Note Title 10/24/2018

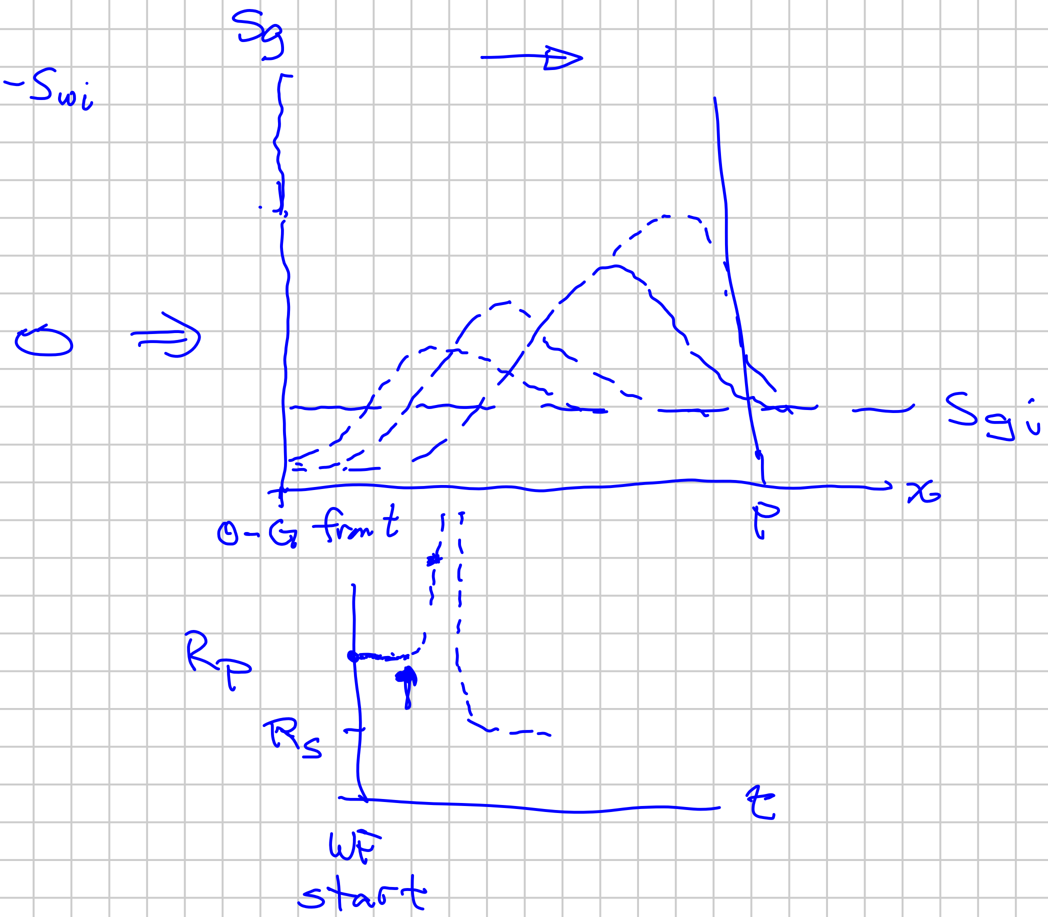
* Standing's Notes on Mobility

$\mu_w \sim 0.5$ cp

N.S. Oils $\mu_o < 2$ cp $\rightarrow$ 0.3-0.2

(10-15 cp)

$S_o = 1 - S_g - S_{wi}$



BUCKLEY-LEVERETT THEORY

* Comments on Buckley-Leverett theory and Standing notes (all books...) discussion & presentation of BL theory.

  - When it may not "work"
  - How to check / verify
  - Why it might not work

$$\frac{q_w}{q} = f_w = \frac{1 + \frac{k_o}{q\mu_o}\left[\frac{\partial P_c}{\partial x} - \Delta\rho g \sin\alpha\right]}{1 + \frac{k_o}{k_w}\cdot\frac{\mu_w}{\mu_o}}$$

AS $k_o = k \cdot k_{ro}$ AND IGNORING $\frac{\partial P_c}{\partial x}$ BECAUSE SMALL

$$f_w = \frac{1 - a k_{ro}}{1 + \frac{k_{ro}}{k_{rw}}\cdot\frac{\mu_w}{\mu_o}} \quad \text{WHERE} \quad = \frac{1 - a k_{ro}}{1 + M(S)}$$

$$a = \frac{0.488\, k\, \Delta\rho \sin\alpha}{q\,\mu_o}$$

IF
$\Delta\rho$ = gm/cc
k = DARCY
q = BBL/DAY/FT^2
μ_o = cp

$$\text{"}q\text{"} = v_D = q_R / A_\perp \;;\; A_\perp(x) = \text{constant}$$

f_w = fractional flow of displacing phase/fluid

$$= \frac{q_w}{q_w + q_o} = \frac{(v_D)_w}{(v_D)_w + (v_D)_o}$$

Simplify for Horizontal flow ($\alpha = 0$)

$$f_w = \frac{1}{1 + \frac{k_{ro}}{k_{rw}}\frac{\mu_w}{\mu_o}} = \frac{1}{1 + \frac{k_{rw}}{k_{ro}}(S_w)\left(\frac{\mu_w}{\mu_o}\right)} = f_w(S_w)$$

$$S_{wi} \le S_w \le 1 - S_{orw}$$

Inclined Flow: $$f_w = \frac{1 - a\,k_{ro}(S_w)}{1 + \frac{k_{rw}}{k_{ro}} \cdot \frac{\mu_w}{\mu_o}}$$

R+F

$$\underbrace{(a\,k_{ro})}_{\text{Gravity-Rate (Velocity) Term}} = \left(\frac{k_o}{\mu_o}\right) \cdot (\Delta\rho\, g \sin\alpha) \cdot \frac{1}{q}$$

F $\qquad \lambda_o \qquad$ F $\qquad$ Controllable

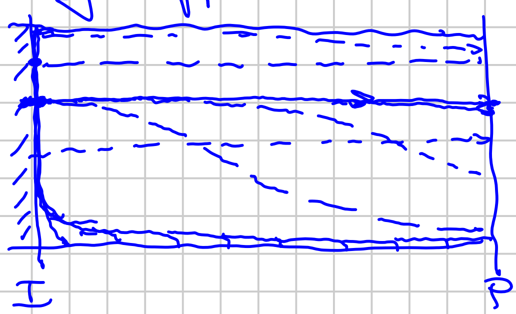
$$\Delta\rho = \rho_w - \rho_o$$

$\rho_o = 800\ kg/m^3$

$\rho_w = 1000\ kg/m^3$

Theory only applies to 1D flow

H:



1" Core

Layer
10 m

$$\begin{Bmatrix} q \\ v \end{Bmatrix} > \underbrace{\begin{Bmatrix} q \\ v \end{Bmatrix}^*}_{?} \Rightarrow \text{get 1D flow}$$

I:

Assuming 1D RL Theory Applies ... read & study notes ...

Notes on Mobility Ratios Used in Fluid Displacement Calculations.

All calculations that involve one fluid displacing a second fluid involve the ratio of the mobilities of the two fluids.

The mobility of a fluid is defined by me (MBS) as the ratio of effective permeability to viscosity.

Alternative: $\lambda_p \equiv \frac{k_{rp}}{\mu_p}$ $\left[\frac{1}{cp}\right]$

$$\lambda_o = k_o/\mu_o \quad \text{md/centipoise} \quad \text{md/cp} \tag{1}$$

$$\lambda_g = k_g/\mu_g \quad " \tag{2}$$

$$\lambda_w = k_w/\mu_w \quad " \tag{3}$$

Note that effective permeability in the above equations depend on saturation, saturation history (drainage or imbibition process) as well as the character of the porous rock.

In systems in which one fluid is displacing a second, it is common practice to call the fluid that is increasing in saturation the "displacing fluid" or "displacing phase". The fluid that is decreasing in saturation is called the "displaced fluid" or "displaced phase". The mobility ratio is the ratio of the mobility of the displacing fluid to that of the displaced fluid.

$$M = \lambda_{displacing} / \lambda_{displaced} \tag{4}$$

* <1950: Muskat $M = \frac{\lambda_{displaced}}{\lambda_{displacing}}$

For example, when water is displacing oil, as when aquifer water moves into an oil reservoir, the mobility ratio of the operation is written

$$M_{wo} = \lambda_w/\lambda_o = \frac{k_w}{k_o} \cdot \frac{\mu_o}{\mu_w} \tag{5}$$

changes a lot $\left\{ \frac{k_{rw}}{k_{ro}}(S's, \ldots) \right.$ R+F (F) ↳ ~ constant

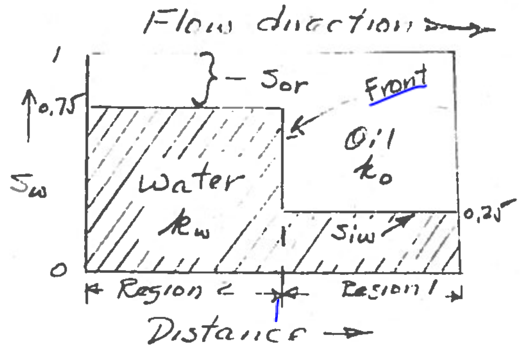


Figure 1.

Figure 1 illustrates partial displacement of oil by water. Only water is flowing in Region 2 behind the water/oil front, while only oil is flowing in Region 1 ahead of the front. In specifying the mobility ratio of this system, the effective water permeability in Region 2 is evaluated at the residual oil saturation, S_{or} S_{orw}. The effective oil permeability in Region 1 is evaluated at the irreducible water saturation S_{iw}. The mobility ratio is,

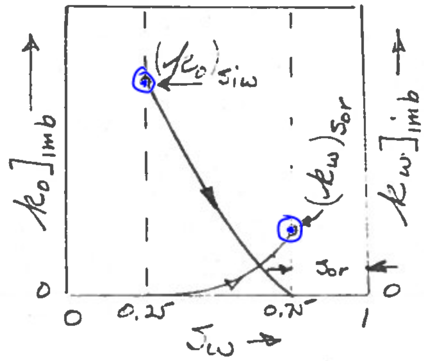


Figure 2

$$M = \frac{(k_w)_{Sor}}{(k_o)_{Siw}} \cdot \frac{\mu_o}{\mu_w} = \frac{k_{rw}(S_{orw})}{k_{ro}(S_{iw})} \qquad (6)$$

The situation of constant fluid saturation behind the front with some residual displaced phase is often refered to as a "leaky piston" displacement.

$S_{oi} \rightarrow S_{orw}$ (not $S_{oi} \rightarrow 0$)

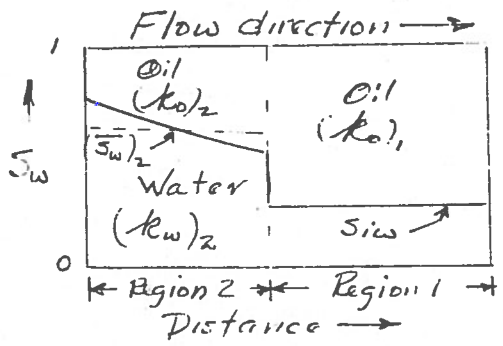


Figure 3

Figure 3 illustrates what is termed a "Buckley-Leverett" type displacement. With this type of displacement both oil and water are flowing in Region 2 (as the front advances). Only oil is flowing in Region 1. In specifying the mobility ratio of the system, the mobility of Region 2 ~~is~~ can be evaluated at the average saturation condition by the relationship:

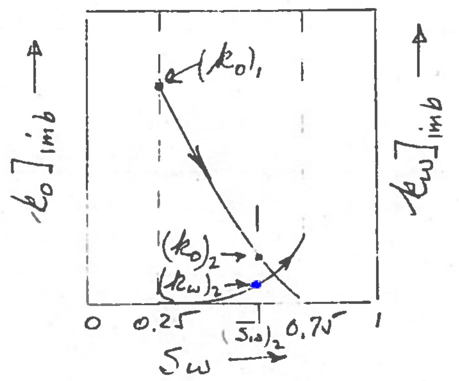


Figure 4.

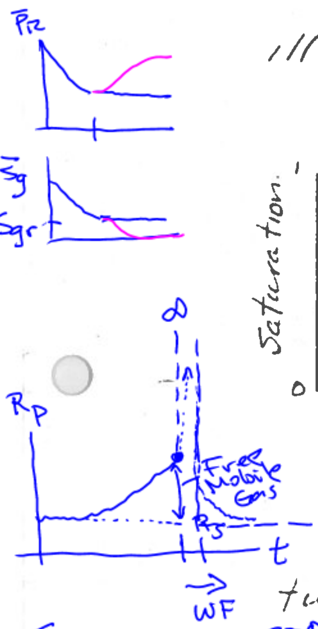
$$\lambda_2 = \left(\frac{(k_w)_2}{\mu_w} + \frac{(k_o)_2}{\mu_o} \right) \qquad (7)$$

@ $\bar{S}_{w2}$

The mobility ratio becomes.

$$M_{wo} = \frac{\lambda_2}{\lambda_1} = \left[\frac{(k_w)_2}{\mu_w} + \frac{(k_o)_2}{\mu_o} \right] \Big/ \frac{(k_o)_1}{\mu_o} \qquad (8)$$

The above effective permeabilities are illustrated in Figure 4.



S_{Hcrw} = const 35%
S_{orw} (S_{gi} | S_{gr})?

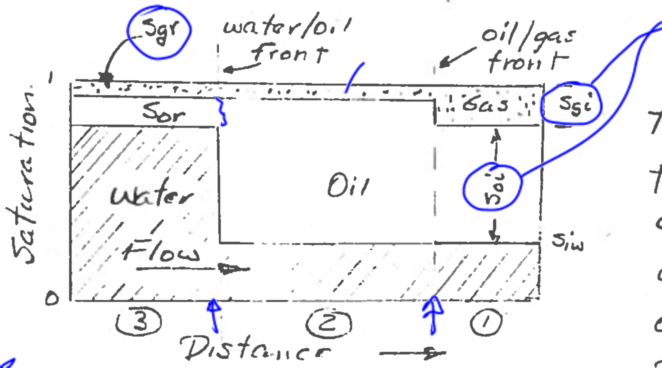


Figure 5

Figure 5 illustrates two "leaky piston" displacement fronts often used in calculating a process of water displacing oil and gas. In Region 1 only gas phase is flowing. In Region 2 only oil phase is flowing. And in Region 3 only water is flowing. The two mobility ratios would be written as.

$$M_{og} = \frac{\lambda_2}{\lambda_1} = \frac{(k_o)_{S_{iw}, S_{gr}}}{(k_g)_{S_{gi}}} \cdot \frac{\mu_g}{\mu_o} \qquad (9)$$

and.

$$M_{wo} = \frac{\lambda_3}{\lambda_2} = \frac{(k_w)_{S_{or}+S_{gr}}}{(k_o)_{S_{iw}, S_{gr}}} \cdot \frac{\mu_o}{\mu_w} \qquad (10)$$

Mobility ratios for most reservoir displacements lie between about 0.1 and 10. Mobility ratios less than 1 are generally considered as "favorable" in that the displacement front has fairly regular (smooth) features. This is illustrated by the front appearance at three successive times in Figure 6. Mobility ratios greater than 1 give more ragged displacement fronts as illustrated by Figure 7. The term "fingering" is often used to designate the erratic front behavior of high mobility ratio displacements.

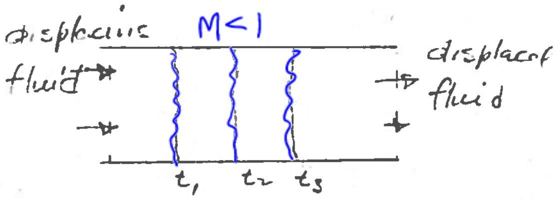


Figure 6

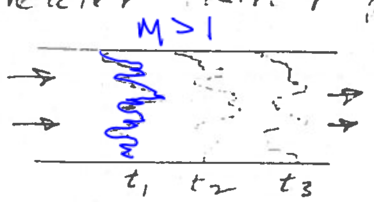


Figure 7