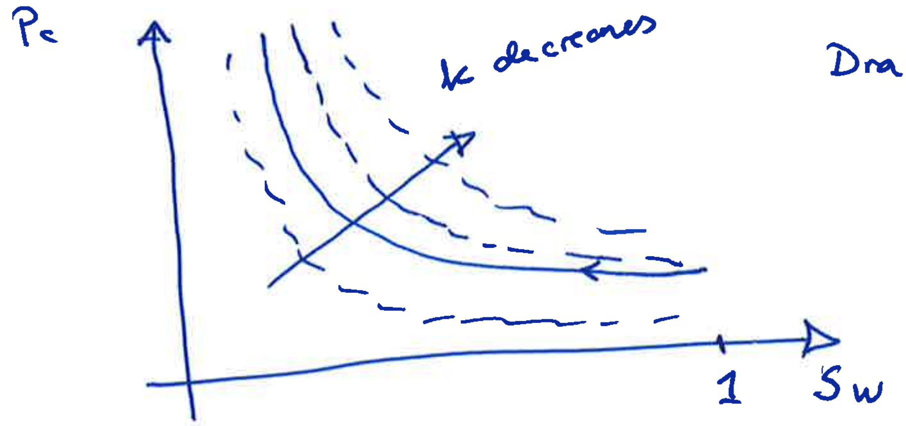
Capillary Pressure Curve



Drainage

$$P_c = P_o - P_w$$

1 tube   o (w / r)   entry pressure $P_c = \dfrac{2\sigma_{ow}\cos\theta}{r}$

J - function ,

- practical tool to scale the capillary pressure curve for rocks within the same lithology

$$P_c = P_c(S_w) \; , \quad k = \frac{\varphi r^2}{8} \; , \quad P_c = \frac{2\sigma_{ow}\cos\theta}{r}$$

$$r = \sqrt{8}\sqrt{\frac{k}{\varphi}} \Rightarrow P_c = \frac{2\sigma_{ow}\cos\theta}{\sqrt{8}\sqrt{k/\varphi}}$$

for a single tube $\qquad P_c = \dfrac{\sigma_{ow}\cos\theta}{\sqrt{k/\varphi}} \dfrac{1}{\sqrt{2}}$

$$P_c = \frac{\sigma_{ow}\cos\theta}{\sqrt{k/\varphi}} J(S_w)$$

Leveretts J-function

$$J(S_w) = \left[\frac{\sqrt{k/\varphi}\, P_c}{\sigma_{ow}\cos\theta}\right]^{lab}$$

Example

if we use air/water in the lab

$\sigma_{awg} = 70\,mN/m$ to measure P_c

~~What~~ how would be in the case

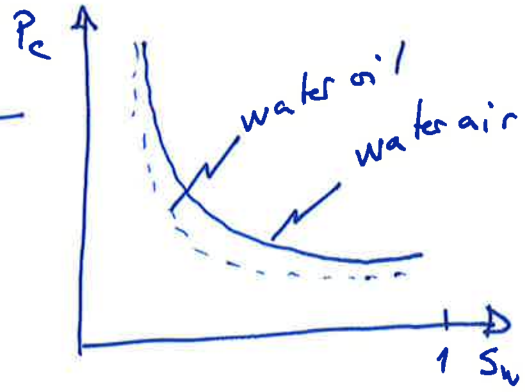
of oil and water?

$$J(S_w)^{water/air} = J(S_w)^{water/oil}$$

$$\left[\frac{\sqrt{k/\varphi}\,P_c}{\sigma_{wg}\cos\theta}\right]^{water/air} = \left[\frac{\sqrt{k/\varphi}\,P_c}{\sigma_{ow}\cos\theta}\right]^{water/oil}$$

$$\frac{P_c^{water/air}}{\sigma_{wg}} = \frac{P_c^{water/oil}}{\sigma_{ow}}$$

$$P_c^{water/oil} = \frac{\sigma_{ow}}{\sigma_{wg}} P_c^{water/air}$$



$\sigma_{ow} = 25\,mN/m < \sigma_{wg}$

e) We will consider the J-function defined in the following way:

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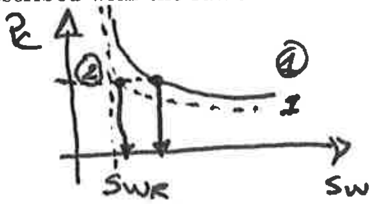
$$J(S_w) = \frac{\sqrt{K/\phi}}{\sigma \cos\theta} p_c(S_w)\,.$$

$$P_c = \frac{\sigma \cos\theta \, J}{\sqrt{K/\varphi}}$$

$P_c = \Delta\rho g h$ height above FWL

$h = \frac{P_c}{\Delta \rho g}$

In the following we will put $\cos\theta = 1$. Assume that we have a porous medium that varies in permeability within the same lithology. We divide this variation in two groups, one with low permeability 200 mD (group 1), and one with a high permeability 500 mD (group 2). Assume that they have the same porosity. Group 1 and 2 can be described with the same J-function, decide if the following statements are true or false:



Yes i) J(S_w) (group 1) = J(S_w) (group 2)

Yes ii) $p_c(S_w)$ (group 1) > $p_c(S_w)$ (group 2)

No iii) Residual saturation is larger for the low permeable group

Yes iv) Entry pressure is lower for the high permeable rock

No v) For a given height over the free water level, the water saturation is the same for the two groups

The J-function for the two groups is given in Table 1. Use $\theta = 0$, σ_{ow}=30 mN/m, $\phi = 0.30$, $\rho_w = 1050$ kg/m^3, ρ_o=850 kg/m^3.

f) From Table 1, find the water saturation as a function of height over the free water level(p_o=p_w) for the low permeable and high permeable rock. That is, make a table with one column with the water saturation and corresponding columns for the height over the free water level for the low and high permeable rock.(Assume that 1D $\simeq$ 1(μm)^2)

Table 1: J function

S_w	$J(S_w)$
1.000	0.00
0.950	0.22
0.900	0.31
0.750	0.55
0.600	1.02
0.450	1.66
0.300	2.84
0.250	3.80
0.235	4.23
0.235	5.29

$P_c = \Delta\rho g h$

In the following we will take a closer look at an oil reservoir. We will define the following volumes:

Reservoir		Surface
ΔV_g^R	$\longrightarrow$	$\Delta V_{g,g}^S + \Delta V_{o,g}^S$
ΔV_o^R	$\longrightarrow$	$\Delta V_{o,o}^S + \Delta V_{g,o}^S$.

On the left hand side there is a reservoir volume of gas (ΔV_g^R) and oil (ΔV_o^R). When one unit of oil is taken up to surface conditions, there is produced a volume of oil ($\Delta V_{o,o}^S$) and a volume of gas originally dissolved in the oil ($\Delta V_{g,o}^S$), accordingly for the gas phase. We will ignore the possibility for dissolved oil in the gas phase, i.e. $\Delta V_{o,g}^S = 0$.

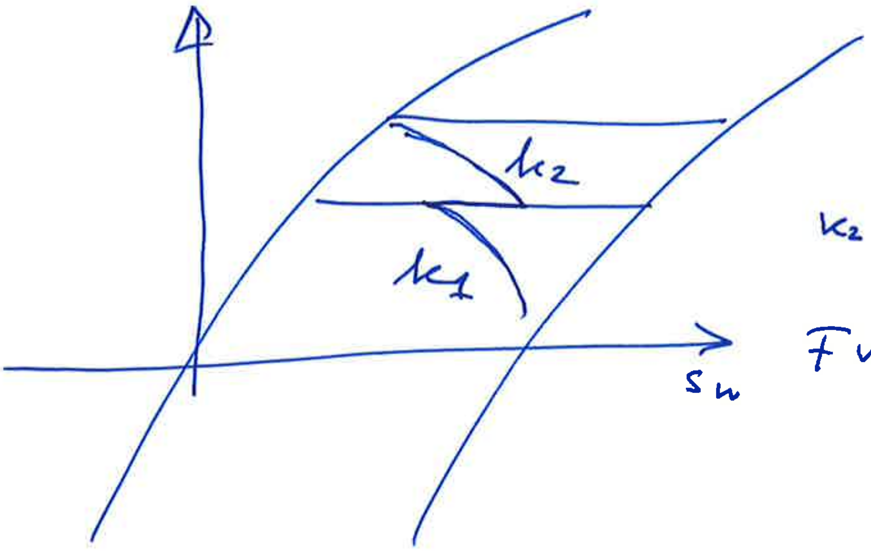
g) Define the volume factors B_o, B_g, dissolved gas oil ratio R_s and total produced gas oil ratio R_p. If the pressure is larger than the bubble point pressure, show that $R_p = R_s$.

The equations for material balance is:

$$F \;= N(E_o + m\,E_g + E_c) + W_e\,B_w\,. \tag{1}$$

where:

$F \;= N_p[B_o + (R_p - R_s)B_g] + W_p B_w$



$k_2 < k_1$

FWL

Darcy law single phase

$$q = \frac{k A}{\mu} \frac{\Delta P}{L}$$

absolute permeability
rock property

2-phase Darcy law:

$$q_w = \frac{k_w \cdot A}{\mu_w} \frac{\Delta P_w}{L}$$

$$P_o - P_w = P_c(S_w)$$

$$q_o = \frac{k_o A}{\mu_o} \frac{\Delta P_o}{L}$$

relative permeabilities: $k_{r,w} = \dfrac{k_w}{k}$

$$k_{r,o} = \frac{k_o}{k}$$

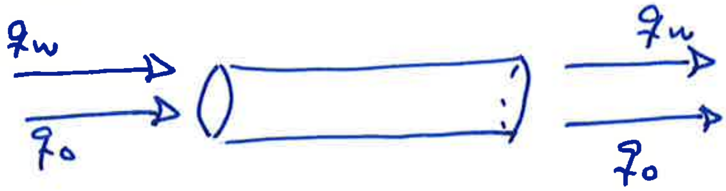
$$q_i = \frac{k_{r,i} K A}{\mu_i} \frac{\Delta P_i}{L}$$

- relative permeabilities are a function of saturation

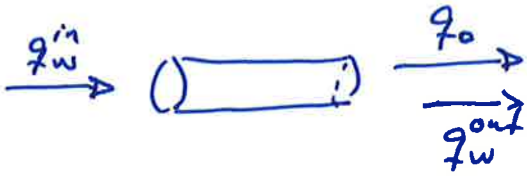
$k_{r,i} \in [0, 1]$ $\longrightarrow$ measure experimentally

Measure rel perm

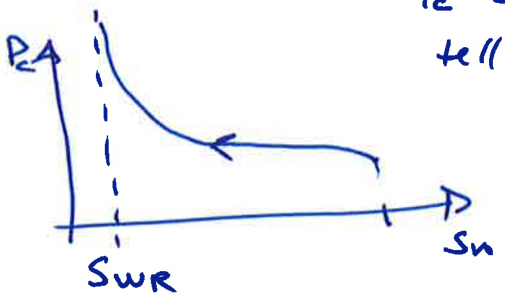
① Steady state



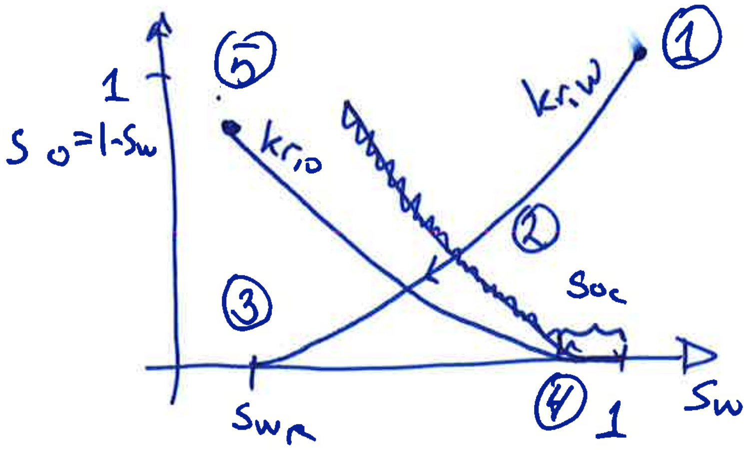
② unsteady state



① Drainage



P_c-curve <u>**does not**</u> tell about the time it takes to drain the core



① $k_{rw} = 1$ $\quad S_w = 1$
($k_{ro} = 0$)

② when oil enters the water rel. perm drops

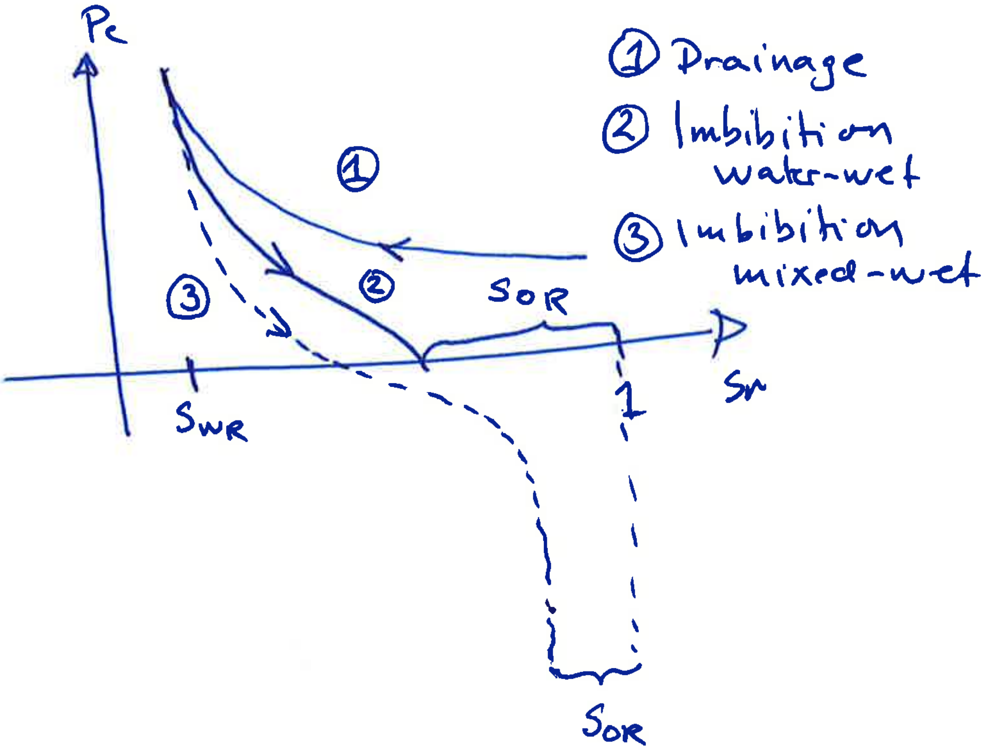
③ $k_{rw} = 0$ $\quad S_w = S_{wR}$

④ $k_{ro} = 0$ until $S_o = S_{oc}$

⑤ $k_{ro} \approx 0.7$ at $S_w = S_{wR}$

Imbibition

$\left(P_c = \frac{2\sigma\cos\theta}{r} \right)$



relperm for imbibition