Lecture Twelve: Initial Saturation Distribution in a Reservoir

12.1. Fluid Contacts

The determination of initial fluid contacts in the reservoir, such as the gas–oil contact (GOC) and oil-water contact (OWC), through different methods are available to the engineer's disposal. These include:

1. A production test which involves the direct determination of GOC and OWC during the drilling of a well prior to setting the casing.

2. The other method includes application of geophysical logs such as electrical and radioactive.

3. In addition to these, SCAL (which includes capillary pressure) represents one of the most reliable methods of determining the fluid contacts in a reservoir.

Fluid contacts, and initial fluid saturation distribution in a hydrocarbon reservoir prior to its exploitation can be derived from capillary pressure data, this requires the conversion of *Pc*–*Sw* data to height–saturation data, which can be achieved by:

$$h = \frac{2\,\sigma cos\theta}{r\; g\; \Delta\rho} \qquad \ldots\ldots. (11\text{-}8)$$

Equation (11-8) can be expressed in terms of capillary pressure:

$$Pc = gh\Delta\rho$$

$$h = \frac{Pc}{g\;\Delta\rho} \qquad \ldots\ldots. (12\text{-}1)$$

where:

h = the height above the plane of 0 capillary pressure between the nonwetting and wetting fluids.

Pc = the capillary pressure.

Δρ = the density difference between nonwetting and wetting phase at reservoir conditions.

g = the gravitational constant.

In Equation (12-1), when a value of g is 9.81 m/s2, *Pc* is in N/m^2, and the density difference is in kg/m^3,

$$h(m) = \frac{0.102\ Pc\ (N/m^2)}{g\ \Delta\rho\ (kg/m^3)} \qquad \text{....... (12-2)}$$

whereas in oil-field units, when g is 32.2 ft/s2, *P*c is in lbforce/in.2, and the density difference is in lbmass/ft3:

$$h(ft) = \frac{144\ Pc}{\Delta\rho} \qquad \text{....... (12-3)}$$

Pc = capillary pressure, psia

Δρ = density difference between the wetting and nonwetting phase, lb/ft3

h = height above the free-water level, ft

In order to understand the application of height‐saturation data to determine the fluid distribution, zonation, and fluid contacts in a reservoir, we consider the drainage capillary pressure curve.

12.1.1. Displacement pressure, pd

The capillary pressure at 100% water saturation that is necessary to force the nonwetting phase into a capillary filled with the wetting phase. This minimum capillary pressure is known as the *displacement pressure*, pd

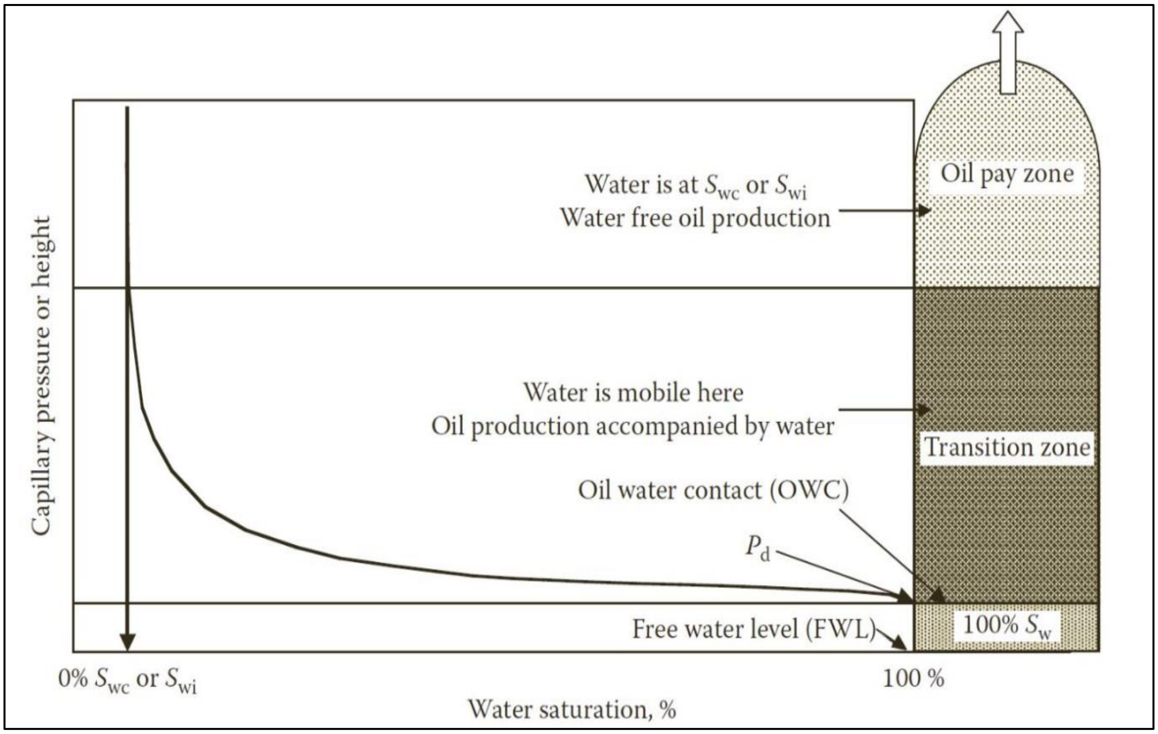

Fig. 12-1: Profile of fluid distribution, zonation, and fluid contacts based on the capillary pressure or height versus water saturation data.

12.1.2. Free Water Level, FWL

From the capillary pressure curve, the FWL occurs at zero capillary pressure at which water saturation is 100%. Consequently, the FWL is represented by the base of the height‑saturation curve below which a water zone or aquifer may exist.

However, moving upward vertically from the base of the height‑saturation curve in Figure (12-1), the water saturation is still 100% up to a certain finite value of 'h' that is an outcome of the capillary entry pressure or displacement pressure (Pd) or the threshold pressure.

FWL can be expressed mathematically by the following relationship:

$$FWL = WOC + \frac{144P_d}{\Delta\rho} \qquad \text{……. (12-4)}$$

where:

pd = displacement pressure, psi (from capillary pressure curve).

$\Delta\rho$ = density difference, lb_{mass}/ft^3.

FWL = free-water level, *ft*.

OWC = Oil-Water contact, *ft*.

12.1.3. Oil-Water Contact, OWC

As shown in Figure (12-1), the OWC and 100% water saturation point on the height‑saturation curve is represented by the coordinates $pc = pd$; Sw = 100%. In

Equation (12-3), Pc can be replaced by pd to express the OWC **in terms of height above the FWL**:

$$WOC = \frac{144P_d}{\Delta\rho} \quad \text{……. (12-5)}$$

where:

OWC = Oil-Water contact, *ft*.

Pd = displacement pressure, psi (from capillary pressure curve).

$\Delta\rho$ = density difference, lb_{mass}/ft^3.

In terms of depth, the OWC is defined as the uppermost depth in the reservoir where a 100% water saturation exists, which can be mathematically expressed as:

$$WOC = FWL - \frac{144P_d}{\Delta\rho} \quad \text{……. (12-6)}$$

12.1.4. Transition Zone

The presence of transition zones in petroleum reservoirs resulting from the capillary forces, the absence of which would result in complete segregation of the fluid phases.

The relationship as expressed in Equation (11-8), when applied for $h_{@swi}$ -h_{owc} suggests that the transition zone thickness is basically influenced by:

$$h = \frac{2\,\sigma cos\theta}{r\;g\;\Delta\rho} \qquad \text{……. (11-8)}$$

(1) The radius of the pore, r.

A reservoir rock system having small pore sizes has a large transition zone (typical characteristics of low-permeability chalk reservoirs) than a system comprised of large pore sizes. Additionally, the more uniform the pore sizes (well-sorted grains) resulting in thinner transition zones. Such uniform pore size systems will also have high permeabilities; thus, the thickness of the transition zone can also be indirectly related to permeability; a high-permeability reservoir rock system has shorter transition zones than low-permeability reservoirs.

(2) The difference in density, Δρ.

As far as the influence of Δρ is concerned, from a practical standpoint, in a gas reservoir having a gas-water contact, the thickness of the transition zone will be small since the density difference is large (gravity dominating over capillarity). In the case of oil (smaller density difference); resulting in a larger thickness of the transition zone.

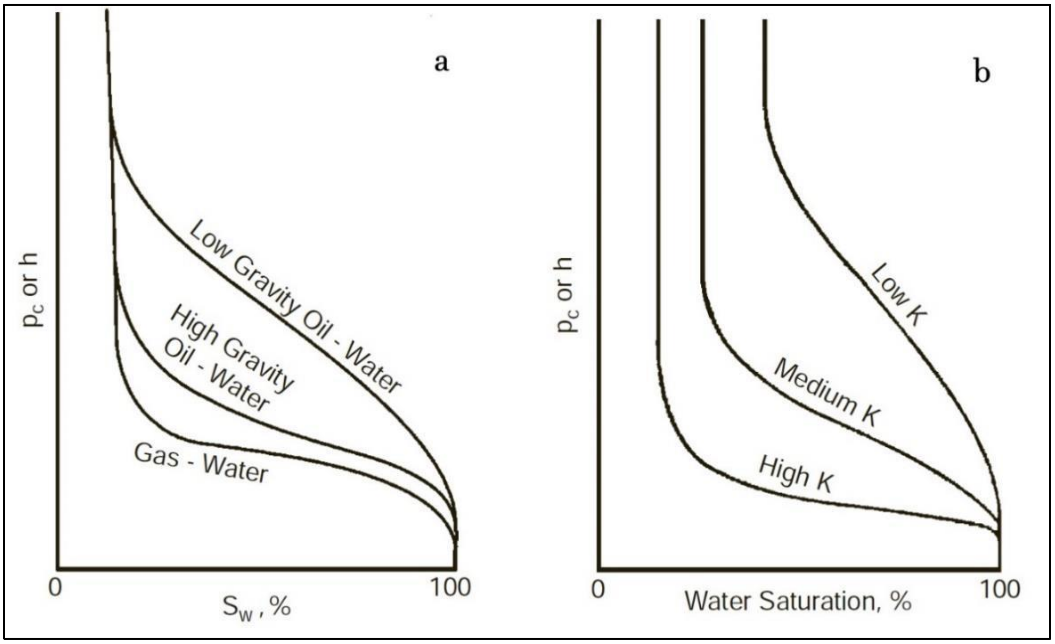

Fig. 12-2: Transition zone variation with (a) fluid gravity, (b) permeability

Example 1

The reservoir capillary pressure-saturation data of the Big Butte Oil Reservoir is shown graphically in Figure (12-3). Geophysical log interpretations and core analysis establish the WOC at (5023 *ft*). The following additional data are available:

- Oil density = 43.5 lb/ft^3.
- Water density = 64.1 lb/ft^3.
- Interfacial tension = 50 dynes/cm.

Calculate:

- Connate-water saturation (S_{wc}).
- Depth to FWL.
- Thickness of the transition zone.
- Depth to reach 50% water saturation

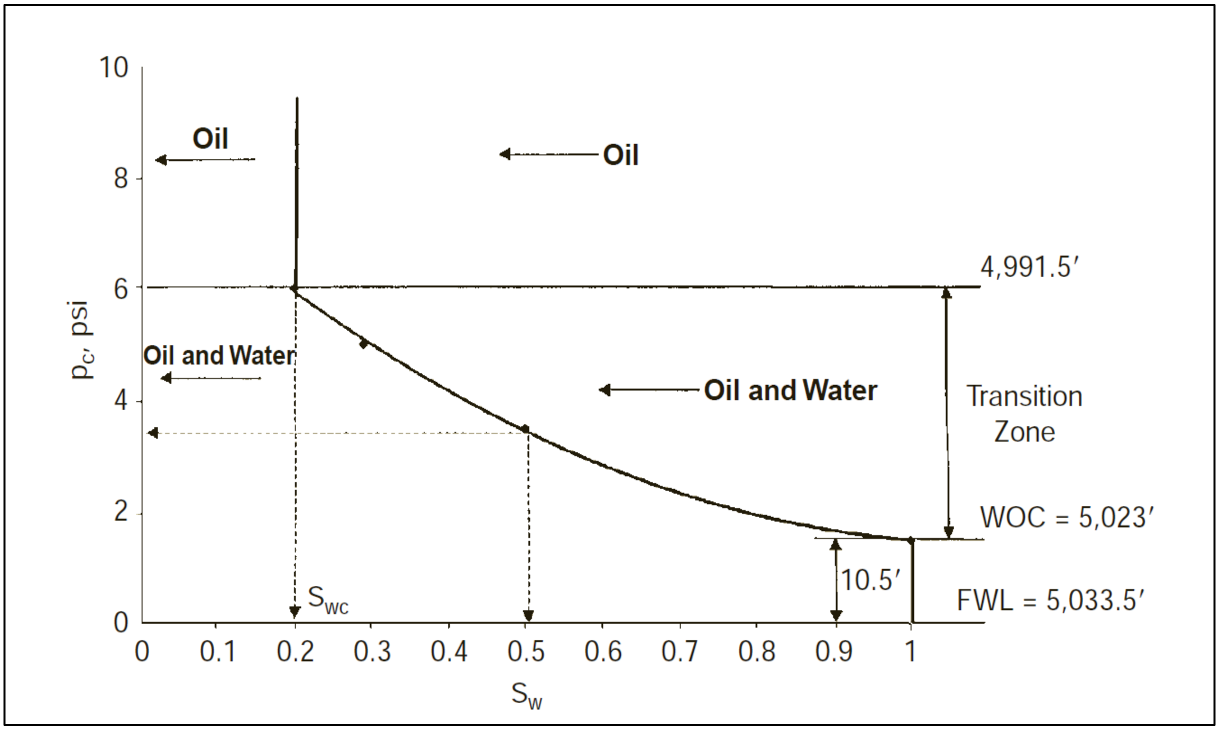

Fig 12-3: Capillary pressure-saturation data.

Solution:

a. From Figure (12-3), connate-water saturation is 20%.

b. Applying Equation (12-4) with a displacement pressure of 1.5 psi gives:

$$FWL = WOC + \frac{144P_d}{\Delta\rho}$$

$$FWL = 5023 + \frac{144 \times 1.5}{(64.1 - 43.5)} = 5033.5\ ft$$

c. Thickness of transition zone can be calculated by applying Equation (12-3) with *Pc* difference at WOC and Pc at S_w=S_{wc}:

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

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

d. *Pc* at 50% water saturation = 3.5 psia.

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

$$h(ft) = \frac{144 \times\ 3.5}{(64.1 - 43.5)} = 24.5\ ft$$

$$Depth_{Sw=50\%} =\ 5033.5 -\ 24.5 = 5009\ ft$$

12.1.5. Oil Pay Zone or Clean Oil Zone

The oil pay zone or the clean oil zone is represented by the zone above the upper demarcation line of the transition zone. Since the oil pay zone contains water at its irreducible saturation, the oil production from the clean oil zone is water-free.