

Development of Black Oil Correlations for approximation of PVT properties for Integrated Production Modeling for Heera Oil Field.



Ajoy Lal Dutta, Minati Das

Abstract— *Integrated Production Modeling approach mainly aims at integrating the Inflow performance and Outflow Performance of oil wells along with the analysis of the multiphase flow through wellhead up to the processing plant. Results of Reservoir and Production simulation studies heavily rely upon the accuracy of the PVT data as input. It is observed that sufficient high-quality experimental data from PVT Lab are not always available for fluids characterization. It makes the use of PVT modeling with Equation of state (EOS), Simulation techniques, and other statistical and empirical regression approaches viz. Black Oil Correlations to provide approximations of these PVT physical properties. Black Oil Correlations developed by previous researchers were based on crudes of different geologic locations with different crude compositions, paraffinicity and chemical properties and have their own range of applicability. Hence, for the reservoir fluids of a new study area, to achieve better approximation of PVT properties new regional correlations are required.*

In this work, a study has been made for determination of the four most important PVT properties based on limited available lab determined PVT data sets, by developing four regional black oil PVT correlations for (i) Bubble Point Pressure (ii) Oil Formation Volume Factor (iii) Solution Gas Oil Ratio and (iv) Dead Oil Viscosity, for a part of Heera Oil Field of Western Indian Offshore. These correlations were developed by taking reference of a few existing correlations and determined the new coefficients by Non-linear regression analysis. Comparative error analysis shows that these correlations are capable of better approximations of these physical properties with least Average Percentage Relative Error and Average Absolute Percentage Relative Error. Hence found as best suitable for the reservoir fluids of Heera Field. These correlations may be useful for calculation of important PVT data required for Integrated Production Modeling and optimization of Heera Field wells and for any oil field with similar geologic location and with reservoir fluids having similar ranges of physical properties.

Keywords— *Black Oil PVT Correlations, Bubble Point Pressure, Oil Formation Volume Factor, Dead Oil Viscosity, Solution GOR.*

Manuscript published on November 30, 2019.

* Correspondence Author

Ajoy Lal Dutta*, Research Scholar, Department of Petroleum Technology, Dibrugarh University, Dibrugarh, Assam, India. Email: dutta_al@ongc.co.in

Prof. Minati Das, Dean, Faculty of Earth Sciences and Energy, Dibrugarh University, Dibrugarh, Assam, India. Email: minatidas@dibru.ac.in

© The Authors. Published by Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP). This is an [open access](https://creativecommons.org/licenses/by-nc-nd/4.0/) article under the CC-BY-NC-ND license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

I. INTRODUCTION

Integration of Reservoir Engineering and Production System Optimization studies encompass single or multiphase flow of reservoir fluid from the reservoir boundary through the Well-conduit up to the processing plant. The pressure and temperature drop estimation and changes in flow regime require intense quality data of reservoir fluid properties. Reservoir Fluid properties can be correlated as functions of Pressure, Temperature, Oil Gravity and Gas Gravity [1].

Reservoir Fluid Characterization in the form of PVT data accounts for more than 80% of the quality of a well model. To determine PVT properties at different pressures and temperatures within the operating ranges of the entire production system, at different points of the lifespan of the reservoir with PVT sampling and frequent Laboratory experiments have proven to be expensive. Sufficient high-quality experimental data as required for Integrated Production Modeling does not always available. It compels to model the fluid properties using statistical and empirical approaches, for a better approximation of PVT data.

PVT modeling in well-modeling simulators are done with (i) Compositional Model and (ii) Black Oil PVT Models [2]. Compositional Model or Equation of State (EOS) models require the detailed composition of fluids [3], numerous computations and the process reported being computationally expensive. Whereas, Black Oil PVT Model uses consistent Black Oil PVT Correlations based on limited available lab analyzed PVT data for the further approximation of PVT properties and reported as relatively computationally inexpensive.

In the last few decades, numerous Black Oil PVT correlations developed by previous Researchers. Standing [4] presented correlations for estimation of Bubble Point Pressure, Solution GOR and Oil Formation Volume Factor (OFVF) for California Oils. Lasater [5] correlation for bubble point was based on reservoirs of Canada. Beggs and Robinson [6] suggested correlation for Dead Oil Viscosity for oil of API 16-58 Degree and indicated that it tends to overstate the viscosity when temperature level ranges below 100°F. Glasco [7] claimed that his correlations approximate more accurately for North Sea oils than Standing's [4] correlations. Works of [8], [9], [10], [11], [12], [13], [14] [15], [16], [17] presented different correlations for approximation of different PVT properties. New correlation development also reported with the use of PC-based programming methods as well as Genetic Algorithm methodologies. Lower the values of E_r and E_a through statistical error analysis, a better approximation of PVT properties can be achieved from such correlations [18], [19].

Development of Black Oil Correlations for approximation of PVT properties for Integrated Production Modeling for Heera Oil Field.

These reported correlations were developed based on the lab determined PVT properties of the Crude samples from different Geological Locations with crudes of different composition, paraffinicity and chemical properties. Each Correlation poses own Limitations and applicability ranges.

Considering the above, the present study has been made to develop Regional Correlations for calculation of four most important PVT properties (i) Bubble Point Pressure (P_b) (ii) Oil Formation Volume Factor (OFVF) (iii) Solution Gas Oil Ratio (SGOR) and (iv) Dead Oil Viscosity (μ_{od}); for the reservoir fluids of part of Heera oil field of western offshore basin of India.

Heera Oil Field is the second largest prolific Indian offshore oil field after Mumbai High with commercial production since 1984. It is a mature field and reservoir pressure depleted below the bubble point. The field was producing under depletion drive in initial 6 years up to 1990. It was observed that the Reservoir Pressure depleted from the initial range of 2000-2150psi to 1300-1375psi and the field experienced a sharp decline in production [20]. During depletion-mode, no water cut increase was observed indicating negligible aquifer influx/support. Water injection for pressure maintenance was started in Heera field in September 1990. Presently, out of 168 wells, more than 90% of wells are producing on Continuous Gas Lift Assistance [21]. Production history shows increasing water cut trend, decreasing Formation Gas Oil Ratio (FGOR) and a further increase in demand for lift gas. Developed regional PVT correlations of this work will be vital for reservoir fluid characterization, for Integrated Production Modeling studies and simulation experiments aimed at production optimization.

II. METHODOLOGY

The study is based on the following methodology:

1. Collection of PVT lab data, Reservoir study data, Flowing Gradient Survey data, Isobar Maps, Field regional geothermal data, other relevant data from Heera Field of western offshore basin.
2. Selection of few correlations from literature for approximation of (i) Bubble Point Pressure (P_b) (ii) Oil Formation Volume Factor (OFVF) (iii) Solution Gas Oil Ratio (SGOR) and (iv) Dead Oil Viscosity (μ_{od}).
3. Calculation of estimated values of the physical property using the selected correlation equations and using the PVT lab data sets.
4. Calculation of Relative Errors by comparing with the available PVT Lab Experimental Value of the particular property, against each Estimated Values.
5. Calculation of Average Percentage Relative Error (E_r) for each correlation.
6. Selection of reference correlation/equation with least E_r value for development of new correlation.
7. Calculation of Root Mean Square (RMS) Error for each data set. Total RMS error was calculated and formulated the problem as a RMS error minimization problem. The problem was solved by Non-Linear Regression using EXCEL SOLVER and determined new co-efficients for the new correlation.
8. Calculation of Estimated Values with the new correlation with new co-efficients.
9. Error Analysis to be done by calculating Average Percentage Relative Error (E_r) and Average Absolute Percentage Relative Errors (E_a), for the reference

correlation and newly developed correlation. Values of E_r and E_a are calculated as below-

$$E_r = (1/nd) * \sum E_i \quad (1)$$

$$E_a = (1/nd) \sum |E_i| \quad (2)$$

$$E_i = [(X_{exp} - X_{est}) / X_{exp}] * 100 \quad (3)$$

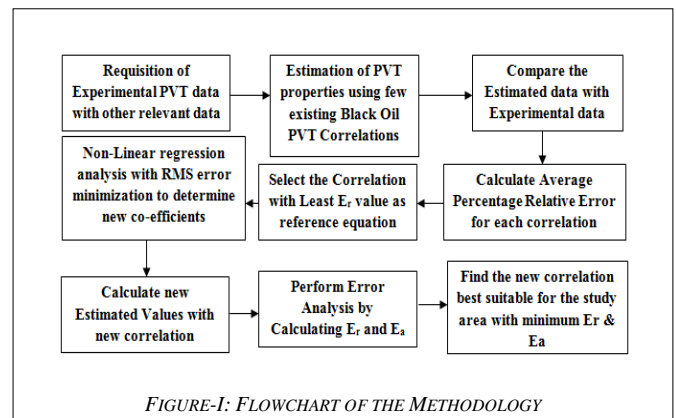
Where, $i=1,2,3,\dots,nd$

nd = Number of data points.

X_{exp} = Experimental values

X_{est} = Estimated values

10. Comparison of Error Percentages to ensure minimization of error by Non-linear Regression Analysis.
11. If both E_r and E_a values are found to be the minimum, the new correlation developed can be said as best suitable for the estimation of PVT properties of the study area.



III. DEVELOPMENT OF CORRELATIONS

A. Correlation for Oil Formation Volume Factor:

1) Requisition of Data:

For the present study 23 laboratory analyzed PVT data sets have been collected from study area. Each sample wise data sets comprised of Reservoir Temperature, Bubble point pressure, Gas Oil Ratio, Oil formation volume factor, Dissolved gas relative density, stock tank oil relative density.

2) Ranges of Data:

The ranges of data used as PVT data sets for OFVF (B_o) correlation development are tabulated as table-1.

TABLE I. RANGES OF PVT DATA USED FOR OFVF CORRELATION

| Physical Property | Minimum | Maximum |
|---|---------|---------|
| R_s =Solution Gas Oil Ratio (SCF/STB) | 284 | 849 |
| Oil relative density (γ_o) (Water=1) | 0.8178 | 0.8472 |
| Temperature ($^{\circ}$ F) | 180 | 229 |
| Gas Specific Gravity (γ_g) | 0.88 | 1.32 |

3) Selection of reference correlation:

For calculation of estimated values for Oil Formation Volume Factor (OFVF) correlations of Petrosky [12], Shammasi [14] Standing [4], Vasquez & Beggs [8] and Hanafy et al. [13], were selected and used with the laboratory analyzed 23 data sets. Experimental OFVF values were used to compare with these five existing correlation based Estimated values and calculated Relative Error against each data set.

Average Relative Error (E_r) percentages were calculated for each correlation and tabulated as Table-II.

TABLE II. AVG. PERCENTAGE RELATIVE ERROR FOR OFVF

| Average Percentage of Relative Error (E_r) | | | | |
|--|----------|---------|----------|---------|
| Petrosky | Shammasi | Vasquez | Standing | Hanafy |
| -3.2297 | 0.9816 | 10.3314 | -0.9487 | -0.6328 |

The percentage of Average Relative errors found less than one percent for Shammasi (0.9816%), Standing (-0.94878%) and Hanafy et al (-0.6328%). But, to keep the consideration of the effects of Oil gravity and Reservoir temperature on OFVF, Hanafy et al. was not considered as reference equation. The correlation of standing [4] had been chosen as reference correlation to develop new empirical correlation minimizing the errors.

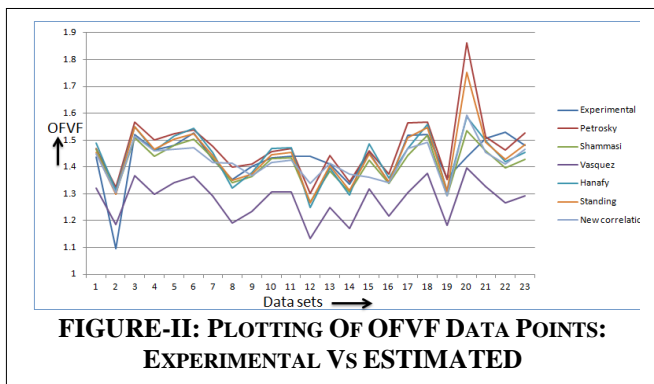


FIGURE-II: PLOTTING OF OFVF DATA POINTS: EXPERIMENTAL VS ESTIMATED

4) Development of New Correlation for OFVF (B_o) Approximation:

By Least-squares regression technique for curve fitting, using EXCEL's SOLVER, the new co-efficients for Correlation for OFVF approximation with reference to Standing [4] were determined, and tabulated in Table-III.

TABLE III. NEW CO-EFFICIENTS FOR NEW B_o CORRELATION

| Coefficient | Standing's Value | New Value |
|-------------|------------------|-----------|
| a | 0.972 | 0.744596 |
| b | 1.47 | 0.829233 |
| c | 1.25 | 6.79808 |

The new correlation for OFVF (B_o) developed in the present study takes the form-

$$B_o = 0.744596 + 0.829233 * 10^{-4} (R_s (\gamma_g / \gamma_o) 0.5 + 6.79808 * T) 1.175 \quad (4)$$

5) Error Analysis

Equation (4) was used to estimate new B_o values. As mentioned above in methodology, the error analysis between the Standing [4] reference correlations and the newly developed empirical correlations (4) in this present study for

Oil formation volume factor were carried out and results tabulated as Table-IV.

TABLE IV. COMPARATIVE ERROR ANALYSIS FOR NEW B_o CORRELATION

| Error Analysis | Standing [4] Correlation | Equation (4), New Correlation developed in the present study |
|----------------|--------------------------|--|
| Er | -0.9487 | 0.3214 |
| Ea | 3.4581 | 3.4475 |

B. Correlation for Bubble Point Pressure (P_b):

1) Requisition of Data:

For the present study 23 laboratory analyzed PVT data sets were requisitioned from study area. Sample wise data sets comprised of Experimental P_b (Psia), Temperature ($^{\circ}F$), Specific Gravity of Gas and API of the crude sample.

2) Ranges of Data:

The ranges of data used were tabulated as Table-V.

TABLE V. RANGES OF PVT DATA USED FOR P_b CORRELATION

| Physical Property | Minimum | Maximum |
|--|---------|---------|
| R_s =Solution Gas Oil Ratio (SCF/STB) | 284 | 849 |
| T =Reservoir Temperature ($^{\circ}F$) | 180 | 229 |
| Oil API (γ_o) | 35.5 | 41.7 |
| Gas Specific Gravity (γ_g) | 0.8 | 1.36 |

3) Selection of reference correlation:

From the literature review it has been observed that empirical bubble point pressure is a function of Solution Gas Oil ratio, relative oil density, gas specific gravity and reservoir temperature.

$$P_b = f (R_s, \gamma_o, \gamma_g, T) \quad (5)$$

The equation for Standing's [4] correlation was-

$$P_b = 18.2 ((R_s / \gamma_g) 0.83 (10^{0.00091T} / 10 0.0125 \gamma_o) - 1.4) \quad (6)$$

Shammasi's [14] general equation for bubble point correlation was-

$$P_b = \gamma_o^m e^{-nq} [R_s (460 + T) \cdot \gamma_g]^s \quad (7)$$

Where m, n, s are unknown co-efficients and $q = \gamma_o \cdot \gamma_g$

Shammasi [14] determined the values of co-efficients as in Table-VI.

TABLE VI. VALUES OF CO-EFFICIENTS OF SHAMMASSI [14]

| Co-efficient | Shammasi's Values |
|--------------|-------------------|
| m | 5.527215 |
| n | 1.841408 |
| s | 0.783716 |

Comparison among the P_b values estimated using the correlations of Shammasi [14], Hanafy [13], Standing [4] and Petrosky [12] was done and calculated E_r are presented in Table-VII.

TABLE VII. AVG. PERCENTAGE RELATIVE ERROR FOR P_B

| Average Percentage Relative Error | | | |
|-----------------------------------|----------|----------|------------|
| Petrosky | Hanafy | Standing | Shammasi's |
| -30.2547 | -58.7544 | -28.8105 | -11.7390 |

For these present studies Shammasi's [14] correlation was based on global data and in this study for P_b estimation it was found as with least Average percentage of Relative error in comparison to the other correlations. Hence, Shammasi's [14]

equation was selected as reference correlation for developing new correlation for P_b. Data points of different correlations and Experimental values are plotted as Figure-II.

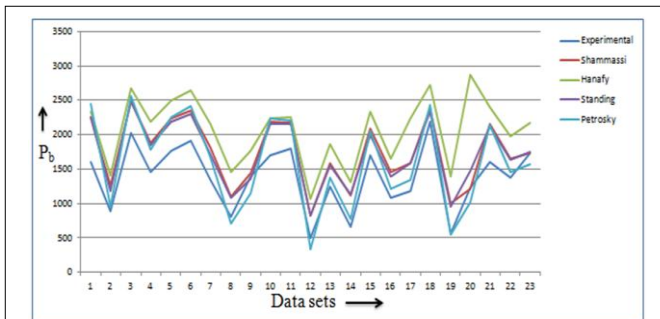


FIGURE-II: PLOTTING OF BUBBLE POINT PRESSURE DATA POINTS: EXPERIMENTAL VS ESTIMATED

4) Development of New Correlation for P_b Approximation:

By Least-squares regression technique for curve fitting, using MS-EXCEL's SOLVER, was applied and determined the new co-efficients for Correlation for Bubble Point Pressure with reference to (7). The new coefficients are found as tabulated in Table-VIII.

TABLE VIII. CO-EFFICIENTS DETERMINED FOR NEW P_B CORRELATION

| Coefficients | Shammasi Co-efficients | New Co-efficients determined by Present study |
|--------------|------------------------|---|
| m | 5.527215 | 7.8076228 |
| n | 1.841408 | 2.2239006 |
| s | 0.783716 | 0.8212156 |

With the new co-efficients for the new P_b correlation takes the form as-

$$P_b = \gamma_o^{7.8076228} e^{-2.2239006q} [R_s (460+T). \gamma_g]^{0.8212156} \quad (8)$$

Where m, n, s are unknown co-efficients and q = $\gamma_o \cdot \gamma_g$

5) Error Analysis

Equation (8) was used for estimation of P_b values. Error analysis between the Shammasi reference correlation (7) and the newly developed empirical correlation for Bubble Point Pressure was carried out and results tabulated as Table-IX.

TABLE IX. ERROR ANALYSIS FOR NEW CORRELATION FOR P_B

| Error Analysis | Shammasi (2001) Correlation | New Correlation developed in the present study |
|----------------|-----------------------------|--|
| E _r | -11.739 | 5.471 |
| E _a | 8.165 | 1.893 |

C. Correlation for Dead Oil Viscosity:

1) Requisition of Data:

From the literature it is found that, Dead Oil Viscosity can be expressed as a function of Temperature and API gravity of the crude oil samples.

$$\mu_{od} = f(T, API) \quad (9)$$

For Dead oil viscosity, 10 experimental data sets collected from Study Area. Each dataset consist of Reservoir Temperature, Experimental Viscosity and API gravity of crude.

2) Ranges of data:

Analyzing the data sets, the ranges of relevant physical properties for the present study for Dead Oil Viscosity Correlation, are tabulated in Table-X.

TABLE X. RANGES OF PVT DATA USED FOR DEAD OIL VISCOSITY CORRELATION DEVELOPMENT

| Physical Property | Minimum | Maximum |
|------------------------------------|---------|---------|
| Dead Oil Viscosity μ_{od} (cP) | 0.67 | 1.42 |
| T (Reservoir temperature) (°F) | 209 | 223 |
| Oil API | 36 | 41.5 |

3) Selection of reference correlation:

Labedi [11], Beggs and Robinson [6], Beal [22] and Glasso [7] correlations for Dead Oil Viscosity were selected for calculation of the estimated values. Estimated values were compared with the experimental values to calculate the Relative error against each data set and tabulated as Table-XI.

TABLE XI. AVG. PERCENTAGE RELATIVE ERROR DEAD OIL VISCOSITY ESTIMATION

| Average Percentage Relative Error | | | |
|-----------------------------------|----------|---------|--------|
| Labedi | Beggs | Glaso | Beal |
| 50.8690 | -40.1541 | -9.9258 | 8.1913 |

It was observed that the values estimated by Beal's [22] correlation for Dead oil viscosity mostly in close agreements with the laboratory analyzed values of the dead oil viscosities. The average percentage of relative error found as 8.191%, which is the lowest as compared with the other correlations used in this present study. Hence, for development of new correlation for Dead oil viscosity, Beal's correlation was considered as reference.

Proposed dead oil viscosity correlation with reference to the Beal's correlation for Dead oil viscosity estimation is-

$$\mu_{od} = (a+b*10^7/API^{4.53})*(c/(T+200))^x \quad (10)$$

Where, $x=10^{(0.43+d/API)}$

Values of co-efficients proposed by Beal were, a=0.32,

b=1.8, c=360 and d=8.33

4) Development of New Correlation for Dead Oil Viscosity Approximation:

The collected PVT experimental μ_{od} values and estimated μ_{od} values using the selected correlations were plotted, before performing curve fitting exercise with Non-linear regression analysis and data points are presented in Figure-III.



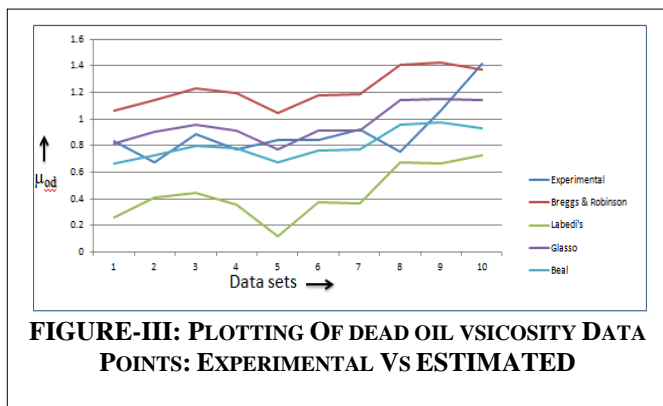


FIGURE-III: PLOTTING OF DEAD OIL VSICOSITY DATA POINTS: EXPERIMENTAL VS ESTIMATED

Non Linear regression analysis was performed to minimize the RMS error using EXCEL's SOLVER. New co-efficients determined by minimizing total RMS error. Results presented in Table-XII.

TABLE XII. COEFFICIENTS OF NEW CORRELATION FOR DEAD OIL VISCOSITY

| Coefficients | Beal's Co-efficients | Present study |
|--------------|----------------------|---------------|
| a | 0.32 | 0.40805 |
| b | 1.8 | 1.900253 |
| c | 360 | 274.1619 |
| d | 8.33 | -12.5711 |

The newly developed correlation for dead oil viscosity calculation for the crudes the study area takes the form as-

$$\mu_{od} = (0.40805 + 1.900253 * 10^7 / API^{4.53}) * (274.1619 / (T + 200))^x$$
 (11)

Where, $x = 10(0.43 - 12.5711 / API)$

5) Error Analysis:

The error analysis between the Beal's reference correlation (10) and the newly developed empirical correlation (11) in this present study for Dead Oil Viscosity was carried out and results tabulated as Table-XIII.

TABLE XIII. COEFFICIENTS OF NEW CORRELATION FOR DEAD OIL VISCOSITY

| Error Analysis | Beal's Correlation | New Correlation developed in the present study |
|----------------|--------------------|--|
| E_r | 8.19133 | -2.274 |
| E_a | 15.54 | 12.869 |

D. Correlation for Solution Gas Oil Ratio (SGOR):

1) Requisition of Data:

For estimation of SGOR, 35 experimental data sets were collected from the study area. Every data set consists of Specific Gravity of Gas, API, Reservoir Pressure, and Reservoir Temperature with Measured SGOR values.

2) Ranges of data:

Analyzing the experimental data from Heera field, the present study for development of Correlation for SGOR, is found to be bounded by the data ranges tabulated as table-XIV.

TABLE XIV. RANGES OF PVT DATA USED FOR DEVELOPMENT OF NEW CORRELATION FOR SOLUTION GOR.

| Physical Property | Minimum | Maximum |
|---|---------|---------|
| API (γ_{API}) | 35.5 | 41.4 |
| Reservoir Pressure; P (P _{sia}) | 500 | 2251 |

| | | |
|-----------------------------|--------|-------|
| Reservoir Temperature; (°F) | 207 | 223 |
| Specific Gravity of Gas; | 0.8825 | 1.291 |
| SGOR; SCF/STB | 259 | 797 |

3) Selection of reference correlation:

The correlations of Standing [4], Hanafy [13], Glasco [7] and Petrosky [12] were used to compare the estimated data against the experimental data sets. Average Relative Error Percentage was calculated for each correlation and tabulated as Table-XV.

TABLE XV. CALCULATED AVG. PERCENTAGE RELATIVE ERROR FOR CORRELATIONS OF SGOR

| Average Percentage Relative Error | | | |
|-----------------------------------|---------|----------|----------|
| Standing | Hanafy | Glasco | Petrosky |
| 5.518% | 21.734% | -15.097% | -4.485% |

From the above analysis, it was seen that, the Average Parentage of Relative error for the Petrosky [12] correlation was found as minimum as -4.48% as compared with the other three. Hence, for development of new correlation for SGOR, Petrosky's [12] correlation was considered as reference.

The empirical correlation Petrosky [12] for Gulf of Maxico oil was-

$$R_s = \{[(P/112.727) + 12.34] \cdot \gamma_g^{0.8439} \cdot 10^x\}^{1.73184}$$
 (12)

Where, $x = (7.916 * 10^{-4} * \gamma_{API}) - (4.561 * 10^{-5} * T^{1.3911})$

4) Development of New Correlations for Solution GOR:

The collected PVT experimental values and estimated SGOR values using the selected correlations were plotted, before curve fitting exercise with Non-linear regression analysis and data points are presented in Figure-IV.

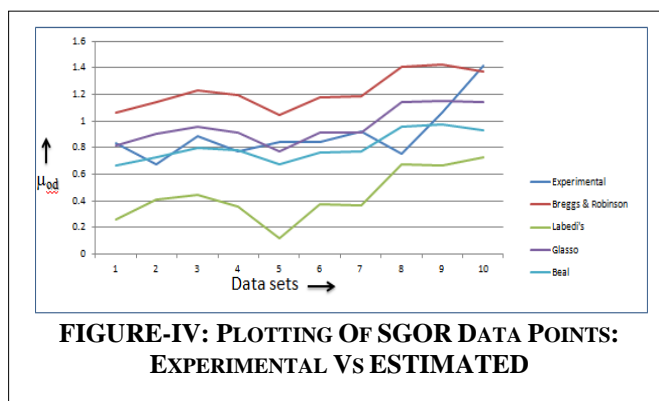


FIGURE-IV: PLOTTING OF SGOR DATA POINTS: EXPERIMENTAL VS ESTIMATED

By using SOLVER of MS-EXCEL, the regression analysis was done to minimize error with RMS technique and the new co-efficients were found and presented in Table-XVI.

TABLE XVI. NEW COEFFICIENTS DETERMINED FOR NEW SGOR CORRELATION

| Coefficients | Petrosky Co-efficients | Present study |
|--------------|------------------------|---------------|
| a | 112.727 | 200.1819 |
| b | 0.8439 | 0.015192 |
| c | 1.73184 | 1.894852 |

Development of Black Oil Correlations for approximation of PVT properties for Integrated Production Modeling for Heera Oil Field.

With the results, the newly developed correlation for Solution GOR calculation for the crudes of the study area takes the form as-

$$R_s = \{[(P/200.1819)+12.34] \cdot \gamma_g^{0.015192 \cdot 10^x} \cdot 1.894852\} \quad (13)$$

Where, $x = (7.916 \cdot 10^{-4} \cdot \gamma_{API}) - (4.561 \cdot 10^{-5} \cdot T^{1.3911})$

5) Error Analysis:

The comparative statement of error analysis between the Petrosky's correlations (12) and the new empirical correlations (13) proposed in this present study for SGOR are presented as Table-XVII.

| Error Analysis | Petrosky's Correlation | New Correlation developed in the present study |
|----------------|------------------------|--|
| Er | -4.485 | 2.731 |
| Ea | 17.141 | 16.868 |

IV. DISCUSSION

Accuracy of results of Reservoir and production simulation studies heavily relies upon the quality of the PVT data as input. For the study area, PVT lab analyzed data sets were available based on the reservoir fluid samples of 35 exploratory wells. As the reservoir pressure depletes with producing life and reservoir fluid properties changes with it. Estimation of fluid properties of each well and at different times of producing life require frequent PVT sampling and lab analysis. To avoid these repetitive expensive work, an effort was made to develop four regional Black Oil PVT Correlations to calculate four most important PVT properties (i) Bubble Point Pressure (P_b) (ii) Oil Formation Volume Factor (OFVF) (iii) Solution Gas Oil Ratio (SGOR) and (iv) Dead Oil Viscosity (μ_{od}) using few easily surface measurable data along with historical reservoir data, to approximate PVT properties of the producing fluid of each well at any point of producing life, with minimum errors; which is required for Integrate Production Modeling and optimization studies.

For development of regional correlation for Oil Formation Volume Factor (OFVF), correlations of Petrosky [12], Shammasi's [14], Standing [4], Vasquez & Beggs [8] and Hanafy et al. [12] were used to estimate values in the present study. Selected Standing [4] correlation as reference correlation with -0.948% Average Percentage Relative Error (E_r). By performing Non-linear regression analysis E_r value was further minimized to 0.321% by determining new coefficients, which is lower than the (-0.632%) value of E_r for Hanafy (1997). Error Analysis further shows that new correlation shows minimization of Ea value to 3.4475 from 3.4581 of the reference correlation. Hence, the new correlation developed is found most suitable for OFVF approximation for the reservoir fluids of the study area.

For development of regional correlation for Bubble Point Pressure (P_b), in this study, estimated data were calculated using the correlations of Shammasi [14], Hanafy [13], Standing [4] and Petrosky [12] and the Average Percentage Relative Error (E_r) were compared. As E_r value for Shammasi [14] correlation was found to be minimum as -11.739, this correlation was chosen as the reference correlation. For minimization of RMS error, non-linear regression analysis was carried out to determine new coefficients. By estimating new P_b values with new coefficients, it was successfully minimized E_r value to 5.471%. Error Analysis also shows minimization of Ea value to 1.89% only, from 8.165% for the reference

correlation. Hence, the new correlation developed is found most suitable for Bubble Point Pressure approximation for the reservoir fluids of the study area.

In this study, Labedi [11], Beggs and Robinson [6], Beal [22] and Glasso [7] correlations for Dead Oil Viscosity (μ_{od}) were selected for calculation of the estimated values and E_r values were calculated for development of regional correlation for μ_{od} . It was found that Beal [22] correlation shows the minimum value of E_r as 8.191% and this correlation was chosen as the reference correlation. For minimization of RMS error, non-linear regression analysis was carried out to determine new coefficients. By estimating new μ_{od} values with new coefficients, it was successfully minimized E_r value to -2.274%. Error Analysis also showed the minimization of Ea value to 12.86%, from 15.54% for the reference correlation. Hence, the new correlation developed is found most suitable for Dead Oil Viscosity approximation for the reservoir fluids of the study area.

For development of regional correlation for Solution Gas Oil Ratio (SGOR), in this study correlations of Standing [4], Hanafy [13], Glasso [7] and Petrosky [12] for SGOR were used to calculate estimated values for 35 data sets and compared with Experimental values of SGOR and E_r values were determined. In comparison, it was found that Petrosky [12] correlation shows minimum E_r value of -4.485% and this correlation was chosen as the reference correlation. For minimization of RMS error, non-linear regression analysis was carried out to determine new coefficients. By estimating new SGOR values with new coefficients, it was successfully minimized E_r value to 2.731%. From Error Analysis it was found that new correlation has lower Ea value of 16.868%, reduced from 17.141% for the reference correlation. Hence, the new correlation developed is found most suitable for SGOR approximation for the reservoir fluids of the study area.

V. CONCLUSION

The new regional Black Oil PVT Correlations for the approximation of (i) Bubble Point Pressure (P_b) (ii) Oil Formation Volume Factor (OFVF) (iii) Solution Gas Oil Ratio (SGOR) and (iv) Dead Oil Viscosity (μ_{od}) are found to be best suited for the reservoir fluids of the study area. Minimization of Average Percentage Relative Error and Average Absolute Percentage Relative errors were achieved by Non-linear regression with total RMS error minimization technique. A study on error analysis shows that the newly developed correlations fit better than the reference correlations.

Though the present correlations have been developed specifically for a part of Heera Offshore Oil Field, these correlations can be used for all types of oil and gas mixtures with properties falling within the ranges of data (as given in Table-I, V, X and XIV) used in this study.

From the above study it is finally concluded that the newly established correlations based on regression analysis taking the reference of earlier researcher's correlations, (i) Standing [4] for OFVF (ii) Shammasi [14] for P_b (iii) Beal [22] for μ_{od} and (iv) Petrosky [12] for SGOR, can be considered as excellent reliable predictive tool for estimating these four crude oil PVT properties.

These newly modified and developed PVT correlations can be used either to calculate PVT properties required as input data for simulators for production optimization studies or can easily be incorporated into production optimization software.

ACKNOWLEDGMENT

The authors are grateful to Oil and Natural Gas Corporation Limited (ONGCL), especially N&H Asset for the support provided for this academic study.

REFERENCES

1. T. Ahmed and P. D. McKinney, "Advanced Reservoir Engineering". Oxford, United Kingdom: Gulf Professional Publishing, 2005.
2. Petroleum Experts, "User Manual IPM PROSPER Version 11.5," no. January. Petroleum Experts Limited, Edinberg, Scotland, pp. 1–1527, 2010.
3. Ø. Fevang, K. Singh, C. H. Whitson, and N. Pera, "SPE 63087 Guidelines for Choosing Compositional and Black-Oil Models for Volatile Oil and Gas- Condensate Reservoirs," in SPE Annual Technical Conference and Exhibition held in Dallas, Texas, 1- 4 Oct., 2000, pp. 1–11. <https://doi.org/10.2118/63087-MS> (Accessed on: 08-August-2018)
4. M. . Standing, "A Pressure –Volume-Temperature Correlation for Mixtures of California Oils and Gases," in *Drilling and Production Practice, API*, 1947. <https://www.onepetro.org/conference-paper/API-47-275> (Accessed on: 11-June-2018)
5. J. A. Lasater, "Bubble Point Pressure Correlation," *SPE 957-G*, no. May, 1958. <https://doi.org/10.2118/957-G> (Accessed on: 14-June-2018.)
6. H. D. Beggs and J. F. Robinson, "Estimating the Viscosity of Crude Oil Systems," *J. Pet. Technol. Trans., AIME*, no. September, pp. 1140–1141, 1975.
7. Glasco, "Generalized PVT Correlations," *SPE 8016*, no. Published in May, 1980.
8. M. Vasquez and Beggs, "Correlation for Fluid Physical Property Predictions," *JPT*, no. JUNE, 1989.
9. Khan and M. A. AL-Marhoun, "Viscosity Correlations for Saudi Arabian Crude Oils," in *SPE 15720; Presented at Fifth SPE Middle East Oil Show held in Manama, Bahrain. March 7-10, 1987*.
10. M. A. AL-Marhoun, "PVT Correlations for Middle East Crude Oils," *J. Pet. Technol.*, no. MAY, pp. 650–666, 1988.
11. R. M. Labedi, "PVT Correlations of the African Crudes." p. PhD Thesis, Colorado School of Mines, 1982.
12. G. E. Petrosky and F. F. Farshad, "Viscosity Correlations for Gulf of Mexico Crude Oils," in *paper SPE 29468 presented at the Production Operations Symposium of the SPE, Oklahoma City, OK, 1995*. <https://doi.org/10.2118/29468-MS> (Accessed on 21-June-2018).
13. H. H. Hanafy, S. M. Macary, Y. M. ElNady, A. A. Bayomi, and M. H. El Batany, "Empirical PVT Correlations Applied to Egyptian Crude Oils Exemplify Significance of Using Regional Correlations," in *SPE-37295-MS, International Symposium on Oilfield Chemistry, 18-21 February, Houston, Texas, 1997*. <https://doi.org/10.2118/37295-MS> (Accessed on:22-June-2018)
14. A. A. Al-Shammasi, "Bubble Point Pressure and Oil Formation Volume Factor Correlations," in *SPE-53185-MS, Middle East Oil Show and Conference, 20-23 February, Bahrain, 1999*. <https://doi.org/10.2118/53185-MS> (Accessed: 23-June-2018)
15. M. N. Khan, H. M. Bilal, M. Shoaib, W. Shaukat, and T. Shakil, "Fluid Characterization of a Retrograde Gas Condensate Reservoir for the Simulation Study," in *SPE-163134-MS, SPE/PAPG Annual Technical Conference, 3-5 December, Islamabad, Pakistan, 2012*. <https://doi.org/10.2118/163134-MS>. (Accessed on: 23-July-2018)
16. K. A. Fattah, M. H. Sayyouh, U. Cairo, and A. H. El-Banbi, "New Modified Black-Oil Correlations for Gas Condensate and Volatile Oil Fluids," in SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, 29 Sept- 2 Oct. (SPE 102240), 2006., <https://doi.org/10.2118/102240-MS> (Accessed on: 01-August-2018)
17. K. A. Fattah and A. Lashin, "Improved oil formation volume factor (B o) correlation for volatile oil reservoirs : An integrated non-linear regression and genetic programming approach," *Journal of. King Saud University. - Engineering Science.*, pp. 0–6, 2016. <http://dx.doi.org/10.1016/j.jksues.2016.05.002> (Accessed on: 06-Nov-2018).
18. M. Das, P. K. Gogoi, and B. J. Saikia, "New Empirical Correlation for Oil Formation Volume Factor and Bubble Point Pressure of Crude Oils

for a Part of Upper Assam Oil Fields India.," *J. Appl. Geochemistry*, vol. 9, no. 2, pp. 170–182, 2007.

19. M. Das, P. K. Gogoi, and B. J. Saikia, "Development of Correlation of Oil Formation Volume Factor for Certain Fields of Eastern Part of Upper Assam Basin," *Indian J. Pet. Geol.*, vol. 15, no. 2, pp. 31–41, 2006.
20. T. K. Mandal *et al.*, "Review of Gas lift wells of Heera Field (Unpublished Report)." Institute of Oil & Gas Production Technology, ONGC, Panvel, pp. 1–181, 2016.
21. ONGC Reports, "Neelam & Heera Asset," *ONGC Reports*, 2018. [Online]. Available: <http://tiny.cc/uz5ec2>. [Accessed: 22-Aug-2018].
22. T. Ahmed, *Reservoir Engineering Handbook*, Second. Gulf Professional Publishing, 2001.

AUTHORS PROFILE



Ajoy Lal Dutta, Research Scholar at the Department of Petroleum Technology, Dibrugarh University, Assam, India. He pursued BE in Mechanical Engineering from Assam Engineering College and M.Tech in Petroleum Exploration and Production from Dibrugarh University. He is currently working for Oil and Natural Gas Corporation Ltd. (ONGC), as Superintending Engineer (Production) with 10 years experience in Offshore Oil Field Production Monitoring, Well problem analysis, Gas Lift Optimization, Smart Wellhead Platform Commissioning, Oil & Gas Processing and Onshore Control Room for Offshore Operations. He poses another 3 years experience in Onshore Oil Field Management with exposure to Production Operation Coordination, Vigilance Administration, Contract Management and Central Tank Farm Operations.



Prof. Minati Das, Dean, Faculty of Earth Sciences and Energy, Dibrugarh University, Assam, India. She has Six years industrial experiences in Oil & Natural Gas Corporation Ltd. as Reservoir Engineer and Assistant Director (Reservoir). She poses Thirty two years (approx) postgraduate teaching experiences in Reservoir Engineering in the Department of Petroleum Technology, Dibrugarh University. Completed two major research projects in consultation with oil industry (OIL & ONGC) under TIFAC-CORE, Department of Science & Technology, New Delhi. Research areas of interest: Petroleum Geology, Reservoir Engineering & Production Engineering. Established a Centre of Excellence (CORE) in Clastic Petroleum Reservoir Engineering in Dibrugarh University under Mission REACH. She received Prof. J.S.R. Krishna Rao, Dr. R. Dhana Raju, medal for the best paper published in the "Journal of Applied Geochemistry" (ISAG) for the year 2007. She was Awarded Associate membership of International congress of Chemistry & Environment (A.I.C.C.E.). She organized numbers of International Short term courses, National workshop and seminars in fields of Petroleum Technology. She has published numbers of Research papers in National and International Journals; presented numbers of technical papers in National and International Conferences, Proceedings/ Technical Workshop/ Symposium/Seminars. She has also edited one book and has two book chapters to her credit.