

Estimating the PVT Properties for Crude Oil from a Southern Iraqi Oil Field

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Abstract. The PVT properties of crude oil are important to calculations of production and reservoir performance. These properties can be determined in the laboratory at specified conditions of pressure and temperature. To estimate PVT fluid properties at a wider range of conditions of pressure and temperature, an empirical correlation should be used where there are no laboratory measurements. These empirical correlations can, however, only be used after making the appropriate adjustments to the specified crude oil samples. In this study, the data from laboratory measurements of the PVT properties for five oil samples were used. These five samples were collected from different wells within the Luhais oil field. The measurements were taken at reservoir conditions with slight differences from one sample to another. The five samples were then adjusted to the empirical correlations and the saturation pressure determined. The resulting models of the samples after adjustment were combined to estimate a generalised model of the fluid properties that represented the properties of the studied crude oil. The properties of formation volume factor, gas oil-ratio, and viscosity with respect to pressure at reservoir temperature, assumed to be 185 °F, are thus presented in this paper.

1. Introduction

Reservoir fluid properties are important data in the calculation of many aspects of production and reservoir engineering, including designing surface equipment, optimising separator conditions, examining multiphase flow in tubes, performing well test analysis, estimating hydrocarbon reserves, creating reservoir simulation models, predicting reservoir performance, and examining hydrocarbon flow through porous media, as well as leading to improved oil recovery applications. Thus, these properties need to be determined at the highest degree of accuracy possible.

These properties may be measured directly in a laboratory or estimated indirectly by using empirical correlations as discussed in the literature. The measurement of fluid properties in a PVT laboratory represents the most accurate method. In particular, the use of empirical correlations may not be accurate where the fluid samples that are used in development of these correlations are limited. Usually, these properties are measured in laboratory conditions related to pressure at reservoir temperature (isothermal conditions). In such cases, empirical correlations may be used to estimate the properties at wider ranges of pressure and temperature.

There are many correlations provided in the literature, raising the question of which correlation to use in each case. For this paper, isothermal fluid properties were available for seven data points at bubble point pressure measured in PVT laboratory for fluid samples from the Luhais oil field, in addition to 40 points of oil formation volume (FVF), and 21 points of viscosity. These data points were thus compared



to many empirical correlations from the literatures to determine the proper correlations to apply to estimate the fluid properties of oil from this field at the required pressure and temperature.

The first common correlation for estimating saturation pressure and the formation volume factor of crude oil was proposed by Standing in 1947[1]. This correlation developed from four factors: the gas oil ratio, the temperature, and the gravity of both oil and gas. In his correlation, Standing utilised 105 data points gained from experimental measurement of the bubble point pressure for 22 mixture samples from California oil fields. The arithmetic average error was 4.8 percent. After this correlation was published, many other correlations were presented for different crude samples based on the same parameters, generally using more experimental data compared with Standing's work. Lasater's correlation from 1958 was built using 158 data points from measures of bubble-point pressure. The fluid samples used to develop this correlation were collected from Canada, South America, and the Western and Mid-Continental United States. The same physical parameters employed by Standing, were used in this correlation but with different assumptions of combinations.

Glaso used 41 data points from North Sea oils samples in 1980. These samples differed from the previous samples in that they contained varying amount of paraffinic oil and large amounts of nonhydrocarbon gases. He studied the effects of the nonhydrocarbon gases and presented a correction procedure to be applied to the data before using in the correlation. In 1980, Vasquez and Beggs [5] developed a correlation based on 600 PVT laboratory measurement data points from samples taken from over all the world. The authors showed that the gas specific gravity is related to conditions of separation. They thus proposed an equation to correct this gas specific gravity to separator conditions before calculating oil formation volume factor and bubble pressure. In 1993, Petrosky and Farshad [6] presented a new correlation based on 81 PVT laboratory measurement for crude samples from Gulf of Mexico oil fields. The maximum error percent for these correlations was 6.66%. The equation of correlation of bubble point pressure was the same as in the equation that provided by Standing but with new calculated constants; the average absolute error was 3.28%.

Oil viscosity is one of more important properties that affects oil flow in porous media. There are many correlations that could be used to estimate the viscosity of dead, saturated, and undersaturated oil. In 1946, Beal [7] proposed a graphical correlation to estimate the viscosity of dead, saturated and undersaturated crude oil at a range of pressures and temperatures from 14.7 to 8,000 psi and 60 to 300 °F, respectively. Beal's correlation was built by using 953 oil samples from United State oil fields. Chew and Connally [8] presented a correlation to predict saturated oil viscosity in 1959. They developed their correlation depending on the solution to the gas oil ratio and viscosity of the dead oil at reservoir pressure and temperature. They tried to improve the correlation by using additional parameters such as formation volume factor, the viscosity of C_7^+ fraction, gravity of oil and gas, and saturation pressure, but no additional relationship was found. The oil systems for this correlation's development were from the United States and other North American crude oils. In 1975, Beggs and Robinson [9] developed an empirical correlation to calculate the viscosity for dead and saturated oil. The number of oil systems used to develop this correlation was 600, and the number of observations data points for dead and saturated oil were 460 and 2,073, respectively. The average error was -0.64% for dead oil and -1.83% for saturated oil. In 1980, Glaso [4] proposed a correlation to calculate the viscosity for dead oil. This correlation developed from laboratory measurements data of 26 oil systems. In 1980, Vasquez and Beggs [5] also presented a mathematical expression to predict undersaturated oil viscosity. They used 3,593 points of laboratory measurement data for oil systems collected from oil fields all over the world. The correlation was represented by a relationship between the viscosity and pressure above saturation pressure. The relationship was thus based on the viscosity at saturation pressure and the bubble point pressure. Another correlation was also proposed by Dindoruk and Christman [10] in 2004 to calculate oil viscosity.

2. Saturation pressure

The Standing, Lasater, Glaso, Vazquez-Beggs, and Petrosky correlations were used for comparison with the measured data. The input parameters for the five correlations were R_s , γ_g , T and API . R_s is the ratio of the total gas liberated from all the stages of the separator test to the stock tank oil; γ_g is the produced

gas specific gravity, evaluated as the weighted average to gas oil ratio at each stage of the separator test; T is the temperature of measuring the bubble point pressure; and API represents the oil gravity of the residual oil in the stock tank.

Absolute errors were calculated for the measured and the estimated bubble point pressure by using the five correlations. The values of these errors are tabulated in table 1 and used as a matching indicator. The Absolute Average Error (AAE) values ranged from 2.58% with Lasater's correlation to 29.11% with Vazquez-Beggs. Therefore, the Lasater's correlation represents the most appropriate method to estimate the bubble point pressure at any temperature. The solution to the gas oil ratio can also be estimated using Lasater's correlation.

Table 1. Absolute error of estimating the bubble point pressure.

| Sample | Standing | Lasater | Glaser | Vazquez-Beggs | Petrosky-Farshad |
|--------|----------|---------|--------|---------------|------------------|
| 1 | 10.28 | 4.57 | 21.07 | 17.72 | 14.73 |
| 2 | 14.21 | 1.12 | 31.40 | 24.46 | 21.36 |
| 3 | 15.44 | 0.22 | 26.58 | 23.05 | 20.55 |
| 4 | 17.08 | 4.01 | 34.51 | 27.24 | 24.85 |
| 5 | 14.34 | 0.71 | 25.74 | 22.10 | 19.46 |
| 6 | 12.28 | 0.34 | 29.09 | 22.19 | 19.71 |
| 7 | 23.55 | 7.13 | 35.41 | 31.88 | 30.89 |
| AAE | 15.31 | 2.58 | 29.11 | 24.09 | 21.65 |

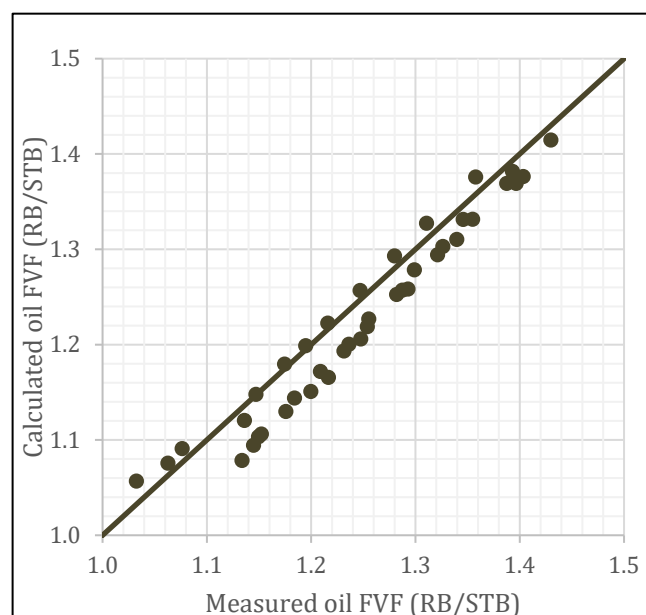
3. Oil formation volume factor

Forty points of measured data and four correlations used to make the matches with the oil formation volume factors. The four correlations were Standing, Glaser, Vasquez-Beggs, and Petrosky-Farshad. The AAEs ranged from 2.19% to 4.19%, as shown in Table 2. The closest correlation was Petrosky-Farshad and the cross plot of this correlation is thus shown in Figure 1.

Table 2. AAE of estimating the oil formation volume factor.

| | Standing | Glaser | Vasquez-Beggs | Petrosky-Farshad |
|-----|----------|--------|---------------|------------------|
| AAE | 2.51 | 4.19 | 3.22 | 2.19 |

Figure 1. Cross plot of the measured and the calculated oil formation volume factors using the Petrosky-Farshad correlation.



4. Viscosity

The available data that used to obtain matched correlations for oil viscosity included 21 data points. These points included 4 points for dead oil, 4 points for saturated oil, and 13 points for undersaturated oil. The viscosity of the three states of oil was first matched. Then, dead oil viscosities were compared with four correlations, Beal, Glaso, Beggs-Robinson, and Dindoruk-Christman. The AAE percent for each correlation was calculated, as tabulated in Table 3. The minimum AAE of these correlations was 23.52% for the Beggs-Robinson method. To reach a better match, a modification was applied to the Beggs-Robinson equation, which was thus shifted by as seen in Table 5. The absolute errors of using the modified equation are tabulated in the fifth column of Table 3.

Table 3. Absolute error of estimating the dead oil viscosity.

| Sample | Beal | Glaso | Beggs-Robinson | Beggs-Robinson* | Dindoruk-Christman |
|--------|-------|-------|----------------|-----------------|--------------------|
| 1 | 39.70 | 35.92 | 28.35 | 6.93 | 40.46 |
| 2 | 34.26 | 30.03 | 20.12 | 4.98 | 35.19 |
| 3 | 36.52 | 33.03 | 23.93 | 1.14 | 38.10 |
| 4 | 35.80 | 32.96 | 21.69 | 2.14 | 37.54 |
| AAE | 36.57 | 32.98 | 23.52 | 3.80 | 37.82 |

* Calculated by using the modified Beggs-Robinson correlation

The viscosity of the saturated oil was compared with the four correlation types, Beal, Chew-Connally, Beggs-Robinson, and Dindoruk-Christman. The error percent for each correlation is illustrated in Table 4. The minimum AAE (2.41%) was found for the Chew-Connally correlation, making this the most suitable correlation to estimate oil viscosity at bubble pressure for crude oil from the Luhais oil field.

Table 4. Absolute error percent of estimating the saturated oil viscosity (at bubble point pressure).

| Sample | Beal | Chew-Connally | Beggs-Robinson | Dindoruk-Christman |
|--------|-------|---------------|----------------|--------------------|
| 1 | 27.78 | 2.33 | 6.92 | 36.02 |
| 2 | 29.85 | 2.31 | 5.44 | 31.16 |
| 3 | 27.14 | 2.31 | 6.78 | 34.76 |
| 4 | 21.13 | 2.67 | 6.58 | 14.86 |
| AAE | 26.47 | 2.41 | 6.43 | 29.20 |

The third section of viscosity estimation is estimating the viscosity of the undersaturated oil. Three correlations were used in this paper and compared with 13 laboratory data points. The error percentages are presented by the cross plot shown in **Figure 2** for the Beal, Vasquez-Beggs and Dindoruk-Christman correlation. The AAE for Vasquez-Beggs correlation was 4%, which was lower than that of Beal's at 7.08% and Dindoruk-Christman at 7.27%. Thus, the Vasquez-Beggs correlation appears to be the best choice for estimating the viscosity of undersaturated Luhais crude oil at pressures above the bubble point.

5. Results

The matched correlations can be applied to estimate the properties of oil from the Luhais oil field at any field conditions of pressure and temperature. The mathematical expressions of these matched correlations for each property are illustrated in Table 5.

The fluid properties at reservoir temperature were thus calculated by applying the matched correlations and using the average GOR, gas specific gravity, and API values from the sample data. The results are shown in Figure 3 through Figure 5.

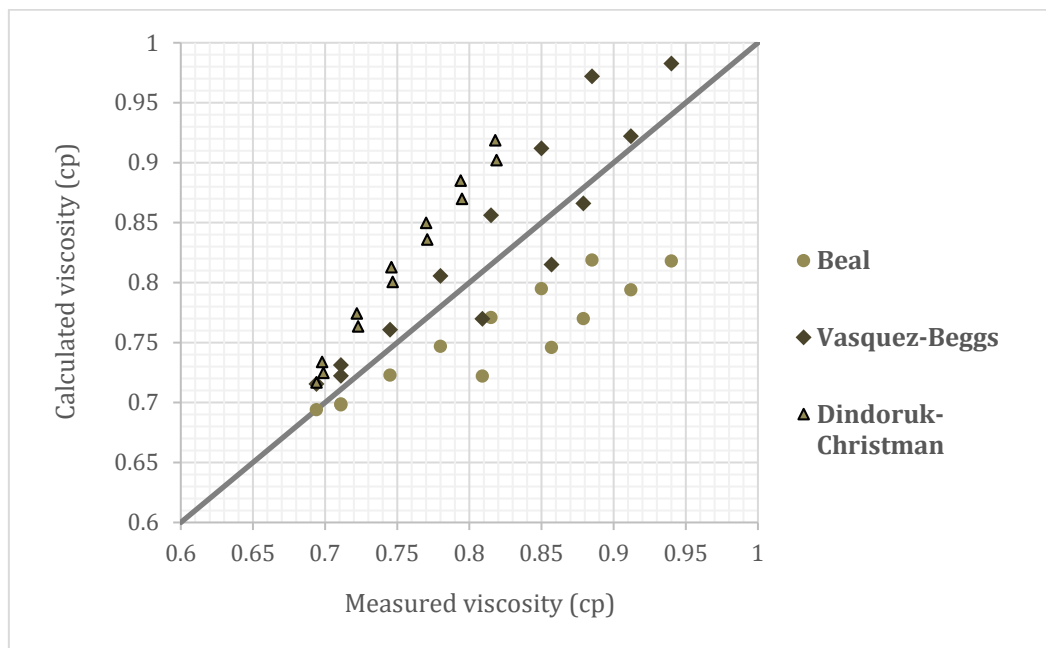


Figure 2 Cross plot of the calculated and measured viscosity for undersaturated oil

Table 5. Matched correlations for the properties of Pb, FVF, and viscosity

| Property | Correlation | Equation |
|---------------------------------|-------------------------|---|
| Saturation Pressure | Lasater | $P_b = (P_f * T) / \gamma_g$ |
| | | $P_f = 0.38418 - 1.20081 y_g + 9.64868 y_g^2$ |
| | | $y_g = \frac{R_s / 379.3}{(R_s / 379.3 + 350 / M_o)}$ |
| Oil FVF | Petrosky-Farshad | $B_o = 1.0113 + 7.2046(10^{-5}) (X^{3.0936})$ $X = (R_s^{0.3738} \gamma_g^{0.2914} / \gamma_o^{0.6265}) + 0.24626(T - 460)^{0.5371}$ |
| Viscosity of Dead Oil | Modified Beggs-Robinson | $\mu_{OD} = 10^X - 0.2$ $X = y T^{-1.163}$ $y = 10^{3.0324 - 0.02023 \gamma_o}$ |
| Viscosity of saturated oil | Chew-Connally | $\mu_{OB} = 10^A (\mu_{OD})^B$ $A = R_s [2.2 (10^{-7}) R_s - 7.4 (10^{-4})]^{-0.515}$ $B = 0.68 (10^{-c}) + 0.25 (10^{-d}) + 0.062 (10^{-e})$ $c = 8.62 (10^{-5}) R_s, \quad d = 1.1 (10^{-3}) R_s,$ $e = 3.74 (10^{-3}) R_s$ |
| Viscosity of undersaturated oil | Vasquez-Beggs | $\mu_o = \mu_{OB} (P/P_b)^A$ $A = 2.6 P^{1.187} 10^{-3.9 (10^{-5}) P - 5}$ |

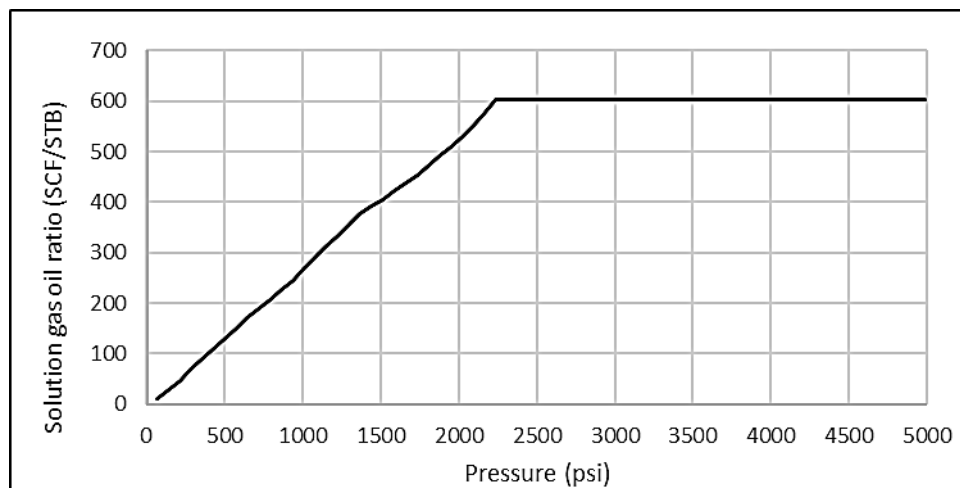


Figure 3. Solution gas oil ratio curve at reservoir pressure (temperature 185 °F)

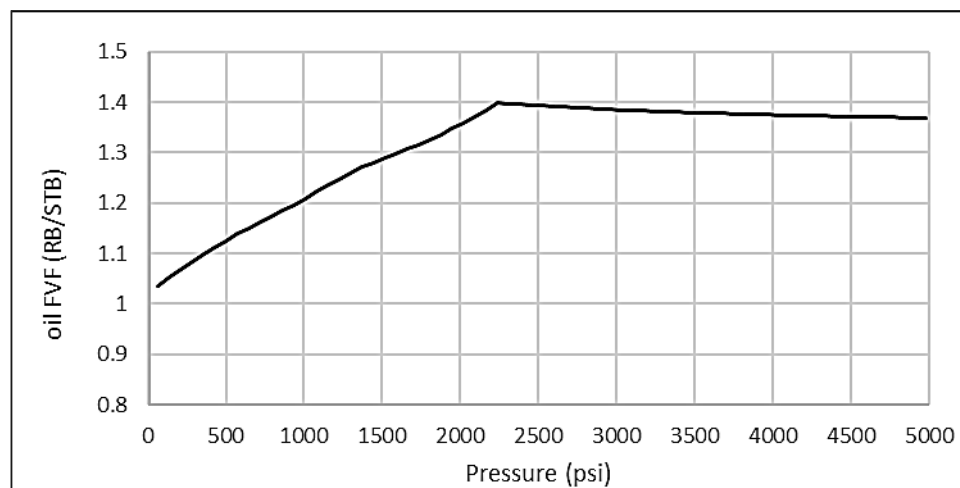


Figure 4. Oil FVF at reservoir pressure (temperature 185 °F)

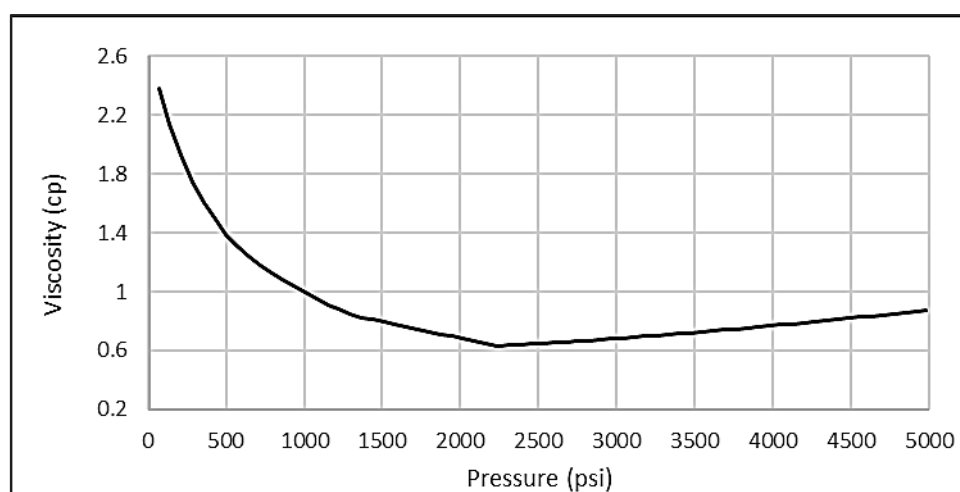


Figure 5. Oil viscosity at reservoir pressure (temperature 185 °F)

6. Conclusions

The appropriate correlations to estimate oil PVT properties for the crude oil of the Luhais oil field were defined in this paper. These properties, namely P_b , R_s , B_o , and viscosity, were estimated for this oil field at reservoir pressure and temperature to allow a black oil simulator to be used in further simulation studies of the Luhais oil field.

7. Abbreviation

| | |
|-----|-------------------------------|
| AAE | : Average Absolute Error |
| FVF | : Formation Volume Factor |
| PVT | : Pressure Volume Temperature |
| RB | : Reservoir Barrel |
| SCF | : Standard Cubic Feet |
| STB | : Stock Tank Barrel |

8. Nomenclatures

| | |
|------------|---------------------------------------|
| B_o | = Oil formation volume factor, RB/STB |
| M_o | = Apparent molecular weight, gm/mole |
| P | Pressure above bubble point, psi |
| P_b | = Bubble point pressure, psi |
| R_s | = Solution gas oil ratio, SCF/STB |
| γ_g | = Gas specific gravity (air = 1) |
| γ_o | = Oil specific gravity |
| μ_o | = Undersaturated oil viscosity, cp |
| μ_{OB} | = Oil viscosity at bubble point, cp |
| μ_{OD} | = Dead oil viscosity, cp |
| API | = Oil gravity, degree |
| T | = Temperature, °R |

9. References

- [1] South Oil Company PVT Laboratory Reports for Wells Lu 02 Lu 05 Lu 06 Lu 17 and Lu 36 Unpublished Reports Basra
- [2] M S 1947 A Pressure-Volume-Temperature Correlation for Mixtures of Californian Oils and Gases in *Drill and Prod Pract* New York
- [3] J L 1958 Bubble Point Pressure Correlation *Journal of Petroleum Technology* **10** no 05 pp 65 - 67
- [4] O G 1980 Generalised Pressure-Volume-Temperature Correlations *Journal of Petroleum Technology* **32** no 05
- [5] M V and H B 1980 Correlations for Fluid Physical Property Prediction *Journal of Petroleum Technology* **32** no 06 pp 968 - 970
- [6] G E Pand F F F 1993 Pressure-Volume-Temperature Correlations for Gulf of Mexico Crude Oils in *SPE Annual Technical Conference and Exhibition 3-6 October* Houston Texas
- [7] C B 1946 The viscosity of air water natural gas crude oils and its associated gases at oil field temperatures and pressures *Trans AIME* **165** pp 94-115
- [8] J C and C C 1959 A Viscosity correlation for gas-saturated crude oils *Trans AIME* **216** p 23-25
- [9] H B and J R 1975 Estimating the viscosity of crude oil systems *JPT* **27** no 09 p 1140-1141
- [10] B D and P C 1990 PVT properties and viscosity correlations for gulf of mexico oils *SPE* 89030