University of Mosul

College of Petroleum and Mining Engineering

Department of Petroleum Reservoir Engineering

Applied Reservoir Engineering II

Third Year

Lecture 2

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4- The Water-Drive Mechanism

Many reservoirs are bounded on a portion or all of their peripheries by water-bearing rocks called aquifers. The aquifers may be so large compared to the reservoir they adjoin as to appear infinite for all practical purposes, and they may range down to those so small as to be negligible in their effects on the reservoir performance.

It is common to speak of edge water or bottom water in discussing water influx into a reservoir. Bottom water occurs directly beneath the oil, and edge water occurs off the flanks of the structure at the edge of the oil, as illustrated in Figure 11-8. Regardless of the source of water, the water drive is the result of water moving into the pore spaces originally occupied by oil, replacing the oil and displacing it to the producing wells.

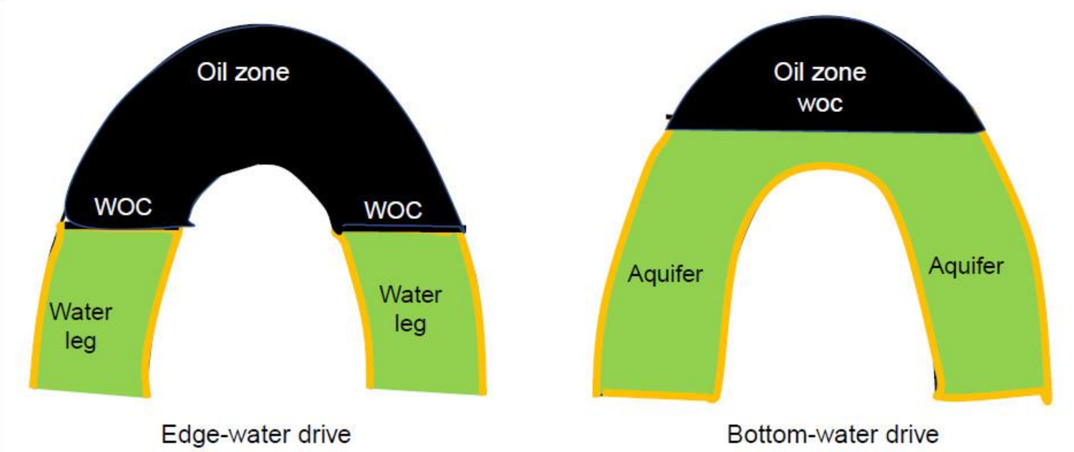

FIGURE 11-8 Edge and bottom-water drive.

The main characteristics that can be used for identification of the water-driving mechanism:

Reservoir Pressure

The reservoir pressure decline is usually very gradual. Figure 11-9 shows the pressure-production history of a typical water-drive reservoir. It is not uncommon for many thousands of barrels of oil to be produced for each pound per square inch drop in reservoir pressure. The reason for the small decline in reservoir pressure is that oil and gas withdrawals from the reservoir are replaced almost volume for volume by water encroaching into the oil zone.

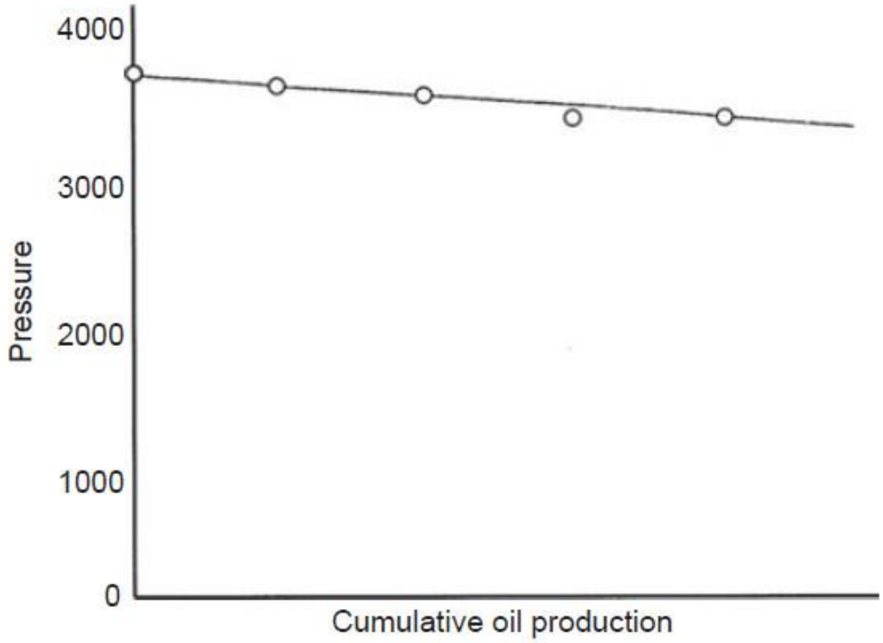

FIGURE 11-9 Pressure-production history for a water-drive reservoir.

Water Production

Early excess water production occurs in structurally low wells. This is characteristic of a water-drive reservoir, and, provided the water is encroaching in a uniform manner, nothing can or should be done to restrict this encroachment, as the water will probably provide the most efficient displacing mechanism possible.

Gas-Oil Ratio

There is normally little change in the producing gas-oil ratio during the life of the reservoir. This is especially true if the reservoir does not have an initial free gas cap. Pressure will be maintained as a result of water encroachment, and therefore there will be relatively little gas released from this solution.

Ultimate Oil Recovery

Ultimate recovery from water-drive reservoirs is usually much larger than recovery under any other producing mechanism. Recovery is dependent upon the efficiency of the flushing action of the water as it displaces the oil. In general, as the reservoir heterogeneity increases, the recovery will decrease due to the uneven advance of the displacing water.

The ultimate oil

Recovery normally ranges from 35% to 75% of the original oil in place. The characteristic trends of a water drive reservoir are shown graphically in Figure 11-10 and are summarized below:

Characteristics	Trends
Reservoir pressure	Remains high
Surface gas-oil ratio	Remains low
Water production	Starts early and increases to appreciable amounts
Well behavior	Flow until water production gets excessive
Expected oil recovery	35 to 75 percent

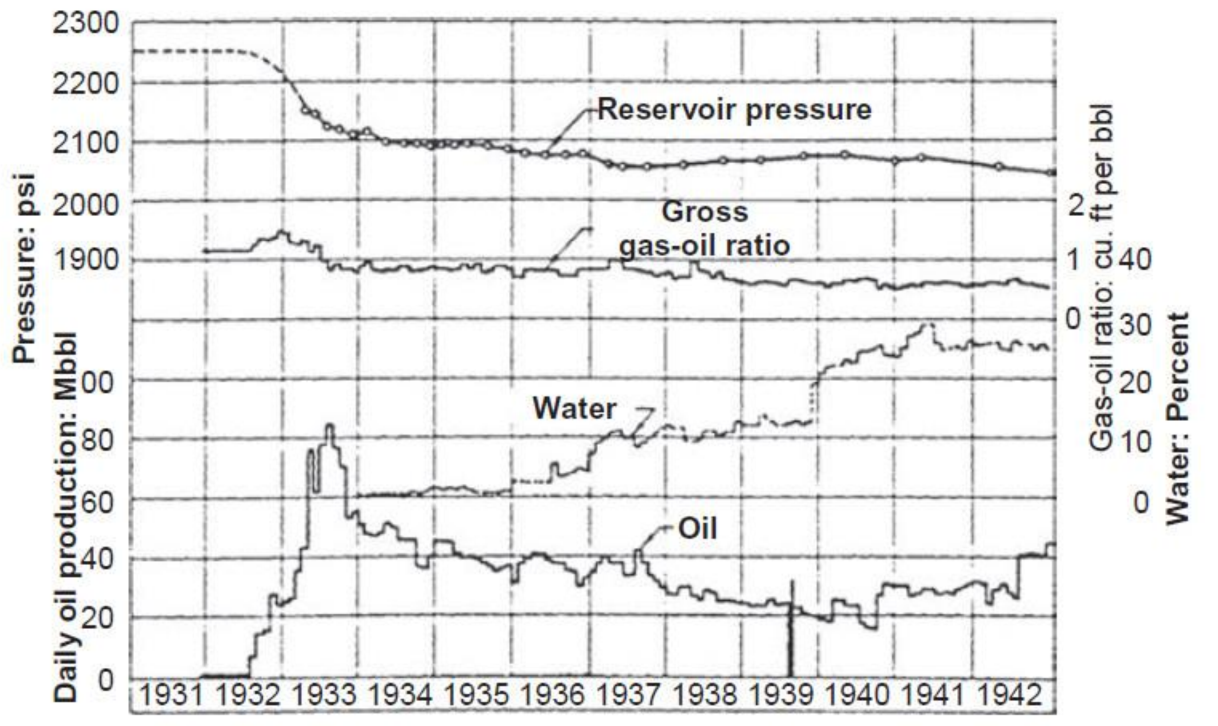

FIGURE 11-10 Production data for a water-drive reservoir. *(After Clark, N. J.,* Elements of Petroleum Reservoirs, *SPE, 1969. Courtesy of API).*

5- The Gravity-Drainage-Drive Mechanism

The mechanism of gravity drainage occurs in petroleum reservoirs as a result of differences in densities of the reservoir fluids. The fluids in petroleum reservoirs have all been subjected to the forces of gravity, as evidenced by the relative positions of the fluids, i.e., gas on top, oil underlying the gas, and water underlying oil. The relative positions of the reservoir fluids are shown in Figure 11-11. Due to the long periods of time involved in the petroleum accumulation-and-migration process, it is generally assumed that the reservoir fluids are in equilibrium. If the reservoir fluids are in equilibrium, then the gas-oil and oil-water contacts should be essentially horizontal.

Although it is difficult to determine precisely the reservoir fluid contacts, best available data indicate that, in most reservoirs, the fluid contacts actually are essentially horizontal. Gravity segregation of fluids is probably present to some degree in all petroleum reservoirs, but it may contribute substantially to oil production in some reservoirs depending on the degree of the reservoir dip angle.

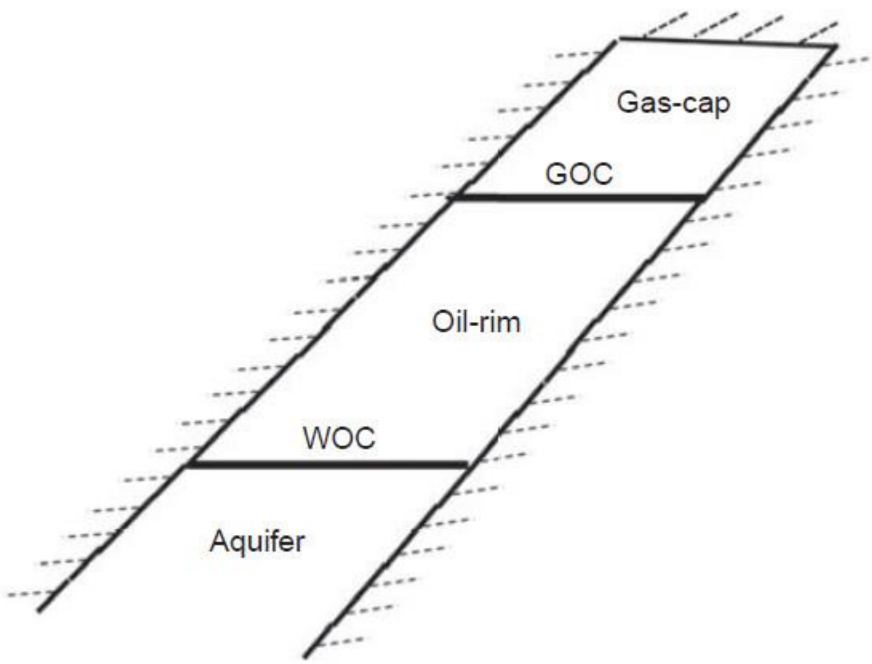

FIGURE 11-11 Initial fluids distribution in a combination-drive oil reservoir.

Cole (1969) stated that reservoirs operating largely under a gravity drainage producing mechanism are characterized by:

Reservoir Pressure

Variable rates of pressure decline, depending principally upon the amount of gas conservation. Strictly speaking, where the gas is conserved and reservoir pressure is maintained, the reservoir would be operating under combined gas-cap drive and gravity-drainage mechanisms. Therefore, for the reservoir to be operating solely as a result of gravity drainage, the reservoir would show a rapid pressure decline. This would require the upstructure migration of the evolved gas where it later would be produced from structurally high wells, resulting in rapid loss of pressure.

Gas-Oil Ratio

Low gas-oil ratio from structurally low wells. This is caused by migration of the evolved gas upstructure due to gravitational segregation of the fluids. On the other hand, the structurally high wells will experience an increasing gas-oil ratio as a result of the upstructure migration of the gas released from the crude oil.

Secondary Gas Cap

Formation of a secondary gas cap in reservoirs that initially were undersaturated. Obviously the gravity-drainage mechanism does not become operative until reservoir pressure has declined below the saturation pressure, since above the saturation pressure there will be no free gas in the reservoir.

Water Production

Little or no water production. Water production is indicative of a water drive.

Ultimate Oil Recovery

Ultimate recovery from gravity-drainage reservoirs will vary widely, due primarily to the extent of depletion by gravity drainage alone. Where gravity drainage is good, or where producing rates are restricted to take maximum advantage of the gravitational forces, recovery will be high. There are reported cases where recovery from gravity-drainage reservoirs has exceeded 80% of the initial oil in place. In other reservoirs where depletion drive also plays an important role in the oil recovery process, the ultimate recovery will be less.

In operating a gravity-drainage reservoir, it is essential that the oil saturation in the vicinity of the wellbore must be maintained as high as possible. There are two basic reasons for this requirement:

_ *A high oil saturation means a higher oil flow rate*

_ *A high oil saturation means a lower gas flow rate*

If the evolved gas migrates upstructure instead of toward the wellbore, then a high oil saturation in the vicinity of the wellbore can be maintained. It should be pointed out that the oil production rate must be managed not exceed a certain critical rate to allow for the gas migration up the structure and form a secondary gas cap. This critical rate is given by:

$$q_o = \frac{7.83 \times 10^{-6} k\, k_{ro} A \left(\rho_o - \rho_g\right) \sin(\alpha)}{\mu_o}$$

Where:

q_o = oil production rate, bbl/day
ρ_o = oil density, lb/ft^3
ρ_g = gas density, lb/ft^3
A = cross sectional area open to flow, ft^2
k = absolute permeability, md
α = dip angle, radians; i.e. $\sin(\pi\ \alpha/180)$

In order to take maximum advantage of the gravity-drainage-producing mechanism, wells should be located as structurally low as possible. This will result in maximum conservation of the reservoir gas. A typical gravity-drainage reservoir is shown in Figure 11-12.

Factors that affect ultimate recovery from gravity-drainage reservoirs are:

_ *Permeability in the direction of dip*

_*Dip of the reservoir*

_ *Reservoir producing rates*

_ *Oil viscosity*

_ *Relative permeability characteristics*

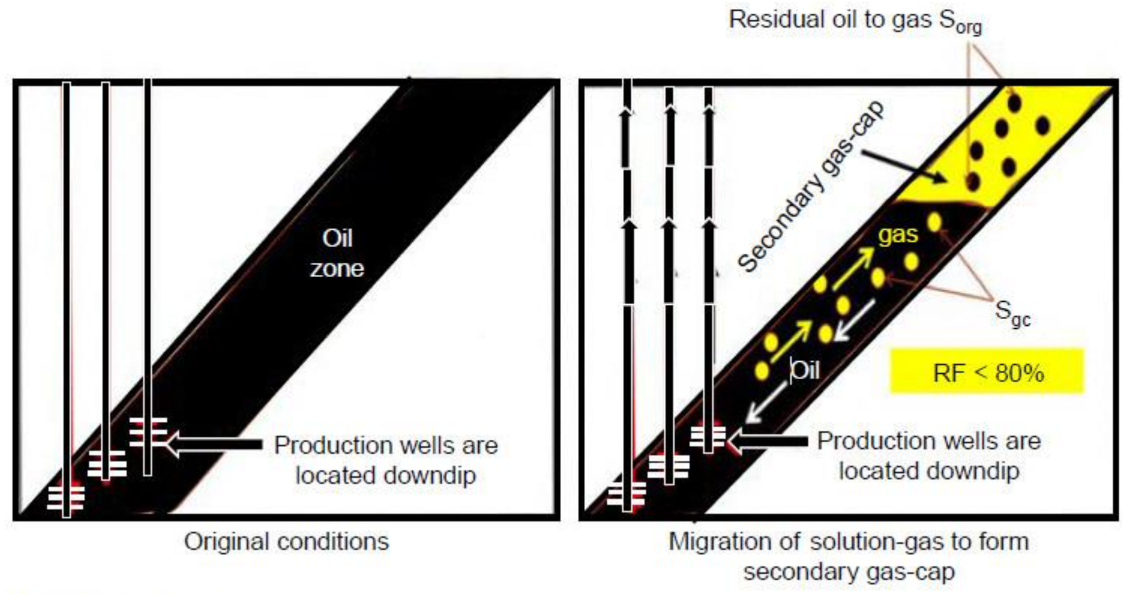

FIGURE 11-12 Gravity-drainage reservoir.

6- The Combination-Drive Mechanism

The driving mechanism most commonly encountered is one in which both water and free gas are available in some degree to displace the oil toward the producing wells. The most common type of drive encountered, therefore, is a combination-drive mechanism as illustrated in Figure 11-13.

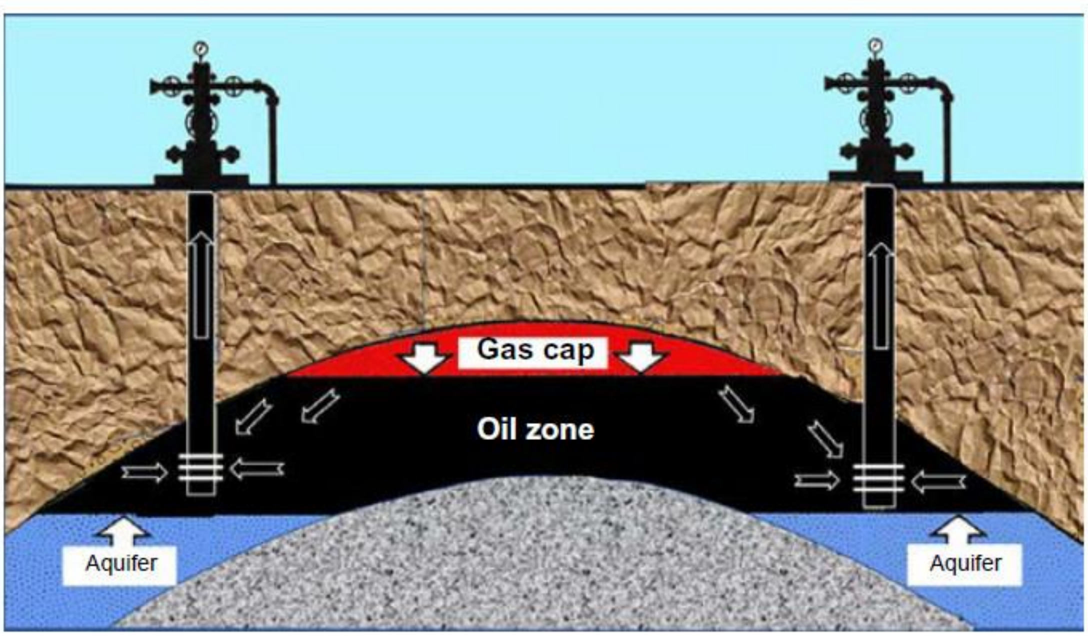

FIGURE 11-13 Combination-drive mechanisms.

Two combinations of driving forces resulting from the presence of a gas-cap and an aquifer. The ultimate recovery factor from this combination drive mechanism is a strong function of:

_ *Size of the gas cap*

_ *Strength of the aquifer*

_ *Wells' locations in reference to GOC and WOC*

_ *Managing and controlling production rate to avoid or delay gas and water coning*

_ *For tilted reservoirs, gravity segregation can play an important role in providing additional recovery by allowing liberated gas to migrate to the gas cap*

Combination-drive reservoirs can be recognized by the occurrence of a combination of some of the following factors:

a. Relatively rapid pressure decline. Water encroachment and/or external gas-cap expansion are insufficient to maintain reservoir pressures.

b. Water encroaching slowly into the lower part of the reservoir. Structurally, low-producing wells will exhibit slowly increasing water-producing rates due to water coning. To delay or minimize water coning, production wells located near the WOC should be reduced to or below the well critical flow rate.

c. If a small gas cap is present, the structurally high wells will exhibit continually increasing gas-oil ratios due to the occurrence of gas-coning. To delay or minimize gas coning, production wells should periodically shut in, and production wells should be controlled at or below the critical flow rate.

d. Ultimate recovery from combination-drive reservoirs is usually greater than recovery from depletion-drive reservoirs but less than recovery from water-drive or gas-cap-drive reservoirs. Actual recovery will depend upon the degree to which the up-dip wells located near the GOC and down-dip wells located near the WOC are managed by controlling their production rates not to exceed the calculated critical rates.