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Investigating the Impact of PVT Analysis Errors on Material Balance Calculations for Oil Reservoirs

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Abstract

Original hydrocarbons in place calculations using material balance equation are sensitive to the input data uncertainty, these inputs are production data, pressure data, and PVT data. In literature, most of research done to study the effect of input data uncertainty are focused on the production data uncertainties, but for the effect of PVT data uncertainty on MB calculations are rarely considered. This paper discusses the impact of PVT data uncertainty on MB calculations for volumetric oil reservoirs. In this work, the MB calculations for volumetric oil reservoirs are investigated versus PVT data errors. Synthetic errors are introduced into reservoir fluid properties that are used as inputs for the MBE such as oil formation volume factors , solution gas oil ratio, and bubble point pressure the amount synthetic errors introduced to all PVT parameters were ±5% and ±10% in order to account for typical PVT laboratories errors. The MB calculations were performed for different three volumetric oil reservoirs using the erroneous PVT data and the resulting OOIP values are compared to the base case of each reservoir. The average relative errors observed in the calculated OOIP for sample-01 from errors introduced to all PVT parameters ±5% and ±10% were -1%, -7%, 18%, 36%, respectively. In case for Sample-02 the relative errors for the same introduced errors were -16% and -20%, 21%, and 44%, respectively, while, in Sample-03 the relative errors were -26%, -44%, 31%, and 81%, respectively.

Keywords*: Obomkpa coal; Organic macerals; Vitrinite; Pyrolysis; Combustion; Nigeria.*

1. Introduction

Characterization of the reservoir is an vital step earlier before conducting any studies for reservoir simulation. This step is requieded to detect uncertainty range in reservoirs [1]. The material balance equation is a simple, efficient, and important tool for reservoir engineers [2]. Material balance methods are still usually used in analyzing performance of reservoirs and evaluation the OGIP and OOIP. The MB calculations require reservoir pressure, production, and PVT data in order to build a well-calibrated MB model that can be used for estimate the OHIP (oil and/or gas), identify the reservoir drive mechanism and its indices and predict the future performance of the reservoir pressure/production [3]. If any one of these input data has inaccuracies or errors, it will effect automatically on the output of the material balance equation [4]. The data quality of each input parameter for MBE is a vital concern. Usually, the oil and gas production data are measured inaccurate as the oil and gas company's revenues are based on these data [5]. However, the reservoir pressure measurements are quite limited and in some cases are questionable due to reservoir heterogeneities, some averaging procedures are used to compute the reservoir pressure history [6]. Reservoir pressure uncertainties and their effects on MB calculations have been investigated by many different researchers and well documented. Also, PVT data can be uncertain, due to the absence of a representative fluid sample for PVT analysis, sampling cost, and uncertainty of measurements or obtained data. Therefore in case of the absence of the experimental measurements, using empirical correlations instead for MB calculations is necessary [7]. Mc-Ewen used a statistical method to get straight line equation through the origin thereby isolating the uncertainty in the dependent variable with minimum square fitting method was used to get results [8]. L. Mattar and R. McNeil presented metod to evaluation original gas-in-place (OGIP). This method involves cumulative production versus a p/z plot of the flowing pressure. A straight line was drawn over the pressure data and at that time, a parallel line also was drawn over the reservoir pressure to get the original gas-in-place. [9]. Heather and Robert decided the uncertainty comes from some causes such as incomplete data sets, measurement errors, and mathematical model errors. error type can be reduced by using human effort and other perfect tools, but it will never be removed [10].

This paper will investigate the deviations of OOIP calculated by MBE against the introduced errors into all PVT data of three different reservoirs. For these different cases, the pressure and production data are assumed to be measured in an accurate manner and only the uncertainty of PVT data is considered.

2 Case Studies

Three reservoirs located in the Western Desert of Egypt were used in the MB calculations. These reservoirs are oil reservoirs contained different oils and the solution gas drive (depletion drive) is the dominant drive mechanism and no secondary recovery method is applied upon the study time. PVT data for each reservoir are acquired from the PVT laboratory analysis. Using the MBAL tool of the PETEX package is used to build the material balance models for each reservoir. The first reservoir contains black oil which has low gas-solution ratio (R_s) about 272 SCF/STB, 25 °API, and 1.2 oil formation volume factor (B_o). The second reservoir is containing a volatile oil which has gas-solution ratio (R_s) about 1,312 SCF/STB, 33 °API, and 1.7 oil formation volume factor (B_o), while the third one is containing more volatile oil which has gas-solution ratio (R_s) about 3,390 SCF/STB, 41 °API, and 2.7 oil formation volume factor (B_o). All of these reservoirs pressure went below the bubble point pressure (P_b) as per reservoir pressures measurements.

3. Methodology

The general material balance equation for an oil reservoir can be written in the following expression [11]:

$$F = N\,E_t + W_e$$

$$F = N_p\left(B_o - (B_g * R_s)\right) + B_g\left(G_p - G_i\right) + \left(W_p - W_i\right)B_w$$

$$E_t = (B_o - B_{oi}) + (R_{si} - R_s)\,B_g + m\,B_{oi}\left(\frac{B_g}{B_{gi}} - 1\right) + (1+m)\,B_{oi}\left[\frac{S_{wc}\,C_w + C_f}{1 - S_{wc}}\right](P_i - P)$$

where, $\boldsymbol{F}$: The underground withdrawal (RB), $\boldsymbol{N}$: Original oil in place (STB), and $\boldsymbol{E_t}$: The total expansion term of an oil and its dissolved gas, gas cap, connate water, and pore volume compaction.

The above equation explained the general material balance equation and its parameters which mainly pressure, production and PVT data [12]. There are many computer programs are used to perform the different calculations for the different forms of material balance equations that could be used according to the reservoir type (oil and/or gas) [13]. The work started with building the MBAL models of each reservoir using the base case PVT data, then using PVT cell in PVT lab in order to introduce synthetic errors in each PVT sample that used to test the impact of such errors on the OOIP estimated from MBE. The new PVT data sets were used to recalculate the MBE which resulted in a new OOIP estimation. The relative errors percentage for the different cases are calculated using the following equation;

$$\%\,error = \frac{trial\ value - base\ value}{base\ value}$$

where, **trial value**; is the new calculated OOIP using the erroneous PVT data and **base value**; is the calculated OOIP using the original PVT data [14].

The original PVT parameters and the erroneous data are plotted on the plot for each parameter; the data for Reservoirs 01, 02 and 03 were summarized in Table 1, and the oil formation factor curves are shown in Figure 1, and the gas in solution ratio curves are shown in Figure 2. For Reservoir 02, the data summary is tabulated in Table 1, and the oil formation factor curves are shown in Figure 3, and the gas in solution ratio curves are shown in Figure 4. For Reservoir 03, the data summary is tabulated in Table 1, and the oil formation factor curves are shown in Figure 5, and the gas in solution ratio curves are shown in Figure 6.

Table 1. Summary for reservoirs 01,02, and 03

parameter	units	Reservoir 01	Reservoir 02	Reservoir 03
Reservoir pressure	psi	5,165	4,892	2,551
Reservoir temperature	°F	282	271	199
Rsi	SCF/STB	3,392	1,312	272
°API		41	32.7	25
γ_{gas}		1	0.89	1.02
CO_2	Mole%	6	3.6	0.6
H_2S	Mole%	0	0.0	0.0
Bubble point	psi	3,392	4,452	1,015

Table 2. Models results for reservoirs 01, 02, and 03 MBAL

PVT data error	Reservoir 01		Reservoir 02		Reservoir 03	
	OOIP	Relative error	OOIP	Relative error	OOIP	Relative error
10%	10.7	-7%	14.8	-20%	4.7	-44%
5%	11.4	-1%	15.6	-16%	6.2	-26%
0%	11.5	0%	18.6	0%	8.4	0%
-5%	13.6	18%	22.5	21%	11.0	31%
-10%	15.7	36%	26.8	44%	15.2	81%

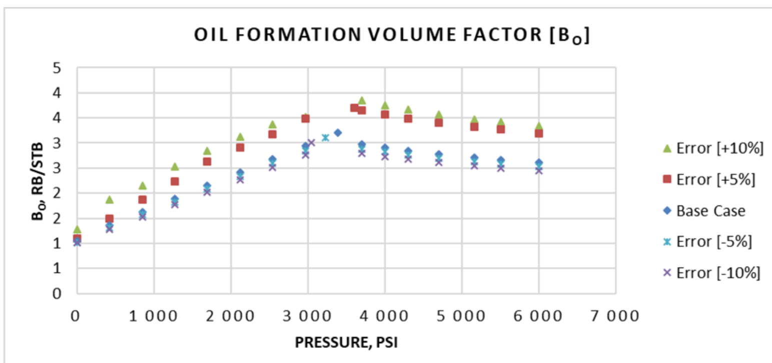

Figure 1. Oil formation volume factor for Reservoir 01; [Base case and erroneous PVT]

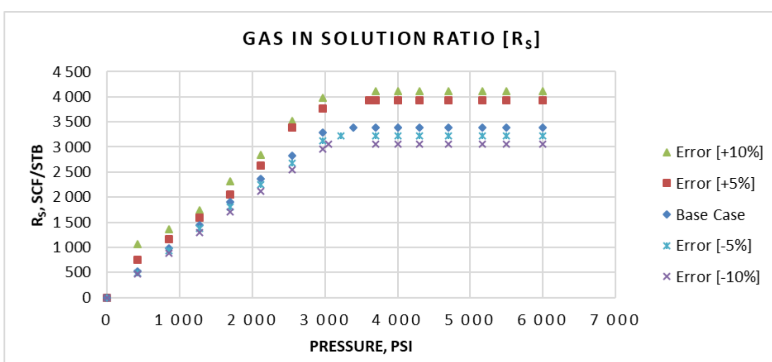

Figure 2. Gas in solution ratio for Reservoir 01; [Base case and erroneous PVT]

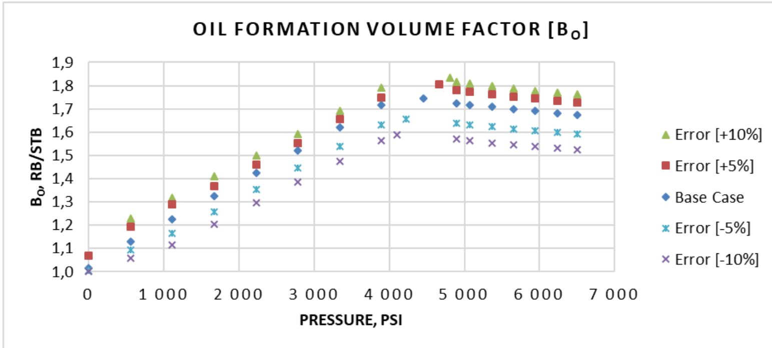

Figure 3. Oil formation volume factor for Reservoir 02; [Base case and erroneous PVT]

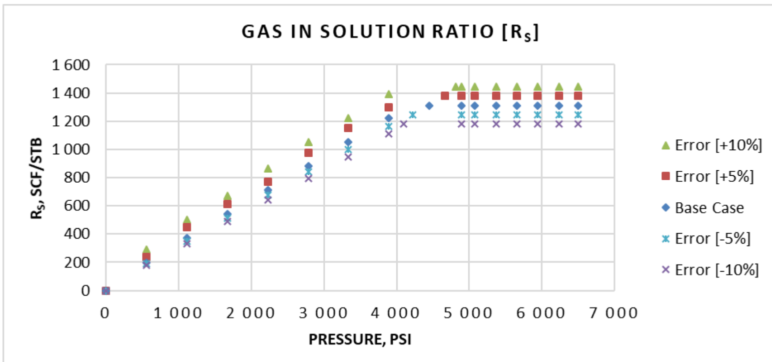

Figure 4. Gas in solution ratio for Reservoir 02; [Base case and erroneous PVT]

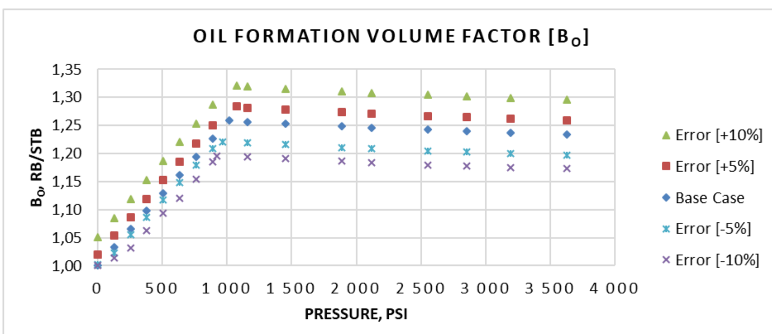

Figure 5. Oil formation volume factor for Reservoir 03; [Base case and erroneous PVT]

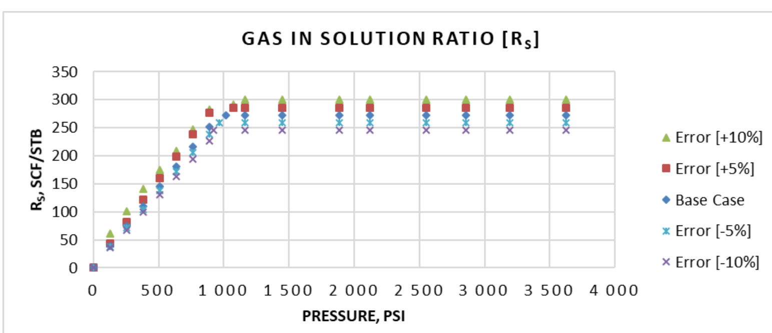

Figure 6. Gas in solution ratio for Reservoir 03; [Base case and erroneous PVT]

3. Results and discussion

3.1. For reservoir 01

It is a solution gas drive reservoir located in the Western Desert of Egypt, its initial pressure of 5,165 psi, the reservoir fluid is volatile oil as the B_o is greater than 2.0 RB/STB and the R_{si} is greater than 3,000 SCF/STB with an oil gravity up to 41°API. The average reservoir porosity is 10% and 20% initial water saturation. The reservoir was put on production in January 2008 and producing till now under the primary recovery. The OOIP as calculated from the base case model of MBAL is 11.5 MMSTBO and the reservoir has produced about 2.2 MMSTBO which about 19% recovery factor up to date of calculation. The introduced errors in all PVT parameters resulted in errors in the calculation of OOIP. Table 2 summarizes the MBAL results of the base model and introduced error models. We observed that the positive errors in PVT data resulted in lower calculated OOIP (+10% introduced error gives -7% relative error), on the other hand the negative errors resulted in higher calculated OOIP (-10% introduced error gives +36% relative error), which indicates the negative errors have larger impact than the positive ones.

3.2. For reservoir 02

It is a solution gas drive reservoir located in the Western Desert of Egypt, its initial pressure of 4,892 psi, the reservoir fluid is less volatile than Reservoir 01 as the B_o is about 1.6 RB/STB and the R_{si} is 1,250 SCF/STB with an oil gravity up to 33°API. The average reservoir porosity is 12% and 32% initial water saturation. The reservoir was put on production in August 2011 and producing till now under the primary recovery. The OOIP as calculated from the base case model of MBAL is 18.6 MMSTBO and the reservoir has produced about 1.03 MMSTBO which about 5.5% recovery factor up to date of calculation. The introduced errors in all PVT parameters resulted in errors in the calculation of OOIP. We observed that the positive errors in PVT data resulted in lower calculated OOIP (+10% introduced error gives -20% relative error), on the other hand the negative errors resulted in higher calculated OOIP (-10% introduced error gives +44% relative error), which indicates the negative errors have larger impact than the positive ones.

3.3. For reservoir 03

It is a solution gas drive reservoir located in the Western Desert of Egypt, its initial pressure of 2,552 psi, the reservoir fluid is black oil as the B_o is about 1.17 RB/STB and the R_{si} is 270 SCF/STB with an oil gravity up to 25°API. The average reservoir porosity is 12% and 32% initial water saturation. The reservoir was put on production in November 2014 and producing till now under the primary recovery. The OOIP as calculated from the base case model of MBAL is 8.4 MMSTBO and the reservoir has produced about 0.54 MMSTBO which about 6.4% recovery factor up to date of calculation. The introduced errors in all PVT parameters resulted in errors in the calculation of OOIP. We observed that the positive errors in PVT data resulted in lower calculated OOIP (+10% introduced error gives -44% relative error), on the other hand, the negative errors resulted in higher calculated OOIP (-10% introduced error gives +81% relative error), which indicates the negative errors have larger impact than the positive ones.

The general observation from the three reservoirs that the black oil is more sensitive for PVT data as its models have the highest errors in the calculated OOIP on both sides positive and negative introduced errors. In Figure 7, the resulted errors in the calculated values OOIP are plotted versus the introduced errors in PVT data and Figure 8 shows the calculated OOIP against the introduced errors in PVT data.

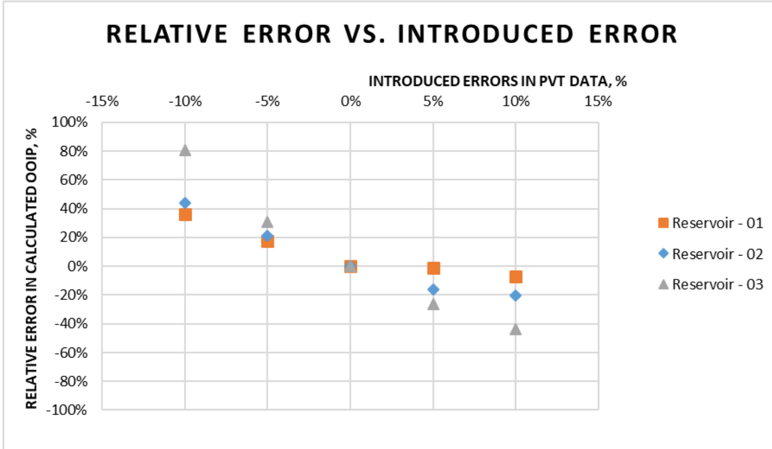

Figure 7. Relative errors in calculated OOIP vs. introduced errors in PVT data

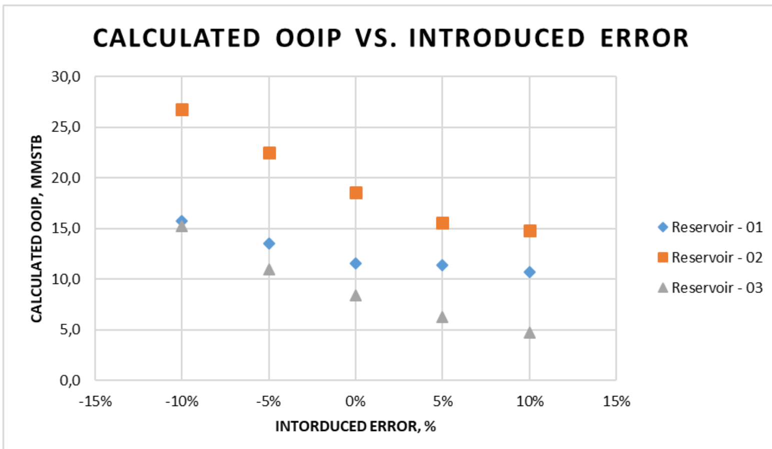

Figure 8 Calculated OOIP vs. introduced errors in PVT data

4. Conclusion

According to the work done in this research, the impact of PVT data errors on the calculated OOIP using MBE can be significant in all types of reservoir fluids and became badly on black oil reservoirs such as Reservoir 03 in this work. The PVT data should be calibrated with the production and pressure data (comparing the R_{si} from PVT analysis with the producing GOR) in order to make sure all of these data are in an agreement with each other which will help to reduce the uncertainties of the calculations of the MBE. In Figure 7, the resulted errors in the calculated values OOIP are plotted versus the introduced errors in PVT data and Figure 8 shows the calculated OOIP against the introduced errors in PVT data. The reservoir engineer should have a good understanding of the MBE assumptions, limitations, and calculations techniques and apply these concepts in order to get the best results of the MBE.

Nomenclature

PVT	*Pressure-Volume – Temperature relationship*
MB	*Material Balance*
MBE	*Material Balance Equation*
OOIP	*Original Oil In-Place*
OHIP	*Original hydrocarbons In-Place*
B_o	*Oil Formation Volume Factor, RB/STB*
B_{oi}	*Initial Oil Formation Volume Factor, RB/STB*
W_e	*Water Influx, RB*
N_p	*Produced Oil Volume, STB*

B_g	*Gas Formation Volume Factor, CF/SCF*
B_{gi}	*Initial Gas Formation Volume Factor, CF/SCF*
G_p	*Produced Gas Volume, SCF*
G_i	*Injected Gas Volume, SCF*
W_p	*Produced Water Volume, BBL*
W_i	*Injected Water Volume, BBL*
B_w	*Water Formation Volume Factor, RB/STB*
R_{si}	*Initial Gas In Solution Ratio, SCF/STB*
M	*Gas Cap volume to Oil volume*
S_{wc}	*Connate Water Saturation, fraction*
C_w	*Water Compressibility Factor, psi^{-1}*
C_f	*Formation Compressibility Factor, psi^{-1}*
P_i	*Initial Reservoir Pressure, psi*
P	*Average Reservoir Pressure, psi*
GOR	*Gas To Oil Ratio, SCF/STB*
MMSTBO	*Million Stock Tank Barrel of Oil*

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