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Research paper

Micellar-polymer for enhanced oil recovery for Upper Assam Basin

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Abstract

One of the major enhanced oil recovery (EOR) processes is chemical flooding especially for the depleted reservoirs. Chemical flooding involves injection of various chemicals like surfactant, alkali, polymer etc. to the aqueous media. Bhogpara and Nahorkatiya are two depleted reservoirs of upper Assam basin where chemical flooding can be done to recover the trapped oil that cannot be recovered by conventional flooding process. Micellar-polymer (MP) flooding involves injection of micelle and polymer to the aqueous phase to reduce interfacial tension and polymer is added to control the mobility of the solution, which helps in increasing both displacement and volumetric sweep efficiency and thereby leads to enhanced oil recovery. This work represents the use of black liquor as micelle or surfactant that is a waste product of Nowgong Paper Mills, Jagiroad, Assam, which is more efficient than the synthetic surfactants. The present study examines the effect of MP flooding through the porous media of two depleted oil fields of upper Assam basin i.e. Bhogpara and Nahorkatiya for MP EOR. This work also compares the present MP flood with the earlier work done on surfactant (S) flooding. It was experimentally determined that the MP flood is more efficient EOR process for Bhogpara and Nahorkatiya reservoirs. The study will pertain to the comprehensive interfacial tension (IFT) study and the displacement mechanism in conventional core samples.

Keywords: Black liquor; Critical micelle concentration; Interfacial tension; Porous media; Enhanced oil recovery

1. Introduction

Enhanced oil recovery, commonly known as tertiary oil recovery, is an eminent method of maximizing oil recovery from the mature oil fields whose production has reached its peak and has started to decline. The planning for improving, maximizing or enhancing oil production strategies through EOR methods is one of the most critical challenges facing the oil industries today. EOR involves injection of more exotic and correspondingly more expensive fluids other than water and non-miscible gases. This method mobilizes and recovers the oil that has been left behind or cannot be produced economically by conventional means. Approximately 30–60% or more of the reservoirs' original oil can be extracted using EOR as compared to primary and secondary recovery methods with 20–40%. EOR includes so many methods such as thermal methods which incorporates conventional steam, cyclic injection, steam assisted gravity drainage and in-situ combustion, chemical injection which incorporates surfactant, polymer, alkaline, surfactant with foam, gas injection which involves N_2, CO_2, flue, NGL and injection of microbes which is also known as microbial enhanced oil recovery [1].

Basic mechanisms involved in chemical flooding are reduction in interfacial tension between oil and brine, solubilization of released oil, change in the wettability toward more water wet, reducing mobility contrast between crude oil and displacing fluid. Chemical flooding is found to be recovering more oil from the depleted reservoirs such as surfactant flooding, micellar-polymer, alkaline, polymer flooding etc. Among EOR techniques, micellar-polymer (MP) flooding process has the potential as it uses surfactant to reduce interfacial tension (IFT) and therefore, allow the oil to flow through porous media [2]. Beneficial synergistic effect by combining surfactant and alkali in a chemical flood has been reported in the literature [3–8]. The capillary forces reduce on addition of surfactants, which trap

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Nomenclature

EOR	enhanced oil recovery
IFT	interfacial tension
CMC	critical micelle concentration
S	surfactant
MP	micellar-polymer
g/ml	gram per milliliter
mPa.s.	millipascal.second
ppm	parts per million
mg/l	milligram per liter
k_{ro}	relative permeability of oil
S_{wi}	irreducible water saturation
k_{rw}	relative permeability of water
S_{or}	residual oil saturation
mN/m	millinewton per meter

the oil inside the pores of the rock. The surfactant slug helps to displace the majority of the oil from the contacted reservoir, by reduction of the interfacial tension between oleic phase and aqueous phase. The surfactant flooding in petroleum reservoirs is an effective way of recovering a fraction of remaining oil and widely recognizable for providing an ultra low IFT ($\approx 10^{-3}$ mN/m) between the oil and the aqueous solution containing surfactant. Several surfactants have been investigated in the literatures [9–13]. Babakhani et al. (2011) from his investigations found that around 60% of the reserves were recovered with the help of chemical flooding. Surfactant reduces the IFT value and polymer solution controls mobility and increases the volumetric sweep efficiency, thereby enhanced oil recovery [14]. Gurgel et al. also highlighted the use of various chemical methods for further oil displacement from the depleted reservoirs which can be achieved by attaining ultra-low interfacial tensions and reduced fluid viscosity in the oil reservoirs. He mentioned the importance of interfacial science, physico-chemical properties of chemical systems and geological characteristics of the rock matrices to plan and obtain a high yield processes through optimization and modeling techniques [15]. Mandal (2015) from his analysis also found that chemical flooding mainly operates on two basic mechanisms, increase of macroscopic and microscopic displacement efficiencies. The increase in macroscopic efficiency can be obtained by polymer injection which increases the viscosity of displacing fluid and improves the mobility ratio whereas the increase in microscopic efficiency can be obtained by alkali/surfactant injection through reduction of IFT, emulsification of oil and water, solubilization of interfacial films, wettability reversal, etc. [16].

Reduction of IFT is a major contributor for increasing the oil recovery from the depleted reservoirs. If IFT is reduced, the emulsification of residual oil will be easier and EOR will prove to be more efficient. Many literatures have supported the particular phenomenon [17,18]. Surfactant plays an important role in reducing the IFT by getting adsorbed into the liquid–liquid interface and alters the wetting properties of reservoir rock and fluid. Howard (1927) reported, for the first time, a patent on surfactant-based chemical EOR where surface tension between reservoir rock and crude oil was reduced using soap or any other aqueous solutions [19]. De Groote (1929) granted a patent where he claimed that water soluble surfactants help to improve oil recovery [20]. Johnson et al. (1982) invented black liquor (BL) that can be able to inject into an oil-bearing subterranean formation before or simultaneously with the emulsion of chemical flood that gets adsorbed on the active mineral surfaces of the matrix formation and efficaciously reduces the surfactant adsorption in the chemical flood. The effluent or BL is used alternatively to displace the surfactant from the mineral surfaces that eventually helps in increasing the recovery of crude oil [21]. Novosad (1983) claimed that the advantages of lignosulfonates have not come from the activity as a sacrificial agents [22]. With addition of lignosulfonate, the lowering of IFT can be achieved, which was quantitatively similar to that observed by the addition of NaCl, which was provided in the solution when it was below the optimum salinity level. However, the quantity of lignosulfonate required was much smaller for lowering IFT [23]. Several surfactants of petroleum sulfonate have been examined to produce such low interfacial tensions. However, this petroleum sulfonate is high in cost and one of the major issues in surfactant flooding processes. The possibilities of using lignosulfonates, which were almost four times cheaper as compared with petroleum sulfonates for EOR operations, have been reported [24–28]. About 10% of the total spent liquors in Canada were processed to recover useful products such as lignosulfonates [29] for various applications that involves EOR.

The main objective of this work is to use a locally available surfactant for an effective chemical flood. Especially, we will investigate the use of inexpensive black liquor (BL), where the main constituent is sodium lignosulfonate, which is readily available from Nagoan Paper Mill at Jagiroad, Assam as a substitute for the more expensive or commercial surfactant [30]. This work also examines the comparison between MP and surfactant flooding on the two depleted oil fields of upper Assam basin i.e. Bhogpara and Nahorkatiya. The experiments are conducted on the description of multiphase flow in porous media based on Darcy's law and JBN method for unsteady-state displacements. JBN [31] method is a direct calculation method derived from the simplified theory and formulation of immiscible displacement through porous media according to Buckley and Leverett [9].

2. Experimental analysis

2.1. Materials

The materials used for the preparation of emulsion were distilled water and paraffin oil with a density of 0.5742 g/ml and viscosity 220 mPa.s. The brine solution used is 3000 ppm of NaCl in DW having viscosity (μ_w) of 1 mPa.s. The surfactant used is BL whose main constituent is Na-lignosulfonate, which is cheap and locally available as waste from Nagoan Paper Mill, Jagiroad. The polymer used is polyacrylamide with a density of 1.02 g/ml and viscosity 1.5 mPa.s.

Table 1
Fluid formulation.

Concentration type	Formulation
Surfactant (S) concentration	BL 0.5–1.5 wt%
Polymer concentration	Polyacrylamide 2000–3500 mg/l
Brine	3000 ppm NaCl

The core samples were from well no. BH(A) and NH(B) which were cut into small cylindrical section of 7 cm length and 3.8 cm diameter, and were cleaned using Soxhlet apparatus with a solvent mixture of xylene and toluene (50:50) which took approximately 80 hours. They were then cleaned with ultrasonic cleaner and finally dried with humidity control oven. The total time taken for drying of all the samples is approximately 20 hrs.

Fluid formulation [Table 1] will be composed of locally available Nagoan black liquor (BL) whose main constituent is Na-lignosulfonate [$C_{10}H_{14}N_2Na_2O_8 2H_2O$] with a molecular weight of 372 g/mol, a waste from Nowgong Paper Mills, Jagiroad, Assam [32]. A polyacrylamide polymer will be used for mobility control. The polymer concentration will be chosen to provide a favorable mobility ratio between the oil bank and displacing fluid.

2.2. Methods

2.2.1. IFT test

The sample MP was prepared by mixing 20 ml of brine, 20 ml of polymer and 20 ml of micellar thoroughly in the ratio of 1:1 by vigorous shaking in bottles. Then in this sample 40 ml of paraffin oil was added and the bottles were mixed gently and allowed to equilibrate for 4 weeks.

After that the IFT test was conducted in KRUSS Easy Dyne Tensiometer, which is used for measurements of the surface tension of liquids, the interfacial tensions between two liquids and measurements of the density of a liquid. The main principle of the measuring method is the attractive forces between molecules which provide a certain work to change the size of a liquid interface or surface. The interfacial or surface tension is the force to be spent referring to the circumference of the surface. The term surface tension is used when the liquid phase borders to a gaseous phase, the term IFT refers to an interface between two liquids.

The EasyDyne S measures the surface or interfacial tension with a measuring probe suspended from a force sensor. This probe is a ring or a plate consisting of a material with optimum wetting properties (platinum respectively platinum–iridium) and the experiments were conducted using Du Nouy ring method [33].

2.2.2. Displacement experiments

The setup for permeability test essentially comprises a cylindrical section of 0.3048 m length and 0.0381 m packed with crushed rock sample, pressure gauges, sample reservoir, sample collector, stirrer and a pump all connected by pipes of 0.0127 and 0.022225 m outside diameter as shown in Fig. 1.

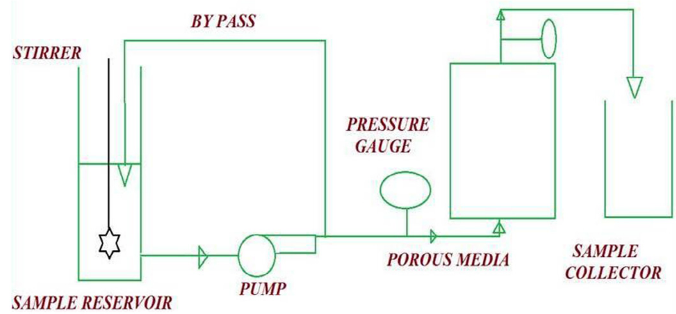

Fig. 1. Permeability apparatus.

The core sample was crushed in such a way that the grains were not broken. The crushed grains were made into a pack by using emseal, purchased locally, compressed uniformly in order to obtain a pack of uniform packing characteristics, and packed into the test cylinder. The permeability experiment was not carried with the actual core obtained from the oil field because the clay minerals in the actual core samples encountered problems like swelling and also to gain further understanding of the physical mechanisms of emulsion flow in porous media. The measured effective porosity obtained by TPI-219 Teaching Helium Porosimeter before flooding was found to be in between 18.78 and 21.90%. The pack was covered with a sieve of 320 mesh size at the top and the bottom. Flooding solutions were stirred in the reservoir and injected at the bottom of the cylindrical section at a constant volumetric flow rate of 0.0002 m/s by self-priming monoblock 186.425 watt (0.25 HP) pump supplied by Telco, Coimbatore, India. The inlet and outlet pressures of the cylindrical section were recorded from pressure gauges.

The general procedure for the coreflood experiment was:

1. The core was saturated with brine.
2. The core was placed in an oven and heated to reservoir temperature.
3. The core is flooded with brine at 6 m/d until it was saturated with brine to determine the absolute permeability [K] of the core sample
4. Paraffin oil was flooded at 3 m/d until no more brine was produced (about 2 PV) to determine the relative permeability of oil to water at irreducible brine saturation [k_{ro} at S_{wi}]. The S_{wi} averaged 0.30.
5. Water was flooded at 3 m/d until no more oil was produced (about 2 PV) to determine the relative permeability of water to oil at residual oil saturation [k_{rw} at S_{or}]. The S_{or} averaged 0.70.
6. The sequence of chemical floods, surfactant and micellar-polymer (MP) was injected at 0.3048 m/d (1 ft/d)

3. Results

3.1. IFT test

The results of the IFT experiments are represented graphically below in Fig. 2. The IFT test shows that with the addition of surfactant into the aqueous phase, the IFT between the aqueous and oleic phases reduces and further addition of

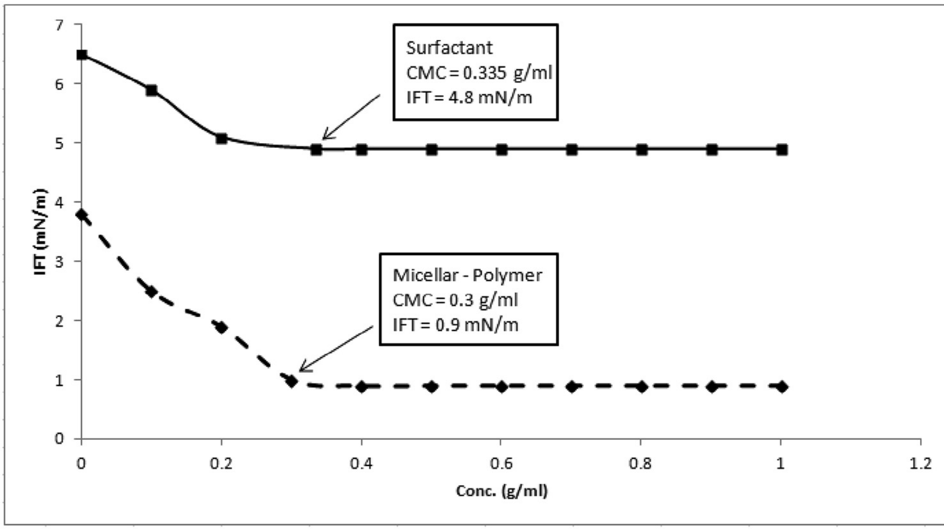

Fig. 2. IFT between the phases of surfactant solution [34] and micellar-polymer emulsion.

surfactant further reduces the IFT value to 4.8 mN/m with a CMC value of 0.335 g/ml [34]. With the addition of micellar-polymer emulsion into the aqueous phase, the IFT value reduced to a very low value of 0.9 mN/m with a CMC value of 0.3 g/ml which may lead to more enhanced oil recovery from the porous media.

3.2. Displacement experiments

The results of the core flood experiments are represented graphically below in Figs. 3 and 4 and are shown in tabulated form in Table 2.

4. Discussion

Several mechanisms may be responsible for enhanced oil recovery from the porous media of Bhogpara and Nahorkatiya oil fields. These may be reduced IFT, better mobility ratio and reduced chemical interaction.

Better IFT behavior was most evident when comparing the two floods as in Fig. 2. The value of IFT obtained with the addition of surfactant was 4.8 mN/m with CMC value as 0.335 g/ml whereas with the addition of micellar-polymer

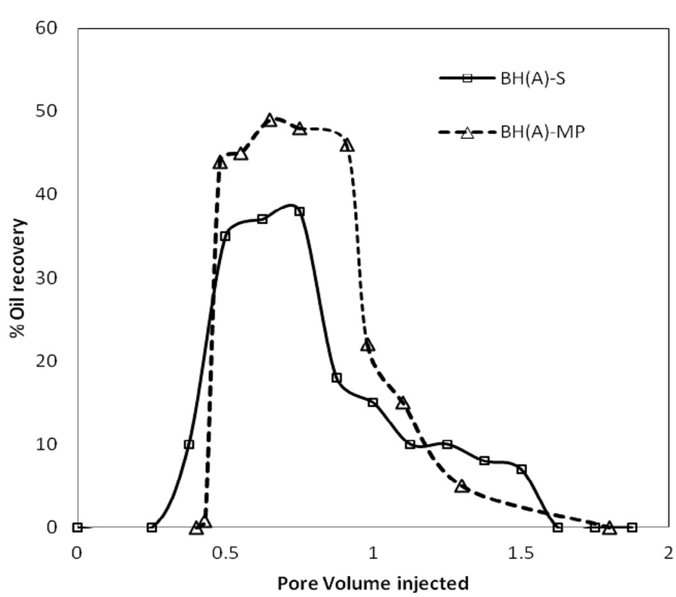

Fig. 3. Oil recovery by S and MP flooding for BH(A).

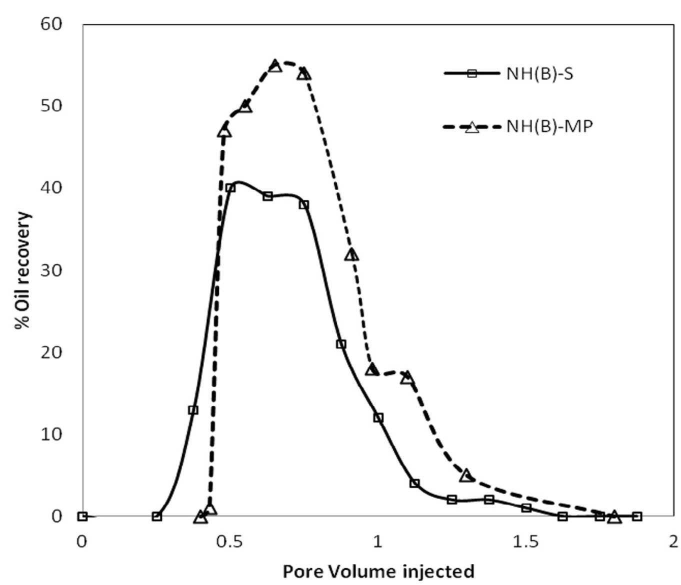

Fig. 4. Oil recovery by S and MP flooding for NH(B).

Table 2
Core flood results obtained.

Flood	Core sample	% EOR
MP		50
S	BH(A)	38
MP		56
S	NH(B)	40

emulsion, the IFT was found to be 0.9 mN/m with CMC value as 0.3 g/ml. Without having much difference in the CMC value, MP emulsion shows much reduced IFT value. Therefore, the IFT experiments prove that addition of surfactant gives rise to low IFT between the oleic and the aqueous phase but addition of MP emulsion, which is a Winsor Type-I emulsion, gives rise to lowest IFT which are very much in demand in enhanced oil recovery projects. Reduction of IFT finally leads to the release of residual oil droplets from the capillaries in the porous media, thereby increasing substantially the amount of petroleum obtainable from a given porous media. Many literatures have reported that addition of surfactants lowers the IFT, thereby leading to enhanced oil recovery [17,18].

The maximum recovery achieved by S flooding is 38% and 40% whereas by MP flooding, recovery is 50% and 56%, which is quite high as compared to S flooding. This may be due to more reduction of IFT due to addition of Winsor Type-I MP emulsion and presence of polymer in MP helps to reduce the mobility of the water, thus forcing the water to flow through more flow channels in the rock and thereby providing a good volumetric sweep. Therefore in MP flood, surfactant has been found to increase oil production and polymer solution was found to be a significant means of controlling mobility and increasing volumetric sweep efficiency as is also found by Babakhani et al. [14].

5. Conclusions

The emulsions prepared and used for the above study have been characterized in terms of IFT and finally efficiency was determined by displacement experiment. In S flooding, there is only lowering of IFT which helps in releasing 40% oil from the porous media. However, in MP flooding, micelle helps in lowering the IFT value and added polymer helps in increasing the volumetric sweep efficiency thereby helping in releasing the residual droplets from the porous media and enhances the oil recovery. Therefore, the enhanced oil recovery was more from MP flooding as compared with S flooding. The injection of a micellar slug into the core samples of two depleted reservoirs leads to the release of oil from the pores of the reservoir rock like a grease releases from dishes using dishwashing detergent followed with flushing by water. The micellar solution helps to release much of the oil trapped in the rock of the oil-bearing formation in the reservoir. Further enhancement of the oil production, polymer-thickened water is injected behind the micellar slug for mobility control. This method has one of the highest recovery efficiencies of the current EOR methods and one of the cost effective method than any other EOR methods to implement BL as micelle in MP flooding which is a waste product.

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