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# A New Oil Formation Volume Factor Correlation of Egyptian Crude Oils

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**Abstract:** Knowledge of reservoir fluid properties is very important in reservoir engineering calculations such as reserve estimates and numerical reservoir simulations. Laboratory measurements are the most dependable methods for pressure-volume-temperature (PVT) analysis of reservoir fluid properties. Under circumstances, the absences of such measurements are unavailable, hence, resorted to use empirical PVT correlations**.** Within the current research, a new correlation for estimating oil formation volume factor at bubblepoint pressure of Egyptian crude oils using nonlinear multiple regression technique has been developed. In developing the correlation, 162 PVT data sets from Egyptian crude oils were used. The data were collected from different fields in Egypt and covered a wide range of crude oils ranging from heavy to volatile oils. The data consisted of oils with oil formation volume factor at bubblepoint pressure ranging from 1.068 to 2.43 bbl/stb, $^o$API of 17 to 46, solution gas oil ratio of 52 to 2254 scf/stb, gas gravity of 0.6 to 1.474 and temperature of 107 to 310$^o$F. The developed correlation was taken as a function of solution gas oil ratio, oil gravity, gas relative density and reservoir temperature. Statistical and graphical analyses have been used to evaluate the performance of the developed correlation. Correlation performance was also compared with published correlations. It was found that the new correlation estimates oil formation volume factor at bubblepoint pressure of Egyptian crude oils much better than the published ones. The obtained outcomes include an average relative error (ARE) of 0.06, an average absolute error (AARE) of 2 and coefficient of regression ($R^2$) of 0.98.In the current research, PVT data sets were collected from Egyptian reservoirs and regression analysis were used to obtain oil FVF correlation.

**Key words:** PVT Correlations; Oil Formation Volume Factor; Egypt.

## INTRODUCTION

Reservoir engineering calculations such as material balance, reserve estimates and reservoir simulation are pressure-volume-temperature (PVT) data dependable.
PVT is the study of the variations of volume of a fluid as function of pressure and temperature.
These data can be attained either by conducting a laboratory study on reservoir fluid samples or calculated by using empirical PVT correlations.
Laboratory analysis is the most accurate method to obtain the PVT data. However, unfortunately in some cases it is expensive to conduct laboratory studies for many reasons such as failure to obtain a representative sample.
In this case the empirical correlations are used. In the literature there are two types of these correlations. The first set is the generic, which covers a wide range of data. The second sets of correlations were developed to cover a data for a specific region.
This paper develops an oil formation volume factor (oil FVF) at bubblepoint pressure correlation of Egyptian crude oils. Also, study the performance of the existing empirical correlations in the literature such as Standing[1], Arps[2], Vazquez-Beggs[3], Glaso[4], AL-Marhoun[5], Abdul-Majeed[6],Kartaotmodjo-Schmidt[7],Dokla-Osman[8],Macary-EL-Batanony[9], AL-Marhoun[10], Omar-Todd[11], Petrosky[12], Farshad[13], Al-Mehaideb[14], AL-Shammasi[15] and Solaimon[16].

### PVT Data Description

A number of 162 PVT data sets collected from different fields in Egypt. The data sets consist of oil formation volume factor, solution gas oil ratio, gas relative density, oil gravity and reservoir temperature. Table 1 lists the data used in the current research with a wide range of each PVT property items.

## METHODOLOGY

Statistical and graphical error analyses are used to evaluate the performance of the oil FVF at bubblepoint pressure literature correlations using the Egyptian PVT Data base.
To achieve this, the most frequently used statistical methods have been adopted for this study namely: The average percent relative error (Er), the average absolute percent relative error (Ea) and the correlation coefficient ($R^2$).Also, the cross plot is used as graphical error analysis method. These statistical and graphical error indicators are presented in the appendix.

### Development of Oil Formation Volume Factor at Bubblepoint Pressure Correlation

Nonlinear multiple regression analysis was used to develop a correlation of oil formation volume factor at bubblepoint pressure as a function of field data. A total of 162 experimental data points were used to develop the saturated oil formation volume factor. The correlating parameters are the solution gas oil ratio, the gas gravity, the reservoir temperature, and the stock-tank oil gravity.
Numerous models were tried as regression equations to develop a correlation of oil formation volume factor at bubblepoint pressure. The following correlation is adopted in this paper.

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$$\beta_o = a1 + a2[R_s (\frac{\gamma_g}{\gamma_o})^{a3} + a4\ T)^{a5}$$

Where
a1= 0.893
a2= 7.15 E-4
a3= 0.316
a4= 1.656
a5= 0.969

The average relative error, the average absolute relative error and coefficient of correlation are 0.06, 2 and 0.98 respectively. The ranges of the parameters covered in this correlation are presented in Table 1. The cross plot of the experimental versus the estimated saturated oil formation volume factor is presented in Figure 1. Most of the data points of the presented correlation fall very close to the 45$^o$ line as illustrated in Figure 1.

## COMPARISON OF CORRELATIONS

The measured oil formation volume factors at bubblepoint pressure of Egyptian crude oils were compared to the values predicted by Standing[1], Arps[2], Vazquez-Beggs[3], Glaso[4], AL-Marhoun[5], Abdul-Majeed[6], Kartaotmodjo-Schmidt[7], Dokla-Osman[8], Macary-EL-Batanony[9], AL-Marhoun[10], Omar-Todd[11], Petrosky[12], Farshad[13], Al-Mehaideb[14], AL-Shammasi[15] and Solaimon[16]correlations.
Table 2 lists the statistical accuracy of oil formation volume factor at bubblepoint pressure for the mentioned correlations and the one developed in this study. Figure 1 shows the crossplots for all correlations. As illustrated in Table 1, Standing, Dokla-Osman, Farshad correlations and the currently utilized correlation yielded low relative errors. This proves that the latter four oil formation volume factor correlations are more general than the other correlations used in this study. Figure 1 shows the crossplots for all correlations used in this study and it is clear from the figure that all correlations underpredict oil formation volume factor at bubblepoint except Macary and EL-Batanony. This correlation overpredicts the value of the property.

## CONCLUSIONS

Based on the results of these evaluations, the following remarks are worth mentioning.
1. An empirical correlation for estimating the oil formation volume factor at the bubblepoint pressure for Egyptian crude oils has been developed.
2. Deviations from experimentally data, indicated as average relative error, average absolute relative error and coefficient of correlation were lower for this study than for estimations based on other published empirical oil formation volume factor at the bubblepoint pressure correlations.

Table1: Data Description of Egyptian Crude Oil

| PVT Property | Minimum | Maximum | Mean |
|---|---|---|---|
| Solution GOR, scf/stb | 52 | 2254 | 687 |
| Oil FVF at Bubble Point, bbl/stb | 1.068 | 2.43 | 1.49 |
| Reservoir Temperature | 107 | 310 | 220 |
| Oil API Gravity | 17 | 46 | 32 |
| Gas Relative Density, (air=1) | 0.6 | 1.474 | 0.817 |

Table2: Statistical Accuracy of Oil FVF at Bubblepoint

| Oil FVF Correlations | AE% | AAE% | $R^2$ |
|---|---|---|---|
| Standing | -3.26 | 3.66 | 0.93 |
| Arps | -6.12 | 6.38 | 0.80 |
| Vazquez and Beggs | -5.97 | 6.00 | 0.83 |
| Glaso | -6.28 | 6.37 | 0.85 |
| AL-Marhoun 1 | -4.84 | 4.90 | 0.87 |
| Abdul-Majeed | -5.67 | 5.87 | 0.81 |
| Kartaotmodjo and Schmidt | -4.20 | 4.39 | 0.91 |
| Dokla and Osman | -2.48 | 3.31 | 0.94 |
| Macary and EL-Batanony | 5.95 | 6.14 | 0.78 |
| AL-Marhoun 2 | -4.25 | 4.35 | 0.91 |
| Omar and Todd | -4.98 | 5.17 | 0.90 |
| Petrosky | -4.36 | 4.56 | 0.92 |
| Farshad | -2.03 | 2.75 | 0.96 |
| Al-Mehaideb | -3.46 | 4.37 | 0.9 |
| AL-Shammasi | -3.98 | 4.1 | 0.92 |
| Solaimon | -2.74 | 8.34 | 0.62 |
| Ramadan | 0.06 | 2 | 0.98 |

**Nomenclature**

| | |
|---|---|
| $\beta_o$ | Oil formation volume factor, bbl/stb |
| $\gamma_o$ | Oil gravity |
| $\gamma_g$ | Gas gravity |
| Rs | Solution gas oil ratio, scf/stb |
| T | Temperature, $^o$F |

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## Appendix

### Statistical Error Analysis

The following three statistical parameters were used in this study to evaluate the accuracy of the correlations.

1- Average percent relative error

$$E_r = \frac{1}{n_d}\sum_{1}^{n_d} E_i$$

Where

$$E_i = \left(\frac{x_{measured} - x_{estimated}}{x_{measured}}\right)_i * 100(i = 1,2,\dots n_d)$$

2- Average absolute percent relative error

$$E_a = \frac{1}{n_d}\sum_{1}^{n_d} E_i$$

3- Coefficient of correlation

$$r^2 = 1 - \sum_{1}^{n_d}(x_{measured} - x_{estimated})^2 / \sum_{1}^{n_d}(x_{measured} - x_{avarage})^2$$

The lower the values of Er the more equally distributed are the errors between positive and negative values. The lower value of $E_a$the better the correlation.
The correlation coefficient describes the range of connection between two variables namely experimental and estimated values obtained from the correlation.
The value of $r^2$ varies from -1 to +1. As the value of coefficient of correlation approaches +1, it means there is a strong positive relationship between these two variables.

### Graphical Error Analysis

In this method of analysis, all estimated values are drawn versus the experimental values, and thus crossplot is formed.A 45o straight line is plot on the crossplot on which the estimated value is equal to the experimental value. The closer the plotted data points are to this line, better the correlation.

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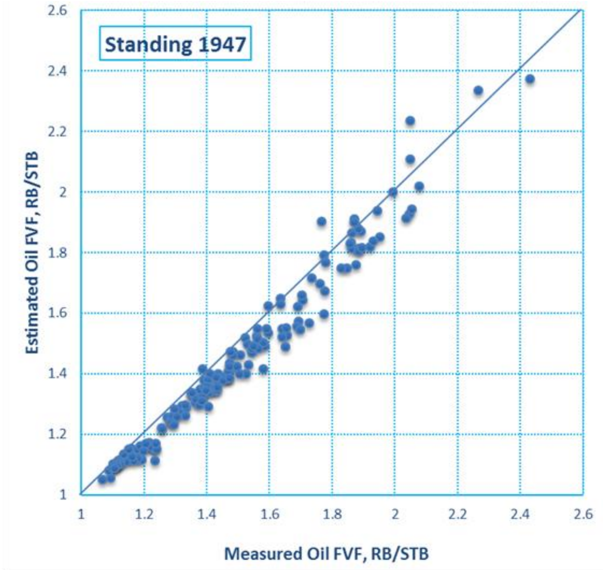


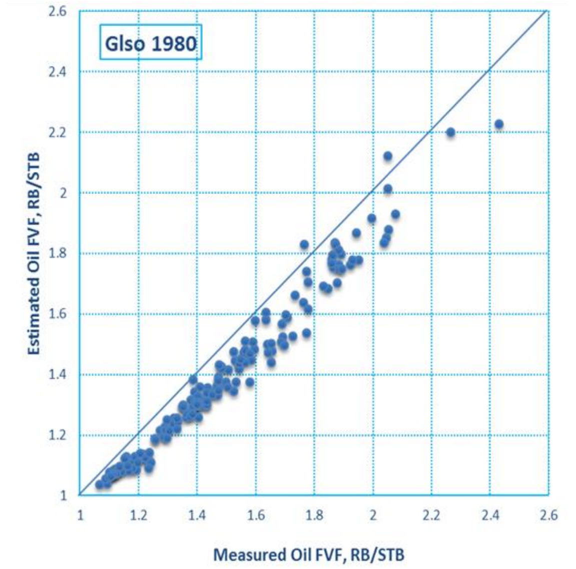


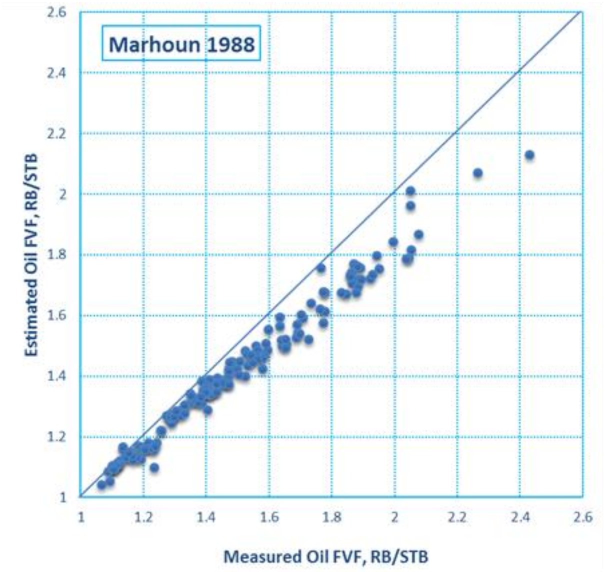


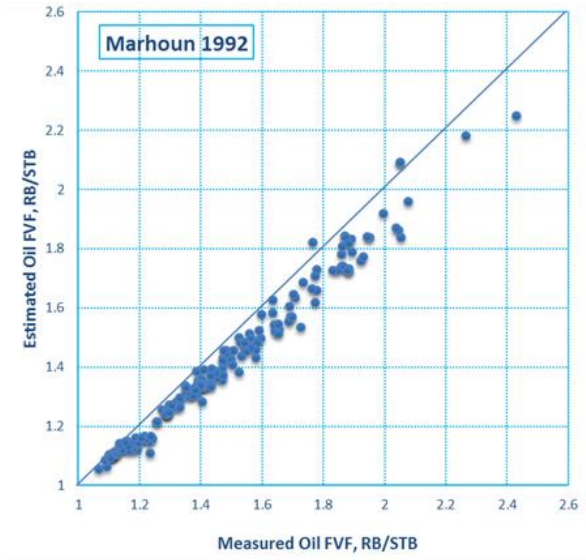


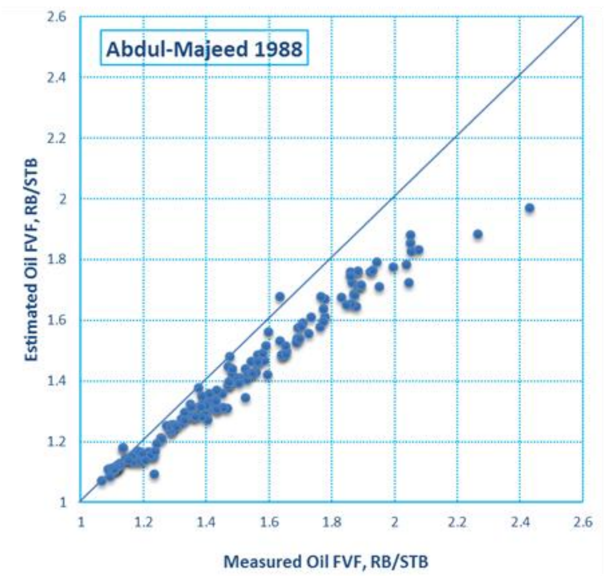


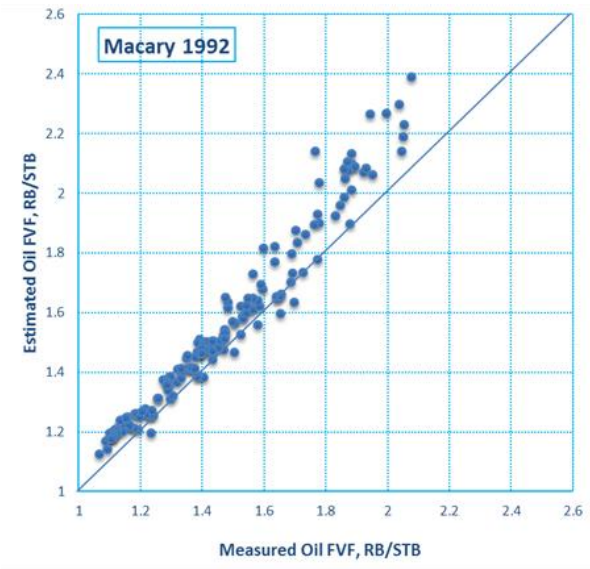

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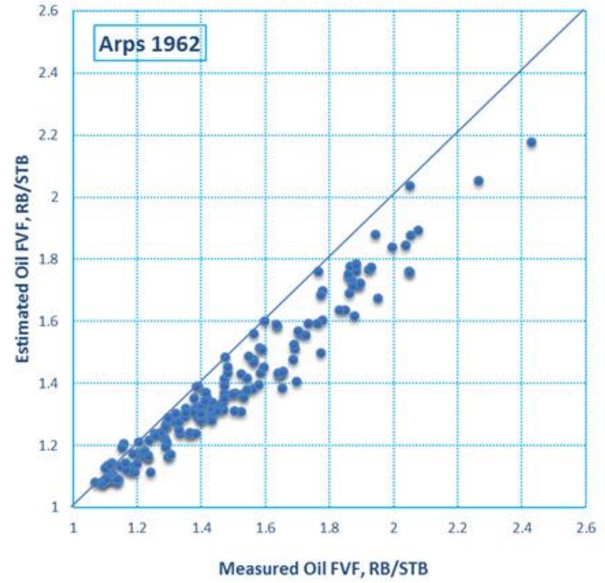


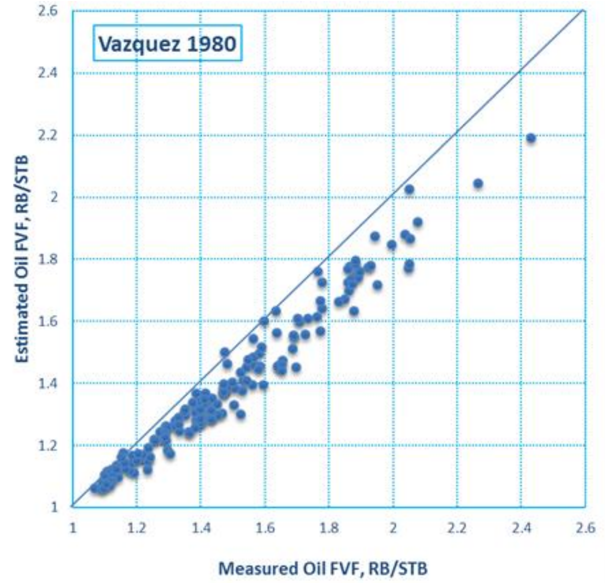


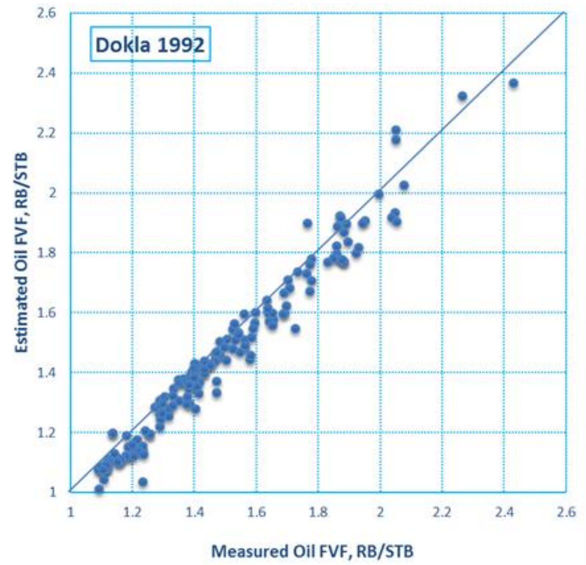


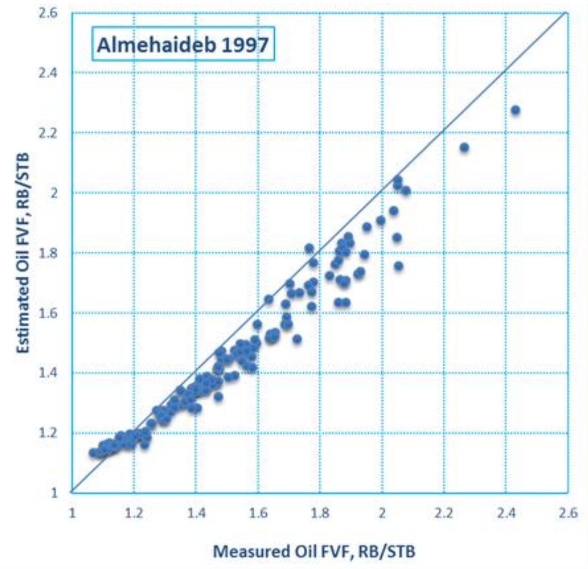


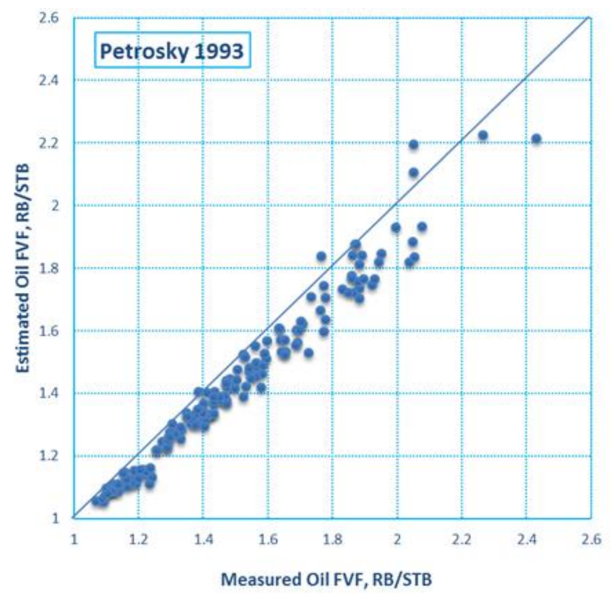


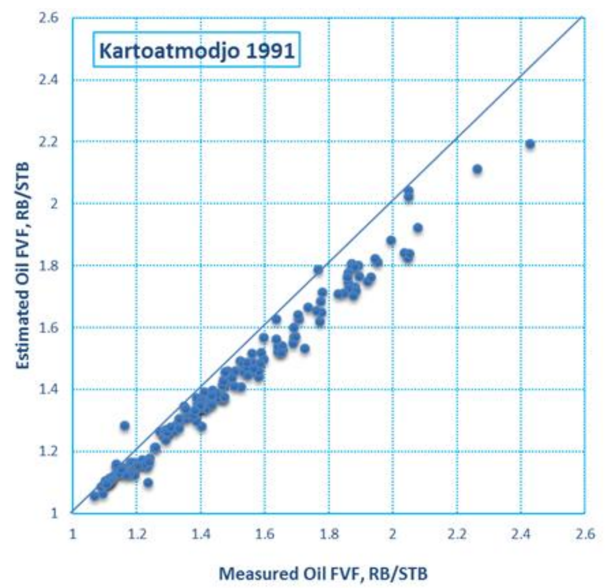

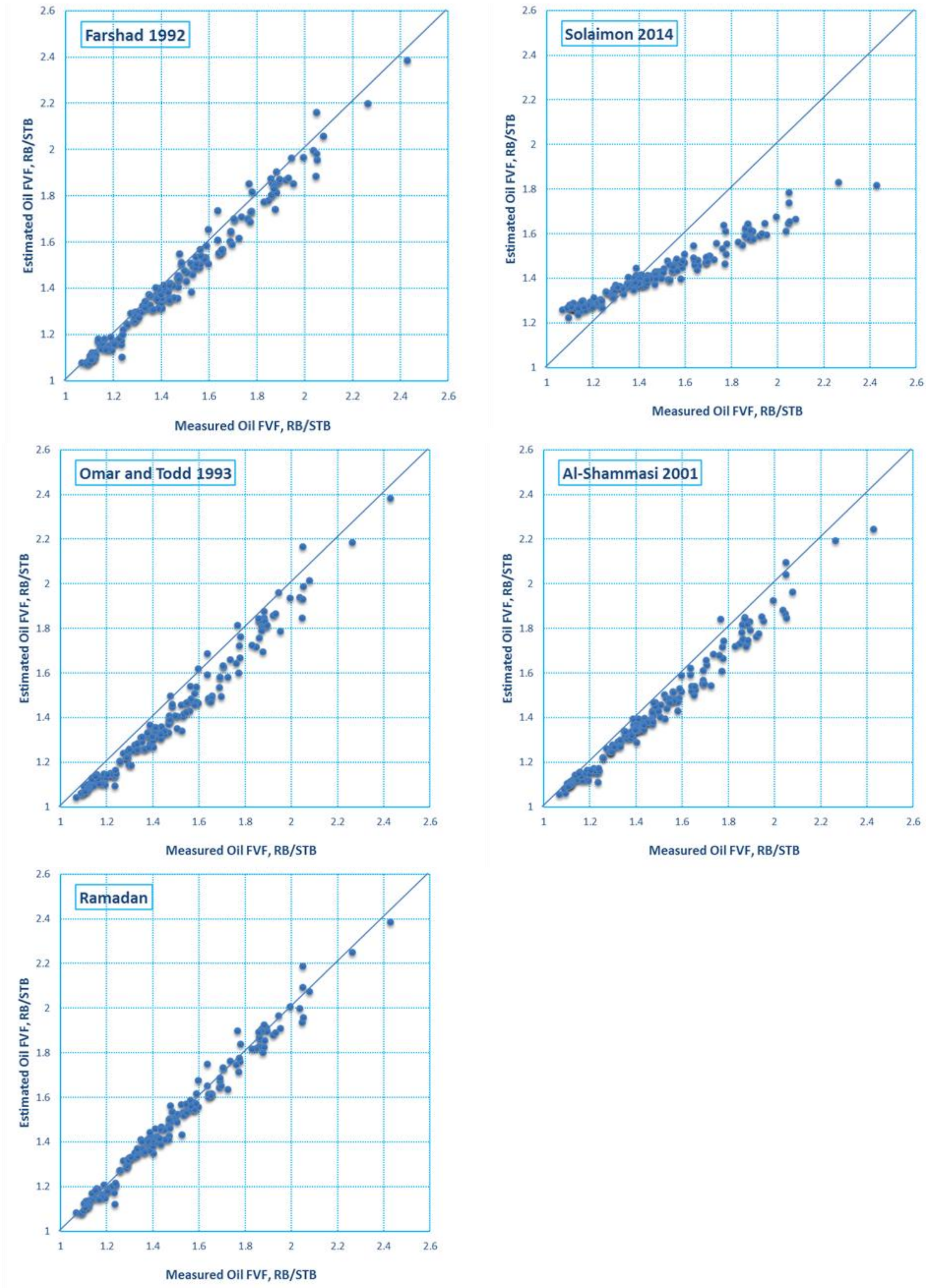


Figure1: Crossplots for FVF at Bubblepoint Pressure