LECTURE №6

RESERVOIR ENERGY AND FORCES OPERATIVE IN RESERVOIRS. OIL RESERVOIR DRIVES. OIL RECOVERY UNDER DIFFERENT DRIVES

Fluids flow to oil and gas wells because of the differential between the formation and bottom-hole pressures. The magnitude of this pressure differential depends on the rate of liquid (or gas) withdrawals from the well, the physical properties of the reservoir rocks and fluids and also on the type of reservoir energy that causes oil and gas to move.

Until quite recently, it was considered that the influence of each well extented to a comparatively small area of the formation around the bottom hole, so that each well had a limited drainage area. This view proved to be erroneous. It is now definitely established that the whole area of every oil and gas reservoir, together with the wells constitutes a single hydraulically interconnected system (unless, of course, the formation is split up into separate blocks by tectonic dislocations). Thus the influence of producing wells drive area, right up to the boundaries of the reservoir.

Hence it follows that the type and reserves of energy and forces operative in the reservoir that drive the oil and gas to the bottom holes of wells must be considered in the structure of the entire reservoir and of the adjacent areas, and also in relation to the properties of the reservoir fluids and the rocks of the entire reservoir.

Every oil and gas reservoir has an initial energy reserve. This energy reserve is consumed in moving the oil and gas through the formation to the well. The energy reserve of a reservoir depends on the magnitude of formation pressure. In the general case, the sources of reservoir energy, which cause oil and gas to flow to the well are:

- the elastic energy of compressed reservoir rocks and fluids;

- the energy of free gas and of the gas evolving from the oil when pressure is reduced;

- potential energy of water encroachment;

- the potential energy of the static pressure of the oil itself due to gravity.

There may be single dominant type of reservoir energy, driving the oil and gas, or else they may be driven by a number of forces. Further on it will be shown that the energy characteristics of a reservoir determine the entire process of development and exploitation.

Let us consider in greater detail the nature and the character of manifestation of the types of reservoir energy mentioned above. There are **6 oil reservoir drives:**

- **elastic drive;**
- **solution gas drive;**
- **water drive;**
- **gas cap drive;**
- **gravity drive;**
- **combination drive.**

The drive of a reservoir is determined both by conditions created artificially as result of the development and the production of a reservoir, and also by natural conditions. A particular mechanism of a reservoir drive may be established, maintained, controlled and even replased by a different mechanism. It depends to a large extent on the rate of fluid and gas withdrawals and on artificial measures carried out during the exploitation of the reservoir (such as injecting a driving agent into the reservoir). Geological conditions and the specific sourse of formation energy only help to establish a particular driving mechanism but do not only fully determine it.

Elastic drive. *Condition elastic drive* - excess reservoir pressure above the saturation pressure. Bottom-hole pressure not less than the saturation pressure.

Oil is a single-phase state. The influx of oil to the wells is due to the elastic properties of reservoir rocks and fluids.

In the case of an *elastic-water drive* the changes observed in the reservoir behaviour are of a different nature. A typical feature of the elastic-water drive mechanism is a decline in pressure during the initial period. Thereafter, if fluid withdrawals remain constant, the rate of pressure decline tapers off. This is due to the fact that with time, the zone of reduced pressure extends to an ever increasing area of the reservoir, and to maintain a given influx of fluid by elastic expansion of the reservoir rocks and fluids a smaller pressure decline is required than in the initial period. If the bottom-hole pressure is maintained constant, the flow at the wells at first diminishes rapidly, but later on the rate of decrease tapers off. The elastic properties of reservoir rocks and fluids are nicely characterised by the fact that any change in pressure at any point in the reservoir is not transmitted through the formation instantaneously but at a certain rate.

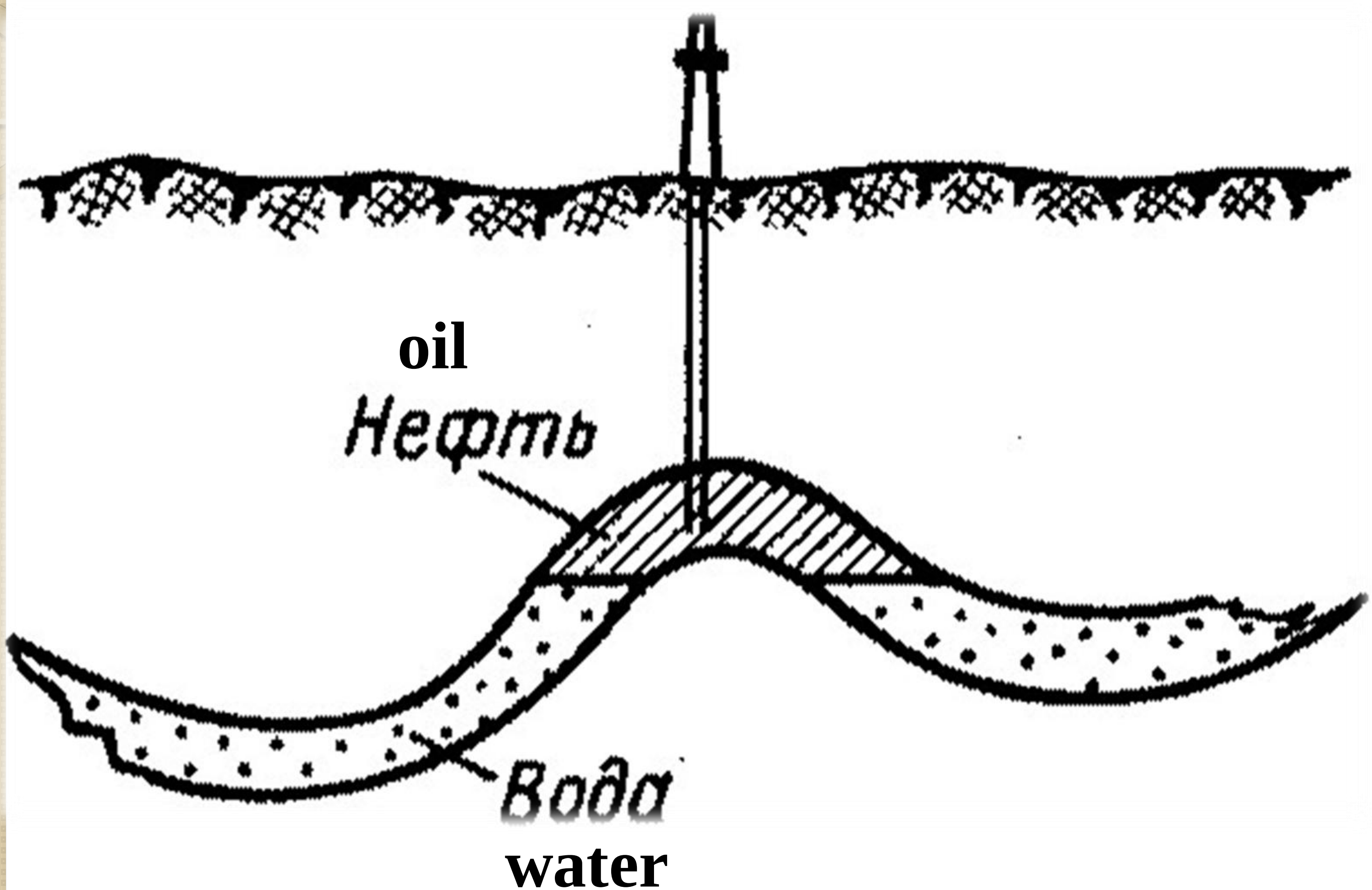
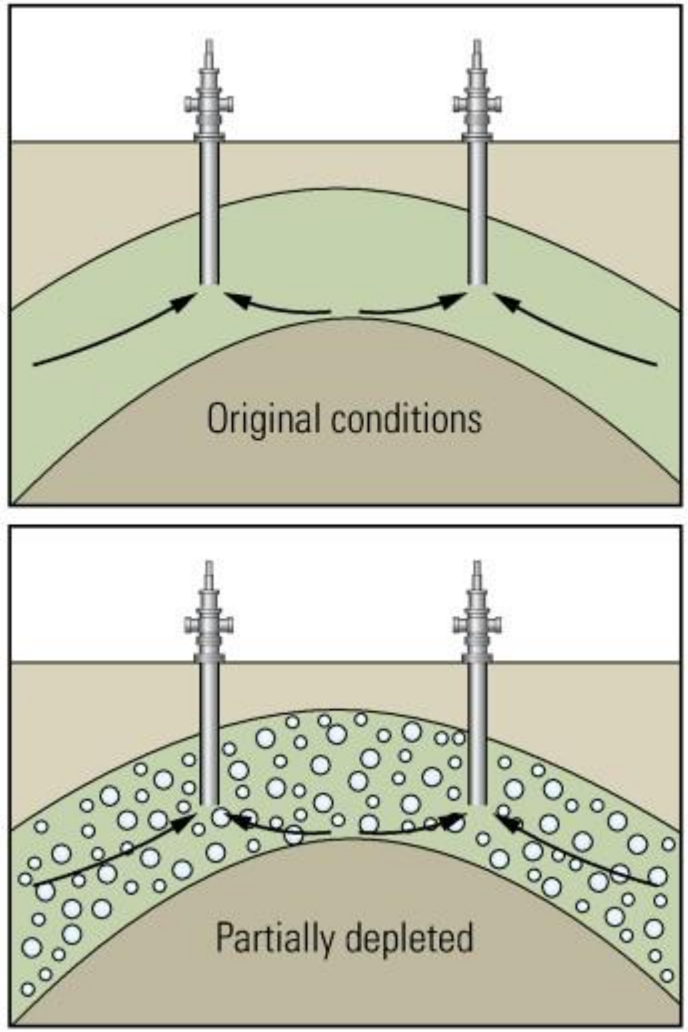


Fig. 1 – Elastic-water drive

When disclosure well oil reservoir under the action of elastic expansion will initially sail up the hole with sites located in very close proximity to the hole. But because of the oil from these sites arrives into the well, the pressure in them decreases, which in turn causes the inflow of oil from more remote areas. This process will evolve over time, and at some point the pressure begins to fall in the aquifer of the reservoir. Since then, the water from the aquifer region will begin to enter the reservoir area previously occupied by water and displace the oil towards the well.

Solution gas drive (or **dissolved gas drive).** Occurs when the reservoir pressure is less saturation pressure and gas bubbles released from the oil at lower pressure expands, to displace oil wells (in the reservoir moves carbonated oil). Solution drive found in deposits, which initially oil saturated gas. Due to the high mobility of the gas efficiency solution gas drive is small.

In a solution gas drive lighter hydrocarbon components that exist as a liquid in the reservoir before it is produced come out in the form of gas as the reservoir produced. The dissolved gas coming out of the oil expands. In solution gas drive reservoir pressure declines rapidly and continuously and wells generally require pumping or some other artificial lift at an early stage. The gas-oil ratio is lowering slowly, then rises to a maximum and drops.

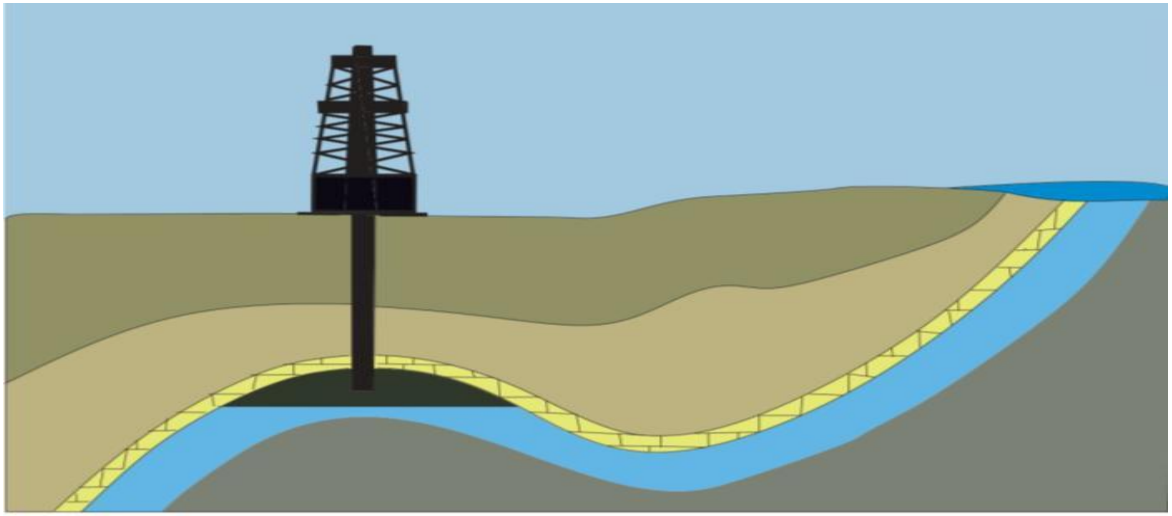


Gas in the saturated oil of a solution-gas drive system comes out of solution after the reservoir pressure drops below the bubblepoint

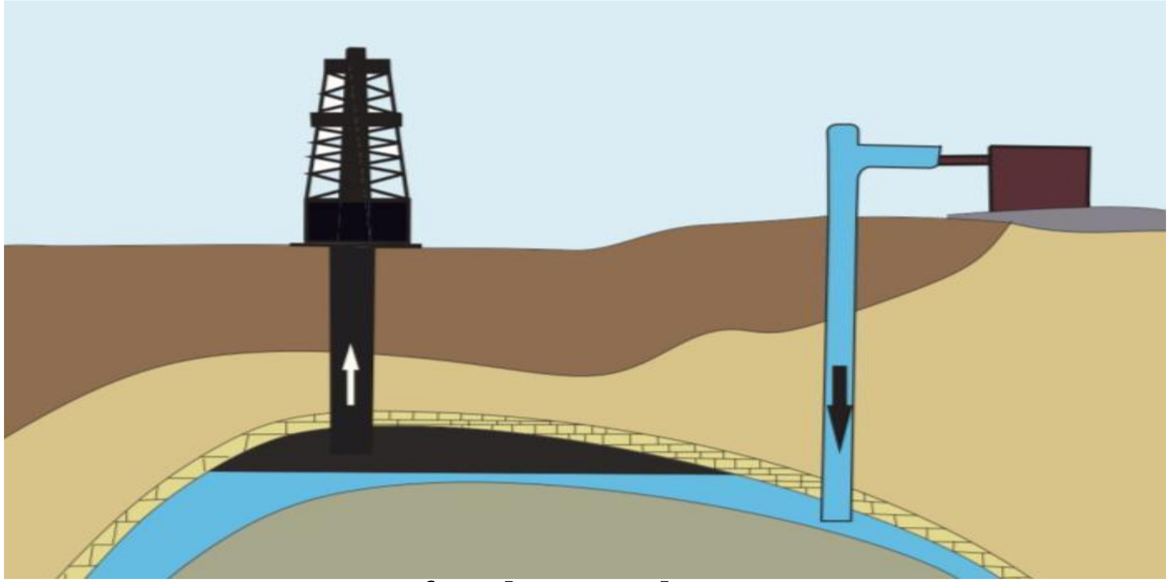
Water drive. Oil displaced under the pressure of natural or artificial water download at a pressure above the saturation pressure. In *natural water drive* systems the oil is driven to the bottom hole under the natural pressure of edge water. A water drive can also be created *artificially* by injecting water through special injection wells.

In the case of a water drive in its pure form, oil withdrawn from the reservoir is displaced, volume for volume, by encroaching water. The perimeter of the oil drainage boundary then continuously shifts and contracts. During the exploitation of a water drive reservoir there is first observed a certain decline in reservoir pressure establishing a pressure differential which causes the encroachment of water on the productive zone.

The stabilization of reservoir pressure with time in the case of a steady rate of oil production proves that water drive operates with complete replacement of the withdrawn oil by water. However, if the rate of oil withdrawals from the reservoir continually increases, a time may come when at the given pressure, through capacity of the water drive system becomes inadequate and the volume of water entering the reservoir is less than the volume of oil withdrawals. In this case reservoir pressure begins to decline and the water drive mechanism may be replaced by the solution gas drive. As a result of the slow decline in reservoir pressure in water drive reservoirs production from wells remains



Natural water drive system



Artificial water drive system

zone of drainage boundary

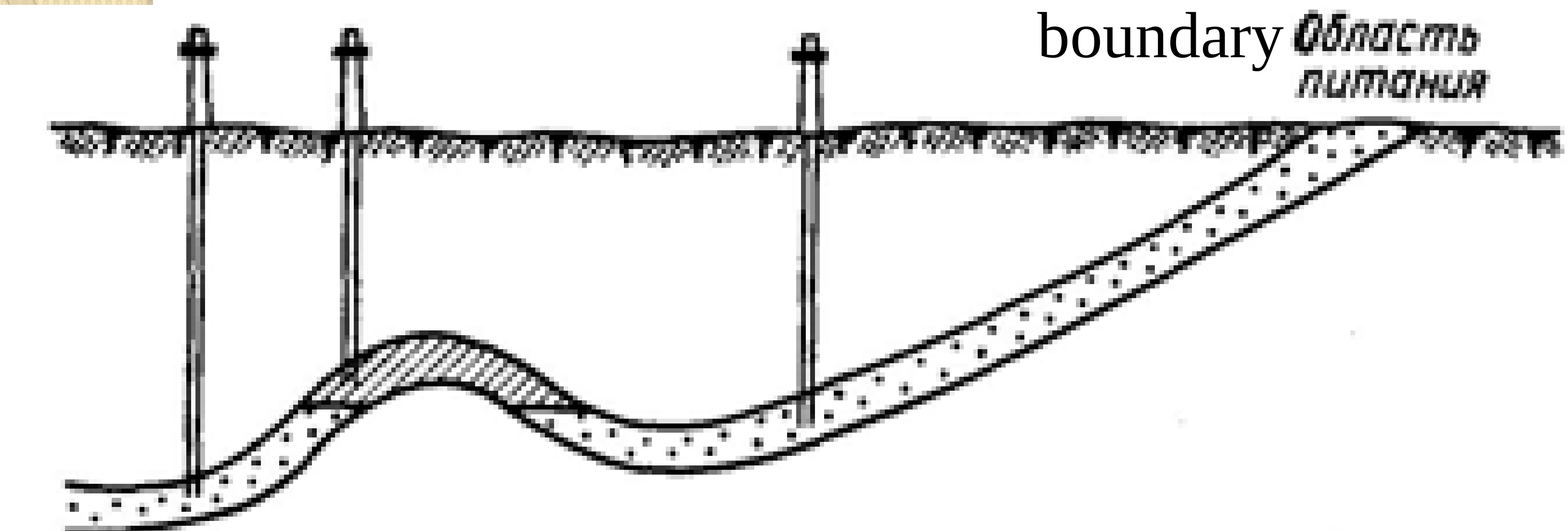
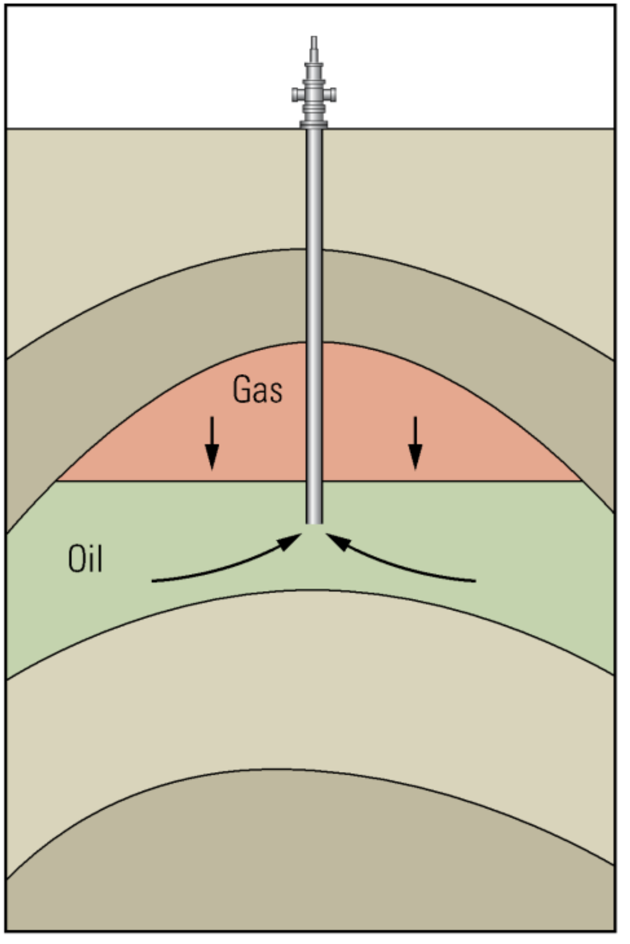


Fig. 2 - Natural water drive

steady for a long time. The gas factor too usually remains constant until the pressure at bottom holes drops below saturation pressure.

In **gas cap drive** reservoirs the process of displacement of oil by the expanding gas is usually accompanied by gravity effects: the oil flows by gravity to the lowest parts of the reservoir and the gas released from solution rises to the upper zone and replenishes the gas cap. These effects are the more pronounced the greater are the angle of dip of the strata, the permeability of reservoir rock, and the lower the rate of liquid withdrawals, i.e., the rate of filtration. The replenishment of the expanding gas cap by the gas evolving from solution slows down the rate of decline of reservoir pressure. Gravitation segregation of oil and gas in gas cap reservoirs is also largely responsible for the fact that the gas-oil ratio of wells remote from the gas zone of the reservoir can remain low for a long time. In wells which are close to the gas-oil contact, the gas-oil ratio usually increases rapidly, so that ultimately the wells may begin to produce gas alone. Under favourable geological conditions these gravitational effects may result in the appearance of a gas cap even where there was none originally and then the reservoir operates mainly by the energy of gas released from solution, i.e., by a solution gas drive mechanism.



Gas cap drive is energized by expanding gas that fills the voids that occur after liquids are removed

The **gravity drive** is due to the fact that oil-bearing formations are not horizontal but tilted. The magnitude of the static pressure then depends upon the angle of the dip of the strata. In low-dipping strata the oil can also flow to the wells by gravity, particularly in thick formations. The level of fluid in the reservoir then drops below the capping, this being the case of movement of fluid with a free surface. In some cases gravity is the only type of energy causing oil to move to the wells. This occurs most frequently in closed-type deposits after prolonged exploitation when the energy of gas drive has been depleted.

Combination drive. Depletion and water drives can be characterized as pure drive mechanisms; however, another drive is one that can best be described as a combination drive. One such drive has a gas cap above the oil and water below it. Both the gas cap and the water drive the oil into and up the wellbore to the surface. Another type of combination drive has gas dissolved in the oil with water below it. Both the water and the gas coming out of solution drive the oil to the surface.

Oil recovery under different drives.

The oil recovery factor of a reservoir, defined as the ratio between recovered oil and the initial reserve of oil.

According to the experimental and statistical field data the recovery factor may have the following values depending on the expulsive forces operative in the reservoir:

elastic-water drive ….. 0.4-0.7

solution gas drive …... 0.05-0.3

water drive …………. 0.5-0.8

gas cap drive ……….. 0.1-0.4

gravity drive ……….. < 0.1

The highest recovery factor is assured by the water drive since in this case the oil is displaced by water, the viscosity of which under reservoir conditions may be greater than that of the oil. In any case, the viscosity of water is many times greater than that of gas. It is known that the greater the viscosity of the displacing agent in relation to that of the oil, the greater is oil recovery. When water drive reservoirs are produced for a long time (until the water breaks through into the wells), there is a single-phase movement of the oil in the oil-bearing part of the reservoir as it is displaced by the water acting, as it were, as a piston.

In the case of a gas cap drive oil recovery is somewhat lower than with a water drive because in this case oil is displaced by gas which is of considerably lower viscosity than oil and does not wet the rock. In such cases, even a small decline in reservoir pressure results in the release of gas from the oil which reduced the phase permeability to oil. However, when the dip of the strata is rather steep (not less than 12-15°) and other conditions are favourable to gravitational segregation of oil and gas, the oil recovery factor may be rather high.

Very low oil recovery factors are observed when solution gas supplies the main driving force. In this case, a considerable part of the energy of the expanding gas is spent on slippage to the bottom holes without performing any useful work in displacing oil.

Besides high recovery rates, deposits with pressure drives are usually characterised by a high production rate and a relatively short producing life. Therefore, in field practice, it is extremely important already at the initial stage of production of a reservoir to determine its natural potential and to decide on a general development plan accordingly.

It is exceedingly important to establish the nature of the sources of reservoir energy operative in the given reservoir, the possibility of utilising natural energy to achieve maximum oil recovery or the necessity of supplementing this energy artificially by injecting some kind of a driving agent into the reservoir to secure more effective drainage.