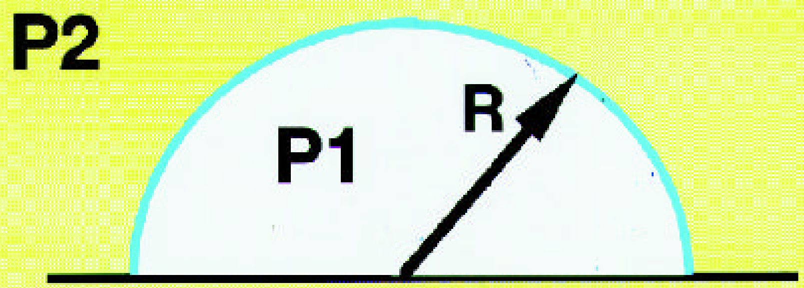
●apillarity

PETROPHYSICAL LECTURES

CAPILLARITY

CAPILLARITY IS DUE TO SURFACE TENSION



$$\Delta P = P1 - P2$$

$$\Delta P.\Pi R^2 = 2\,\Pi .R.\sigma$$

$$\rightarrow \sigma = \frac{R\,.\,\Delta P}{2}$$

Surface tension

Free Water Level (FWL)

For a very wide tube capillary rise and pressure differential will be equal to zero and the water level will be the same inside and outside the tube.

FOL (Free Oil Level)

The FOL is located at the transition of the gas bearing to the oil bearing zone (GOC)

100% Water Level

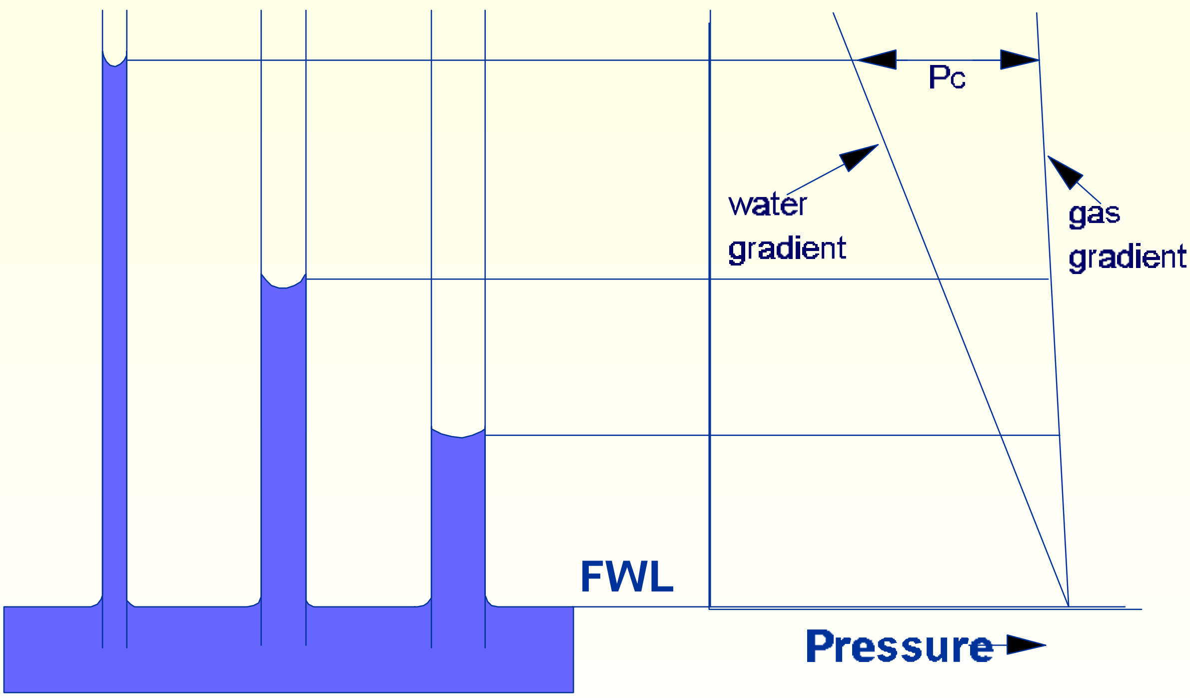
The 100% Water Level is the level where hydrocarbons start from the bottom up to occupy pore space in a water-wet reservoir.

Oil Water Contact (OWC) or Gas Water Contact (GWC)

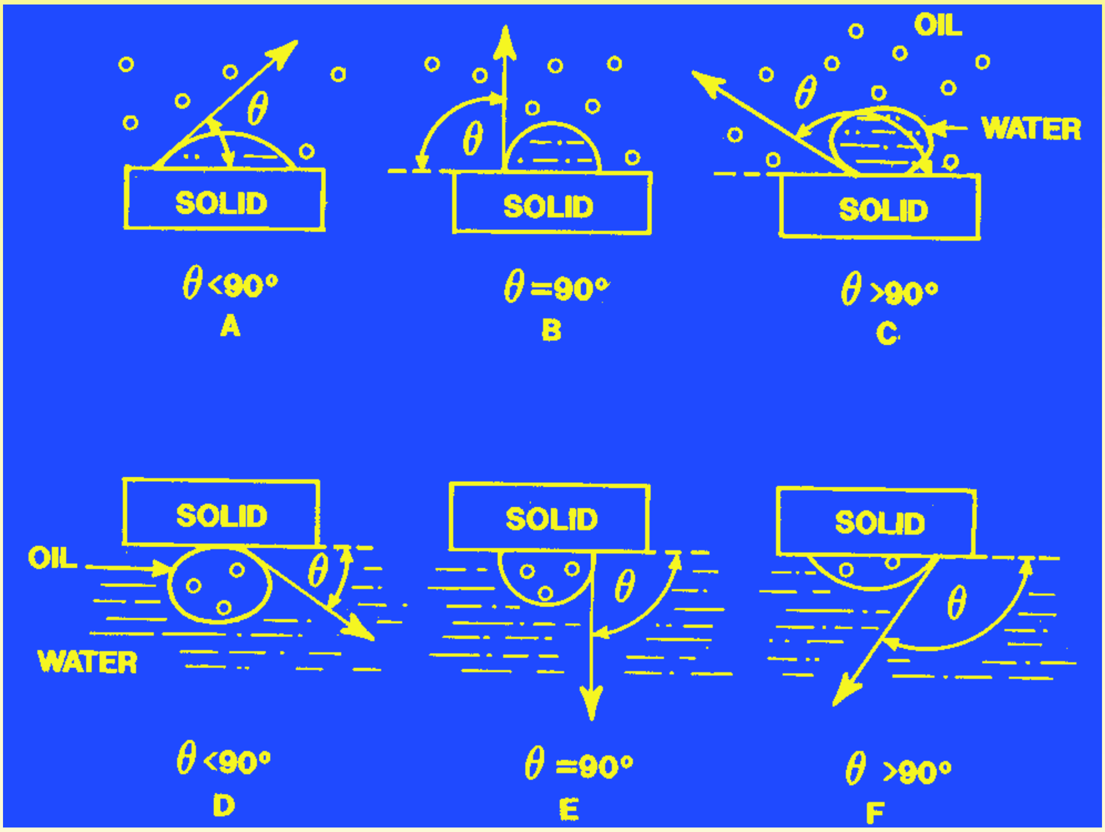
The definitions that the OWC or GWC are the levels above which water free oil and gas are present at a Sw or So of 50 %.

Connate water saturation / Irreducible water saturation

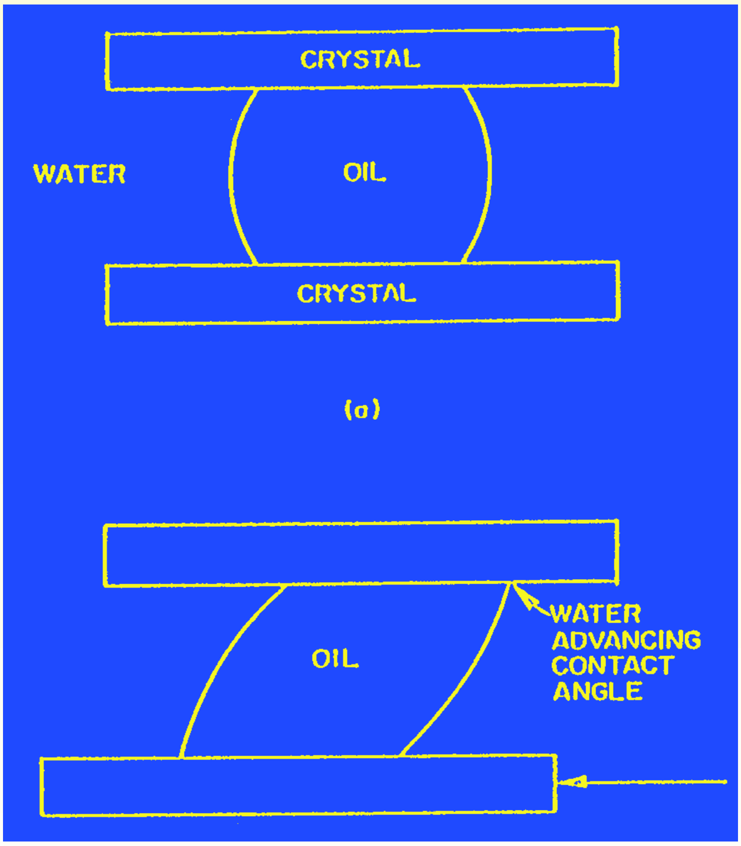
The connate water saturation refers to the smallest water saturation that can be reached in a water wet reservoir at the top of the oil column.



Capillarity — Adhesion tension and wettability

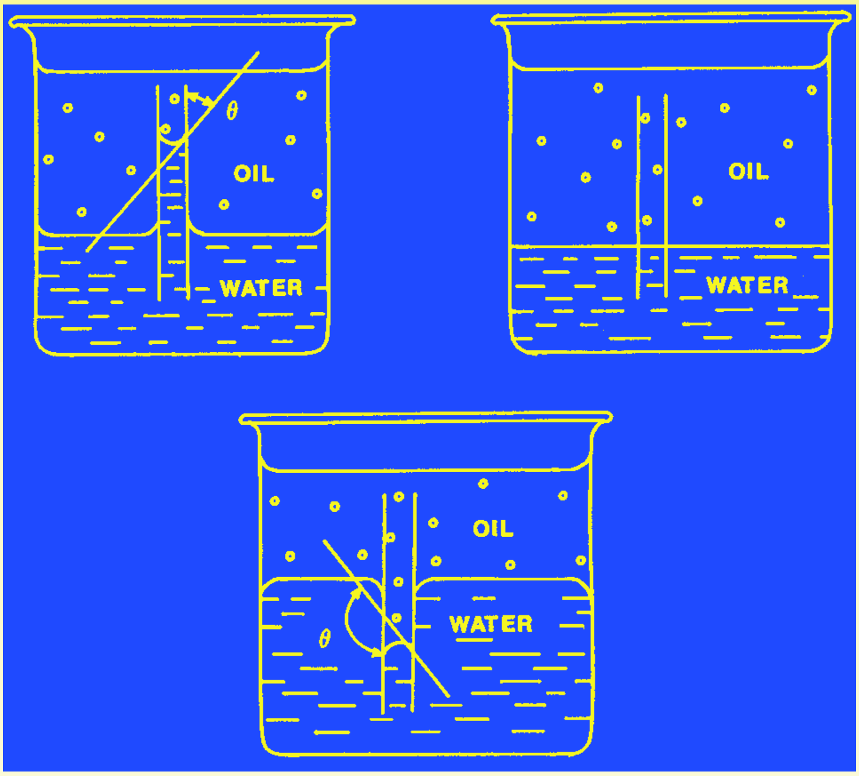


Contact angles for water-oil (a,b,c) and oil-water (d,e,f), measured through the denser phase.

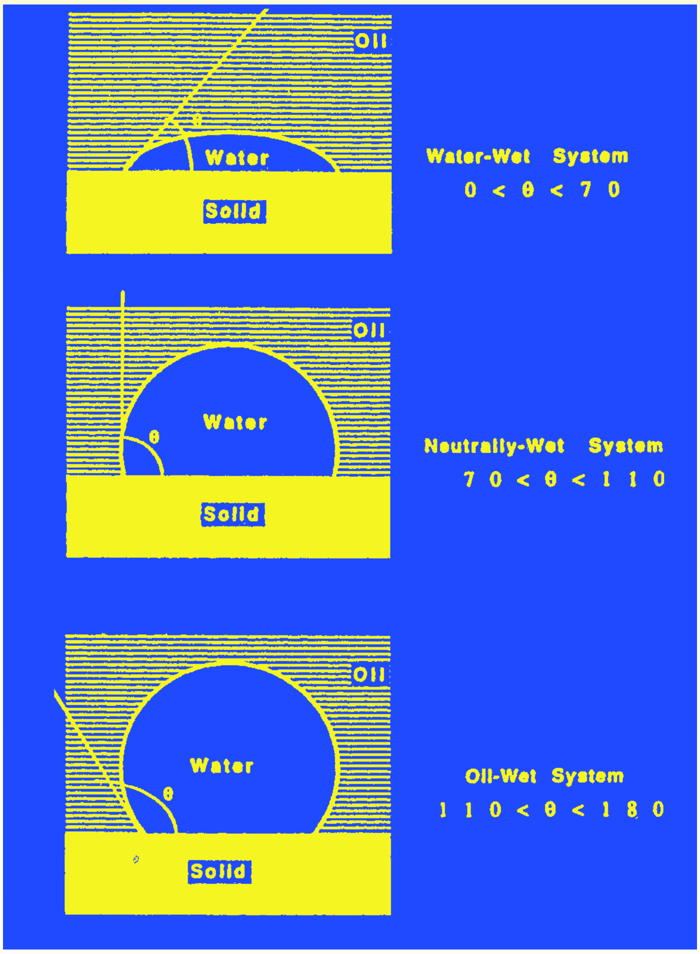


Method to measure advancing and receding contact angles

Capillarity — Adhesion tension and wettability



Three wetting conditions for water and oil in contact in a capillary, using the contact angle method.



Menisci capilaries for different wettabilities

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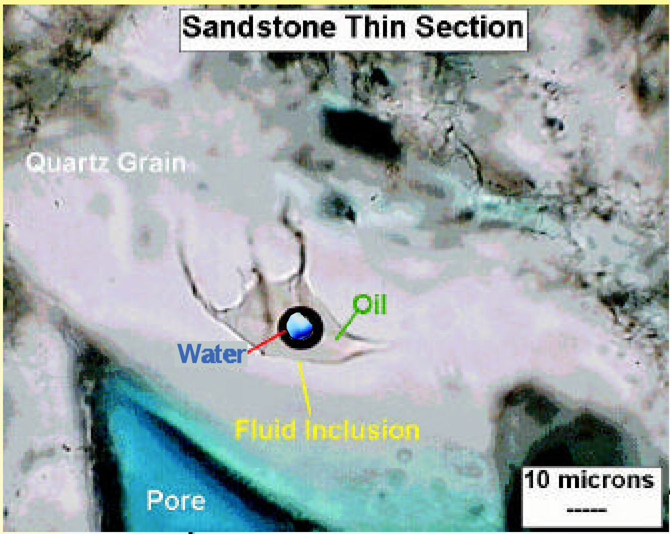
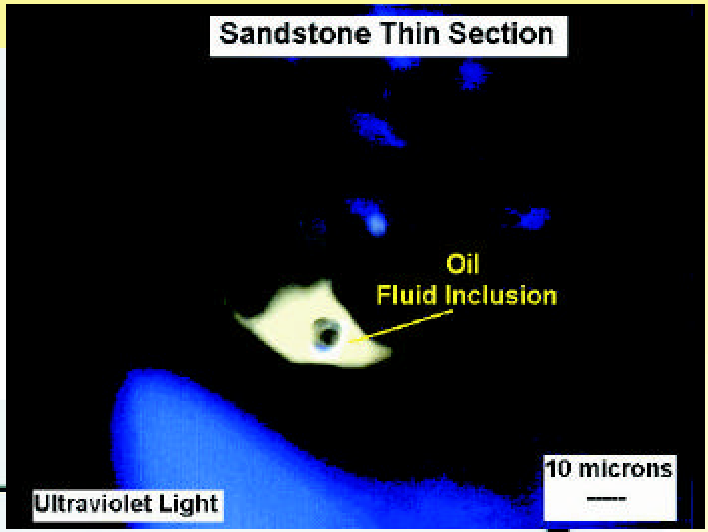
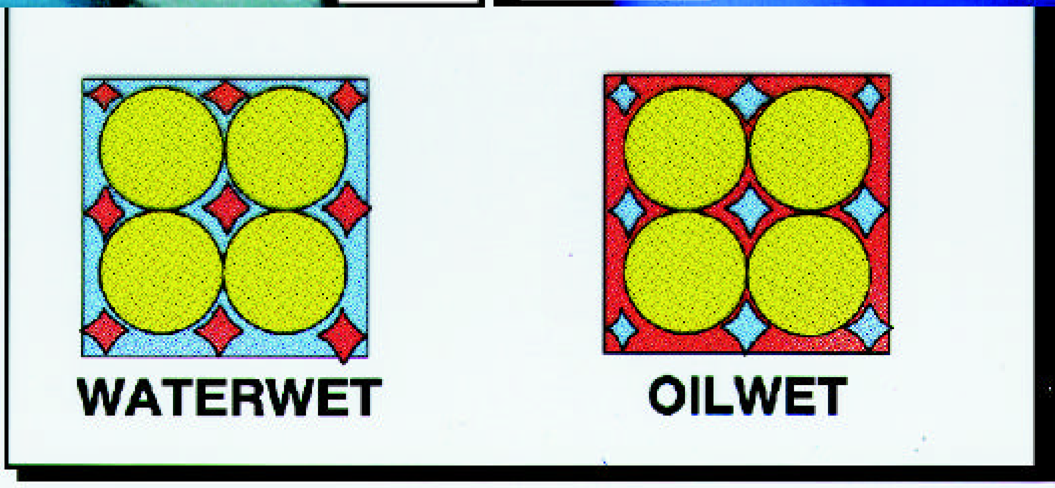
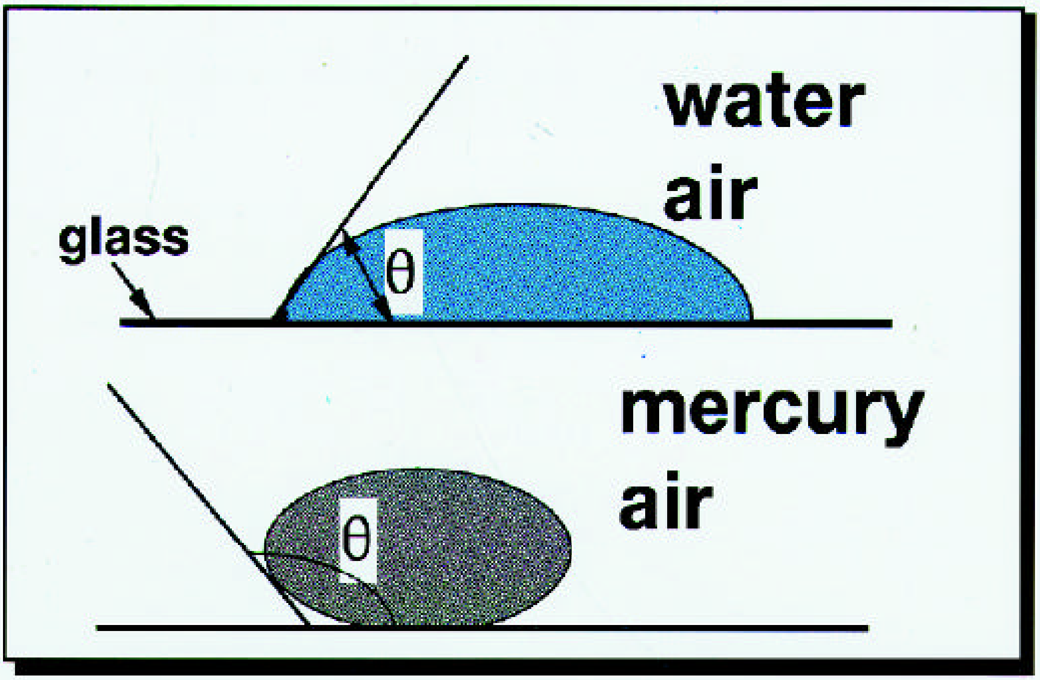

Sandstone Thin Section
Quartz Grain
Oil
Water
Fluid Inclusion
Pore
10 microns


Sandstone Thin Section
Oil
Fluid Inclusion
Ultraviolet Light
10 microns

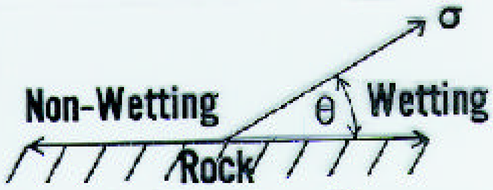

WATERWET
OILWET


water
air
glass
θ
mercury
air
θ

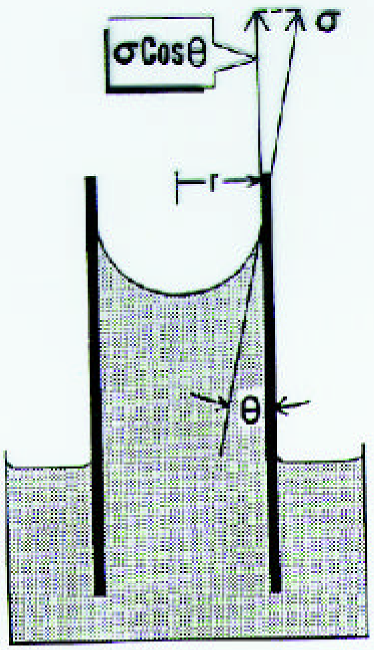
Capillarity

Capillary pressure in a tube

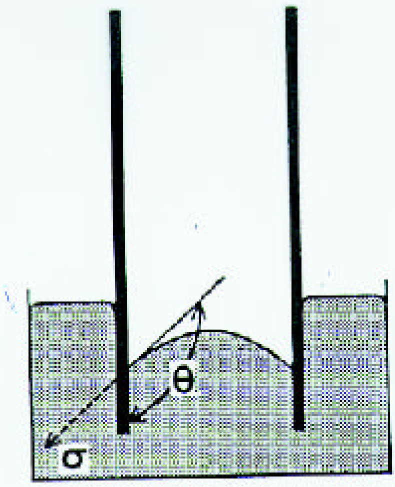
Surface Free Energy



Static Wetting Diagram
For
Liquid - Liquid System



Capillary Rise
Of
Wetting Liquid



Capillary Depression
Of
Non-Wetting Liquid

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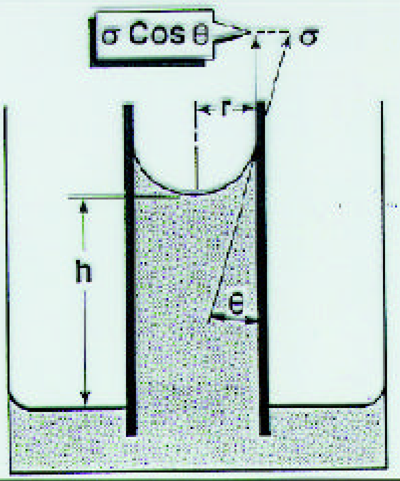
Capillary pressure in a tube

PETROPHYSICAL LECTURES

CAPILLARITY 4



FORCE DOWN = FORCE UP

$$P_c \,.\, \text{AREA} = \sigma_v \,.\, \text{RIM}$$

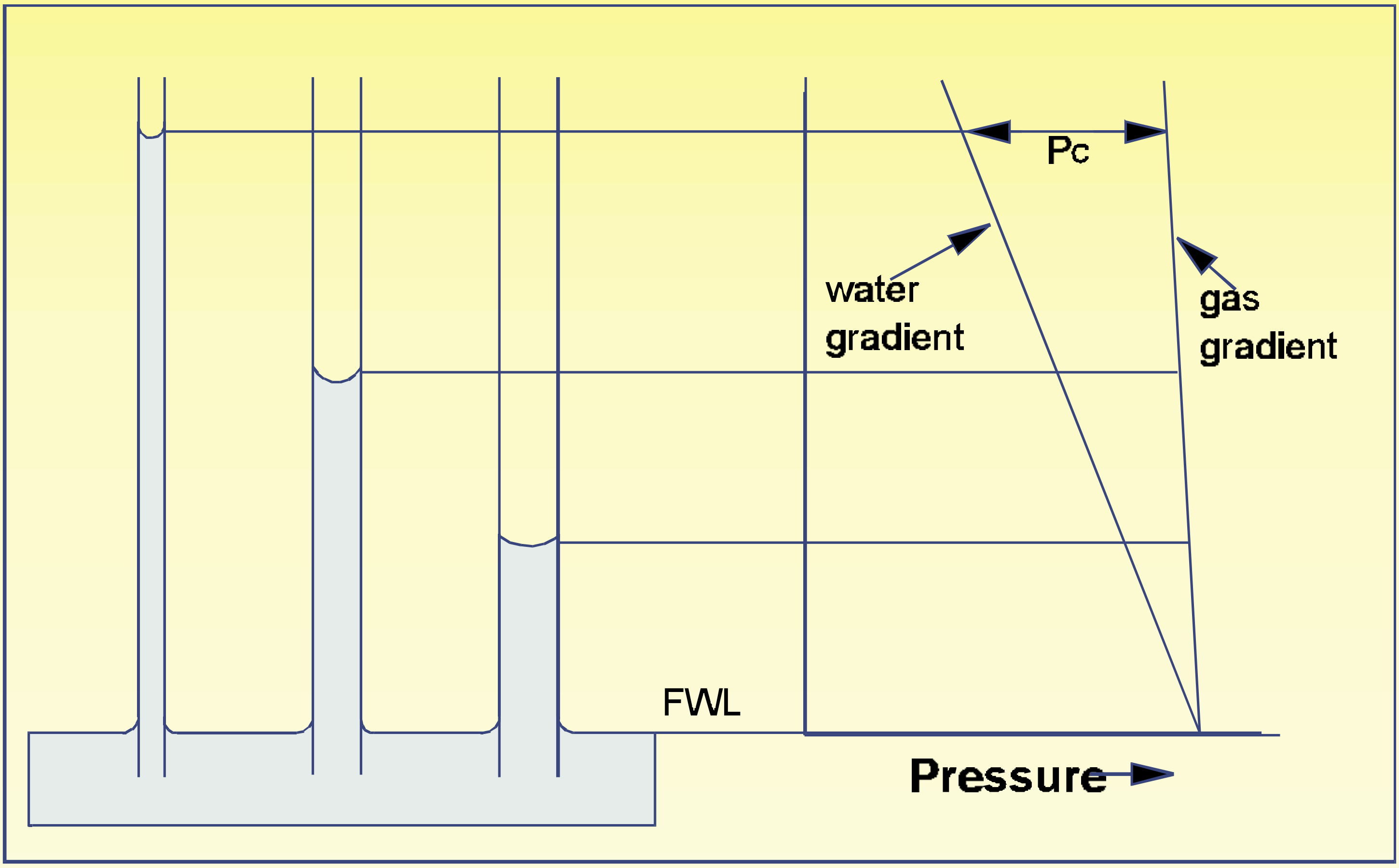
$$\Delta \rho.g.h.\,\Pi R^2 = \sigma \cos(\theta)\, 2\,\Pi R$$

$$P_c = \frac{2\,\sigma \cos(\theta)}{R} = \Delta \rho.g.h$$

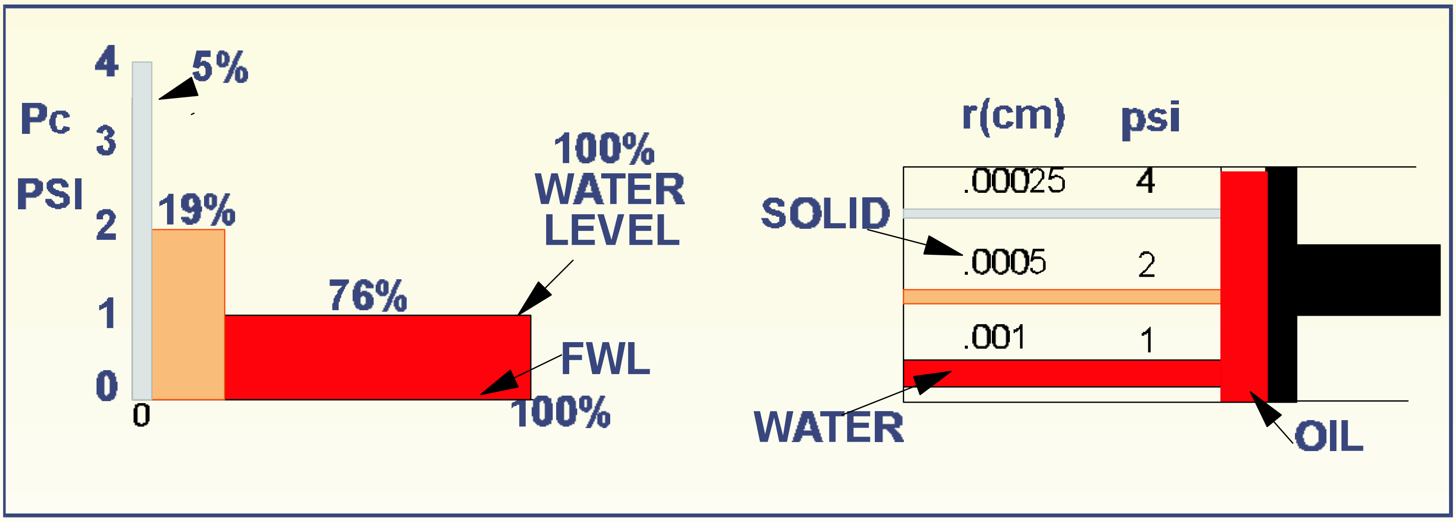
$$h = \frac{P_c}{\Delta \rho.g} = \frac{2\,\sigma \cos(\theta)}{R.\Delta \rho.g}$$

Capillarity

Capillary pressure curves



Schematic representation of capillary pressure in reservoir rock



Displacement of water by oil and corresponding capillary pressure curve

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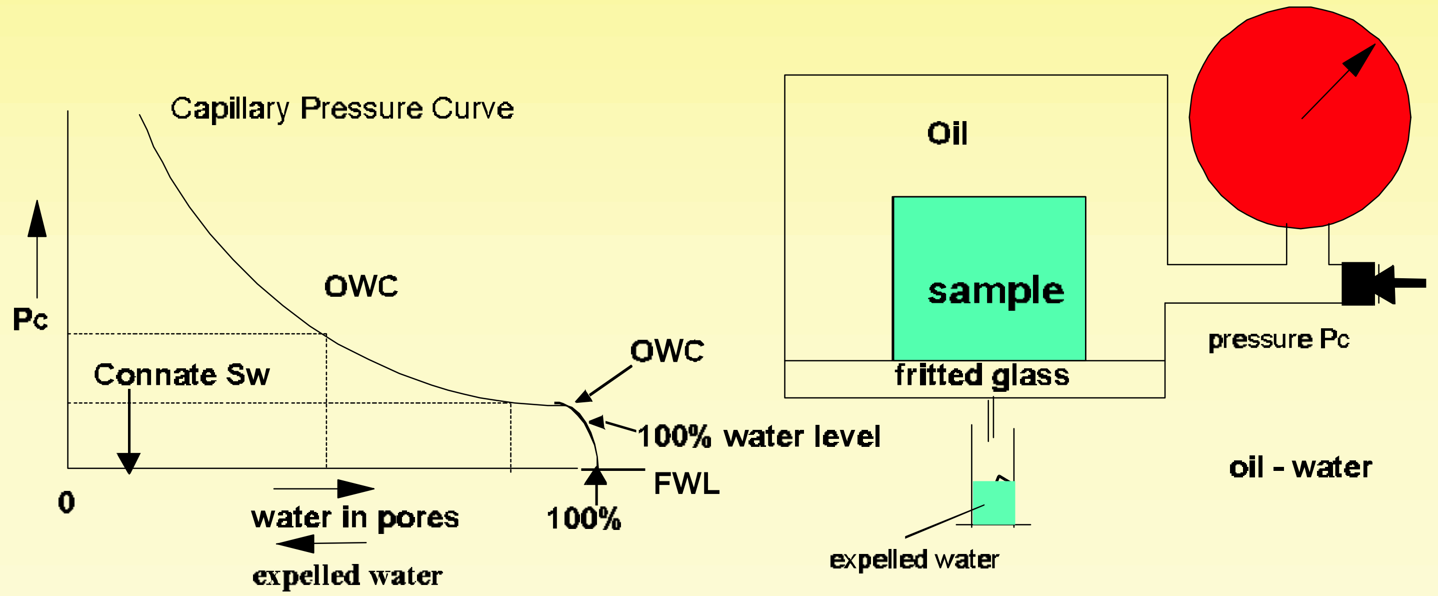
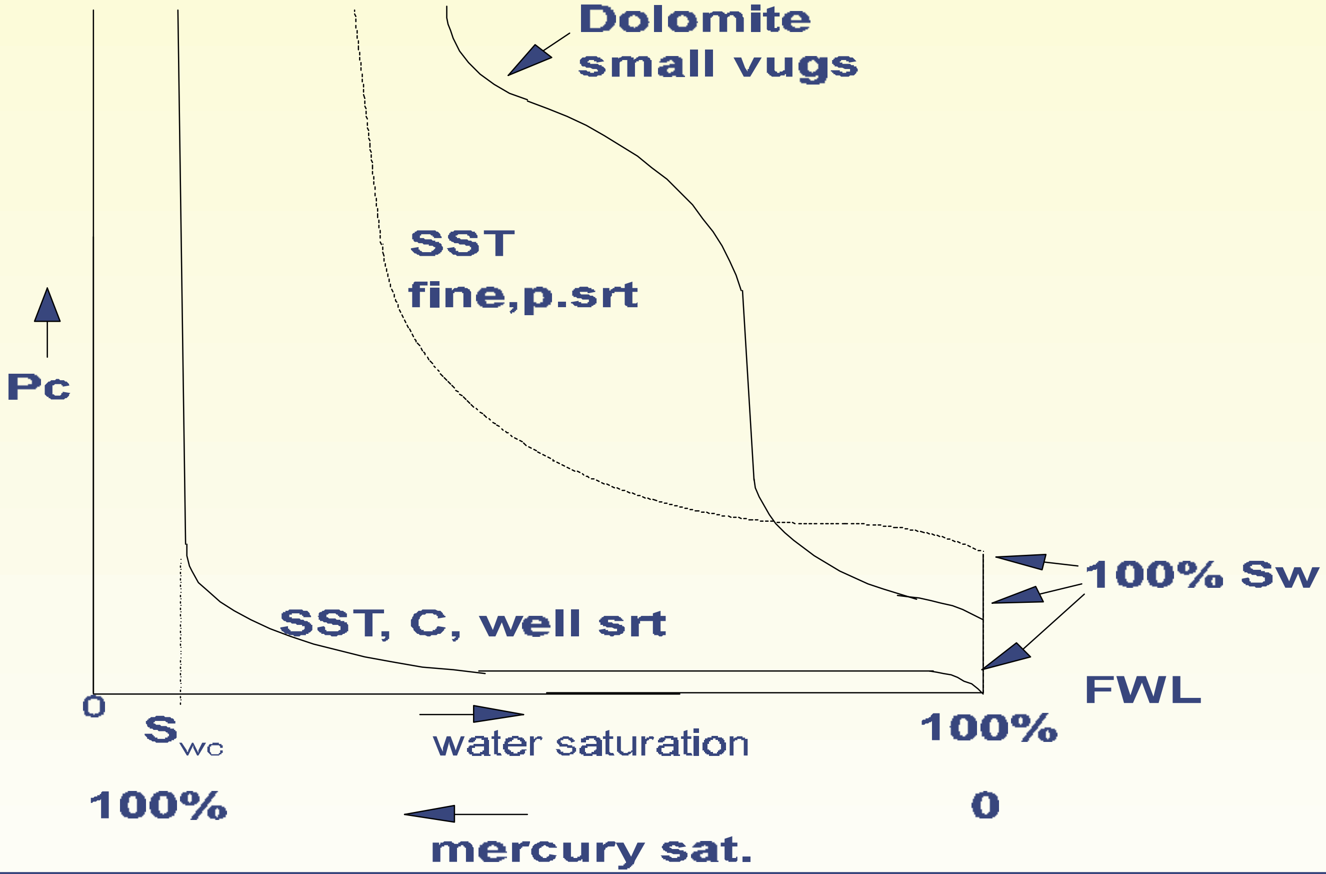
Capillary pressure curves



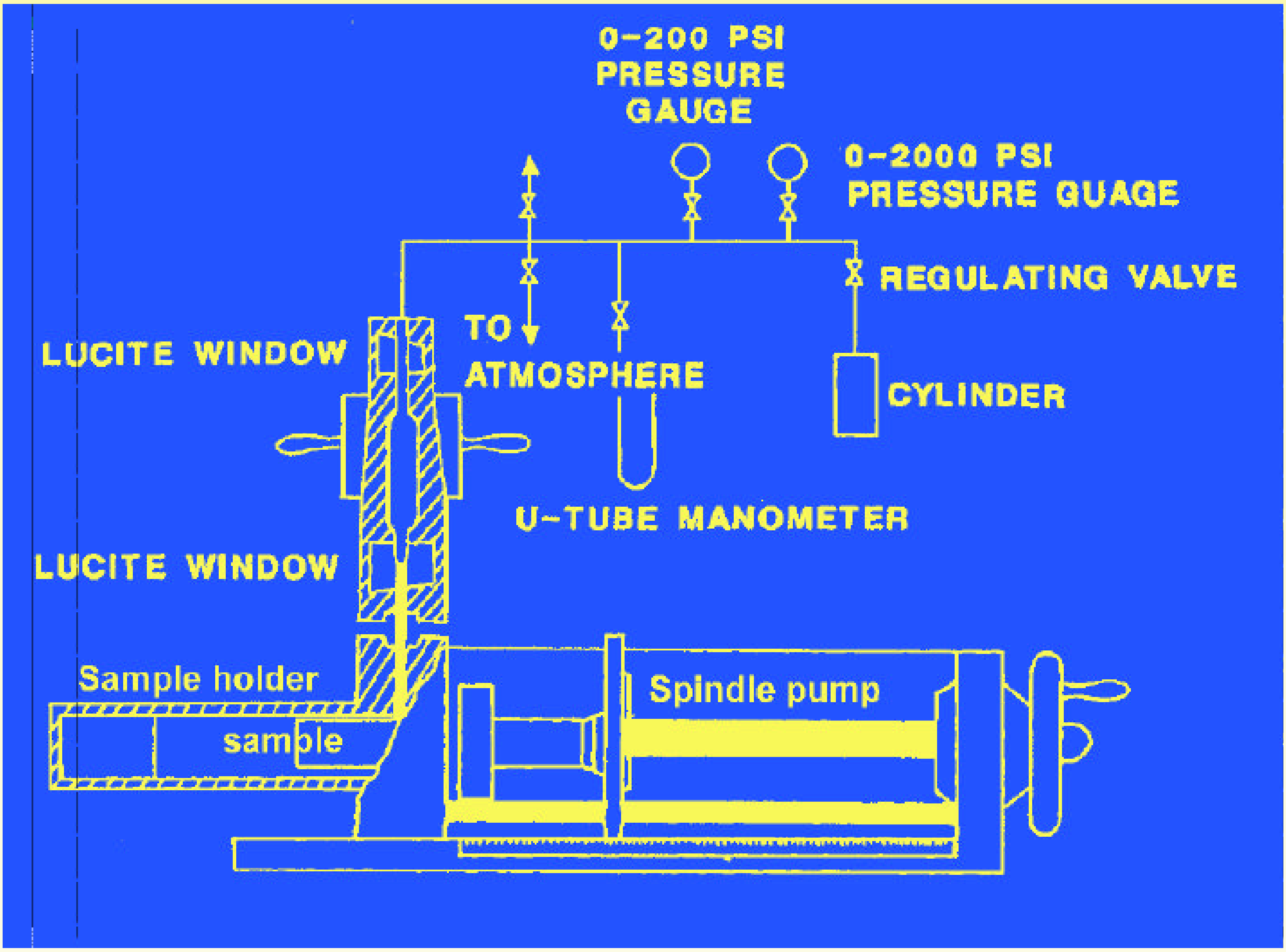
Capillary pressure curve measurement and capillary pressure curve



Capillary pressure curves examples

Methodology

Apparatus for capillary pressure curve measurements using mercury as a working fluid



The measured data are applicable for:

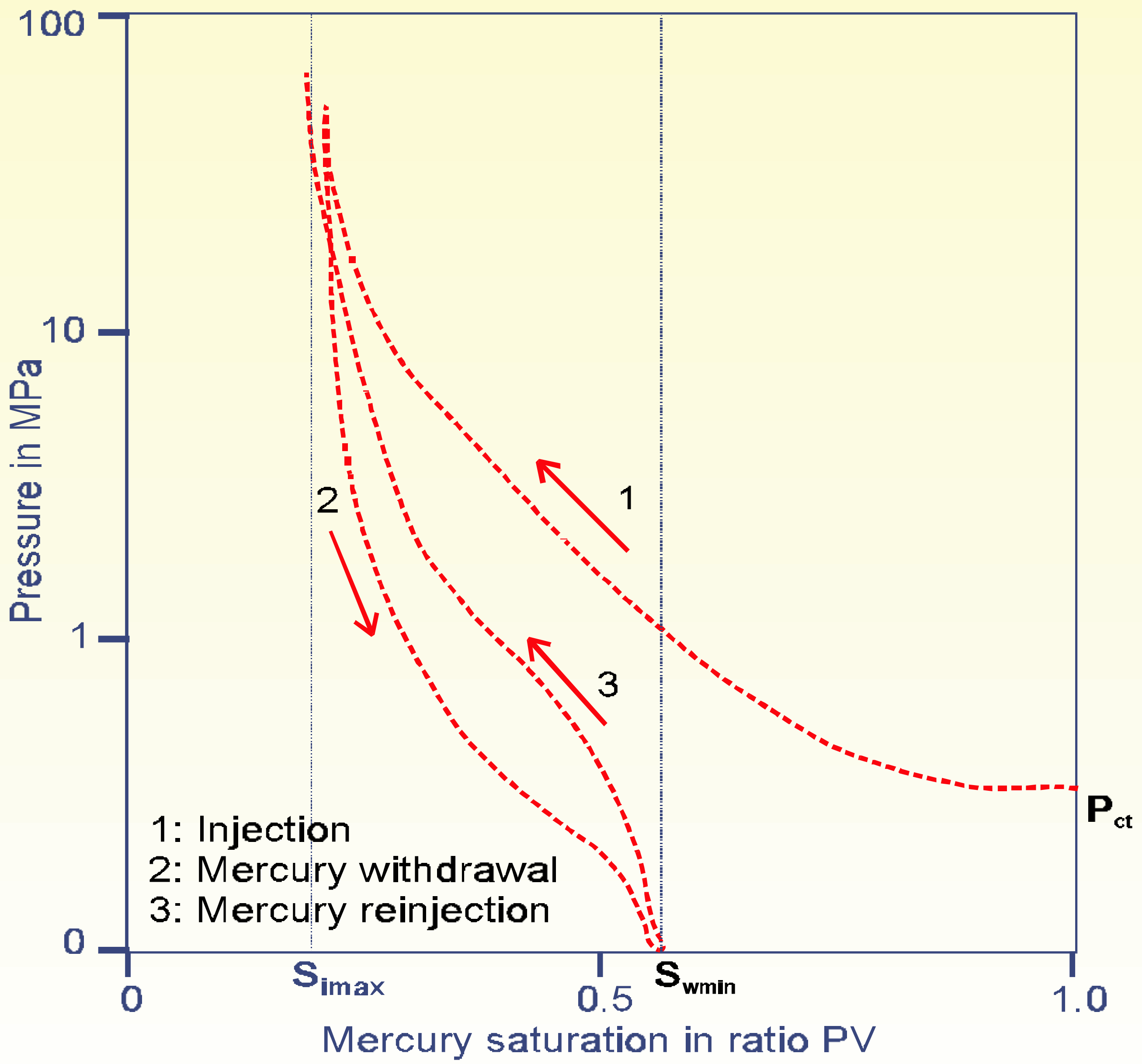
- the analysis of the response of capillary pressure curves.
- the determination of the pore size distribution.
- to gather attributes of pore geometry.

Disadvantages of the mercury injection method:

- ✓ Mercury vapour is toxic syndrome. Strict safety precautions when used.
- ✓ Mercury cannot be safely removed after injection. Thus the core is chemical waste.
- ✓ Destructive when high pore pressures have to be used on weak matrix samples

Mercury injection procedure:

- ✓ Core cleaned, dried, pore volume & permeability measured.
- ✓ Core placed in the air tight sample chamber.
- ✓ Sample chamber is evacuated, mercury injected and pressure increment recorded.
- ✓ Incremental pore volumes of injected mercury plotted versus injection pressure to get the injection capillary pressure curve
- ✓ At pressure limit mercury withdrawal of by pressure reduction. At P = 0 remaining Hg defines the Sw-min
- ✓ Third cap-curve by mercury re-injection till the maximum pressure, giving Si-max



●apillarity — From lab values to field values

Using lab-values in the reservoir,the measured air/mercury capillary pressure curves, correction for the differences in contact angles and interfacial tensions between the laboratory fluids and reservoir fluids combinations have to be made.

$$\Delta P = P_1 - P_2 = \frac{2 \cdot \gamma \cdot \cos(\theta)}{r}$$

Air and mercury filled sample:

$$P_c(Hg/air) = \frac{2.\gamma.\cos(\theta)}{r} = \frac{2 \times 480 \times 0.776}{r}$$

Oil and water filled reservoir:

$$P_c(oil/water) = \frac{2.\gamma.\cos(\theta)}{r} = \frac{2 \times 35 \times 1}{r}$$

●ombined oil - water - solid system:

$$\frac{P_c(Hg/air \text{ at surface})}{P_c(oil/water.\text{ in reservoir})} = \frac{480 \times 0.776}{35} = 10.5$$

Similarly for a gas - water - solid system

$$\frac{P_c(Hg/air \text{ at surface})}{P_c(gas/water.\text{ in reservoir})} = \frac{480 \times 0.776}{72} = 5.1$$

Interfacial tensions and contact angles of various fluid/solid systems.

System	θ	cos(θ)	γ (dyne/cm)	γ*cos(θ)
air/fresh water/solid	0	1	72	72
air/saline water/solid	0	1	83	83
oil/water/solid	0	1	35	35
kerosene/brine/solid	0 (30)	1 (0.866)	50 (48)	50 (42)
air/kerosene/solid	0	1	24	24
toluene/brine/solid	0	1	38	38
air/mercury/solid	40 for air	0.766	480	368

Note: γ is the interfacial Tension, 1 dynes/cm = 0.001 N/m or 1 mN/m

Capillarity — From lab values to field values

To convert the maximum pressure measured on a capillary pressure curve in the laboratory, into an equivalent height above the FWL for reservoir conditions.

$$h = \frac{P_c}{(\rho_{water} - \rho_{air}) \cdot g}$$

$$h = \frac{2.\gamma \,.\, \cos(\theta_{o/w})}{r.\; g.\; (\rho_{water} - \rho_{oil})}$$

$$h = \frac{\gamma_{res} \,.\, \cos(\theta)_{res} \,.\, P_c(\max.lab).C}{\gamma_{lab} \,.\, \cos(\theta)_{.lab} \,.\, g.\Delta\rho}$$

γ_{res} :IFT or inter facial tension of the fluids/solid of the reservoir in mN/m

θ_{res} : contact angle fluid/solid reservoir in degrees

γ : IFT of the fluids/solid of the laboratory in mN/m

θ : Contact angle fluids/solid laboratory in degrees

$P_{c(max.lab)}$: Maximum pressure measured in the laboratory in bar

: Gravity acceleration in 9.81 m/sec^2

$\Delta\rho$: Density difference reservoir fluids in kg/m^3

C : Constant : 100,000 when using the above units

Input values for laboratory cap. curves used

LABORATORY	γ	θ	$\cos(\theta)$	$\gamma*\cos\theta$	P_{cmax} (bar)
air/brine	72	0	1	72	12
kerosene/brine	50	0	1	50	1.4
kerosene/brine	48	30	0.866	42	1.4
air/kerosene	24	0	1	24	5
mercury/air	480	140	0.766	368	4000

CHAPTER 4: EXERCISES

Question 1:

In Scheveningen a new giant sea aquarium is placed on a foot of Bentheimer sandstone. This porous sandstone is used to trap water during leakage. Unfortunately the aquarium burst and lost much water in de sandstone. The centre part is fully saturated with water and the question is: will the floor of the Scheveningen pier give away or not? or what is the porosity of the sandstone?

Dry core weight: 423 gram, density of the water: 1.05 $g.cm^{-3}$ and saturated weight: 461 gram.

The sample dimensions are: 110 mm length and 38 mm diameter.

CHAPTER 4: EXERCISES

Question 2:

In Babylon American, Chinese, German, Dutch and African reservoir and hydrological engineers have to cooperate in the water and energy supply for the building of a big tower. Both absolute units and hybrid units are used to define permeability. In the end a conversion table is made to compare values. Fill the table with cgs-units (centimeter, gram, seconds), SI-units (m,kg,s), Darcy units, oilfield units and hydrological units.

			Absolute units			Hybrid units	
Parameter	Symbol	Dimension	SI	cgs	hydrology	Darcy	oilfield
Length	I	L	m	cm			ft
Mass	m	M	kg	g			lb
Time	t	T					hr
Velocity	v	L/T					ft/sec
Rate	Q	L^3/T					stb/d (liquid) Mscf/d (gas)
Pressure	P	$(ML/T^2)/L^2$	N/m^2	$dyne/cm^2$		atm	psia
Density	ρ	M/L^3					lb/cu.ft
Viscosity	η	M/LT				cp	cp
Permeability	k	L^2				Darcy	mD ($10^{-15} m^2$)

CHAPTER 4: EXERCISES

Question 3:

Good old Kozeny had problem with some ideas about grain surfaces. He did have a uniform sandstone with a permeability of 480 mD and a porosity of 17 %. He wanted to know:

- The average pore throat radius

- The surface specific areas of the pores S_{Vp} and grains S_{Vgr}.

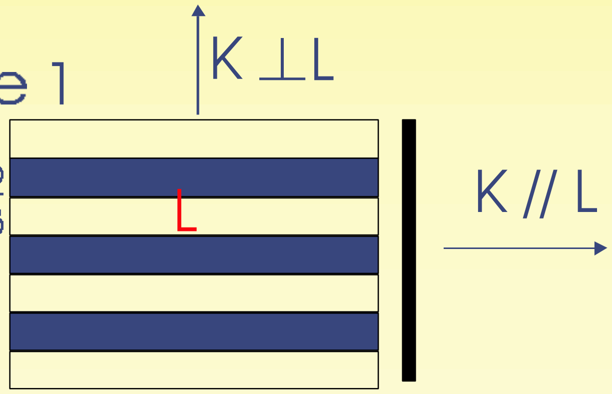
He assumed that the flow channels were tubes. Use the equations 4.15 and 4.16 to solve this problem.

Question 4:

Compare the electrical resistivity of a body with the fluid resistivity when zones in a body do have different permeabilities or resistivities:

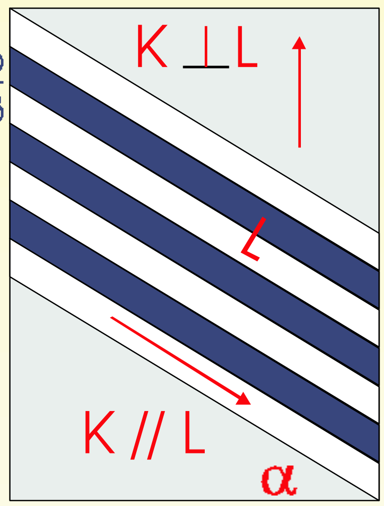
Case 1

K1, d1
K2, d2
K3, d3
etc.



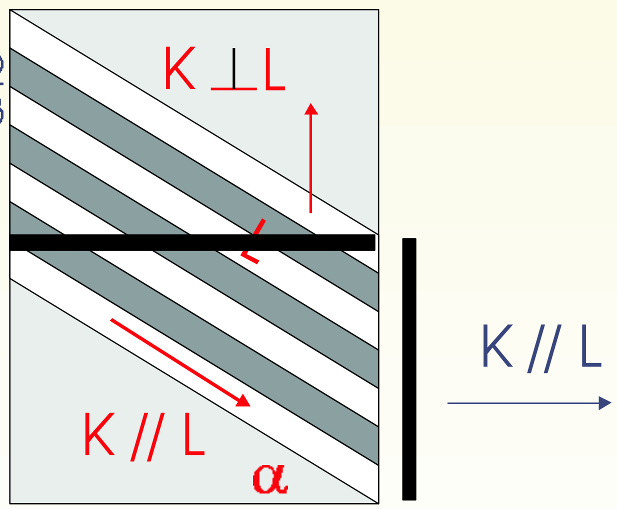
Case 2

K1, d1
K2, d2
K3, d3
etc.



Case 3

K1, d1
K2, d2
K3, d3
etc.



Question 5:

From acertain reservoir is known that it is anoil / water / solid water wet system;
The values from the laboratory are: r = 10μm, ρ_{water}= 1.0, and ρ_{oil}= 0.7 g/cm^3 (10^3.kg/m^3)

The boss wants to know:

- the capillary pressure, P_c , and
- the capillary rise, h

Use table 4.6 to solve your problems.

Question 6:

From an oil reservoir the following parameters are known:

- IFT oil = 26 mN/m, with contact angle zero.
- Density difference of the brine/oil = 200 kg/m^3
- The laboratory measured a mercury/air capillary pressure curve with a maximum pressure of 100 bar.

use equation 4.37 and table 4.7 to solve your problems; the height of the free water level.

Question 7

In Turkey a new small oil reservoir was detected in a slowly dipping and fractured layer. The part that reached the surface contained an aquifer filled with water from the mountains. Both the gouvernement and the oil company wanted to know the reservoir permeabilities.

The gouvernement uses the conventional system (D) and the reservoir engineers use the units from the american oil industry (mD). Calculate both values with different units.

Lab values:

- Cylindrical core: Length 100 mm, diameter 40 mm.
- Fluid viscosity: 2.5 cp
- Flow rate: 0.021 l/min
- Pressure drop: 3.4 atm