The Lease Pumper's Handbook

Chapter 15
Enhancing Oil Recovery

Section D

TERTIARY RECOVERY

D-1. Introduction to Tertiary Recovery.

Third-stage—tertiary—recovery is usually implemented and introduced slowly during water flood or pressure maintenance programs. However, in some reservoirs it is implemented soon after the first well is drilled. As with secondary recovery, tertiary methods should be introduced very early in the life of a field while income and profits can justify the additional equipment and installation expenses.

Although the term may not be used consistently throughout the industry, tertiary recovery, as used here, means that two or more forces are added to the formation. This can include water and heat for steam, water and carbon dioxide (CO_2) slugged alternately into the reservoir, polymers, or many other systems. Three of the more common processes that will be encountered are miscible displacement, chemical, and thermal. Variations for each are listed below.

Miscible displacement processes
- Miscible hydrocarbon processes
- CO_2 injection
- Inert gas injection

Chemical processes
- Surfactant-polymer injection
- Polymer flooding
- Caustic flooding

Thermal processes
- Steam stimulation
- Steam flooding
- Hot water injection
- In-situ combustion (fire flood)

Some of the goals in enhanced recovery within the reservoir include:

- Lowering interfacial tension to allow the oil to be recovered.
- Wettability change of the formation rock from oil-wet to water-wet.
- Wettability change from water-wet to oil-wet.
- Emulsification and entrapment.
- Solubilizing the rigid films at the point of the oil-water interface.

D-2. Miscible Displacement Processes.

Miscible hydrocarbon displacement. Miscible displacement processes involve the introduction of a fluid or solvent into the reservoir that will completely mix with reservoir oil and release the forces that cause the retention of oil in the rock matrix. This allows the solvent-oil mixture to be swept to the producing well. Some of these fluids or solvents are:

- Alcohol
- Refined hydrocarbons
- Condensed hydrocarbon gasses

- CO_2
- Liquefied petroleum gasses
- Exhaust gasses

Fluids or solvents that mix with the oil in the reservoir can be very expensive and cost many times the value of the recovered oil. After the slug of fluids or solvents is injected, alternate slugs of cheaper water or gas are used to make the process profitable by receiving maximum benefits.

There are three different miscible hydrocarbon displacement processes for improving recovery:

- Miscible slug process
- Enriched gas process
- High-pressure lean gas process

The use of inert miscible gas injection is increasing, and projects of this type are expected to continue to expand. They may potentially be used to recover a high percentage of the enhanced recovery reserves in the United States

CO_2 injection. This process involves pumping carbon dioxide into injection wells and, after sweeping it through the reservoir, recovering the natural gas and CO_2 from nearby wells. The CO_2 is separated from the natural gas and re-injected many times.

Combining CO_2 with heavy oils is difficult. Temperature, pressure, and oil composition conditions are difficult for carbon dioxide to obtain. Even if it does not fully combine, however, it will function as a solution gas drive. CO_2 is soluble in both oil and gas and causes fluids to swell. This is far more efficient than the injection of LPG and natural gas.

There are, however, some disadvantages to CO_2 injection. Since it thins the emulsion, it may cause early breakthrough to the producing wells, reducing sweep efficiency, and allowing large pockets of heavy crude to be bypassed and left in the formation. Water may be alternately slugged into the formation to reduce this fingering. It also dramatically increases the volume of CO_2-saturated water that is produced.

When CO_2 combines with water, it forms highly corrosive carbonic acid. Wellheads are usually prepared by installing stainless steel seals, bolts, and other trim to combat the problem.

Initial projects indicate that CO_2 flood might result in as much as 40% of the total oil recovered.

Inert gas injection. Inert gas injection procedures are very similar to injecting lean or dry natural gas. Although the scope of nitrogen (N_2) injection projects indicates that a higher pressure is needed to get ideal mixing action, inert gas is exposed to crude oil many times as it is swept through the formation and will result in an increase in production. Inert gas injection appears to be ideal for a limited number of reservoirs.

D-3. Chemical Processes.

Chemical flood processes are not used extensively and account for less than 1% of total tertiary recovery. This is because the processes are characterized by high cost, complex technology, and high risk.

Surfactant-polymer injection. This is a two- step process. The first step is injection of a surfactant slug. A surfactant is a wetting agent that breaks the surface tension between substances. The second step is the injection of a polymer mobility buffer. The surfactant slug may also be referred to as *micellar solution*, *micro-emulsion*, *soluble oil*, or *swollen micelle*. The purpose of the surfactants is to lower interfacial tension and to displace oil that cannot be displaced by water alone. The purpose of the polymer is to provide mobility control for a more piston-like displacement.

This system has not been totally satisfactory because of the adsorption of surfactants on the reservoir rock, slug breakdown, and the lowering of the ability to mobilize oil.

Polymer flooding. Polymers are substances with large molecules. When mixed with water, polymers increase the viscosity of the water, thus enhancing sweep efficiency.

There are two classes of polymers used in oil recovery:

- Polyacrylamides
- Polysaccharrides

Polyacrylamides are generally used in concentrations of 50-1000 parts per million. The use of polyacrylamides decreases the mobility of the injected fluid by decreasing the permeability of the reservoir rock.

A polysaccharride reduces the mobility of the injected fluid by increasing the viscosity of the fluid with very low levels of permeability reduction occurring in the reservoir rock. Although this results in a complex flow behavior, the viscosities of these fluids are significantly higher than water and result in a significant increase in long-range production.

Caustic or alkaline flooding. Caustic or alkaline flooding is a process wherein the alkalinity of injected water is raised to improve recovery beyond basic waterflooding. Water with a pH of 7 is considered neutral. As the pH value of a substance decreases toward 1, the substance is more acidic. As the numbers increase from 8 to the maximum of 14, the substance is more alkaline. A level of 12-13 approaches the maximum level of alkalinity practical for this process.

Caustic flooding is an economical option, because the cost of caustic chemicals is low compared to other tertiary enhancement systems. The final production gained is less, but the cost can be substantially cheaper, thus resulting in a higher income.

D-4. Thermal Processes.

Steam stimulation. Steam stimulation is a general term used when steam is injected into a well, then produced back out through the same well. This method is also referred to as *cyclic steam injection*, *steam soak*, or *huff and puff*.

With this process, up to 1,000 barrels of water per day are super-heated and injected into the well. Steam injection is continued for 10-30 days, then the well is shut in for a soak period of 1-4 weeks. During this shut-in period, heat dissipates into the reservoir. This thins or reduces the viscosity of the heavy crude oil, expands the volume of the oil causing fluid movement, and allows it to be pushed through the reservoir more easily.

The well is returned to production and produced until it has again slowed down to the level that the process of steam injection needs to begin again. After much of the reservoir oil has been recovered from the wells, then the cyclic steam flood may be converted to steam injection. The steam is injected into one well, and the resulting fluids are produced from other nearby wells. Steam flood in some reservoirs has resulted in a dramatic increase in production stimulation.

Steam and hot water injection. Steam injection continues to grow in importance in enhanced recovery. Steam injection accounts for approximately 20% of enhanced recovery processes. Steam flood wells are drilled on an approximate five-acre spacing and require a reservoir depth of approximately ten or more feet. Steam flood is most effective in wells no deeper than 5,000 feet.

Steam flood acts in a similar manner as water flood in relation to injection and producing well arrangements. The obvious advantage is crude oil expansion. It continues to expand as the pressure drops, and a water bank develops as the steam condenses.

Hot water injection is effective to some degree but, because of heat loss, it is not as effective as steam flood and can result in fingering and loss of sweep efficiency.

In-situ combustion. *In-situ* means "in place" and in-situ combustion indicates that a fire will be ignited within the formation. By injecting compressed air into the injection well this fire is driven across the reservoir. The heat generated by the fire will reduce the viscosity of the oil leading to a drop in pressure, which will allow the oil to expand, resulting in movement and possibly increased production.

There are two different in-situ combustion processes. In the first, **forward combustion**, the fire is ignited in the formation near the air injection well, and with continuing air injection the fire and produced oil is driven toward nearby producing wells.

The second process is referred to as *reverse combustion*. In this process, the fire is ignited in the formation near the air injection well, and after fire has been driven for a predetermined distance from the injection well the air injection is switched to the nearby producing wells. The fire will continue to burn toward the nearby wells, while the oil production direction is reversed and produced through the initial air injection well.

The in-situ method is not always cost effective. Because of the large amount of heat left behind from forward combustion, several other methods other than the dry combustion described above are being developed. These are referred to as *wet* and *partially wet combustion.*