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SURFACTANT AND SURFACTANT-POLYMER FLOODING FOR LIGHT OIL: A GUM ARABIC APPROACH

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Abstract

Literatures show that 40% to 55% of oil reserves are usually left insitu after primary and secondary recovery processes such as water flooding. This remaining reserve has to be recovered by Enhanced Oil Recovery process. Surfactant-Polymer flooding is one of the viable Enhanced Oil Recovery processes for recovering additional by lowering the interfacial tension between the oil and water and reducing water mobility. In this research, two sets of experiments were performed. First, the optimum surfactant concentration was determined through surfactant polymer flooding using a range of surfactant (Sodium Dodecyl sulphate, SDS) concentration of 0.1% to 0.6% and 15% of polymer (gum Arabic). Secondly, another set of experiments to determine the optimum flow rate for surfactant flooding was performed.
The result of the first set of experiment shows a range of oil recovery of 59% to 76% for water flooding and a range of 11.64% to 20.02% additional oil recovery for surfactant Polymer flooding for a range of surfactant flow rate of surfactant concentration of 0.1% t0 0.6%. For the second sets of experiments, a range of oil recovery of 64% to 68% for water flooding and a range of 15% to 24% additional oil recovery for surfactant flooding for a range of surfactant flow rate of surfactant flow rate of 1cc/min to 6cc/min. The Optimum surfactant flow rate resulting in the highest oil recovery for the chosen core dimension and parameter is 3cc/min.

Keywords*:* Enhanced Oil Recovery; Polymer; Surfactant flooding; Surfactant-Polymer flooding; Polymer flooding; Displacement efficiency; Gum Arabic.

1. Introduction

It is generally considered that only approximately one-third of the oil present in known reservoirs is economically recoverable with primary-recovery methods using gas pressure and other natural forces in the reservoir, and secondary recovery by water flooding. Enhanced Oil Recovery (EOR) is oil recovery by injecting materials that are not present in a petroleum reservoir. One of the important methods in EOR is chemical flooding such as surfactant flooding. Injection of surfactant increases the oil recovery. Chemical flooding in the petroleum industry has a larger scale of oil recovery efficiency than water flooding. On the other hand, it is far more technical, costly and risky. Furthermore, it has always been the desire of the industry to improve overall recovery through tertiary recovery one of which is chemical methods which has a potential of raising oil recovery to about 40 to 65% of the total reserve after water flooding activities.

Surfactant flooding, a chemical EOR method consists of the injection of a surfactant slug to reduce the interfacial tension (IFT) between oil and water which consequently reduces the capillary force and mobilizes the residual oil trapped after water flooding. The addition of polymer to the surfactant slug helps to control mobility and increases the sweep efficiency. Undoubtedly, the viability of the surfactant enhanced oil recovery method from a number of literatures, Oil and gas journals, technical papers presented at SPE conferences in different parts of the world at different times. To mention few, in 1927, Uren and Fahmy [1] conducted research and concluded that an inverse relationship exists between oil-water interfacial tension and the percentage of oil recovery by water flooding. In that same year a patent was issued to Atkinson that proposed the use of aqueous solutions of soap or other materials to decrease the "surface tension" between oil and the flooding medium and thereby increase the recovery of oil. During the next 25 years a major part of the reported research on the use of surfactants to recover oil was carried out by a group at Pennsylvania State University. This group recognized that interfacial tension, wetting conditions (contact angle), and surfactant adsorption were important factors. From the beginning of the 1970s, some of the technical journals, symposiums and conferences considering the use of surfactant for enhanced oil recovery includes Halbert and Inks [2] in 1971; Holm [3] in 1971; Healy et al. [4] in 1975; Dreher and Sydansk [5], in1976; Healy and Reed [6] in 1977; Nelson and Pope [7] in 1978; Glover *et al.* [8] in 1979; Meyers and Salter [9] in 1980; Puerto and Reed [10] in 1983; Bouabboune [11] in 2006; Santanna *et al.* [12] in 2009. The adsorption of surfactants on solids was extensively studied by Somasundaran and Fuerstenau, [13-14]; Scamehorn *et al.* [15] in 1982).

A field test was conducted in 2011 by Feng *et al.* [16] on the numerical simulation of surfactant flooding in low Permeability Oil field of China using Yanchang reservoir with simulation result showing that surfactant flooding is one of the most effective ways to improve development effect in low permeability reservoir. They also noted that enhanced oil recovery by reducing the injection pressure and increasing injection rate is effective for tight reservoirs. Feng *et al.* [16] result concluded that the optimal surfactant concentration for that oil field is 2% with an additional oil recovery of 0.22%. However, they admitted that although surfactant injection could improve recovery, the result they obtained is not ideal. Reason was because there were not enough injection wells for proper sweeping of the reservoir. Consequently, larger zones were not affected by the surfactant flood. Feng [16] and his company did a good work but the reservoir system adopted is not applicable to the Niger-Delta reservoir system which has a good permeability. As well the result obtained from the flood could also be discouraging.

Abhijit *et al.* [17] in 2011, established in their study that the surface tension of surfactant increases in the presence of polymer. They also performed an experiment on surfactant and surfactant-polymer flooding for Enhanced Oil Recovery using sodium dodecyl sulphate (SDS) but partially hydrolyzed polyacrylamide PHPA was used to control mobility. They obtained additional oil recovery of 20% for surfactant flooding and 23% for polymer augmented surfactant flooding but the effect of surfactant flow rate was not investigated.

Onuoha and Olafuyi [18] in 2013 came up with a laboratory study on the use of Gum Arabic for mobility control. In an ASP flooding they conducted, the displacement efficiencies of two ASP slugs were compared and calculated to be 90.2% for sodium hydroxide, lauryl sulphate and Gum Arabic slug and 77.9% for sodium hydroxide, Tween 80 and Gum Arabic slug. Other laboratory works on the use of gum Arabic as Polymer in chemical EOR processes were performed in 2014 includes that of Orivri *et al.* [19], Atsenuwa *et al.* [20] and that of Avwioroko *et al.* [21]. Orivri *et al.* [19] in 2014 performed an experimental work on the effect of wettability on surfactant flooding. They used Teepol as surfactant and gum Arabic as EOR polymer and additional 16% to 19% oil recovery was achieved at for the various wettability variation tested.

Atsenuwa *et al.* [20] experimented the effect oil viscosity of heavy oil on surfactant-polymer flooding using lauryl sulphate also known as sodium dodecyl sulphate (SDS) and gum Arabic for mobility control. The polymer, gum Arabic with SDS achieved a good displacement efficiency of about up to 65% of the initial residual oil after water flooding of a 140cp oil. Avwioroko and his group [21] took a step forward by considering the recovery potential of an ASP slug formulated with sodium hydroxide, Tween 80) and gum Arabic on heavy oil. An additional oil recovery of 44%-57% after water flooding was recorded at the different wettability investigated

Gum Arabic as found in nature exists as a neutral or slightly acidic calcium, magnesium or potassium salts of complex polysaccharide [22-23]. It readily dissolves in water to give clear solutions ranging in colour from very pale yellow to orange-brown and with a pH of ~45 [24].

The overall viscosity (resistance factor) of partially hydrolysed Gum Arabic is a pointer to its usage for mobility ratio and for improving sweep efficiency of oil in the reservoir.

This research work attempts to study the effect of surfactant flooding injection rate on oil recovery and to investigate the recovery potential of Gum Arabic as polymer for mobility control in light oil recovery.

2. Materials and methods

2.1 Materials

2.1.1 Porous media

Class IV Soda Lime Glass Spheres from MO-SCI Speciality Products, L.L.C, A subsidiary of MO-SCI Corporation 4040 Hypoint North Rolia, MO 65401 USA were used as porous media in all flooding experiments. The Glass beads have a particle size distribution of -60 +80 mesh. The beads were etched with dilute H_2SO_4 in order to make it strongly water wet which is typical of the reservoirs system in Niger Delta, Nigeria and then rinsed properly with water until there were no more traces of acid on the beads. This was confirmed with a litmus paper. Then oven dried. A Transparent core holder was used to pack the Class IV Soda Lime Glass Spheres and vibrated with each incremental addition of beads. Vibration continued until the entire granular material dispersed evenly and packed closely in the core holder. The average porosity of the cores is 0.3678.

2.1.2 Core holder

A transparent and cylindrical core holder of diameter 2.37cm, length 25.6cm and a bulk volume of 112.9ccwas used to pack the glass spheres.

2.1.3 Shenehen pump

A Shenehen pump was used for saturating the core with brine,mineral oil and then the chemical slug. The pump has a flow rate range that can be adjusted depending on the tubing diameter and the setting of the revolution per minutes.

2.1.4 Mineral oil

The crude oil used for the experiments was from a field in Niger Delta, Nigeria. The oil was blackish brown in appearance with a viscosity of 4.5cp at 25°C, a specific gravity of 0.865, density of 0.865g/cc and an API gravity of 32.02 API degree.

2.1.5 Brine

Synthetic brine was prepared from sodium chloride and distilled water by adding 2% by weight of the sodium chloride to the distilled water and mixing thoroughly with a magnetic stirrer to obtain a concentration of 2% wt. by weight solution of NaCl.

2.1.6 Surfactants

The surfactants used in this study are sodium dodecyl sulphate (SDS or NaDS). Sodium dodecyl sulphate (SDS or NaDS) or sodium laurel sulfate or sodium lauryl sulfate (SLS)is an organic compound with the formula $CH_3(CH_2)_{11}OSO_3Na$, molar mass of 288.372 g/mol, density of 1.01 g/cm³, melting point 206°C, 479K, refractive index (n_D) 1.461. SDS is white or cream-coloured in appearance and is odourless. It is an anionic surfactant used in many cleaning and hygiene products.

2.1.7 Polymer (Gum Arabic)

The Gum Arabic samples were obtained from different Acacia tree species (A. Senegal, A. Sieberiana and A.nilotica) found naturally in surrounding forests of Batagawara Village , Katsina state. Samples were collected from the tree barks as dry nodules or lumps. The crude samples consisted of mixtures of large and small nodules admixed with bark and organic debris. Hand picked select gum (HPSG) method [25] was used to separate the neat, quality gum from other constituents. The dried sample (hard nodules) was then ground into fine powder (to pass 0.4mm mesh screen). The prepared samples were kept in tight containers and stored at room temperature.

2.2 Methods

2.2.1 Chemical slug preparation

First, a set of six different aqueous solutions of surfactant and polymer were prepared with brine using surfactant concentrations from 0.1% to 0.6% with 15% Gum Arabic using a magnetic stirrer and were allowed to stay for 48 hours in order to allow for the Gum Arabic to hydrate toachieve a desired viscosity. The aqueous solutions were then filtered in order to remove un-dissolved fines which can cause permeability impairment or create the problem of injectivity. These slugs were used for the first set of experiments to determine the optimum concentration of surfactant necessary to mobilize oil.

Secondly, another set of two solutions of surfactant using the optimum surfactant concentration 0.5% by weight determined from the first sets of experiments. And a Gum Arabic slug of 50,000ppm or 5% was also prepared separately.

The preparation of Gum Arabic solution is that which requires exceptional consideration. The polymer solution was carefully prepared with the use of a magnetic stirrer. The polymer powder was carefully sprinkled in minute quantities at the tip of the vortex created in the liquid by the Stirrer. This was necessary to avoid the formation of lumps which are difficult to dissolve. Failure to have a clear solution would result in the clogging of the pore spaces of the core hence impairing its permeability. The magnetic stirrer was used to stir up the solution for 30 minutes until a consistent solution was formed. The stirring was performed at a low speed (rpm) in a bid to avoid shear thinning or mechanical degradation due to shear stress. The solution was then kept and allowed to stay overnight to ensure full hydration before being filtering. The slugs viscosity measurements were measured with NDJ-8S digital viscometer. The viscosity surfactant-polymer slug with 15% polymer was measured to be 23cp at 25°C while for 5%Polymer slug was 7cp at 25°C.

Table 1 SP slug composition

Materials	Name	Concentration
Salt	Sodium chloride	2.0wt %
Surfactant	Lauryl Sulphate (SDS)	0.1wt % to .6% wt
Polymer	Gum Arabic	150000ppm

Table 2 Surfactant solution composition

Materials	Name	Concentration
Salt	Sodium chloride	2.0wt %
Surfactant	Lauryl Sulphate (SDS)	0.5% wt

Table 3 Polymer slug composition

Materials	Name	Concentration
Salt	Sodium chloride	2.0wt %
Polymer	Gum Arabic	50000ppm

2.2.2 Experimental setup

The core holder filled with Class IV soda lime glass spheres dry spherical glass and vibrated with each incremental addition of glass beads until the entire granular material dispersed evenly and packed closely in the core holder was mounted on the retort stand and ready to be saturated with fluids (Brine and oil). Figure 1, shows the experimental set up.

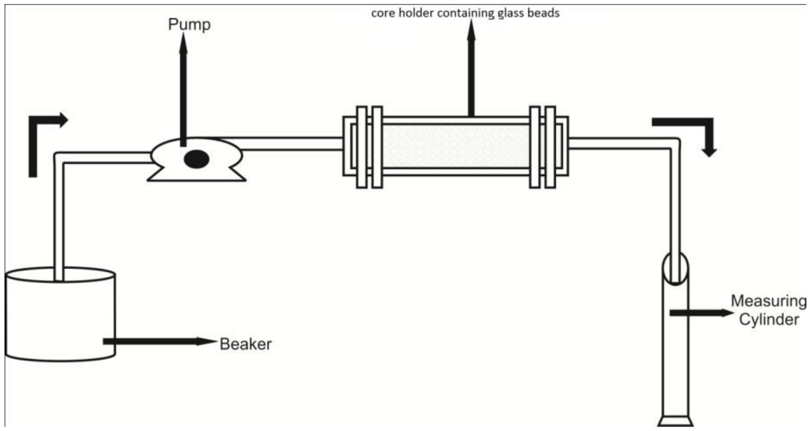

Fig.1. The experimental set up.

2.2.3 General core flood description

The core flood procedure includes the method of core preparation, core assembly, core holder loading, vibration, brine saturation (imbibition), oil flooding, water flooding and chemical flooding, collection and analysis of the effluent samples for cumulative oil recovery.

2.2.4 Brine saturation (imbibition)

After core preparation and assembly, it was saturated with brine. Part of the objective of imbibition is to completely saturate the pore spaces with brine and eliminate air, thus mimicking the initial condition before oil migration. This was done at the rate of 1cc/min and performed vertically while injecting from below, so that the brine displaces air in the core hence avoiding trapping air in the pore spaces and resulting into two phase system. This is shown in figure 2 below.

Fig.2 Core saturation with brine.

2.2.5 Oil flooding (drainage)

After brine flooding or imbibitions process, oil flooding or drainage process was performed in order to saturate the core with oil thus mimicking oil migration. This technique of oil flooding enabled us to determine initial oil saturation, residual water saturation, effective oil permeability, and drainage relative permeability. Oil flood was conducted to saturate the pore volume and obtain accurate residual water saturation which is the initial water saturation of an oil reservoir. The effluent fluids were collected in measuring cylinders. The volume of displaced water was measured which equals the volume of the oil saturation in the core. Oil flooding was continued until 100% oil cut.

2.2.6 Water flooding

Water flooding was carried out and results were taken in order to account for oil production by both primary and secondary production methods and to also determine residual oil saturation before chemical flooding. The cores were flooded with 1.5PV of brine to experience a water cut of about 90%. This was done at a constant flow rate of 2cc/min to achieve general residual oil saturation after water flooding. The effluent fluids were collected with measuring cylinders. The residual oil saturation was estimated based on the volumes of oil in the measuring cylinders.

2.2.7 Chemical flooding

Two sets of chemical flood were performed. First, six cores, after water flooding, surfactant polymer slugs of surfactant concentration from 0.1% to 0.6% by weight with 15% Gum Arabic were used to flood the core to determine the optimum surfactant concentration for the core-fluid system. The SP slug was pumped at the rate of 2cc/min and the effluents were collected with measuring cylinder.

Secondly, another six sets of cores were prepared for surfactant flooding. An optimum surfactant concentration gotten from the first sets of core flooding experiments was used with 5% Gum Arabic for mobility control. Surfactant solutions of 0.75PV were injected at different flow rate of 1cc/min, 2cc/min, 3cc/min up to 6cc/min. Then the Gum Arabic solution of 5% wt. was injected at a flow rate of 2cc/min after Surfactant flood for each of the cores. The effluents were collected with measuring cylinders for analysis.

3. Results and analysis

The summary of the results from the first sets of experiments of SP flooding is presented in the table 4 below.

Table4 Summary of the results of SP flooding.

Expt. No.	SP slug Design.	Oil recovery by water flood at 90% water cut (% OOIP)	Additional Recovery by SP flooding (% OOIP)	Displacement Efficiencies Of the each SP Slug
S1	SDS (0.1% wt) + NaCl (2% wt.) + 15% wt. Gum Arabic	64.38	11.64	32
S2	SDS (0.2% wt.) + NaCl (2% wt.) + 15% wt. Gum Arabic	73.53	12.06	45
S3	SDS (0.3% wt.) + NaCl (2% wt.) + 15% wt.Gum Arabic	65.25	13.00	36
S4	SDS (0.4% wt.) + NaCl (2% wt.) + 15% wt. Gum Arabic	59.36	16.35	40
S5	SDS (0.5% wt.) + NaCl (2% wt.) + 15% wt. Gum Arabic	75.48	20.02	85
S6	SDS (0.6% wt.) + NaCl (2% wt.) + 15% wt. Gum Arabic	76.22	19.26	71

The summary of the results from the second sets of experiments of Surfactant flooding is presented in the table 5 below

Table 5 Summary of the result for surfactant flooding

Expt. No.	Injection rate of surfactant slug. SDS (0.5% wt.) of 0.75PV	OOIP, %, S_{oi}	(%) S_{wi}	Oil recovery after flooding with 1.5PV of water @ 2cc/min	Additional Recovery by Surfactant flooding (% OOIP)	Displacement Efficiencies of the S flooding (%)
S1	1cc/min	85.39	14.61	67.84	16.22	38.53
S2	2cc/ min	83.84	16.16	65.44	17.56	50.82
S3	3cc/ min	86.16	13.84	66.20	24.10	66.26
S4	4cc/ min	83.53	16.70	65.42	19.43	58.68
S5	5cc/ min	86.84	13.16	64.46	19.56	59.69
S6	6cc/ min	86.36	13.64	64.69	15.54	59.2

3.1 Relative permeability curve

The imbibition process was performed in the laboratory by first saturating the core with the water (wetting phase), then displacing the water to its irreducible (connate) saturation by injection oil. This "drainage" procedure was designed to mimic the original fluid saturations that were found when a reservoir is discovered. The wetting phase (water) was reintroduced into the core and the water (wetting phase) was continuously increased. This was the imbibition process and is use to produce the relative permeability data (see table 6) needed for water drive or water flooding calculations [26].

The relative permeability values of water and oil during imbibition are calculated from water saturation data for one of cores using Pirson's correlation below.

$$S_w^* = (s_w - s_{wc})/(1 - s_w) \quad (1)$$

$$K_{rw} = \sqrt{(S_w^*)}S_w^3 \quad (2)$$

$$K_{ro} = (1 - S_w^*)[1 - (S_w^*)^{0.25}\sqrt{s_w}]^{0.5} \quad (3)$$

Table.6 Relative permeability of water and oil during imbibition

Sw	Sw%	Sw*	krw	kro
0.146	14.6	0	0	1
0.344009	34.40086	0.23186	0.019603	0.591519
0.56711	56.71105	0.493104	0.128077	0.307892
0.684419	68.44189	0.630467	0.254564	0.189443
0.700972	70.09716	0.64985	0.277656	0.174474
0.712487	71.24865	0.663333	0.294575	0.164325
0.721483	72.14825	0.673867	0.308294	0.156549
0.725441	72.54408	0.678502	0.314472	0.153171

It can be noted from the relative permeability curves that the nonwetting phase (oil) loses its mobility at higher values of water saturation. The Relative permeability curves also show a correlation or match in the finding of Craig in 1971 [27]. who suggested the rules of thumb to differentiate between strongly oil- wet and water wet system. He noted that water saturation at which water and oil relative permeabilities intersect should be greater than 50% for water wet system. From the relative permeability curve below, the Krw and Kro intersect at 66%. This establishes that the cores are water wet.Fig.3 shows the Relative permeability of water and Oil of one of the cores used in the experiment.

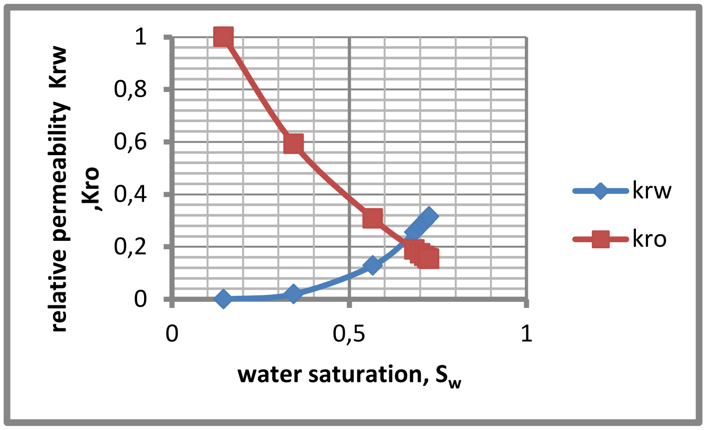

Fig.3. Shows the relative permeability of water and oil

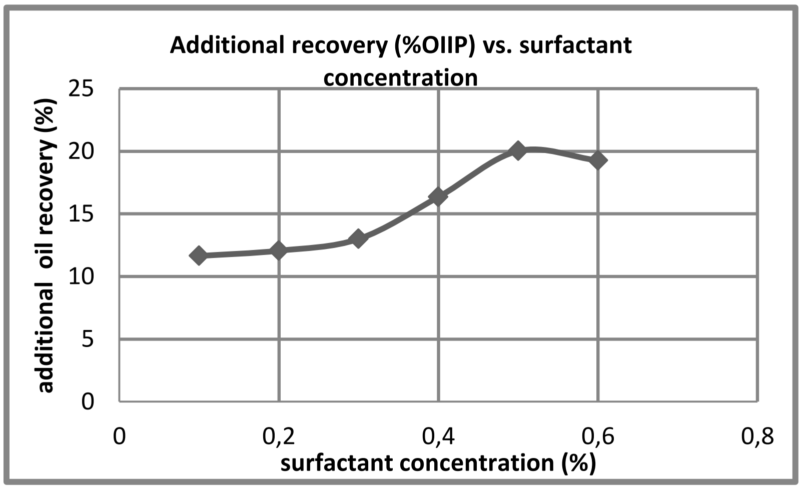

Fig.4. A plot of additional oil recovery against surfactant concentration for SP flooding

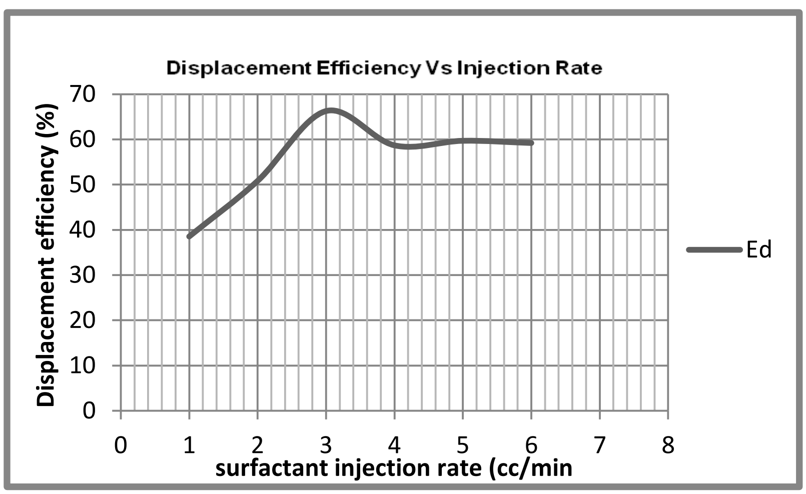

Fig.5 A plot of displacement efficiency against surfactant flow rate for S slooding

3.2 Surfactant polymer flooding and surfactant flooding

The recovery of oil by both surfactant and surfactant polymer flooding can characterized under the following: The influence of surfactant concentration, effect of polymer concentration and effect of surfactant injection rate.

3.3 The influence of surfactant concentration

From table 4 and Figure 4, 0.1%, 0.2%, 0.3%, 0.4%, 0.5% and 0.6% of S in SP slug produced 11.64%, 12.06%, 13.00%, 16.35%, 20.02% and 19.26% of the OOIP respectively. It is can be observed that the additional oil recovery increases as the concentration of surfactant increases in the surfactant-polymer slug. The additional oil recovery attained maximum at 0.5% of S and began to get stable. This shows that the critical micelle concentration CMC has been reached. This further establishes that the critical micelle concentration for surfactant is one of the important parameter for surfactants flooding. The CMC is the concentration of which surfactant solutions begin to form micelles in large amount [17,28].

3.4 Effect of polymer concentration

For the surfactant polymer flooding, the highest recovery was 20.02% of OOIP even at a polymer concentration of 15% wt. (table.4and Fig.4). For the surfactant flooding, 5% wt. polymer concentration mobilized 19.56% of OOIP with a displacement efficiency of 66.26% (table.5 and Fig.5). Abhijit *et al.* [17] explains that the surface tension of the surfactant solutions increases in the presence of polymer and Hongyan *et al.* [29] reported that because of elevation of system viscosity upon the addition of polymer, the diffusion of surfactant from water phase towards oil/water interface slows down, extending the time for IFT to reach the super low level.

3.5 Effect of surfactant flooding flowrate

From visual observation of the core flood, at a low surfactant flooding rate of 1cc/min, it was observed that there was gravity segregation or channeling of the surfactant slug. The slug was observed to flow at the lower section of the core. At 2cc/min, there was still some level gravity segregation noticed but more core volume was accessed compared to the previous flow rate. However, at 3cc/min, the surfactant slug was observed to access the entire core volume. It can be said that, the increased surfactant injection rate allows for easy capillary imbibition of surfactant and making proper diffusion into the matrix of the core possible. Thus increasing surfactant-oil and surfactant-water contact. The more the number of oil and water contacted through proper surfactant imbibitions, the better the reduction of capillary pressure. Based on the Surfactant ability to reduce interfacial tension and its increased injection rate, it easily passed through tinny pore throats accessing more core fluid (i.e. oil and water) in the core matrix.

Also high injection rate of the surfactant solution also generate a pressure that has a mechanical impact on the interfacial tension of the fluid (oil and water) it comes in contact with and thus hastening interfacial tension reduction. However, at a higher rate, the surfactant slug fingers and find it way to the production end, thus reducing its access to the core matrix and resulting in lower oil recovery.

4. Conclusion

From the result of this study, the following conclusions can be made.

1. Surfactant concentration in a SP slug can affect the amount of oil recoverable.
2. The flow rate of surfactant can affect additional oil recovery.
3. Gum Arabic is suitable for mobility control in surfactant enhanced oil recovery processes.
4. Higher polymer concentration can inhibit surfactant dispersion in SP flooding although, higher polymer concentration further reduces mobility ratio.
5. With increased surfactant imbibitions rate, the amount of polymer required to mobilized residual oil after water flooding in S flooding reduces compare with SP flooding.

6. Surfactant flooding can produce a relatively the same recovery with less polymer concentration as the case of SP flooding if appropriate surfactant injection rate is used.
7. The investment on polymer can be reduced with the use optimum surfactant injection rate.
8. The injectivity problem of SP flooding can be taken care of if the technique of S flooding at optimum injection rate is followed by polymer flooding at less concentration is adopted.

Nomenclatures

CMC	*Critical Micelle Concentration*
EOR	*Enhanced Oil Recovery*
K	*Absolute permeability, Darcy*
Kro	*Relative permeability to Oil, Darcy*
Krw	*Relative permeability to water Darcy*
OOIP	*Original oil in place*
P	*Polymer*
PHPA	*Partially hydrolyzed polyacrylamide*
PV	*Pore volume*
S	*Surfactant*
SDS	*Sodium dodecyl sulfate*
Sor	*Residual oil saturation*
SP	*Surfactant-polymer*
Swi	*Irreducible water saturation*
Sw^*	*Effective water saturation*
Sw	*Water saturation*
Swc	*Connate water saturation*
Ø	*Porosity*

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