Enhanced Oil Recovery Methods- An Overview

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Abstract

After primary and secondary recovery processes around 65% of oil still lays trapped in the reservoir. This trapped oil could be residual or by-passed oil. Residual oil occurs as a result of high capillary action of water that keeps the oil immobile. Basic purpose of enhanced oil recovery (EOR) processes is to improve sweep and displacement efficiency. The main basic mechanism of EOR is the reduction in interfacial tension between oil and brine, solubilization of released oil and change in the wettability towards more water wet and also reducing mobility contrast between crude oil and displacing fluid. During flooding the reservoir with surfactants, it is very important to ascertain the right quantity of surfactant that would yield the maximum recovery without unnecessary wastage of the surfactant because of its high cost. The main selection of surfactant is based on ability to reduce IFT between crude and brine, thermal stability, tolerance to salinity and hardness of brine, Solubility in brine, Phase behavior parameter, adsorption test under static and dynamic conditions and displacement studies under reservoir conditions. The present paper gives an overview of the various studies on the various enhanced oil recovery methods

Keywords:. Enhanced oil recovery, EOR, Chemical flooding, Surfactant flooding

I. INTRODUCTION

World demand for petroleum has been steadily on the increase with the International Energy

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Agency (IEA) projecting that the world petroleum consumption will rise from 3564 MTOE in 2007 to as much 5471 MTOE in 2015 and 6301 MTOE in 2030.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 duplicate well and reservoir conditions. Core flooding phase, commonly known as Enhanced Oil Recovery (EOR), can substantially improve extraction efficiency. Laboratory development of these techniques involves setups that pumps or core analysis pumps, such as Teledyne Isco Syringe Pumps, are used in laboratory testing of these Enhanced Oil Recovery [1-5]. Fig. 1 shows the oil recovery with EOR.

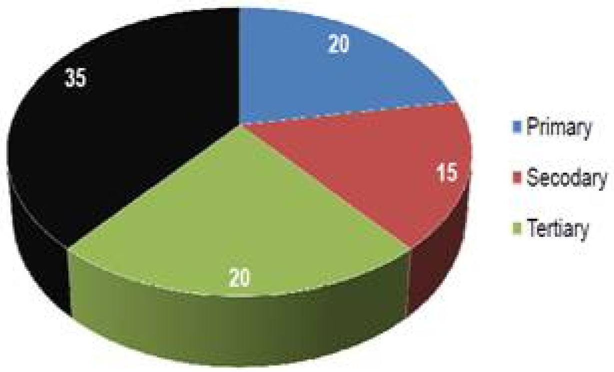

Fig. 1. Oil recovery on percent basis

II. OIL FIELD DEVELOPMENT

During the primary recovery stage, reservoir drive comes from a number of natural mechanisms. These include: natural water displacing oil downward into the well, expansion of the natural gas at the top of the reservoir, expansion of gas initially dissolved in the crude oil, and gravity drainage resulting from the movement of oil within the reservoir from the upper to the lower parts where the wells are located. Recovery factor during the primary recovery stage is typically 5-15%.While the underground pressure in the oil reservoir is sufficient to force the oil to the surface, all that is necessary is to place a complex arrangement of valves (the Christmas tree) on the well head to connect the well to a pipeline network for storage and processing [6-10]. Over the lifetime of the well the pressure will fall, and at some point there will be insufficient underground pressure to force the oil to the surface. After natural reservoir drive diminishes, secondary recovery methods are applied. They rely on the supply of external energy into the reservoir in the form of injecting fluids to increase reservoir pressure, hence replacing or increasing the natural reservoir drive with an artificial drive. Sometimes pumps, such as beam pumps and electrical submersible pumps (ESPs), are used to bring the oil to the surface. Other secondary recovery techniques increase the reservoir's pressure by water injection, natural gas reinjection and gas lift, which injects air, carbon dioxide or some other gas into the bottom of an active well, reducing the overall density of fluid in the wellbore. Typical recovery factor from water-flood operations is about 30%, depending on the properties of oil and the characteristics of the reservoir rock [7]. On average, the recovery factor after primary and secondary oil recovery operations is between 35 and 45%. 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. Thermally enhanced oil recovery methods (TEOR) are tertiary recovery techniques that heat the oil, thus reducing its viscosity and making it easier to extract [8].

Surfactants (detergents) are injected to alter the surface tension between the water and oil in the reservoir, mobilizing oil which would otherwise remain in the reservoir as residual oil. Another method to reduce viscosity is flooding. Tertiary recovery allows another 5% to 15% of the reservoir's oil to be recovered. Tertiary recovery begins when secondary oil recovery isn't enough to continue adequate extraction, but only when the oil can still be extracted profitably. This depends on the cost of the extraction method and the current price of crude oil. When prices are high, previously unprofitable wells are brought back into use and when they are low, extraction is curtailed [11-14].

Microbial treatments are another tertiary recovery method. Special blends of the microbes are used to treat and break down the hydrocarbon chain in oil thus making the oil easy to recover as well as being more economic versus other conventional methods. In some states, such as Texas, there are tax incentives for using these microbes in what is called a secondary tertiary recovery. Very few companies supply these, however companies like Bio Tech, Inc. have proven very successful in water floods across Texas [15-17].

III. BASIC MECHANISM OF ENHANCED OIL RECOVERY

For an EOR to be effective, the two important parameters that must be taken into consideration are the mobility ratio and the capillary number. Mobility of a fluid is defined as the ratio of the effective permeability to the viscosity of the fluid as:

$$\lambda = K_i / \mu_i$$

Where λ = Mobility, K = Effective Permeability , μ = Fluid Viscosity ,i = oil, water or gas

While mobility ratio, M, is defined as the mobility of the displacing fluid divided by the mobility of the displaced fluid [15-20]. For maximum displacement efficiency, M should be ≤ 1 for favorable mobility ratio. If M>1, then it means that the displacing fluid, for example, water in a water flood moves more easily than the displaced fluid, for example, oil. In case of enhanced oil recovery, mobility ratio can be made smaller, in order words, 'improved' by one of the following ways;

- Lowering the viscosity of the displaced fluid, for example, oil
- Increasing the viscosity of displaced fluid
- Increasing the effective permeability to oil
- Decreasing the effective permeability to the displacing fluid.

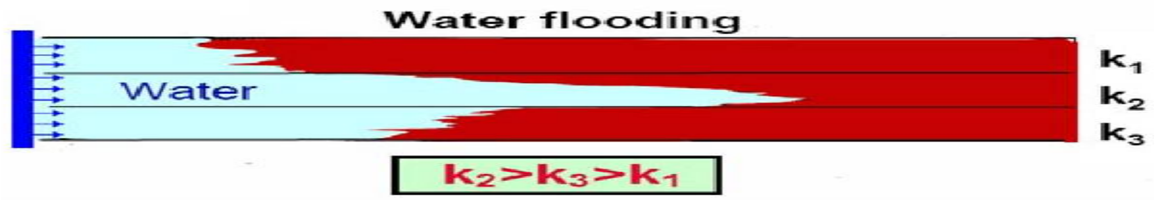

Fig. 2: Fingering of water into the oil bank for mobility ratios greater than 1

IV. ENHANCED OIL RECOVERY METHODS

There are various classifications of enhanced oil recovery and the method used depends on reservoir geology and fluid properties. Miscible displacement is the dominant recovery method in Canada; with steam injection growing fast as heavier oil/bitumen resources are exploited [21-23]. In United States of America, steam injection is the principal recovery method with miscible carbon dioxide flooding coming next. A broad classification is basically thermal and non-thermal where thermal methods are applied to heavy oil reservoirs and non-thermal applied to light oils.

Chemical flooding methods are targeted at recovering of residual oil left in the reservoir after water flooding. It involves the use of a polymer or surfactant to improve mobility ratio and

capillary number. Chemical flooding is further subdivided into polymer flooding, surfactant flooding, alkaline flooding, miscellar flooding, alkaline-surfactant-polymer (ASP) flooding.
This involves the addition of a very small amount of water-soluble, high molecular weight polymer to the displacing water in order to increase the apparent viscosity of the water and lower the mobility ratio. Thus polymer flooding is primarily used when displacing high viscosity oils . However because the viscosity of heavy oil is high and there is a limit to polymer concentration due to cost and mechanical consideration for injection pressures, polymers are likely to be of little benefit for heavy oil with viscosity of more than 100 mPa.S.

Mobilization of residual oil trapped by capillary forces in the porous medium is the main mechanism with surfactant flooding characterized by a reduction in IFT and residual oil saturation. A suitable surfactant should lower the oil-water IFT sufficiently and adsorbs little on the rock matrix. The main problem with surfactant is loss to the rock matrix through several mechanisms like adsorption, precipitation and phase behavior changes.
Alkaline flooding is a very complex process. The aim of flooding the reservoir with alkaline is to form a surfactant in situ, which arises as a result of reactions between the injected alkali and the acid components of the crude oil. A problem with this method is that alkaline consumption is very high due to reactions with clay. Alkaline flooding began with the injection of sodium carbonate solution in Bradford area of Pennsylvania in 1925 and since then, work on this process has continued.

This process, as the name suggests, is a combination of the three processes namely alkaline, surfactant and polymer flooding in which the three slugs are used in sequence. Alternatively, the three fluids could be mixed together and injected as a single slug. The objective of the ASP flooding process is to reduce the amount of chemical consumed per unit volume of oil required and invariable a reduction in cost. It is evident that there are various types of EOR, thus the choice of which method to apply to a particular reservoir becomes challenging. Taber et al. came up with a set of screening criteria that should guide petroleum engineers on the particular choice of EOR method to use. The major considerations for the EOR processes are both the fluid properties and the reservoir characteristics.

The aim of surfactant flooding is to recover residual oil held back by capillary forces after water flooding. Injection of surfactant solution leads to a reduction in this interfacial tension between oil and water thereby leading to a mobilization of the residual oil. If the efficiency of surfactant is very good, then the reduction in Interfacial tension (IFT) could be as much as 104 which corresponds to a value in the neighborhood of 1μN/m. Trapped oil droplets or ganglions are mobilized due to a reduction in interfacial tension between oil and water after surfactant solution has been injected. The coalescence of these drops leads to a local increase in oil saturation. An oil bank will start to flow, mobilizing any residual oil in front. Behind the oil bank, the surfactant helps to prevent the mobilized oil from being re-trapped. The ultimate residual oil will be determined by interfacial tension between oil and surfactant solution behind the oil bank. The high cost of surfactant leads to the injection of only a small portion of the pore volume in most cases. The surfactant slug thus has to be displaced by water, in some cases containing polymer which through its ability to increase viscosity prevents fingering and breakdown down of slug. Surfactant slug thus has to be displaced by water, in some cases containing polymer which through its ability to increase viscosity prevents fingering and breakdown down of slug. The pressure drop across trapped oil has to overcome the capillary forces that trap oil in order for residual oil saturation in water flooded zones to be reduced. This represents what happens when IFT between oil and water is reduced by surfactants. The residual oil saturation corresponds to the capillary number, the dimensionless ratio between the viscous and capillary forces.

For efficient displacement of the oil bank towards the producing wells, the mobility ratio has to be as low as possible. Low mobility ratio prevents fingering of the surfactant slug into the oil bank and also reduces large-scale dispersion caused by permeability contrasts, gravity segregation and well pattern. The volumetric sweep efficiency is improved upon by low mobility ratio because a lot of the injected fluids are forced into areas far from the line between injector and producer wells. Simulation studies have been used to further confirm that low mobility ratio is of very high importance in oil recovery.

V. ENVIRONMENTAL AND HEALTH FACTORS

Surfactants have an excellent health and environmental profile. Almost all commercial surfactant types have oral toxicity at par with naturally occurring compounds like salt. Many surfactants are either naturally occurring or made by simple modifications of natural compounds. The human body contains many surfactants. The best known are the phospholipids that make up the cell membrane. These are essentially low water solubility anionic surfactants. Our lungs produce natural surfactants that make it easier for our lungs to expand and bring in air. Loss of lung surfactant leads to a disease known as sudden adult respiratory distress syndrome. The big exception to the generally benign nature of surfactants is their aquatic toxicity. Very low concentrations of surfactants in surface water can be highly toxic to all forms of aquatic life, from insects to fish, reptiles and amphibians. Consequently, a major environmental consideration in the introduction of any new surfactant molecule is determining whether it is sufficiently biodegradable to lose its surface activity before being emitted from municipal or industrial waste treatment plants. Even ppm concentrations of non-degraded surfactants can kill wide ranges of aquatic organisms. Due to the high cost of surfactant production caused by petrochemical feedstock's, considerable attention has been given to non-edible vegetable oils as an alternative source of feedstock. In this, a new non-edible oil derived surfactant based on Jatropha plant was synthesized [14]. A single step route was used for synthesizing epoxidized methyl ester sulfonate (EMES) for enhanced oil recovery application. The performance of the resultant surfactant was studied by measuring the interfacial tension between the surfactant solution and crude oil, and its thermal stability at reservoir temperature. The EMES showed properties similar to sodium dodecyl sulfate, such as the reduction of interfacial tension to 3.45 mN/m. The advantage of the newly EMES is the low cost of production that makes it a promising surfactant for enhanced oil recovery application and other uses.

VI. POLYMER-SURFACTANT INTERACTIONS

The basic forces controlling polymer-surfactant interactions are the same as those involved in other solution or interfacial properties of amphiphilic systems, namely van der Waals and dispersion forces, the hydrophobic effect, dipolar and acid-base interactions, and electrostatic interactions. The relative importance of each type of interaction will vary with the natures of polymer and surfactant so that the exact characters of the complexes formed may be almost as varied as the types of material available for study. Two critical concentrations, one known as critical aggregate concentration, also designated as (CAC) and the other as critical micelle concentration (CMC), characterize this interaction. The CAC corresponds to the onset of the interaction between the surfactant and the polymer, while CMC corresponds to the concentration at which saturation of the polymer occurs. When a surfactant is added to the polymer solution, it is often observed that processes such as micellization appear to begin at surfactant concentrations below the critical micelle concentration (CMC) of the material in the absence of polymer [18-23].

VII. CONCLUSIONS

A lot of research work has been done on the surfactant based EOR during the recent past. EOR will be one of the answers in meeting the world's long term demand for energy producing the maximum from existing oil fields is responsible resource . Right selection of EOR process and accurate knowledge about the reservoir holds key to the success of EOR process. The oil-rich emulsion plays an important role for low IFT in the surfactant system. We can see that petroleum sulfonates is useful in surfactant flooding as a primary surfactant. Lastly we can say that surfactant based enhanced oil recovery exist that reduce project technical risk. It can make a much more significant contribution to world oil supply than is currently forecast, it is a long term business.

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