



# **Evaluating the Challenges in Pressure – Volume – Temperature (PVT) Analysis of Gas Condensate Reservoirs**

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## **Authors' contributions**

*This work was carried out in collaboration between both authors. Author ABU designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ABU and JUA managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.*

## **Article Information**

DOI: 10.9734/JERR/2020/16i317168

### Editor(s):

(1) Dr. Djordje Cica, University of Banja Luka, Bosnia and Herzegovina.

### Reviewers:

(1) Alemu Gurmessa Gindaba, Wollega University, Ethiopia.

(2) Alexander Gilmanov, University of Tyumen, Russia.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/58666>

**Received 02 May 2020**

**Accepted 06 July 2020**

**Published 31 August 2020**

**Original Research Article**

## **ABSTRACT**

**Aims:** The variations in production performances of the Black oil and compositional simulation models can be evaluated by simulating oil formation volume factor (Bo), gas formation volume factor (Bg), gas-oil ratio (Rs) and volatilized oil-gas ratio (Rv). The accuracy of these two models could be assessed.

**Methodology:** To achieve this objective some basic parameters were keyed into matrix laboratory (MATLAB) using the symbolic mathematical toolbox to obtain accurate Pressure Volume Temperature (PVT) properties which were used in a production and systems analysis software to generate the production performance and hydrocarbon recovery estimation. Standard black oil PVT properties for a gas condensate reservoir was simulated by performing a series of flash calculations based on compositional modeling of the gas condensate fluid at the prescribed conditions through a constant volume depletion (CVD) path. These series of calculations will be carried out using the symbolic math toolbox. PVT property values obtained from both compositional modeling and black oil PVT prediction algorithm are incorporated to determine the production performance of each method for comparison.

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**Results:** The absolute open flow for the black oil PVT algorithm and the compositional model for the Rs value of 500 SCF/STB and Rs value of 720SCF/STB were 130,461 stb/d and 146,028 stb/d respectively showing a 10.66% incremental flow rate.

**Conclusion:** In analyzing PVT properties for complex systems such as gas condensate reservoirs, the use of compositional modeling should be practiced. This will ensure accurate prediction of the reservoir fluid properties.

*Keywords: Pressure–Volume–Temperature (PVT); gas condensate reservoir; black oil; compositional model; flow rate.*

## 1. INTRODUCTION

Oil and gas accumulations occur in underground traps formed by structural and/or stratigraphic features. Fortunately, the hydrocarbon accumulations usually occur in the more porous and permeable portion of beds, which are mainly sands, sandstones, limestones, and dolomites; in the inter-granular openings; or in pore spaces caused by joints, fractures, and solution activity [1].

A reservoir is that portion of a trapped formation that contains oil and/or gas as a single hydraulically connected system. Hydrocarbon fluids are usually in either single phase state or two-phase state. Single phase are the Liquid (Oil) with dissolved gas and dry gas reservoirs while the two phase state are Gas with vaporized liquids which are recovered at the surface as NGL i.e. Gas condensate reservoirs [2].

If there are hydrocarbons vaporized in this gas phase that are recoverable as natural gas liquids on the surface, the reservoir is called gas condensate or gas distillate (the older name). In this case there are liquid (condensate or distillate) reserves as well as the gas reserves to be estimated [3].

Black Oil Pressure Volume Temperature (PVT) model is widely used for PVT analysis of gas condensate reservoirs because of its relative simplicity. While using the BO PVT model on gas condensate reservoirs, certain assumptions are made which leads to violation of species material balance [4].

These assumptions are that the total amount of stock tank oil will be conserved throughout the reservoir's depletion process and that the total amount of surface gas will be conserved throughout the reservoir's depletion process. This violation of species material balance principle leads to significant errors which include a consistent underestimation of the standard

PVT properties, wrong estimation of the amount of hydrocarbon in place (HIIP) and a wrong prediction of the production performance of the reservoir. Hence the use of BO PVT model in determining PVT properties for Gas condensate reservoirs is inefficient [5].

The proposed solution is to make use of Compositional PVT models in determining the accurate PVT properties of gas condensate reservoirs.

[6] in his work simulated Standard BO PVT properties of a gas condensate reservoir based on hypothetical reservoir. Simulation results demonstrated that species material balance can be violated by the BO PVT model. In [7] procedure, he makes use of the equation of state (EOS) to predict the stock tank oil and separator gas yields by flashing the appropriate reservoir simulated oil and gas mixtures. [8] on the other hand flashed the composition using Standing's K value.

This work is limited to simulation; hence no experiments will be carried out. Parameters will be set and keyed into Mat lab (version 9.4) software using the symbolic math toolbox to obtain the accurate PVT properties. The property values obtained will be uploaded in Prosper software to generate the production performance and hydrocarbon recovery [9].

## 2. MATERIALS AND METHODS

### 2.1 Simulating Standard BO PVT Properties

In this study, standard black oil PVT properties for a gas condensate reservoir is simulated by performing a series of flash calculations based on compositional modeling of the gas condensate fluid at the prescribed conditions through a constant volume depletion (CVD) path [10]. These series of calculations will be carried out using the symbolic math toolbox in Matlab

software; quantities and properties of each phase of hydrocarbon mixtures will be calculated based on a given composition, pressure, and temperature data. =Bo, Bg, Rs, and Rv values are calculated using the definition presented in Fig. 1.

Find  $(n_{g+EG,j})$  and  $n_{o,j}$

Amount of moles of reservoir gas before the removal of excess gas  $(n_{g+EG,j})$  and moles of reservoir oil  $(n_{o,j})$  at every pressure level  $j$  are calculated based on remaining moles of reservoir fluid (gas and oil) after excess gas removal at every pressure level  $j - 1$  ( $n_{T,j-1}$ ) and the overall molar fraction of gas phase at every pressure level  $j$  ( $f_{ng,j}^{pvt}$ ), using Equations (1) and (2).

$$n_{g+EG,j}\{lbmol\} = n_{T,j-1}\{lbmol\} \times f_{ng,j}^{pvt} \quad (1)$$

Where:  $n_g$  = Amount of gas,  $G_j$  = Amount of surface gas,  $j$  = Pressure level and  $f_{ng}$  = gas phase fraction

$$n_{o,j}\{lbmol\} = n_{T,j-1}\{lbmol\} \times (1 - f_{ng,j}^{pvt}) \quad (2)$$

Where:

$n_o$  = Amount of oil

Find  $G_{fg,j}$  and  $N_{fg,j}$

The volumes of surface gas ( $G_{fg,j}$ ) and stock tank oil ( $N_{fg,j}$ ) in reservoir gas at pressure level  $j$  are calculated from the remaining mole of reservoir gas ( $n_{g,j}$ ) and the molar fractions of surface gas ( $y_{g,j}$ ) and stock tank oil ( $y_{o,j}$ ) in reservoir gas, using Equations (3) and (4) in [6].

$$G_{fg,j}\{SCF\} = (y_{g,j} \times n_{g,j}\{lb\ mol\}) \times 379.56 \{SCF/lbmol\} \quad (3)$$

Where:

$G_{fg,j}$  = Volume of surface gas at every pressure level  $j$

$$N_{fg,j}\{STB\} = \frac{(y_{o,j} \times n_{o,j})\{lbmol\} \times MW_{g,j}^{PVT}\{lbm/lbmol\}}{\rho_{o,g,j}^{STO}\{lbm/ft^3\} \times \left(\frac{5.615 ft^3}{bbl}\right)} \quad (4)$$

Where:

$N_{fg,j}$  = Volume of stock tank oil in reservoir gas at pressure level  $j$

Find  $n_{T,j}$  and  $c_{i,j}$

The remaining moles of reservoir fluid ( $n_{T,j}$ ) and overall composition ( $c_{i,j}$ ) inside PVT cell at pressure level  $j$  after gas removal are updated by removing moles of excess gas ( $n_{EG,j}$ ) and recalculating overall composition using Equations (5) and (6) in [6].

$$n_{T,j} = n_{T,j-1} - n_{EG,j} \quad (5)$$

where

$n_{T,j}$  = remaining moles of reservoir fluid at pressure level  $j$

$$c_{i,j} = \frac{x_{i,j} \times n_{o,j} + y_{i,j} \times n_{g,j}}{n_{T,j}} \quad (6)$$

Where:

$c_{i,j}$  = Overall composition in PVT cell at pressure level  $j$

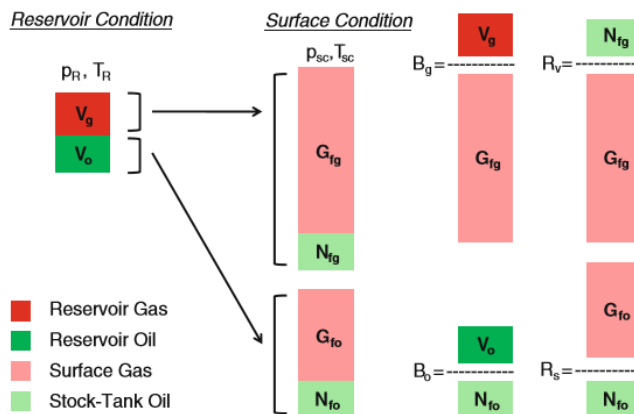


Fig. 1. Graphical representation of standard PVT properties [11]

### 2.2 Production Performance Simulation

PVT property values obtained from both compositional modeling and black oil PVT prediction algorithm are uploaded into PROSPER software to determine the production performance of each method and compare their results. Production performance of each method is generated.

### 3. RESULTS AND DISCUSSION

PVT properties as obtained from flash calculation is tabulated in Table 1.

Fig. 2 is a plot of the simulated oil formation volume factor (Bo) and solution gas oil ratio (Rs) plotted against the reservoir pressure.

The Percentage errors observed by implementing the BO PVT algorithm compared to those using rigorous flash calculations is shown in Table 2.

Percentage errors observed by implementing the Walsh–Towler BO PVT model compared to those using the compositional model are presented in parentheses. The combination of the underestimated amount of surface gas remaining in reservoir oil ( $G_{ro}$ ) values with overestimated amount of stock tank oil remaining in reservoir oil ( $N_{ro}$ ) values as a result of the violation of the species material balance principle by the BO PVT model translated into seriously underestimated  $R_s$ .

Table 1. PVT properties from flash calculation

Pressure (Psia)	$B_o$ (Rb/Stb)	$B_g$ (Rb/Mstb)	$R_s$ (Scf/Stb)	$R_v$ (Stb/Mmscf)
3224		1.20		204
3,000	2.37	1.25	1,570	155
2,750	2.07	1.34	1,207	125
2,500	1.87	1.46	954	105
2,250	1.72	1.61	761	90
2,000	1.60	1.81	720	79
1,750	1.51	2.07	476	71
1,500	1.43	2.43	366	65
1,250	1.36	2.94	272	62
1,000	1.30	3.72	191	61
750	1.25	5.05	121	65
500	1.20	7.81	59	78

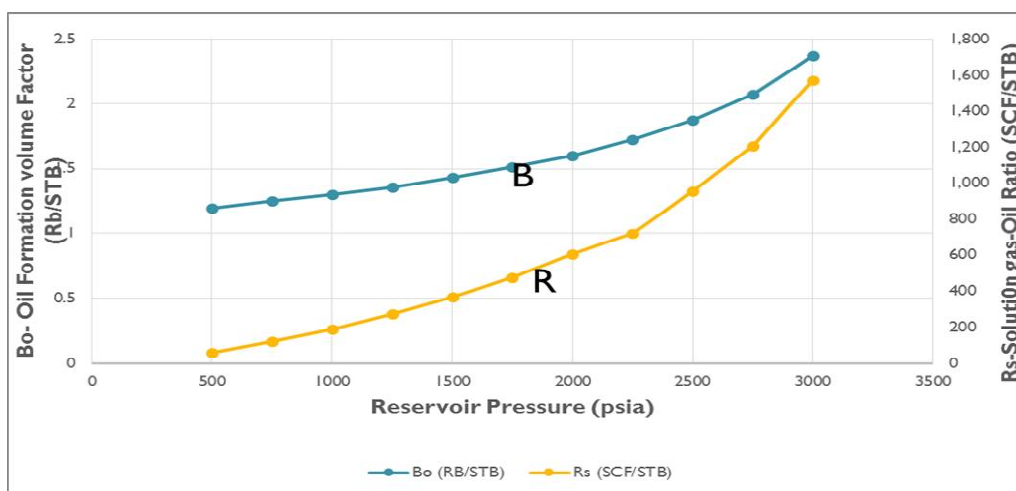
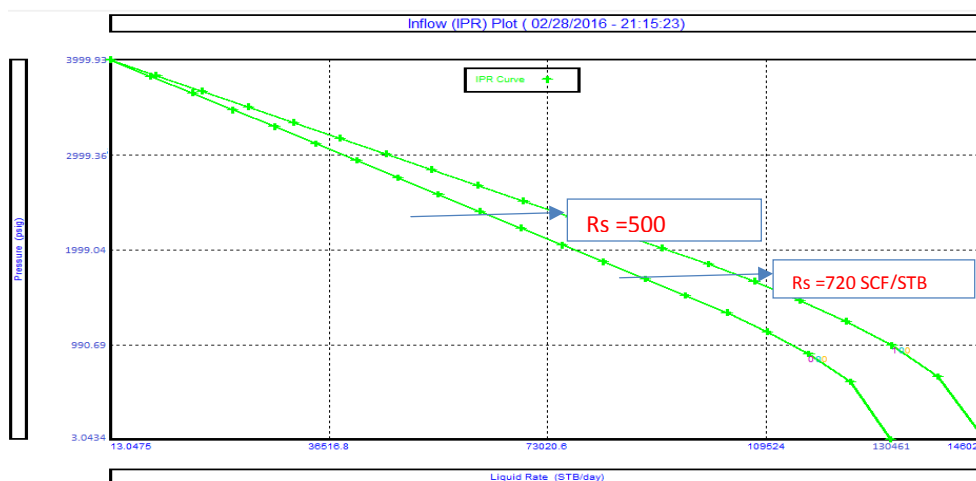


Fig. 2. Simulated oil formation volume factor and solution gas-oil ratio of gas

**Table 2. PVT properties from BO PVT algorithm**

Pressure (psia)	B <sub>o</sub> (RB/STB)	B <sub>g</sub> (RB/MSTB)	R <sub>s</sub> (SCF/STB)	R <sub>v</sub> (STB/MMSCF)
3224		1.20		204
3,000	2.33 (-1%)	1.25	1,529 (-3%)	155
2,750	2.02 (-2%)	1.34	1,152 (-5%)	125
2,500	1.82 (-3%)	1.46	887 (-7%)	105
2,250	1.66 (-4%)	1.61	684 (-10%)	90
2,000	1.53 (-4%)	1.81	500 (-14%)	79
1,750	1.43 (-5%)	2.07	379 (-20%)	71
1,500	1.34 (-6%)	2.43	259 (-29%)	65
1,250	1.27 (-7%)	2.94	154 (-43%)	62
1,000	1.20 (-8%)	3.72	61 (-68%)	61
750	1.14 (-9%)	5.05	-22 (-118%)	65
500	1.08 (-10%)	7.81	-96 (-261%)	78

The plot showing the IPR curves of both models is shown in Fig. 3.

**Fig. 3. IPR curve showing production performance of both models**

When the data from the BO PVT algorithm prediction was used, where  $R_s = 500$  SCF/STB, the production prediction obtained in terms of liquid flow rate was 130,461 STB/day. When data from the result of the rigorous flash calculation carried out in obtaining accurate PVT properties was used, where  $R_s = 720$  SCF/STB, the liquid flow rate was 146,028 STB/day. A significant difference of over 10,000 STB/day is obtained.

#### 4. CONCLUSION

At the end of this research, conclusions based on the results obtained are drawn, these include:

- Standard BO PVT properties of a gas condensate reservoir have been rigorously simulated based on hypothetical reservoir fluid and prescribed reservoir and surface

production conditions to provide insight into the limitations of black-oil PVT formulations. Simulation results demonstrated that species material balance conservation of surface gas and stock tank oil pseudo-components can be violated by the BO PVT model, while still honoring overall material balance. The limitation stems from assumption inherent to the pseudo-component model, which requires the composition of every pseudo-component to remain the same regardless of pressure.

- The violation of the species material balance principle by the BO PVT model leads to significant errors in standard BO PVT property estimations when techniques

that rely on species material balance statements are used.

- c) A case example shows that calculated reservoir oil-related PVT properties such as oil formation volume factor (Bo) and solution gas–oil ratio (Rs) using BO PVT property prediction algorithms can be significantly underestimated due to the BO PVT model limitations as shown in Table 2.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge everyone who contributed in one way or the other to the successful completion of research. Specifically, we want to acknowledge Dr. Charles I. C. Anyadiegwu who supported this work but was later indisposed to complete it secondly, all the lecturers in the department of Chemical and Petroleum Engineering, University of Uyo. And finally, Mrs. Kufreabasi Aniedi for her support and encouragement.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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