University of Mosul

College of Petroleum and Mining Engineering

Department of Petroleum Reservoir Engineering

Applied Reservoir Engineering II

Third Year

Lecture 1

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Oil Recovery Mechanisms

Each reservoir is composed of a unique combination of geometric form, geological rock properties, fluid characteristics, and primary drive mechanism.

Although no two reservoirs are identical in all aspects, they can be grouped according to the primary recovery mechanism by which they produce. It has been observed that each drive mechanism has certain typical performance characteristics in terms of:

- Ultimate recovery factor
- Pressure decline rate
- Gas-oil ratio
- Water production

The recovery of oil by any of the natural drive mechanisms is called primary recovery. The term refers to the production of hydrocarbons from a reservoir without the use of any process (such as fluid injection) to supplement the natural energy of the reservoir.

Primary Recovery Mechanisms:

For a proper understanding of reservoir behavior and predicting future performance, it is necessary to have knowledge of the driving mechanisms that control the behavior of fluids within reservoirs. The overall performance of oil reservoirs is largely determined by the nature of the energy, i.e., driving mechanism, available for moving the oil to the wellbore. There are basically six driving mechanisms that provide the natural energy necessary for oil recovery:

- Rock and liquid expansion drive
- Depletion drive
- Gas cap drive
- Gravity drainage drive
- Combination drive

1- Rock and Liquid Expansion:

When an oil reservoir initially exists at a pressure higher than its bubble-point pressure, the reservoir is called an undersaturated oil reservoir. At pressures above the bubble-point pressure, crude oil, connate water, and rock are the only materials present. As the reservoir pressure declines, the rock and fluids expand due to their individual compressibilities. The reservoir rock compressibility is the result of two factors:

- Expansion of the individual rock grains
- Formation compaction

Both of the above two factors are the results of a decrease of fluid pressure within the pore spaces, and both tend to reduce the pore volume through the reduction of the porosity.

As the expansion of the fluids and reduction in the pore volume occur with decreasing reservoir pressure, the crude oil and water will be forced out of the pore space to the wellbore. Because liquids and rocks are only slightly compressible, the reservoir will experience a rapid pressure decline. The oil reservoir under this driving mechanism is characterized by a constant gas-oil ratio that is equal to the gas solubility at the bubble point pressure.

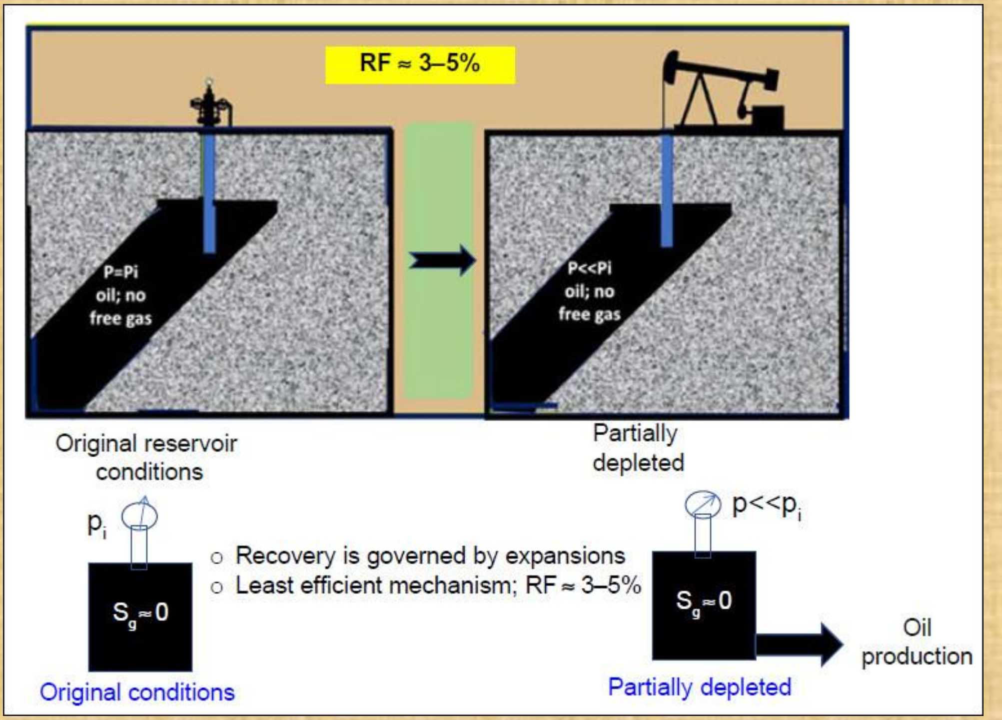

Figure 1: Oil reservoir under rock and fluid expansion driving mechanism.

2- The Depletion Drive Mechanism

This driving form may also be referred to by the following various terms:

● Solution gas drive

● Dissolved gas drive

● Internal gas drive

In this type of reservoir, the principal source of energy is a result of gas liberation from the crude oil and the subsequent expansion of the solution gas as the reservoir pressure is reduced. As pressure falls below the bubble-point pressure, gas bubbles are liberated within the microscopic pore spaces. These bubbles expand and force the crude oil out of the pore space as shown conceptually in

Figure 2.

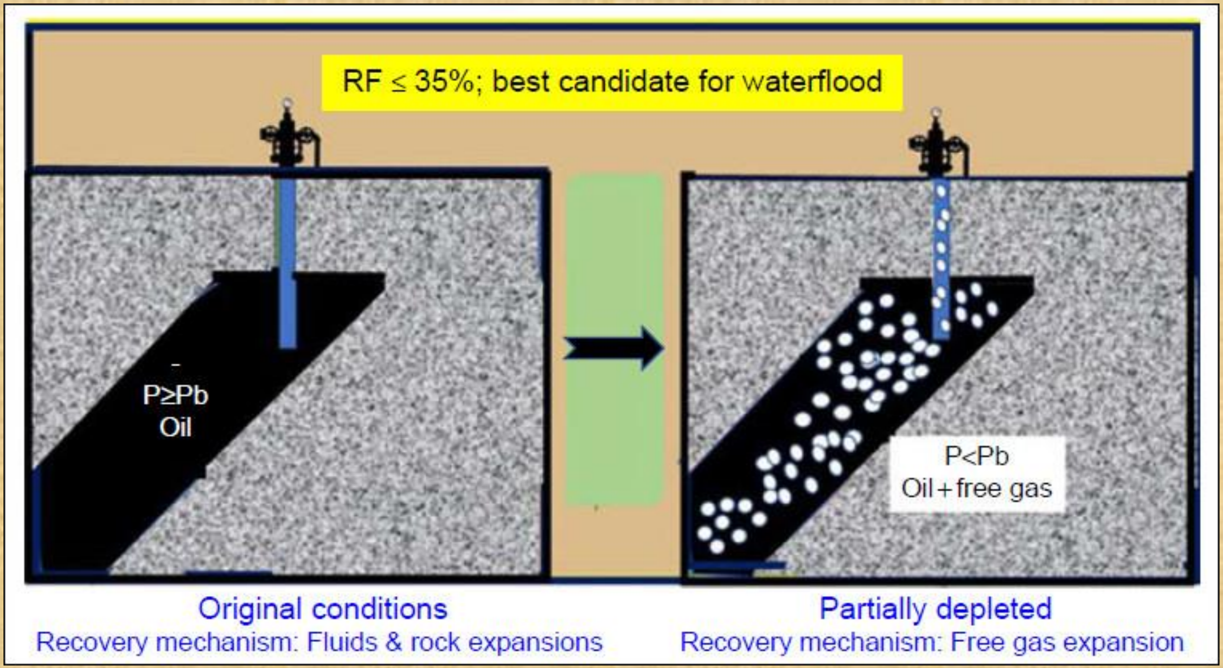

Figure 2: Solution gas – drive reservoir.

The depletion-drive reservoir can be identified by the following characteristics:

● **Reservoir pressure:** The reservoir pressure declines rapidly and continuously. This reservoir pressure behavior is attributed to the fact that no extraneous fluids or gas caps are available to provide a replacement of the gas and oil withdrawals.

● **Water production:** The absence of a water drive means there will be little or no water production with the oil during the entire producing life of the reservoir.

● **Gas-oil ratio:** A depletion-drive reservoir is characterized by a rapidly increasing gas-oil ratio from all wells, regardless of their structural position. After the reservoir pressure has been reduced below the bubble-point pressure, gas evolves from solution throughout the reservoir. Once the gas saturation exceeds the critical gas saturation, free gas begins to flow toward the wellbore and gas-oil ratio increases.

● **Ultimate Oil Recovery:** Oil production by depletion drive is usually the least efficient recovery method. This is a direct result of the formation of gas saturation throughout the reservoir. Ultimate oil recovery from depletion-drive reservoirs may vary from between 20% and 35% based on the crude oil gas-solubility.

The above characteristic trends occurring during the production life of depletion-drive reservoirs are shown in Figure 3 and summarized in the table below:

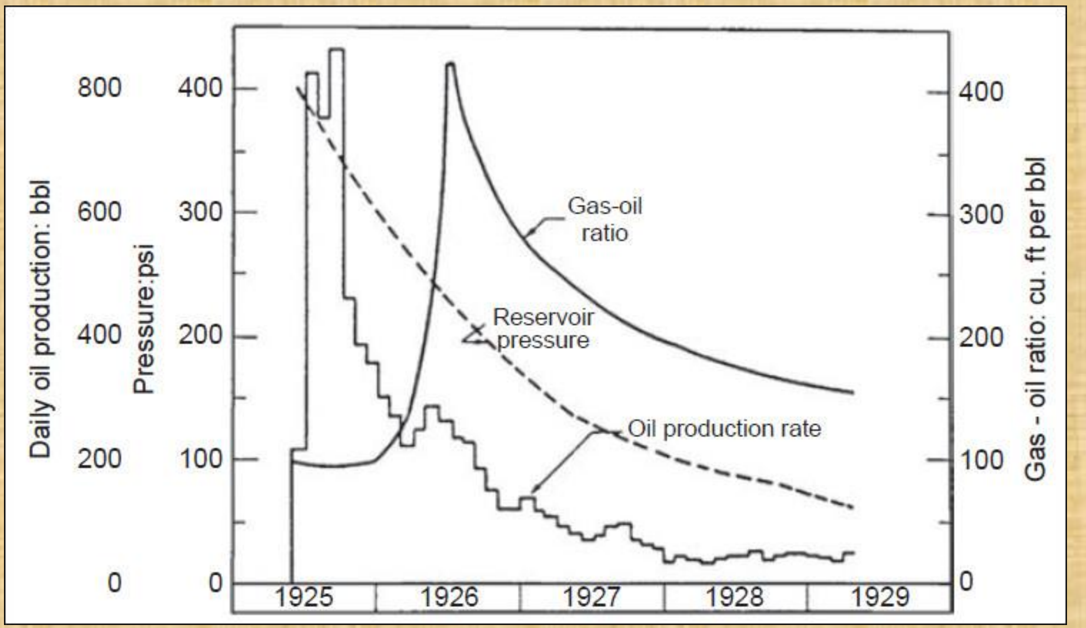

Figure 3: Production data of a solution gas drive reservoir.

Characteristics	Trend
Reservoir pressure	Declines rapidly and continuously
Gas-oil ratio	Increases to maximum and then declines
Water production	None
Well behavior	Requires pumping at early stage
Oil recovery	5 to 30%

3- Gas Cap Drive

Gas-cap-drive reservoirs can be identified by the presence of a gas cap with little or no water drive as shown in Figure 4.

Due to the ability of the gas cap to expand, these reservoirs are characterized by a slow decline in the reservoir pressure. The natural energy available to produce the crude oil comes from the following two sources:

● Expansion of the gas-cap gas

● Expansion of the solution gas as it is liberated

The main characteristics associated with gas-cap drive are as follows:

○ **Reservoir pressure:** The reservoir pressure falls slowly and continuously. Pressure tends to be maintained at a higher level than in a depletion drive reservoir. The degree of pressure maintenance depends upon the volume of gas in the gas cap compared to the oil volume.

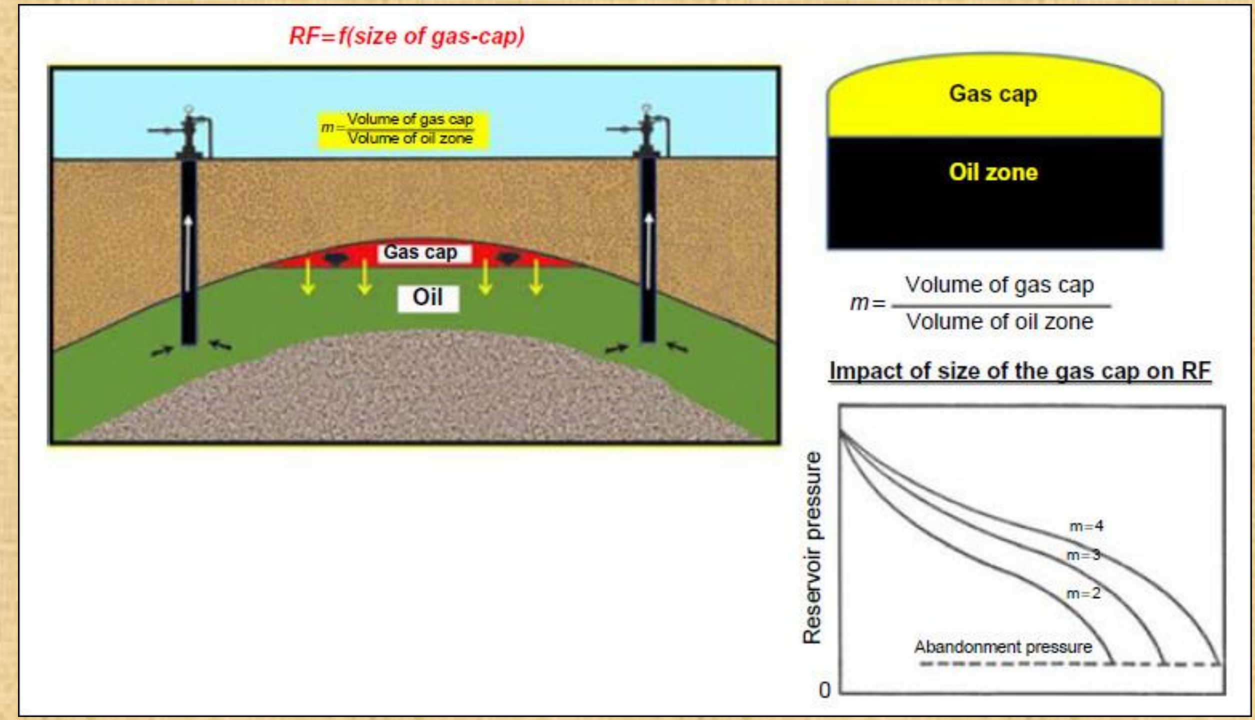

Figure 4: Gas-cap drive reservoir.

○ **Water production**: Absent or negligible water production.

○ **Gas-oil ratio:** The gas-oil ratio rises continuously in up-structure wells. As the expanding gas cap reaches the producing intervals of upstructure wells, the gas-oil ratio from the affected wells will increase to high values.

○ **Ultimate oil recovery**: Oil recovery by gas-cap expansion is actually a frontal drive displacing mechanism that, therefore, yields a considerably larger recovery efficiency than that of depletion-drive reservoirs. This larger recovery efficiency is also attributed to the fact that no gas saturation is being formed throughout the reservoir at the same time. Figure 5 shows the relative positions of the gas-oil contact at different times in the producing life of the reservoir. The expected oil recovery ranges from 20% to 40%.

○ **Well behavior:** Because of the effects of gas-cap expansion on maintaining reservoir pressure and the effect of decreased liquid column weight as it is produced out of the well, gas-cap-drive reservoirs tend to flow longer than depletion-drive reservoirs.

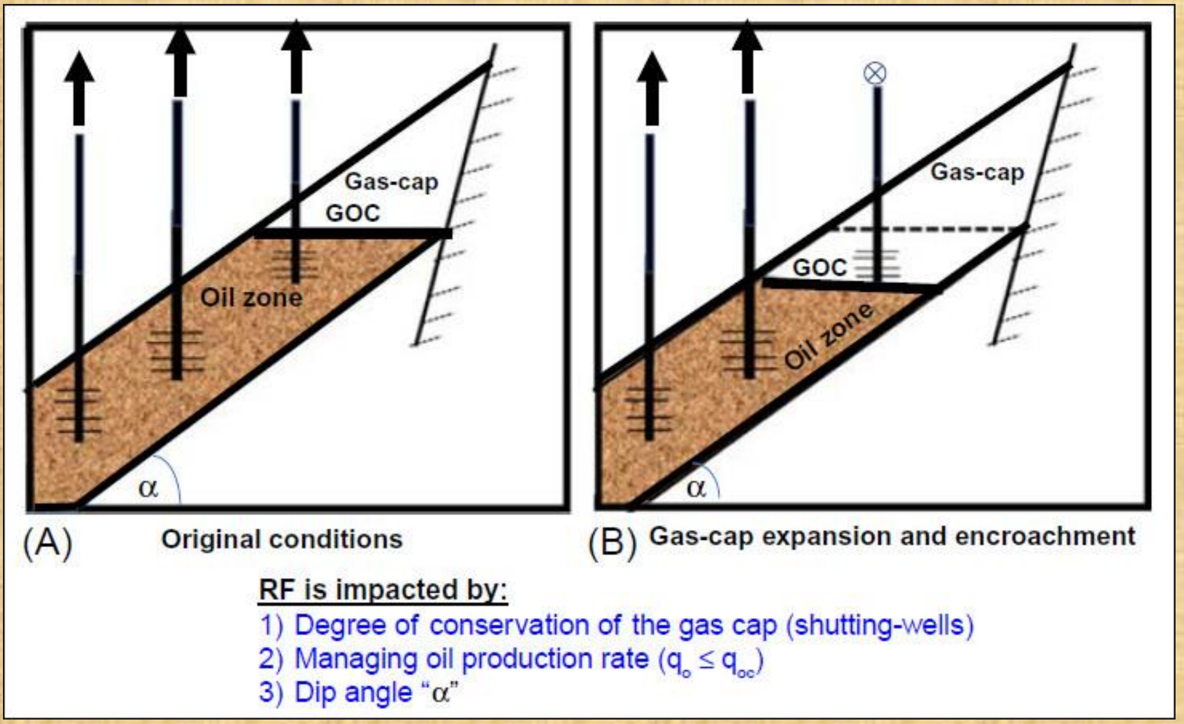

Figure 5: Gas- cap expansion and encroachment.

The ultimate oil recovery from a gas-cap-drive reservoir will vary depending largely on the following six important parameters:

● **Size of the Original Gas Cap:**

As shown graphically in Figure 6, the ultimate oil recovery increases with increasing the size of the gas cap.

● **Vertical Permeability:**

Good vertical permeability will permit the oil to move downward with less bypassing of gas.

● **Oil Viscosity**

As the oil viscosity increases, the amount of gas bypassing will also increase, which leads to a lower oil recovery.

● **Degree of Conservation of the Gas**

In order to conserve gas and thereby increase ultimate oil recovery, it is necessary to shut in the wells that produce excessive gas.

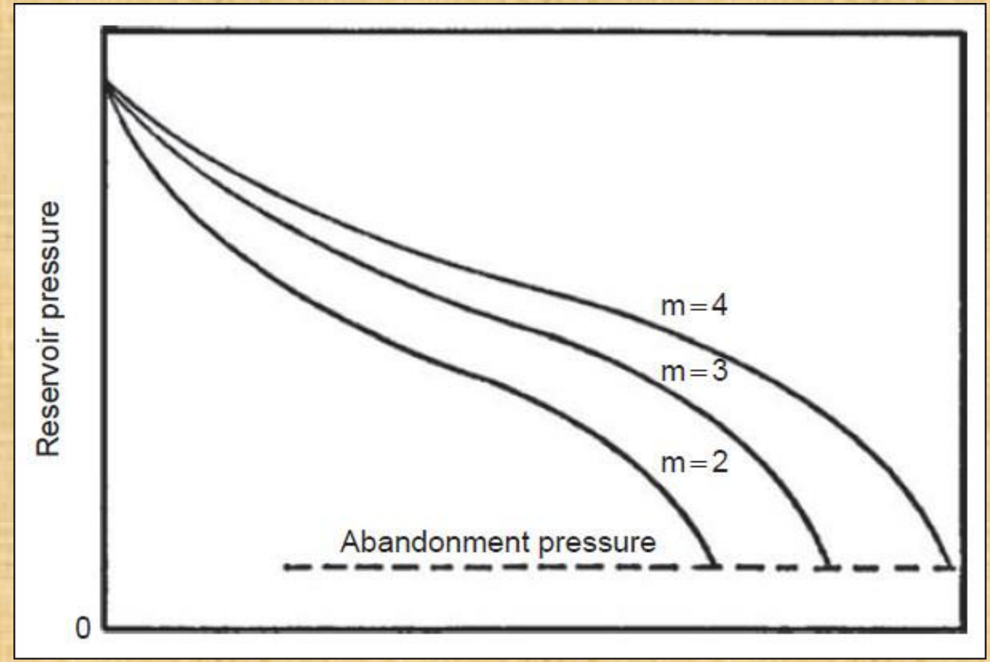

Figure 6: Effect of gas cap size on ultimate recovery factor.

- **Oil Production Rate**

As the reservoir pressure declines with production, solution gas evolves from the crude oil and the gas saturation increases continuously. If the gas saturation exceeds the critical gas saturation, the evolved gas begins to flow in the oil zone. As a result of creating a mobile gas phase in the oil zone, the following two events will occur:

- The effective permeability to oil will be decreased as a result of the increased gas saturation.
- The effective permeability to gas will be increased, thereby increasing the flow of gas.

- **Dip Angle**

The size of the gas cap, a measure of reservoir energy available to produce the oil, will in large part determine the recovery percent to be expected. Such recovery normally will be 20 to 40 percent of the original oil in place; if some other features are present to assist, however, such as a steep angle of dip that allows good oil drainage to the bottom of the structure, considerably higher recoveries (up to 60 percent or greater) may be obtained.