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New Correlations for Gas Oil Ratio and Oil Formation Volume Factor for Gas Condensate Reservoirs

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ABSTRACT: The PVT properties are used in a wide variety of reservoir engineering calculations such as material balance calculations and finite difference numerical simulations. For gas condensate reservoirs, the main PVT properties that are used to predict the gas condensate reservoir behavior are solution gas oil ratio, oil formation volume factor, gas formation volume factor and vaporized oil gas ratio. The best source of the PVT properties is the laboratory PVT analysis of reservoir fluid samples. In the absence of the experimentally measurement of these properties, the PVT properties must be calculated from empirical correlations. In this paper, new correlations were developed to determine the gas oil ratio and oil formation volume factor for gas condensate reservoirs. To estimate the constants of the new correlations of the gas oil ratio and oil formation volume factor for gas condensate reservoirs, about 300 values obtained from PVT reports of gas condensate fluid samples, were used. Whitson and Torp's method was used to generate the values of oil formation volume factor and used them for developing the new correlations for oil formation volume factor. These samples were selected to cover a wide range of gas condensate reservoirs properties such as pressure, temperature and oil gravity.

KEYWORDS: Gas oil ratio; Oil formation volume factor; gas condensate reservoir; Correlations.

1 INTRODUCTION

The main PVT properties that are used for predicting the gas condensate reservoir behavior are solution gas oil ratio, oil formation volume factor, gas formation volume factor and vaporized oil gas ratio. These PVT properties are defined as

$$B_o = \frac{V_o}{V_{oo}} \qquad B_g = \frac{V_g}{V_{gg}}$$

$$R_s = \frac{V_{go}}{V_{oo}} \qquad R_v = \frac{V_{og}}{V_{gg}}$$

Numerous authors have discussed how the differential-vaporization data are manipulated to derive oil formation volume factor, gas formation volume factor and solution gas oil ratio. Obtaining the black-oil PVT properties for gas condensates and volatile oils is less straightforward because these reservoir fluids require determination of vaporized oil gas ratio in addition to oil formation volume factor, gas formation volume factor and solution gas oil ratio.

Whitson and Trop [1] presented methods for evaluating constant volume depletion (CVD) data obtained from experimental analysis of gas condensate and volatile oil reservoirs. They estimated first fluid properties from measured CVD data by using material balance equation, then using material balance results and separation flash program to calculate the black oil formation volume factor and solution gas oil ratio and finally investigation of the Peng Robinson (PR) equation of state as a tool for matching measured PVT data and studying vapor/liquid phase behavior during CVD.

Coats [2] gave a procedure for estimating PVT properties of a gas condensate reservoir by using equation of state. He determined solution gas oil ratio, oil formation volume factor, gas formation volume factor and vaporized oil gas ratio as a function of pressure with constant surface gravities.

Walsh [3] developed a simple method computes the black oil PVT properties of gas condensate reservoirs which is called Walsh – Tower algorithm. This method required only data normally available from a standard constant volume depletion such as oil produced, gas produced, gas compressibility factor for both single and two phase and retrograde liquid volume fraction to obtain the so-called block oil PVT properties (solution gas oil ratio, oil formation volume factor, gas formation volume factor and vaporized oil gas ratio) of gas condensate reservoirs. The method does not require k-values, equation of state, flash routines or empirical correlation.

El-Banbi et al. [4] developed a new set of MOB PVT Correlations to investigate the four PVT functions (solution gas oil ratio, oil formation volume factor, gas formation volume factor and vaporized oil gas ratio). The new correlations were validated using the generalized material balance equation calculation with data generated from a compositional reservoir simulator. This new correlations depend only on readily available parameters in the field and can have wide applications when representative fluid sample are not available. They concluded that the new oil gas ratio correlation in accurate within 10.4% for gas condensate reservoirs and 15% for volatile oil reservoir.

Siddique et al. [5] demonstrated the calculation of the PVT properties below the saturation pressure for a gas condensate reservoir by application Walsh – Tower algorithm and k-values flash method (Whitson – Trop method). Then they applied Havlena – Odeh and Cole plot method to estimate initial gas inplace. They noted that the main limitations of Walsh – Tower algorithm are that the resulting standard PVT properties apply to only the set of separation condition used in PVT reports and requires the recovery data from CDV report. Most but not all laboratories include these data. If these data are not included, it can be computed by performing flash calculation.

2 FLUID SAMPLES

About 300 data points were collected from different Middle East gas condensate fields which are being used in this study to modify the correlations for calculating gas oil ratio and oil formation volume factor for gas condensate reservoirs. The samples were selected to cover a wide range of gas condensate properties. The ranges of the data used were shown in Table (1).

Table 1. The range of data used

Reservoir, rock and fluid properties	Range	Unit
Pressure	1000 - 9200	psia
Temperature	150 - 350	F
API	36 - 75	API
Gas oil ratio	500 - 2252840	SCF/STB
Oil formation volume factor	0.82 – 5.8	Bbl/STB

3 GAS OIL RATIO

Several correlations were used to test the data. These correlations include the following:

- Standing correlation
- Vasques and Beggs correlation
- Glaso correlation
- Al-Marhoun correlation
- Petrosky correlation, and
- Kartoatmodja and Schmith correlation

Because these correlations were developed for oil reservoirs not for gas condensate reservoirs, all the above correlations gave the average absolute error higher than 50% if the original correlations parameters constants were used. Therefore, the Galso and standing correlations (1) and (2) were modified using regression analysis technique.

$$R_s = \left[N_{PB}\frac{API^{A_1}}{T^{A_2}}\right]^{A_3} ---------------(1)$$

Where:

$$N_{PB} = 10^{A_4 - (A_5 - A_6 \log(P))^{A_7}}$$

$$R_s = \gamma_g\left[\left(\frac{P}{A_1}+A_2\right)10^{A_3 API - A_4 T}\right]^{A_5} ---------(2)$$

The new parameters for modified Glaso and modified Standing correlations are given in Tables (2) and (3) respectively. These new parameters for modified Glaso and modified standing correlations were obtained from regression analysis of the data samples. The average absolute error calculated by using modified Glaso correlation was 13.24%. While the modified Standing correlation showed higher average absolute error (32.84%).

Table 2. modified Glaso correlation parameters

A_1	3.188907
A_2	-3.24028
A_3	1.951737
A_4	-9.22168
A_5	12.03274
A_6	1.412587
A_7	0.364746

Table 3. modified Standing correlation parameters

A_1	61.00705
A_2	173.8931
A_3	1.736704
A_4	-0.3131
A_5	0.023712

4 OIL FORMATION VOLUME FACTOR

Several correlations were tested for the selected data samples. These correlations include the following:

- Standing correlation
- Vasques and Beggs correlation
- Glaso correlation
- Al-Marhoun correlation
- Petrosky correlation, and
- Kartoatmodja and Schmith correlation

Because the above correlations gave the average absolute error higher than 20% when the original correlations parameters constants were used. Al-Marhoun correlation and Petrosky correlation parameters which are given by equations (3) and (4) were modified by using regression analysis technique.

$$B_o = A_1 + A_2(T+460) + A_3F + A_4F^2 ------------(3)$$

Where:

$$F = R_S^{A_5} \times \gamma_g^{A_6} \times \gamma_o^{A_7}$$

$$B_o = A_1 + A_2\left[R_s^{A_3}\left(\frac{\gamma_g^{A_4}}{\gamma_o^{A_5}}\right) + A_6 \times T^{A_7}\right]^{A_8} ---------- (4)$$

The new parameters for modified Al-Marhoun and modified Petrosky correlations are given in Tables (4) and (5) respectively. These new parameters for modified Al-Marhoun and modified Petrosky correlations were obtained from regression analysis of the data samples. The average absolute error calculated by using modified Al-Marhoun correlation was 2.2%. While the average absolute error of the modified Petrosky correlation was 2.31%.

Table 4. modified Al-Marhoun correlation parameters

A_1	0.49708936
A_2	0.00029807
A_3	0.00146134
A_4	6.0873×10^{-6}
A_5	0.53536941
A_6	-12.2606295
A_7	10.2302013

Table 5. modified Petrosky correlation parameters

A_1	0.739195998
A_2	2.13816×10^{-5}
A_3	0.327085506
A_4	-6.8693667
A_5	-5.1799551
A_6	0.11860528
A_7	0.561332521
A_8	3.003458476

5 VALIDATION OF THE NEW CORRELATIONS

The actual data and the data results from new modified correlations are plotted to gather in Figures (1) to (4) to show that the crossplot of data results from new developed correlations almost fall on the 45° line implying excellent correlation.

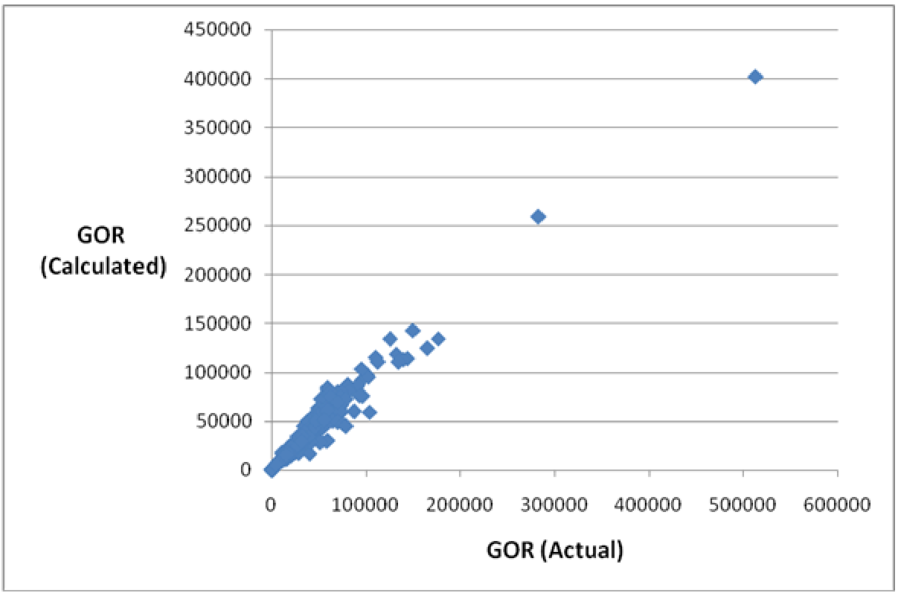

Fig. 1. Crossplot of actual data against predicted data from new modified Glaso correlation

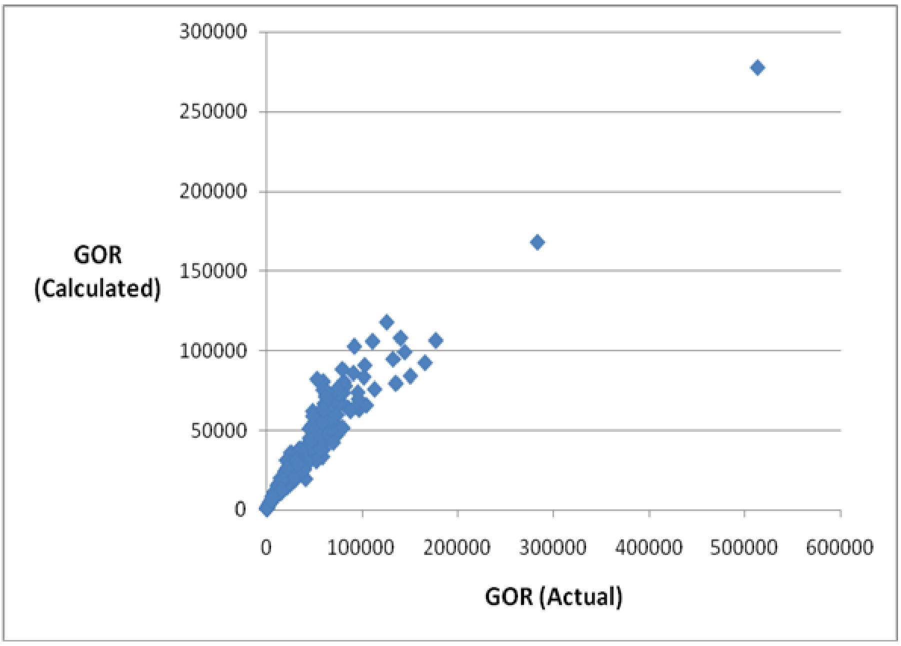

Fig. 2. Crossplot of actual data against predicted data from new modified Standing correlation

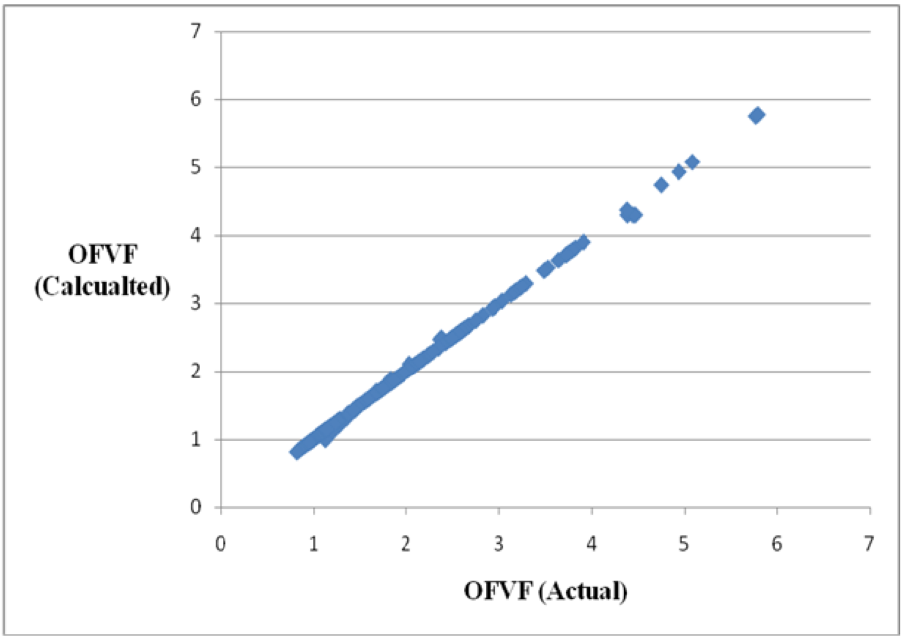

Fig. 3. Crossplot of actual data against predicted data from new modified Al-Marhoun correlation

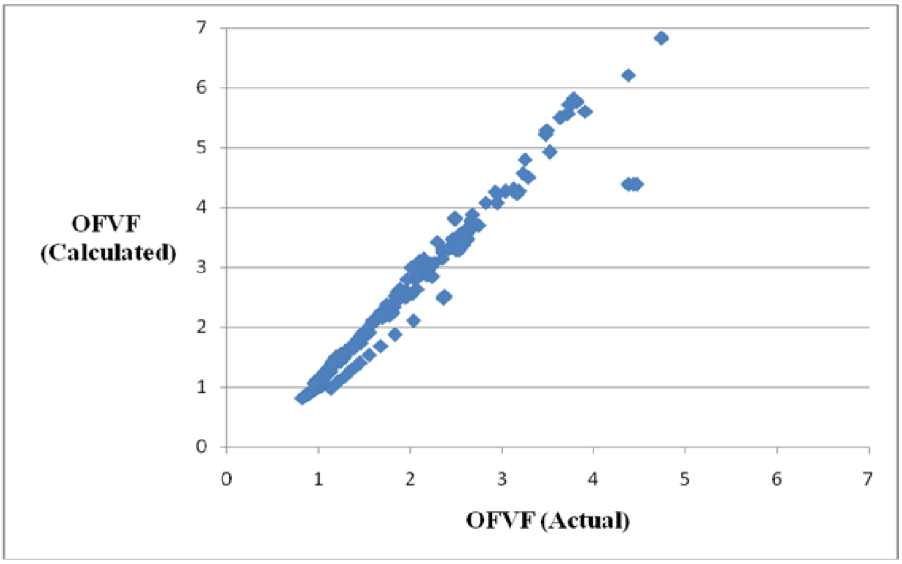

Fig. 4. Crossplot of actual data against predicted data from new modified Petrosky correlation

6 Conclusions

- The new correlation for gas oil ratio was modified to increase its accuracy when used with gas condensate reservoirs.
- The oil formation volume factor correlation was modified to increase its accuracy when used with gas condensate reservoirs.
- The new modified correlations for gas oil ratio and oil formation volume factor can be used in generalized material balance calculations for gas condensate reservoirs.

NOMENCLATURES

API = Oil gravity

Bo = Oil formation volume factor

Bg = Gas formation volume factor

P = Reservoir pressure, psia

Rs = Gas oil ratio

Rv = Vaporized oil gas ratio

T = Reservoir temperature, F

Vg = Reservoir gas volume

Vgg = Volume of surface gas produced from the reservoir gas

Vgo = Volume of surface gas produced from the reservoir oil

Vo = Reservoir oil volume

Vog = Volume of stock tank oil produced from the reservoir gas

Voo = Volume of stock tank oil produced from the reservoir oil

γg = Specific gravity of gas

γ_o = Specific gravity of oil

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