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Original article

Evaluation of Crude Oil Thermophysical Properties Utilizing PVTp Software

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Abstract
Reservoir fluid characteristics play a critical role in reservoir engineering calculations. While direct laboratory measurements provide the most reliable source for these parameters, such data are often unavailable or too expensive to obtain. Under these circumstances, researchers conventionally use empirical correlations to estimate the required fluid properties. Over the past decade, researchers have increasingly applied artificial neural networks to improve the precision of PVT correlations. In this study, the performance of the most prominent empirical PVT correlations available in the literature was evaluated using 50 laboratory PVT reports from local crude oils. The findings revealed that existing correlations failed to provide accurate predictions for the PVT properties of the XX reservoir. Consequently, this research utilizes two distinct approaches to predict these parameters. New empirical PVT correlations were specifically formulated for the XX reservoir oils based on readily available field production data. Using non-linear multiple regression analysis via the Statistical Analysis System (SAS), correlations were developed for bubble point pressure, solution gas-oil ratio at bubble point, oil formation volume factor at bubble point, dead oil viscosity, saturated oil viscosity, undersaturated oil viscosity, and undersaturated oil compressibility. A comprehensive dataset comprising more than 50 PVT reports collected from 10 distinct oil fields within the XX reservoir was utilized to build these models. The results demonstrate that the newly proposed correlations significantly outperform existing published models in estimating the PVT behavior of XX reservoir crudes.
Keywords: Bubble Point Pressure, Undersaturated Oil Viscosity, Dead Oil Viscosity, Oil Formation Volume Factor.

Introduction

Physical properties of reservoir fluids constitute an essential foundation across a wide spectrum of petroleum engineering applications. Critical engineering tasks including reserve estimation, fluid transport modeling in porous media, multiphase pipe flow hydraulics, surface and subsurface equipment sizing, and production efficiency optimization rely fundamentally on accurate fluid property data. These pressure-volume-temperature (PVT) characteristics are typically acquired via direct laboratory experimentation or estimated utilizing empirical correlations.

While experimental PVT testing represents the benchmark approach for characterizing fluid phase behavior, preliminary appraisals of exploratory wells and early facility planning often demand fluid behavior forecasts before representative downhole samples can be successfully retrieved. Moreover, extensive fluid analyses may not be economically viable for marginal or low-priority reservoirs. In such scenarios, empirical modeling serves as a necessary surrogate.

Furthermore, empirical correlations are indispensable for estimating pressure drop profiles in multiphase piping networks, which require evaluating fluid properties across fluctuating pressure and temperature gradients. Although laboratory PVT measurements can map property variations across varying pressures, such evaluations are routinely conducted under isothermal conditions. Consequently, the temperature dependence of fluid behavior must be inferred through empirical models. However, the overall reliability of empirical PVT correlations remains constrained due to the intricate, multi-component thermodynamic nature of crude oil systems.

This study aims to achieve the following specific objectives:

1. Assess Existing Empirical PVT Models: Evaluate and analyze published empirical PVT correlations to determine their applicability and performance when tested against the regional fluid dataset of the XX reservoir.
2. Develop Nonlinear Regression-Based Empirical Correlations: Formulate optimized mathematical models for predicting bubble point pressure (Pb), solution gas-oil ratio at bubble point (Rsb), oil formation volume factor at bubble point (Bob), dead oil viscosity (μod), saturated oil viscosity (μob), undersaturated oil viscosity (μo), and undersaturated oil compressibility (co). These traditional empirical formulations are developed using multi-variable nonlinear regression techniques within the Statistica 6.0 software package, utilizing field-specific data from the XX reservoir.

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3. Construct Artificial Neural Network (ANN) Predictive Models: Design and train advanced Artificial Neural Network models based on the Backpropagation (BPN) algorithm implemented via the MATLAB environment to accurately predict Pb, Rsb, Bob, μod, undersaturated oil viscosity, and undersaturated oil compressibility for the XX reservoir crudes.
4. Optimize Hydrocarbon Recovery and Production: Analyze the fundamental physical characteristics of reservoir hydrocarbons to support and enhance long-term field development, extraction efficiency, and production optimization strategies.

Application and experimentation

Data acquisition for this study encompasses fluid samples and PVT measurements retrieved from three primary oil reservoirs: (BB), (HH), and (AA).

Neural network simulation or SNN

As a subdiscipline of artificial intelligence, an artificial neural network (ANN) constitutes a computational paradigm designed to emulate fundamental biological learning mechanisms and specific functional dynamics of the human central nervous system. These architectures function as parallel, adaptive information processing systems capable of establishing non-linear mappings, structural transformations, and complex associations between input and output datasets. Consequently, ANNs represent the most widely implemented intelligent pattern-recognition strategy for empirical data modeling.

The core architectural components of a neural network consist of discrete processing units (neurons) linked through adjustable connection parameters, known as synaptic weights. Network optimization relies on an iterative mathematical learning algorithm that begins with an initial state of prior weights generally assigned through pseudo-random distribution functions and progressively refines these values through successive computational cycles. In this context, the learning process entails the dynamic adjustment and back propagation of connection weights until the system meets specified convergence benchmarks, such as driving the Mean Squared Error (MSE) below a prescribed error tolerance.

This operational training can be executed through either supervised or unsupervised learning paradigms. Under the supervised framework typically deployed within feedforward neural network architectures the algorithm requires matched input-output training pairs, wherein data flows unidirectionally without lateral or backward feedback loops during the forward propagation phase.

The operational mechanism of an artificial neural network (ANN) relies on an information-processing framework that shares structural and functional characteristics with biological neural systems. As a computational implementation of artificial intelligence algorithms, these networks function as automated systems built upon the following core operational principles:

1. **Distributed Computation:** Information processing is executed across numerous elementary computational units, designated as neurons.
2. **Inter-Neuron Communication:** Signal transmission between individual neurons occurs through interconnected communication channels.
3. **Synaptic Weighting:** Each communication link is modulated by an assigned numerical weight, which scales or multiplies the transmitted signal passing through it.
4. **Nonlinear Activation Transformation:** Each neuron aggregates its incoming weighted signals into a net cumulative input, subsequently applying an activation function—typically nonlinear to compute and yield its final output signal.

Petroleum reserves and analysis

Standard experimental protocols are systematically implemented to characterize the complex phase behavior of petroleum reservoir fluids across various operational stages during production and processing. The thermodynamic phase envelope is fundamentally governed by pressure, volume, and temperature (PVT) relationships, which require accurate laboratory composition analysis, fluid characterization, and numerical modeling to simulate in-situ reservoir properties. Collaborative initiatives among major energy companies have substantially refined PVT methodologies; Consequently, data derived from empirical phase behavior studies provide indispensable operational insights required for optimizing facility design and maintaining cost-effective processing operations.

In technical practice, comprehensive PVT fluid analyses are conducted to delineate the physical behavior of reservoir fluids and establish the thermodynamic properties of crude oil and natural gas samples. Extended production timeframes directly inflate capital and operating expenditures, thereby compressing the overall profit margins of field development projects. Therefore, precise characterization of the subsurface hydrocarbon mixture is paramount to assessing reservoir

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deliverability and fluid mobility under present production conditions, enabling petroleum geologists and engineers to formulate the most economically viable extraction strategies.
The integration of PVT analysis spans virtually every phase of the hydrocarbon extraction lifecycle. Through these standardized tests, critical fluid parameters specifically the bubble point pressure are determined, providing fundamental inputs for modeling fluid flow regimes within the wellbore and reservoir. Ultimately, utilizing empirical fluid data ensures accurate phase behavior predictions, underpinning sound operational and field management decisions.

First description

Understanding in-situ fluid transport mechanisms within producing formations represents the fundamental foundation for comprehensive reservoir studies. Accurate characterization of these properties requires retrieving representative subsurface crude oil samples under actual stratigraphic pressure and temperature conditions. These samples are subsequently transferred to specialized laboratory cylinders and introduced into a high-precision PVT (pressure-volume-temperature) cell. Comprehensive laboratory measurements are then performed to generate an integrated PVT report, supplying essential thermodynamic data required for reservoir engineering calculations, field development planning, and maximum economic recovery.
In this domain, the PVTp software package serves as a robust analytical tool for reservoir and production engineers, enabling rapid and accurate predictions of process condition impacts on hydrocarbon mixture compositions. The thermodynamic and compositional behavior of diverse fluid systems, including dry gas mixtures, gas condensates, retrograde condensates, volatile oils, and black oils can be reliably modeled. PVTp functions either as a standalone analytical engine or as a utility for generating fluid property lookup tables, reduced pseudo-component compositions, and tuned EOS parameters (such as critical temperature Tc, critical pressure Pc, acentric factor ω, volume shift parameters, and binary interaction coefficients). These outputs are routinely integrated into reservoir simulators, well performance analysis suites, and surface process modelers. Given the industry's shift toward integrated asset modeling linking the reservoir, wellbores, surface gathering networks, and processing facilities, establishing consistent PVT characterizations across all system levels is paramount.
Furthermore, PVTp bridges the operational gap between reservoir engineers (who typically require simplified fluid descriptions with up to five pseudo-components) and process engineers (who demand detailed full-component modeling). The software facilitates compositional manipulation and forecasting using two primary modeling methodologies:

1. **The Black Oil Model:** For generalized, empirical fluid behavior calculations.
2. **The Equation of State (EOS) Model:** For detailed, compositional fluid characterization to optimize hydrocarbon recovery strategies.

Empirical Correlations and Evaluation Studies

Over the past six decades, petroleum engineers have recognized the critical importance of formulating and deploying empirical correlations to estimate thermodynamic PVT properties. Continuous research within this domain has yielded a succession of predictive models designed to evaluate complex phase behavior.

Bubble Point Pressure (Pb)

The bubble point pressure (Pb) of a hydrocarbon mixture is defined as the highest thermodynamic pressure at which the first gas bubble liberates from the liquid oil phase at a given temperature. Since the 1940s, significant research efforts have focused on establishing empirical formulations for predicting Pb. Thermodynamically, bubble point pressure is correlated as a function of key field-measured parameters: solution gas-oil ratio (Rs), dissolved gas gravity (Yg), stock-tank oil API gravity (Yo), and system temperature (T).

Standing Correlation

Standing pioneered the development of empirical models for estimating bubble point pressure. His correlation was constructed using 105 experimentally determined PVT data points gathered from 22 crude oil-natural gas systems across California fields. Standing formulated Pb as a function of four fundamental parameters: reservoir temperature (T), solution gas-oil ratio (Rs), stock-tank oil gravity (Yo), and specific gas gravity (Yg).
Standing's work established a landmark precedent by integrating these four specific operational parameters, which subsequently became the foundational inputs for nearly all subsequent empirical PVT correlation studies. He reported an average relative error of 4.8%.
Mathematically, the Standing correlation for bubble point pressure is expressed as follows:
Pb=18.2 [(Rsb / \ Y g)(0.00091 T - 0.0125 \ Y API) - 1.4]

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Vasquez and Beggs Correlation
Vasquez and Beggs developed a new correlation for bubble point pressure based on mathematical rearrangement of their solution gas oil ratio correlation, which was developed using 5008 data points taken from 600 laboratory PVT analyses from various fields all over the world. The Vasquez and Beggs [1] correlation is:

Pb = ((C1Rsb) / \Ygs 10((-C3 \Y_API) / (T + 460)))(1 / C2)
1. When (Heavy to Medium Oil)
   - C1 = 27.64
   - C2 = 1
   - C3 = 11.17
2. When (Light Oil)
   - C1 = 56
   - C2 = 1.18
   - C3 = 10.39

Al-Marhon
Al-Marhon developed an empirical correlation for determining bubble point pressure using 160 experimentally obtained data points from the PVT analyses of 69 bottom hole fluid samples from Middle East oil reservoirs and expressed as functions of reservoir field data. Al-Marhon reported an average absolute error of 3.66%[2]. He used nonlinear regression methods to develop the following correlations:
Pb = C1RsbC2 ygC3 yoC4 (T + 460)C5
where:

Coefficient	C1	C2	C3	C4	C5
Value	5.38088e-3	0.715082	-1.87784	3.1437	1.32657

Petrosky and Farshad Correlation

Petrosky and Petrosky & Farshad presented a bubble point pressure correlation similar to standing correlation with new calculated constants

Pb = 112.727 [(R_sb^0.5774 / \Y_g^0.8439) 10^X - 12.34]

where: X = 4. 561 × 10–5 T1.3911 — 7. 916 × 10–4 γAPI1.54

Solution Gas Oil Ratio at bubble point
The solution gas –oil ratio RS is defined as the number of standard cubic feet of gas that will be dissolved in one stock-tank barrel of crude oil at a certain pressure and temperature. The solution gas-oil ratio is a strong function of pressure, temperature, API gravity, and gas gravity. The correlation for solution gas-oil ratio is usually derived from bubble point pressure correlation. [3]

Standing Correlation
Standing developed a correlation for determining the solution gas-oil ratio for California crude oils as a function of pressure, gas specific gravity, API gravity, and system temperature. The standing correlation for solution gas-oil ratio is a rearrangement of his correlation for estimating the bubble point pressure.

Laster Correlation
Laster presented a new correlation for calculating solution gas-oil ratio at bubble point using 158 data points from 137 different crude oil systems from the US, Canada, and South America [4]. Laster solution gas-oil ratio correlation is:

Rsb = (132755 \Yo yg) / (MO(1 - yg))

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Vasquez and Beggs Correlation

Vasquez and Beggs developed a new correlation for calculating solution GOR. The correlation was obtained by regression analysis using approximately5008 measured gas-oil ratio data points taken from 600 laboratory PVT analyses from various fields all over the world. Based on oil gravity, the measured data were divided into two groups. This division was made at the value of oil gravity of 30° API[5]. The new correlation has the following form:

Rsb = [(Ygs Pb^C2)/C1 10^((C3 Y_API)/(T+460))]

Coefficient	API ≤ 30	API > 30
C_1	27.64	56.060
C_2	1.0937	1.187
C_3	11.172	10.393

Glaso Correlation

Glaso proposed a correlation for estimating the gas- oil ratio as a function of the API gravity, gas specific gravity, pressure and temperature. The correlation was developed from studying 45 North Sea crude oil samples. Glaso reported an average error of 1.28%.[6]

Coefficient	API ≤ 30	API > 30
A	1.115	0.256
B	0.702	0.782
C	19.620	20.294

Oil Formation Volume Factor at bubble point

Oil formation volume factor (FVF) is defined as the number of reservoir barrels of oil and dissolved gas that must be produced to obtain one stock barrel of stable oil at the surface (rb/stb). The oil formation volume factor is a strong function of pressure, temperature, oil gravity and gas gravity. Most of the published empirical Bo correlations utilize the following generalized relationship.

Bo=f (Rs, γo, γg, T)

Standing Correlation

Standing developed a correlation for calculating the oil formation volume factor as a function of solution GOR, gas specific gravity, oil gravity, and system temperature. The correlation was developed using the same data used to develop his bubble point and solution gas oil ratio correlations. An average error of 1.2% was reported for the correlation [7]. The standing oil FVF correlation is:

Bob = 0.9759 + 0.00012 [Rs (γg / γo)^0.5 1.25(T - 460)]^1.2

Vasquez and Beggs Correlation

Vasquez and Beggs developed a new correlation for estimating oil FVF at bubble point as a function as Rs, γo, γg, and T. The correlation was developed using the same data that was used in developing their bubble point pressure correlation. [8] Vasquez and Beggs reported an average error of 4.7% for the following correlation:

Bob = 1.0 + C1 Rs + (T - 520) (API / γgs) [C2 + C3 Rs]

Coefficient	API ≤ 30	API > 30
C_1	4.677×10^{-4}	4.670×10^{-4}
C_2	1.751×10^{-5}	1.100×10^{-5}
C_3	-1.811×10^{-8}	1.337×10^{-9}

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Glaso Correlation
Glaso developed new correlation for calculating oil formation volume factor at bubble point pressure using the same data was used to develop a correlation for bubble point pressure[10]. The new correlation for oil FVF has the following form:
Bob=1.0+10A
A= -6.58511+2.91329 (log Bob*)-0.27683 (log B ob*) 2

Bob* = Rs (γg / γo)^0.526 + 0.968(T - 460)

Al-Najjar et al. Correlation
Al-Najjar et al. developed a correlation for oil formation volume factor for different Iraqi oil reservoirs using the same data which used in developing bubble point pressure correlation. [11] Al-Najjar correlation has the following form:
Bob=0.96325+4.9×10-4 F

F = Rsb (γg / γo)^0.5 + 1.25 T

Al-Marhon
Al-Marhon developed an empirical correlation for estimating oil FVF at bubble point[12]
Bob= 0.47069+0.862963 × 10-3 T+0.182594 × 10-2 F+0.318099 × 10-5 F2

Data preparation and description
A black oil reservoir fluid study involves a series of laboratory procedures designed to provide values of physical properties (e.g., density, gas gravity, oil viscosity, bubble point pressure, solution gas -oil ratio, and oil formation volume factor). A "study" typically consists of five main procedures performed on a sample of reservoir fluid: composition analyses, a flash vaporization test, a differential vaporization test, separator tests, and measurement of oil viscosity. Standard laboratory PVT tests are carried out on the basis that two different thermodynamic process; flash and differential liberation; occur as reservoir fluid are produced to the surface.
Differential liberation is defined as a process where gas is removed from contact with the oil as it release from solution. By contrast, in a flash liberation of gas, all of the produced gas remains in contact with the oil, at equilibrium conditions.
The number of PVT samples collected was 50 samples. Number of samples used for bubble point pressure, solution gas oil ratio, oil formation volume factor was 50 oil samples, while the number of PVT sample used for viscosity correlations was 50 oil samples

Calculate the current PVT
This is done by illustrating the behavior of the most popular correlations as compared to the used data in "bubble point" for bubble point, solution gas oil ratio at bubble point and oil formation volume factor at bubble point correlations, and "below bubble point" for dead oil viscosity correlation (at atmospheric pressure and system temperature), and "above bubble point" for undersaturated oil viscosity and isothermal oil compressibility correlations.
Table 1. Statistical Accuracy of Bubble Point Pressure, Pb (The existing correlations for these properties are based on reservoir temperature (T), bubble point pressure(Pb), stock tank oil gravity(API), solution gas-oil ratio at bubble point(Rsb),gas gravity(γg), dead oil viscosity(μ**o**d) and saturated oil viscosity(μ**o**b). Since the correlating parameters and the correlated properties are available in standard PVT report, the accuracy of a particular correlation have been checked by comparison with data in a PVT lab report.
The most popular correlations are applied in the used database and the results are presented as cross plot and statistical analysis. Cross plot is a plot of the calculated values from the correlation versus experimental values from the PVT report. A perfect correlation would plot as a straight line with a slope of 45°. Statistical analysis was used to evaluate the performance of the correlations. The standard deviation and average absolute percentage error were the major statistical parameters used as a comparative criterion for the testing of evaluated correlations. Evaluation of Bubble Point Pressure Correlations
In this section, Standing, Glaso, Vasquez and Beegs, Petrosky and Farshad, Al-Marhon, Al-Najjar, Velard, Al-Aboodi and Al-Shammasi correlations for bubble point pressure are evaluated using 50 data points. All of the above correlations for Pb are based on (T), (API), (Rsb), and (γg). Statistical error analysis was used to evaluate the performance of the correlations. The statistical accuracy of bubble point pressure is shown in Table 1

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Table 1. Various Correlations

Correlation	AAERR %	SD %
Velarde	4.253732	4.96529
Al-Najjar	4.606703	5.428116
Al-Marhoun	8.481473	5.944776
Al-Shammasi	12.68183	5.61652
Standing8	14.82187	7.77427
Petrosky& Farshad	16.615	5.6025
Vasquez & Beggs	26.4219	8.34676
Al-Aboodi	32.79324	12.7474

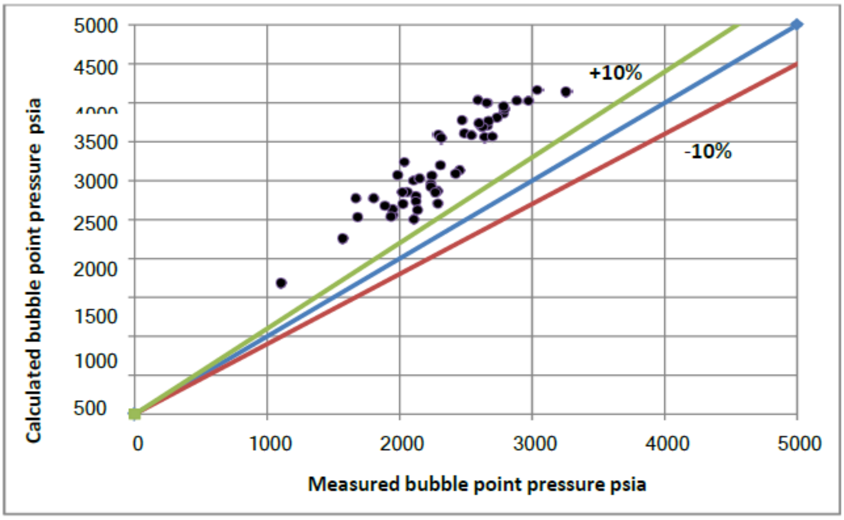

Fig.1 Cross Plot for Bubble-Point Pressure, Pb (Glaso's Correlation)

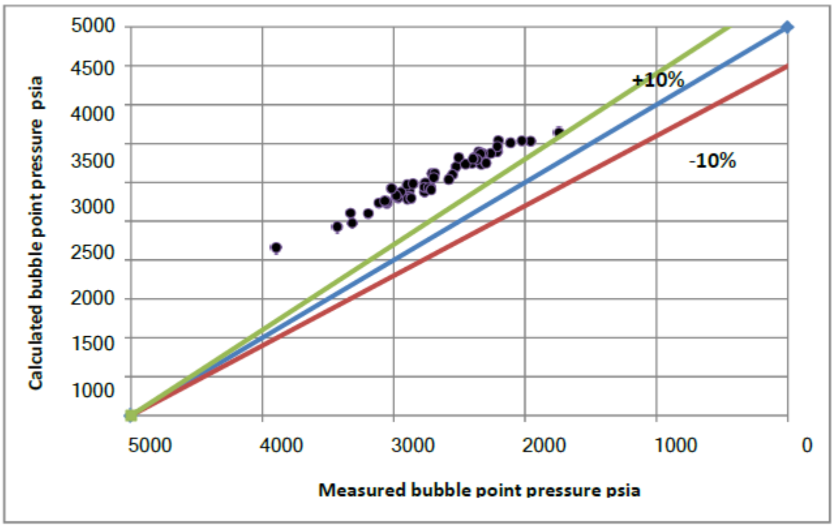

Fig. 2 Cross Plot for Bubble-Point Pressure, Pb (Al-Aboodi's Correlation)

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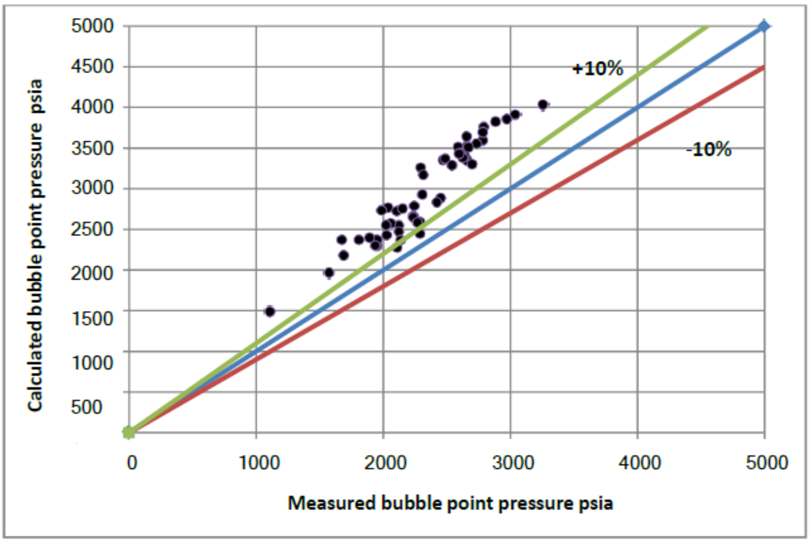

Fig.3 Cross Plot for Bubble-Point Pressure, Pb (Vasquez &Beggs's Correlation)

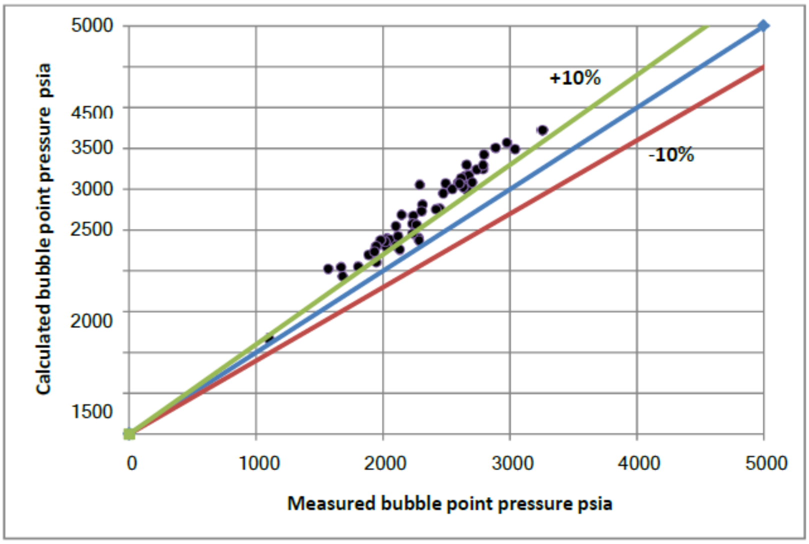

Fig.4 Cross Plot for Bubble-Point Pressure, Pb (Petrosky &Farshad's Correlation)

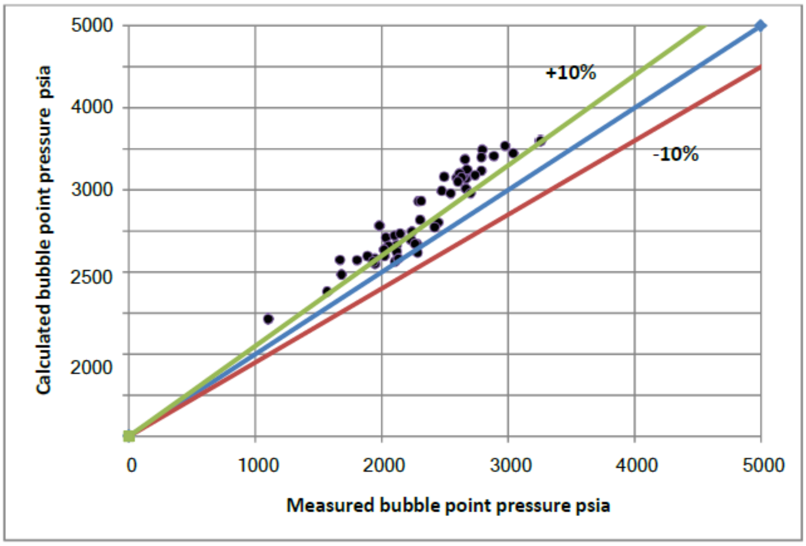

Fig.5 Cross Plot for Bubble-Point Pressure, Pb (Standing's Correlation)

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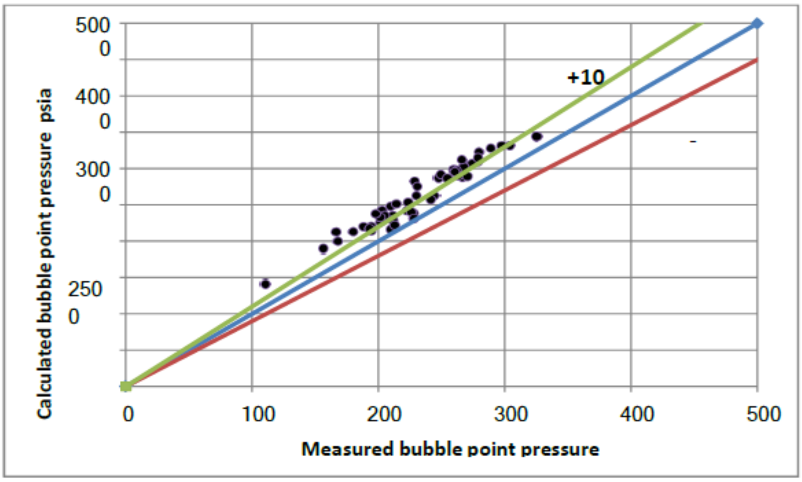

Fig.6 Cross Plot for Bubble-Point Pressure, Pb (Al-Shammasi's Correlation)

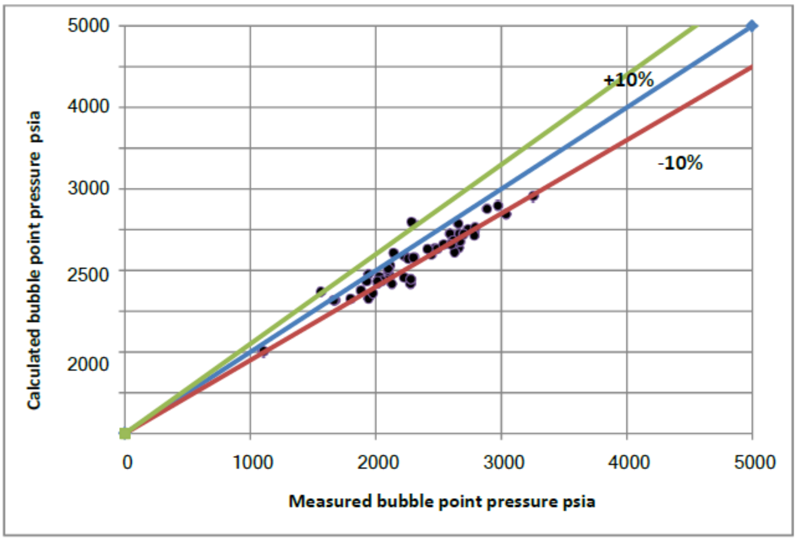

Fig.7 Cross Plot for Bubble-Point Pressure, Pb (Al-Marhon's Correlation)

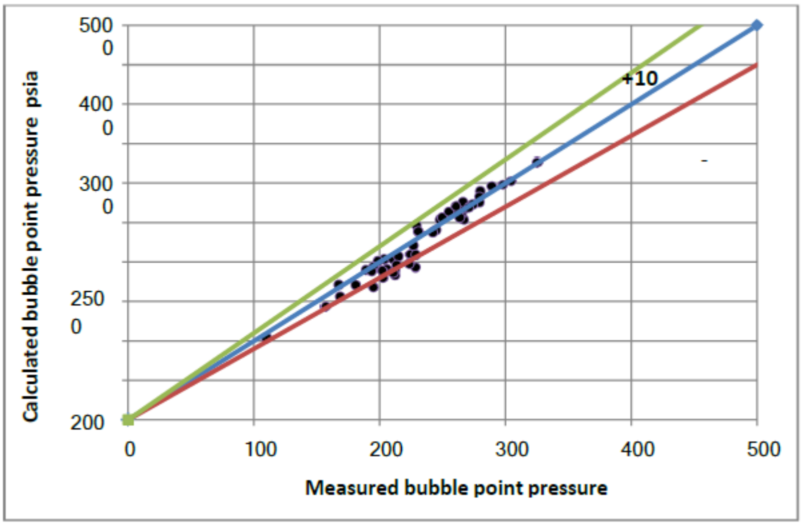

Fig.8 Cross Plot for Bubble-Point Pressure, Pb (Al-Najjar's Correlation)

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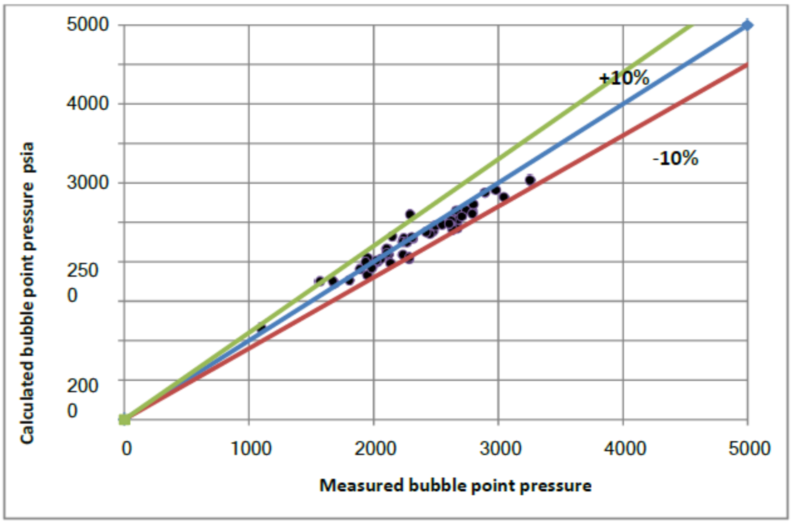

Fig.9 Cross Plot for Bubble-Point Pressure, Pb (Velard's Correlation)

As can be seen from Table (1) and Figures (1) through (9) Velard's correlation performs the lowest average absolute relative error and also appears to be more consistent (best standard deviation). However, in all cases the errors in calculated values have been considered momentous and permitting further effort to develop an improved correlation. So that Velard's correlation may be used to develop the new bubble point pressure correlation for XX reservoir.

Most of the correlations for gas-oil ratio are simply the bubble point pressure correlation and solved for solution gas oil ratio. The statistical accuracy of solution gas oil ratio is shown in Table 2. Cross plot analysis explains the performance of the correlations in Figures (10) through (15).

Table 2 Statistical Accuracy of Gas-Oil Ratio at Pb, Rsb (Various Correlations)

Correlation	**AAERR %**	**SD %**
Al-Najjar	9.10867	8.073319
Al-Aboodi	9.219902	11.23628
Al-Marhoun	13.41007	9.471504
Standing	14.7226	7.01194
Petrosky& Farshad	15.4874	4.763984
Vasquez & Beggs	22.2255	5.85063
Lasater19	26.51304	32.8703
Glaso10	32.491	6.18778

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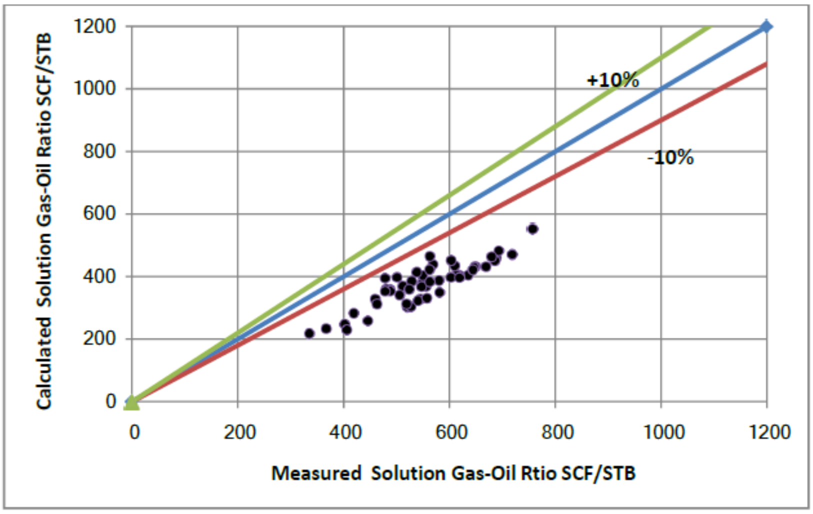

Fig.10 Cross Plot for Solution GOR at Pb, Rsb (Glaso's Correlation)

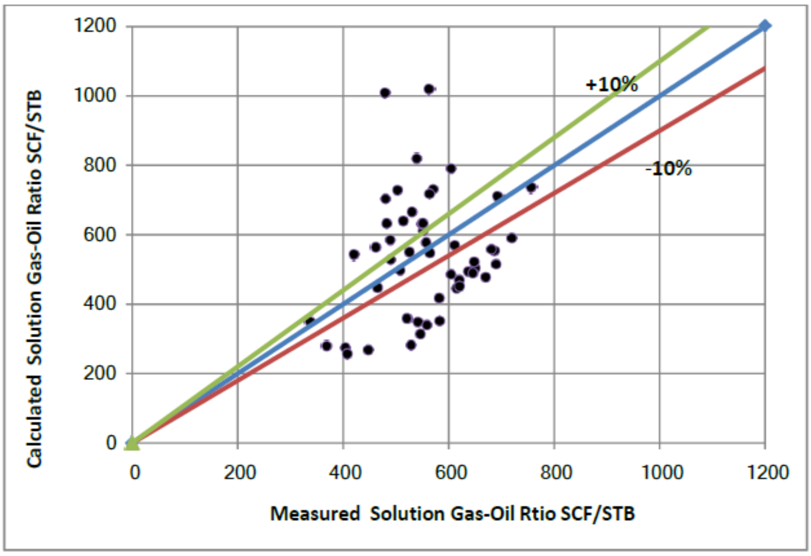

Fig.11 Cross Plot Solution GOR at Pb, Rsb (Lasater's Correlation)

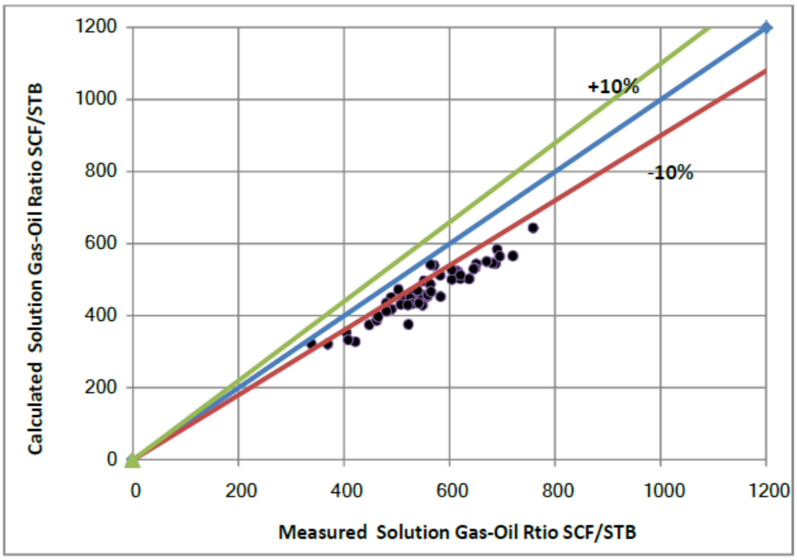

Fig.12 Cross Plot for Solution GOR at Pb, Rsb (Petrosky &Farshad's Correlation)

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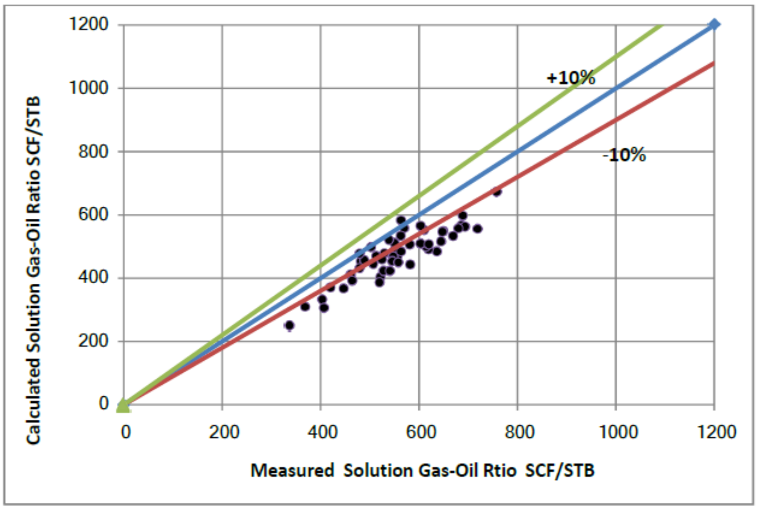

Fig.13 Cross Plot for Solution GOR at Pb, Rsb (Standing's Correlation)

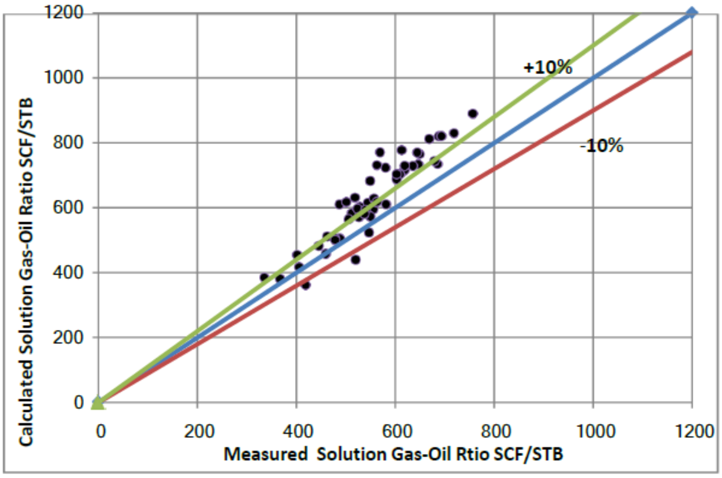

Fig.14 Cross Plot for Solution GOR at Pb, Rsb (Al-Marhoun's Correlation)

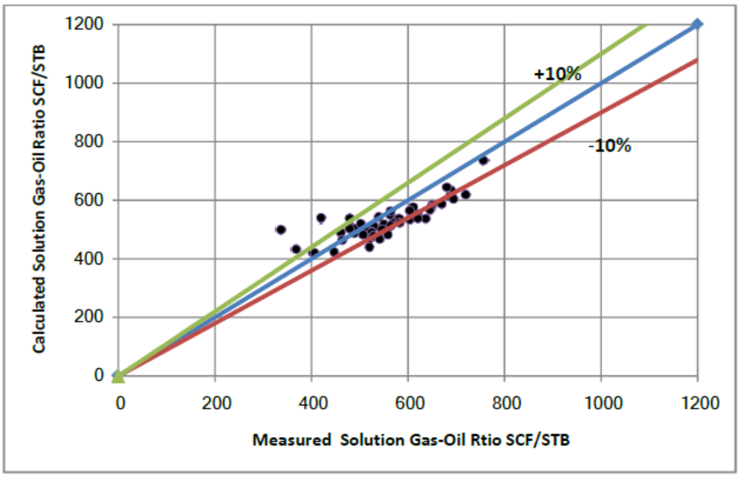

Fig.15 Cross Plot for Solution GOR at Pb, Rsb (Al-Aboodi's Correlation)

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Conclusions

Based on the findings of this study, the following main conclusions are drawn:

1. **Development of Customized Empirical Models:** New, site-specific empirical PVT correlations were successfully formulated for XX reservoir crude oil fields utilizing non-linear multiple regression analysis. The developed models cover bubble point pressure (Pb), solution gas-oil ratio at bubble point (Rsb), oil formation volume factor at bubble point (Bob), dead oil viscosity (μod), saturated oil viscosity (μob), undersaturated oil viscosity (μoa), and undersaturated oil compressibility (co). Comparative evaluations demonstrate that all newly proposed correlations exhibit significantly superior statistical accuracy and predictive capability compared to existing published models.
2. **Performance of Formation Volume Factor (Bob) Models:** The newly developed correlation for bubble point oil formation volume factor (Bob) demonstrated the highest accuracy among all evaluated formulations. Nevertheless, previously published Bob correlations also yielded highly reliable and acceptable estimates for the XX reservoir crude oils.
3. **Overall Predictive Reliability:** The newly established models consistently predict key thermodynamic PVT properties with high statistical precision, characterized by exceptionally low average absolute relative error (AARE) values across the entire field dataset.

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