Primary Recovery Mechanisms

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. 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:

1) Rock and liquid expansion drive.
2) Depletion drive.
3) Gas cap drive.
4) Water drive.
5) Gravity drainage drive.
6) Combination drive.

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 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:

(1) expansion of the individual rock grains.
(2) formation compaction.

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.
Depletion drive.

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 below.
Oil production by depletion drive is usually the least efficient recovery method. Ultimate oil recovery from depletion drive reservoirs may vary from less than 5% to about 30%. The low recovery from this type of reservoir suggests that large quantities of oil remain in the reservoir and, therefore, 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:
(1) expansion of the gas cap gas.

(2) expansion of the solution gas as it is liberated.

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.

Oil recovery by gas cap expansion is actually a frontal drive displacing mechanism which, therefore, yields considerably larger recovery efficiency than that of depletion drive reservoirs. The expected oil recovery ranges from 20% to 40%.

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

1) **Size of the original gas cap**: the ultimate oil recovery increases with increasing size of the gas cap.

2) **Vertical permeability**: Good vertical permeability will permit the oil to move downward with less bypassing of gas.

3) **Oil viscosity**: As the oil viscosity increases, the amount of gas bypassing will also increase, which leads to a lower oil recovery

4) **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.

5) **Dip angle**: When the gas cap is considered the main driving mechanism, its size is a measure of the reservoir energy available to produce the crude oil system. Such recovery normally will be 20% to 40% of the original oil in place, but if some other features are present to assist, such as steep angle of
dip which allows good oil drainage to the bottom of the structure, considerably higher recoveries (up to 60% or greater) may be obtained. Conversely, extremely thin oil columns may limit oil recovery to lower figures regardless of the size of the gas cap.

**Water drive.**

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.

the reservoir may outcrop at one or more places where it may be replenished by surface water as shown schematically in Figure below.
The decline in the reservoir pressure is usually very gradual. The pressure–production history of a typical water drive reservoir is shown in the figure. 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. Several large oil reservoirs in the Gulf Coast areas of the United States have such active water drives that the reservoir pressure has declined by only about 1 psi per million barrels of oil produced.

Water production is the main concern of this type of drive mechanism since 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.

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 and the degree of activity of the water drive. The ultimate oil recovery normally ranges from 35% to 75% of the original oil-in-place.

**Gravity drainage drive.**

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. 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, the best available data indicates that, in most reservoirs, the fluid contacts actually are essentially horizontal.

The reservoir pressure decline rates are variable depending on the amount of gas conservation. If 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 only as a result of gravity drainage, the reservoir would show a rapid pressure decline.

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. There are three important factors that affect ultimate recovery from gravity drainage reservoirs:

1) **Permeability in the direction of dip**: Good permeability, particularly in the vertical direction and in the direction of migration of the oil, is a prerequisite for efficient gravity drainage.

2) **Reservoir producing rates**: Since the gravity drainage rate is limited, the reservoir producing rates should be limited to the gravity drainage rate, and then maximum recovery will result. If the reservoir producing rate exceeds the gravity drainage rate the depletion drive producing mechanism will become more significant with a consequent reduction in ultimate oil recovery.

3) **Oil viscosity**: Oil viscosity is important because the gravity drainage rate is dependent upon the viscosity of the oil. In the fluid flow equations, as the viscosity decreases the flow rate increases. Therefore, the gravity drainage rate will increase as the reservoir oil viscosity decreases.

**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. Two combinations of driving forces are usually present in combination drive reservoirs:

(1) depletion drive and a weak water drive, or
(2) depletion drive with a small gas cap and a weak water drive.

In addition, gravity segregation can also play an important role in any of these two drives.

These types of reservoirs usually experience a relatively rapid pressure decline. Water encroachment and/or external gas cap expansion are insufficient to maintain reservoir pressures.

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 it is possible to reduce the magnitude of recovery by depletion drive. In most combination drive reservoirs it will be economically feasible to institute some type of pressure maintenance operation, either gas injection or water injection, or both gas and water injection, depending upon the availability of the fluids.