum_{j=1}^{n} h_j}$$

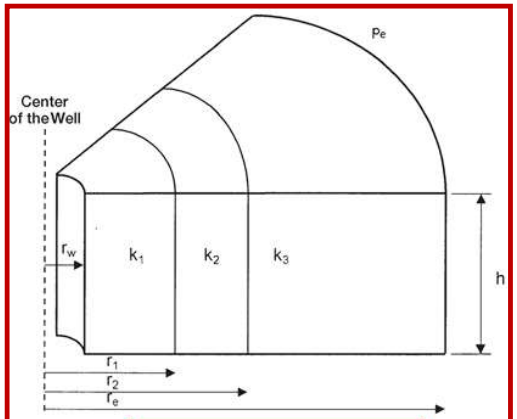
Weighted-average permeability



$$k_{avg} = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} (L/k)_i}$$

Harmonic-average permeability

Linear System



$$k_{avg} = \frac{\text{Ln}\,(r_e/r_w)}{\sum_{j=1}^{n} \left[\frac{\text{Ln}\,(r_j/r_{j-1})}{k_j} \right]}$$

Harmonic-average permeability

Radial System

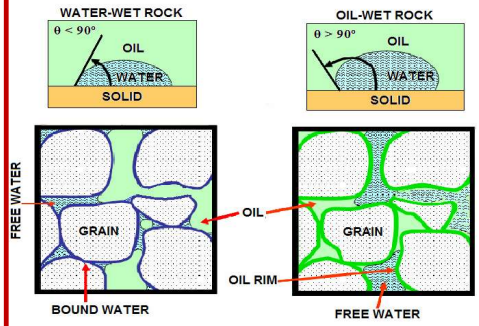
Heterogeneous rock formations

$$k_{avg} = \exp \left[\frac{\sum_{i=1}^{n} (h_i \ln (k_i))}{\sum_{i=1}^{n} h_i} \right]$$

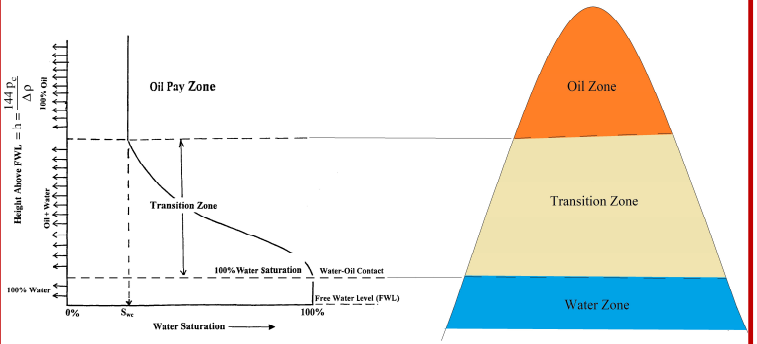
k_i = permeability of core sample i
h_i = thickness of core sample i
n = total number of samples

Geometric-average permeability

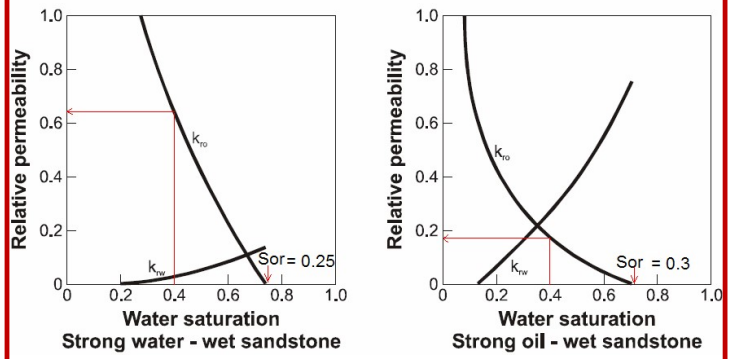
Review for Important Topics of Reservoir Engineering I



Wettability



Capillary Pressure of Reservoir Rocks



Relative Permeability Curves for a Water-Oil System

THANK YOU