THE EFFECT OF INTERFACIAL TENSION ON RECOVERY FACTOR FOR A SELECTED MALAYSIAN OILFIELD

Seyed Alireza Zad
(MSc. in Petroleum Engineering, University Technology PETRONAS, Malaysia.)
Email: s.alireza.zad@gmail.com
Hamidreza Ashtari
(MSc. in Mining Engineering-Rock Mechanics,
Azad University of Bafgh, Yazd, Iran.)

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ABSTRACT

The recovery factor can be increased by reduction in Interfacial Tension (IFT) due to reducing of capillary pressure .A residual oil saturation (S_{or}) remains in rock which has been water flooded because, under usual reservoir condition, the driving force which can be generated is not enough to push out oil trapped by capillary forces . Since these capillary forces can be reduced by reducing the IFT a frequently studied method of increasing oil recovery has been the use of surfactants to reduce the water-oil interfacial tension.

In this study the purpose is to define how IFT reduction can lead to recovery factor improvement by studying of the MIRI oil field (northern Sarawak, Malaysia). Different IFTs are based on measured values which achieved by experimental approach and led to different recovery factors.

INTRODUCTION

Oil recovery operations traditionally could be defined into three stages: primary, secondary, and tertiary. Naturally mechanisms existing in a reservoir such as, solution gas drive, gas-cap drive, natural water drive, fluid and rock expansion, and gravity drainage, are known as primary oil recovery operation. Secondary recovery, the second stage of operations, usually was implemented after primary production declined. Waterflooding, pressure maintenance, and gas injection were called secondary oil recovery operation. Tertiary recovery which is more likely known as "enhanced oil recovery" (EOR) and the third stage of production, was that obtained after secondary stage (usually waterflooding).Tertiary processes used miscible gases, chemicals, and/or thermal energy to displace additional oil after the secondary recovery process became uneconomical. Lower IFT‘s, oil swelling, oil viscosity reduction, wettability modification, or favourable phase behaviour are some results of interactions between injected fluid(s) of some type into a reservoir. All these processes would be considered as EOR.

Even if waterflooding were continued indefinitely, a large quantity 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. The ratio of viscous forces, which favor oil mobilization, to capillary forces, which favour oil trapping, is quantified by the capillary number (N_C). Surfactants can generate a lower IFT between water and oil phases, leading to the mobilization of trapped oil. Surfactant performance depends upon many target specific conditions, such as oil properties, reservoir temperature and ionic conditions. The objective of this work is to study the effect of interfacial tension (IFT) on recovery factor of the MIRI oilfield.

An important aspect of any EOR process is the effectiveness of process fluids in removing oil from the rock pores at the microscopic scale. Microscopic displacement efficiency(E_D) largely determines the success or failure of a process. For crude oil, E_D is reflected in the magnitude of S_{or}, (i.e., the residual oil saturation) in places contacted by the displacing fluids. Because EOR processes typically involve the injection of multiple fluid slugs, the efficiency of displacement of these slugs through the reservoir is also of interest. Poor efficiency leads to early deterioration and breakdown of the slugs, which in turn leads to poor project performance. Capillary and viscous forces govern phase trapping and mobilization of fluids in porous media and thus microscopic displacement efficiency [1]. However this work was only studied the surfactant injection and its effect on displacement efficiency, an understanding of the magnitude of these forces is required to understand the recovery mechanisms involved in EOR processes.

Whenever immiscible phase coexist in a porous medium as in essentially all processes of interest, surface energy related to the fluid interfaces influences the saturation, distributions, and displacement of the phases. Water coexists with oil in a reservoir even when the reservoir has not been waterflooded or flooded by a natural water drive. Even though the water may be immobile in this case, interfacial forces can still influence performance of subsequent flow processes. If a reservoir has been waterflooded or there is a natural water drive, then water saturation will be high and the water phase will be mobile. Most EOR processes use fluids that are not completely miscible with the oil phase and/or the water phase .Interfacial forces must then be examined to determine their significance for oil recovery.

Surface and interfacial tension of fluids result from molecular properties occurring at the surface or interface. Surface tension is the tendency of a liquid to expose a minimum free surface. Surface Tension may be defined as the contractile tendency of a liquid surface exposed to gases. The interfacial tension is a similar tendency which exists when two immiscible liquids are in contact [2].

During displacement of oil by an immiscible injection fluid, some of the oil behind the flood front and the pores of the medium is trapped, depending on the relative capillary and viscous forces. Changes in the viscous/capillary force ratio can be measured by the dimensionless group,$\rho V/U \cos\theta$, known as capillary number, N_C[3]. The capillary number is used to correlate oil recovery from two types of core displacement experiments: (1) displacement experiments in which oil is no longer continuous at the flood front but has been already trapped in the pores of the rock by a previous flooding agent and (2) displacement experiments in which oil is continuous at the flood front. The first type, the N_C concept is applied to the reduction in trapped oil saturation by the increase in the viscous/capillary force ratio. This type of correlation applied in this work.

The primary target of surfactant-polymer flooding is the residual oil saturation caused by capillary forces trapping oil at the pore scale. The goal of using surfactant for enhanced oil recovery is to reduce the IFT until the capillary number is high enough to mobilize all of the residual oil [4].

Core flood experimentation in chemical EOR is a mean to test how effectively a surfactant formulation can recover oil. A formulation showing good solubilisation and aqueous stability in phase behaviour can be selected for a core flood experiment. The target of a chemical flood is the residual oil saturation trapped by pore-scale capillary forces in a sample rock core [5]. The rock is similar or the same as reservoir rock that the crude oil originated from.

EXPERIMENTAL PROCEDURES

Surfactant Properties:

SDS (Sodium Dodecyl Sulfate) is a commercial surfactant. The properties of SDS is shown in Table1.SDS was measured for 2500ppm, 4000ppm, and 5000ppm.

Table 1
Sodium Dodecyl Sulfate

commercial class	Ionic(anionic)
MMW	18,000g
CMC	6 to 8mM
PH	5 to 8

Oil and Brine Properties

The crude oil used for these experiments was obtained from the MIRI oil field of northern Sarawak, Malaysia and had not been subjected to any type of chemical treatment. The MIRI light crude had a gravity of 32.3̊ API. The properties of crude are shown in Table 2.

Core Properties

One Berea sand stone, approximately 2.5 inches, was used. The pore volume of the core was 17.052 cc, with the permeability of 233.918 md, and porosity of %19.94.Detailed properties are shown in Table 3.

Table 2
Crude Oil Analysis [6]

NO	TEST	METHOD	UNIT	RESULT
1	Density@15°c	ASTM D4052	Kg/l	0.8638
2	API Gravity	ASTM D1298	degree	32.3
3	Basic Sediment & Water	ASTM D4007	vol%	0.026
4	Water	ASTM D4006	vol%	0.025
5	Reid Vapor Pressure	ASTM D323	kpa	29
6	Total Acid Number	ASTM D664	mgKOH/g	0.27
7	Flash Point	JP 170	°C	<19.0
8	Pour Point	ASTM D97	°C	-9
9	ASTM Color	ASTM D1500	-	D 8.0
10	Total Sulphur	ASTM D4294	wt%	0.078
11	Salt Content	IP 265	ib/1000bbls	10.1
12	Nitrogen Content	ASTM D4629	ppm	272
13	Wax Content	ASTM D482	wt%	0.001
14	Ash Content	UOP 46	wt%	2.3
15	KinematicViscosity@40°c	ASTM D445	cSt	3.002
16	kinematic Viscosity@70°c	ASTM D445	cSt	1.788
17	Characterisation Factor	UOP 375-59	-	11.5
18	Gross Calorific Value	ASTM D240	MJ/kg	44.35
19	Mercury	MERCURY ANALYSER	ppb	2
20	Asphaltenes	ASTM D3279	wt%	<0.5

Table 3
Berea Sandstone's Properties

Diameter(mm)	38.05
Length(mm)	75.22
Weight(g)	178.7
K air (md)	233.9
VP (cc)	17.05
Φ (%)	19.94
V grain (cc)	68.48
V bulk (cc)	85.53
ρ grain (g/cc)	2.612
ρ bulk (g/cc)	2.091

The brine used in this experiment was saline water which was consists of distilled water and Sodium Hydroxide (NaOH) with concentration of 10,000 ppm.

Apparatus

Two apparatuses were used in this study:

1. The IFT 700, to measure the interfacial tension , is shown in Figure1. The IFT 700 is designed to determine interfacial tension and contact angle, but also to observe heat and mass transfer phenomena. The experiment can be operated at high pressure (up to 69 MPa, 10.000 psi) and high temperature (up to 200°C). Basically a pendant drop or standing bubble/drop (Drop Fluid) may be generated in a second immiscible fluid (Pressure Fluid). The drop shape image is computed, and then the interfacial tension is computed from solving algorithm of the Laplace equation.

Figure 1
The IFT-700

The facial tension between distilled water and air is defined as calibration of IFT-700 by the manufacturer. Before running the equipment the surface tension of distilled water and air is measured in room temperature (by generating of water droplet), and compared to the standard surface tension (which is 72.8 $\frac{\text{dyne}}{\text{cm}}$ in 20°C). IFT-700 was used in the same condition which core was flooded. The flooding process was under 1000-1100 psi pressure and 60° C temperature. Three concentrations of SDS were tested. The period between calculation of interfacial tension and contact angle was one second. This frequency is determined by the time to acquire an image and to post process the results [7].

2.The TEMCO RPS-800-10000 HTHP Relative Permeability Test System is designed for Permeability and Relative Permeability flow testing of core samples(Figure 2), at in-situ conditions of pressure and temperature[8].

The process is segmented in five steps:

1. Brine saturation.
2. Crude injection.
3. Water flooding.
4. Surfactant injection.
5. Cleaning and drying the core.

The core was saturated with 10,000 ppm brine for eight hours for each run and then was injected with 200 cc of brine again. Crude then injected into the core to reach the initial condition of,S_{oi} , and S_{wir} .Flow rate was 1.0 cc/minute with the inlet pressure of 1000 psig and temperature of 64 ^{o}C .Water flooding was the next injection and conducted with 10.PV which means 170cc of water was injected into the core .After reaching to residual oil saturation, surfactant was injected with the flowrate of 1.0 cc/min and at the end the core was cleaned and dried and saturated for the next run. Before each run the core saturated with brine within eight hours and at the end of each it was cleaned and dried within two hours. The core was cleaning and drying with CO2/Solvent core cleaner. The reason for using only one core was to evaluate the effect of different IFTs on recovery factor in the same porous medium with the same permeability.

Figure 2
RPS-800-10000

RESULT AND DISCUSSION

The first step was to generate a droplet of oil into the surfactant and then the camera captured the droplet each second, for one minute and for each capture calculated the contact angle and Interfacial tension. The different results in one minute are illustrated in figures 4 and 5 for two concentrations of surfactant and figure 6 for the brine. Figure 3 is shown the droplet generated by oil in brine. The lower the IFT, the more difficult to generate a droplet.

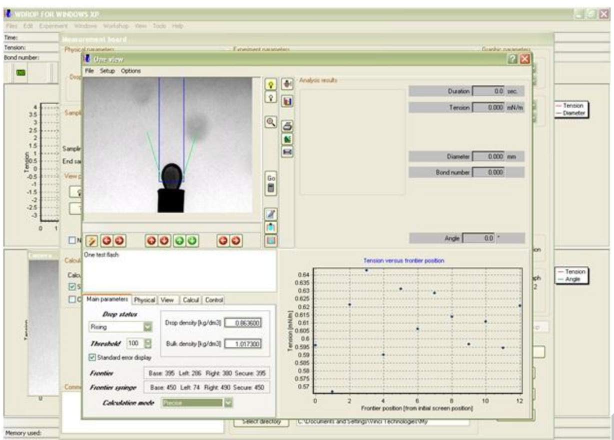

Figure 3
Measurement of Contact Angle

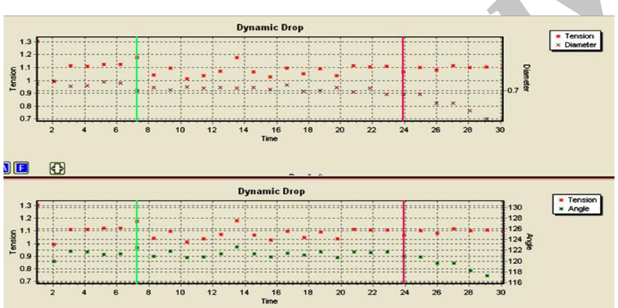

Figure 4
IFT between oil and SDS (2500 ppm)

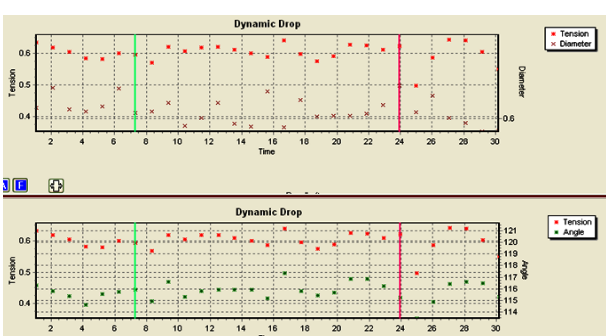

Figure 5

IFT between oil and SDS (5000 ppm)

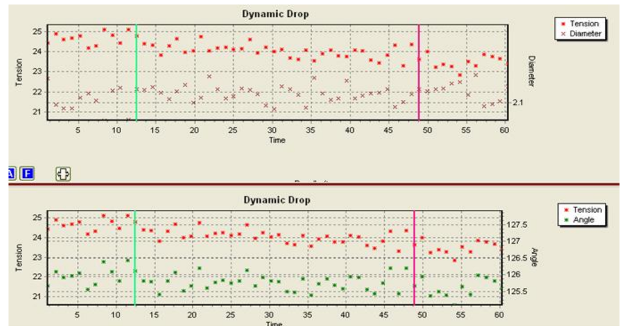

Figure 6
IFT between oil and brine

The relationship between obtained IFTs and different concentrations are illustrated in figure 7 . Three concentrations of SDS were tested as following:

0.25Wt % (2500ppm), 0.4Wt% (4000ppm), and 0.5Wt % (5000ppm) and the Interfacial tension obtained were 1.37, 0.91, and 0.72(dyne/cm), respectively.

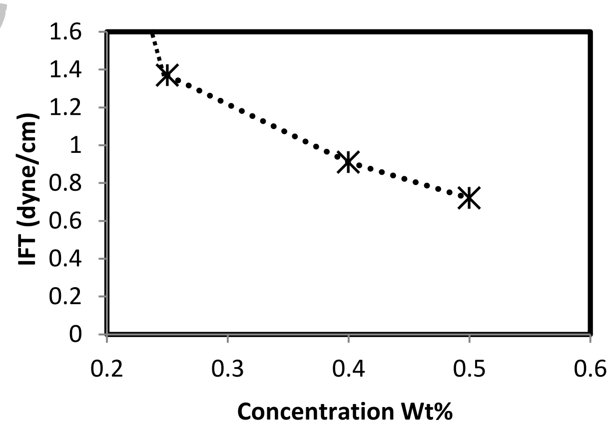

Figure 7 Concentration Vs.IFT

The injection rate for Oil and Waterflooding and surfactant were 1.00 ml per minute. The outlet tubes capacity was 8.20 ml/minute which was considered during the core floodings (From outlet to BPR).

The recovery factor for all water floodings was close enough to be considered as constant. The value obtained from water flooding was 0.452 and S_{o}=0.62.Figures 8 to 10 show the recovery improvement due to SDS injection with quite normal concentrations which are been used in real.

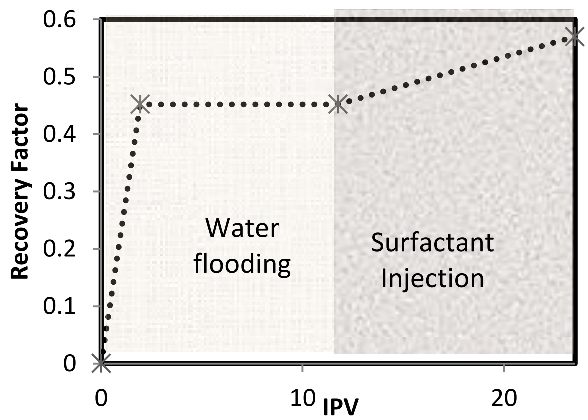

Figure 8
Recovery improvement by SDS (0.25 wt%)

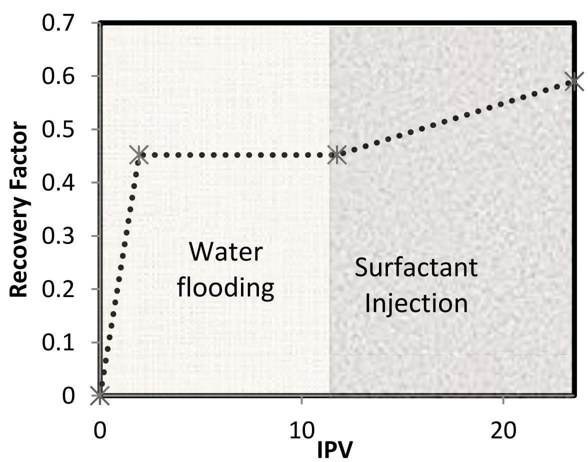

Figure 9
Recovery improvement by SDS(0.4 wt%)

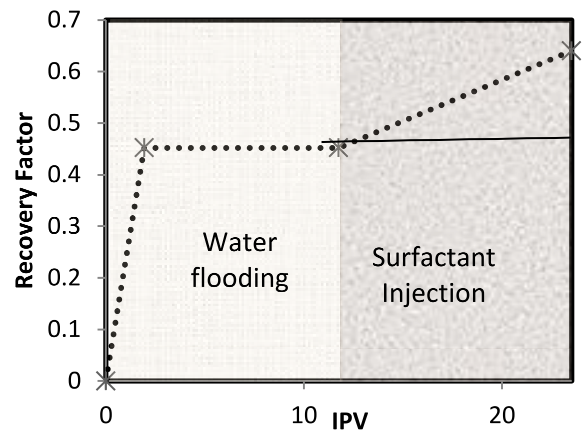

Figure 10
Recovery improvement by SDS(0.5wt%)

.For SDS additional recovery of 0.113, 0.169 and 0.188 were obtained

CONCLUSION

The recovery factor was affected by reduction of Interfacial Tension due to increase of capillary number (N_C). IFT decreased with the increase of concentration and the decreasing was almost linear whit a slight slope.

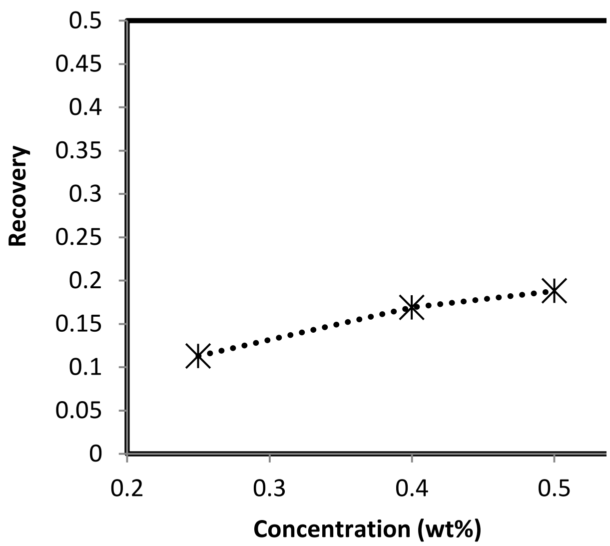

Figure 11

Concentration Vs.Recovery Factor

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