Determination of Optimum Concentration of Surfactant Flooding for Enhanced Oil Recovery (EOR) For Light Oil

By

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Abstract

A greater portion of Original Oil in Place (OIIP) is left unrecovered from the reservoir after primary and secondary recovery due to depletion of the primary energy of the reservoir, poor sweep efficiency during water flooding and the trapping of oil droplet by capillary forces because of high Interfacial tension (IFT). Consequently, surfactant flooding is done to reduce this high IFT between oil and water, thereby making it easy for oil to coalesce and flow from the reservoir to the production wells. In this project the optimum concentration of surfactant needed for surfactant flooding was determined by strongly flooding water wet core samples with surfactant (teepol) slugs of different concentrations ranging from 0.1% to 1.5% surfactant by weight and thereafter mobilizing the coalesced oil with polymer. Eight (8) experiments were carried out with 8 different concentrations of surfactant to brine. Results obtained from the experiment showed that 0.9% surfactant concentration is more effective in lowering the interfacial tension between oil and water as it was found to have the highest incremental oil recovery. This further confirms the range of surfactant concentration usually used for EOR processes.

Keywords: reservoir; sweep efficiency; Interfacial tension; coalesced oil; water flooding; polymer; surfactant flooding; production wells; optimum concentration; surfactant concentration; incremental oil recovery.

Introduction

The use of crude oil plays an important role in the world's economy today. In the last few years, Enhanced Oil Recovery (EOR) processes have gained interest from the research and development phases to the oil field EOR implementation. The renewed interest has been furthered by current high oil price environment, the increasing worldwide oil demand, the maturation of oil fields worldwide and the few new reservoirs[1]. As the decline in the primary energy of a reservoir is typical as production continues, hence it becomes pertinent to maintain pressure in the reservoir to achieve optimum production and maximize ultimate recovery. Under such conditions water or/and gas is injected into the reservoir depending on reservoir characteristics[2]. During water flooding, the sweep efficiency achieved is usually not as good as desired causing a substantial amount of oil to be bypassed in the reservoir. Even if water flooding were continued indefinitely, over half of the original oil in place (OOIP) would remain in the reservoir. This is due to both poor sweep and the trapping of oil droplets by capillary forces due to the high interfacial tension (IFT) between water and oil. Surfactant flood EOR is thus used to recover residual oil by lowering the water-oil

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interfacial tension, eliminating, or reducing the capillary forces, reducing the water-oil mobility ratio and by boosting the natural energy in the reservoir, resulting to the recovery of large and economical quantities of remaining oil in place.

Surfactants have been investigated for use in enhanced oil recovery for over 40years. Early work focused on the injection of micro emulsions containing high concentrations of surfactant, co-solvent, and oil[3], which while technically successful was not economically viable due to the high chemical costs and low oil price at the time. Later work focused on reducing the amount of chemical required and emphasized low concentration aqueous surfactant solutions with polymer added for mobility control rather than the injection of a micro emulsion. Another trend in the literature involves a more empirical approach, whereby the chemicals (which may include one or more surfactants, co-solvent, alkali, etc.) observed to exhibit the lowest IFT given the investigated crude, reservoir temperature, and often formation salinity is taken as optimum, and a surfactant-polymer slug is injected at these conditions[4]. Major weaknesses of this approach include; lack of robustness to measurement error and local heterogeneities and susceptibility of surfactant to phase trapping. Wu studied the surfactant flooding optimization for several field scale projects[5]. His focus was primarily on onshore sandstone reservoirs, and his optimization study focused on chemical concentrations, slug sizes, and adsorption. In addition, an economic analysis was used to determine the optimum design. He concluded that a large surfactant slug size at low concentrations was the optimum design. However, it is important to understand that his results were heavily dependent on the low price of oil at the time of his study and on an assumed very low value of surfactant adsorption.

When a surfactant solution has been injected into the reservoir, the injected solution effectively controls the phase behaviour properties in the oil reservoir, thus mobilizing the trapped crude oil by lowering the IFT between the injected liquid and the oil. The oil bank will start to flow and mobilize any residual oil in front of the bank. Re-trapping of the oil bank is prevented by the surfactant slug flowing behind. Nowadays many mature reservoirs under water flood have decreasing production rates despite having 50-75% of the original oil in place left inside the reservoir[6]. In such cases, it is likely that surfactant flooding can increase the economic productivity. To achieve low residual oil saturations when neglecting wettability alteration by surfactants, the interfacial tension must be reduced from oil-brine values of about 20-30 mN/m to 0.001-0.01 mN/m [7]. The surfactant-brine-oil phase behaviour is strongly affected by the salinity of the brine[8]. The structure of a surfactant also determines its solubility in either brine or oil,

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increasing the importance of the non-polar end of the surfactant will increase oil solubility. This can be accomplished by increasing the non-polar molecular weight, decreasing the tail branching, decreasing the number of polar groups, and decreasing the strength of the polar part of the surfactant [9]. Surfactant systems are sensitive to high temperature and high salinity therefore surfactants that can resist these conditions should be used[10]. Polymers are also often added to the injected surfactant solution, to increase viscosity, thus maintaining mobility control[11]. The optimization criterion in surfactant flooding is to maximize the amount of oil recovered, while minimizing the chemical cost. While it is necessary to reach low IFT for the surfactant system, minimizing only the IFT may not always coincide with optimal oil recovery, as low IFT is not the only essential condition to meet to get a successful and efficient oil recovery[12]. Attention to the optimal salinity is crucial to include as well[13].

Materials and Methods

Materials and Apparatus Used

*Surfactan*t: Teepol, Gum Arabic Polymer: Used for mobilization, Brine: Water impregnated with salt, crude oil: A typical oil from the Niger Delta (light oil) with specific gravity 0.865, API gravity of 32^0 and dark brown in colour, core holder: It is used to hold the core. (bulk volume of 112.9 cc), porous media: Glass beads, pump: Used to pump chemical slug into the core, beakers: A glass container used in holding fluid in the laboratory, Measuring cylinder: A piece of laboratory equipment used to accurately measure the volume of liquid, Electric mixer: Powered by an electric motor used for mixing, Magnetic stirrer: It is a laboratory device that employs a rotating magnetic field to cause a stir bar, Fann viscometer: An instrument used to measure the viscosity of liquids, stop watch: A time piece that can be started or stopped for exact timing, Electric weighing balance: It is used in weighing objects or substance in the laboratory.

Methods

Standard and working Slugs

The Chemical slug was prepared as follows.

i. Brine preparation: 2% brine by weight was dissolved in 98% water, stirred using the magnetic stirrer and filtered. The optimum salinity of a reservoir was 2%

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Figure 1: Brine Preparation

ii. Polymer preparation: 10% by weight polymer (Gum Arabic) gotten from the tree was oven dried, milled to powder form and sieved. The sieved polymer was dissolved in 90% water and mixed with an electric stirrer. 10% Polymer with viscosity of 14cp was used for mobilization.

Figure 2: **Polymer preparation**

Surfactant preparation: 0.1%, 0.3%, 0.5%, 0.7%, 0.9%, 1.1%, 1.3%, 1.5% by weight of surfactant was added to prepared brine respectively.

Observation: As the percentage of surfactant increases, it takes a longer mixing time and more foam begins to appear during the mixing process.

Glass Beads Preparation

-60 + 80 microns beads size were washed and treated with 5% H_2SO_4 solution to etch the glass beads. The glass beads were rinsed properly with enough water sieved and oven dried. The dry glass beads are now 100% water wet. The core holder was filled with glass beads, vibrated and compacted to achieve low permeability.

Experimental Flooding Procedure

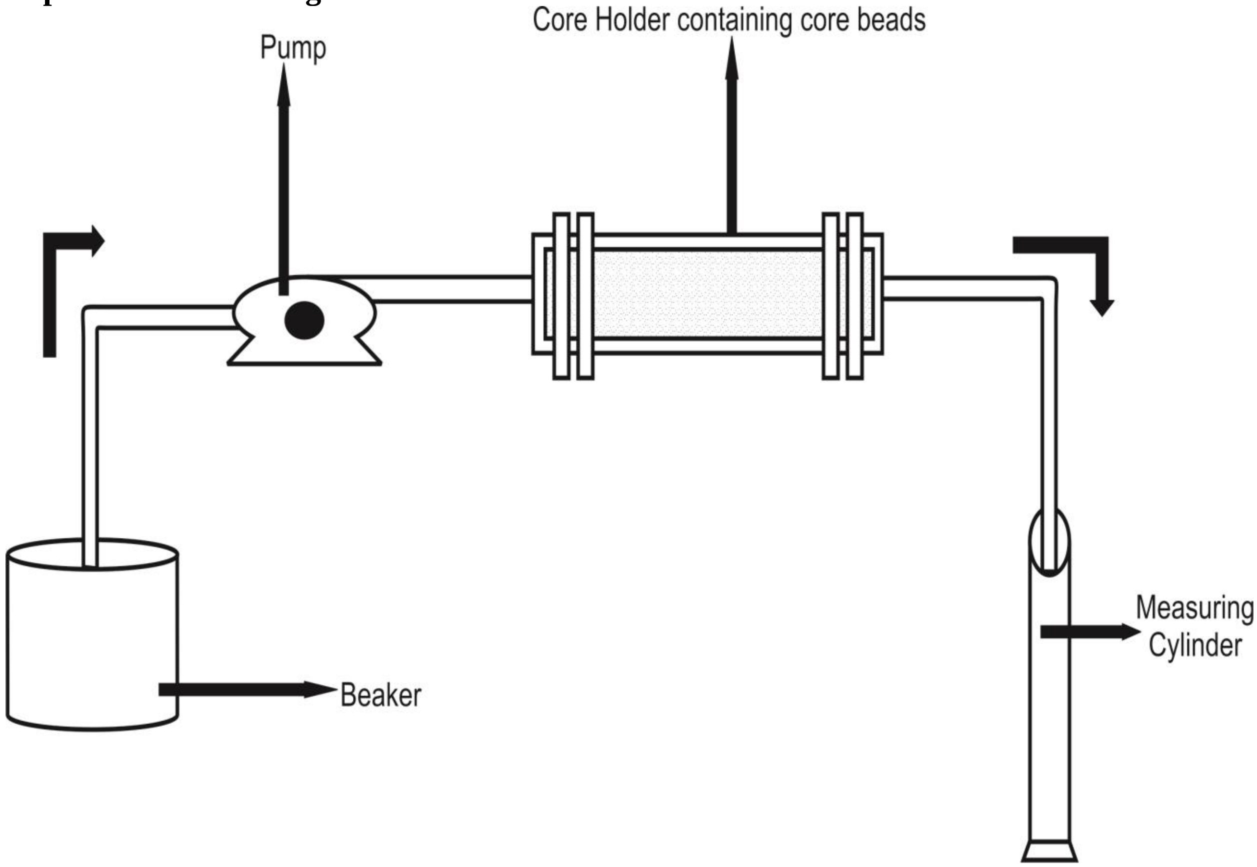

Figure 3: Experiment Schematic

The core was flooded and saturated with 2% brine using Peristaltic pump. This was the imbibition process for the water wet core. The brine saturated core was flooded and saturated with oil by pumping in oil (to mimic migration of oil in the reservoir). The volume of water that was displaced from the core while oil was pumped in was measured. The volume of water collected equals the volume of oil in the core. After the oil saturation, the core was flooded with brine by pumping brine into the core. The quantity of oil recovered even after breakthrough was measured and recorded. The breakthrough time was also recorded. This was followed with the core been flooded with 0.1% surfactant concentration to recover the trapped oil after the water flooding. Low oil recovery was achieved because the surfactant dissolved in the oil to reduce the interfacial tension but didn't have the needed energy to push the oil out. The recovery was recorded and analyzed. The core was flooded with 10% polymer to water for mobility control after the surfactant flooding. The quantity of oil recovered was measured and recorded. These was repeated for the whole flooding procedure with freshly cleaned core sample, varying the concentration of surfactant to brine i.e. 0.3%,0.5%, 0.7%, 0.9%, 1.1%, 1.3%, 1.5% surfactant to brine by weight.

Figure 5: Flooding process

Results and Discussions

The results obtained from the eight (8) different experiments are presented and discussed below. Each experimental result is depicted by Tables n,j; and while n is constant for each experiment, j ranges from i, ii and iii and a figure which represents the incremental oil recovery curve, which is a plot of oil production rate, cc/min against time, min.

Results

Flooding was carried out; water was injected at intervals of 4 minutes. For each of these times, the water injected was equal to the volume of oil collected because of a steady state displacement.

Table a(i) shows the results obtained for injected water and produced oil during water flooding for the first experiment. At the early time of this process, appreciable oil recovery was recorded till the eight (8) minutes, after which oil recovery became insignificant. This necessitated the initiation of surfactant flooding as shown in table a(ii). It was observed that after twelve (12) minutes, there was no significant change in the cumulative oil produced and after the entire process, the oil recovered was 2.3cc. This made it imperative for the mobility of the displacing slug to be improved by introducing polymer to complement the recovery by IFT reduction. During this period, the capillary forces at the interface separating the oil and water are being lowered, resulting from the balance between the hydrophobic and hydrophilic portions of the surfactant. Table a (iii) shows the oil recovered by polymer flooding. This results as the viscosity of the mobilizing slug is increases, and this in turn improves the oil recovery. The oil produced when there was mobility control was 6.2cc compared to the 2.3cc recovery during the surfactant flooding. The flooding process ended when there no significant oil recovery. Figure 6 represents the incremental oil recovery curve, cc/min for experiment 1.

Table a(i) – Experiment 1 water flooding oil recovery

WATER FLOODING 1	BTT =7mins, 57secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Water saturation, Sw %**	**Frictional flow,fw %**	**H2O injected,PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0	9.0	21.3230	0	0.2132	22.9024
2	8:00	1.0	7.8	39.6904	11.8243	0.4215	42.6304
3	12:00	6.1	2.7	45.4961	72.1284	0.6298	48.8662
4	16:00	6.8	1.8	49.0852	82.3529	0.8332	52.7211
5	20:00	6.5	2.3	53.906	76.8581	1.0415	57.8987
6	24:00	7.9	1.1	55.7706	91.2541	1.2548	59.9017
7	28:00	7.9	0.9	57.1429	93.4122	1.4631	61.3757
TOTAL			**25.6**				

Table a (ii) – Experiment 1 surfactant flooding oil recovery

SURFACTANT FLOODING 1, surfactant concentration = 0.1					
Time mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV,surfactant injected cc**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.4	8.4	8.8	1.6798	62.4339
8:00	0.5	8.3	8.8	1.8966	63.7566
12:00	0.6	8.2	8.8	2.1010	65.3439
16:00	0.8	8.4	9.2	2.3276	67.4603
TOTAL	**2.3**				

Table a (iii) – Experiment 1 polymer flooding oil recovery

POLYMER FLOODING 1					
Time mins	Oil recovered, cc	water/polymer collected, cc	Total, cc	PV,polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.4	8.3	8.7	2.5296	68.5185
8:00	0.4	8.2	8.6	2.7340	69.5767
12:00	0.6	8.4	9.0	2.9409	71.1640
16:00	2.0	6.8	8.8	3.1576	76.4550
20:00	1.8	6.8	8.6	3.3695	81.2169
24:00	0.6	8.2	8.8	3.5862	82.8042
28:00	0.4	8.6	9.0	3.8079	83.8624
TOTAL	6.2				

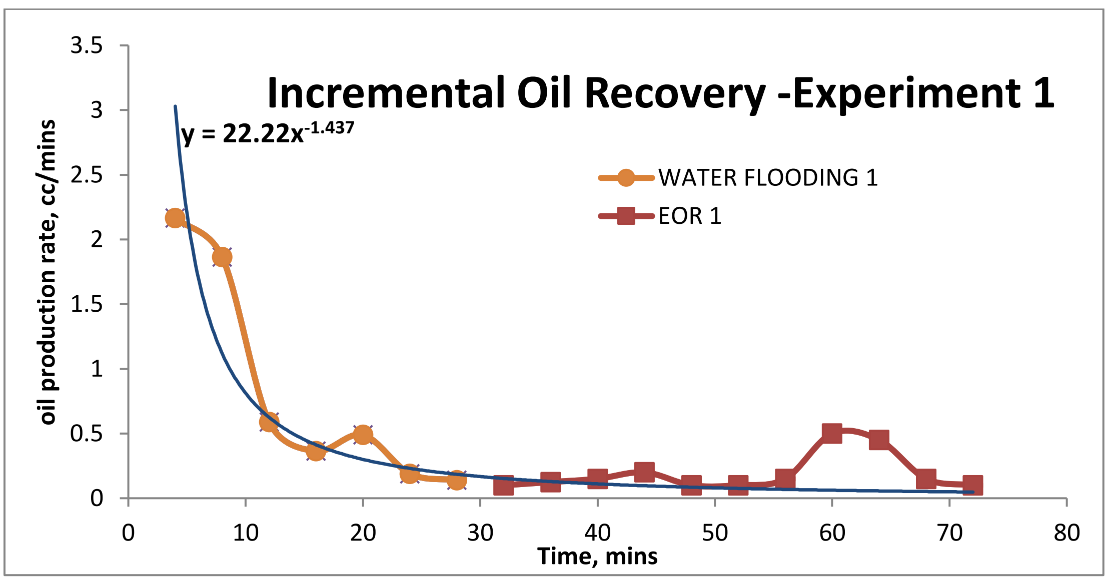

Figure 6: **Oil Recovery Curve- Experiment 1**

The results for experiments 2 to 8 while altering the surfactant concentrations were presented in the tables as shown below.

Table b (i) – Experiment 2 water flooding oil recovery

WATER FLOODING 2	**BTT =7mins, 30secs**						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0	8.8	21.7407	0	0.2174	22.9191
2	8:00	0.4	8.5	42.7103	4.6745	0.4374	45.0252
3	12:00	5.9	3.0	49.5410	68.9483	0.6574	52.2261
4	16:00	7.3	1.4	52.2585	87.3504	0.8722	55.0910
5	20:00	7.3	1.3	54.7191	88.4083	1.0845	57.6849
6	24:00	7.8	1.0	56.4084	92.2297	1.3019	59.4657
7	28:00	8.1	0.7	57.3265	95.7770	1.5193	60.4336
TOTAL			**24.7**				

Table b(ii) – Experiment 2 surfactant flooding oil recovery

SURFACTANT FLOODING 2, surfactant concentration = 0.3					
Time mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV, surfactant injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.4	8.6	9	1.7506	61.5176
8:00	0.6	8.2	8.8	1.9769	63.1436
12:00	0.6	8.1	8.7	2.2005	64.7697
16:00	0.8	8.0	8.8	2.4267	66.9377
TOTAL	**2.4**				

Table b (iii)– Experiment 2 polymer flooding oil recovery

POLYMER FLOODING 2					
Time mins	Oil recovered, cc	water/polymer collected, cc	Total, cc	PV, polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.4	8.4	8.8	2.6530	68.0217
8:00	0.4	8.1	8.5	2.8715	69.1057
12:00	0.5	8.3	8.8	3.0977	70.4607
16:00	2.5	6.0	8.5	3.3162	77.2358
20:00	1.4	6.8	8.2	3.5270	81.0298
24:00	0.6	8.2	8.8	3.7532	82.6558
28:00	0.3	8.6	8.9	3.9820	83.4688
TOTAL	6.1				

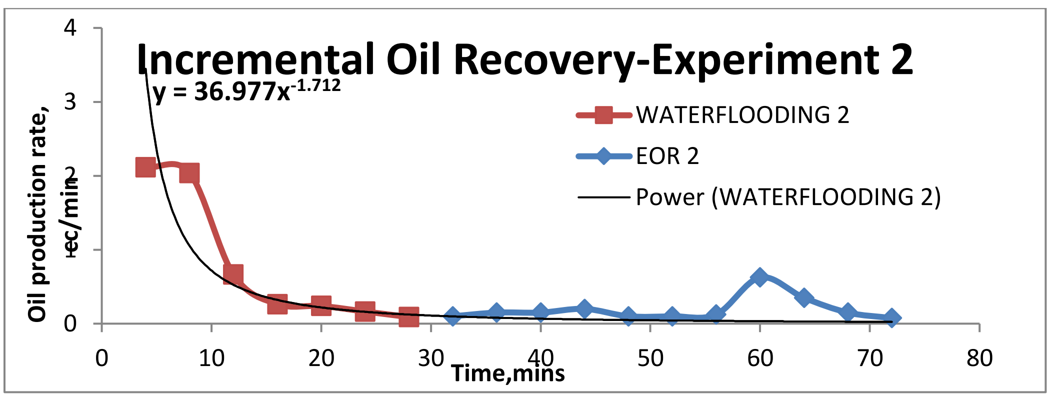

Figure 7: Oil Recovery Curve-Experiment 2

Table C (i) – Experiment 3 water flooding oil recovery

WATER FLOODING 3	BTT =9mins, 30secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	8.7	20.3337	0	0.2033	22.5869
2	8:00	0.0	8.3	39.6941	0	0.3969	44.0927
3	12:00	6.5	2.3	44.4560	76.8581	0.6027	49.3822
4	16:00	7.2	1.6	47.5148	86.1539	0.8060	52.7799
5	20:00	7.1	1.3	49.8436	88.1206	1.0021	55.3668
6	24:00	7.7	0.9	51.1992	93.2526	1.20210	56.8726
7	28:00	7.9	0.8	52.3114	94.5299	1.4063	58.1081
TOTAL			**23.9**				

Table C(ii)– Experiment 3 surfactant flooding oil recovery

POLYMER FLOODING 3					
Time mins	**Oil recovered, cc**	**water/polymer collected, cc**	**Total, cc**	**PV,polymer Injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.1	8.5	8.6	2.4550	64.5946
8:00	0.1	8.4	8.5	2.6618	64.8649
12:00	0.2	8.8	9.0	2.8808	65.4054
16:00	1.9	6.6	8.5	3.0876	70.5405
20:00	1.8	6.7	8.5	3.294404	75.40541
24:00	0.5	8.1	8.6	3.50365	76.75676
28:00	0	9.4	9.4	3.73236	76.75676
TOTAL	**4.6**				

Table C (iii) – Experiment 3 polymer flooding oil recovery

POLYMER FLOODING 3					
Time mins	Oil recovered, cc	water/polymer collected, cc	Total, cc	PV,polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.1	8.5	8.6	2.4550	64.5946
8:00	0.1	8.4	8.5	2.6618	64.8649
12:00	0.2	8.8	9.0	2.8808	65.4054
16:00	1.9	6.6	8.5	3.0876	70.5405
20:00	1.8	6.7	8.5	3.294404	75.40541
24:00	0.5	8.1	8.6	3.50365	76.75676
28:00	0	9.4	9.4	3.73236	76.75676
TOTAL	**4.6**				

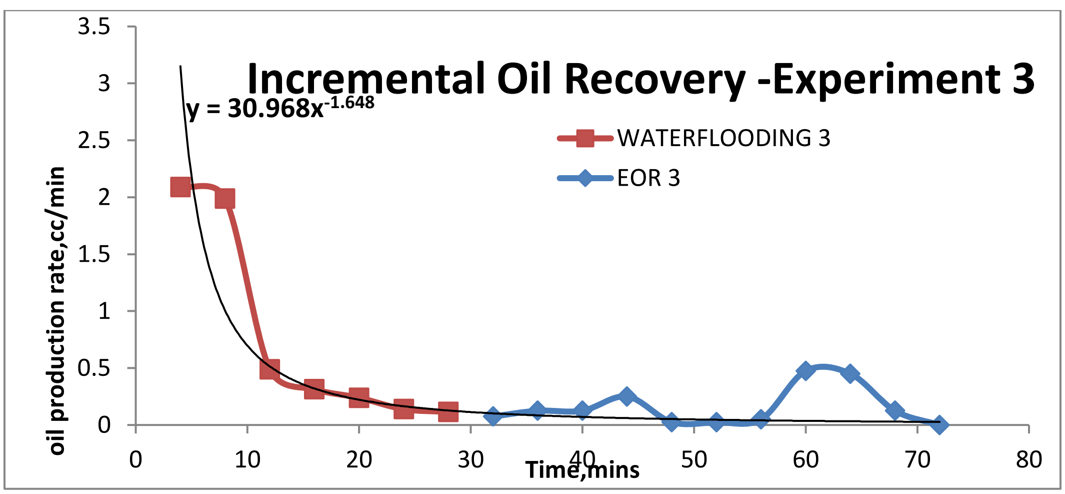

Figure 8: Oil Recovery Curve- Experiment 3

Table d (i) – Experiment 4 water flooding oil recovery

WATER FLOODING 4	BTT =7mins, 20secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	8.6	20.28782	0	0.202878	22.3166
2	8:00	0.8	7.4	37.62724	10.18182	0.395928	41.38996
3	12:00	5.8	2.6	43.17304	71.98582	0.593893	47.49035
4	16:00	7.0	1.7	46.50755	83.76068	0.799228	51.1583
5	20:00	7.0	1.3	48.85925	87.97127	0.994735	53.74517
6	24:00	7.2	1.2	50.96525	89.3617	1.192699	56.06178
7	28:00	7.3	1.0	52.57985	91.74147	1.388206	57.83784
TOTAL			**23.8**				

Table d (ii) – Experiment 4 surfactant oil flooding

SURFACTANT FLOODING 4, surfactant concentration = 0.7					
Time Mins	oil recovered, cc	water/surfactant collected, cc	Total, cc	PV, surfactant injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.6	7.9	8.5	1.597052	59.45946
8:00	0.7	7.7	8.4	1.80344	61.35135
12:00	0.7	7.8	8.5	2.012285	63.24324
16:00	0.8	7.8	8.6	2.223587	65.40541
TOTAL	2.8				

Table d(iii) – Experiment 4 polymer flooding oil recovery

POLYMER FLOODING 4					
Time mins	**Oil recovered, cc**	**water/polymer collected, cc**	**Total, cc**	**PV, polymer Injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.5	8.0	8.5	2.432432	66.75676
8:00	0.5	7.9	8.4	2.638821	68.10811
12:00	0.6	7.9	8.5	2.847666	69.72973
16:00	1.4	7.0	8.4	3.054054	73.51351
20:00	2.2	6.2	8.4	3.260442	79.45946
24:00	0.4	8.0	8.4	3.46683	80.54054
28:00	0.2	8.1	8.3	3.670762	81.08108
TOTAL	**5.8**				

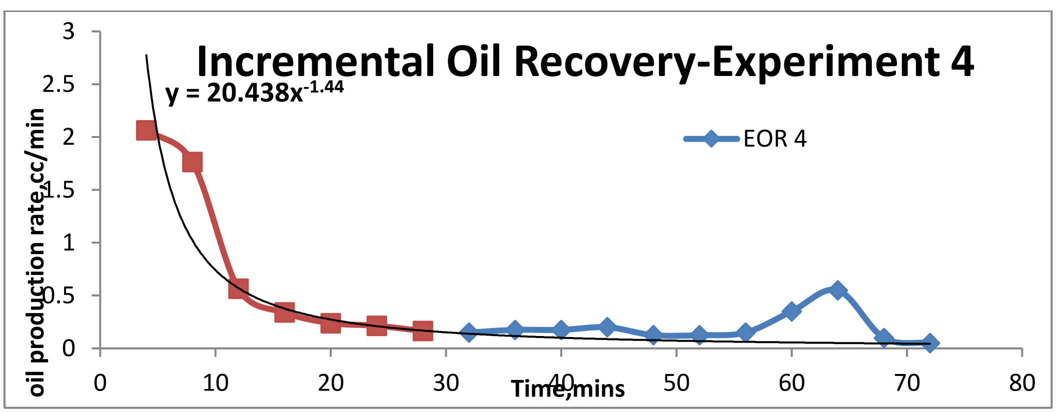

Figure 9: Oil Recovery Curve-Experiment 4

Table E(i) – Experiment 5 water flooding oil recovery

WATER FLOODING 5	BTT =6mins, 25secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	8.4	20.24408	0	0.202441	21.20301
2	8:00	1.7	6.9	36.71931	20.58824	0.409907	38.45865
3	12:00	6.0	2.6	42.39052	72.66436	0.617373	44.3985
4	16:00	6.7	1.9	46.30294	81.14187	0.824838	48.49624
5	20:00	7.1	1.5	49.21034	85.98616	1.032304	51.54135
6	24:00	7.2	1.4	51.86648	87.19723	1.23977	54.32331
7	28:00	7.5	1.1	53.76884	90.83045	1.447236	56.31579
TOTAL			**23.8**				

Table E (ii) Experiment 5 surfactant flooding oil recovery

SURFACTANT FLOODING 5, surfactant concentration = 0.9					
Time Mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV, surfactant injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.9	7.7	8.6	1.663317	58.68421
8:00	1.0	7.7	8.7	1.88191	61.31579
12:00	0.9	7.7	8.6	2.09799	63.68421
16:00	1.0	7.5	8.5	2.311558	66.31579
TOTAL	**3.8**				

Table E(iii) – Experiment 5 polymer flooding oil recovery

POLYMER FLOODING 5

Time mins	Oil recovered, cc	water/polymer collected, cc	Total, cc	PV, Injected	polymer	Cumulative recovery(Np), OIIP(N)	oil %
4:00	0.5	8.0	8.5	2.525126		67.63158	
8:00	0.6	8.0	8.6	2.741206		69.21053	
12:00	0.6	8.0	8.6	2.957286		70.78947	
16:00	2.1	6.5	8.6	3.173367		76.31579	
20:00	2.2	6.4	8.6	3.389447		82.10526	
24:00	0.9	7.8	8.7	3.60804		84.47368	
28:00	0.4	8.2	8.6	3.824121		85.52632	
TOTAL	**7.3**						

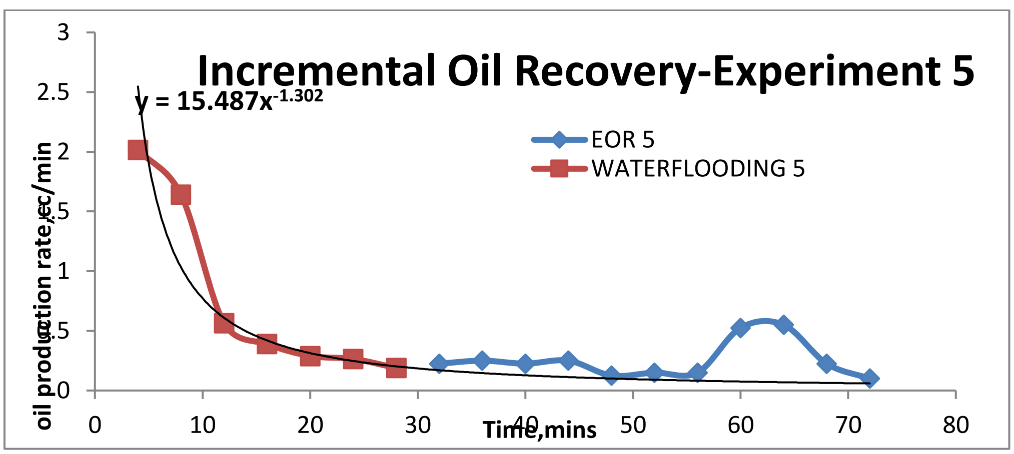

Figure 10 Oil Recovery Curve- Experiment 5

Table F (i) – Experiment 6 water flooding oil recovery

WATER FLOODING 6	**BTT =6mins, 25secs**						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	9.0	21.86147	0	0.218615	23.39768
2	8:00	0.4	8.5	42.46032	4.674457	0.434704	45.44402
3	12:00	5.5	3.1	49.4228	66.609	0.643218	52.89575
4	16:00	7.3	1.5	52.34488	86.31757	0.856782	56.02317
5	20:00	7.4	1.2	54.50938	89.61938	1.065296	58.33977
6	24:00	7.1	0.9	55.91631	92.72388	1.258658	59.84556
7	28:00	8.0	0.9	57.32323	93.48915	1.474747	61.35135
TOTAL			**25.1**				

Table F(ii) – Experiment 6 surfactant oil flooding

SURFACTANT FLOODING 6, surfactant concentration = 1.1					
Time mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV, surfactant injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.9	7.3	8.2	1.681818	63.78378
8:00	0.7	7.6	8.3	1.891414	65.67568
12:00	0.6	7.8	8.4	2.103535	67.2973
16:00	0.4	8.2	8.6	2.320707	68.37838
TOTAL	**2.6**				

Table F(iii) – Experiment 6 polymer flooding oil recovery

POLYMER FLOODING 6					
Time mins	Oil recovered, cc	water/polymer collected, cc	Total, cc	PV, polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.2	8.5	8.7	2.540404	68.91892
8:00	0.2	8.6	8.8	2.762626	69.45946
12:00	0.2	8.4	8.6	2.979798	70
16:00	3.0	5.8	8.8	3.133838	70.81081
20:00	1.6	7.2	8.8	3.356061	75.13514
24:00	0.2	8.4	8.6	3.573232	75.67568
28:00	0.1	8.6	8.7	3.792929	75.94595
TOTAL	5.5				

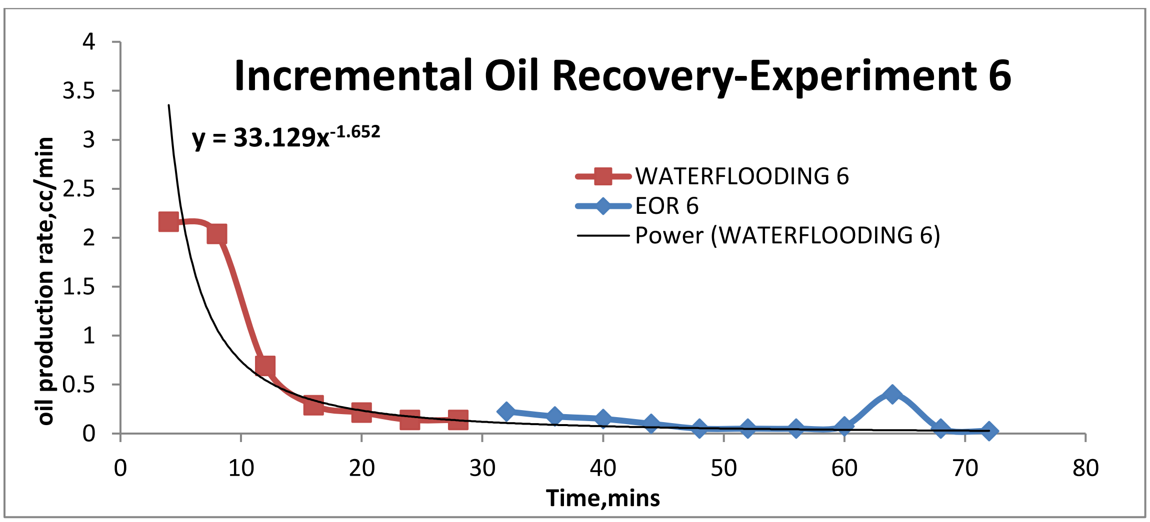

Figure 11 Oil Recovery Curve-Experiment 6

Table G (i) – Experiment 7 water flooding oil recovery

WATER FLOODING 7	BTT =7mins, 13secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	8.9	21.50036	0	0.215004	22.81905
2	8:00	0.8	7.9	40.48816	9.57265	0.424982	42.97143
3	12:00	5.3	3.4	48.16942	63.4188	0.634961	51.12381
4	16:00	7.0	1.7	51.57933	83.76068	0.844939	54.74286
5	20:00	7.4	1.4	54.23546	87.5	1.05743	57.5619
6	24:00	7.4	1.2	56.38909	89.61938	1.264896	59.84762
7	28:00	7.7	1.0	58.0402	92.13675	1.474874	61.6
TOTAL			**25.5**				

Table G (ii) – Experiment 7 surfactant flooding oil recovery

SURFACTANT FLOODING 7, surfactant concentration = 1.3					
Time mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV, surfactant injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.7	7.9	8.6	1.690955	63.46667
8:00	1	8.1	9.1	1.919598	66.13333
12:00	0.6	8.2	8.8	2.140704	67.73333
16:00	0.4	8.2	8.6	2.356784	68.8
TOTAL	**2.7**				

Table G (iii) – Experiment 7 polymer flooding oil recovery

POLYMER FLOODING 7					
Time mins	Oil recovered, cc	water/polymer collected, cc	Total , cc	PV, polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.2	8.4	8.6	2.572864	69.33333
8:00	0.3	8.7	9.0	2.798995	70.13333
12:00	0.3	8.7	9.0	3.025126	70.93333
16:00	2.8	6.0	8.8	3.246231	78.4
20:00	1.8	6.5	8.3	3.454774	83.2
24:00	0.4	8.6	9.0	3.680905	84.26667
28:00	0.2	8.4	8.6	3.896985	84.8
TOTAL	6.0				

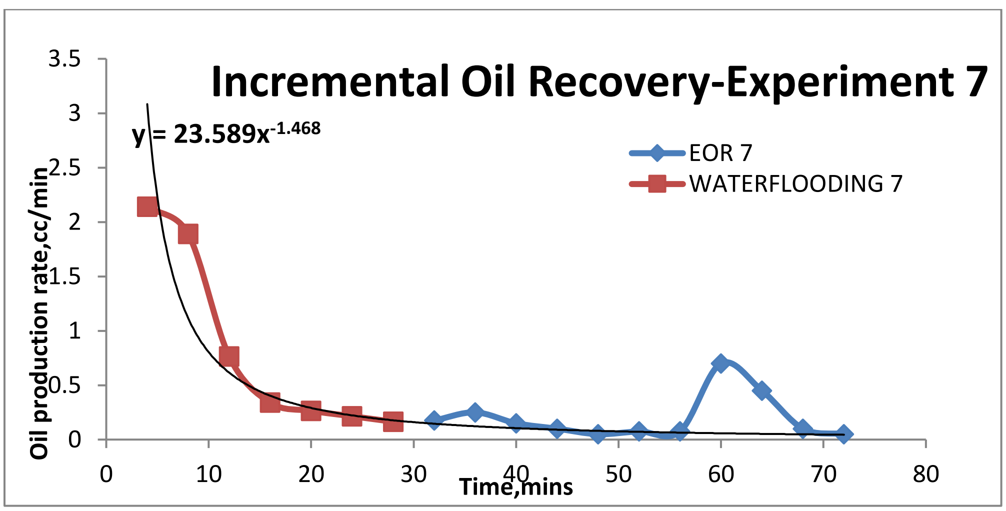

Figure 12: Oil Recovery Curve-Experiment 7

Table H (i)– Experiment 8 water flooding oil recovery

WATER FLOODING 8	BTT =5mins, 50secs						
S/N	**Time, mins**	**Water, cc**	**Oil, cc**	**Sw %**	**fw %**	**H2O injected, PV injected**	**Cumulative oil recovery(Np), % OIIP(N)**
1	4:00	0.0	8.2	19.3590	0	0.19359	21.0433
2	8:00	4.0	4.8	30.4213	46.8750	0.4018	33.0680
3	12:00	5.0	4.0	39.5315	57.2519	0.6149	42.9708
4	16:00	7.0	2.0	43.7612	80.1527	0.8280	47.5685
5	20:00	7.6	1.4	46.5268	87.0229	1.0412	50.5747
6	24:00	7.8	1.2	48.8043	89.3130	1.2543	53.0504
7	28:00	8.0	1.0	50.5938	91.6031	1.4674	54.9956
8	32:00	8.6	0.8	51.8952	94.1606	1.6903	56.4103
9	36:00	8.3	0.6	52.7086	96.1390	1.9009	57.2944
TOTAL			**24**				

Table H (ii)– Experiment 8 surfactant flooding oil recovery

SURFACTANT FLOODING 8, surfactant concentration = 1.5					
Time mins	**oil recovered, cc**	**water/surfactant collected, cc**	**Total, cc**	**PV,surfactant injected**	**Cumulative oil recovery(Np), % OIIP(N)**
4:00	0.4	8.2	8.6	2.1108	58.3554
8:00	0.5	8.5	9.0	2.3304	59.6817
12:00	0.8	7.4	8.2	2.5305	61.8037
16:00	1.0	8.0	9.0	2.7501	64.4562
TOTAL	**2.7**				

Table H (iii) – Experiment 8 polymer flooding oil recovery

POLYMER FLOODING 8

Time mins	Oil recovered , cc	water/polymer collected, cc	Total , cc	PV, polymer Injected	Cumulative oil recovery(Np), % OIIP(N)
4:00	0.6	8.2	8.8	2.9649	66.0478
8:00	0.8	7.8	8.6	3.1747	68.1698
12:00	1.2	7.6	8.8	3.3895	71.3528
16:00	2.0	6.4	8.4	3.5944	76.6578
20:00	1.7	7.0	8.7	3.8067	81.1671
24:00	0.8	8.1	8.9	4.0239	83.2891
28:00	0.6	8.2	8.8	4.2387	84.8806
TOTAL	6.7				

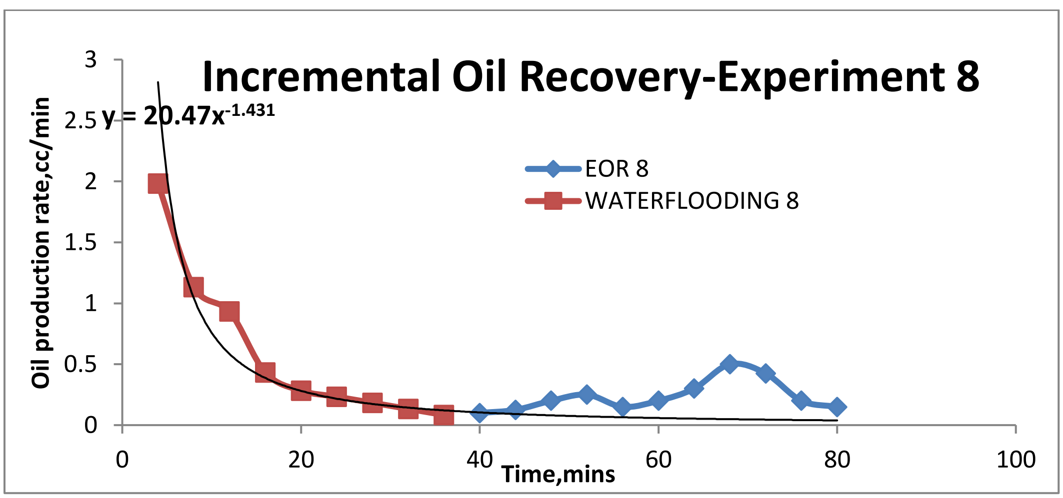

Figure 13 Oil Recovery Curve-Experiment 8

Table I – Summary of Incremental Oil Recovery

EXPERIMENT	% SUFACTANT CONCENTRATION	INCREMENTAL OIL RECOVERY , (cc)
1	0.1	6.3635
2	0.3	7.8185
3	0.5	5.8825
4	0.7	7.5663
5	0.9	10.1389
6	1.1	6.3219
7	1.3	7.9061
8	1.5	9.3906

At the early time of the water flooding process for all the experiment, appreciable oil recovery was recorded till the eight (8) minutes, after which oil recovery became insignificant. This necessitated the initiation of surfactant flooding as shown in each of the tables n(ii). It was observed that after twelve (12) minutes, there was no significant change in the cumulative oil produced and after the entire process. This made it imperative for the mobility of the displacing slug to be improved by introducing polymer to complement the recovery by IFT reduction.

As seen from Table I, this is the summary of the incremental oil recovery depicted in Figure 6 to Figure 13, and surfactant concentration in percentage by weight of solution. At 0.1% concentration, the incremental oil recovered was 6.4 cc. As the surfactant concentration was increased to 0.3% and 0.5%, the incremental oil recovered increased and later reduced as listed above. This behavior was exhibited when the surfactant concentration was increased from 0.7% to 0.9% and from 0.9% to 1.1%. This indicates that recovery does not necessarily increases with increasing surfactant concentration in the mobilizing slug.

Conclusion

The Objective of this study was to obtain an optimum concentration of surfactant that can be used for flooding to increase oil recovery in a light oil reservoir. The task was accomplished by conducting 8 sets of core flood experiments with varying surfactant concentrations. Since no incremental oil recovery close to that recovered at a concentration of 0.9% was recorded with increasing surfactant concentration, the optimum surfactant concentration was found to be 0.9% by weight of surfactant in a slug. Further addition of more surfactants becomes uneconomical for a light oil reservoir. The experimental results also clearly establish that use of surfactant in Chemical Enhanced Oil Recovery improved recovery in light oil reservoirs.

Recommendation

In enhanced oil recovery, surfactants should be used in several formulations to enhance oil production. Some of these formulations are surfactant-alkali flooding, surfactant-polymer flooding, and alkali-surfactant-polymer flooding.