University of Mosul

College of Petroleum & Mining Engineering

Department of Petroleum & Refining Engineering

Petroleum Reservoir Engineering

Third Year

Lecture 2

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Wettability:

Wettability is defined as the tendency of one fluid to spread on or adhere to a solid surface in the presence of other immiscible fluids. Figure 1 illustrates the concept of wettability. Small drops of three liquids (mercury, oil, and water) are placed on a clean glass plate. The three droplets are then observed from one side as illustrated in Figure 1. It is noted that the mercury retains a spherical shape, the oil droplet develops an approximately hemispherical shape, but the water tends to spread over the glass surface.

The tendency of a liquid to spread over the surface of a solid is an indication of the wetting characteristics of the liquid for the solid. This spreading tendency can be expressed more conveniently by measuring the angle of contact at the liquid-solid surface. This angle, which is always measured through the liquid to the solid, is called the contact angle θ.

The contact angle θ has achieved significance as a measure of wettability. As shown in Figure 1, as the contact angle decreases, the wetting characteristics of the liquid increase. Complete wettability would be evidenced by a zero contact angle, and complete nonwetting would be evidenced by a contact angle of 180^o. For intermediate wettability, contact angles of 60^o to 90^o.

The wettability of reservoir rocks to the fluids is important in that the distribution of the fluids in the porous media is a function of wettability. Because of the attractive forces, the wetting phase tends to occupy the smaller pores of the rock and the nonwetting phase occupies the more open channels.

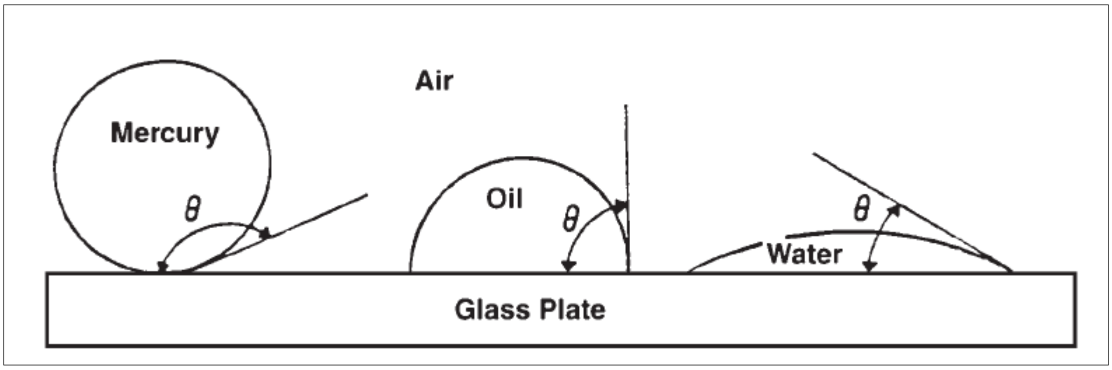

Figure 1: Illustration of wettability.

Surface and interfacial tension:

In dealing with multiphase systems, it is necessary to consider the effect of the forces at the interface when two immiscible fluids are in contact. When these two fluids are liquid and gas, the term ***surface tension*** is used to describe the forces acting on the interface. When the interface is between two liquids, the acting forces are called ***interfacial tension.***

Consider the two immiscible fluids, air (or gas) and water (or oil), as shown schematically in Figure 1. A liquid molecule, which is remote from the interface, is surrounded by other liquid molecules, thus having a resulting net attractive force on the molecule of zero. A molecule at the interface, however, has a force acting on it from the air (gas) molecules lying immediately above the interface and from liquid molecules lying below the interface.

Resulting forces are unbalanced and give rise to surface tension. The unbalanced attraction force between the molecules creates a membrane like surface with a measureable tension, i.e., surface tension. As a matter of fact, if carefully placed, a needle will float on the surface of the liquid, supported by the thin membrane even though it is considerably more dense than the liquid.

The surface or interfacial tension has the units of force per unit of length, e.g., dynes/cm, and is usually denoted by the symbol σ.

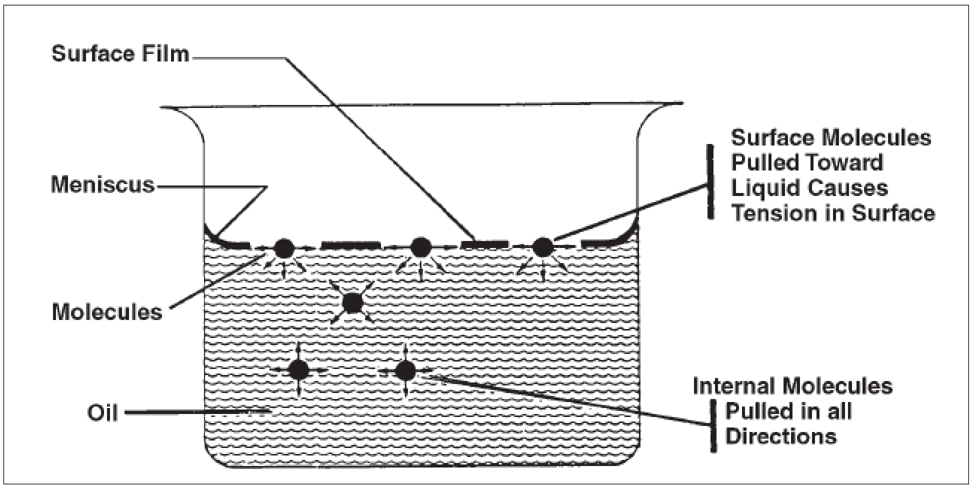

Figure 1: Illustration of surface tension.

If a glass capillary tube is placed in a large open vessel containing water, the combination of surface tension and wettability of tube to water will cause water to rise in the tube above the water level in the container outside the tube as shown in Figure 2.

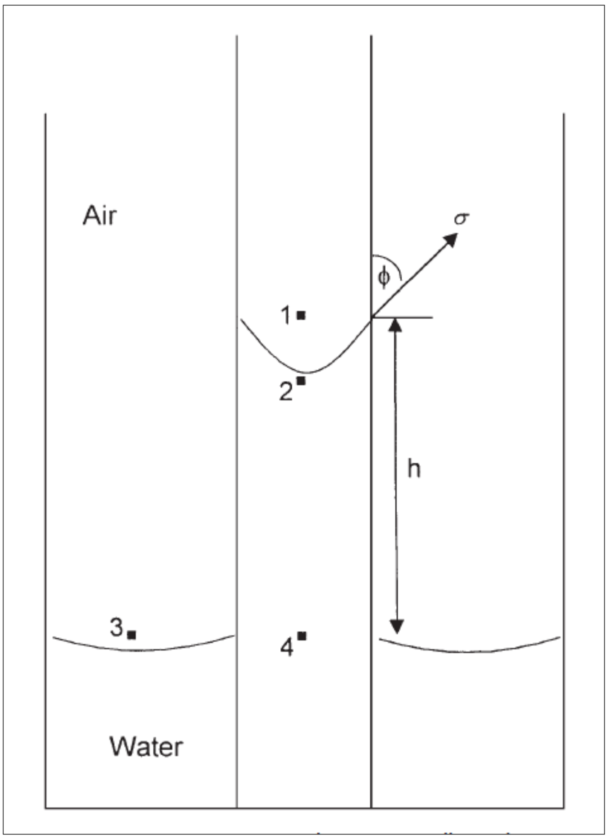

Figure 2: Pressure relations in capillary tubes.

The water will rise in the tube until the total force acting to pull the liquid upward is balanced by the weight of the column of liquid being supported in the tube. Assuming the radius of the capillary tube is r, the total upward force F_{up}, which holds the liquid up, is equal to the force per unit length of the surface times the total length of the surface, or:

$$F_{up} = (2\pi r)(\sigma_{gw})(\cos\theta) \qquad \text{--------------------- (1)}$$

where σ_{gw} = surface tension between air (gas) and water (oil), dynes/cm
θ = contact angle
r = radius, cm

The upward force is counteracted by the weight of the water, which is equivalent to downward force of mass times acceleration, or:

$$F_{down} = \pi r^2 h (\rho_w - \rho_{air}) g$$

where h = height to which the liquid is held, cm
g = acceleration due to gravity, cm/sec^2
ρ_w = density of water, gm/cm^3
ρ_{air} = density of gas, gm/cm^3

--------------------- (2)

Because the density of air is negligible in comparison with the density of water, the equation 2 is reduced to:

$$F_{down} = \pi r^2 \rho_w g$$ --------------------- (3)

Equating equation 1 with 3 and solving for the surface tension gives:

$$\sigma_{gw} = \frac{r h \rho_w g}{2 \cos \theta}$$ --------------------- (4)

In the case of two liquids (water and oil). Because the density of oil is not negligible, equation 4 becomes:

$$\sigma_{ow} = \frac{r h g (\rho_w - \rho_o)}{2 \cos \theta}$$ --------------------- (5)

where ρ_o = density of oil, gm/cm^3
σ_{ow} = interfacial tension between the oil and the water, dynes/cm

Capillary pressure:

The capillary forces in a petroleum reservoir are the result of the combined effect of the surface and interfacial tensions of the rock and fluids, the pore size and geometry, and the wetting characteristics of the system. Any curved surface between two immiscible fluids has the tendency to contract into the smallest possible area per unit volume. This is true whether the fluids are oil and water, water and gas (even air), or oil and gas. When two immiscible fluids are in contact, a discontinuity in pressure exists between the two fluids, which depend upon the curvature of the interface separating the fluids. We call this pressure difference the ***capillary pressure***, and it is referred to by P_c.

The displacement of one fluid by another in the pores of a porous medium is either aided or opposed by the surface forces of capillary pressure. As a consequence, in order to maintain a porous medium partially saturated with nonwetting fluid and while the medium is also exposed to wetting fluid, it is necessary to maintain the pressure of the nonwetting fluid at a value greater than that in the wetting fluid.

Denoting the pressure in the wetting fluid by Pw and that in the nonweting fluid by Pnw, the capillary pressure can be expressed as:

Capillary pressure = (pressure of the nonwettong phase) – (pressure of the wetting phase)

$P_c = P_{nw} - P_w$ ------------------------- (6)

That is, the pressure excess in the nonwetting fluid is the capillary pressure, and this quantity is a function of saturation. This is the defining equation for capillary pressure in a porous medium.

There are three types of capillary pressure:

- Water-oil capillary pressure (denoted as P_{cwo})
- Gas-oil capillary pressure (denoted as P_{cgw})
- Gas-water capillary pressure (denoted as P_{cgw})

Applying the mathematical definition of the capillary pressure as expressed by equation 6, the three types of the capillary pressure can be written as:

$P_{cwo} = P_o - P_w$

$P_{cgo} = P_g - P_o$

$P_{cgw} = P_g - P_w$

Where P_g, P_o, and P_w represent the pressure of gas, oil, and water, respectively.

If all the three phases are continuous, then:

$Pcgw = P_{cgo} + P_{cwo}$

In the case of gas-water system, the equation for computing the capillary pressure is:

$Pc = gh\,(\rho_w - \rho_g) = gh\Delta\rho$ ---------------------- (7)

Where Δρ is the density difference between the wetting and nonwetting phase. The density of gas is negligible in comparison with the water density.

The capillary pressure equation can be expressed in terms of the surface and interfacial tension by combining equations 6 and 7 with equations 4 and 5 to give:

- **Gas-liquid system**

$$P_c = \frac{2\,\sigma_{gw}\,(\cos\theta)}{r}$$

and

$$h = \frac{2\,\sigma_{gw}\,(\cos\theta)}{r\,g\,(\rho_w - \rho_{gas})}$$

where ρ_w = water density, gm/cm^3
σ_{gw} = gas-water surface tension, dynes/cm
r = capillary radius, cm
θ = contact angle
h = capillary rise, cm
g = acceleration due to gravity, cm/sec^2
p_c = capillary pressure, dynes/cm^2

- **Oil-water system**

$$p_c = \frac{2\,\sigma_{ow}\,(\cos\theta)}{r}$$

and

$$h = \frac{2\,\sigma_{wo}\,(\cos\theta)}{r\,g\,(\rho_w - \rho_o)}$$

where σ_{wo} is the water-oil interfacial tension.