Petroleum Res. J. Vol. 14 (2002); P. 59-66, 2 Figs.

Miscible Gas Displacement of Facha and Gir Reservoir Oils Using Farrud Reservoir Gas (Ghani Field)

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الإزاحة بمزج الغاز لمكمني الجير والفاشا باستخدام غاز الفارود المكمني

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تم تنفيذ برنامج معملي لدراسة جدوى الاسترداد الإضافي بالأزاحة الامتزاجية بغية رؤية إمكانية استخدام غاز (الفارود) كمذيب لزيادة المسترد النفطي لمكمني الفاشا والجير بحقل الغاني.

تضمّن برنامج الدراسة تحاليل الضغط والحجم والحرارة التقليدية واختبارات الانتفاخ للزيت، وكذلك اختبارات الإزاحة باستخدام الأنبوب الرفيع.

وتم استخدام هذه البيانات مع البيانات التحليلية الأخرى للغاز المذاب والزيت المتبقى في حسابات مركبات إنتفاخ الزيت والمسترد النفطي.

وبإضافة غاز الفارود إلى زيت مكمني الفاشا والجير تم إجراء إختبارات الانتفاخ، واحتوت ثماني خلطات تم تحضيرها بنسب 10، 20، 30، 40، 50، 60، 70، و80 جزئي مئوي من غاز الفارود. ومن خلال علاقات الضغط والحجم للخلطات المتحصل عليها بين الغاز المحقون والزيت المكمني عند درجة حرارة المكمن، تم حساب ضغط التشبع للخلطة وقابلية ذوبان الغاز المحقون ومعامل انتفاخ الزيت، وكثافة الخلطات حيث تم استنباط تفاصيل وزن المادة بمركبات اختبارات الانتفاخ بناء على تحاليل مركبات (C_1 إلى $C_{30}+$) الزيت المكمني مع الغاز المحقون بتوسع.

من أجل تحديد الضغط الأدنى للامتزاجية لغاز الفارود تم تنفيذ ست اختبارات ضغط باستخدام الأنبوب الرفيع لزيت الفاشا المكمني التي يتراوح ضغطها من 1500 إلى 4000 رطل على البوصة المربعة وتم كذلك تنفيذ سبع اختبارات ضغط باستخدام الأنبوب الرفيع لزيت الجير المكمني يتراوح ضغطها من 1000 إلى 4000 رطل على البوصة المربعة. ووجد أن الضغط الأدنى للامتزاجية لزيت الفاشا المكمني 2445 رطل على البوصة المربعة، أما بالنسبة لزيت الجير المكمني فكان 2495 رطل على البوصة المربعة.

إن دراسات الإمتزاجية لكلا المكمنين أظهرت أن الضغط الأدنى للإمتزاجية أعلى بكثير وفوق ضغط المكمنين (1347 رطل على البوصة المربعة للفاشا و1310 رطل على البوصة المربعة للجير). وإن نوع الإمتزاجية التي تم الحصول عليها تتوافق مع نتائج اختبارات الإنتفاخ وتظهر الدفع بتكثيف الغاز.

Abstract: *An enhanced oil recovery laboratory program of miscible displacement has been carried out in order to determine the feasibility of using Farrud hydrocarbon gas as a solvent to increase oil recovery from Facha and Gir reservoirs of Ghani field.*

The study program included conventional PVT analysis, oil-swelling tests, and slim tube displacement tests. These data with dissolved gas and stock-tank oil analytical data were used in compositional, oil swelling and oil recovery calculations.

Swelling tests were performed by adding Farrud hydrocarbon gas to Facha and Gir reservoir oils. Eight mixtures were prepared

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containing 10, 20, 30, 40, 50, 60, 70, and 80-mole percentage of Farrud gas. From P-V relations of injection gas-oil mixtures at reservoir temperature; mixture saturation pressure, injection gas solubility, oil-swelling factor and mixture densities were calculated.

A detailed material balance of swelling test fluid hydrocarbon components were investigated, based on extended (C_1 to C_{30+}) compositional analysis of the reservoir oil and injected gas.

In order to determine Farrud gas minimum miscibility pressure (MMP), slim tube displacement tests at six gas injection pressures ranging from 1500 to 4000 psig were performed on Facha reservoir oil and at seven pressures ranging from 1000 to 4000 psig on Gir reservoir oil.

The MMP for Facha reservoir oil was found 2445 psig and for Gir reservoir oil was found 2495 psig. Miscibility studies revealed that minimum miscibility pressures are extremely high and beyond the reservoir pressure (1347 psig for Facha and 1310 psig for Gir). The type of miscibility development is in agreement with the results of the swelling test indicating a condensing gas drive.

INTRODUCTION

Most of the oil fields of Libya have been producing for the last 25 years with high water cuts and gas oil ratios. Employment of enhanced oil recovery techniques (EOR) to maintain production from these fields at reasonable rates is a crucial matter. The National Oil Corporation (NOC) has adopted miscible gas flooding scheme for increasing oil recovery as the main EOR techniques supported by the availability of huge amounts of natural resources of carbon dioxide (CO_2) and hydrocarbon gases in Libya.

Ghani Field is one of the major oil fields in Libya, and is of a multi-reservoir type. Facha, Gir and Farrud reservoirs are among the main reservoirs in this field.

The availability of Farrud gas in the vicinity of Facha and Gir reservoirs encouraged the operating company (Veba Oil Operations Company) to think seriously of using Farrud gas as a miscible injection gas to increase the recovery from both Facha and Gir reservoirs.

Bottom hole samples from both reservoirs (Facha and Gir) and Farrud surface gas samples were used in this study. The whole experimental program of this study was carried out at the Petroleum Research Centre, Tripoli (PRC).

METHODOLOGY

PVT Analysis

In order to determine original oil PVT properties, a sufficient amount of oil was transferred from a sample cylinder to a high pressure, windowed PVT cell maintained at the reservoir temperature.

Constant composition expansion (CCE) test is made to obtain pressure volume (PV), relationship at reservoir temperature, from which the saturation pressure at reservoir temperature was determined. Having completed the (CCE) test, the separator flash test was conducted. Subsequently, basic PVT properties in terms of formation volume factor (FVF) and produced gas oil ratio were calculated for each of the two oils.

Differential liberation test was performed using an additional amount of reservoir oil at reservoir temperature. From the measured volumetric data and released gas compositional analyses, differential oil formation volume factors (B_{od}), solution gas factor (R_{sd}), gas deviation factor (Z) and gravities were evaluated.

High pressure rolling ball viscometer was evacuated and filled with original reservoir oil. A differential gas liberation process was performed to obtain oil viscosity versus pressure relationship at reservoir temperature. Viscosity values at respective pressure points were calculated from the viscometer calibration data for both oils.

COMPOSITIONAL ANALYSIS

The extended compositional analysis of reservoir oil was obtained by combining the results of separator analysis of solution gas, liberated during single-stage flash separator test. An additional separator test was performed with the separator temperature set at the reservoir temperature. The stock-tank oil was collected after the separator test and associated formation volume factor, gas-oil ratio and stock-tank density data using appropriate mass balance calculations.

ChromPack gas chromatograph (G/C) was used to obtain the analysis of flash gas samples from which gas molecular weight and density were calculated. Known weight of stock-tank oil was fractionated using Hempel-type distillation column. Four to five fractions in the boiling point ranging from 30 °C to 490 °C were collected. The fractions were weighted and subjected to molecular weight determination by benzene freezing point depression method, and gas chromatographic analysis using fused silica capillary (G/C) technique to obtain weight percent composition of hydrocarbon constituents.

The distillation residue (C_{30+} fraction) was also weighted and then its molecular weight was determined using benzene freezing point depression method. The C_5-C_9 fraction and C_{30} fraction gravimetric and compositional data were combined to calculate respective stock-tank oil analysis. Calculated stock-tank oil composition was then combined using flash gas-oil ratio with the composition of single-stage flash gas to obtain original reservoir oil molecular composition.

SLIM TUBE MISCIBILITY TESTS

Slim tube, filled with toluene, was pressurized to above saturation level. Toluene was then displaced by live oil after two pore volumes were injected. The system was then heated until particular test, *i.e.* reservoir temperature had stabilized. When thermal equilibrium had been established as verified by no fluid production from back-pressure regulator, Farrud hydrocarbon injection at controlled flow rate was started. During the slim tube oil displacement runs, the following experimental data were measured and recorded at time intervals of approximately 60 minutes:

- Time
- Upstream pressure (Farrud HC injection pressure);
- Downstream pressure (back-pressure regulator);
- Amount of mercury injected (pump reading);
- Amount of produced oil (glass receivers);
- Amount of produced gas (gasometer);
- Oven and room temperature, atmospheric pressure.

A run was completed after 1.2 to 1.3 pore volumes (V_{sys}) of Farrud gas (as measured on the volumetric pump) was injected. The upstream valve of the slim tube was then closed and the system pressure was slowly released to the atmospheric pressure. The additional oil produced during this process (blow down oil) was collected and added to the cumulative oil previously produced. The apparatus was then allowed to cool down to room temperature, slim tube assembly removed from the oven and weighed to obtain gravimetric balance data for oil recovery calculations.

Preparation for next run involved injection of toluene into the system to remove all of the remaining oil. Appearance of clean toluene at the down stream end of the system indicated the system being ready for the next run.

Evaluation of data during a slim tube displacement run included the following main steps:

- Cumulative volume of gas injected as measured on the mercury positive displacement pump at room temperature and constant injection pressure were converted to volumes at test temperature by applying pump calibration factors and mercury expansion coefficients according to the following formula:

$$V_{inj} = V_m [1 + B_{Hg} (t - t_r)] \quad (1)$$

Where

V_{inj} = volume of injected hydrocarbon fluid at reservoir temperature and injection run.

V_m = volume of mercury injected at room temperature and run pressure.

B_{Hg} = coefficient of thermal expansion of Hg at run pressure.

t = reservoir temperature.

t_r = room temperature.

The reservoir condition volumes were converted to pore volume basis:

Farrud HC injected in No. of PV = V_{inj} / PV. (2)

Pore volume used is equal to V_{sys} of slim tube assembly

- Cumulative produced oil recovery was calculated from measured stock-tank oil volumes as a percentage of original oil-in-place (OOIP) using stage separator test.

FVF data:

Oil recovery (%OOIP) = (V_{sto} FVF / PV) * 100 (3)

Where:

Vsto = Cumulative produced stock-tank oil volume (60 °F and 14.7 psia)

FVF = Oil formation volume factor at slim tube test run pressure and reservoir temperature relative to slim tube oil at 60 °F and 14.7 psia.

Total or final recovery after 1.2 PV of Farrud fluid injected was also determined from the gravimetric material balance since the weights of the slim tube containing residual oil after a displacement test were always recorded.

Total oil recovery obtained from the produced oil volumetric data (Eq.3) was higher than the recovery calculated from gravimetric determination of residual oil by using appropriate oil density and FVF data. The difference was more pronounced at higher displacement pressure, which indicates the development of miscibility might be through a condensation process which becomes predominant at lower temperature.

It is characterized by an extraction of medium molecular weight range (C_5-C_{12}) hydrocarbons from injection gas into a dense liquid phase. As a result of this process, a miscible transition zone develops between injected gas and reservoir oil, which efficiently displaces oil.

The other consequence of the process of miscibility development through a condensing drive is an increase of measured produced oil volume (leading to higher than 100%) recovery since part of it was extracted from the injected gas phase. This can be seen from the composition of the produced gas, which contains more light components than Farrud hydrocarbon gas injected. This presumably accounts for the difference in recovery calculated by the volumetric and gravimetric methods used.

RESULTS AND DISCUSSIONS

I - Facha Reservoir

PVT data of Facha reservoir fluid at reservoir temperature of 144 °F is illustrated in Table 1.

During the swelling tests, it was observed that Facha reservoir oil generally tends to emulsify with mercury. Already, after charging the RUSKA 3-window PVT-cell with Facha reservoir oil at 5680 psig (400 kg/cm^2) about 5 mm oil-mercury emulsion formed at the oil-mercury interlayer. During the first five subsequent injections of Farrud gas, the emulsifying tendency increased continuously and finally a column of five cm of emulsion was formed in which the mercury droplets were smaller than 0.1 mm in diameter. During the 5th gas injection (50:50 moles), additionally some asphalt precipitation was observed on the inner surface of the high pressure window PVT-cell. After injection of the 6th gas volume (40:60 mole ratios), severe asphalt precipitation coated the inner wall of the cell window. Simultaneously, the emulsifying tendency increased.

During the PVT cell rocking after 7th gas injection (30:70 mole ratio), more asphalt precipitated and its colour changed to black-grey.

Emulsifying tendency reached maximum and produced 10 cm high emulgated oil-mercury interlayer. During the 8th gas injection at 4970 psig, no difficulties were observed to dissolve this gas volume in the swelled oil. The volume of emulsion remained about the same; however, the asphaltene precipitation was relocated nearly completely from the inner PVT-cell window. It settled as a fine black powder on top of and in the uppermost part of the oil-mercury emulsion. During the constant composition expansion and equilibrium conditions at 1500 psig (105 kg/cm^2), a small shrinkage of the emulsion layer was observed; the amount of precipitated asphalt remained unchanged.

During the course of the subsequent swelling test stages, the oil-mercury emulsion volume decreased only slightly, but did not vanish until the end of the test. After the end of the test, residual oil was bled out from the cell together with finely dispersed precipitated asphalt as well as oil-mercury emulsion. During the cleaning procedure of the 3-window RUSKA PVT-cell, toluene was used to remove residuals from cell window and walls.

The asphalt precipitate remained insoluble also in some aliphatic and aromatic solvents as well as in the mixtures of aromatic and more polar solvents.

The efficiency of Farrud gas to mobilize and displace Facha oil was investigated by measurements of oil produced from slim tube at reservoir temperature of 144 °F and at gas constant injection pressure of 1500, 1850, 2200, 3000 and 4000 psig.

Table 1. PVT data of Facha reservoir fluid at reservoir temperature of 144 °F.

Saturation Pressure (Pb)	235	psia
Flash Formation Volume Factor (B_{of})*	1.1781	bbl/stb
Flash Gas-Oil Ratio (R_f)	207	scf/stb
Differential Formation Volume Factor (B_{od})*	1.1648	bbl/stb
Differential Gas-Oil Ratio (R_d)	161	scf/stb
Thermal Expansion Coefficient at 235 psia	6.63 E -4	cc/cc/°f
Compressibility Coefficient :		
From 1500 to 750 psig	6.50 E -6	cc/cc/psig
From 750 to 235 psig	2.10 E -5	cc/cc/psig
* FVF = oil volume at Pb 144 °F/ stock tank oil at 60 °F		

The oil recovery data are based on volumetric material balance calculations and were checked by gravimetric determination of initial and residual oil in the slim tube.

This resulted in oil recovery in excess of 100% at gas injection higher than MMP when employing flash FVF values to convert produced oil volumes to reservoir oil volumes.

The phenomenon, attributed to the gas condensing mechanism of miscibility development, has no influence on the proper MMP determination. Slim tube runs NO.1 and 2 at 1500 and 1850 psig respectively, show non-miscible displacement features with elongated oil recovery curve and low (71.72 and 82.22%) total oil recovery at 1.2 PV of Farrud gas injected.

The miscible nature of the displacement process is further evidenced by cumulative gas versus produced oil ratio. As shown in Table 2, early gas breakthrough in both cases is also indicative that no appreciable miscible zone formation took place during the runs.

Table 2. Slim tube run pressures with corresponding fraction of pore volume Farrud gas injected at breakthrough (Facha reservoir).

Run pressure, psig	PV of Farrud gas injected at breakthrough
1500	0.77
1800	0.85
2200	0.91
3000	1.00
3500	1.00

Final oil recovery of 92.54% obtained during the slim tube test No. 3 at 2200 psig and corresponding injected gas breakthrough at 0.91 PV are both suggesting near miscible oil displacement conditions. This implies an advanced degree of miscible zone development and corresponding efficiency of oil displacement approaches of first contact miscible process.

The three higher-pressure slim tube runs No. 4, 5 and 6 at 3000, 3500 and 4000 psig are typical for a miscible process characterized with maximum displacement efficiency due to fully developed miscible zone. The measured overall oil recoveries during these runs are in excess of 100% original oil in place.

The explanation of this is related to the mechanism of achieving the dynamic miscibility. The compositional analysis of Farrud injection gas shows increased C_2-C_5 content. When such enriched hydrocarbon gas is injected into reservoir, dynamic miscibility results from the transfer of C_2-C_5 hydrocarbons until a miscible zone develops.

Experimental evidence for enriched gases (or condensing) drive process being operative during slim tube oil displacements in this study is considered to be the following:

- At pressures above MMP, oil recoveries determined using volumetric material balance are larger than 100% of initial oil.
- Additional gravimetric material balance data are consistent with the above volumetric data showing net increase of hydrocarbons material at miscible conditions
- Fluid produced from the slim tube at and after 1 PV of gas injected had light brownish appearance and vaporized quickly at room temperature.

Cumulative Facha oil recovery data at 1.2 PV of Farrud gas injected, (Table 3) were plotted versus corresponding injection pressures, (Fig.1). From this curve, the minimum miscibility pressure (MMP) of Facha oil-Farrud gas system was found to be 2445 psig at reservoir temperature of 144 °F.

Table 3. Slim tube oil recovery at 144°F of Facha reservoir using Farrud hydrocarbon gas.

Gas injection pressure (psig)	Oil recovery at 1.2 PV gas injected (%)
1500	71.72
1850	82.22
2200	92.54
3000	111.66
3500	112.70
4000	112.92

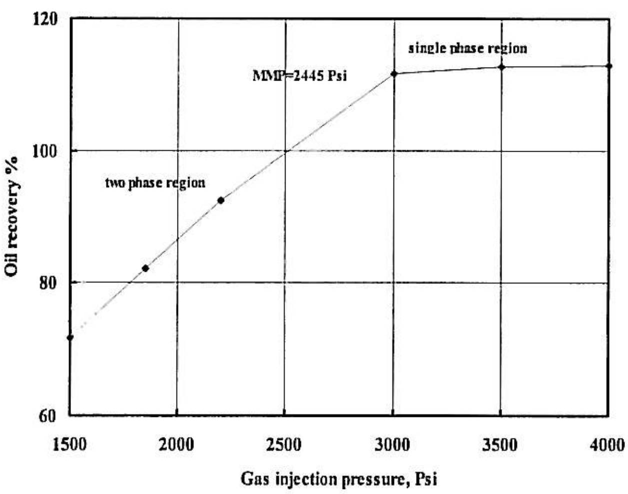

Fig. 1. Prevent oil recovery Vs gas injection pressure (facha reservoir).

II- Gir Reservoir

Conventional PVT experimental study was carried out on Gir reservoir oil at reservoir temperature of 140 °F. Results of such study are illustrated in (Table 4).

The results of the swelling tests revealed the same phenomenon observed with Facha swelling test. That is, Gir reservoir oil tends to emulsify with mercury. After charging the CORELAB long window high pressure PVT-cell, with Gir oil already at 5680 psig, 4 mm of oil-mercury emulsion spontaneously occurred on top of the mercury surface.

During the subsequent Farrud gas injection from injections No. 1 to 6, the volume of emulsion increased continuously up to 40 mm. In this gray emulsion, the diameter of the mercury droplets was far below 0.1 mm. During the 6^{th} gas injection at 4260 psig asphalt precipitation started, covering the inner wall of the cell window with glittering crystal-like particles. By increasing the pressure of the system, the asphalt particles disappeared. When the pressure was decreased, the growth of the asphalt particles reappeared and increased until bubble point pressure was reached.

The Farrud gas injection at the 7^{th} stage (60:40 mole ratio) was performed at 3550 psig. Attempts to dissolve the gas in the swelled oil volume by rocking the cell, increasing or decreasing the pressure, failed. After each rocking of the cell, a gas- like layer (4 cm) remained separately on top of the cell window. At pressures between 5400-5700 psig, this gas or fluid changed its color to a semitransparent fluid exhibiting an intense green fluorescence. Below this uppermost layer, a clearly separated reddish-brown fluid 4 cm high occurred. In this region, some brown asphalt patches occupied the cell window. Below this second layer, again semitransparent and green fluorescent layer (4-5 cm) could be observed, it was followed by a fourth layer colored red-brown but transparent. Finally, to the lowest end of the cell, a layer was found that exhibited a color like crude oil.

Repeated rocking of the PVT cell (including upside down turning) always produced the same sequence of separated, stable and non-miscible layers. Increasing or decreasing the pressure in the cell changed the relative size of the layers or caused disappearance of some. However, the build-up of the immiscible phases could be repeated arbitrarily without change with changing pressure.

Over the following night, a breakdown of electricity occurred in the laboratory causing cooling of the whole equipment down to 95 °F (35 °C). First pressure check at 5660 psig (400 Kg/cm^2) showed that at this pressure a single-phase liquid could be obtained. It was expected that during heating of the test mixture to the reservoir temperature it finally would arrive at the same five immiscible layers, and a gas cap.

However, when reservoir temperature had been attained, a significant change in the system behavior was observed.

The swelled oil was now a single phase liquid. Consequently, the test was continued by conventional PV-relation procedure. Attempts to restore the state of immiscibility by increasing the pressure after arriving below the bubble point pressure failed.

During the measurements of PV-relation, a very different behavior was observed.

At start of the measurement, precipitated asphalt particles in patches and glittering crystals coated the inner wall of the cell window. Through the stepwise pressure reduction, more asphalt precipitated like a yellow-brownish paint on the cell window. At lower pressure, dissolution of the asphalt patches and crystals followed this behavior to globules and fine droplets, which subsequently transformed to a black low viscous immiscible liquid running down the cell window in fine streams.

Commencing the 8^{th} Farrud gas injection (20:80 mole ratio) a similar behavior of the swelled oil was expected as observed in the previous stage, or a complete change into a super-critical fluid. The gas was injected at 3550 psig (250 Kg/cm^2), which is close to the expected bubble point pressure. However, the gas dissolved quickly

Table 4. PVT data of reservoir Gir reservoir fluid at reservoir temperature of 140 °F.

Saturation Pressure (pb)	555	psia
Flash Formation Volume Factor (B_{of})*	1.3487	bbl/stb
Flash Gas-Oil Ratio (R_f)	341	scf/stb
Differential formation Volume Factor (B_{od})*	1.2232	bbl/stb
Differential Gas-Oil ratio (R_d)	306	scf/stb
Thermal Expansion Coefficient at 555 Psia	6.687E-04	cc/cc/°f
Compressibility Coefficient :		
From 1500 to 1000 psig 6.45E-06	cc/cc/psig	
From 1000 to 555 psig 2.13E-06	cc/cc/psig	
*FVF= oil volume at Pb 140 °F/stock tank oil at 60 °F		

in the swelled oil of the seventh stage. The conventional PV-relation was performed but revealed that it became very difficult to accurately define bubble point pressure.

The observations of the behavior of the swelled oil showed considerable changes during pressure decrease. The swelled oil mixture showed differentiation similar to the 7^{th} stage but no gaseous phase occurred in the pressure range between 6000 to 4200 psig. Some different colours and layers partly immiscible were observed, but not clearly distinguishable. The asphaltic matter showed very different behaviour during the stepwise pressure decrease. First asphalt-like matter condensed as a brown paint- on the inner surface of the cell window, changing during further pressure reduction into fine streams of black liquid and droplets running down the cell window. Below the bubble point pressure, the liquid asphalt became a solid mass (3100-2600 psig). Finally, the cell window was completely covered with masses of solid asphalt.

By pressure increase, the behavior could be reversed. Below 2600 psig, after a gas volume of several cubic centimeters had developed, the asphalt diminished from the cell window. It was not dissolved but formed a finely divided black powder which accumulated as a 10 mm thick precipitate on the top of the oil-mercury emulsion. This asphalt precipitation did not change during the subsequent constant composition expansion and release of gas at equilibrium conditions of 1500 psig, as well as during the two injection and releases of 20 mole percent of Farrud gas.

After the complete flash-down of all gas from the swelled oil, more asphalt matter had precipitated, coating not only the cell window but also the inner surface of the metal cell body. At the stage of discharging of the CORELAB PVT-CELL and final cleaning procedure, it was found that the black asphalt was insoluble in all non-polar solvents and mixtures of the solvents.

A total of seven slim tube tests at 1000, 1500, 1700, 2000, 2500, 3000 and 4000 psig and reservoir temperature of 140 °F were conducted using Gir oil and Farrud injection gas in order to evaluate the oil displacement process characteristics and determine minimum miscibility pressure (MMP) for the fluid system investigated .

The main features of the Gir oil slim tube tests in terms of mechanism of dynamic miscibility development and associated experimental oil recovery checks are closely similar to those of Facha oil and are briefly as follows:

- Slim tube tests No.1, 2 and 3 at 1000,1500 and 1700 psig exhibit non miscible gas drive characteristics as documented by measured respective oil recoveries of 58.6, 69.4 and 62.1%. The injected gas breakthrough data, in (Table 5), are consistent with the trend of slow development of the miscibility zone with increasing injection pressure.

Table 5. Slim tube run pressure with corresponding fraction of pore volume Farrud gas injection at breakthrough (Gir reservoir)

Run pressure, psig	P.V. of Farrud gas injected at breakthrough
1000	0.40
1500	0.58
1700	0.68
2000	0.77
2500	0.95
3000	1.0
4000	1.0

- Slim tube run No. 4 at 2000 psig indicates a moderate degree of near-miscibility since both oil recovery and gas breakthrough values have increased in comparison with lower pressure runs.
- The three slim tube runs no. 5 and 6 were miscible processes characterized with 100% of higher oil recoveries and complementary injected gas breakthrough values.

The amount and feature of Gir oil produced during high pressure slim tube displacements furnished evidence for the same conclusions about the type of mechanism responsible for development of multi-contact miscibility as in the case of Facha oil. Condensing gas drive is operative also in the case of Gir oil miscible displacement, which is documented by both gravimetric material balance data and physical appearance of the oil produced at high injection gas pressures.

On the basis of data provided in Table 6, the cumulative Gir oil recovery was plotted versus injection pressure in figure (2) and the value of 2495 psig was

Table 6. Slim tube oil recovery at 140 °F of Gir reservoir using Farrud hydrocarbon gas.

Gas injectionpressure, psig	Oil recovery at 1.2 PV gas injected, %
1000	43.62
1500	65.45
1700	75.13
2000	88.75
2500	108.07
3000	109.50
4000	112.49

determined as MMP for Gir oil-Farrud injection gas system at reservoir temperature of 140 °F.

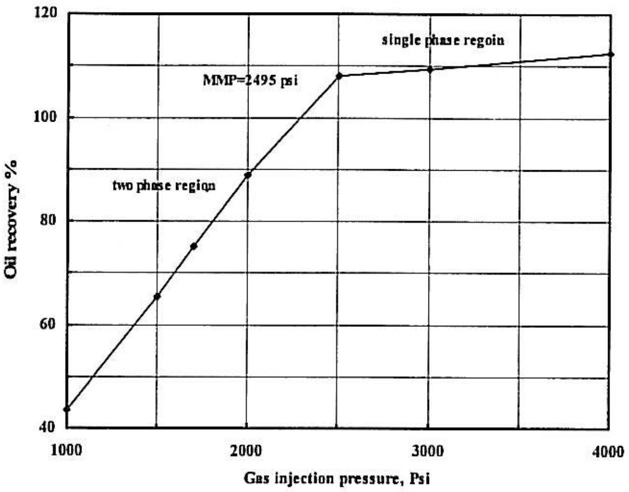

Fig. 2. Prevent oil recovery Vs gas injection pressure (Gir reservoir).

CONCLUSIONS

1. The results of this study revealed that Facha and Gir reservoir oils are both under-saturated oils compared to their reservoir pressures. The released gases from flash and differential vaporization studies exhibit gas compositions highly enriched in heavier hydrocarbons from ethane to pentanes and low methane content.
2. Swelling tests showed that injections of Farrud gas into Facha and Gir reservoir oil already reach reservoir pressure at injection ratios 1:1 to 1:1.5 moles (oil : gas). At the highest injection ratios of 1:4 moles (oil : gas) especially swelled Gir oil exhibit multi-phase behavior at all pressures above the bubble point pressure. The swelling test studies exhibit general behavior of highly gas-enriched reservoir oils.
3. Mass balance checks were performed using densities of all oils and mixtures. The calculated densities from start to end of swelling tests are close to the measured densities of the residual oil after the swelling test procedure. Therefore, the compositional data reported are consistent and show good reliability.
4. Minimum miscibility pressure (MMP) for Facha and Gir reservoir oils using Farrud injection gas have been determined to be 2445 and 2459 psig respectively. These figures are considered extremely high and far beyond the reservoir pressures. The type of miscibility development is in agreement with the results of the swelling test indicating a 'condensing gas drive'.
5. The reservoir oil migration and accumulation history and stratigraphic as well as tectonic events have not been discussed. However, composition of original Farrud gas and gas composition of gas released from swelling tests exhibit similarities pointing to an equilibrium separation process occurring at a certain geological or time of oil accumulation.
6. In general, when it comes to miscibility studies, achieving single-phase state does not always mean that oil-gas miscibility is reached, as gas condensation could be the case. Facha and Gir reservoir oils with Farrud gas injection is a good example of such a case.
7. Also, reaching the minimum miscibility pressure does not always increase the mobility of reservoir oil and consequently increase oil recovery. It could create problems of solid precipitation of asphaltic type that result in damaging formation permeability.

AKNOWLEDGEMENT

We wish to thank Veba Oil Operations Company for giving the chance to the Petroleum Research Centre to explore its capability through the course of study. Special thanks are due to all PRC staff who assisted in conducting the experimental work.

REFERENCES

[1] Yelling, W.F., and Metcalfe, R.S, 1980 (January). Determination and prediction of CO_2 minimum miscibility pressure. *JPT 160-168.*

[2] Glaso, O, 1985 (December). Generalized minimum miscibility pressure correlation. Soc.Pet.Eng. *J 927-934*

[3] DesBrisay, C.L., Gray, J.W., and Spivak, A, 1975 (August). Miscible flood performance of the Intisar (D) field, Libyan Arab Republic. *J. Pet. Tech. 935-943.*

[4] Firoozabadi and Aziz, 1986 (November). Analysis and correlation of nitrogen and lean gas miscibility pressure. *SPE, Reservoir Engineering 575-582.*

[5] Simon, R. and Graue, D.J., 1965 (January). Generalized correlation for predicting solubility, swelling, and viscosity behavior of CO_2 crude oil system. *JPT,102-106.*

[6] Coats, K. H.1980 (October). An equation of state compositional model. *Soc. Pet. Eng .J.363-376.*

[7] Kremesec, V.J., Jr. And Sebastian, H.M.1988 (May). CO_2 Displacement of reservoir oils from Berea cores: laboratory and simulation results, *SPERE 496-504.*