Al-Ayen University
College of Petroleum Engineering

Reservoir Engineering II

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Lecture 2: Primary Recovery Mechanisms

Ref.: ***Reservoir Engineering Handbook*** by **Tarek Ahmed**, Fifth Edition, Ch. 11

Outlines

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INTRODUCTION

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

- It has been observed that each drive mechanism has certain typical performance characteristics in terms of:
  - Pressure decline rate
  - Gas-oil ratio
  - Water production
  - Ultimate oil recovery

- 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:

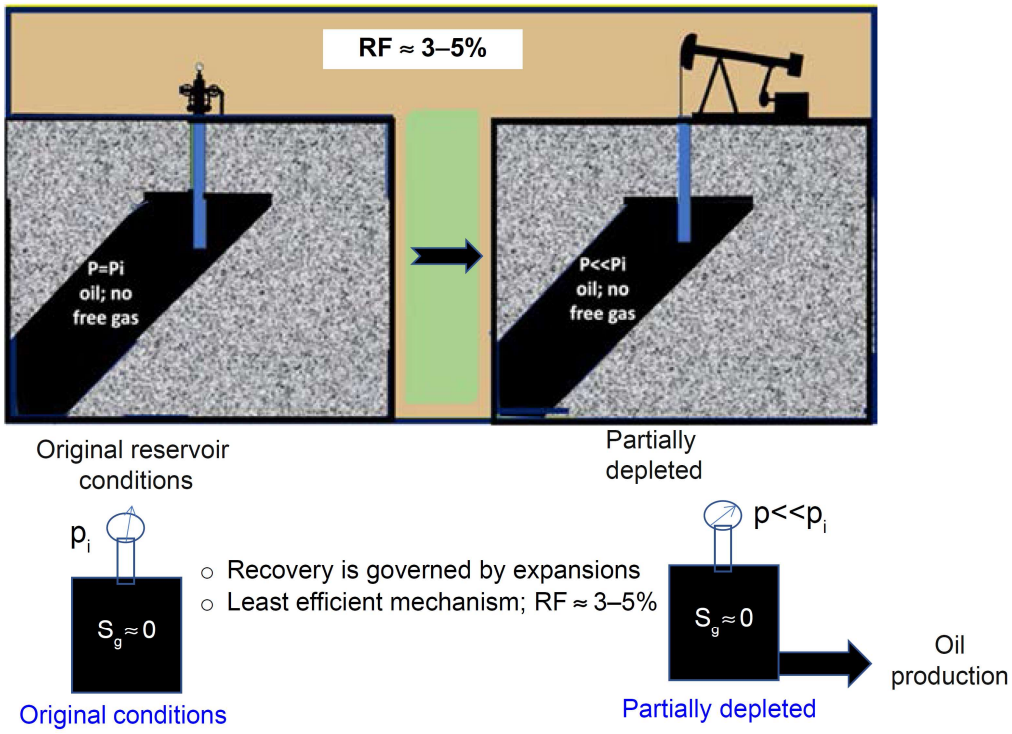
  - Rock and liquid expansion drive
  - Depletion drive
  - Gas cap drive
  - Water drive
  - Gravity drainage drive
  - Combination drive

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.
- 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.*
  - *The reservoir will experience a rapid pressure decline.*

Rock and Liquid Expansion

- For a volumetric reservoir with a heavy oil of a low gas solubility and a low bubble point pressure, the reservoir driving mechanism results a small oil recovery ranging between 3-5%.
- The Figure shows a conceptual illustration of the impact of the low gas solubility on the reservoir recovery performance.



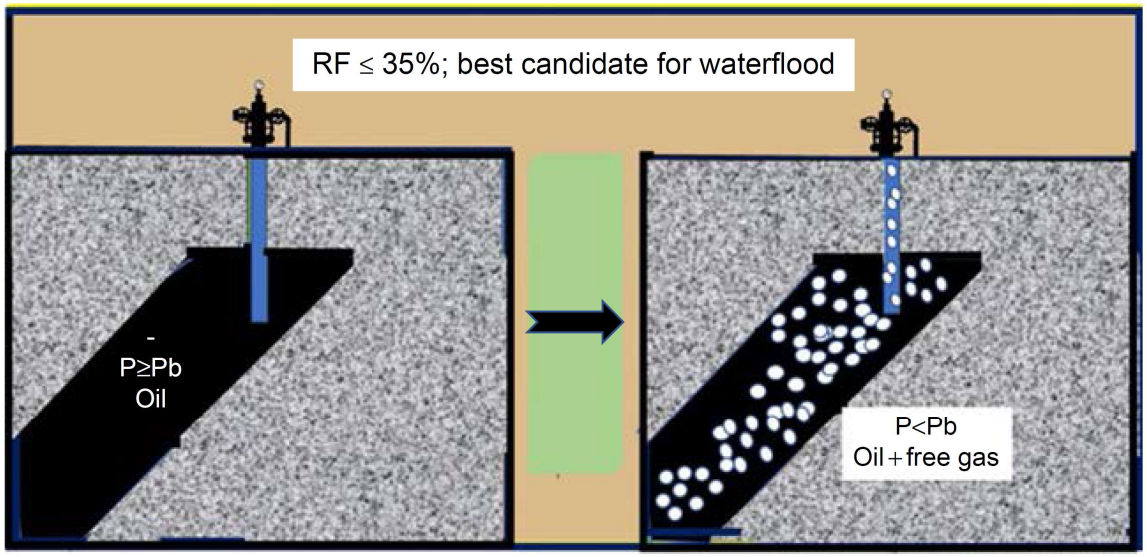
Heavy oil reservoir under rock and fluid expansions driving mechanism

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*

- 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.



Solution gas-drive reservoir

Depletion Drive Mechanism

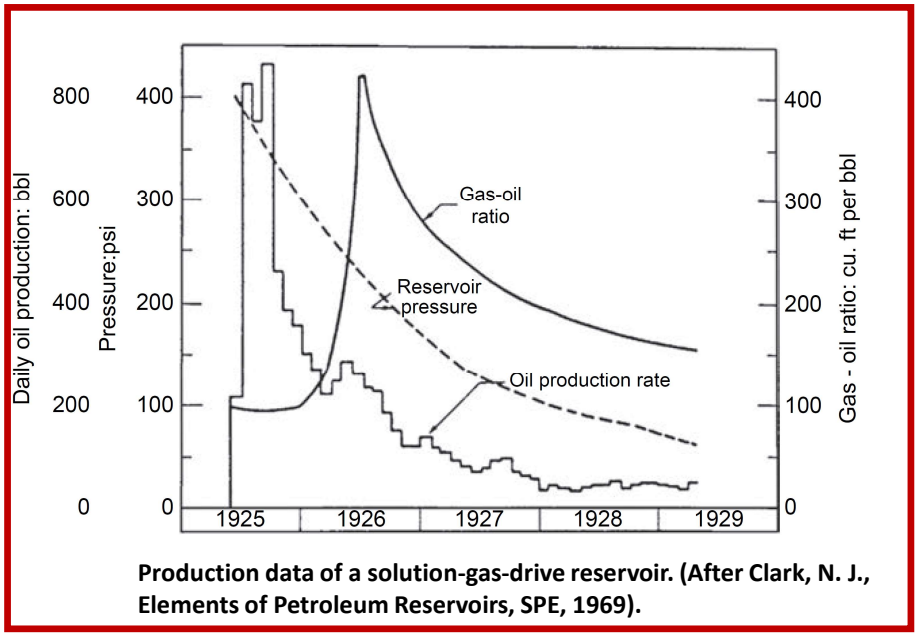
- Cole (1969) suggests that a depletion-drive reservoir can be identified by the following characteristics:

Reservoir pressure:

The reservoir pressure declines rapidly and continuously.

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.



Production data of a solution-gas-drive reservoir. (After Clark, N. J., Elements of Petroleum Reservoirs, SPE, 1969).

Gas-oil ratio:

- The gas-oil ratio rapidly increases from all wells, regardless of their structural position.
- Once the gas saturation exceeds the critical gas saturation, free gas begins to flow toward the wellbore and gas-oil ratio increases.
- With a high vertical permeability, a secondary gas cap may form.

Oil recovery:

- Oil recovery by depletion drive between 5 to 30%, based on the crude oil gas-solubility.
- Depletion-drive reservoirs are considered the best candidates for secondary recovery applications.

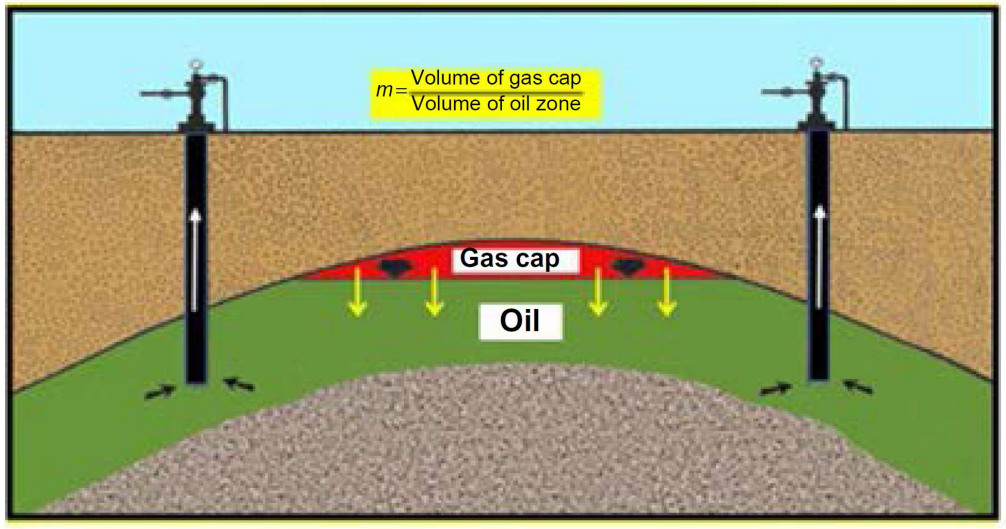
Gas-Cap Drive

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

RF = f(size of gas-cap)



Gas-cap drive reservoir. (After Clark, N. J., Elements of Petroleum Reservoirs, SPE, 1969).

Gas Cap Drive

Cole (1969) and Clark (1969) presented a comprehensive review of the characteristic trends associated with gas-cap-drive reservoirs. These characteristic trends are summarized below:

Reservoir pressure:

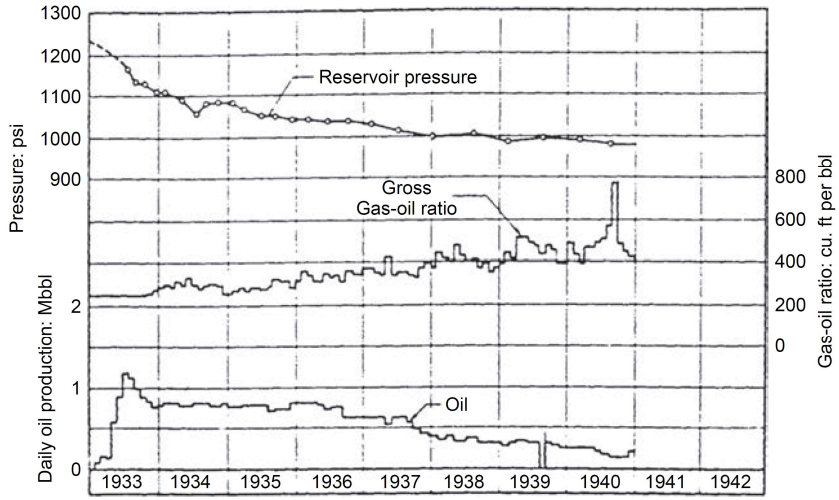
- The reservoir pressure falls slowly and continuously.
- Pressure tends to be maintained at a higher level than in a depletion drive reservoir.
- The degree of pressure maintenance depends upon the volume of gas in the gas cap compared to the oil volume.

Water production:

Absent or negligible water production.

Gas-oil ratio:

The gas-oil ratio rises continuously in up-structure wells.



Production data for a gas-cap-drive reservoir. (After Clark, N. J. Elements of Petroleum Reservoirs, SPE, 1969. Courtesy of API).

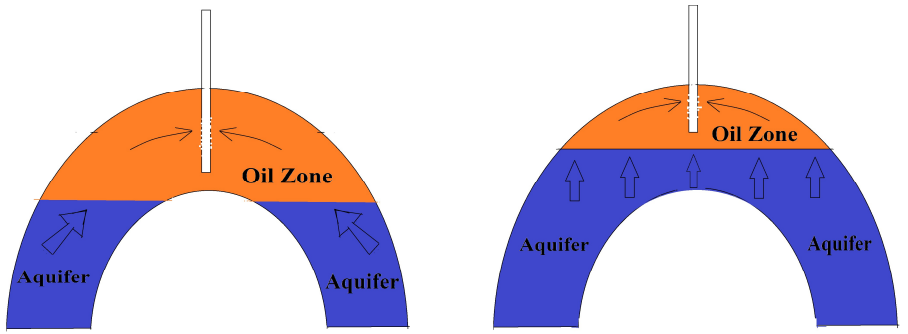
Oil recovery:

- Oil recovery by gas-cap yields a considerably larger recovery efficiency than that of depletion-drive reservoirs. The expected oil recovery by a gas-cap ranges from 20% to 40%.
- The oil recovery from a gas-cap-drive reservoir depending on the following parameters:

  Size of the Gas Cap, Vertical Permeability, Oil Viscosity, Oil Production Rate, Dip Angle, and Degree of Conservation of the Gas.

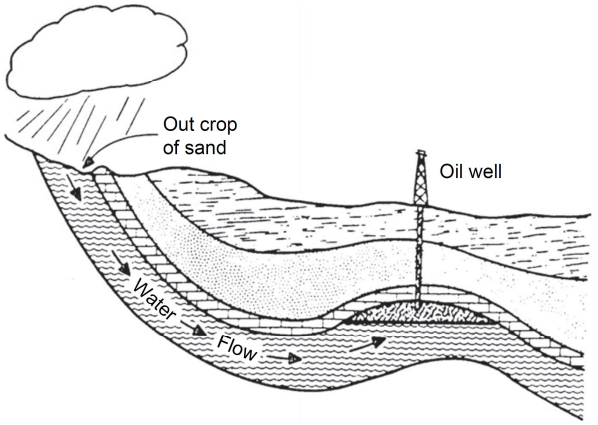
Water-Drive Mechanism

- Many reservoirs are bounded partially or completely by water bearing rocks called *aquifers*.
- It is common to speak of edge water or bottom water in discussing water influx into a reservoir.
- The aquifers may be so large compared to the reservoir, 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.
- The aquifer may be outcropped at one or more places where it may be replenished by surface water as shown schematically in the Figure.



Edge-water drive **Bottom-water drive**

Edge and bottom-water drive



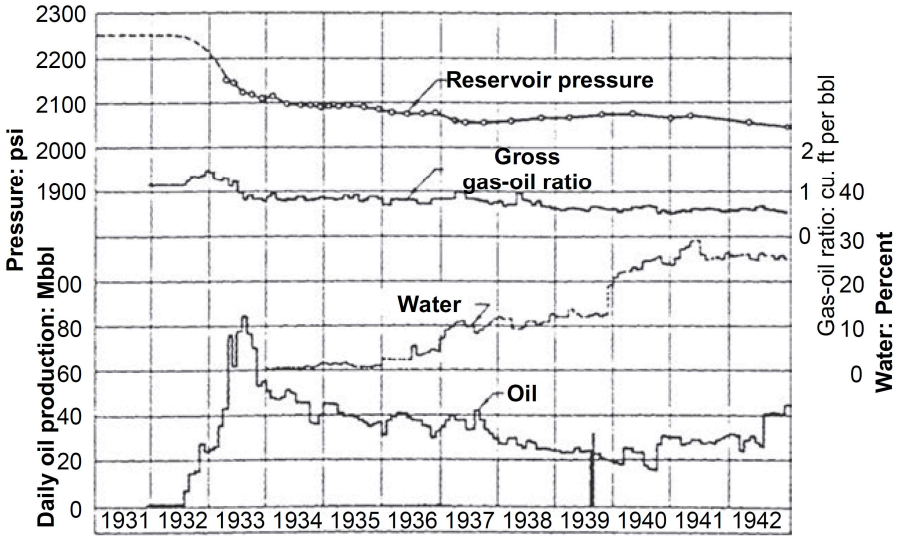
Reservoir having artesian water drive. (After Clark, N. J., Elements of Petroleum Reservoirs, SPE, 1969).

Water-Drive Mechanism

Cole (1969) presented the following characteristics for identification of the water-driving mechanism:

Reservoir pressure:

- The reservoir pressure decline is usually very gradual as shown in the Figure.
- 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.



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

Water production:

Early excess water production occurs in structurally low wells.

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.

Oil recovery:

Ultimate recovery from water-drive reservoirs is usually much larger than recovery under any other producing mechanism. The ultimate oil recovery normally ranges from 35% to 75% of the original oil in place.

Gravity-Drainage-Drive Mechanism

The mechanism of gravity drainage occurs in petroleum reservoirs as a result of differences in densities of the reservoir fluids. Cole (1969) stated that reservoir 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.

Gas-oil ratio:

- Low gas-oil ratio from structurally low wells.
- 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. 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.

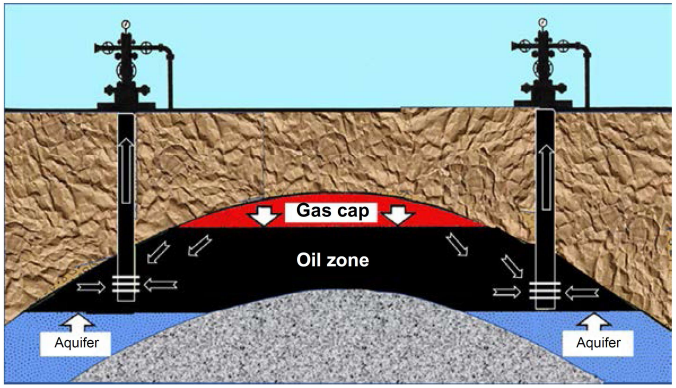
Oil recovery:

Ultimate recovery from gravity-drainage reservoirs will vary widely, due primarily to the extent of depletion by gravity drainage alone.

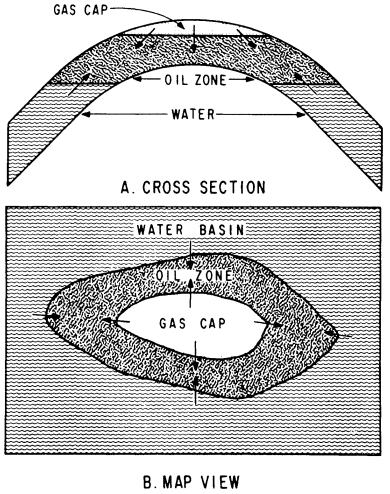
Combination-Drive Mechanism

- 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 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 mechanisms



Combination-drive reservoir (After Clark, N. J., Elements of Petroleum Reservoirs, SPE, 1969).

THANK YOU