University of Mosul
College of Petroleum & Mining Engineering

Enhanced Oil Recovery Processes

Fourth Year

Lecture 4

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Oil displacement effeciency

The ultimate goal of EOR processes is to increase the overall oil displacement efficiency, which is a function of microscopic and macroscopic displacement efficiency. Microscopic efficiency refers to the displacement or mobilization of oil at the pore scale and measure the effectiveness of the displacing fluid in moving the oil at those places in the rock where the displacing fluid contacts the oil (Figure 1). For instance, microscopic efficiency can be increased by reducing capillary forces or interfacial tension between the displacing fluid and oil or by decreasing the oil viscosity.

Macroscopic or volumetric displacement efficiency refers to the effectiveness of the displacing fluids in contacting the reservoir in a volumetric sense. Volumetric displacement efficiency indicates the effectiveness of the displacing fluid in sweeping out the volume of a reservoir, both areally and vertically, as well as how effectively the displacing fluid moves the displaced oil toward production wells (Figure 1).

The overall displacement efficiency of any oil recovery displacement process can be increased by improving the mobility ratio or by increasing the capillary number or both. 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). The capillary number is defined as the ratio of viscous forces to capillary (interfacial) forces

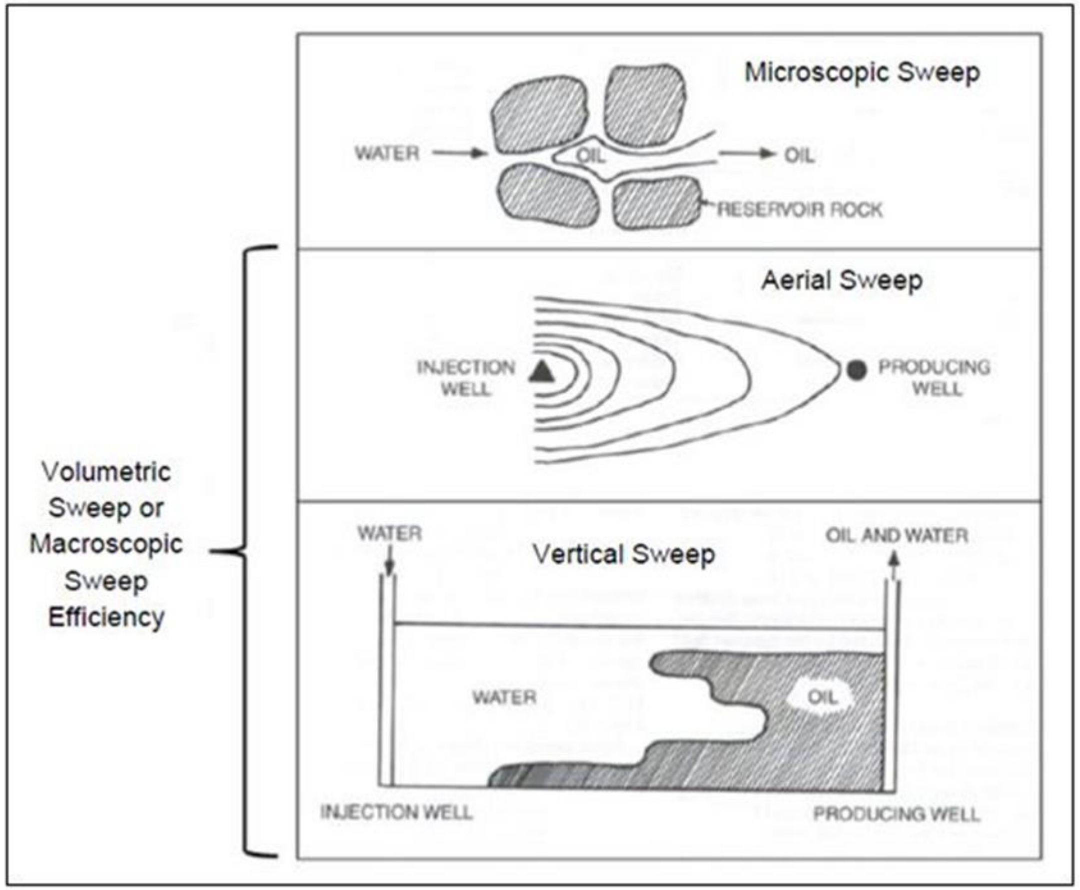

Figure1: Schematic of microscopic and macroscopic sweep efficiencies.

Water injection

1- Introduction:

Water injection, the oldest assisted recovery method, remains the most common method (80% of the oil produced by enhanced recovery in the United States in 1970 was produced by water injection. Oil recovery is increased by an improvement in sweep or displacement efficiency.

In addition to the enhanced recovery objective, water injection may also be used in order to:

1- Maintain the reservoir pressure when the expansion of the aquifer or gas cap is insufficient for the purpose. In this instance the process should be regarded as one of pressure maintenance rather than of enhanced recovery.

2- Dispose of the brine produced with the oil if surface discharge is not possible (e.g. into lakes or fresh water sources).

The water may be injected into an underlying or neighbouring aquifer

2- The selection of water injection as an enhanced recovery method:

When the natural reservoir energy is judged to be insufficient, the choice of enhanced recovery method is made according to both technical and economic criteria.

2.1 Technical factors

The two most common injection fluids are water and gas, and we shall examine the advantages and disadvantages of them both.

Gas injection falls into two categories:

a- Miscible gas injection.

b- Non-miscible gas injection.

If conditions are technically suitable for miscible gas injection it may be the best method, since the microscopic displacement efficiency will be improved.

In the case of non-miscible gas injection, the following points should be noted:

Water injection is to be preferred in all cases where there are no practical constraints, due to the more favourable mobility ratio obtained.

In reservoirs containing highly under-saturated oil, water injection is all the more suitable since the low gas-oil ratios would result in only small volumes of gas being available for gas injection. Moreover, a considerable volume of gas has to be injected before a free gas phase can be formed in the reservoir.

In reservoirs containing saturated oil, water is the preferred injection fluid as long as the permeability to water is sufficiently high. However, in reservoirs containing volatile oil (very high GOR) other methods such as miscible gas injection may yield a higher recovery.

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an undersaturated oil reservoir is defined as a reservoir in which the initial pressure is greater that the bubble-point pressure of the crude oil. This results in a single, liquid hydrocarbon phase in the reservoir

2.2 Economic factors

To examine the cost of an injection project, the various elements to be considered being:

a- The cost of studies and laboratory work.

b- The cost of drilling additional wells.

c- The cost of converting producers into injectors.

d- The capital and operating costs of the surface equipment: pumps, lines, tanks, filters, etc.

3- Factors to consider in water injection:

For determining the suitability of a candidate reservoir for water injection, the following reservoir characteristics must be considered:

a- Reservoir geometry

b- Fluid properties

c- Reservoir depth

d- Lithology and rock properties

e- Fluid saturations

f- Reservoir uniformity and pay continuity

g- Primary reservoir-driving mechanisms

Reservoir geometry:

The areal geometry of the reservoir will influence the location of wells and, if offshore, will influence the location and number of platforms required. The reservoir's geometry will essentially dictate the methods by which a reservoir can be produced through water-injection practices.

Fluid properties:

The physical properties of the reservoir fluids have pronounced effects on the suitability of a given reservoir for further development by water injection. The viscosity of the crude oil is considered the most important fluid property that affects the degree of success of a water injection project. The oil viscosity has the important effect of determining the mobility ratio that controls the sweep efficiency.

Reservoir depth:

Reservoir depth has an important influence on both the technical and economic aspects of a secondary or tertiary recovery project. Maximum injection pressure will increase with depth. The costs of lifting oil from very deep wells will limit the maximum economic water-oil ratios that can be tolerated, thereby reducing the ultimate recovery factor and increasing the total project operating costs. On the other hand, a shallow reservoir imposes a restraint on the injection pressure that can be used, because this must be less than fracture pressure.

Lithology and rock properties:

Reservoir lithology and rock properties that affect flood ability and success are:

- Porosity
- Permeability
- Clay content
- Net thickness

In some complex reservoir systems, only a small portion of the total porosity, such as fracture porosity, will have sufficient permeability to be effective in water-injection operations.

Clay minerals that present in some sands may clog the pores by swelling and deflocculating when water injection is used.

Tight (low-permeability) reservoirs or reservoirs with thin net thickness possess water-injection problems in terms of the desired water injection rate or pressure. The water injection rate and pressure are roughly related by the following expression:

$$p_{inj} \propto \frac{i_w}{hk}$$

where p_{inj} = water-injection pressure
i_w = water-injection rate
h = net thickness
k = absolute permeability

The above relationship suggests that to deliver a desired daily injection rate of iw in a tight or thin reservoir, the required injection pressure might exceed the formation fracture pressure.

Fluid saturations:

In determining the suitable of a reservoir for water injection, a high oil saturation that provides a sufficient supply of recoverable oil is the primary criterion for successful injection operations. Higher oil saturation at the beginning of injection operations increases the oil mobility that gives higher recovery efficiency.

Reservoir uniformity and pay continuity:

Reservoir uniformity is one of the major physical criteria for successful water injection. If the formation contains a stratum of limited thickness with a very high permeability (i.e. theif zone), rapid channelling and bypassing will develop. Unless this zone can be located and shut off, the producing water-oil ratios will soon become too high for the injection operation to be considered profitable.

Areal continuity of the pay zone is also a prerequisite for a successful water injection project. Isolated lenses may be effectively depleted by a single well completion, but an injection mechanism requires that both the injector and producer be present in the lens. Breaks in pay continuity and reservoir anisotropy caused by depositional conditions, fractures, or faulting need to be identified and described before determining the proper well spanning and the suitable injection pattern orientation.