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Analytical Methodology to Reconstruct Fluid Composition for Retrograde Condensate Field with an Initial Oil Rim in the aim of Full Fluid Characterization

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Abstract

In the majority of retrograde condensate fields with an initial oil rim, fluid samples are taken below saturation pressure, therefore they are considered not representative to reservoir fluid. This article focuses on a mathematical methodology applied to reconstruct a new fluid which is more accurate and representative to reservoir fluid of retrograde condensate using the results of existing CVD experiment data for full fluid characterization. Oil rim fluid characterization is also detailed.

Keywords: CVD; Dropout; Fluid reconstruction; Fluid characterization; Quality Check; PVTp; Retrograde condensate; Oil rim.

1. Introduction

This study was initiated in Sep 2014 as a part of a reserve study to investigate liquid recovery optimization opportunities in the field of Study.

Field of study originally contained a huge gas cap in equilibrium with a thin oil rim. Consequently, the initial pressure of field at datum of GOC equals to the saturation pressure of both gas cap and oil rim. Production of field started on Mar-2010. Quantities of condensate have been dropping out of the original reservoir fluid since the reservoir pressure fell below the dew point in the beginning of field production as supported by CVD experiment results on gas cap samples.

CVD experiments are performed on gas condensates and volatile oils to evaluate reservoir depletion performance and compositional variation [1]. Measured data can be used in a variety of reservoir engineering calculations, however, in this article it is used for fluid reconstruction and quality check as detailed in the following sections.

Field gas cap and oil rim fluids were characterized as fully compositional using PVTP package from IPM-7.5. This study's fluid compositional modeling shows that the original reservoir fluid was likely to be richer in condensate.

2. Fluid sampling & characterization

Several fluid samples were taken from the field of study, where two samples, one for gas cap and another for oil rim, were elected for full fluid characterization. All fluid modeling was performed using PVTP package from IPM-7.5.

Though more other available complicated, empirical equations of state, several investigators have used the PR EOS to simulate PVT studies of light gas condensates and crude oils [2-4]. The (PR) EOS model was used in all cases of this study, and it well reproduced the AS-1 recombined fluid sample and AS-5 bottom-hole sample experimental PVT data.

2.1. Fluid sampling

Several Oil rim and Gas Cap samples were taken since 1980 up to 2010.

Small differences in composition for most samples of the same fluid type but with differences in Ps. The most accurate available samples of oil rim and gas cap were selected according to less deformation, matching to field data, besides to the available reported lab experiments e.g. there was only one gas cap sample, AS-1 RFR01, with detailed CVD experiment.

Elected samples were collected from AS-5, AS-1 respectively at a FBHP of 2785, 1800 psia respectively prior to commercial production. Table. 1 shows sampling data and some reported PVT properties of elected samples, where a saturation pressure of 2965 psia, initial pressure at GOC, from the initial equilibrium data between gas cap and oil rim, was defined. By comparing the flowing pressures where the two samples were obtained with the saturation pressure, it showed obviously that the samples were obtained at FBHP lower than saturation pressure by 210 psi for oil rim and 1133 psi for gas cap, after depth correction.

Well Name	DST No	Sample type	Prim, seperator GLR*	FBHP@ Perf top	Psat	T. used for Psat eval.	Psat. Corrected	T. used for Psat eval. Corrected	H2S content	Co2 content	Well stream fluid C7+ fraction	Flashed Liquid gravity	Maximum condensate dropout
			scf/bbl	psia	psia	˚F	psia	˚F	ppm	mol%	mol%	API	% of fluid Volume at Pd
AS-1	DST-1	Recomb	47570**	1800	2310	170	2965	183	0	2.54	1.1	62.2	0.5
AS-5	DST1, 1A	B.H.S	587***	2785	2940	181	2965	183	0	1.76	37.7	38.8	N/A

* corrected to lab use.

** @480 psia, 80 deg ˚F

*** @415 psia, 90 ˚F

Table. 1. Fluid sampling conditions and main results for the two characterized samples.

As all DST's gas samples were taken at pressure below the saturation pressure, these samples were not trusted as representative ones to the reservoir fluid. For AS-5 oil sample, less deformation was observed, as FBHP was close to saturation pressure, ~ 3% difference.

2.2. Gas Cap fluid characterization

As the reported PVT properties of fluid in the gas cap, AS-1 sample in table. 1, showed presence of dew point, condensate drop out and temperature of reservoir lies between critical temperature and cricondentherm as can be seen later, figure. 6, fluid in gas cap can be identified as lean retrograde-condensate.

Reservoir performance during gas condensate well production can be divided to four stages [5-7]:

First stage: Single-phase gas reservoir.

For BHP > pd, only single-phase gas exist in reservoir.

Stage 2: Mobile gas, immobile liquid

As BHP declines below pd, condensate drops out around wellbore developing a condensate bank below the critical saturation, hence liquid is immobile.

Stage 3: Mobile gas and liquid

As production continues, condensate accumulates until the condensate saturation exceeds the critical condensate saturation in the zone near the well, and becomes mobile. As the liquid saturation profile continues to increase in magnitude and radial distance, eventually a steady state is reached in which liquid dropout is equal to the liquid production.

Stage 4: Both reservoir pressure and BHP are below the dew point.

The liquid condensation will occur throughout the whole reservoir.

Sampling at surface for AS-1 sample in flow conditions through DST-1, with FBHP less than Pd by 1133 psi as mentioned above, had caused condensate dropout in the area around wellbore. As DST is short normally, condensate saturation did not exceed the critical saturation, hence the dropped condensate was immobile, *stage two in the above classification*. Consequently, flowing gas phase became leaner, higher GLR, resulting in an unrepresentative recombined sample with less heavy fractions. This can be simulated using CVD experiment.

Constant Volume Depletion is an isothermal flash process where the volume of the system is kept equal to the volume at Dew Point. During the CVD experiment, pressure is decreased at previously designated intervals by releasing small amounts of gas from a pressurized gas sample while keeping the volume of gas in the cell constant and equal to the volume at dew point figure 1.

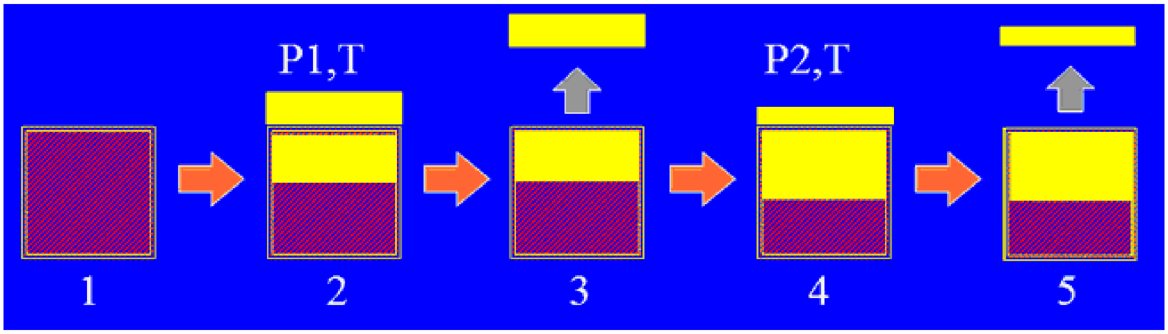

Figure. 1 A schematic illustration of the constant-volume depletion test

The removed gas emulates the gas production of a gas reservoir. In the other hand, as CVD experiment on gas-condensate systems is based on the assumption that the condensate is immobile, the behavior of remaining gas and condensate in the cell emulates the behavior of gas and condensate remained in reservoir, besides, it closely approximates phase behavior of gas flowing in the area near wellbore as long as condensate saturation is below the critical condensate saturation. Although, the CVD experiment does not take into account the net accumulation of the gas condensate due to relative permeability effect. Thus CVD experiments emulates the behavior of producing retrograde condensate reservoirs.

As a result, if the initial reservoir fluid could be reconstructed and modeled, AS-1 RFR01 sample composition could be obtained by applying CVD experiment on the new constructed fluid and analyzing the removed gas at a pressure step of 1800 psia and 196 F (flowing sampling conditions).

This can be done using the following procedure:

1- Reconstruct the initial fluid composition mathematically.

2- Insert the reconstructed composition into a simulator, such as PVTp, and insert the extracted molecular weight and gravity of the c+ if available:

a) Match the PVT model to Pd only.

b) Apply CVD test on the model and export the vapor at pressure step of FBHP @ FBHT to a new stream.

c) Compare the new stream composition with the original fluid sample for quality check. If they are close enough, difference less than 10%, then the reconstructed fluid model is accurate enough and can be used for full fluid characterization.

d) Full fluid characterization using the tuned EOS model.

2.2.1. Fluid Reconstruction using CVD experiment data

Fluid sample composition adjustment was performed to reconstruct the initial, heavier reservoir fluid. Composition modification was performed by extrapolating CVD experimental gas composition percentages beyond the measured dew point (figure 2), resulting in less light and more heavy fractions (figure 4), table 2. C_{12+} molecular weight was adjusted (figure 3).

The main idea of this methodology is that as the existed CVD experiment of AS-1 RFR01 starts with pressure step of 2300 psia, old Pd before correction, we can add the initial pressure, new accurate Pd of 2965 psia, as a pressure step to the CVD experiment. Then the composition of fluid at this pressure step can be estimated by extrapolating the mole fractions of components with pressure from the existed CVD pressure steps. This can be done using trends from Excel program of Microsoft Office Suit. Trends were taken as the best match to experiments data. There were many scenarios of extrapolating components fraction, entered to PVTp software for simulation, and the below mentioned scenario was submitted, as it gave the best results in quality check (figures 2, 3).

Final EOS has 16 components, out of which there are 7 pseudo-components, table. 2.

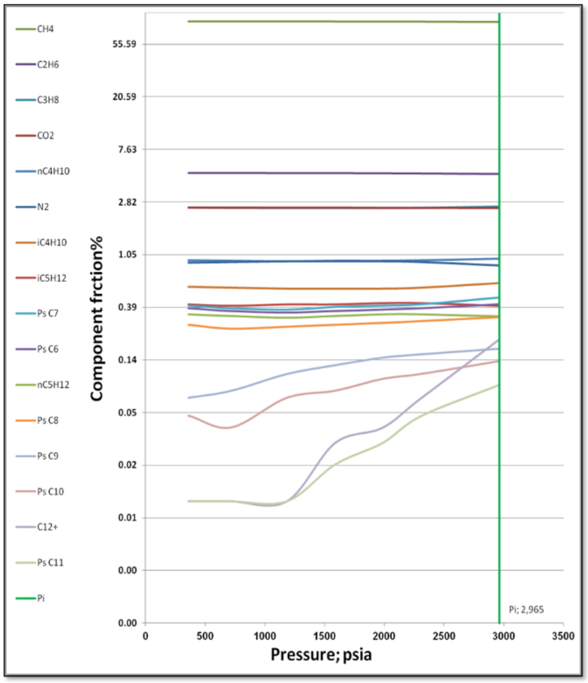

Figure. 2 Extending fluid components fraction from CVD to the initial pressure

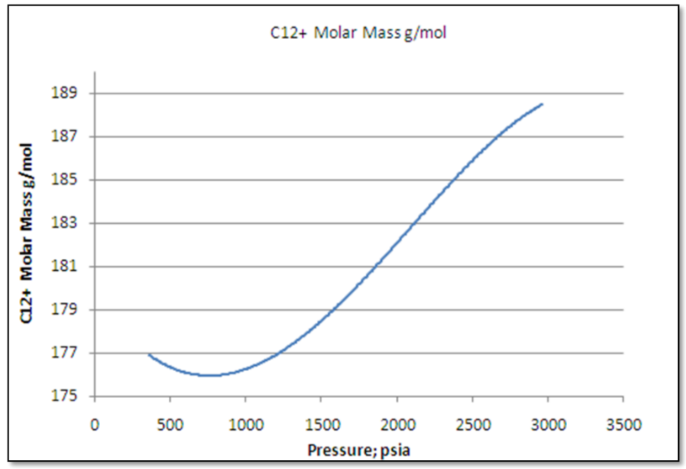

Figure. 3 Extending C12+ Molar Mass from CVD to the initial pressure

Table. 2. Composition of RFR01Reconstructed sample & the original DST sample

Component	Reservoir Fluid; lab	Reservoir Fluid, Reconstructed.	Component	Reservoir Fluid; lab	Reservoir Fluid, Reconstructed.
	%mol	%mol		%mol	%mol
N_2	0.91	0.86	NC5	0.34	0.33
CO_2	2.54	2.53	Pseud C6	0.38	0.41
H_2S	0.00	0.00	Pseud C7	0.41	0.47
C1	85.42	85.05	Pseud C8	0.30	0.32
C2	4.85	4.82	Pseud C9	0.16	0.18
C3	2.53	2.61	Pseud C10	0.11	0.14
IC4	0.56	0.62	Pseud C11	0.05	0.09
NC4	0.94	0.97	Pseud C12+	0.07	0.21
IC5	0.42	0.40			

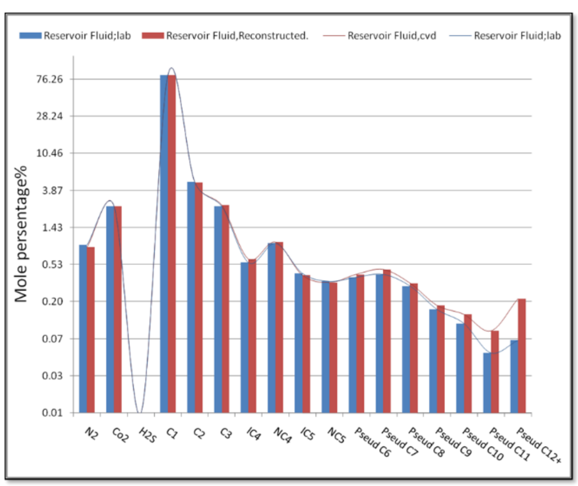

Figure. 4 Comparison between the original and the reconstructed reservoir fluid composition.

2.2.2. Modeling of the new constructed fluid

The new reconstructed fluid was entered into a simulator, PVTp, for tuning, quality check and full fluid characterization.

1. After components mole fractions were entered into PVTp, the model was regressed to Pd of 2965 psia. Both fluids (oil and gas condensate) were characterized using Peng Robinson equation of state (EOS) using minimum regression parameters in order to obtain robust fluid characterization for wider range of pressures and temperatures. Therefore, binary interaction parameters were not used in regression in order to avoid risk of distorting the phase envelope at other (generally lower) temperatures [8]. Instead, critical temperature of plus fraction used as a regression parameter for RFR01 reconstructed sample , as it requires changing less than any other individual EoS parameter [8].

2. CVD test was applied on the reconstructed fluid at FBHT, 196 F during DST, including FBHP as a pressure step, then vapor formed at this pressure step was exported to a new stream at PVTp, Table. 3.

Table. 3. Composition of the New Stream & the original DST sample.

Component	Reservoir Fluid; lab	Reservoir Fluid; CVD	Component	Reservoir Fluid; lab	Reservoir Fluid; CVD
	%mol.	%mol.		%mol.	%mol.
N_2	0.91	0.86	NC5	0.34	0.31
CO_2	2.54	2.53	Pseud C6	0.38	0.39
H_2S	0.00	0.00	Pseud C7	0.41	0.43
C1	85.42	85.44	Pseud C8	0.30	0.29
C2	4.85	4.82	Pseud C9	0.16	0.16
C3	2.53	2.60	Pseud C10	0.11	0.12
IC4	0.56	0.61	Pseud C11	0.05	0.07
NC4	0.94	0.95	Pseud C12+	0.07	0.04
IC5	0.42	0.38			

3. Quality check: Before any experimental PVT data are used for design or study purposes, it is necessary to ensure that there are no errors or major inconsistencies that would render any subsequent work useless.

Fluid gradient of 0.076 psi/ft was obtained from reconstructed sample, which is identical to that from RFT 0.076psi/ft. This gives a good indication for accuracy of fluid reconstruction. By comparing the original lab fluid with the new stream at PVTp, we got a good match, as can be seen in figure(5), which gave a good indication that the reconstructed fluid model is good emulating reservoir fluid, and the EOS model can be used for full fluid characterization.

4. Full fluid characterization: After ensuring the accuracy of the EOS tuned model, the gas cap fluid was fully characterized using it, and below are the main experiments results: (Figures.6-9).

2.3. Oil Rim fluid characterization

As aforementioned, the field of study originally contained a gas cap in equilibrium with a thin oil rim. Consequently, the initial pressure of field at datum of GOC equals to the saturation pressure of both gas cap and oil rim. After precise selection process and quality check, AS-5, BHS (RFR01), was selected for full fluid characterization. Fluid in the oil rim was identified as light oil, API gravity >31.1 (Table. 1). Field oil rim fluid was characterized as fully compositional using PVTP package from IPM-7.5.

2.3.1. Quality Check

Saturation pressure of AS-5 BHS by lab is 2940 psia with less than 1% difference from corrected saturation pressure at GOC (Pi=2965 psia). Besides, it is close to FBHP, 2785 psia, 5% difference. Consequently, less deformation had occurred. No mud filtrate is encountered. So it is considered representative to reservoir fluid.

AS-5 RFR01 Oil sample was entered into PVTp software for full fluid characterization after ensuring an accepted quality.

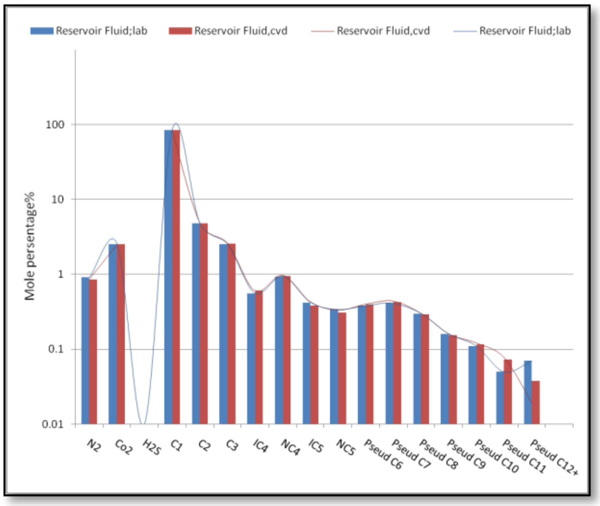

Figure. 5. Comparison between the original and the new stream fluid composition

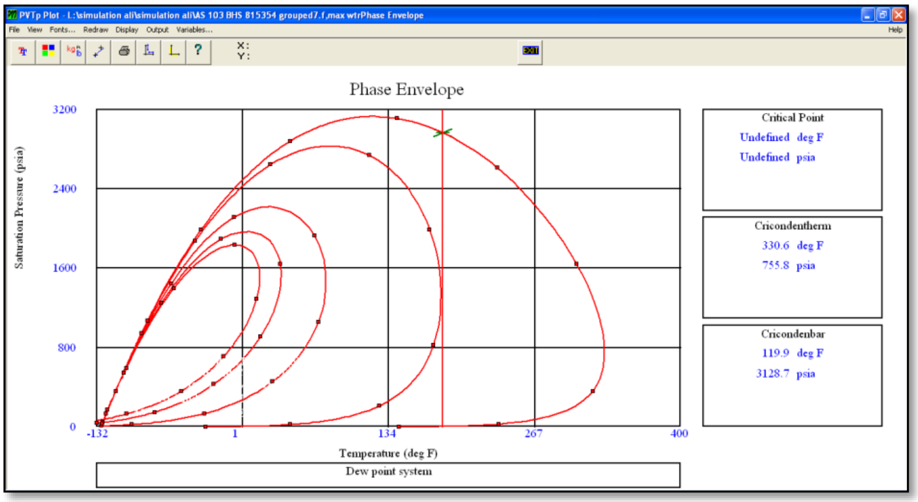

Figure. 6. Phase envelope match (RFR01Reconstructed sample)

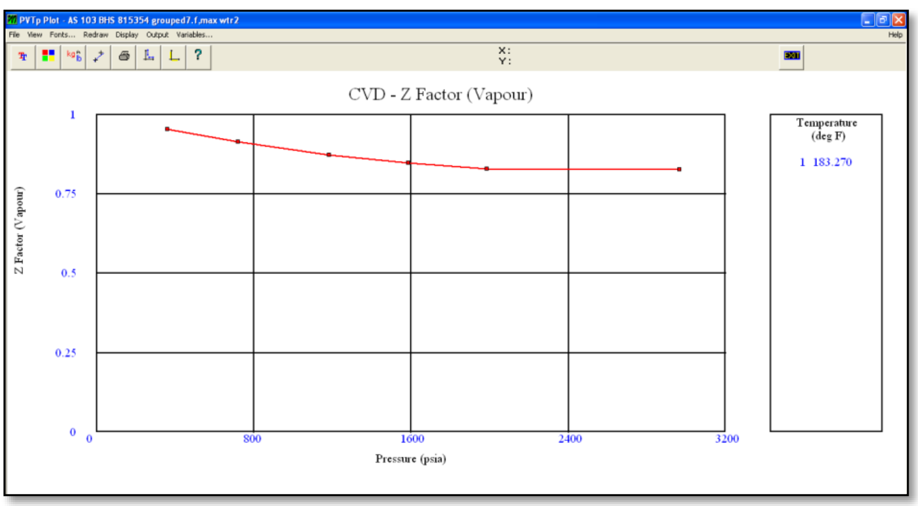

Figure. 7. CVD gas deviation (Z) factor (RFR01Reconstructed sample)

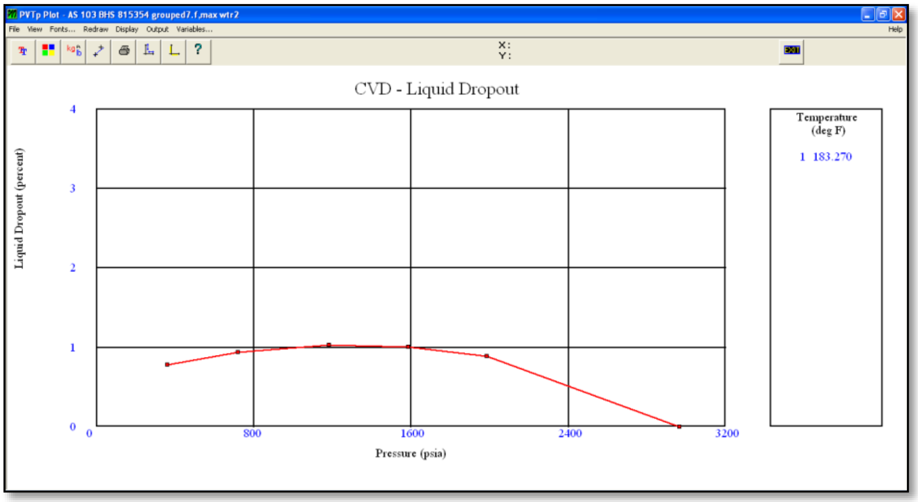

Figure. 8. CVD Liquid dropout (RFR01Reconstructed sample)

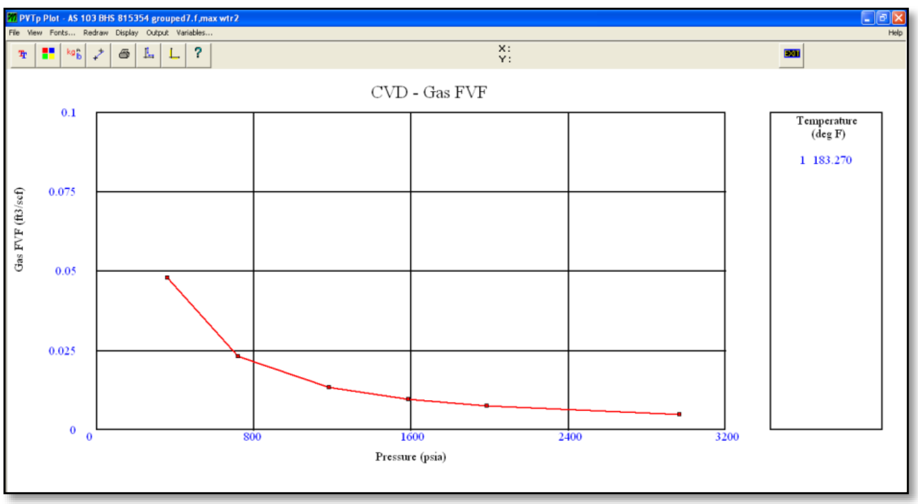

Figure. 9. CVD Gas FVF (RFR01Reconstructed sample)

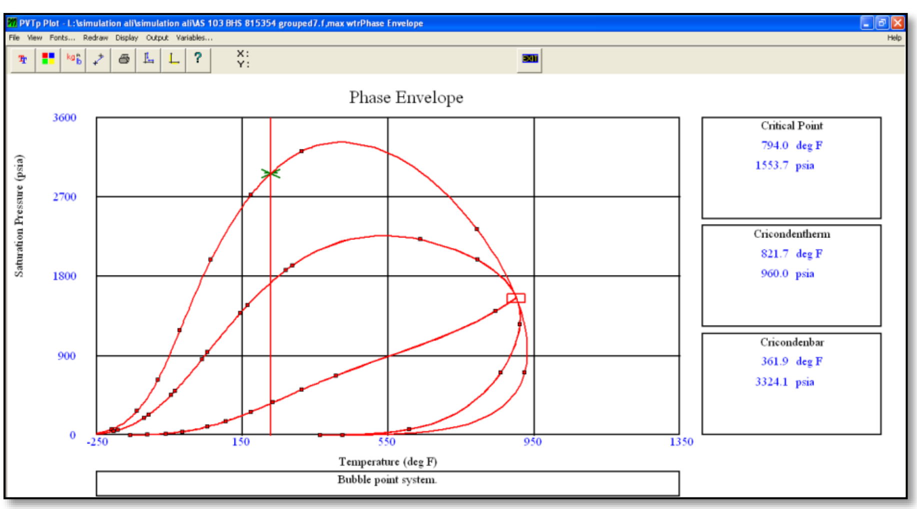

Figure. 10. Phase envelope match (RFR01 Oil sample)

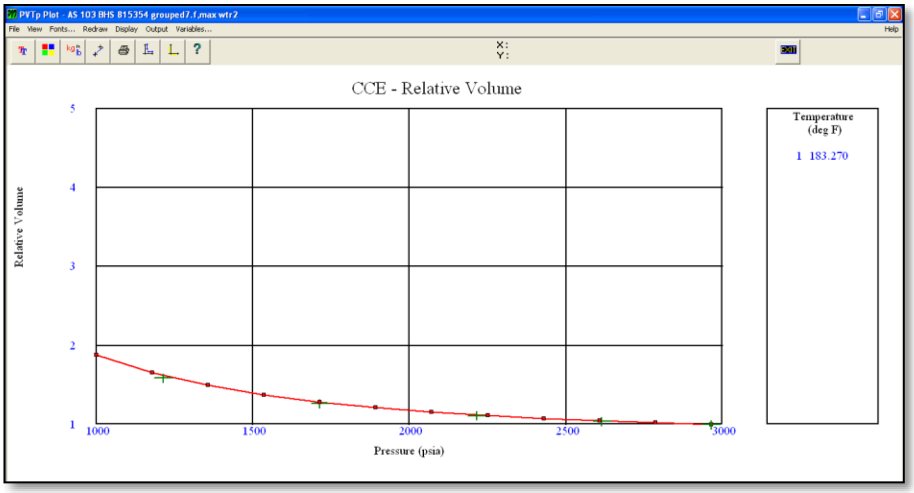

Figure. 11. CCE Relative volume match (RFR01 Oil sample)

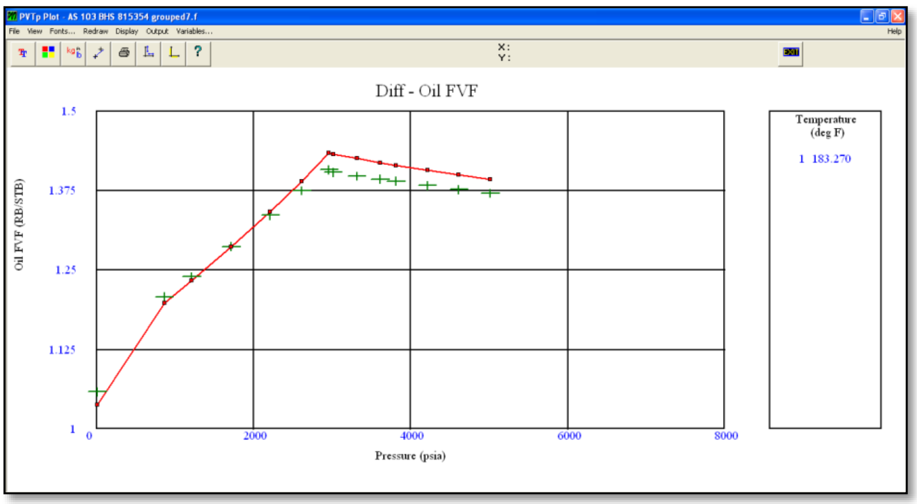

Figure. 12. Differential liberation test – Oil FVF match (RFR01 Oil sample)

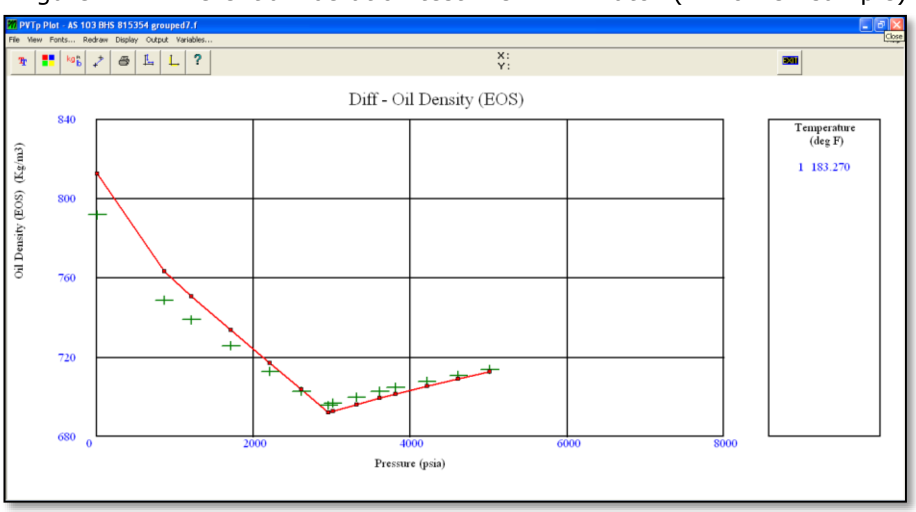

Figure. 13. Differential liberation test – Oil density match (RFR01 Oil sample)

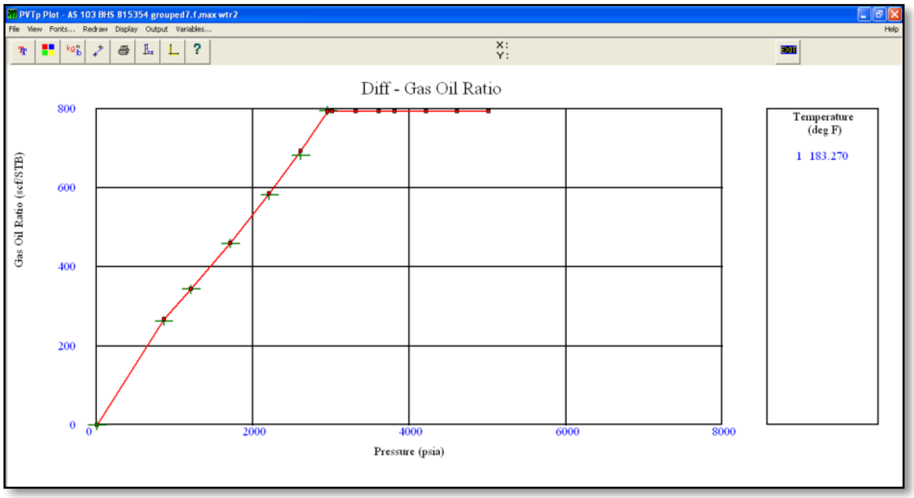

Figure. 14. Differential liberation test – GOR match (RFR01 Oil sample)

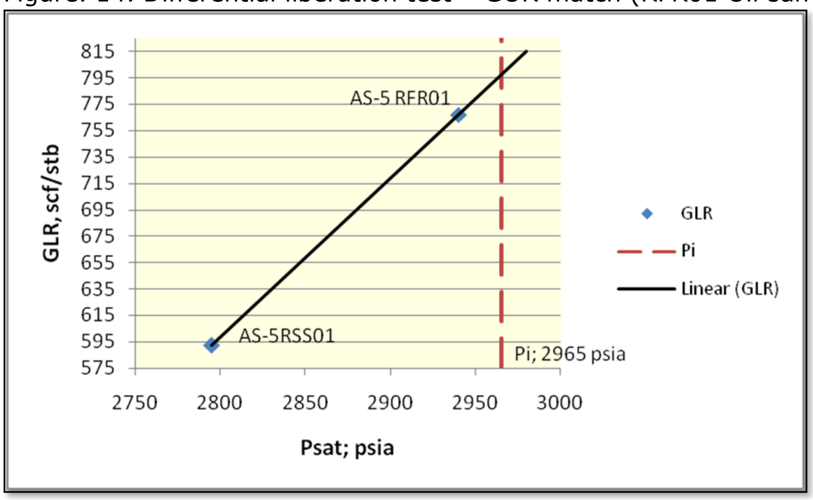

Figure. 15 Correction of Rsi for (RFR01 Oil sample)

2.3.2. Matching to corrected experiments data

As stated previously, Peng-Robinson EOS was used for fluid characterization using minimum regression parameters in order to obtain robust fluid characterization for wider range of pressures and temperatures. Therefore, binary interaction parameters were not used in regression in order to avoid risk of distorting the phase envelope at other (generally lower) temperatures. Instead, critical pressure, temperature and eccentric factor of the heaviest component were used as regression parameters. Reasonable match was obtained. [8]

Following laboratory tests were used for EOS regression of RFR01 oil sample: saturation pressure at 183.2°F; separator GOR; separator oil density; separator oil FVF; separator gas density (last stage only).

Tests were selected according to confidence in their accuracy, lowest possible error and industry recommendations. Exact match for the saturation pressure at reservoir temperature at datum (183.27ºF), figure. 10. Constant composition expansion and differential liberation experiments were used as a quality check of the characterization. Experiments results were corrected to the corrected saturation pressure of 2965 psia instead of old 2940 psia using trend equations. Only the relative volume dataset from CCE was available, and a good match was obtained, (figure. 11). When the results of differential liberation tests were checked, EOS has slightly over predicted oil FVF and oil densities, (figures. 12-13) , whereas excellent match of GOR was obtained, (figure. 14), as the corrected Rsi, 795 scf/stb was obtained from plotting Psat versus GLR for two samples of AS-5 well, AS-5 RFR01 and AS-5 RSS01 [9]. (Figure. 15).

A good match of separator values was obtained, difference < 10%, (tables. 4-5).

Table. 4. Separator conditions for RFR01 oil sample

Separator conditions	Unit	1st stage	2nd stage
Temperature	°F	90	70
Pressure	Psia	115	15

Table.5. Match of separator values for RFR01 oil sample

Value	Unit	Measured	Calculated	Diff %
GOR (1st stage)	scf/stb	654	664	2%
GOR (2nd stage)	scf/stb	33	35	6%
Oil density(1st stage)	g/cc	0.8	0. 820	2%
Oil density(2nd stage)	g/cc	0.833	0.831	0%
Oil FVF	vol/svol	1.356	1.34	1%
Gas density(2nd stage)	g/cc	0.00136	0.00136	0%

Final EOS for oil has 16 components, out of which there is 7 pseudo-component. Composition of RFR01 oil sample is presented in table. 6.

Table. 6. Composition of RFR01 oil sample

Component	Molar composition (%)	Component	Molar composition (%)
N_2	0.15	NC5	1.06
CO_2	1.76	Pseud C6	2.01
H_2S	0.00	Pseud C7	0.04
C1	43.74	Pseud C8	0.45
C2	4.90	Pseud C9	1.31
C3	4.06	Pseud C10	2.29
IC4	1.20	Pseud C11	3.10
NC4	2.26	Pseud C12+	30.50
IC5	1.17		

3. Conclusion

Implemented reconstruction of gas cap fluid and applied correction to experiments data of oil rim sample enabled us to get accurate fluid characterization. The resulted fluid models were used in detailed compositional reserve study for forecasting scenarios of FDP.

This procedure applied in this article for fully characterization of a retrograde condensate cap with an initial oil rim can be examined for similar cases of retrograde condensate caps in equilibrium with initial oil rims, or for retrograde condensate reservoirs fell below dew point before or during sampling, so samples were not representative to reservoir fluid.

Correction of samples properties to the realized saturation pressure and early production data is crucial, as really field data, corrected to lab, is more reliable than PVT data. Caution should be taken, when taking field data.

Gradient from corrected lab data should be compared with gradient from RFT measurement, as a quality check of applied correction.

List of symbols

Bcf	*Billion Cubic Feet.*	*DST*	*Drill Steam Tester.*
MMbbl	*Million Barrel.*	*RFT*	*Repeated Formation Tester.*
GOC	*Gas Oil Contact.*	*CVD*	*Constant Volume Depletion.*

(PR) EOS	*Peng Robinson Equation of State.*	*RSS*	*Recombined Separator Sample.*
AS-1	*Well No. 1*	*°F*	*Fahrenheit.*
PVT	*Pressure Volume Temperature.*	*Ft*	*Foot.*
Pd	*Dew point pressure.*	*GOR*	*Gas Oil Rate.*
Psia	*Pound per Square Inch Absolute.*	*(Z) factor*	*Gas deviation factor or gas compressibility factor*
FBHP	*Flowing Bottom-hole Pressure.*	*FVF*	*Formation Volume Factor.*
Pi	*Initial reservoir pressure.*	*scf/stb*	*Standard cubic foot/stock tank barrel.*
GCR	*Gas Condensate Ratio.*	*API*	*American Petroleum Institute.*
RFR	*Reservoir Fluid Reference.*	*CCE*	*Constant Composition Expansion.*

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