Lecture 5 summary:

Basic reservoir simulation concepts - recovery production.

2.8. Recovery Efficiency

The effectiveness of a displacement process depends on many factors:

- Non controlled factors: reservoir and fluid characteristics, such as depth, structure, and fluid type.

- Controled factors: number and type of wells, well rates, and well locations. The distribution of wells is known as the well pattern.

Recovery efficiency is quantified by comparing initial and final volumes of fluid in place. It takes into account volumetric and displacement efficiencies.

Displacement efficiency E_D accounts for the efficiency of recovering mobile hydrocarbon. Displacement efficiency for oil is defined as the ratio of mobile oil to original oil in place at reservoir conditions:

$$E_D = \frac{V_p S_{oi} - V_p S_{or}}{V_p S_{oi}} = \frac{S_{oi} - S_{or}}{S_{oi}}$$, ------------------------------------ (16)

Where,

V_p initial pore volume

S_{oi} initial oil saturation

S_{or} residual oil saturation

One of the goals of enhanced oil recovery processes is to reduce residual oil saturation and increase displacement efficiency.

Volumetric factors are needed to determine overall recovery efficiency.

Areal and vertical sweep efficiencies are defined by:

$$E_A = \frac{\text{swept area}}{\text{total area}} \quad , \quad E_V = \frac{\text{swept thickness}}{\text{total thickness}} \quad , \text{-------------------- (17)}$$

Reservoir flow models are useful tools for quantifying both swept area and swept thickness.

The product of areal and vertical sweep efficiency is the volumetric sweep efficiency E_{vol}:

$$E_{vol} = E_A \times E_V \quad , \text{-- (18)}$$

Overall recovery efficiency R_E is the product of volumetric and sweep displacement efficiencies:

$$RE = E_D \times E_{vol} = E_D \times E_A \times E_V \quad , \text{---------------------------------- (19)}$$

Even each of the efficiency factors can be relatively large, recovery efficiency will be relatively small. For example, suppose both the areal and vertical efficiencies are 70% and displacement efficiency is 80%, the product of these efficiencies is approximately 39%. This means that even the reservoirs with the best recovery efficiency often have a substantial volume of unrecovered hydrocarbon remaining in the ground.

The most important goal of improved recovery techniques is the recovery of this remaining resource.

Pattern Floods and Spacing

The alignment of the injector-producer pair is very important to effectively flood reservoir. Figure 12 represents some wells patterns.

The well pattern depends, in addition to reservoir geometry and the displacement process, on the desired spacing of wells.

Well spacing depends on the area being drained by a production well. Well density can be increased by drilling additional wells in the space between wells in a process called infill drilling.

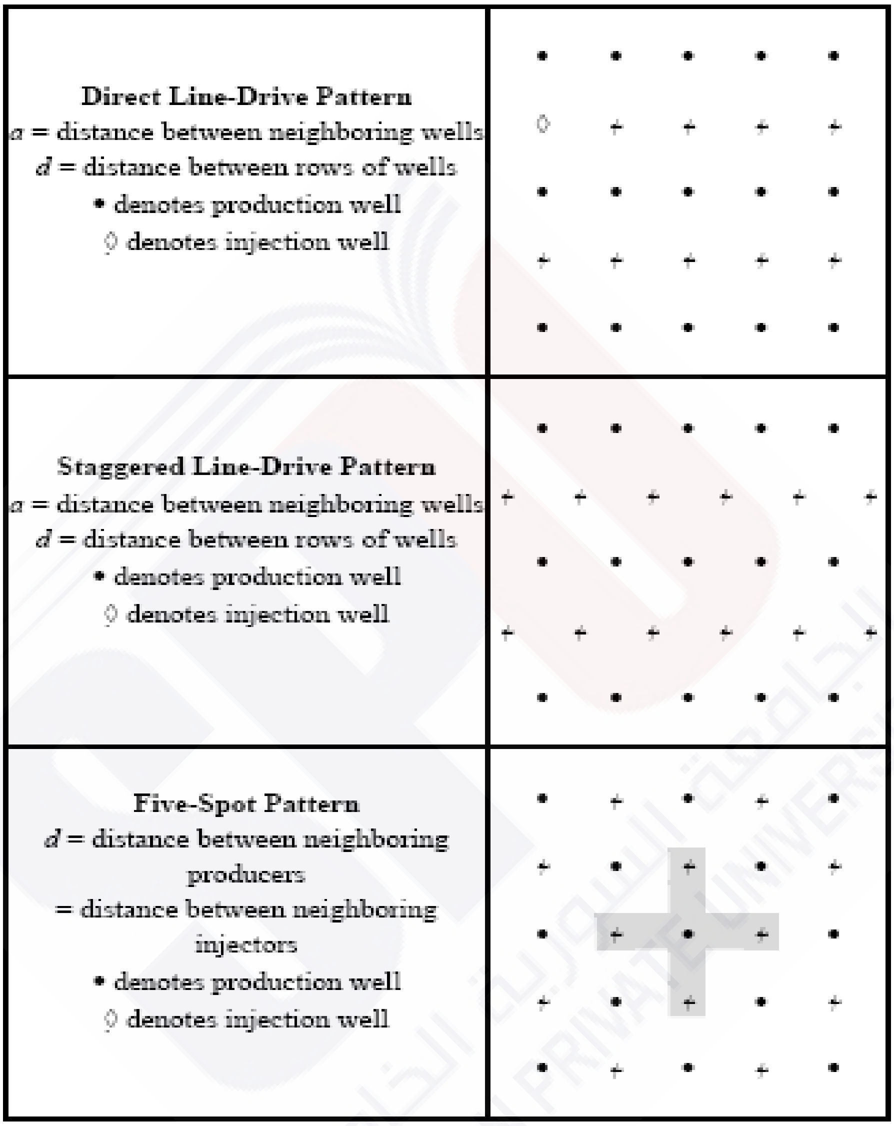

Figure 12. Well Locations in Selected Well Patterns

Drilling Technology

Drilling technology are having a dramatic impact on reservoir management. Four areas of drilling technology are briefly discussed here: infill drilling, multilateral wells, geosteering, and intelligent wells.

Infill Drilling: Infill drilling is a means of improving sweep efficiency by increasing the number of wells in an area to provide access to unswept parts of a field. Infill drilling can be more expensive than a fluid displacement process.

Multilateral Wells

A multilateral well is a well that has more than one flow conduit. Today, multilateral wells make it possible to connect multiple well paths to a common wellbore. Figure 13 illustrates a multilateral well trajectory. Multilateral wells are useful in offshore environments.

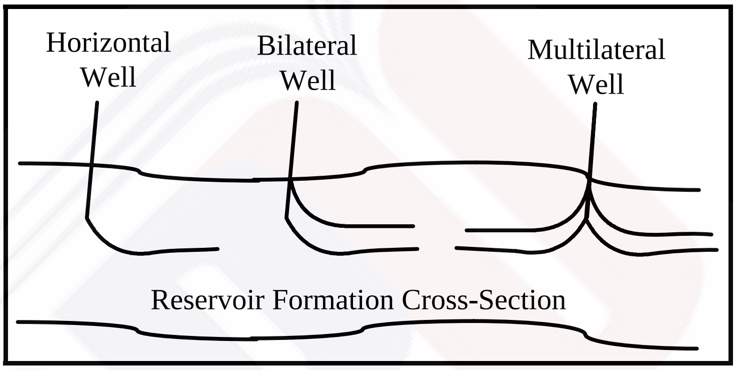

Figure 13. Example of a Multilateral Well

2.9. Recovery Production

The life of a reservoir can be divided into three production stages.

The production life of a reservoir begins when reservoir fluid is withdrawn from the reservoir.

a) Primary Production

Primary production is the first stage of production. It relies entirely on natural energy sources called reservoir drives.

The reservoir drives for oil reservoirs are water drive, solution gas drive, and gas cap drive.

<u>Water drive:</u> the most efficient mechanism. Its recovery ranges from 20% to 30% of the reserves.

Solution gas drive: dissolved gas is liberated as pressure declines. Oil moves with the gas to the wells as the gas moves to the lower pressure zones in the reservoir. Recovery by solution gas drive ranges from 5% to 20% of the reserves.

Gas cap drive: pressure decline causes gas to move from gas cap down toward the producing wells. The gas movement drives oil to the wells, and eventually large volumes of gas will be produced with the oil. Gas cap drive recovery ranges from 20% to 30% of the reserves.

Gravity drainage is the least common of the primary production mechanisms.

A schematic comparison of primary production mechanisms on reservoir pressure and recovery efficiency is sketched in Figure 14.

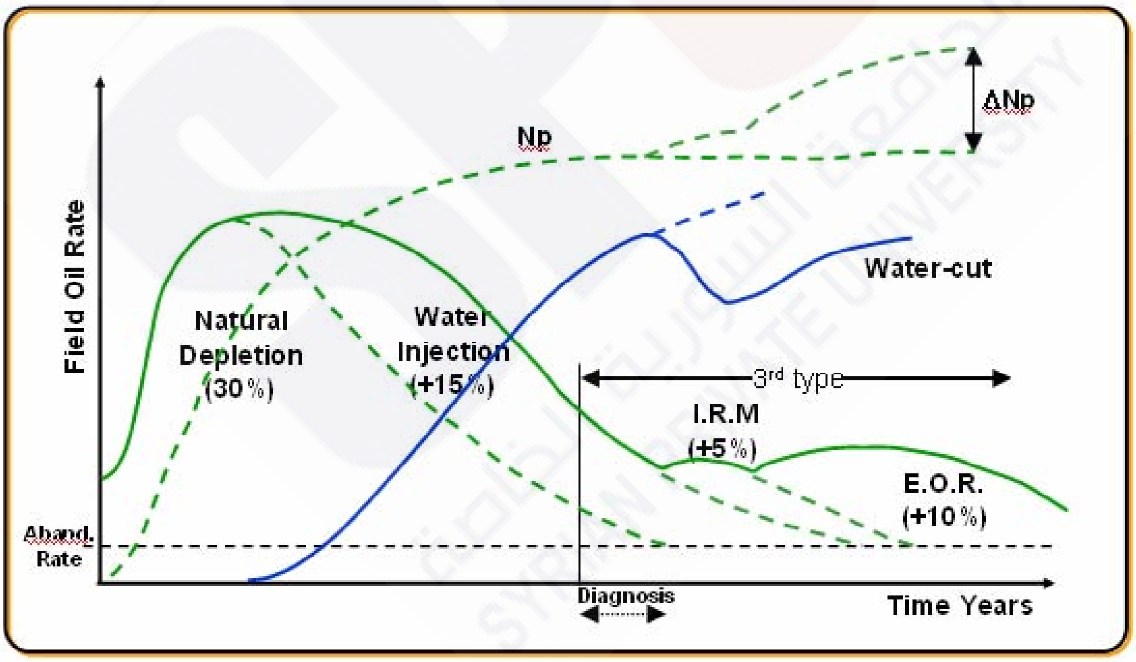

Figure 14. Comparison of primary production mechanisms

b) Improved Production

- Secondary Production

Oil recovery can be increased by using an external energy source, such as water injection or natural gas injection. This may be referred to as pressure maintenance.

- Tertiary Production (**Enhanced Oil Recovery (**EOR))

Methods used to improve oil recovery efficiency by reducing residual oil saturation. Typically the third stage occurred after water flooding.

Tertiary production processes were designed to improve displacement efficiency by injecting fluids or heat. Enhanced recovery processes are often more expensive than infill drilling more wells to increase well density.

EOR processes are usually classified as follows: chemical, miscible, thermal, and microbial.

Chemical Processes

Include polymer and alkaline flooding. Polymer increases the viscosity of the water. Alkaline flooding uses alkaline chemicals that can react with certain types of *in situ* crude. The resulting chemical product is miscible with the oil and can reduce residual oil saturation to water flooding.

Miscible Processes

Miscible flooding methods include carbon dioxide injection, natural gas injection, and nitrogen injection. Miscible gas reduces interfacial.

Thermal Processes

Thermal flooding methods include hot water injection, steam drive, steam soak, and *in situ* combustion. The injection or generation of heat in a reservoir is designed to reduce the viscosity of *in situ* oil and improve the mobility ratio of the displacement process.

Microbial Processes

Microbial EOR uses the injection of microorganisms and nutrients in a carrier medium to increase oil recovery reduce water production in petroleum reservoirs, or both.

2.10. Reserves

According to Society of Petroleum Engineers (SPE) definitions, Reserves are those quantities of petroleum that are anticipated to be commercially recoverable from known accumulations. Table 8 summarizes the SPE definitions of reserves which include both qualitative and quantitative criteria. Although the SPE definitions have been adopted in many parts of the world, they are not universal.

Table 8. SPE Reserves Definitions

Category	**Definitions**
Proved reserves	Those quantities of petroleum that can be estimated with reasonable certainty to be commercially recoverable under current economic conditions, operating methods, and government regulation. They should be at least a 90% probability (P_{90}) that the quantities actually recovered will equal or exceed the estimate.
Probable reserves	Those unproved reserves deemed more likely than not to be recoverable based on analysis of geological and engineering data. There should be at least a 50% probability (P_{50}) that the quantities actually recovered will equal or exceed the estimate.
Possible reserves	Those unproved reserves deemed less likely to be recoverable than probable reserves based on analysis of geological and engineering data. There should be at least a 10% probability (P_{10}) that the quantities actually recovered will equal or exceed the estimate.

The probability distribution associated with reserves definitions can be estimated if the modeling team has performed a sensitivity analysis that generates a set of cases that yield low, medium, and high reserve estimates.

In the absence of data, the normal distribution can be used to estimate occurrence of any particular prediction case with its corresponding economic forecast. Keep in mind, however, that the actual distribution of reserves may not be normal.