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EXPERIMENTAL PINPOINTING OF ENRICHED MISCIBLE GAS COMPOSITION BASED ON INTERFACIAL TENSION MEASUREMENT

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ABSTRACT

Measuring interfacial tension parameter between hydrocarbon injecting gas and live reservoir oil samples is really a good indicator for predicting optimum miscible gas injection scenarios at reservoir condition. Conducting an experimental miscible gas injection project for one of the Iranian oil fields, natural liquefied gas (NGL) and Naphtha was candidate to enrich injecting gas in order to investigate gas composition effects on efficiency of miscibility process. As a result, injecting gas was enriched by NGL and Naphtha samples with predefined ratios. This study aimed to measure and compare interfacial tension parameters between reservoir oil and five synthesized gas samples at different depleting pressures and reservoir temperature. The results showed optimum miscible gas enrichment candidates with minimum interfacial tension parameters at depletion pressure steps.

NOMENCLATURE AND SYMBOLS

ρ	density of fluid
g	the acceleration due to gravity, (9.80665 m/s2)
IFT	Interfacial Tension
NGL	natural liquefied gas
P	interfacial pressure difference
psia	pounds-force per square inch absolute
R1, R2	surface's radii of curvature (the principal radii of curvature)

1. INTRODUCTION

Recently measuring reliable interfacial tension parameter has been turned into a challenging topic in hydrocarbon reservoir fluid laboratories and accurate information on interfacial tension (IFT)

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is of major importance in both petroleum and chemical engineering. Interfacial Tension (IFT) is a measurement of existing cohesive (excess) energy at an interface arising from the imbalance of forces between molecules at an interface (gas/liquid, liquid/liquid, gas/solid, and liquid/solid). When two different phases are in contact with each other the molecules at the interface are imposed with an imbalance of forces. This will lead to an accumulation of free energy at the interface. If the investigated surface is the interface of two immiscible liquids the measurement is normally referred to as interfacial tension.

The importance of IFT is sensed when dealing with EOR processes where the relative magnitude of interfacial (capillary), gravitational and viscous forces considerably affects the recovery of hydrocarbons. The relative permeability, which determines the flow behaviour of reservoir fluids in porous media, strongly depends on the interfacial tension at low interfacial conditions. In other words, viscous forces, as the driving factor for mobilizing oil through porous media and capillary forces, as trapping factor for retaining the reservoir oils within porous media compete with each other continuously through porous media. On the other hand, capillary forces are directly inspired by interfacial tension parameter. Therefore measuring IFT in different processes such as immiscible gas injection leads to find a reliable estimate from capillary trapping forces in reservoir conditions [1].

Oil production and gas injection processes are strongly influenced by the gas/oil interfacial tension and by the wetting behaviour of oil on the porous substrate. Oil recovery is favoured by low gas/oil interfacial tensions and by complete wetting of oil on the water phase that often covers the porous rock. Interfacial forces play an important role in various oil recovery schemes, starting with oil recovery. The gas/oil interfacial tension and the wetting behaviour of oil in the presence of gas, control the distribution of the oil and gas phases within the pore space. Therefore these quantities affect the phase flow parameters such as capillary pressure, phase permeabilities and the quantity of oil remaining after drainage with gas. The interfacial parameters are strongly dependent on thermodynamic (e.g. pressure or composition) conditions.

For instance, in the production of near-critical gas condensates or volatile oils and in near miscible gas injection processes, variations of the gas/oil interfacial tension by several orders of magnitude are not uncommon. Upon such variations, the flow regime changes from emulsion-like flow at very low IFT to a capillary-dominated flow at high IFT. These changes are reflected in the multiphase flow parameters [2].

Figure 1: IFT Experimental set up using Pendant drop technique

2. IFT MEASUREMENT BY PENDANT DROP METHOD

IFT-700 System from Vinci Company was used for measuring surface tension (liquid-gas) and interfacial tension (liquid-liquid) using the pendant drop method (Laplace equation). The whole experimental set up has been depicted in Figure 1.

The pendant drop method is defined as the formation of a liquid drop at the end of a hollow needle, which is submerged in a second bulk fluid. Drop formation is matured under fixed temperature and pressure and the apparatus is mobilized with an accurate snapshot system. After taking the desired snapshot, complete structure of the drop is analyzed with advanced drop shape analysis software. Using the drop dimensions on the achieved image and knowing the needle dimensions, the interfacial tension parameter is determined precisely [3, 4]. It should be reminded that maximum working pressure and temperature of IFT 700 are 10000 psi and 150°C respectively, see Figures 2 and 3.

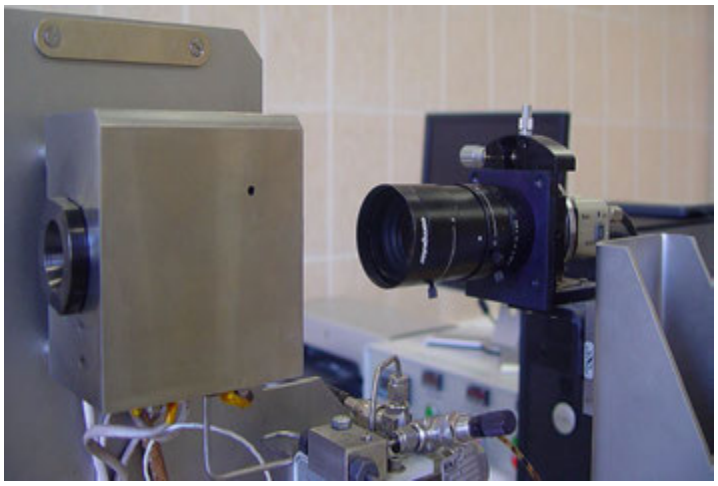

Figure 2: Snapshot system.

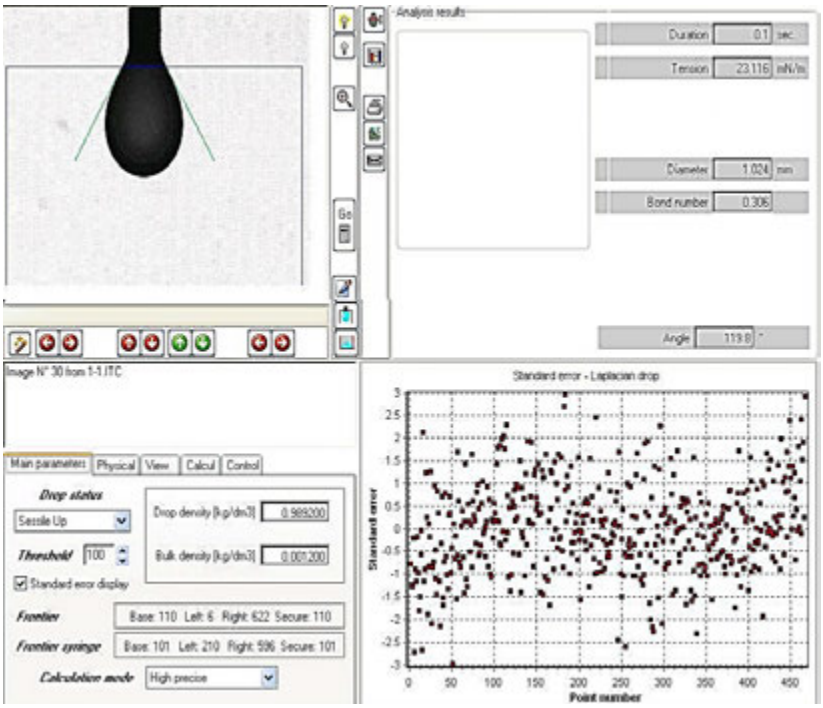

Figure 3: Liquid Drop Snapshot Analysis.

The shape of a drop is determined by its radii of curvature, R1, and R2. In case of a spherical

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drop, these are equal. The relationship between interfacial pressure (the pressure across the interface) and these radii of curvature is called the Young-Laplace Equation

$$P = g\,(1/R1 + 1/R2) \qquad (1)$$

In a column of fluid of density ρ and height h, the interfacial pressure difference $P = \rho gh$.

3. SAMPLE PREPARATION

Reservoir oil sample in pressure steps above the saturation pressure was monophonic and it could be injected through the needle in specified pressure and temperature precisely but below the bubble point, the pressure associated gas cap was evolved and two different phases of liquid and gas were created. Therefore it was decided to design a differential vaporization test simultaneous with working on pendant drop apparatus in order to prepare gas cap-released oil samples in pressure steps below the saturation pressure. To make a long story short, during the differential vaporization test, pressure of the live oil was fixed in predefined pressure steps and evolved gas cap was removed from top of the oil sample in each step and the remaining high-pressure oils were used to inject through pendant drop instrument [5,6].

On the other hand, gas samples should be prepared parallel with the reservoir oil sample. It was decided to enrich injecting gas samples with NGL and Naphtha based on ratios of 213 and 430 SCF/STB. Finally, five synthetic samples were made by recombining injecting gas samples with Naphtha and NGL with ratios of 230 and 430 SCF/STB. Detailed composition analysis and density of five gas samples have been listed in Tables 1 and 2.

Table 1. Composition analysis for five injecting scenarios (MOLE %)

Component	Dry Gas	NGL	NAPHTA	DRY Gas + NAPHTA		DRY Gas + NGL	
				213 bbl/MMSCF	430 bbl/MMSCF	213 bbl/MMSCF	430 bbl/MMSCF
N_2	7.90	0.00	0.00	6.66	5.74	5.86	4.64
CO_2	1.71	0.00	0.00	1.44	1.24	1.27	1.00
H_2S	0.01	0.00	0.00	0.0100	0.0100	0.0100	0.0100
CH_4	84.97	1.88	0.00	71.62	61.74	63.46	50.63
C_2H_6	2.46	28.89	0.00	2.08	1.79	9.30	13.38
C_3H_8	0.89	36.92	0.00	0.75	0.65	10.21	15.78
N-C_4	0.40	14.47	0.57	0.43	0.45	4.04	6.21
I-C_4	0.22	6.33	0.00	0.18	0.16	1.80	2.74
N-C_5	0.17	3.59	4.27	0.82	1.29	1.06	1.59
I-C_4	0.17	3.69	5.20	0.96	1.55	1.08	1.63
Pseudo C_6	0.39	2.31	11.03	2.06	3.30	0.89	1.18
Pseudo C_7	0.31	0.67	16.69	2.88	4.79	0.40	0.46
Pseudo C_8	0.32	0.63	22.09	3.74	6.27	0.40	0.45
Pseudo C_9	0.07	0.45	18.80	3.01	5.19	0.17	0.23
Pseudo C_{10}	0.00	0.11	13.02	2.05	3.56	0.03	0.05
Pseudo C_{11}	0.00	0.03	5.13	0.81	1.40	0.01	0.01
C12+	0.00	0.02	3.20	0.50	0.87	0.01	0.01
Molar Mass (g/mol)	19.43	46.63	109.36	33.55	44.01	26.46	30.66

In other words, the following gas samples should be prepared experimentally by recombining initial gas sample and enriching agents with predefined ratios:

1) Initial dry gas
2) Injecting gas recombined with NGL based on the ratio of 213 SCF/STB which was so-called NGL 213

3) Injecting gas recombined with NGL based on the ratio of 430 SCF/STB which was so-called NGL 430
4) Injecting gas recombined with Naphtha based on the ratio of 213 SCF/STB which was so-called Naphtha 213
5) Injecting gas recombined with Naphtha based on the ratio of 430 SCF/STB which was so-called Naphtha 430

Table 2. The density of oil and gaseous phases through depletion pressure steps @ 200 ºF

Pressure (psia)	Live Oil Density (gr/cc)	Dry Gas Density (gr/cc)	NGL 213 Density (gr/cc)	NGL 430 Density (gr /cc)	Naphtha 213 Density (gr/cc)	Naphtha 430 Density (gr/cc)
Ambient	0.8714	0.0006	0.0009	0.0010	0.0011	0.0015
911	0.8038	0.0434	0.0640	0.0802	0.0839	0.1319
1923	0.7771	0.0938	0.1464	0.1927	0.1946	0.3201
2905	0.7539	0.1405	0.2176	0.2768	0.2839	04180
3085	0.7552	0.1486	0.2288	0.2887	0.2972	0.4307
3485	0.7578	0.1657	0.2517	0.3123	0.3241	0.4555

4. EXPERIMENTAL PROCEDURE

The experimental procedure for measuring interfacial tension parameter using the pendant drop technique can be classified in the following orders:

- Initial preparation and checking of the instrument and stabilizing the instrument temperature at a specified temperature.
- Preparing to bottom hole reservoir oil samples by storing and aging them for a sufficient period of time. This matter is really crucial for asphaltenic oil samples since asphaltene fractions include soluble and insoluble colloid particles and in case of having non-aged reservoir sample, IFT measurements will not be accurate and reliable and they mislead final results.
- Heating up the candidate gas sample (bulk phase) and oil sample using special electrical jackets
- Injecting the bulk phase through the gas chamber at a specified pressure. The chamber has already been vacuumed. Therefore it should be filled two or three times so that equilibrated and homogenized gas is filled through the system.
- Preparing the high-pressure oil sample for each pressure step (This part will be explained in detail in sample preparation section).
- Filling the prepaid oil sample through stainless steel lines and connections of the pendant drop instrument. It should be reminded that enough time should be allocated to reach the equilibrium condition again.
- Opening the microvalve in the way of the pendant drop needle in order to direct the oil sample to the needle. Hence, a well-formed droplet of oil sample is evolved in the gas chamber.
- Taking a digital snapshot from the oil droplet at high pressure and high-temperature conditions
- Detailed analysis of the snapshot using an adjoint image analysis software
- Deriving the real droplet angles and converting it to high pressure and high-temperature interfacial tension parameter.

The temperature could be regulated on liquid and gas phases using the temperature regulator of the instrument but the main challenging issue was pressure parameter [1, 7, 8]

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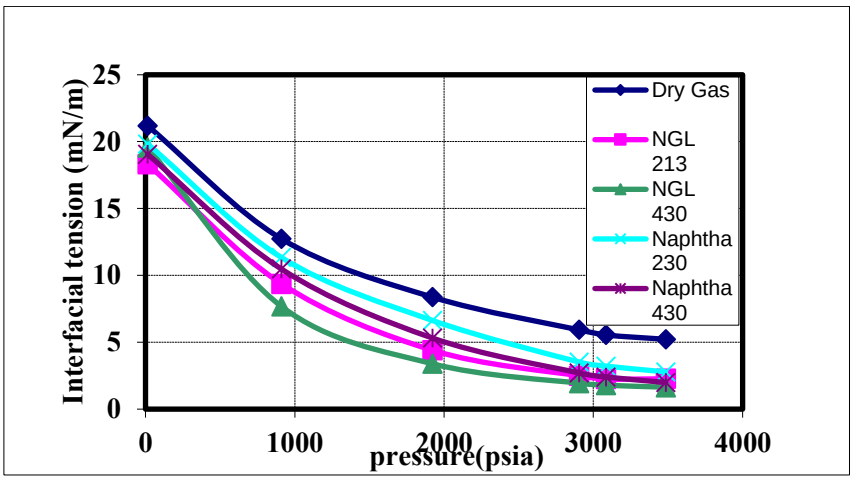

Figure 4. Pressure decline effect on IFT variation for five injecting scenarios

Table 3. IFT between reservoir oil and five gas samples in each depletion pressure steps @200° F

Pressure (psia)	Gas Dry	NGL 213	NGL 430	Naphtha 213	Naphtha 430
Ambient	21.18	18.32	19.56	19.82	19.05
911	12.73	9.37	7.68	11.34	10.47
1923	8.37	4.40	2.25	6.63	5.31
2905	5.93	2.49	1.94	3.62	2.70
3085	5.54	2.25	1.79	3.22	2.40
3485	5.22	2.27	1.64	2.79	1.99

5. RESULTS AND DISCUSSION

Interfacial tension measurement between the injecting phase and reservoir oil is really a crucial parameter and vanishing this parameter really plays a key role in minimizing capillary forces and residual oil saturation in IOR scenarios i.e. miscible gas injection projects. In a gas injection scenario for one of Iranian giant oil fields, injecting gas was decided to be enriched by adding NGL and Naphtha with particular ratios. This study was a survey in order to clarify the effect of associated gas enrichment on damping interfacial tension parameter.

Table 3 & Figure 4 depict that recombining injecting gas samples with NGL led to reducing interfacial tension parameter more effectively rather than recombined samples with Naphtha. Moreover, NGL 430 has the least interfacial tension with reservoir oil in each pressure step and to some extent it can be the best injecting candidate to the oil reservoir. But initial gas sample has completely converse condition. Referring to Table 3 & Figure 4, one can claim that initial injecting sample has the highest interfacial tension in each pressure step and this could be the worst candidate for gas injection scenario.

6. CONCLUSION

The main result of this research aims to pinpoint the best injecting gas candidate based on minimum interfacial tension measurement with a reservoir oil sample. Needless to say that initial injecting sample has the highest interfacial tension in each pressure step and this could be the worst candidate for gas injection scenario.

Meanwhile, recombining injecting gas sample with NGL lead to reduce interfacial tension

parameter more effectively rather than recombined samples with Naphtha. Moreover, NGL 430 has the least interfacial tension with reservoir oil in each pressure step and to some extent, it could be the best injecting gas candidate to the oil reservoir.

7. AVAILABILITY OF DATA AND MATERIAL

All the used and generated data in this study are already presented in this article.

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