An Introduction to Enhanced Oil Recovery

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ABSTRACT

The objective of this paper is to introduce the concept of *Enhanced Oil Recovery or EOR* to the readers. It will focus its discussion on EOR concept and various processes currently applied in the oil and gas industry.

INTRODUCTION

After discovery, most of oil reservoirs typically undergo *primary recovery* period in which natural energy associated with a reservoir is used to recover a portion of the oil. Mechanisms at the early production stage include fluid and rock expansion. In its original, undisturbed condition, the reservoir rock and fluid are under high pressure. When the initial reservoir pressure begins to drop due to oil production, both rock and fluid expand. Fluid will expand much more as compared to rock. This concept is known as *compressibility*. Energy from the rock and fluid (oil and gas) expansion will push the oil towards the producers.

After pressure falls below the *bubble point pressure* (pressure below which the first gas bubble appears from the oil solution) due to fluid withdrawal from the reservoir, additional recovery resulted from gas liberation and expansion (secondary gas cap) can be achieved. For reservoirs connected to aquifers, water encroachment from an aquifer can both displace oil from reservoir pore space and help moderate the pressure decline caused by fluid withdrawal. A typical range for primary recovery efficiency is 12 to 15%[4] of original oil in-place (OOIP).

In order to decrease the rate of pressure decline, gas is injected into the gas cap and/or water is injected into the aquifer so that oil production could be continued. This prolonged period of primary recovery is called *secondary recovery*. Typical recovery factor for secondary recovery is additional

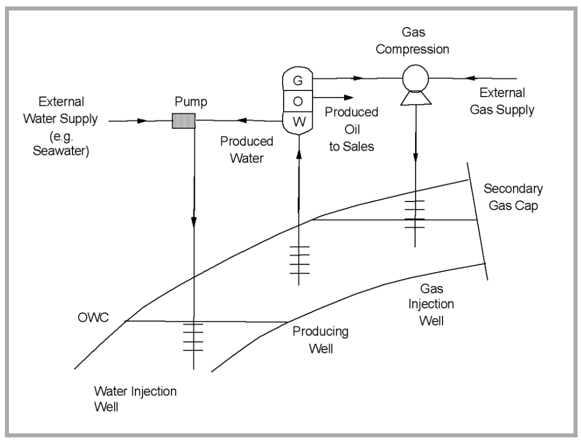

Figure 1: Secondary recovery by water injection

15 – 20%[4] over primary recovery. A schematic diagram of this nature is shown in Figure 1.

The fluid injection after this secondary recovery is referred to Enhanced Oil Recovery (EOR), or traditionally being referred to tertiary recovery as illustrated in Figure 2. Obviously, economics always play the major role in "go - no go" decisions for EOR projects as they involve substantial amount of investment. A cursory examination with the technical criteria is helpful to rule out the less-likely candidates before any expensive reservoir description and economic evaluations are done.

CONCEPT

EOR refer to the processes of *producing liquid hydrocarbon (oil) by methods other than using natural reservoir energy and reservoir repressurising scheme with gas or water*[1]. It involves injection of fluids into a reservoir to recover more oil. The injected fluids interact with the reservoir rock/oil system, creating more favourable conditions to displace or push the oil towards producer wells. The results of the interaction might be in terms of oil swelling, viscosity reduction, lowering of interfacial tension, wettability modification, or favourable mobility ratio between the displacing and the displaced fluid.

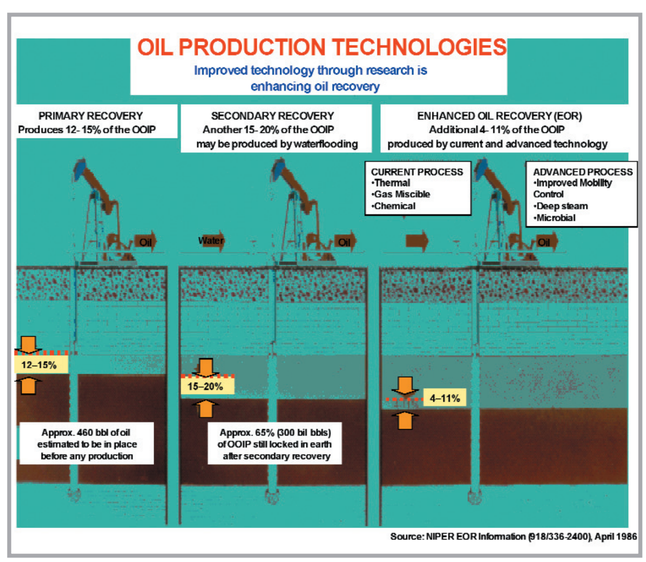

Figure 2: Oil production

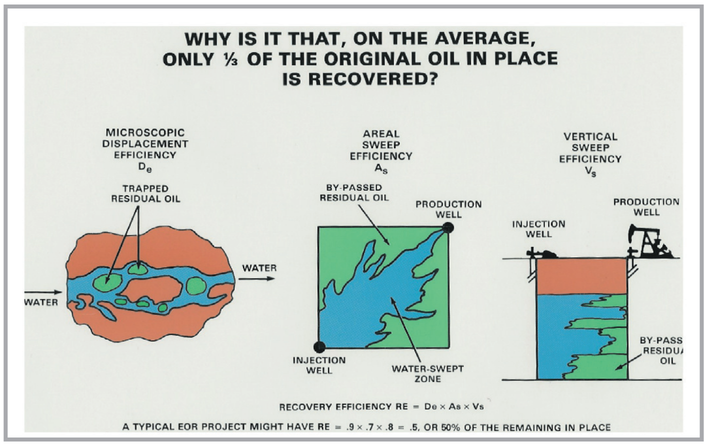

Figure 3: Displacement efficiency
Left – pore displacement (microscopic)
Centre & right – aeal and vertical displacement (macroscopic)

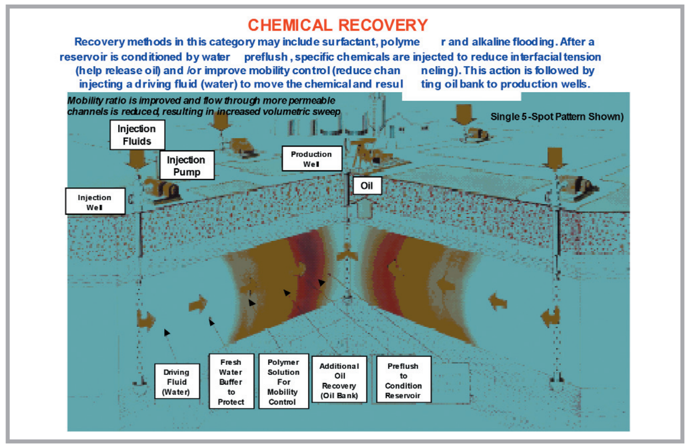

Figure 4: Chemical flooding using alkaline/surfactant/polymer
(Source: NIPER EOR Information, 1986)

To understand EOR better, it is essential to understand the concept of fluid displacement. The overall displacement or *recovery efficiency* is the product of microscopic and macroscopic displacement efficiencies as illustrated in Figure 3.

The microscopic (pore scale) displacement efficiency is a measure of how well the displacing fluid mobilised residual oil in pore space once the fluid contacted the oil droplets within the reservoir rock. Pore space is the void area in between the reservoir rock grains. Normally, oil and water droplets are found within the pore space. In parts of the reservoir, which have been swept, some oil remains trapped. The trapped oil is known as *residual oil*, which can range between 10% to 40% in saturation, depending on pore space sizes, rock wettability and capillary pressure.

On the contrary, the *macroscopic (volumetric)* displacement efficiency is a measure of how well the displacing fluid sweep the oil-bearing parts of the reservoir, areal and vertical. The bulk volume is huge, thus the name macroscopic or volumetric.

The recovery efficiency can be represented in equation form:

RE = De * As * Vs
Where RE = overall recovery efficiency
De = microscopic displacement efficiency
As = areal sweep efficiency
Vs = vertical sweep efficiency

All the efficiencies are stated in fractions with values between 0 to 1. Thus, the closer De, As and Vs values to 1.0, the more efficient the displacement process. For instance:

If De = 0.9, As = 0.7 and Vs = 0.8,
then RE = 0.9 * 0.7 * 0.8 = 0.5

PROCESSES

EOR processes can be classified into four main categories:

1. Chemical EOR

Chemical EOR or chemical flooding processes are injection of liquid chemicals into the reservoir to reduce interfacial tension (IFT) between oil/rock and stabilise flood front. Chemicals such as surfactants (surface active agents), alkaline and polymers are normally used for this purpose. Soaps and detergents are examples of surfactants/alkaline. The chemical flooding processes, as illustrated in Figure 4, can be further subdivided into four systems:

a) *Polymer assisted/augmented* water flooding
b) *Alkaline-polymer* water flooding
c) *Surfactant-polymer* or micellar polymer water flooding
d) *Alkaline-surfactant-polymer (ASP)* water flooding

Basically, in each system, each chemical has its own function. Alkaline pre-conditioned the flooding by controlling pH of the injected water, surfactant reduces oil-rock IFT, while polymer improves reservoir contact and flood efficiency.

2. *Miscible gas EOR*

In *miscible gas EOR or flooding*, displacing fluids in the form of gas (hydrocarbon gases, carbon dioxide, nitrogen or flue gas) are injected to mix with oil to form a single phase. By minimising the IFT (IFT = 0 in single-phase fluid), residual oil saturation will be lowered while microscopic displacement efficiency (De) is maximised.

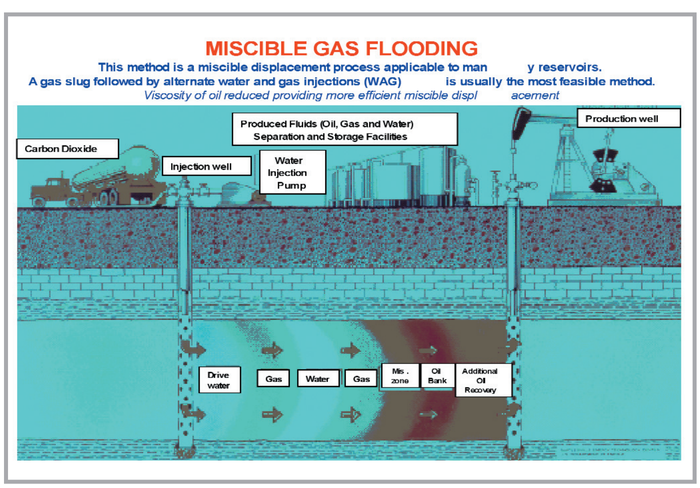

Figure 5: Miscible gas flooding (water-alternating-gas or WAG mode)
(Source: NIPER EOR Information, 1986)

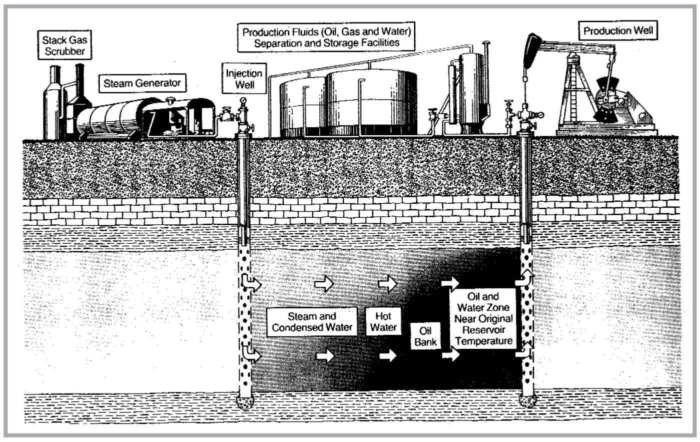

Figure 6: Hot water/steam flooding
(Source: NIPER EOR Information, 1986)

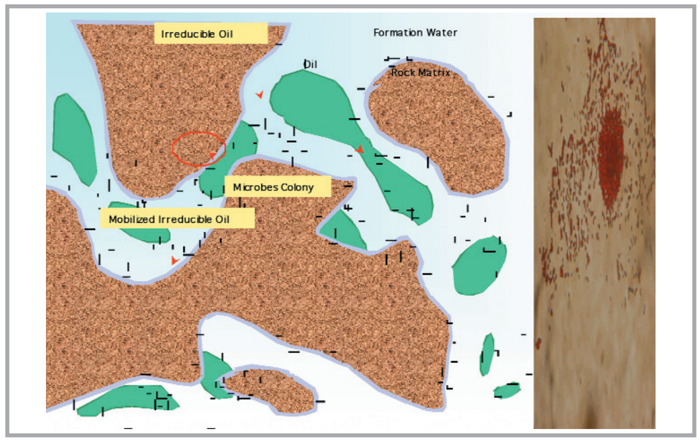

Figure 7: Microbial EOR processes

The carbon dioxide gas (CO_2) miscible process is an example. Through multiple contact between CO_2 and oil, CO_2 rich phase will reach a composition that is miscible with oil. However, in most cases, CO_2 is very mobile (low viscosity) at injection condition. Oil and water are displaced by CO_2, which leads to fingering through oil phase and poor sweep efficiency. An approach to overcome this difficulty is to inject slugs of CO_2 and water alternately. This method is called *water-alternating-gas* or *WAG* process (refer Figure 5). Water helps to stabilise the flood front, reduce CO_2 fingering and improve overall sweep efficiency. Other methods of mobility control are being tested, such as using foam and polymer with CO_2.

Table 1 : 2002 Worldwide EOR Survey
(Source: OGJ Apr 2002))

EOR Projects Survey by Process	Region/Country			Worldwide Total
	U.S.A.	Canada	Rest of World	
Thermal	65	16	77	158
Chemical	4	–	22	26
Gas (all types)	78	31	17	126
Microbial	–	–	3	3
Total Projects	**147**	**47**	**119**	**313**

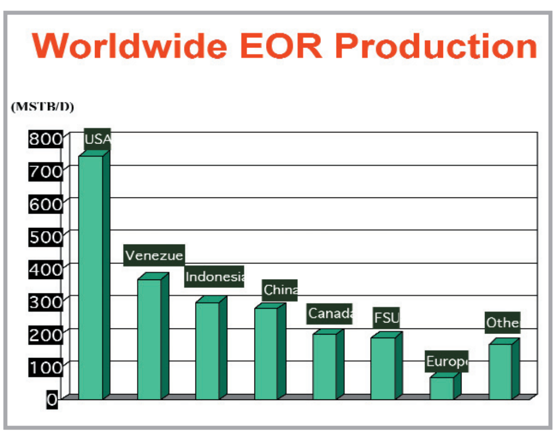

Figure 8: 2002 Worldwide EOR Production
(Source: OGJ APR 2002)

3. Thermal EOR

Thermal EOR processes are those in which heat is added into the reservoir. Additional heat will result in thermal expansion and viscosity reduction of oil, using these techniques:

a) *In-situ combustion* – ignition of a mixture of oxygen-rich hydrocarbon gas in the reservoir.

b) *Hot water / steam flooding* - injection of hot water or steam into reservoir (Figure 6)

4. Microbial EOR

Microbial EOR processes involve injection of microbes into a reservoir or injection of nutrients to stimulate growth of indigenous microbes in the reservoir. The microbes colonise the reservoir rock pore throat and produce various by-products such as gas, acids, biomass and biochemical (surfactants, polymer, and solvents) to further improve reservoir conditions for oil recovery, as illustrated in Figure 7. This technique is still highly experimental compared to the previously mentioned techniques.

Gases such as carbon dioxide, hydrogen and methane, subsequently increase the pressure and expels oil from micro traps in oil reservoir. Biomass works by selective plugging, which is plugging wider pore throat and helps to divert displacement fluids into oil microtraps, resulting in less bypass oil and lower residual oil saturation. Biopolymer improves sweep efficiency while biosurfactant reduces the interfacial tensions between oil and water. Biosolvent thins the oil by lowering its viscosity.

CLOSURE

Is EOR necessary?

There are four main reasons why EOR is necessary for mature oil fields.

- Unsustainable production – more often production rate is difficult to maintain as field matures.
- Low reserve replenishment ratio – cumulative production is more than reserve replenishment.
- Low recovery from existing fields.
- Smaller discoveries – new discoveries tend to be smaller than existing fields.

EOR Application around the World

EOR have been applied globally as shown in Table 1 and Figure 8. North America (United States of America and Canada) have the most numbers of EOR application and highest EOR production. The reason is because their have faced declining reserve since 1970's. EOR was applied as an alternative method to sustain their oil production. Gas and thermal flooding are the most applied process there. Other countries have followed in EOR application or R&D ever since.

All EOR processes have been applied successfully in other parts of the world, meaning that it is a proven technology. However, almost all of EOR projects are for onshore fields application. In Malaysia, all our fields are located offshore. There are challenges to EOR application such as large well spacing (distance in between wells), limited space at surface (offshore platforms), complicated reservoir geology, and higher EOR cost compared to land operations. A comprehensive and detailed feasibility study is required before embarking on EOR technology for any particular field or reservoir.

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REFERENCES

[1] D.W. Green and G.P. Willhite (1998). *"Enhanced Oil Recovery"'* Society of Petroleum Engineers, Richardson, Texas.

[2] B.C. Craft and M.F. Hawkins, revised by R.E. Terry (1991). *"Applied Petroleum Reservoir Engineering"*, 2nd edition, Prentice-Hall Inc., New Jersey.

[3] *"Introduction to Oil & Gas Production"*, American Petroleum Institute (1983), Production Department, Dallas, Texas.

[4] *"Enhanced Oil Recovery"*, National Institute for Petroleum and Energy Research (1986), Bartlesville, Oklahoma.

[5] *"2002 Worldwide EOR Survey"*, Oil & Gas Journal (Apr 2002), 71-83.

[6] D.M. Updegraff (1990). *"Early Research on Microbial Enhanced Oil Recovery"*, Development in Industrial Microbiology, 31: 135 – 142.