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Phase Behaviour Modelling of NC98 Field

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Abstract

Fluid properties in states near a vapor-liquid critical region are the most difficult to measure and to predict with EOS models. The principal model difficulty is that near-critical property variations do not follow the same mathematics as at conditions far away from the critical region. Libyan NC98 field in Sirte basin is a typical example of near critical fluid characterized by high initial condensate gas ratio (CGR) greater than 160 Bbl/MMscf and maximum liquid drop-out of 25%. The objective of this paper is to model NC98 phase behavior with the proper selection of EOS parameters and also to model reservoir depletion versus gas cycling option using measured PVT data and EOS models. The outcomes of our study revealed that, for accurate gas and condensate recovery forecast during depletion, the most important PVT data to match are the gas phase Z-factor and C_{7+} fraction as functions of pressure. Reasonable match, within -3% error, was achieved for ultimate condensate recovery at abandonment pressure of 1500 psia. The smooth transition from gas-condensate to volatile oil was fairly simulated by the tuned PR-EOS. The predicted GOC was approximately at 14,380 ft. The optimum gas cycling scheme, in order to maximize condensate recovery, should not be performed at pressures less than 5700 psia. The contribution of condensate vaporization for such field is marginal, within 8% to 14%, compared to gas-gas miscible displacement. Therefore, it is always recommended, if gas recycle scheme to be considered for this field, to start it at the early stage of field development (at P higher than Pdew).

Keywords: Near critical fluid; gas-condensate; gas cycling; EOS models

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1. Introduction

The recovery performance for many gas-condensate reservoirs, producing under pressure depletion schemes, can be closely simulated by the CVD experiment. Even for other recovery mechanisms, such as gas recycling, the CVD report still of valuable information data required for basic reservoir engineering. EoS characterization and modelling studies have been published [2][9] on different types of gas condensate and volatile oil reservoirs. Each study has its own field data and its own procedures for modifying the cubic EoS to fit experimental PVT data. Most of these methods modify the properties of fractions making up the C_{7+} (Tc, pc,ω , or direct multipliers on the EoS constants Ωa and Ωb) and BIP's between methane and C_{7+} fractions. When an injection gas containing significant amounts of nonhydrocarbons is being studied, the BIP's between nonhydrocarbon and C_{7+} fractions may also be modified. [1] Some methods use nonlinear regression to modify the EOS parameters automatically. [3][7][8]. Others have tried simply to make manual adjustments to the EOS parameters through trial and error approach. [4][6][9].

Coats and Smart [3] recommend five standard EOS modifications: Ωa and Ωb of methane; Ωa and Ωb of the heaviest C_{7+} fraction; and BIP,s between methane and the heaviest C_{7+} fraction. Additional parameters (nonhydrocarbon a and b

and BIP's) are used for systems with significant amounts of nonhydrocarbon components. An alternative to adjustment of a and b would be to modify Tc and Pc instead. Whitson and Michael [1] have achieved their excellent match to the studied phase behaviour for WELL7 gas condensate through the adjustment of shift parameters, tuning of BIP's between methane and all C_{7+} fractions, and tuning of T_c for all C_{7+}fractions.

The main objective of this study is to model the phase behaviour of NC98 near critical gas condensate and volatile oils with the proper selection of EoS parameters and also to model reservoir depletion vs. gas cycling option using PVT data and EoS Models. The main steps to achieve the above main objective are highlighted below:

1. Collect and analyse PVT data for well A3 of NC98 field.
2. Apply 3Parameters EoS's (PR and SRK) to characterize the phase behaviour of the NC98 near critical gas-condensate and near critical volatile oil.
3. Tune EoS's to match the gas-condensate and volatile oil PVT data, Analyse and assess the compositional variation based on PVT measurements and EoS predictions.
4. Apply the tuned EoS to simulate CVD experiment (Reservoir Depletion Mechanism) and to predict Recovery Factor (RF) for both condensate and gas.
5. Compare the RF of Depletion Mechanism versus the Gas Cycling Mechanism using PVT data and Whitson approach.

2. Well A3 Main PVT Characteristics

PVT data obtained from A3-well, located at the central of the field, was used in our study. The main PVT characteristics for A3-well are illustrated by the data obtained from both DST2 and DST4 as shown in the table below.

NC98 field is characterized by rich gas condensate fluid with initial CGR higher than 160 bbl/MMscf and API gravity around 53, underlain by light volatile oil with API gravity around 52.

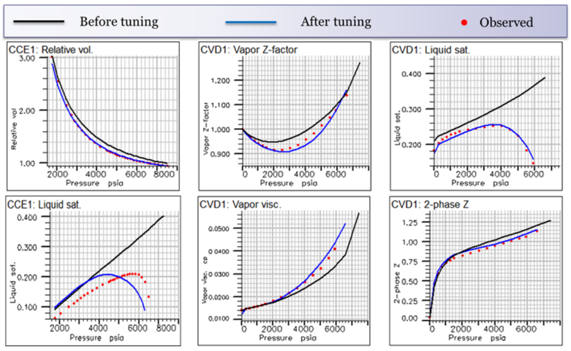


Figure 3.1: Comparison between measured and predicted A3-NC98 PVT properties (DST4)

3. NC98 Phase Behaviour Modelling

The subsequent section summarizes the tuning exercise for both near critical gas condensate and near critical volatile oil and the tuning procedures used for each fluid type. PVTi Eclipse package was used to model these fluid types and to correlate the compositional variation of these fluids with depth.

3.1. Near Critical Gas Condensate Eos Modelling

3.1.1. Case 1

In this case we focused our match on the CVD liquid saturation in addition to the other measured experiments of the CVD, CCE and Flash Separation tests. The CVD liquid drop out is the most challenging experiment to match and usually, as rule of thumb, if it is matched then the CCE liquid saturation will be automatically matched. Also, it is important to match the CVD liquid saturation to reflect the retrograde phenomenon accruing in the reservoir during the depletion stage and also will help in modelling the condensate blockage phenomenon around the well bore and its impact on gas well deliverability. The overall match was good, as shown in Figure 3.1, except for the CCE Liquid drop out which is drastically deviated from the measured data.

Although a good match was achieved for CVD liquid drop-out, but unable to match the CCE liquid saturations which will raise some doubt on measurement accuracy for liquid dropout saturation. Due to the nature of the NC98 fluid (near critical fluid) any minor changes in the pressure during the experiment will impact the measured

Table 2.1: Main characteristics of A3 WELL

Property	A – structure reservoir	
	A3(DST2)	A3(DST4)
Perforation interval TVDSS	14415-14528	14080-14196
Bottom hole or recombined sample	Bottom hole	Recombined
Fluid type	Volatile oil	Gas condensate
P_{res} (Psia)	7082	7082
T_{res} (F)	320	315
P_{sat} (Psia)	6643	6597
B_o (RB/STB)	3.012	4.388
B_g (RB/SCF)	0.0037	0.0038
GOR (SCF/STB)	3768	6013
API	51.49	52.87

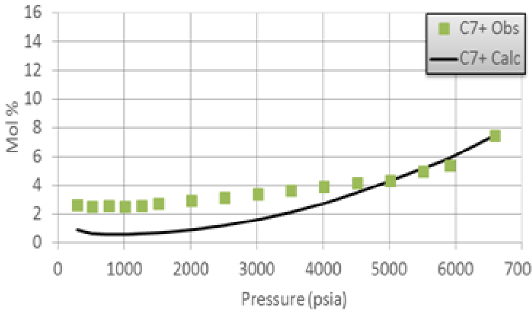


Figure 3.2: C_{7+} compositional vs Pressure (CVD)

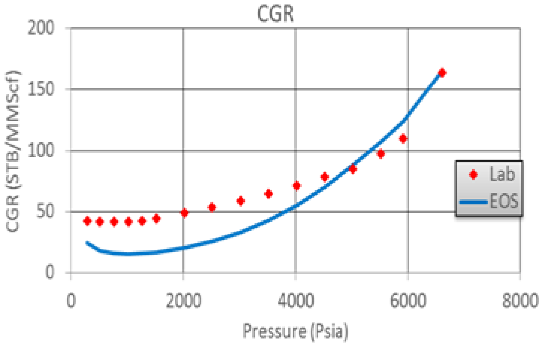


Figure 3.3: Condensate gas ratio (CVD)

results. Usually the experiment has more control on CCE test compared to CVD and therefore the doubt on measurements is most likely on the CVD liquid saturation measurements. Under this tuning scenario, we achieved a perfect match for C_1 composition but not a good match for C_{7+} composition below 4000 psia which directly impacted the match of CGR, as shown in Figures 3.2 and 3.3.

3.1.2. *Case 2*

3P-PR EoS was retuned and forced to match the Z-factor and C_{7+} composition of liberated gas with less focus on CVD liquid drop out measurements. Reasonable match was obtained for C_{7+} as well as all other PVT data except for the CVD liquid drop-out, Figure 3.4. On the other hand CCE liquid saturations was perfectly matched confirming our doubts opinion on the CVD liquid saturation measurement. The good match of the liberated gas C_{7+} concentration has resulted with a perfect match of the CGR, Figures 3.5 and 3.6, and accordingly the condensate recovery predictions. This retuned EoS is more representative for any future simulation studies.

The tuning exercise was achieved by limiting the regression variables within estimated acceptable uncertainties. This step is very important in order to minimize the number of variables used for PVT simulation purposes. The optimum number of variables was obtained by analysing the variable matrix in ECLIPSE PVTi package as this matrix will help identifying the important and sensitive variables to adjust. We carefully selected the weight factors for different experiments depending on the importance of each experiment and property. The C_{7+} was broken into 5 pseudo-fractions

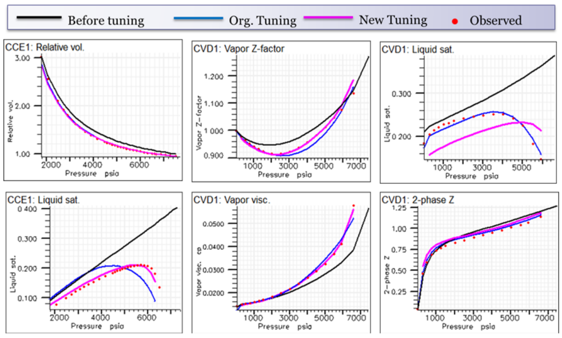


Figure 3.4: Comparison between measured and predicted A3-NC98 PVT properties (DST4)

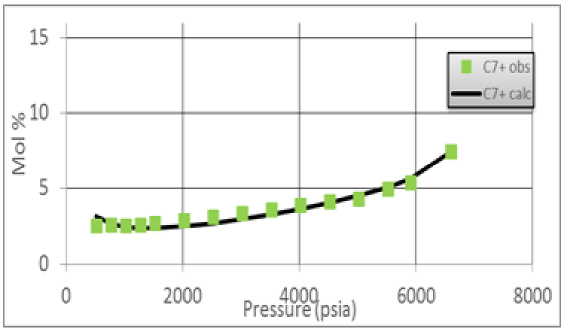


Figure 3.5: C_{7+} compositional vs Pressure (CVD)

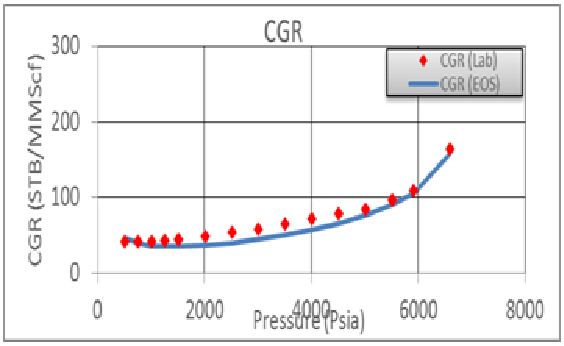
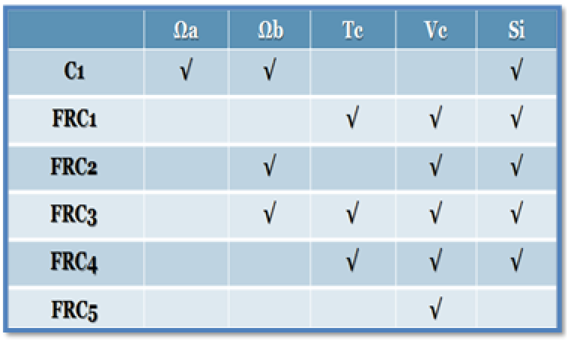


Figure 3.6: Condensate gas ratio (CVD)

Table 3.1: CVD experiment match



	Ωa	Ωb	Tc	Vc	Si
C1	√	√			√
FRC1			√	√	√
FRC2		√		√	√
FRC3		√	√	√	√
FRC4			√	√	√
FRC5				√	

using modified Whitson method [1] by proper selection ofα ,Γ ,M and N coefficients where good selection of these terms have been checked with the proper match to Katz and Firoozabadi [10] chart of molecular weight versus specific gravity with an exponential distribution for molar distribution for the heavy fractions. We adjusted the BIP's to match Pd. In this case we used Chueh-Prausnitz method [11] and we concentrated our adjustment to the (A) coefficient. Also, we adjusted Ωa, Ωb, Tc, Vc, and Si to match the CVD experiment as follows (table3.1):

For the case 1 tuning scenario as discussed above and due to the unreliable match of the C_{7+} composition in the liberated gas, it has impacted the prediction of condensate recovery at pressures below 4000 psia. The overall predicted condensate recovery deviation at abandonment pressure is approximately -10% of measured RF, Figure 3.7. Such under-prediction of condensate recovery of rich fluid like NC98 will impact the field development plan economics. For the case 2 tuning scenario as discussed above and after achieving a reliable match for C_{7+} as well as the CGR as function of pressure. These resulted with good condensate recovery predictions within -3% error at the abandonment pressure of 1500 psia, as shown in Figure 3.8.

3.2. Near Critical Volatile Oil EoS Modelling

Practically it will be more convenient to have one similar EoS to simulate both gas-condensate and volatile oil for NC98 field. The tuned EoS for the gas-condensate was used to predict the PVT properties for Volatile oil. Unfortunately the predictions were very bad compared to measured data.

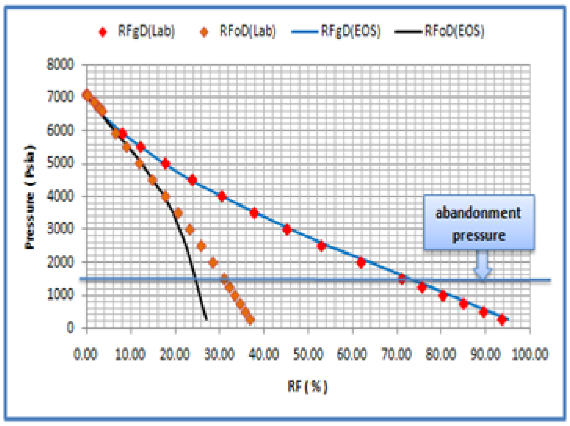


Figure 3.7: Recovery factor for both gas and condensate by depletion

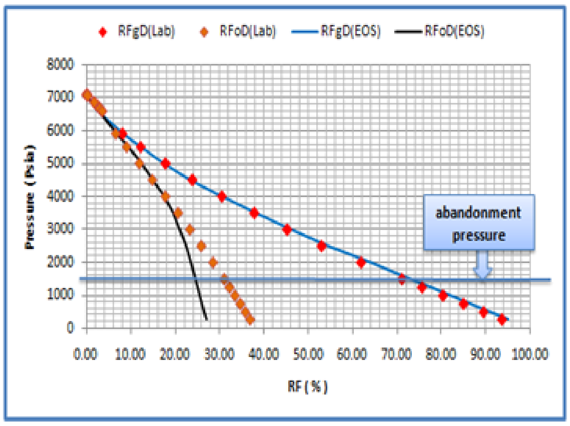


Figure 3.8: Recovery factor for both gas and condensate (2nd model)

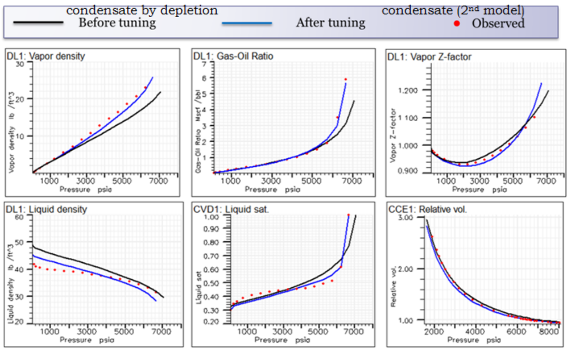


Figure 3.9: Comparison between measured and predicted A3-NC98 PVT properties (DST2)

This led us to retune the 3P-PR EoS in order to properly match the PVT properties of volatile oil. The overall match of the different PVT experiments is fairly reasonable as shown in Figure 3.9, except some acceptable deviations in liquid density due to the nature difficulty associated with the measurement and predictions of near critical volatile oil. The properties trend of volatile oil are compatible with those of gas condensate, and both models were utilized to predict the GOC.

4. Compositional Variation Vs Depth

Two distinct hydrocarbon compositions are recognized, based on the collected PVT data from well A3-NC98. However, the NC98 fluid grading from gas to volatile oil is undistinguished and with no clear interface as the case of traditional gas and black oil. Compositional variation with depth was simulated with Eclipse PVTi package. Plot of the pressures vs. depth for both gas-condensate (DST4) and volatile-oil (DST2) have approximately identified a GOC at 14,380 ftss. The GOC was picked up at the inclination point of the predicted saturation pressures for both gas-condensate and volatile oil, as shown in Figure 4.1, which both almost inclined at the same contact point confirming the reliability and validity of our acheived phase behaviour models.

5. Comparison Between Depletion and Gas Cycling Recovery Factors

The theoretical additional condensate recovery by gas cycling, applying analytical models as outlined in reference [12], is around 60% which is

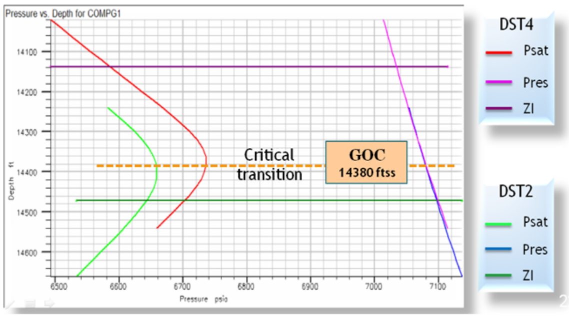


Figure 4.1: Compositional variation versus depth

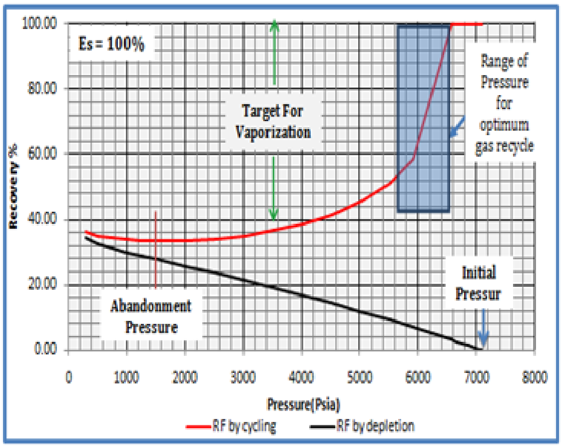


Figure 5.1: Comparison between cycling and depletion

more attractive and worth considering it, as an option, in the development scenarios of NC98 field. A rapid decline of condensate recovery, as shown by the red line of Figure 5.1, is expected to happen within 800 psi below the dewpoint pressure, indicating that the optimum pressure range for gas cycling should happen between 5700 psia to 6500 psia.

6. Target of Vaporization

The final efficiency of vaporized retrograde condensate, EV, is only important for cycling below the dew point, and often the contribution of vaporization to overall condensate recovery is relatively marginal [12]. The impact of EV for NC98 was simulated by the concept of ternary diagram as shown in the Figure 6.1 below, at two different cycling pressures of 6300 psia and 5700 psia. The Ev was estimated by the following expression:

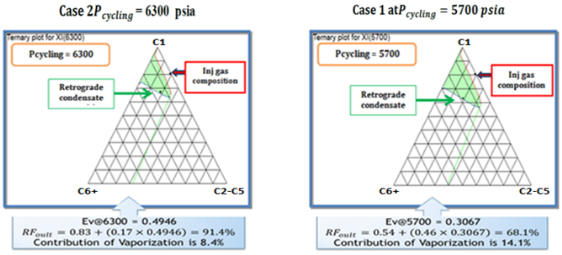


Figure 6.1: Calculation of Ev by ternary plots

$$E_V = \frac{C_6 + (yi@Pcycling)^{-C_6} + (Injgas)}{C_6 + (xi@Pcycling)} \tag{6.1}$$

At Pcycling of 6300 psia, the contribution of vaporization was about 8.4% and at Pcycling of 5700 psia, the contribution of vaporization is 14.1%. As noticed the EV contribution is bit higher at lower cycling pressure, but overall vaporization effects are often less significant than commonly thought compared with miscible gas-gas cycling contribution.

7. Conclusions

1. NC98 is classified as rich gas-condensate fluid with initial CGR higher than 160 bbl/MMscf and API gravity of 53, underlain by volatile oil with approximately similar API gravity (52).

2. Near Critical fluid requires special attention and care during the PVT measurements specially the CVD experiment. A3 PVT data has shown clear discrepancies during the match of CCE and CVD liquid saturations.

3. For forecasting NC98 recoveries during depletion, the most important PVT data to match are the gas phase Z-factor and C_{7+} fraction as functions of pressure. Reasonable match was achieved for ultimate condensate recovery at abandonment pressure (within -3% error) as well as the CGR predictions.

4. The tuned PR EoS for NC98 gas-condensate was not adequate to predict the NC98 volatile oil, which implies to apply again the PR EoS but with different tuned parameters.

5. There is no distinct GOC and the smooth transition from gas-condensate to volatile oil was fairly simulated by the tuned EoS's. The predicted GOC was approximately at 14380 ftss .
6. The optimum gas cycling scheme, in order to maximize condensate recovery, should not be performed at pressures less than 5700 psia. Further simulation studies and economic assessments are necessary to identify the proper pressure for gas cycling development plan.
7. The contribution of condensate vaporization is marginal compared to gas-gas miscible displacement. Therefore, it is always better to start gas cycling at the high pressure and at the early stage of field development.

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Nomenclature

CCE = Constant Composition Expansion
CGR = Condensate Gas Ratio (bbl/MMscf)
CVD = Constant Volume Depletion
DST = Drill Stem Test
EoS = Equation of State
EV = Final Efficiency of Vaporized Retrograde Condensate
GOC = Gas Oil Contact (ft)
GOR = Gas Oil Ratio(scf/stb)
OWC = Oil Water Contact (ft)
PR = Peng–Robinson
PVT = pressure − volume − temperature
RFoult = Is the ultimate condensate recovery due to (a) depletion prior to cycling, (b) cycling, and (c) depletion after cycling(%).
BIP's = Binary Interaction Parameters
Vc = critical volume by ft^3/(ibm mol)
Pc = critical pressure by psia
Tc = critical temperature by R
Ωa , Ωb = constants in cubic EoS
S_i= dimensionless volume – shift variable used in EoS

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