Recovery Mechanism of Heavy Crude Oil By Means Of Chemical Flooding Methods

[1]Dr. T. NAGALAKSHMI and [2]A.SIVASAKTHI

[1] Professor, [2]Ph.D. Research Scholar
[1,2]Department of Petroleum Engineering,
[1,2]Academy of Maritime Education and Training (AMET), Chennai, India

Abstract: Heavy crude oil is one of the unconventional crude oil which is difficult to recovery from the reservoir formation. Chemical flooding is a non-thermal flooding method which uses synthetic chemical for the recovery of heavy oil. Anionic and non-ionic surfactants such as Sodium dodecyl sulphate, tween were performed in some of the heavy oil fields and found to be effective. Polymer flooding namely Arabic gum, polyacrylamide has potential in the recovery of heavy oil. In the laboratory scale, Alkaline-Surfactant-Polymer was tested in the core flooding apparatus and macro emulsion was formed with the heavy oil samples.

Keywords: Alkaline flooding, Chemical flooding, Heavy oil, Surfactants and Polymer

I. INTRODUCTION

Heavy crude oil is thicker and high resistance to flow. The heavy crude oil consists of many undesirable components in larger amount compared to light oil namely asphaltene, resin, wax, sulphur, nitrogen and other metals. ˚API of heavy oil ranges from 10˚ to 22˚ along with the viscosity of 100 -10000 cP. The heavy crude oil reserve is estimated to be twice than the light crude oil. The heavy crude oil refinery takes more energy to refine and provide less valuable products. It has a serve issue while extraction and transportation.

Most heavy crude is found in Canada and Venezuela, though there are deposits throughout the world. Sweet heavy crude has less than 1% sulfur and is primarily found in Africa. Sour sulfur crude is found throughout the rest of the globe along with Venezuela having the largest single deposit. The deposit of heavy crude in Venezuela is greater than any recoverable deposit in the world, including Saudi Arabia and Canada.

Due to the high viscosity, heavy crude oil is mainly recovered by thermal recovery methods such as In-situ combustion, Steam drive methods, Cyclic Steam Stimulation and Steam Assisted Gravity Drainage. Heavy crude oil of slightly viscous and ˚API below 15˚ can be recovered by the non-thermal or chemical flooding methods. The chemical flooding methods can be performed in various ways that is surfactant flooding, polymer flooding, alkaline flooding and alkaline- surfactant-polymer flooding.

II. CHEMICAL FLOODING

2.1 Surfactant Flooding

Surfactant flooding is implemented in the reservoir in order to achieve one of these possibilities such as improve the mobility ratio, increases the capillary number, reduce the interfacial tension and alter the wettability. The surfactants are added in the interface of oil and water system, in which the hydrophilic head orient them towards polar group and hydrophilic tail orient towards the less polar group. The cohesive forces between the two immiscible liquids are destroyed by the introduction of surfactants. The reduction in surface tension helps in mobilizing the oil from the reservoir. When the surfactant is applied in low concentration, it is adsorbed on the rock surface and the effect of interfacial tension reduction is decreased. The adsorption mechanisms of surfactant at interfaces have been extensively studied in order to understand their performance in many processes such as dispersion, coating, emulsification, foaming and detergency. These interfaces are liquid–gas (foaming), liquid–liquid (emulsification) and liquid–solid (dispersion, coating and detergency). The greater the surfactant tendency, the stronger is the effects of interfacial tension reduction [1, 2].

2.1.1 Types of Surfactants

Surfactants used in the chemical flooding are classified into anionic, cationic and non-ionic.

Anionic surfactants are widely used surfactant in the chemical EOR. Anionic surfactants dissociate in water into an amphiphilic anion and a cation. The dissociated cations are usually alkaline metal or quaternary ammonium. Some examples of anionic surfactants are soap, sulfonates, sulphates, phosphates and sulfosuccinates.

Non-ionic surfactants are mostly used next to anionic surfactant in CEOR. This surfactants do not dissociates into ions in aqueous solution. The hydrophilic end consists of alcohol, ether, ester or phenol while hydrophobic end consists of alkyl or alkyl-benzene. The hydrophilic and hydrophobic ends are non-dissociate types. Examples of non-ionic are ethoxylated alcohol, sulfoxides and ethoxylated sorbitan fatty ester.

Cationic surfactants dissociate in water into an amphiphilic cationic and anionic. Cationic surfactants are more expension compared to anionic and non-ionic surfactants because of the high pressure hydrogenation during synthesis of cationic surfactant. Amine oxides, amine salts and quaternary ammonium are the certain cationic surfactants used in CEOR.

2.1.2 Injection of Surfactant

Surfactant flooding is carried out in two ways.

(1) The surfactant is injected in one particular injection well; the surfactant reduces the interfacial tension between the oil and water and then allows the oil to move towards the other production well.

(2) The surfactant is injected in the injection well and allowed to react with the oil and water for a particular time, which reduces the residual oil saturation and the injection well acts as a production well for the oil recovery. This method is commonly known as Huff n Puff process. The main mechanisms involved in surfactants are reducing interfacial tension is reduced between oil and water, oil and rock interfaces by reducing the capillary force which traps the oil in the rocks. The screening criteria of EOR for the surfactant flooding were shown in table 2.1.

Table 2.1 Screening criteria of EOR for the surfactant flooding

Oil viscosity (cP)	Oil gravity, API	Depth (ft)	Reservoir temperature, (̊F)	Permeability, (md)	Salinity (TDS), ppm	lithology
< 20	< 25	< 8500	< 250	> 20	< 50,000	Sandstone

2.2 Polymer Flooding

Polymer is a very large molecule composed of repeating units of a monomer. Polymers are classified mainly into natural and synthetic. The polymer flooding was started only after the primary and secondary recovery methods of crude oil production. At the end of secondary recovery processes, the amount of residual oil and water saturation and necessary parameters will be calculated from the reservoir before the polymer flooding processes. In the polymer flooding mechanism, the high molecular weight polymer is added to the water in specific concentration in order to increase the water viscosity and sweep efficiency. The polymer solution is prepared on the surface and injected into the reservoir through the injection well. The injected polymer solution is restrained in the reservoir for a particular amount of time and then produced from the production well. The recovery efficiency of polymer flooding is 20 % of OOIP [3].

2.2.1 Functions of Polymer flooding processes

Polymer flooding is applied in the reservoir field when the reservoir suffers from poor mobility ratio or reservoir heterogeneity. The polymer flooding helps to increase the viscosity of water in the injection phase. The term mobility ratio (M_r) is defined as the ratio of Mobility of oil (M_O) to the mobility of water (M_W), while the mobility is the ratio of permeability (k) to the dynamic viscosity (μ).

$$\textit{Mobility ratio } (M_r) = M_O / M_W$$

$$(OR) \quad M_r = (K_o/\mu_o)/(K_W/\mu_W)$$

Fig. 2.2. shows the conditions of mobility ratio. The mobility ratio is an essential element in the chemical flooding process water acts as a displacing fluid and oil is the displacement fluid. Mobility of the displacing fluid (water) should be higher than the mobility of the displacement fluid (oil) in other to meet a good crude oil recovery. In terms of ratio, *M_r must be less than 1 to get a favourable displacement of oil.*

Polymer flooding processes will be successful when the mobility ratio, residual resistance factor and injection behaviour are carefully analysed. Residual resistance factor (R_r) is also named as mobility reduction which is the ratio of initial water mobility to the water mobility after polymer injection.

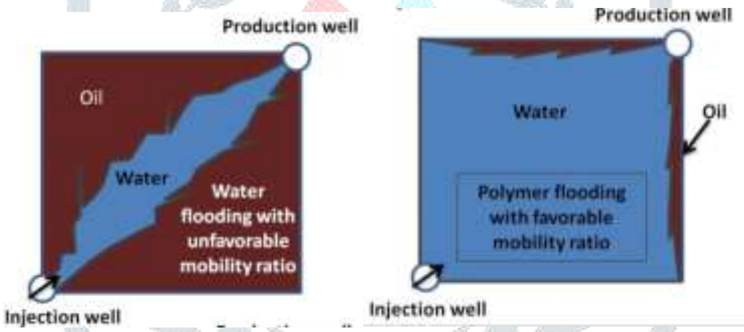

Fig. 2.2. Conditions of mobility ratio in polymer flooding

2.2.2 Selection of Polymer for flooding processes

Polymer applied in the EOR can be a synthetic or biopolymer. The synthetic EOR polymers are polyacrylamide (PAM) and partially hydrolysed polyacrylamide (HPAM) while xanthan gum is a biopolymer. The polymers are selected for the flooding processes according to the conditions of crude oil reservoir and type of the crude oil to be recovered. The selected polymer should avoid the conditions of thermal, chemical, microbial and mechanical degradation. The Polymers mainly applied in EOR namely PAM and xanthan gum are capable of providing a high viscosity in low concentrations [4].

Polyacrylamide (PAM) is a macromolecule which is prepared synthetically in industries by the process of polymerization. PAM is affected by the chemical, thermal and mechanical degradation. PAM is stable up to 90 ˚C. Then, the partially hydrolysed polyacrylamide (HPAM) and other modified polyacrylamide are begun to evolve due to PAM instability in chemical and thermal conditions. HPAM is stable up to 120 ˚C. Xanthan gum (XG) is a high molecular weight, biopolymer which is formed by the bacterial fermentation on the polysaccharides. Xanthan gum is stable from 70 ˚C to 90 ˚C.

The main parameter affects the viscosity of polymer solution are temperature, salt, hardness and pH. The viscosity of the polymer decreases as the temperature of the polymer solution increases. The high salt concentration in the reservoir also affects the viscosity of polymer solution.

2.3 Alkaline Flooding

Alkaline flooding is termed as caustic flooding appears to be the most attractive among the various non thermal processes. Alkaline flooding involves alkaline chemicals such as sodium hydroxide, sodium carbonate or sodium orthosilicate are injected. Alkaline reagents are quite cheap and abundant. The alkaline reagents react with the surface active materials present in the crude oil and form the in-situ formation of the surfactant soap species [5].

The adsorption of the generated surfactants at the oil/water/sand interfaces reduces the interfacial tension and raises the pH of the injected flood water; as a result the residual oil trapped in the fine pores of the reservoir sand is mobilized. In heavy oil reservoirs, the un-recovered oil at the end of the water flooding was bypassed due to the adverse mobility ratio between oil and water, this oil is capable of flow but it depends upon the applied pressure gradients and permeability of the rock. The sodium hydroxide and sodium carbonate are mainly used for the alkaline flooding, while sodium orthosilicates is effective in carbonate reservoir.

The addition of silicates is an enhancement to alkaline flooding. The silicates play two major functions: (1) Act as a buffer to maintain a constant pH level to produce a minimum interfacial tension and (2) Improves surfactant efficiency which is produced as the result of reaction with crude oil and flooded alkaline.

Generally, alkaline flooding is not for the carbonate reservoirs as the presences of enormous calcium ion react with alkaline and deposited on the rock pores. The precipitation of calcium ions ruin the reservoir formation and reduce the oil recovery. The presence of divalent ions such as calcium and magnesium in the formation water leads to the hydroxide precipitation. . The screening criteria for the alkaline flooding were given in the table 2.

Table 2.3 Screening criteria for the alkaline flooding

Oil viscosity (cP)	Oil gravity, API	Depth (ft)	Reservoir temperature, (F)	Permeability, (md)	Salinity (TDS), ppm	lithology
< 200	15 - 35	Not critical	< 200	> 50	< 2500	Sandstone

2.4 Alkaline-Surfactant-Polymer Flooding

2.4.1 SP Flooding

Polymer flooding practices is combined with the action of surfactant which is termed as surfactant-polymer (SP) flooding. SP flooding will have the combined effect of surfactant and polymer. The action of surfactant is to reduce the interfacial tension between the oil and rock as well as the action of polymer is to increase the water viscosity which in turn to improve the displacing fluid mobility are collectively used in the EOR processes to recovery the crude oil from the reservoir [6].

2.4.2 ASP Flooding

ASP flooding is the combination of all the three Alkaline, Surfactant and Polymer flooding. The polymer is injected for improving the sweep efficiency of the reservoir by reducing the oil viscosity. The surfactant is flooded into the reservoir for the reduction of interfacial tension and alters the wettability. Alkaline is introduced in the wells reacts with the acidic components of crude oil; leads to the generation of sodium salts of fatty acids, which acts as a surfactant for achieving the ultra-low interfacial tension between oil and water. ASP flooding becomes more important in recent days due to the high oil recovery efficiency and cost of surfactant and polymer is reduced due to the low usage in concentration [6]. The screening criteria for the ASP flooding were given in the table 2.4.

Table 2.4 Screening criteria for the ASP flooding

Oil viscosity (cP)	Oil gravity, API	Depth (ft)	Reservoir temperature, (F)	Permeability, (md)	Salinity (TDS), ppm	lithology
< 200	> 18	< 8500	< 200	> 20	Not critical	Not critical

III CONCLUSION

Heavy crude oil recovery via chemical flooding was carried out in many heavy oil fields. Many research studies has been carried out in the surfactant flooding and found to increase the recovery of heavy oil. The non-ionic and anionic surfactants were very effective in heavy oil recovery processes. Enhanced Oil Recovery uses the polymers which have a high resistance to polymer degradation, high temperature and salinity stability. The main purpose of the polymer in EOR is to increase the viscosity of water and reduce the permeability of the reservoir. ASP flooding was also performed in the heavy oil recovery and found to be effective.

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