University of Mosul
College of Petroleum & Mining Engineering

# Petrophysical properties of rocks

## Lecture third

**Ammar Albburi**

**Petroleum Reservoir Engineering Department**

**Email**: ammae.ali @uomosul.edu.iq

# LECTURE CONTENTS

- Saturation

# Saturation

Saturation is defined as that fraction, or percent, of the pore volume occupied by a particular fluid (oil, gas, or water). This property is expressed mathematically by the following relationship:

$$S = \frac{Vf}{Vp}$$

Applying the above mathematical concept of saturation to each reservoir fluid gives:

$$S_o = \frac{Vo}{Vp} \quad , \quad S_w = \frac{Vw}{Vp} \quad , \quad S_g = \frac{Vg}{Vp}$$

Thus, all saturation values are based on pore volume and not on the gross reservoir volume. The saturation of each individual phase ranges between zero to 100 percent. By definition, the sum of the saturations is 100%, therefore

$$S_g + S_o + S_w = 1$$

The fluids in most reservoirs are believed to have reached a state of equilibrium and, therefore, will have become separated according to their density, i.e., oil overlain by gas and underlain by water. In addition to the bottom (or edge) water, there will be connate water distributed throughout the oil and gas zones. The water in these zones will have been reduced to some irreducible minimum. The forces retaining the water in the oil and gas zones are referred to as capillary forces because they are important only in pore spaces of capillary size. Connate (interstitial) water saturation is important primarily because it reduces the amount of space available between oil and gas. It is generally not uniformly distributed throughout the reservoir but varies with permeability, lithology, and height above the free water level. Another particular phase saturation of interest is called the critical saturation and it is associated with each reservoir fluid.

- **Connate water**:

Water trapped in the pores of a rock during formation of the rock. The chemistry of connate water can change in composition throughout the history of the rock. Connate water can be dense and saline compared with seawater. Formation water, or interstitial water, in contrast, is simply water found in the pore spaces of a rock, and might not have been present when the rock was formed. Connate water is also described as fossil water.

- **Critical oil saturation,** $S_{oc}$

For the oil phase to flow, the saturation of the oil must exceed a certain value which is termed critical oil saturation. At this particular saturation, the oil remains in the pores and, for all practical purposes, will not flow.

- **Residual oil saturation,** $S_{or}$

During the displacing process of the crude oil system from the porous media by water or gas injection (or encroachment) there will be some remaining oil left that is quantitatively characterized by a saturation value that is larger than the critical oil saturation. This saturation value is called the residual oil saturation, $S_{or}$. The term residual saturation is usually associated with the nonwetting phase when it is being displaced by a wetting phase.

- **Movable oil saturation, $S_{om}$**

Movable oil saturation $S_{om}$ is another saturation of interest and is defined as the fraction of pore volume occupied by movable oil as expressed by the following equation:

$$S_{om} = 1 - S_{wc} - S_{oc}$$

- **Critical gas saturation, $S_{gc}$**

As the reservoir pressure declines below the bubble-point pressure, gas evolves from the oil phase and consequently the saturation of the gas increases as the reservoir pressure declines. The gas phase remains immobile until its saturation exceeds certain saturation, called critical gas saturation, above which gas begins to move.

- **Critical water saturation, $S_{wc}$**

The critical water saturation, connate water saturation, and irreducible water saturation are extensively used interchangeably to define the maximum water saturation at which the water phase will remain immobile.

- **Average saturation**

Proper averaging of saturation data requires that the saturation values be weighted by both the interval thickness h and interval porosity Ø. The average saturation of reservoir fluid is calculated from the following equation:

$$\mathbf{S_{avg.}} = \frac{\sum \mathbf{\emptyset_i * h_i * S_i}}{\sum \mathbf{\emptyset_i * h_i}} \quad \text{---------- (14)}$$