University of Mosul

College of Petroleum & Mining Engineering

Department of Petroleum & Refining Engineering

Enhanced Oil Recovery Processes

Fourth Year

Lecture 2

Principal influences on the efficiency of enhanced recovery

The lack of sufficient natural drive in most reservoirs has led operators to introduce some form of artificial drive, the most basic method being the injection of natural gas or water.

The efficiency of an enhanced recovery method is a measure of its ability to provide greater hydrocarbon recovery than by natural depletion, at an economically attractive production rate.

The efficiency of an enhanced recovery method depends on:

a- The reservoir characteristics.

b- The nature of the displacing and displaced fluids.

1- The influence of reservoir characteristics

The most important characteristics of a reservoir are:

a- Average depth.

b- Structure in particular the dip of the bed.

c- Degree of homogeneity.

d- Petrophysical properties (permeability, capillary pressure, wettability).

A- Depth

Reservoir depth has an important influence on both the technical and economic aspects of an enhanced recovery project.

On the technical level, a shallow reservoir puts a restraint on the injection pressure that can be used, since this must be less than fracture pressure.

Economically, the cost of an enhanced recovery project is directly related to depth, as reflected, for example, in the cost of drilling the extra wells required, or in the compressor power required in the case of gas injection.

B- Dip

The hydrocarbon recovery from a porous medium is greater when gravity plays a part than when it does not. In practice, gravitational forces are only truly effective in reservoirs containing highly permeable sands or in which the dip is unusually large.

For horizontal beds the critical velocity is zero, injected water forming a tongue at the base of the bed and injected gas forming an umbrella at the top of the bed (Fig. 1). These phenomena cause rapid breakthrough of the injected fluid at the production wells.

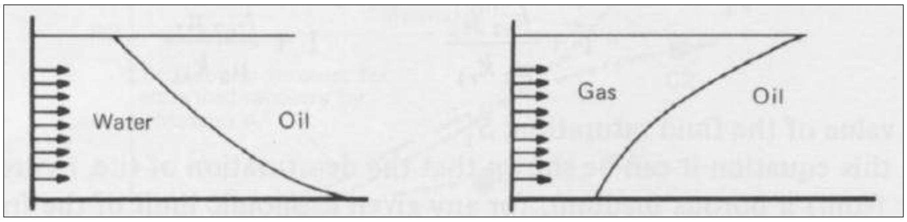

Figure 1

C- Homogeneity

In order to achieve a high recovery of hydrocarbons, there should be no impediment to fluid flow within the reservoir. Possible impediments may be of tectonic (e.g. isolating faults) or stratigraphic nature (e.g. lateral facies variation, lenses, unconformities).

In faulted and fissured reservoirs, and those with high permeability streaks, channelling allows the displacing fluid to bypass some of the oil in place and leads to a low recovery factor.

D- Petrophysical properties

Porosity, permeability, relative permeability, capillary pressure and wettability are all properties which should be taken into account in the study of an enhanced recovery project.

The higher the porosity and the higher the residual oil saturation at the end of the natural recovery phase, the more attractive an enhanced recovery project becomes.

For enhanced recovery as for natural recovery a high permeability is encouraging (high initial oil saturation, larger pore throats, etc.). However, the higher the permeability the greater the chance that the natural recovery will be so high that any enhanced recovery project would be uneconomic.

The effect of capillary forces on recovery efficiency depends on the rate of production. The capillary forces often have a detrimental effect, being responsible for the trapping of oil within the pores. This trapping is a function of the ratio of viscous forces to capillary forces. The residual oil saturation decreases as the ratio of viscous forces to capillary forces increases.

2- The influence of fluid characteristics

The principal fluid property to be taken into account when designing an enhanced recovery project is the viscosity.

If the fluids are highly viscous the displacement velocities will be low. Oil production will be at such a low rate that it will not be economically attractive.

For a given volume of injected fluid, all other things being equal, the residual oil saturation will be higher the higher the oil viscosity.

Viscosity has a further important effect on sweep efficiency in that it is one of the parameters which determine the mobility ratio (mobility ratio is defined as the mobility of the displacing fluid (i.e. water) divided by the mobility of the displaced fluid (i.e. oil).

Enhanced Oil Recovery Processes
Fourth Year
Lecture 1

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Enhanced Oil Recovery Processes

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Lecture 1

Introduction

Oil recovery processes

1- Primary oil recovery

2- Secondary oil recovery

3- Tertiary oil recovery (Enhanced Oil Recovery)

Driving mechanisms that provide the natural energy necessary for oil recovery:

1- Rock and liquid expansion drive

2- Depletion drive or solution gas drive

3- Gas-cap drive

4- Water drive

5- Gravity drainage drive

6- Combination drive

Introduction:

The methods of calculation of reserves in place and of the recovery factors which could be expected by natural depletion. The presence of a gas-cap or an active aquifer generally results in a high recovery factor, by providing a strong natural drive. The lack of sufficient natural drive in most reservoirs has led to introduce some form of artificial drive, the most basic method being the injection of natural gas or water. In the early days of the petroleum industry, reservoirs were allowed to produce naturally until a certain stage of depletion had been reached, generally when the production rates had become uneconomic. This was known as the primary production phase. In the second phase, the recovery was increased by installing methods of artificial drive (water or gas injection) and these were logically known as "secondary recovery methods".

Before undertaking a secondary recovery project, it should be clearly proven that the natural recovery processes are insufficient, otherwise there is risk that the heavy capital investment required may be completely wasted. A certain amount of production data is therefore required.

Natural production depends on a reservoir's internal energy, and arises due to the existence of a higher pressure in the rock pores than at the bottom of the well. All other recovery methods depend on the provision of additional energy to improve of the remaining reserves.

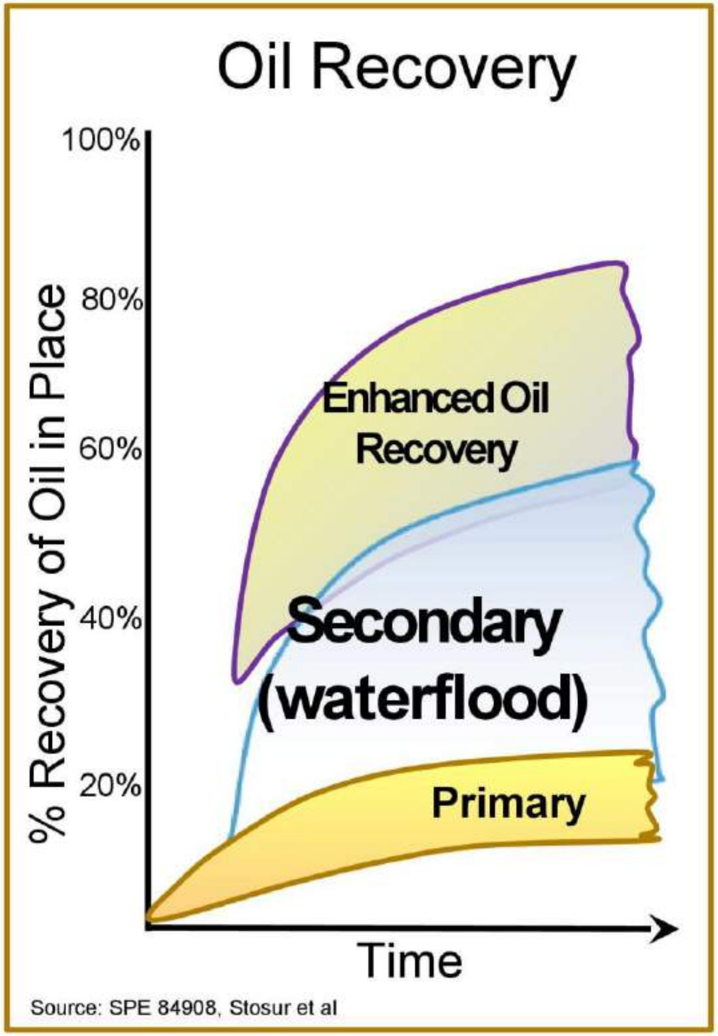
Oil recovery processes

Recovery of hydrocarbons from an oil reservoir is commonly recognized to occur in three recovery stages. These are:

1- Primary oil recovery: This is the recovery of hydrocarbons from the reservoir using the natural energy of the reservoir as a drive.

2- Secondary oil recovery: This is recovery aided or driven by the injection of water or gas from the surface.

3- Tertiary oil recovery (Enhanced Oil Recovery): There are a range of techniques that are applied to reservoirs in order to improve flagging production.



Primary

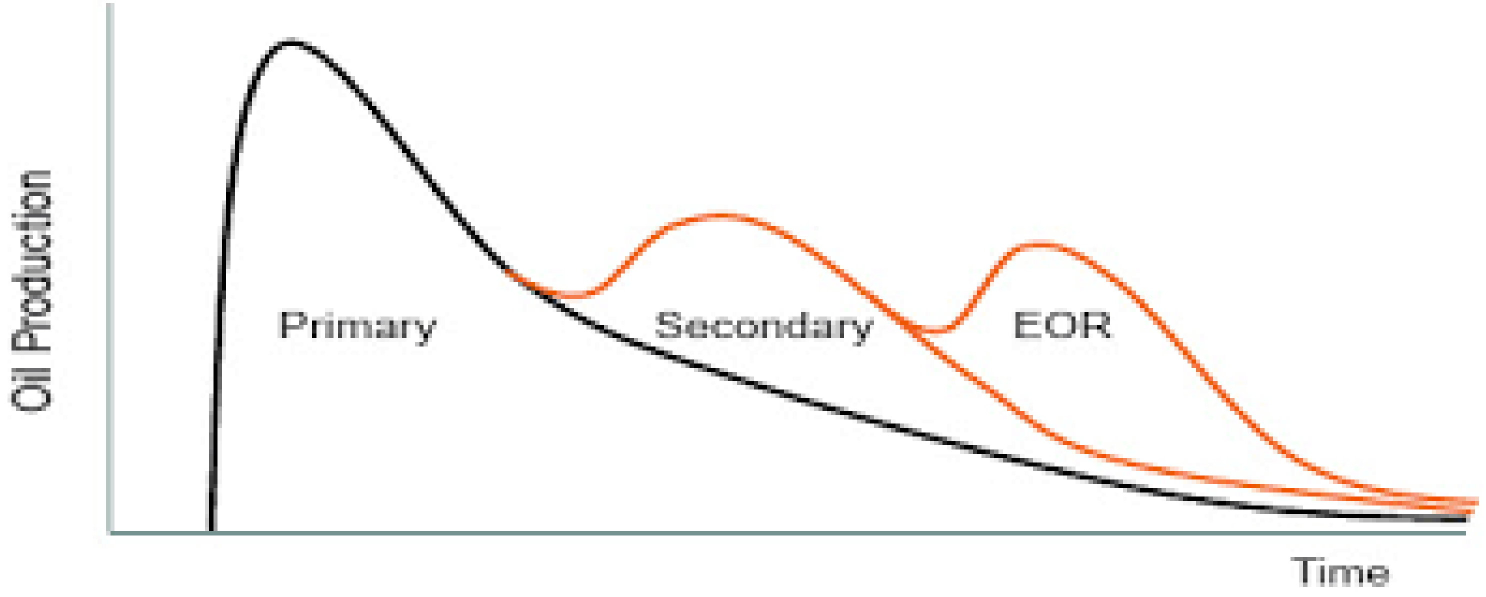
Primary oil recovery refers to the process of extracting oil either via the natural rise of hydrocarbons to the surface of the earth or via pump jacks and other artificial lift devices.

Water Flood

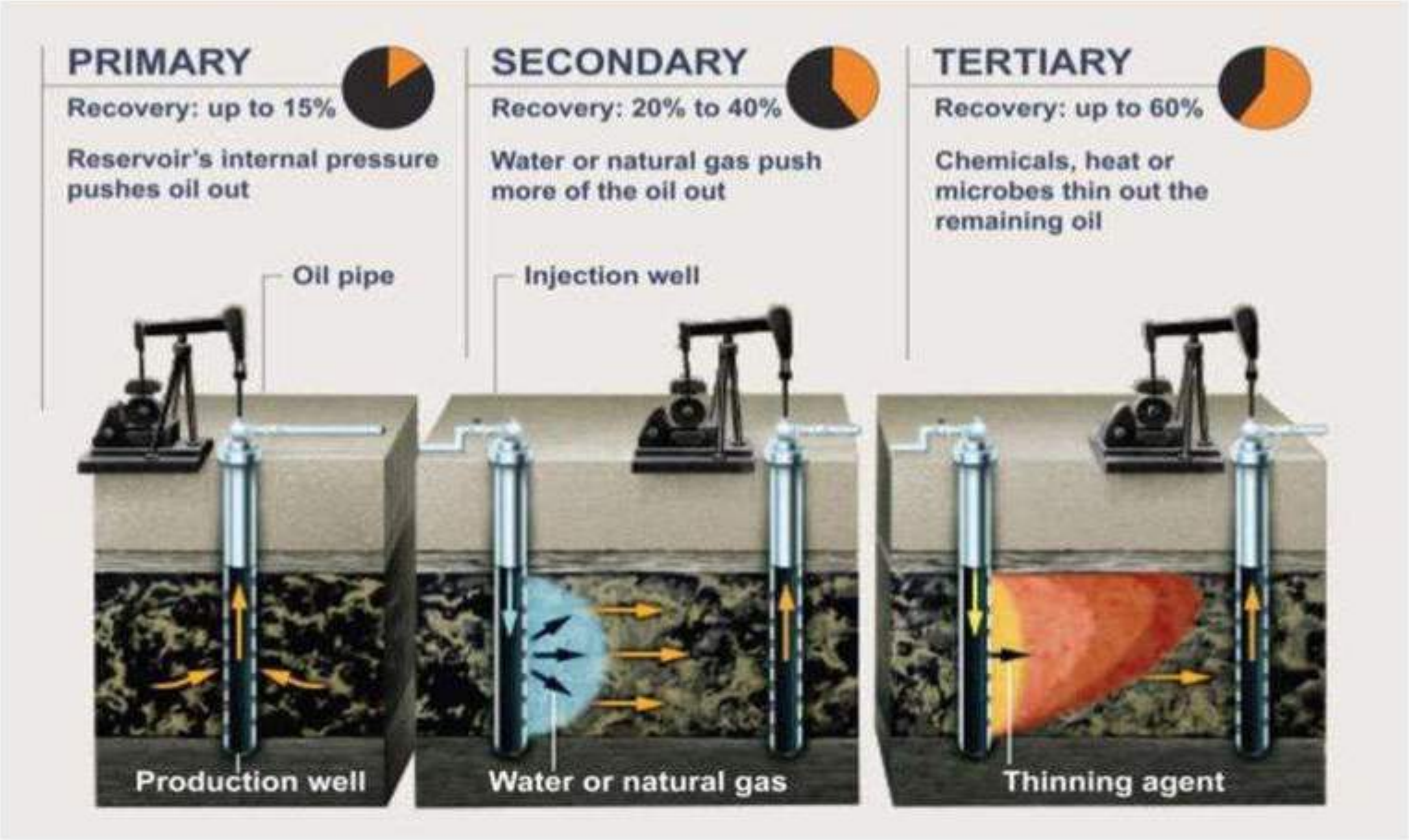
Waterflooding is the use of water injection to increase the production from oil reservoirs. Use of water to increase oil production is known as "secondary recovery.

EOR

Enhanced oil recovery (Tertiary) is the process of recovering oil which can't be extracted from an oil reservoir through primary or secondary recovery techniques.


Oil Production
Primary
Secondary
EOR
Time

Steps of oil field developing



Primary oil recovery

Primary oil recovery uses the natural reservoir energy to drive the oil from the reservoir to producing wells. It refers to the volume of hydrocarbon produced by the natural energy prevailing in the reservoir. In the primary process, the oil is forced out of the petroleum reservoir by existing natural pressure of the trapped fluids in the reservoir.

Each reservoir is composed of a unique combination of geometric form, geological rock properties, fluid characteristics, and primary drive mechanism. Each drive mechanism has certain typical performance characteristics in terms of:

a- Ultimate recovery factor

b- Pressure decline rate

c- Gas-oil ratio

d- Water production

For 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.

During primary recovery the natural energy of the reservoir is used to transport hydrocarbons towards and out of the production wells. These are several different energy sources, and each gives rise to a drive mechanism. Early in the history of a reservoir the drive mechanism will not be known. It is determined by analysis of production data (reservoir pressure and fluid production ratios). The earliest possible determination of the drive mechanism is a primary goal in the early life of the reservoir, as its knowledge can greatly improve the management and recovery reserves from the reservoir in its middle and later life.

There are basically six driving mechanisms that provide the natural energy necessary for oil recovery:

1- Rock and liquid expansion drive
2- Depletion drive or solution gas drive
3- Gas-cap drive
4- Water drive
5- Gravity drainage drive
6- Combination drive

1- Rock and liquid expansion drive:

When an oil reservoir initially exists at a pressure higher than its bubble-point pressure, the reservoir is called an undersaturated-oil reservoir. At pressure 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:

a- Expansion of the individual rock grains

b- Formation compaction

Both of the above two factors are the results of a decrease of fluid pressure within the pore space, 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.

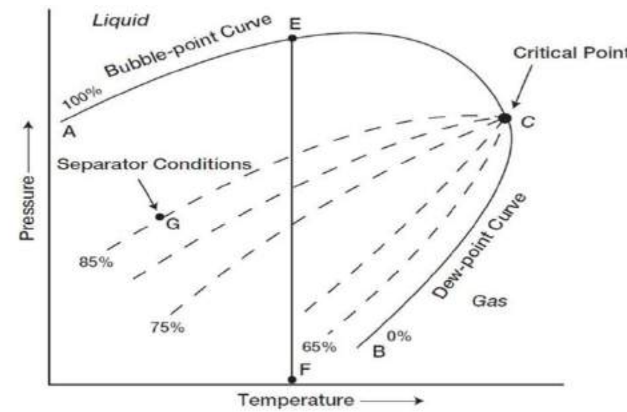


Figure 1-4. A typical phase diagram for a low-shrinkage oil.

This driving mechanism is considered the least efficient driving force and usually results in the recovery of only a small percentage of the total oil-in-place.

<u>Bubble-point pressure ---</u> *is defined as* ***the pressure at which the first bubble of gas appears at a specific temperature****. ... When the reservoir is depleted and its pressure falls below the bubble-point pressure, free gas starts to form in the reservoir.*

In their original condition, reservoir oils include some natural gas in solution. The pressure at which this natural gas begins to come out of solution and form bubbles is known as the bubble point pressure

2- Depletion drive or solution 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. Crude oil under high pressure may contain large amounts of dissolved gas. When the reservoir pressure is reduced as fluids are withdrawn, gas comes out of solution and displaces oil from the reservoir to the producing wells (Figure 1). The efficiency of solution gas drive depends on the amount of gas in solution, the rock and fluid properties, and the geological structure of the reservoir. Recoveries are low, on the order of 10-15 % of the OOIP. Recovery is low, because the gas phase is more mobile than the oil phase in the reservoir. As pressure declines, gas flows at a faster rate than the oil, leading to rapid depletion of reservoir energy, which is noted by increasing gas/oil ratios in the field

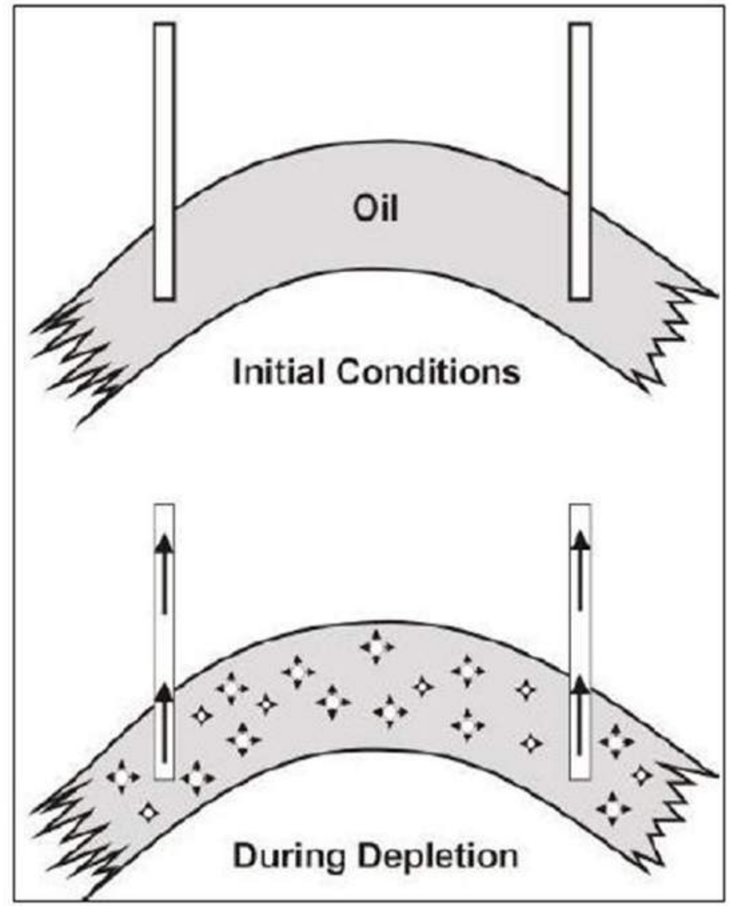


Figure 1: Depletion or solution gas drive reservoir.

3- Gas-cap drive:

Gas-cap drive reservoirs can be identified by the presence of a gas cap which already existing above the reservoir. The presence of the expanding gas cap limits the pressure decrease experienced by the reservoir during production. The actual rate of pressure decrease is related to the size of the gas cap.

The GOR rises only slowly in the early stages of production from such a reservoir because the pressure of the gas cap prevents gas from coming out of solution in the oil and water. As production continues, the gas cap expands pushing the gas-oil contact (GOC) downwards (Figure 2). Eventually the gas-oil contact (GOC) will reach the production wells and the gas-oil ratio (GOR) will increase by large amounts.

The recovery of gas cap reservoirs is better than for solution drive reservoirs (20% to 40% OOIP), and the recovery efficiency depends on the size of the gas cap.

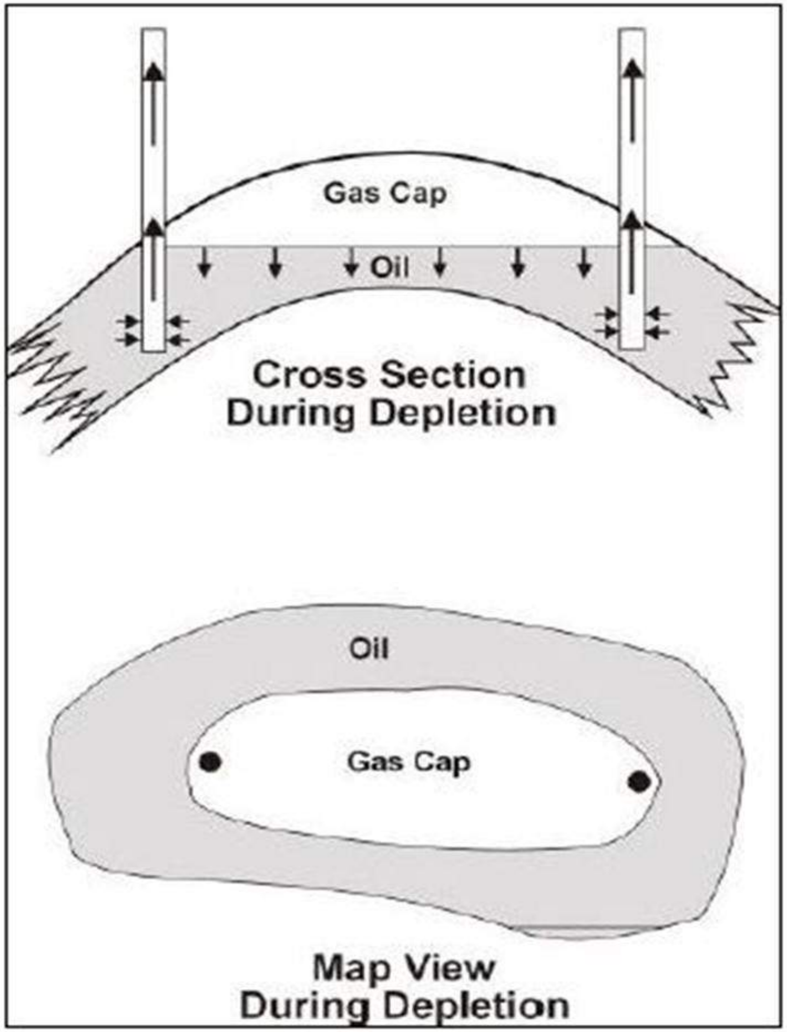


Figure 2: Gas cap drive reservoir.

4- Water drive reservoirs:

The drive energy is provided by an aquifer that interfaces with the oil in the reservoir at the oil-water contact (OWC). As production continues, and oil is extracted from the reservoir, the aquifer expands into the reservoir displacing the oil.

Two types of water drive are commonly recognized:

a- Bottom water drive (Figure 3)

b- Edge water drive (Figure 3)

The pressure history of a water driven reservoir depends upon:

a- The size of the aquifer

b- The permeability of the aquifer

c- The reservoir production rate

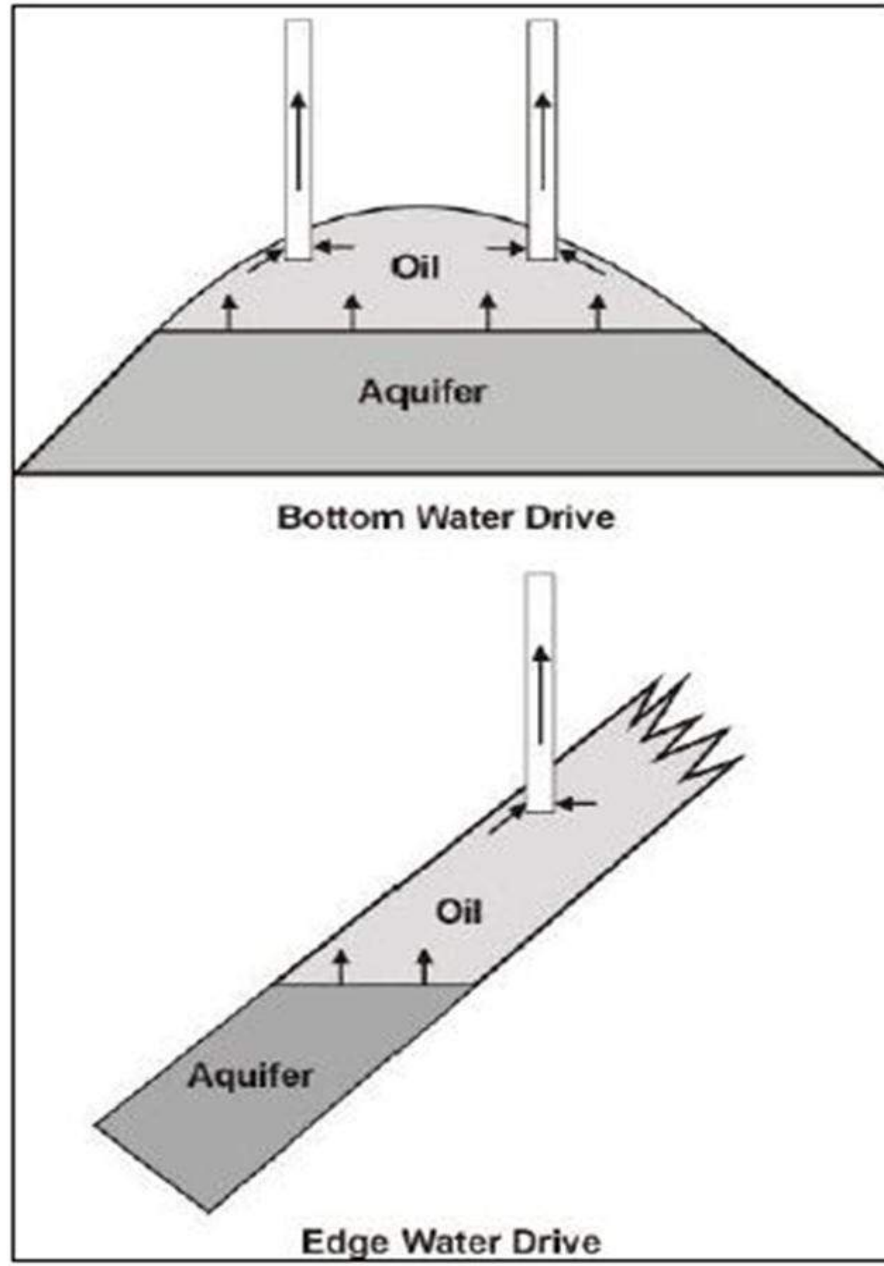


Figure 3: Water drive mechanism.

If the production rate is low, and the size and permeability of the aquifer is high, then the reservoir pressure will remain high because all produced oil is replaced efficiently with water. If the production rate is too high then the extracted oil may not be able to be replaced by water in the same timescale, especially if the aquifer is small or low permeability. In this case the reservoir will fall.

The gas-oil ratio (GOR) remains very constant in a strongly water driven reservoir, as the pressure decrease is small and constant, whereas if the pressure decrease is higher, the GOR increases due to gas comes out from the oil and water in the reservoir.

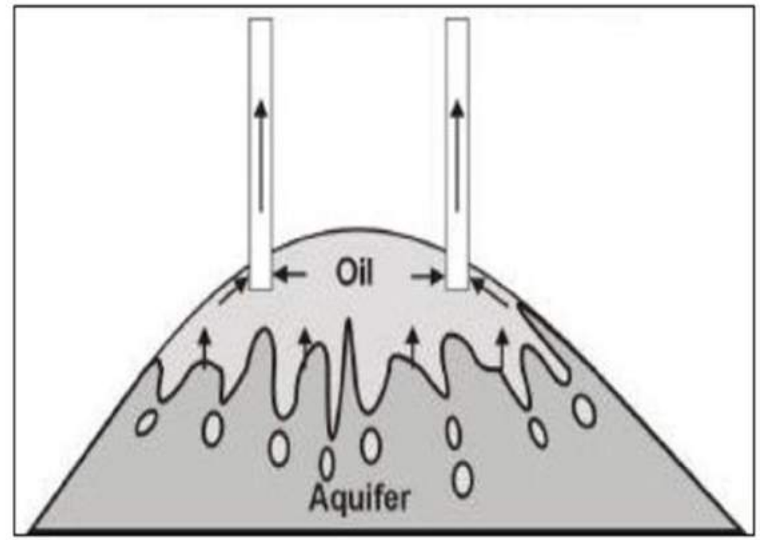


Figure 4: A schematic example of fingering in a water drive reservoir.

The recovery from water driven reservoirs is usually good (20-60% OOIP). The efficiency with which the water displaces the oil in the reservoir depends on reservoir structure, production well placing, oil viscosity, and production rate. If the ratio of water to oil viscosity is large, or the production rate is high then fingering can occur which leaves oil behind in the reservoir (Figure 4).

5- Gravity drainage drive:

The density differences between oil and gas and water result in their natural segregation in the reservoir. This process can be used as a drive mechanism, but is relatively weak, and in practice is only used in combination with other drive mechanisms. Figure 5 shows production by gravity drainage.

The best conditions for gravity drainage are:

a- Thick oil zones.

b- High vertical permeability.

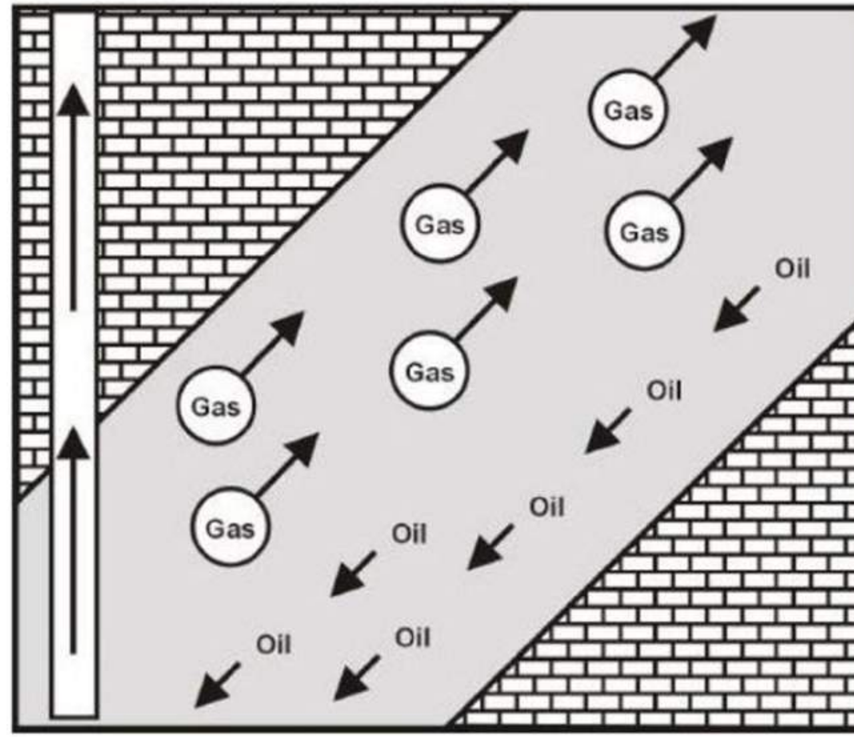


Figure 5: Gravity drainage mechanism.

The rate of production engendered by gravity drainage is very low compared with the other drive mechanisms examined so far. However, it is extremely efficient over long periods and can rise to extremely high recoveries (50-70% OOIP). Consequently, it is often used in addition to other drive mechanisms.

6- 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 6.

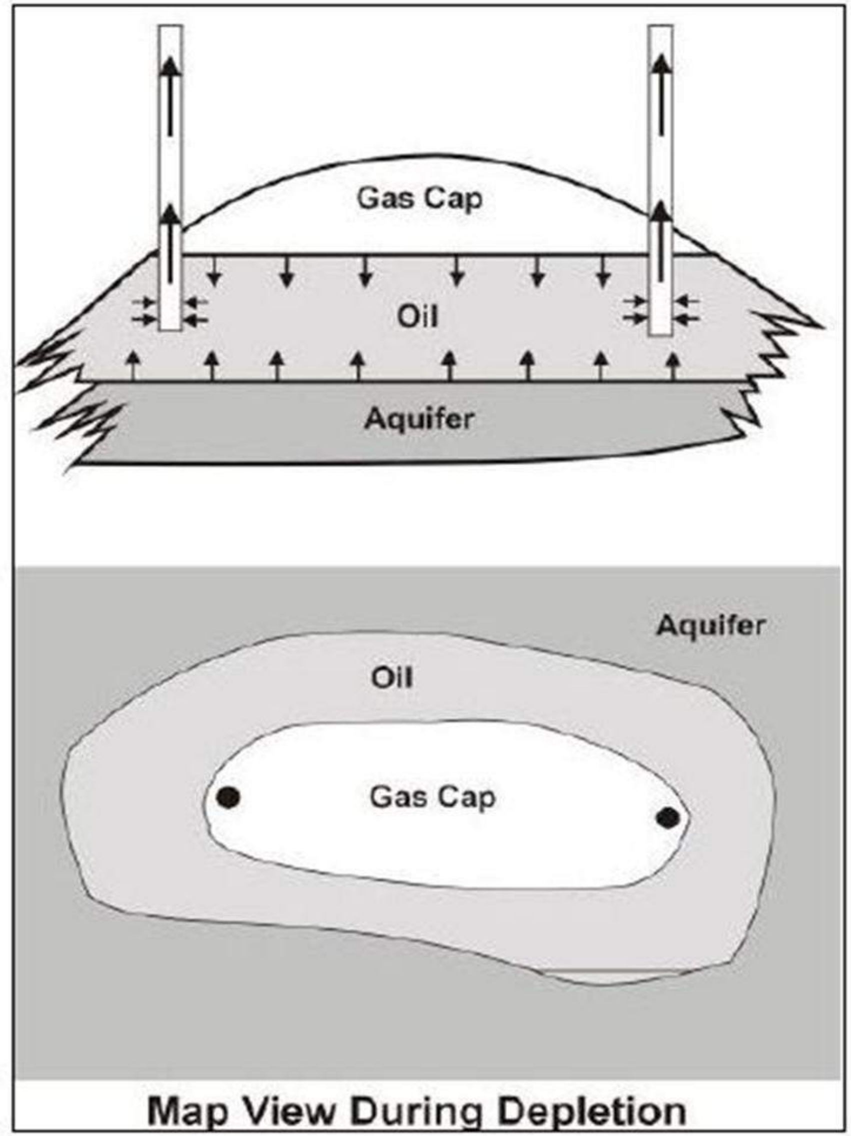


Figure 6: Combination drive reservoir.

Two combinations of driving forces can be present in combination-drive reservoirs. These are

a- Depletion drive and a weak water drive

b- Depletion drive with a small gas cap and a weak water drive