Tikrit University

The College of Petroleum Processes Engineering

Petroleum and Gas Refining Engineering Department

An Introduction to Petroleum Technology

First Class

Lecture (7)

By

Assistant lecturer

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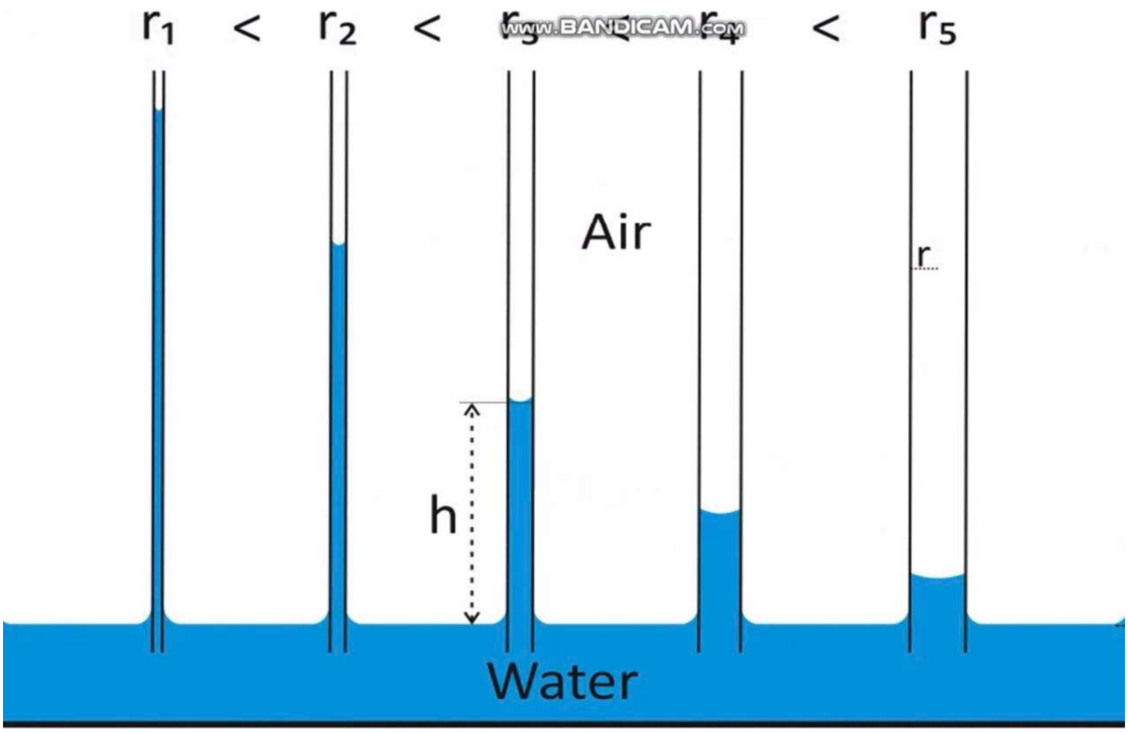
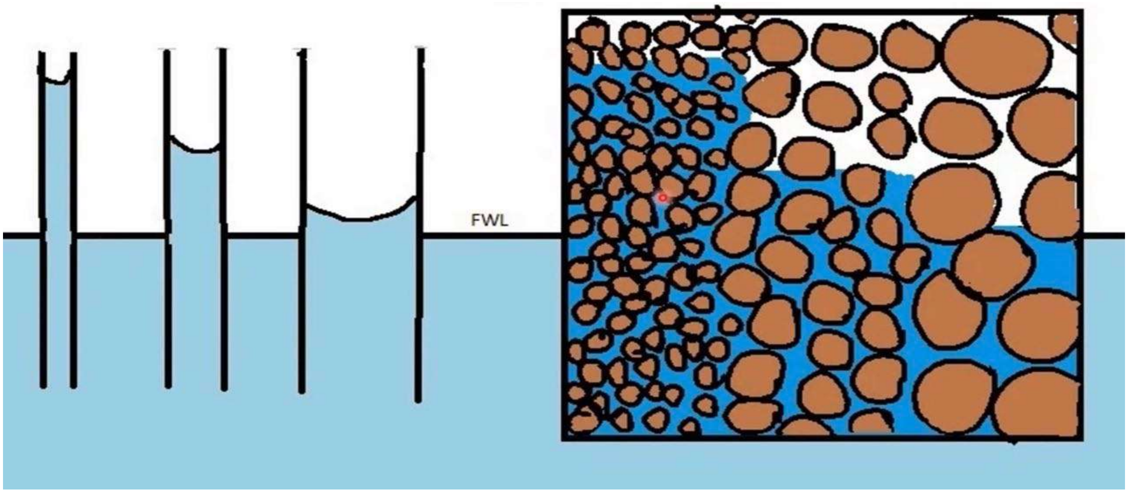
7-1 Capillary pressure:

Capillary pressure is the major factor that controlling the fluid distribution in a reservoir rock when two immiscible fluids in contact with each other in capillary like tubes.





Calculation of capillary pressure:

we can calculate the capillary pressure according to this formula :

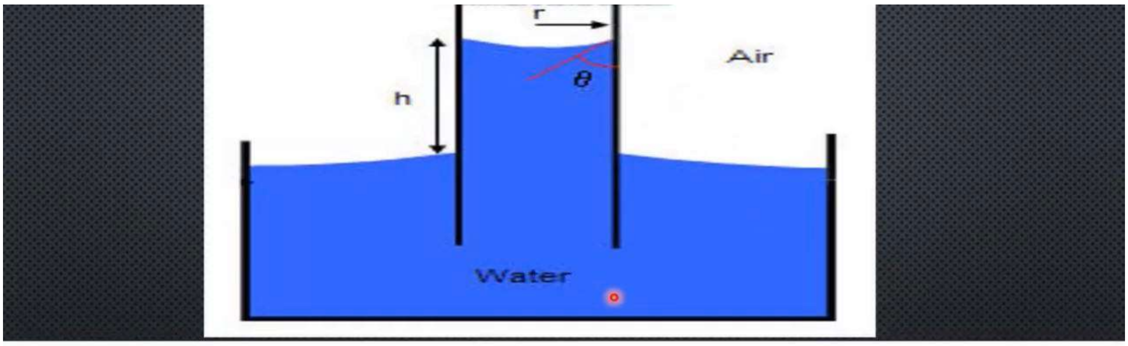
$P_c = P_{NW} - P_W$ **7-1**

Where:

P_c: capillary pressure.

P_{NW}: pressure of Non-wetting fluids.

P_W: pressure of wetting fluids.



$$P_c = p_{air} - p_w = \Delta p = \frac{2\sigma \cos\theta}{r}$$

There are three types of capillary pressure:

1- Water-oil capillary pressure (denoted as P_{cwo})
2- Gas –oil capillary pressure (denoted as P_{cgo})
3- Gas –water capillary pressure (denoted as Pcgw)

$P_{cwo} = Po – Pw$

$P_{cgo} = Pg – Po$

$P_{cgw} = Pg – Pw$

$P = \rho\, g\, h$ 7-2

So that :

$P_{cwo} = Po - Pw = \rho o\ g\ h - \rho w\ g\ h = g\ h\ (\rho w - \rho o) = gh\ \Delta\rho$

Where :

Δρ is the density difference between the wetting and non-wettting phase. In practical units, equation can be expressed as:

$Pc = (\frac{h}{144})\ \Delta\rho$ 7-3

Where :

Pc: capillary pressure , psi

h: capillary rise, ft.

Δρ: density difference , lb/ft3 .

Oil – water system :

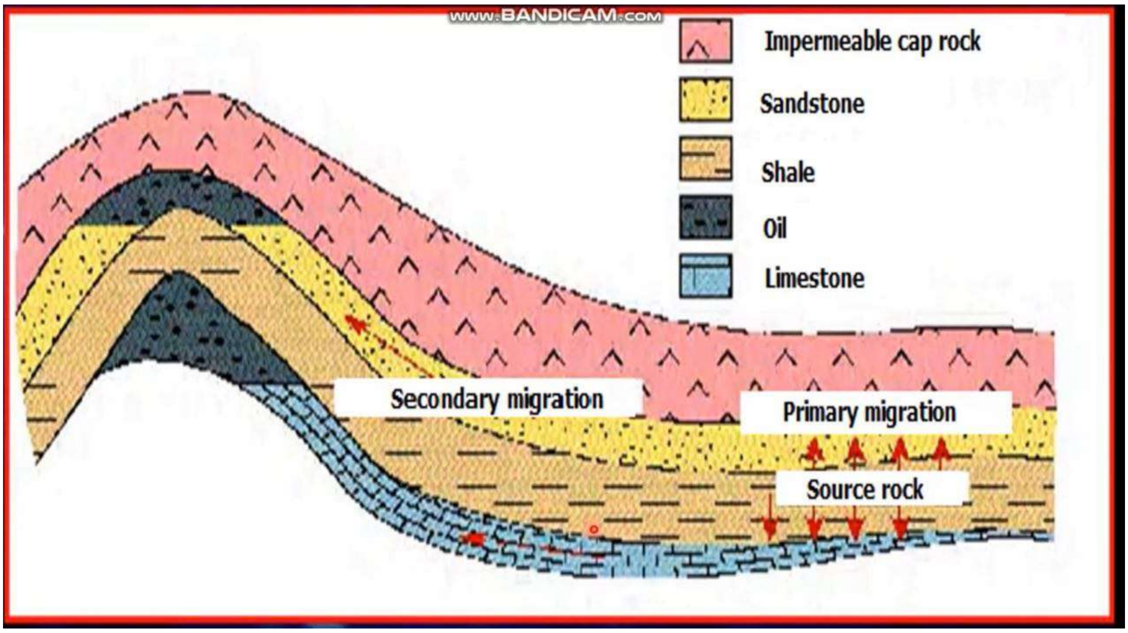
$Pc = (\frac{h}{144})\ \Delta\rho$ or:

$Pc = \frac{2\ б\ ow\ (\ cos\Theta)}{r}$ 7-4

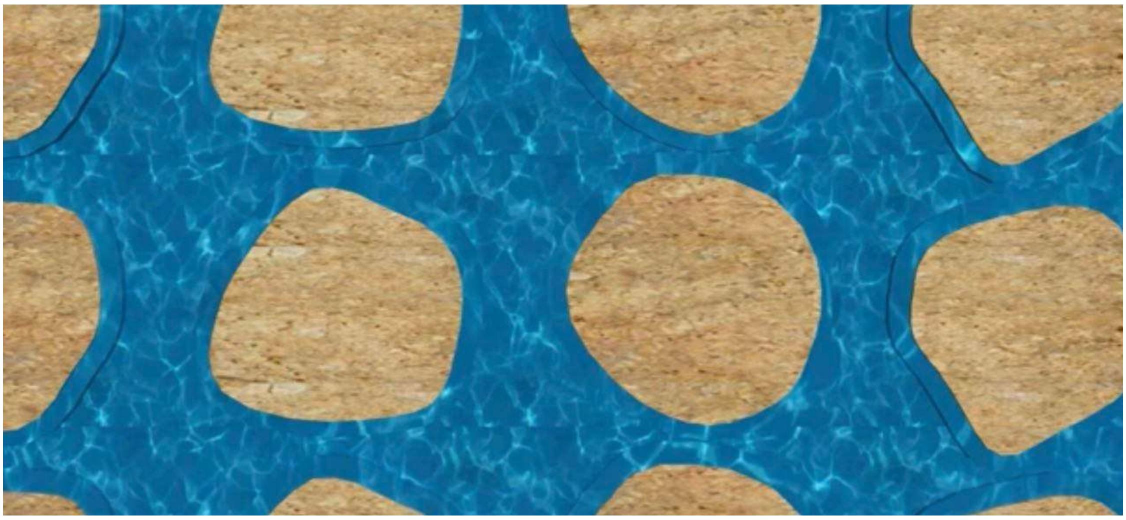
Gas – water system :

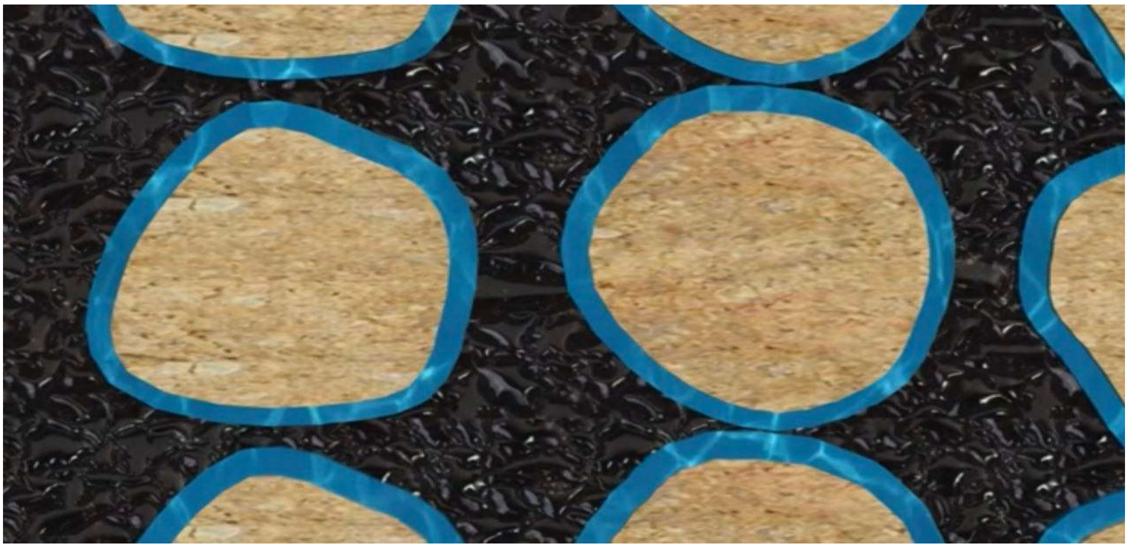
$Pc = (\frac{h}{144})\ \Delta\rho$ or:

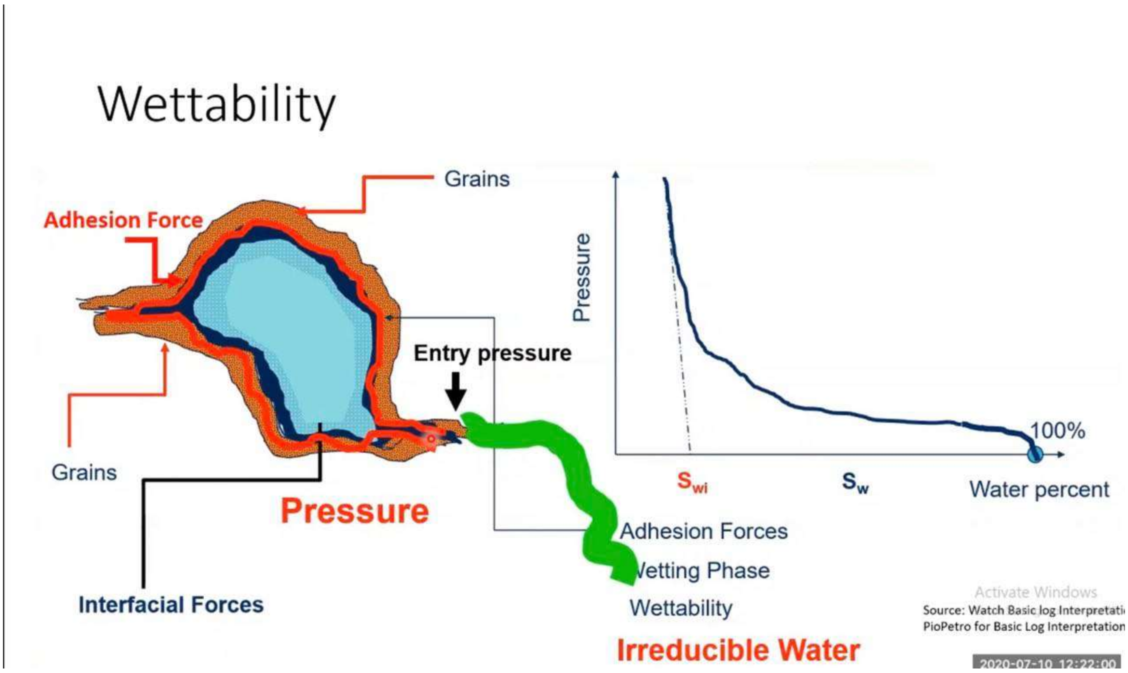
$Pc = \frac{2\ б\ gw\ (\ cos\Theta)}{r}$



The main importance of the capillary pressure is during the secondary migration.







Wettability
Grains
Adhesion Force
Entry pressure
Grains
Pressure
Interfacial Forces
Pressure
100%
S_{wi}
S_w
Water percent
Adhesion Forces
Wetting Phase
Wettability
Irreducible Water
Activate Windows
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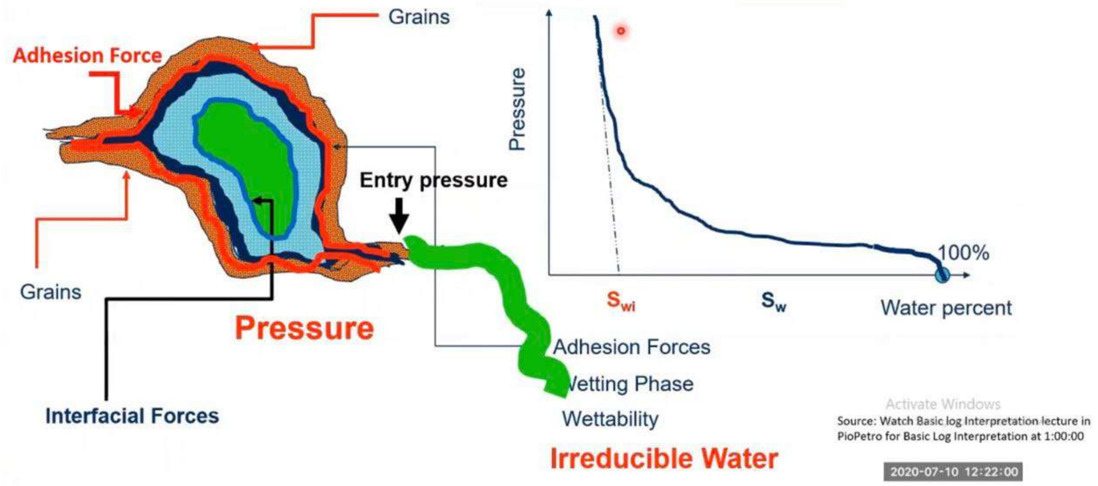
Wettability

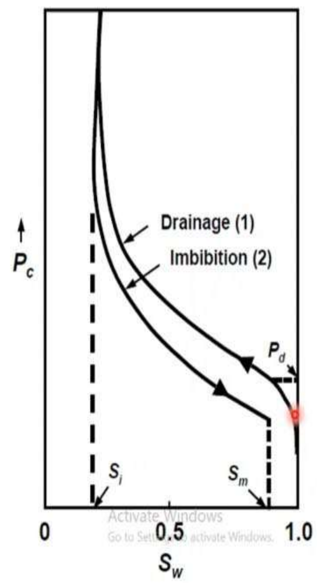


Capillary Pressure

Drainage and Imbibition Capillary Pressure Curves:

The drainage curve is always higher than the imbibition curve.

S_i = Initial or irreducible wetting phase saturation.
S_m = critical non-wetting phase saturation.
P_d = entry pressure or displacement pressure.



The entry (displacement) pressure

is defined as the pressure required to force the non-wetting fluid through an initially wetting-phase-saturated sample.

Capillary Pressure

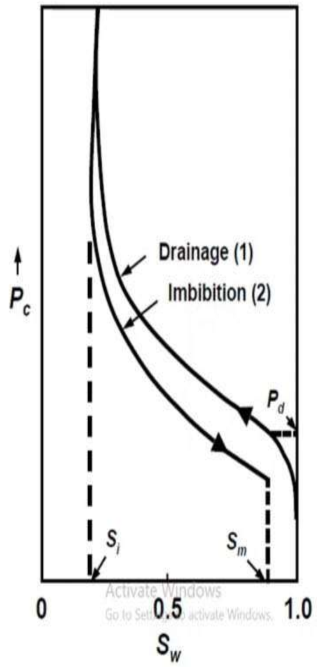
Drainage and Imbibition Capillary Pressure Curves:

Drainage Process:

- Fluid flow process in which the saturation of the non-wetting phase increases.
- Mobility of non-wetting fluid phase increases as non-wetting phase saturation increases.

Imbibition Process:

- Fluid flow process in which the saturation of the wetting phase increases and the non-wetting phase saturation decreases.
- Mobility of wetting phase increases as wetting phase saturation increases.

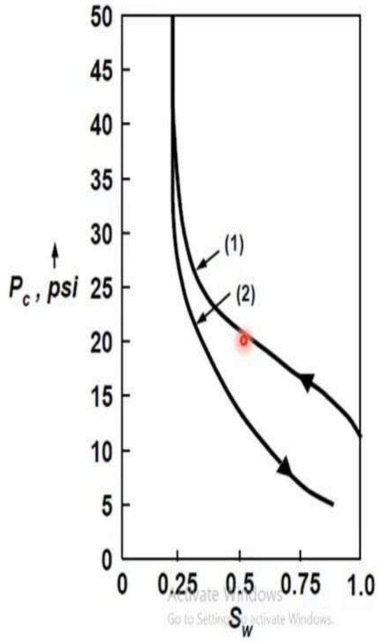


Capillary Pressure

Class Exercise

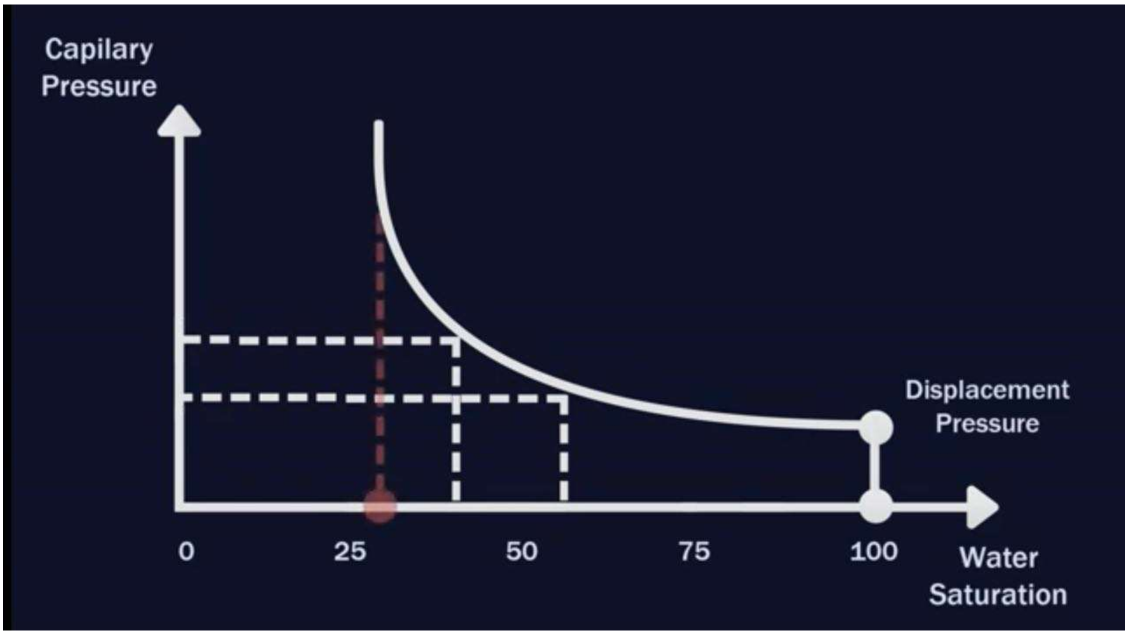
The figure is the result of core flood experiments on a water wet rock. Answer the following questions:

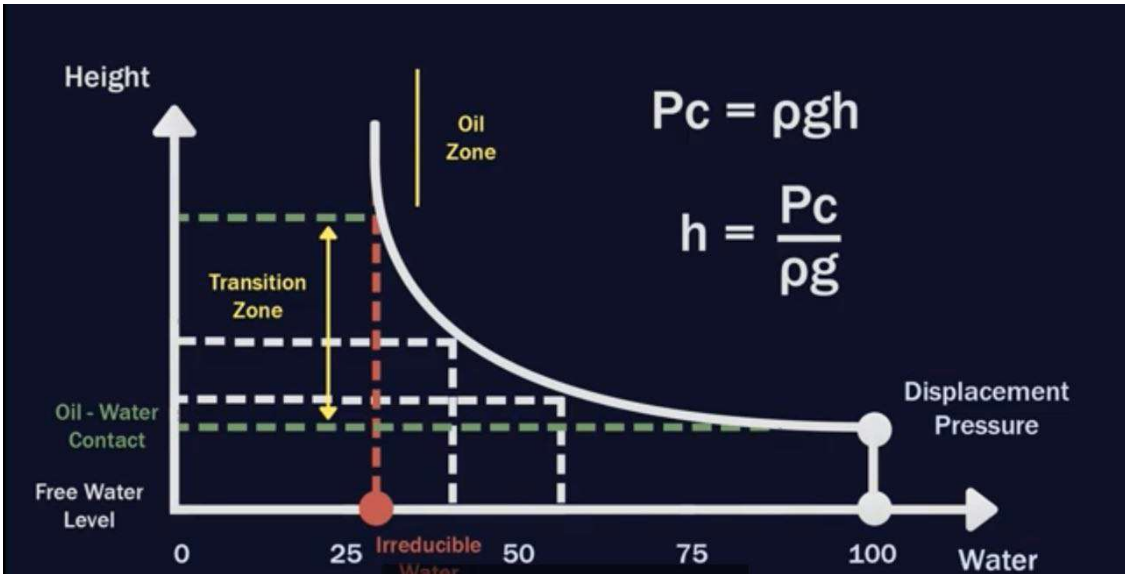
1- What process does curve 1 represent?
2- What process does curve 2 represent?
3- What is the irreducible water saturation?
4- What is the residual oil saturation?
5- What is the displacement pressure?



Solution:

1- Drainage process.
2- Imbibition process.
3- S_w = 0.25
4- S_{or} = 0.13
5- P_d = 15 psi





$$FWL = WOC + \frac{144\ Pd}{\Delta\rho} \qquad 7\text{-}5$$

Where:

Pd = displacement pressure, psi.

$\Delta\rho$ = density difference , lb/ft3

FWL= free water level , ft.

WOC= water –oil contact , ft.

Example1:

Answer to 2, 3, 4, 5, & 6 based on following information:

A core (sample of reservoir rock) at first is saturated 100 % of water then the oil is injected in it. The result of this test is as following: S_w is water saturation, k_w and k_o are effective permeability of water and oil respectively.

2. The absolute permeability for the rock is:
   a) 78.3 b) 45.1 c) 112.7 d) 35.7
3. The wettability of the rock is:
   a) water-wet
   b) oil-wet
   c) intermediate
   d) need more information.
4. The residual water saturation approximately is:
   a) 100 % b) 15 % c) 65 % d) 20 %
5. The relative permeability for oil at S_o = 55 % is:
   a) 0.74 b) 0.62 c) 0.12 d) 0.43
6. The oil will begin to flow when its saturation approximately reachs:
   a) 20 % b) 100 % c) 15 % d) 45 %

S_w (%)	k_w (mD)	k_o (mD)
100	112.7	0
85	68.3	0.4
65	32.8	31.4
45	17.2	84.2
25	2.3	102.4
15	0.1	106.3

Example2:

Calculate the capillary pressure and capillary rise in an oil water system from the following data:

Θ= 30° , ρo = 0.75 gm/cm3 , r = 10^{-4} cm , б ow = 25 dynes/cm>

Solution:

Pc = $\frac{2\,б\,ow\,(cos\Theta)}{r}$ **=** $\frac{2\,(25)\,(cos30)}{0.0001}$**= 4.33 x 10^5 dynes/cm2**

Since 1 dyne/cm2 = 1.45 x 10^{-5} psi then :

Pc = 6.28 psi

Pc = ($\frac{h}{144}$) Δρ (when ρ = lb/ft3)

To convert gm/cm3 to lb/ft3 :

6.28 = ($\frac{62.428\,h}{144}$) (ρw- ρo) (1gm/cm3 = 62.428 lb/ft3)

h= 58 ft

example3:

the reservoir capillary pressure – saturation data of the x oil reservoir is shown graphically in figure . geophysical log interpretations and core analysis establish the WOC at 5023 ft . the following additional data are available:

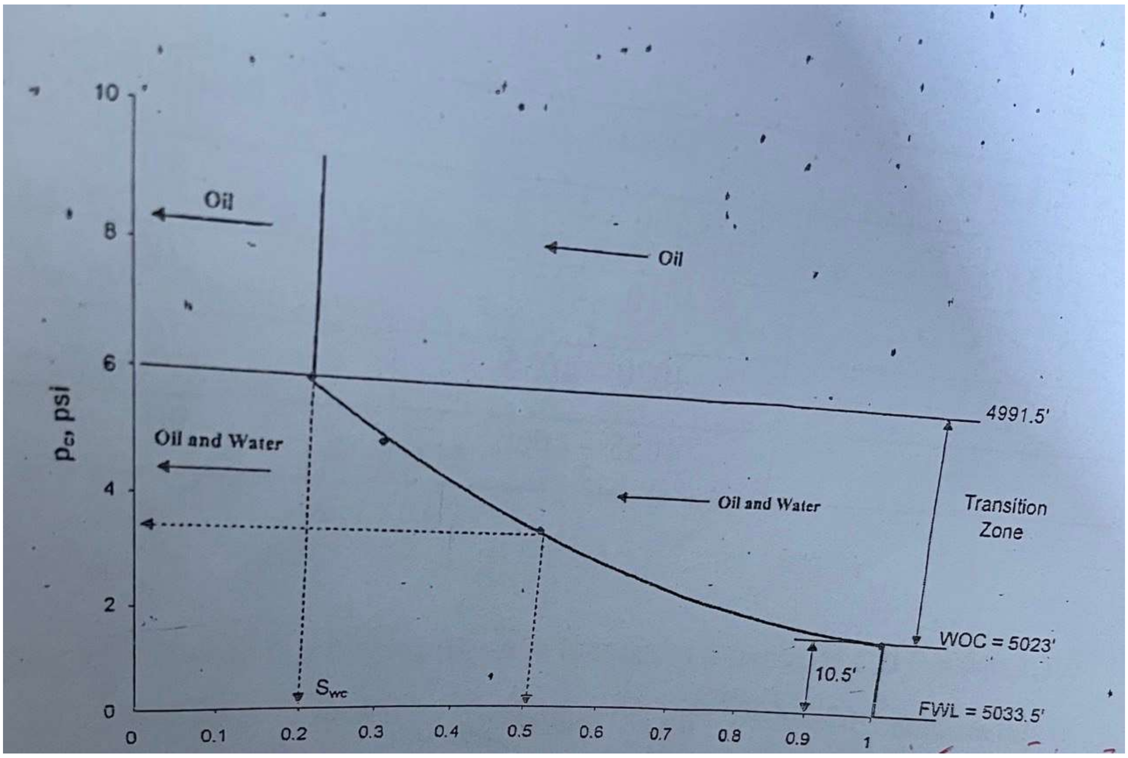
oil density= 43.5 lb/ft3

water density= 64.1 lb/ft3

interfacial tension = 50 dynes /cm

calculate:

1- Connate water saturation.
2- Depth to FWL.
3- Thickness of the transition zone
4- Depth to reach 50% water saturation.



Solution :

1- From figure : connate water saturation is 20%
2- Applying equation with a displacement pressure of 1.5 psi gives

FWL = WOC + (144 Pd)/Δρ= 5023 +(144x1.5)/ (64.1- 43.5)= 5033.5 ft

3- Thickness of transition zone:

$$\frac{144\ (6-1.5)}{(64.1-43.5)} = 31.5 \text{ ft}$$

4- Pc at 50% water saturation = 3.5 psi