Enhanced Oil Recovery (EOR)

Introduction

The life of an oil well goes through three distinct phases where various techniques are employed to maintain crude oil production at maximum levels. The primary importance of these techniques is to force oil into the wellhead where it can be pumped to the surface. Techniques employed at the third phase, commonly known as Enhanced Oil Recovery (EOR), can substantially improve extraction efficiency. Laboratory development of these techniques involves setups that duplicate well and reservoir conditions. Core Flooding Pumps or Core Analysis Pumps, such as Teledyne Isco Syringe Pumps, are used in laboratory testing of these Enhanced Oil Recovery (EOR) techniques.

The Three Stages of Oil Field Development

Primary Recovery — In Primary Recovery, oil is forced out by pressure generated from gas present in the oil.

Secondary Recovery — In Secondary Recovery, the reservoir is subjected to water flooding or gas injection to maintain a pressure that continues to move oil to the surface.

Tertiary Recovery — Tertiary Recovery, also known as Enhanced Oil Recovery (EOR), introduces fluids that reduce viscosity and improve flow. These fluids could consist of gases that are miscible with oil (typically carbon dioxide), steam, air or oxygen, polymer solutions, gels, surfactant-polymer formulations, alkaline-surfactant-polymer formulations, or microorganism formulations.

Importance of Enhanced Oil Recovery

Primary recovery typically provides access to only a small fraction of a reservoir's total oil capacity. Secondary recovery techniques can increase productivity to a third or more. Tertiary Recovery (EOR) enables producers to extract up to over half of a reservoir's original oil content, depending on the reservoir and the EOR process applied.

Rock Core Flooding and Syringe Pumps

Before an EOR method can be employed for a particular well, research must be done to find the optimal choice of method and formulation. Part of EOR research is known as "rock core flooding." From the oil reservoir, a cylindrical rock sample is cut with a hollow drill. Then a syringe pump introduces a fluid into the rock core holder. Depending on the EOR process, core flooding may require hours to days of fluid injection at high pressures and low flow rates for the newly introduced fluid to displace the oil from the rock sample. From the data obtained from rock core flooding, companies doing EOR can devise the best way to recover as much oil as possible.

EOR Methods

Some common EOR methods are discussed below.

Thermal EOR

Injection of steam has historically been the most widely applied EOR method. Heat from steam or hot water dramatically reduces the viscosity of viscous oils, making it flow more readily. There are many variations for this process including cyclic steam injection ("huff 'n puff", where steam is first injected, followed by oil production from the same well), continuous steam injection (where steam injected into wells drives oil to separate production wells), hot water injection, and steam assisted gravity drainage (SAGD) using horizontal wells, among others. Another set of thermal methods, in situ combustion or "fire flooding", involves injection of air or oxygen. In this process, oxidation of some of the oil in place does the following:

1. produces heat that reduces viscosity for the remaining oil
2. cracks some high-molecular weight hydrocarbons into smaller molecules
3. vaporizes some of the lighter hydrocarbons to help miscibly displace oil
4. creates steam that may steam-distill trapped oil

Miscible EOR

Commonly applied in West Texas, this method usually employs supercritical CO_2 to displace oil from a depleted oil reservoir with suitable characteristics (typically containing "light" oils). Through changes in pressure and temperature, carbon dioxide can form a gas, liquid, solid, or supercritical fluid. When at or above the critical point of pressure and temperature, supercritical CO_2 can maintain the properties of a gas while having the density of a liquid. Injected miscible CO_2 will mix thoroughly with the oil within the reservoir such that the interfacial tension between these two substances effectively disappears. CO_2 can also improve oil recovery by dissolving in, swelling, and reducing the viscosity of oil.

In deep, high-pressure reservoirs, compressed nitrogen has been used instead of CO_2. Hydrocarbon gases have also been used for miscible oil displacement in some large reservoirs.

CO_2, nitrogen, hydrocarbon gases, and flue gases have also been injected to immiscibly displace oil. At one extreme of conditions, these displacements may simply amount to "pressure maintenance" in the reservoir (a secondary recovery process). Depending on oil character, gas composition and pressure, and temperature, the displacements could have a range of efficiencies up to and approaching a miscible displacement. CO_2 has also been injected in a "huff 'n puff" or cyclic injection mode, like cyclic steam injection.

Chemical EOR

Three chemical flooding processes include polymer flooding, surfactant-polymer flooding, and alkaline-surfactant-polymer (ASP) flooding. In the polymer flooding method, water-soluble polymers increase the viscosity of the injected water, leading to a more efficient displacement of moderately viscous oils. Addition of surfactant to the polymer formulation may, under very specific circumstances, reduce oil-water interfacial tension to almost zero—displacing trapped residual oil.

Although no large-scale surfactant-polymer floods have been implemented, the process has considerable potential to recover oil.

A variation of this process involves addition of alkaline to the surfactant-polymer formulation. For some oils, alkaline may convert some acids within the oil to surfactants that aid oil recovery. The alkaline may also play a beneficial role in reducing surfactant retention in the rock. For all chemical flooding processes, inclusion of a viscosifier (usually a water-soluble polymer) is required to provide an efficient sweep of the expensive chemicals through the reservoir.

Gels are also often used to strategically plug fractures (or other extremely permeable channels) before injecting the relatively expensive chemical solutions, miscible gases, or steam.

Other EOR Processes

Over the years, a number of other innovative EOR processes have been conceived, including injection of carbonated water, microorganisms, foams, alkaline (without surfactant), and other formulations. These methods have shown varying degrees of promise, but require additional development before such applications will become common.

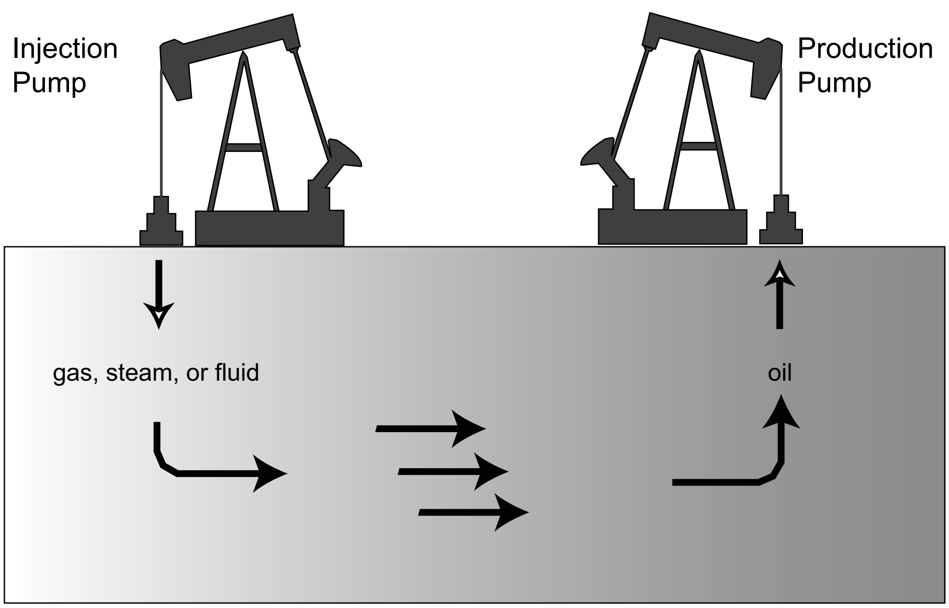

Figure 1: EOR Injection Methods

Why Teledyne Isco Pumps?

Pulseless Flow — This is a critical feature for rock core flooding studies where pressure changes are monitored and logged. It is important for the pump employed to not introduce any pressure variations itself (as with a piston pump). No pulsation at even lowest flow rates means superior minute-to-minute and second-to-second stability.

Accuracy — Digital servo control gives low speed precision and volumetric accuracy.

Continuous Flow — Fluids are often pumped into rock cores for several hours or days. Two Teledyne Isco syringe pumps configured with a valve assembly can accomplish continuous precision metering of unlimited volumes.

Viscous Fluids — The use of extremely viscous fluids or liquefied gases makes Teledyne Isco's syringe pumps the most viable choice in many cases.

Liquefied Gases — Gases such as CO_2 require low leakage, pre-cooling for improved fills, and temperature control.

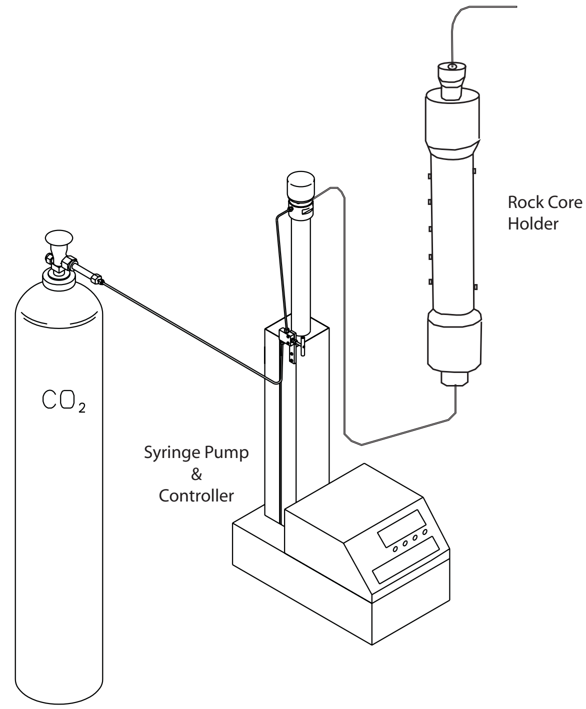

Figure 2: Rock Core Flooding

Table 1: Teledyne Isco Pump Models Available

	1000D[a]	500D	260D	100DX	100DM	65D
Flow Range (ml/min)	0.100 - 408	0.001 - 204	0.001 - 107	0.00001 - 60	0.00001 - 30	0.00001 - 25
Pressure Range (psi)	0 - 2,000	0 - 3,750	0 - 7,500	0 - 10,000	0 - 10,000	0 - 20,000

a. Recommended for rock core flooding applications.

References:
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2. "Exploration & Production Technologies." NETL: E&P Technologies - Improved Recovery - Enhanced Oil Recovery. 18 Oct. 2007 <http://www.netl.doe.gov/technologies/oil-gas/EP_Technologies/ImprovedRecovery/EnhancedOilRecovery/eor.html>
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