Simulation Study of Micellar/Polymer Flooding Process in Sandpack

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Abstract

After natural drive energy of an oil reservoir is depleted, water flooding as a secondary method in enhanced oil recovery, much of oil remained in the reservoir due to bypassing oil. Thus, one of the most important methods to recover oil is micellar/polymer flooding which is more advantageous in terms of recovery factor in sandstone reservoirs. In the current study, an attempt has been made to investigate the effect of vital parameters including surfactant concentration, and salt concentration on surfactant adsorption and oil production via simulation. In addition, System was tested with and without alcohol/polymer and the impact on oil recovery clarified.

The investigations demonstrated that around 60% of reserve recovered by chemical flooding and surfactant. Surfactant has been found to increase oil production. Polymer solutions can be significant means of controlling mobility and increasing volumetric sweep efficiency.

Chemical compositional simulator, UTCHEM, was run to show the effectiveness of micellar flooding and evaluation of results. Simulation results by UTCHEM showed the effectiveness of chemical flooding in sandpack. The maximum Time of simulation would be 1.34 PV and considered in a 2 ft Sand pack. Two wells defined in the simulators as a producer and injector accounted for the system.

Introduction

It is well known that water and oil cannot be mixed until the third component, surfactant or soap, is added to reduce the interfacial tension between oil and water. In order to have an effective micellar flooding, interfacial tension has to be reduced to 0.001 dyne/cm. Since micellar solution makes fluids miscible in the reservoir, almost 100 percent of oil can be displaced especially in the presence of alkaline (Sodium Carbonate). However, due to reservoir rock non-uniformity in the field, the amount of oil recovery is reduced [1]. The main objective of micellar injection is to reduce interfacial tension to enhance oil recovery.

ISBN 978-1-60643-379-9

In some references [2],[3], micellar solution is called as microemulsion. In order to produce microemulsion solution, 20-25 wt% of surfactant needed. However, in order to economically reduce the cost of project due to the price of surfactant, optimum mixing ratio of surfactant can be designed which is less amount, about 5-10 wt% of surfactant [4].

Surfactant phase behavior contains five components which are namely known as oil, water, surfactant, and two alcohols and UTCHEM is capable of simulating and calculating all components simultaneously. The compositional simulator can only model three components when the presence of two alcohols is negligible including surfactant, water and oil. Up to now, two concepts have been developed in order to enhance the oil recovery by using surfactant. First of all, low concentration of surfactant in large pore volumes (about 15 to 60 percent or more) are injected. Second of all, high concentration of surfactant in small pore volumes (3 to 20 percent) is considered. When surfactant with high concentration system moves through pore volumes, it is converted to the low concentration slug [5].

According to the ternary phase diagram of micellar solution shown in Figure 1, there are two regions in which oil can be recovered, single phase and multiple section. The single phase of microemulsion is considerably important and dominant in order to displace oil. Microemulsion (multiphase section) are divided into three categorizes which are namely known as lower phase (l), upper phase (u) and middle phase (m) in equilibrium with excess oil, excess water or both excess oil and water.

In the start of injection, slug is under single condition affecting IFT to be extra-low and oil recovery is high [6]. The amount of oil and water bypassed must be controlled by polymer in microemulsion flooding because it extremely affects the fractional oil recovered [7].
Since the main objective of micellar flooding is to replace oil, not water, it would be eminently suitable for surfactant to become miscible with oil and immiscible with water. This condition can be obtained by upper phase microemulsion. Polymer water (polymer is mixed with water at the back of injection slug) is responsible for displacing micellar slug as small volume of micellar is injected. As micellar is not miscible with polymer water, some of micellar might be trapped as immobile saturation which in some cases is higher than trapped oil. For lower phase system, micellar is miscible with brine but large portion of oil can be bypassed. The advantage of using lower phase system is that micellar is not trapped in the pore volumes. To achieve the optimum design, A middle phase needs to be designed to use the advantages of both lower and upper phase systems [8]. In addition to using surfactant/water and oil, alcohol and salt are also applied to control the viscosity of the solution and improve the solution properties, respectively [9]. Capillary and viscous forces have a significant role in chemical flooding in porous medium with small thickness such as Sandpack. While capillary forces prevent oil to move out of pore volume, viscous forces contributes to recover oil out of pore volumes. There is an index known as capillary number which correlates capillary and viscous forces. By increasing capillary number, residual oil saturation decreases depending upon displacing fluid flow rate, IFT between displaced, displacing fluid and displacing fluid viscosity [10]. The capillary number was determined by the following equation.

$$N_{ca} = \frac{v\mu}{\sigma}$$

Where
σ: The IFT between displacing and displaced fluids (dynes/cm)
μ: Displacing fluid viscosity (cp)
v: Darcy velocity (m/s)

The main objective of chemical flooding process is to reduce IFT and control capillary number index while polymer affects water viscosity. Jean [11] concluded that effective micellar not only depends on IFT, displacing fluid viscosity and displacing fluid velocity but relative permeabilities, residual saturations, fluid viscosities, and phase behavior have influence on oil recovery.

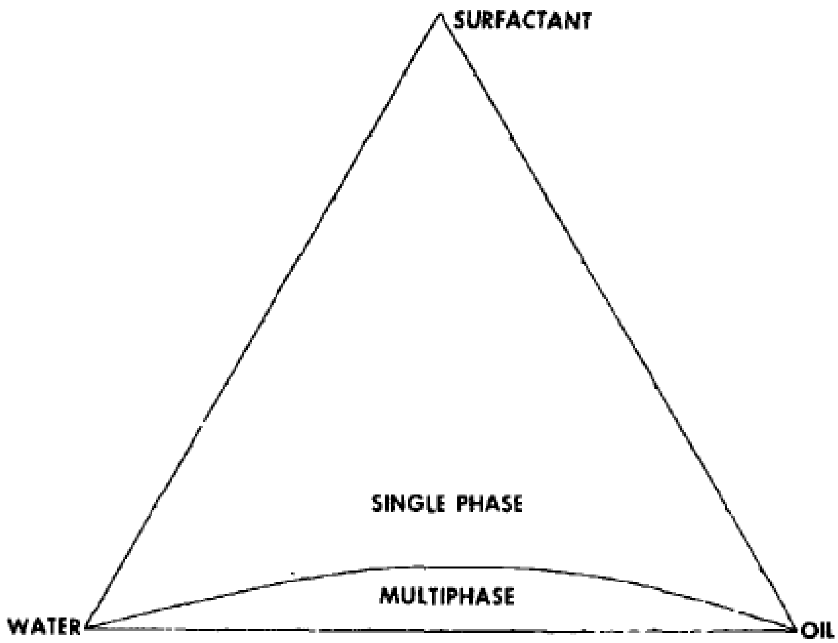

Figure 1: Ternary Diagram of Microemulsion System

In order to recover oil efficiently, surfactant molecules must have two important characterizations:

1. Surfactant molecules have to be amphiphilic meaning molecules need to be able to attract both water and oil.
2. Surfactant molecules have to be accumulated, that is, molecule chains must collect which separate oil and water resulting in the solubilization of oil and water and lower interfacial tension.

Generally, three main factors can affect the behavior of surfactant including oil composition, water composition and reservoir temperature. Surfactant needs to have two sections to recover oil containing water-soluble portion named as hydrophile and oil-soluble portion which is called lipophile [12]. By increasing temperature, water solubilization decreases while oil solubilization would be increased [13].

Description of Simulator

The University of Texas at Austin has been developed UTCHEM for the purpose of Enhanced Oil Recovery processes. UTCHEM is particularly capable of simulating chemical flooding, several physical and chemical models is implemented in UTCHEM. The model is multiphase, multi-component simulator employed in both field and laboratory. UTCHEM is composed of five sections including Reservoir description (reservoir dimensions), Output option (control on oil recovery, other output options), Reservoir Properties in which rock properties (sandpack properties in the current work), Physical properties (data relevant to surfactant and polymer properties etc) and well data (Two vertical wells are defined as injection and production wells in this section). The flowchart of simulator and the relation of parameters are depicted in Figure 2.

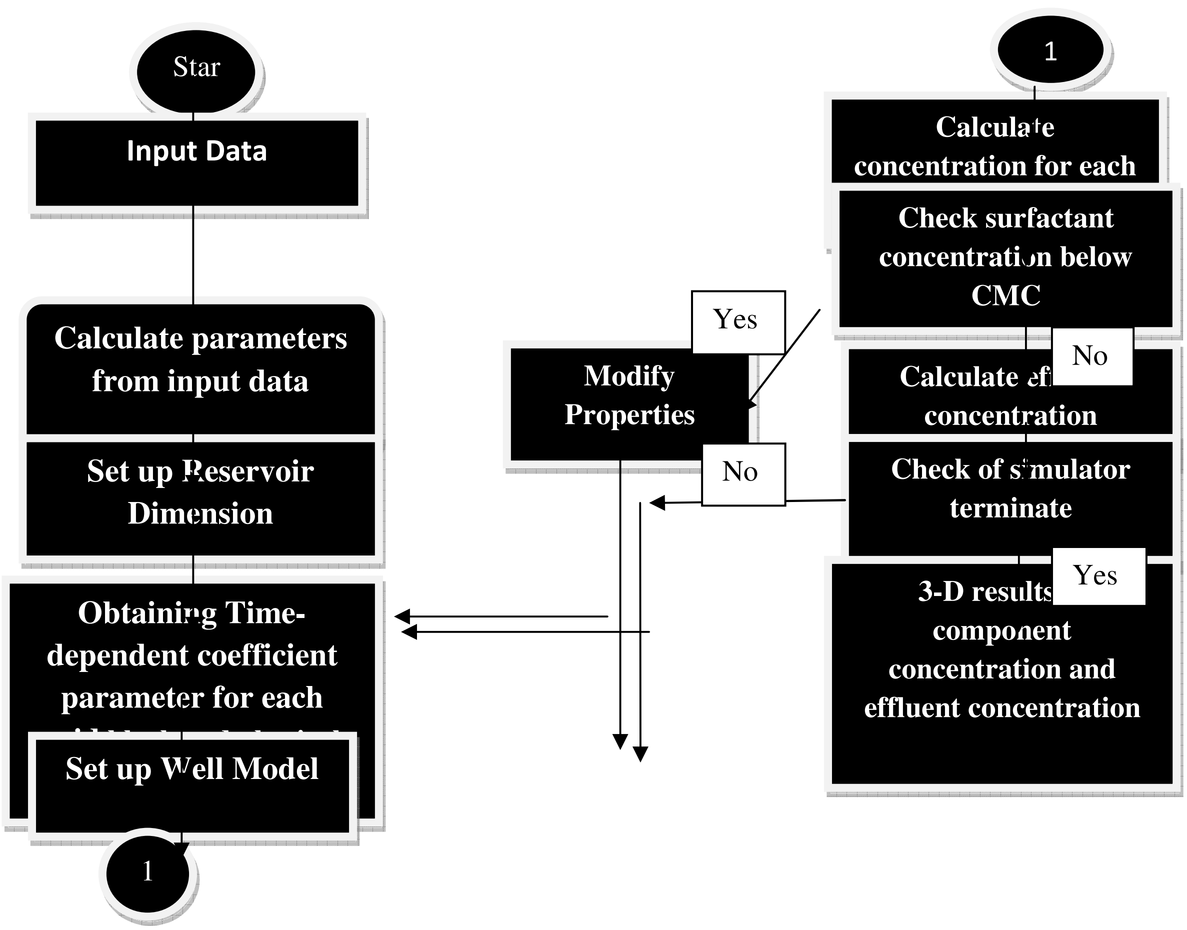

Figure 2. The Flow Chart of the UTCHEM Simulator

Sandpack Characterization

In the present work, simulation study of surfactant flooding by using UTCHEM simulator has been done. The main purpose of the current work is to examine surfactant, salt concentration, the effect of salt and polymer on recovery factor through simulating laboratory parameters. The data related to sandpack and fluid is taken from University Technology of Malaysia's Laboratory. The most important parameter needs to be achieved is effective salinity based on solubilization ratio which would be the average of lower and upper salinity limit. The lower salinity is 0.211 meq/ml of water and upper salinity is 0.322, so effective salinity would be 0.2665 meq/ml of water. This value then should put as an input parameter in UTCHEM.

The porous media for micellar displacement was core plug of 2 ft long and 1 inches diameter of Berea Sandstone (Sandpack). Compositional simulator is used to model micellar displacement to show the effectiveness of the process. The properties of the rock and fluid in which chemical injection has been done are summarized in Table 1. Porosity and permeability can be easily calculated by porosity and permeability meter, water and oil viscosity was measured by viscosity meter. In addition, maximum simulation time to be considered 1.34 PV.

Table 1. Input Parameter of Rock and Fluid Properties

Rock and Fluid Properties	value
Rock material	Berea
Core length	2 ft
Rock porosity	0.28
Rock compressibility	0.0 1/psi
Rock permeability	550 md
Oil viscosity	5.0 cp
Water viscosity	0.9 cp
Constant initial water saturation	0.45
Initial brine salinity	0.4
Initial divalent cation concentration of brine	0.003
Initial pressure	14.5 psi

Physical Property Data

The parameters for polymer and surfactant including critical micellar concentration (CMC), adsorption, and height of bimodal curve are given in Table 2. Calculation of Physical property data is a very time-consuming task. These data would bring into the physical property section. All these data must be taken from laboratory data. For instance, polymer viscosity parameter can be obtained from the curve slope of polymer viscosity versus polymer concentration and then can be put on the simulator or Critical Micellar Concentration (CMC) can be calculated from the sudden change in the slope of curve of surface tension versus surfactant concentration.

Table 2. Physical Property Input Parameter

Property	value
Polymer viscosity parameter	81,2500,2700
Height of bimodal curve	0.131, 0.1, 0.191, 0.026, 0.363, 0.028 vol. fraction
Salinity limit	0.211, 0.322 meq/ml
CMC	0.0001 vol. fraction
Adsorption parameter	1.5, 0.5, 1000
Longitudinal and Transverse Dispersivity	Water:12.0, 4.0 Oil:12.0, 4.0 Surfactant:12.0, 4.0

Simulation Model

A single block containing 242 grid blocks is considered which has 11 grid block in X direction, 11 in Y direction and 2 layers in Z direction. Two vertical wells as producer and injector is considered for the system. Figure 3, 4 shows decrease in residual oil saturation after 1.34 pore volume which is equivalent to 1500 days. In the start of injection, residual oil saturation was to be 34% decreased in 14% in the middle of the core.

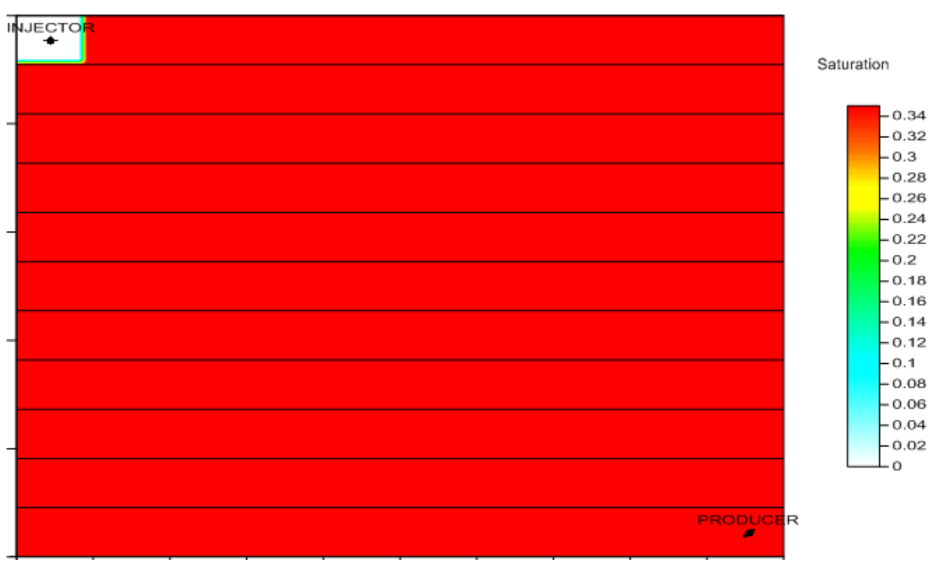

Figure 3. Residual Oil Saturation in the Start of Injection

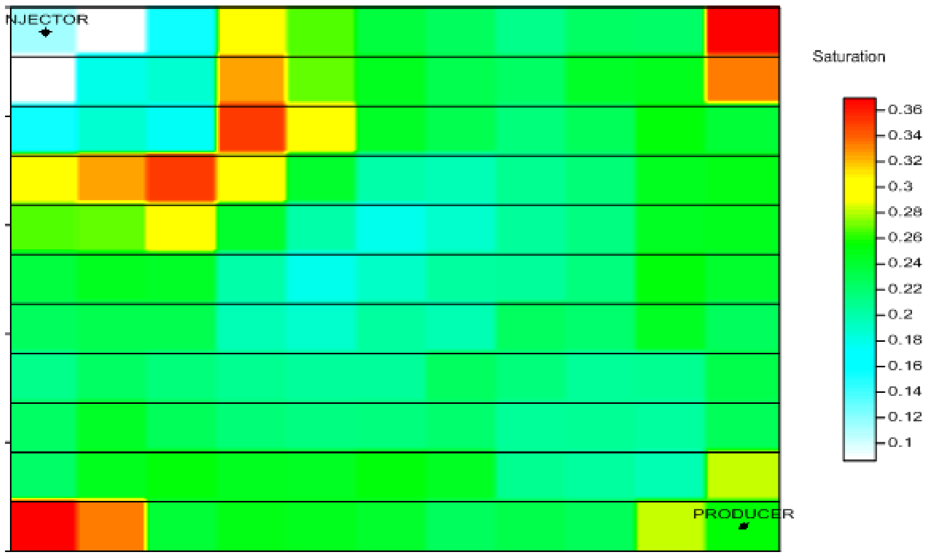

Figure 4. Residual Oil Saturation after 1.34 PV Injection

Simulation Results

The effect of surfactant concentration

Surfactant concentration has an efficient consequence on chemical flooding. Figure 5 indicates the different concentration of surfactant from 0.03 wt% to 0.1 wt%. To examine this parameter, salt concentration and flow rate, polymer concentration is considered to be constant, 0.4 meq/ml of water, 0.025 cuft/day, 0.05 wt%, respectively. The surfactant concentration of 0.1 wt% has the highest recovery factor compared to the other concentrations. However, surfactant adsorption would be critical. In this situation, alkaline and soap materials is employed to prevent the severity of adsorption. Recovery factor is reached 46 percent. After dimensionless time of 0.32 PV, breakthrough of oil is occurred during the process. When surfactant concentration of 0.1 wt% was applied, system would be in the one phase region. Therefore, most of the oil can be recovered in this stage and oil recovery is independent of salt concentration. However, the amount of adsorbed surfactant would be higher than that of 0.1 wt% surfactant concentration demonstrated in Figure 6.

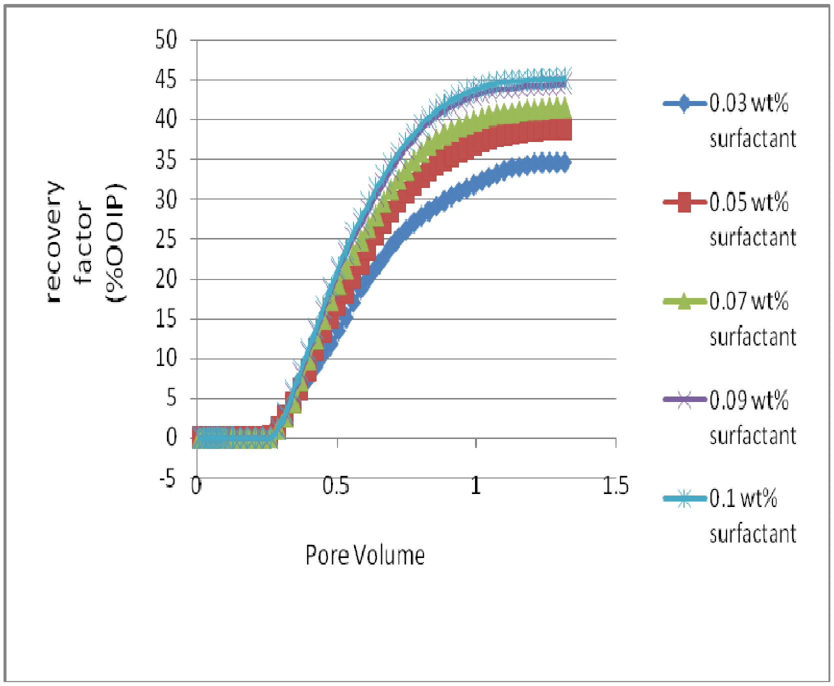

Figure 5: The effect of surfactant concentration on oil production

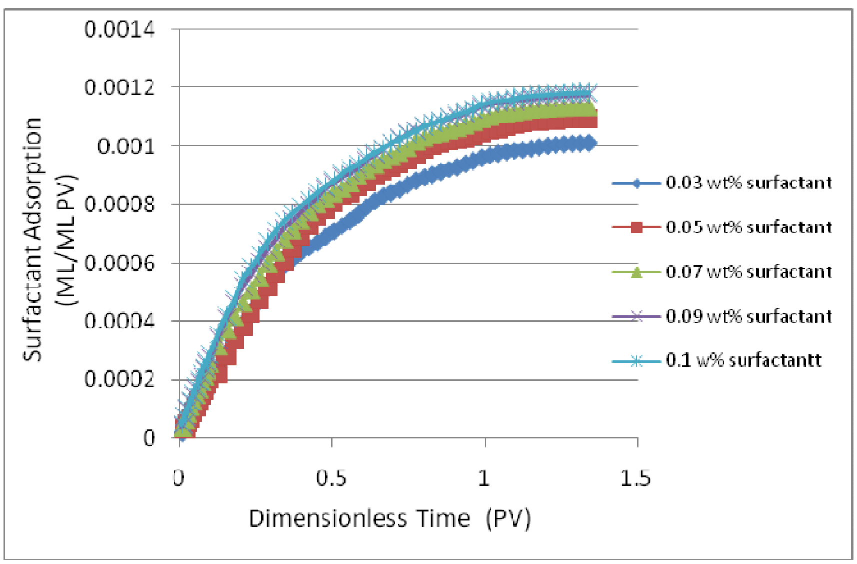

Figure 6: Surfactant adsorption versus Dimensionless Time

Salt Concentration

By increasing salt concentration, system is shifted from lower phase to upper phase. Thus, more oil can be miscible with micellar solution in the reservoir [6]. Figure 7 depicts the impact of salt concentration on oil recovery taken from compositional simulator. Salt concentration is from 0.02 to 0.4 meq/ml of water, lower concentration of surfactant is chosen. As it can be observed, there is a tremendous difference between lower and upper phase in terms of oil recovery. When salt amount increases, system is located in upper phase indicating less oil is bypassed due to viscose fingering.

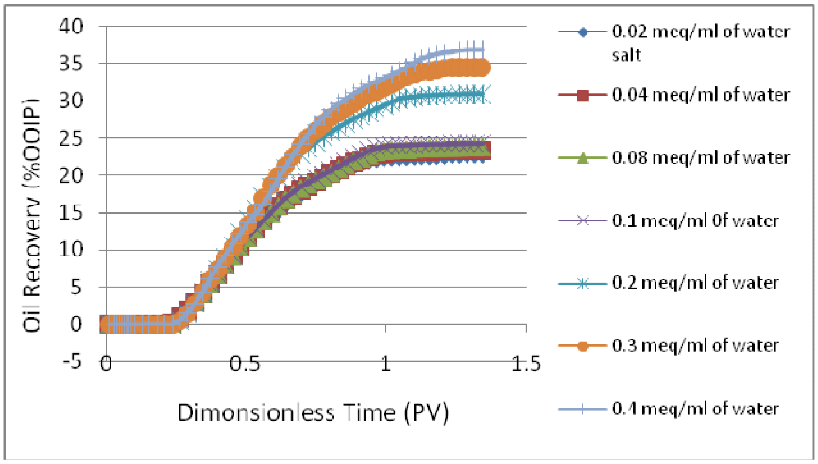

Figure 7: The impact of salt concentration on oil recovery

Control Mobility Agent

Figure 8 presents the impact of polymer on oil recovery. Two cases were investigated with and without polymer. Polymer was used to control volumetric sweep efficiency through mobility control. The mobility control is defined as the ratio of displacing fluid (water) mobility divided by mobility of displaced fluid (oil) mobility. The favorable value of mobility index would be less than 1. By using polymer, water would be more viscose than oil. On the other hand, mobility of oil increases as compared to water.

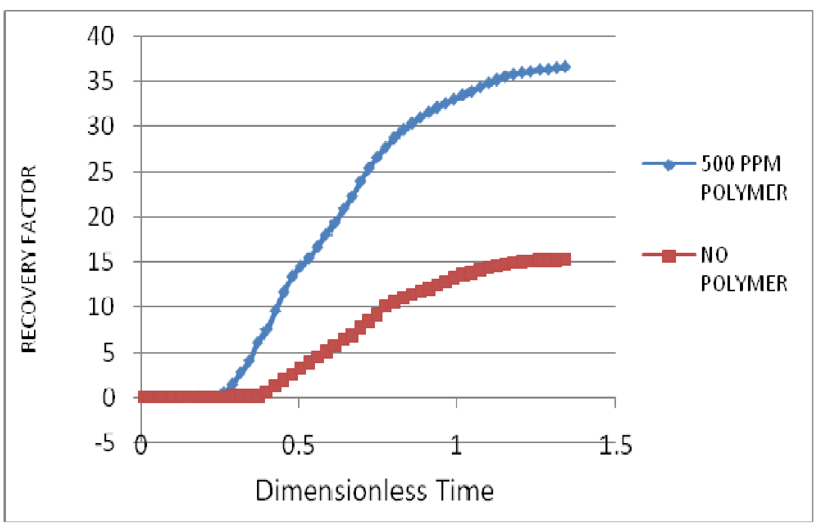

Figure 8: The effectiveness of polymer on recovery factor

In the absence of polymer, viscose fingering is occurred and much of oil remained behind the micellar solution, difference of 20 percent oil recovery indicates the effectiveness of applying polymer.   Polymer viscosity parameters put into simulator was based on Polyacrylamide. By using polymer, the oil production occurred faster than the lack of polymer.

Alcohol as a Co-Surfactant

Alcohol as a co-surfactant is able to enhance the viscosity of solution, improving the performance of micellar flooding. However, no significant difference is observed in the presence/absence of Alcohol. At the end of injection, the difference of 1 % recovery factor has been observed depicted in Figure 9.

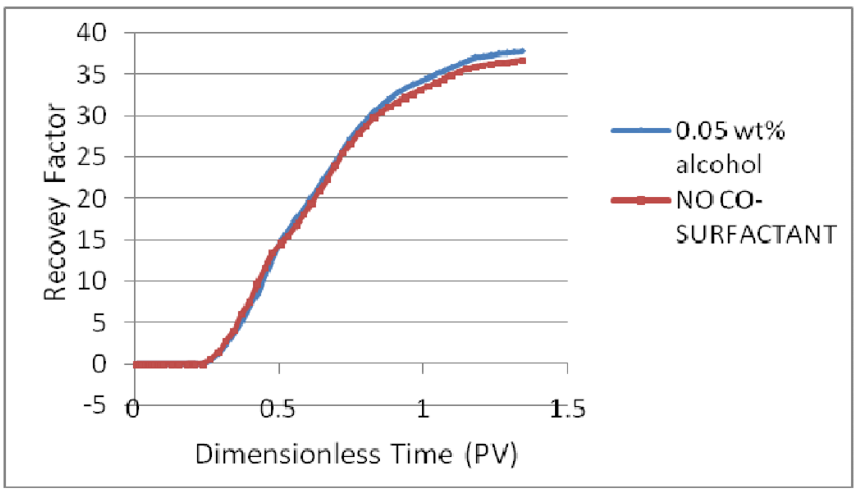

Figure 9: Comparison of injection of micellar solution with/without co-surfactant

The significant impact of alcohol is to control and limit the surfactant adsorption reducing the project prices.

Conclusion

In the current work, the effect of salt and surfactant concentration, the effect of alcohol on oil production and sensitivity on polymer presence through simulation has been done. The conducted results led to following conclusions:

1. Application of polymer in chemical flooding affects the improvement of production since; polymer can increase viscosity of water and prevention of bypassing oil.
2. Increase in surfactant concentration as a solubilizar causes enhance oil recovery but adsorption of surfactant would be another concern that should be considered because surfactant is not economically feasible when price of oil is below 30 $.

ISBN 978-1-60643-379-9

3. The amount of salt in the solution can improve oil recovery since more oil can be miscible with micellar solution. In fact, the system is changed from lower phase to upper phase.
4. Alcohol can increase viscosity of solution and mixed with surfactant. According to the presented results , no big difference in recovery has been observed.

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