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Development of Pressure-Volume-Temperature (PVT) Analysis Software: PVTAsoft 1.2

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Abstract- An understanding of Pressure-Volume-Temperature (PVT) properties is one of the fundamental aspects of reservoir and production engineering. This paper presents PVT analysis software called PVTASoft 1.2. The Software allows the use of empirical PVT correlations to match laboratory data. The platform for the implementation of the software is the Visual Basic .NET interface. The software contained a very rich PVT database for ten different fluid properties for the Niger Delta crude. Some of the main features of the software include: PVT calculator, record update screen, correlations comparison by statistical and graphical presentations. The software will be useful to the industry and academia in the area of fluid property correlations screening, assessment and selection.

Keywords- *PVT Analysis, PVT Calculator, PVT database and PVT Software*

I. INTRODUCTION

Measurements of the physical properties of a fluid are essential to reservoir and production engineering. To perform their calculations, petroleum engineers need to know the fluid's viscosity, density, dissolved gas content, and other factors, as well as how these properties vary with temperature and pressure. Such information, however, is not usually readily available. In the early stages of a well it can be difficult or economically impractical to obtain reliable measurements. Fluid samples, if available, can be subjected to pressure-volume-temperature analyses to determine their properties, but samples are often suspect and PVT analyses usually apply only at reservoir temperature [1]. One solution is to use what are known as correlations. By studying field data and fitting curves to measured results, engineers have developed empirical relationships that relate various fluid properties. These correlations are useful tools for estimating fluid properties from limited information. A variety of methods have been developed and published in the literature over the years that produce varying degrees of success depending upon the application [2, 3, 3, 5, 6].

Pressure-volume-temperature (P-V-T) data are the most fundamental thermodynamic data. For reservoir fluid all of the thermodynamic properties are most often written directly in terms of pressure, temperature, and volume, and comprehensive P-V-T data are the basis for fitting accurate equations of state as well as to validate empirical PVT correlations. These data are also often required for the interpretation of other fluid measurements. More specifically, PVT data representative of the reservoir fluid are needed to validate the well test properly and to provide meaningful interpretation. The estimation of reserves and the design of the best depletion strategy are feasible only when realistic and reasonably accurate values of reservoir fluid properties are available [7].

Software exist in the area of PVT properties for crude oil; PVT Pro, PVT ReCORD, FluidProps, MI-PVT 2.05, PVT Express and others [8,9,10,11]. Majority of these software are proprietary and uses compositions of the crude to make analysis. Others also used easily available field data to do their correlation matches such as Mbal and Prosper as well as Integrated Production Modeling software (IPMS). This set of software are also proprietary and the underlying principles unknown. One shortcoming with this second set of PVT software is that the correlations assessment parameters used are less effective. However, a more improved and comprehensive methodology has been presented by Ikiensikimama and Egbe [1]. Therefore, this work aimed at presenting PVT analysis software called PVTASoft 1.2. This software has the capability to provide a powerful optimization methodology in screening reservoir crude oil properties that handle Bubble point Pressure, Bubble point Oil FVF, Under saturated Oil FVF, Solution Gas-Oil Ratio Correlation, Bubble point Oil Compressibility, Oil Compressibility Correlation, Dead-Oil-viscosity Correlation, Bubble point Oil viscosity Correlation, Under saturated-Oil- Viscosity Correlation and Oil Viscosity below bubblepoint Correlations.

The developed software PVTASoft 1.2 was built on the Visual Basic .Net platform with the following objectives:

- PVT calculator to enable the use of available correlations.
- A means of maintaining a comprehensive database for different reservoir fluid properties for the Niger Delta crude.
- A means of comparative comparison of reservoir fluid properties using various correlations.

- A quick means of comparing different correlations graphically.
- A means of PVT correlations assessment and screening for the industry and educational purpose.

II. Reservoir Crude Oil Fluid Properties

The database used in this study contains the following crude oil fluid properties.

A. Bubblepoint Pressure

Reservoir engineers need to know the bubble-point or "saturation" pressure—the highest pressure at which a bubble of gas is first liberated from the oil. This property can be determined from a PVT analysis of a fluid sample or calculated if the composition is known, this information is frequently unavailable. Correlations exist that are used to estimate the bubble point pressure as a function of reservoir temperature, stock-tank oil gravity, dissolved-gas gravity, and solution gas/oil ratio a the initial reservoir pressure. Seventeen bubblepoint pressure correlations were implemented in this software. These are: Standing [2], Lasater [3], Vazquez and Beggs [4], Glaso [5], Al-Marhoun [6], Dokla and Osman [12], Farshad et al. [13], Macary and El-Batanoney [14], Omar andTodd [15], Petrosky and Farshad [16], Kartoatmodjo and Schmidt [17], Velarde et al. [18], Almehaideb [19], Al-Shammasi [20], Dindoruk & Christman [21], Hemmati and Kharrat [22] and Ikiensikimama [7].

B. Solution Gas –Oil Ratio

The gas/oil ratio is a measure of the amount of gas remaining dissolved in solution at pressures below the bubblepoint pressure. This information is required by both reservoir and production engineering calculations. While not easily measured, the ratio can be estimated by working the bubble-point correlation backwards and solving for the gas/oil ratio. However, the correlations used in the implementation are: Standing [2], Vazquez and Beggs [4], Glaso [5], Obomanu and Okpobiri [23], Udegbunam and Owolabi [24], Al-Marhoun [6], Petrosky and Farshad [16], Farshad et al. [13], Almehaideb [19], Kartoatmojo and Schmidt [17], Dindoruk and Christman [21], Hemmati and Kharrat [22], and Ikiensikimama [7].

C. Oil Formation Volume Factor

Saturated oil taken from a reservoir to the surface will shrink as the dissolved gas evolves from the fluid. The formation volume factor (FVF) provides a measure of this shrinkage. It is the volume occupied by 1 STB oil and any dissolved gas at some elevated pressure and temperature. Petroleum Engineers use this to compare tank volumes to reservoir volumes and flow rates at the surface that of the downhole under varying conditions. Liquid volume is also affected by temperature. If pressure is increased above the bubble point, the fluid is compressed and its viscosity increases. Reservoir engineers need to relate tank volumes to reservoir volumes at different pressures and constant reservoir temperature. Production engineers need to convert flow rates on the surface to those at various pressures and temperatures as the fluid is produced. Two forms of oil formation volume factors were implemented: the bubblepoint oil formation volume factor and the undersaturated oil formation volume factor. The correlations programmed were; Standing [2], Lasater [3], Vazquez and Beggs [4], Glaso [5], Obomanu and Okpobiri [23], Udegbunam and Owolabi [24], Al-Marhoun [6], Abdul-Majeed and Salman [25], Dokla and Osman [12], Petrosky and Farshad [16], Farshad et. al. [13], Al-Marhoun [26], Omar and Todd [15], Almehaideb [19], Marcary and El-Batanony [14], Kartoatmojo and Schmidt [17], Al-Shammasi [20], Dindoruk and Christman [21], Hemmati and Kharrat [22], and Ikiensikimama [7] for bubblepoint oil formation volume factor and Vazquez and Beggs [4], Kartoatmodjo and Schmidt [17], and Ikiensikimama [7] for undersaturated oil formation volume factor.

D. Oil Viscosities

Viscosity is a measure of the fluid's resistance to flow that results from internal friction as the fluid molecules are sheared. Reservoir and production calculations necessitate knowledge of viscosity at various pressures and temperatures. A PVT analysis can be used to measure viscosity at reservoir temperature, but correlations are useful for estimating the changes with temperature as the fluid flows through the production system. Viscosity increases as API gravity and temperature decrease. Dissolved gas lightens the fluid and decreases its viscosity, while increasing the pressure on an undersaturated oil causes its viscosity to increase. Four types of oil viscosities are considered in this work.

1) Dead Oil Viscosity

Nine dead oil viscosity correlations were implemented in this software. These are Beal [27], Beggs and Robinson [28], Glaso [5], Egbogah and Jack [29], Kartoatmodjo and Schmidt [17], Petrosky and Farshad [16], Dindoruk and Christman [21], Hossain et al. [30], and Ikiensikimama [7].

2) Bubblepoint Oil Viscosity

Nine bubblepoint oil viscosity correlations were implemented in this software. These are Chew and Connaly [31], Beggs and Robinson [28], Khan et al. [32], Kartoatmodjo and Schmidt [17], Petrosky and Farshad [16], Almehaideb [19], Dindoruk and Christman [21], Hossain et al. [30], and Ikiensikimama [7].

3) Undersaturated Oil Viscosity

Twelve undersaturated oil viscosity correlations were implemented in this software. These are Beal [27], Kouzel [33], Vazquez and Beggs [4], Khan et al. [32], Al-Khafaji et al. [35], Albdul-Majeed et al. [35], Petrosky and Farshad [16], Almehaideb [19], Dindoruk and Christman [21], Hossain et al. [30], Bergman and Sutton [36], and Ikiensikimama [7].

4) Viscosity below Bubblepoint

Two correlations were used Khan et al. [32] and Ikiensikimama [7].

E. Oil Compressibility

Oil compressibility is the fractional change of the volume of oil as pressure changes. Values of oil compressibility are required in all solutions of transient fluid-flow problems. Oil compressibility can be calculated directly if reservoir-fluid studies are available [37]. When such direct measurements are not available, PVT correlation from the literature are often used. Several oil compressibility correlations exist in the literature, which used crude from other geographical regions of the world. Two types of compressibility factors are considered in this work.

1) Bubblepoint Compressibility

The correlations programmed for the bubblepoint oil compressibility were Calhoun [38], Vazquez and Beggs [4], Labedi [39], Almehaideb [19], Kartoatmodjo and Schmidt [17], Dindoruk and Christman [21], and Ikiensikimama [7].

2) Undersaturated Oil Compressibility

Thirteen undersaturated oil compressibility correlations were implemented in this work These are Vazquez and Beggs [4], Ahmed [40], Labedi [39], Al-Marhoun [26], Farshad et al. [13], Petrosky and Farshad [16], De Ghetto et al. [41], Kartoatmodjo and Schmidt [17], Almehaideb [19], Elsharkawy and Alikhia [42], Al-Marhoun [43], Dindoruk and Christman [21], and Ikiensikimama [7].

III. QUANTITATIVE AND QUALITATIVE SCREENING

Two types of screening techniques are used in this work: Quantitative and Qualitative screening.

For quantitative screening technique, a new approach of combining several statistical parameters into a single comparable parameter called rank was used. These statistical parameters are percent mean relative error (E_r), percent mean absolute error (E_a), percent standard deviation relative (S_r), percent standard deviation absolute (S_a) and correlation coefficient (R). This approach employed multiple combination of these statistical parameters to select the best correlation which is modeled as a constraint optimization problem formulated as;

$$Min\ Z_i = \sum_{j=1}^{m} S_{i,j} q_{i,j} \tag{1}$$

Subject to

$$\sum_{i=1}^{n} S_{i,j} = 1 \tag{2}$$

With

$$0 \le S_{i,j} \le 1 \tag{3}$$

Where $S_{i,j}$ is the strength of the statistical parameter j of correlation i and q_{ij}, the statistical parameter j corresponding to correlation ij = E_r, E_a, …. R^1, where R^1 = (1-R) and Z_i is the rank, RK (or weight) of the desired correlation. The optimization model outlined in Equations 2 to 4 was adopted in a sensitivity analysis to obtain acceptable parameter strengths. The final acceptable parameter strengths so obtained for the quantitative screening are 0.4 for E_a, 0.2 for R, 0.15 for S_a, 0.15 for S_r, and 0.1 for E_r. Finally, Equation 2 was used for the ranking. The correlation with the lowest rank was selected as the best correlation for that fluid property [7]. It is necessary to mention that minimum values were expected to be best for all other statistical parameters adopted in this work except R, where a maximum value of 1 was expected. Since the optimization model (Equations 1 to 3) is of the minimizing sense a minimum value corresponding to R must be used. This minimum value was obtained in the form (1-R). This means the correlation that has the highest correlation coefficient (R) would have the minimum value in the form (1-R). In this form the parameter strength was also implemented to 1-R as a multiplier. Ranking of correlations was therefore made after the correlation had been evaluated against the available database.

For qualitative screening, performance plots were used. The performance plot is a graph of the predicted versus measured properties with a 45^o reference line to readily ascertain the correlation's fitness and accuracy. A perfect correlation would plot as a straight line with a slope of 45^o. It should be noted that the 45^o is not a line of best fit.

IV. PVTASOFT 1.2 PROGRAM DESCRIPTION

A MDI based computer program written with Visual Basic .Net was used to test this methodology. The program is capable of accepting inputs from users or from files. It also has the capability to generate reliable PVT properties for different reservoir conditions. Typical outputs generated from the computer program are PVT parameters as well as associated statistical parameters that are compared to the actual values. Ranking of correlations is therefore made after the calculations have been done and selection of best correlation is done after inspection of the performance plot. The software contains an Access database consisting of ten tables corresponding to the different fluid properties considered in this work. A simple form of the program flow chart is as shown in Figure 1.

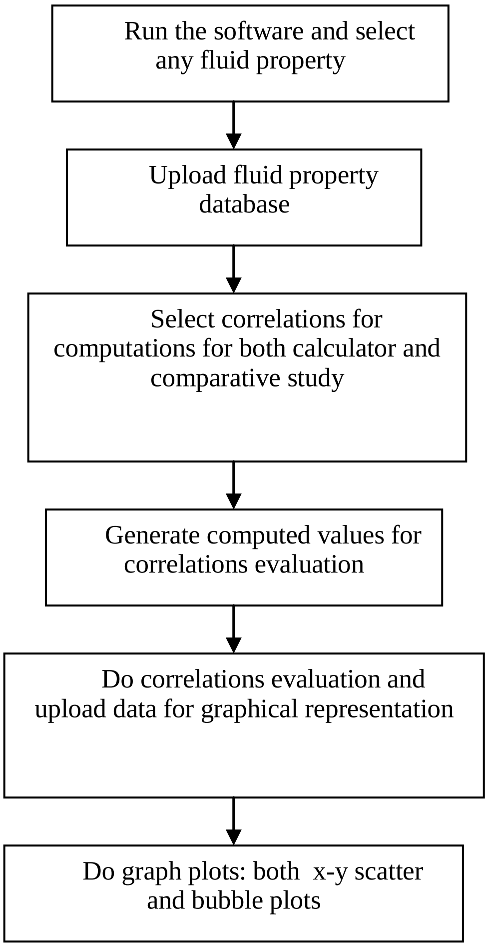


Figure 1. Program Flow Chart

A summary of the procedure used to select the best correlation using the computer program developed as part of this work is outlined below.

Step 1: collate pertinent input data for the different correlations from PVT reports such as API, reservoir pressure, reservoir temperature, solution GOR, etc.

Step 2: Enter input parameters on the appropriate input panel (Figure 2)

Step 3: Calculate the statistical parameters such as E_a, E_r, R, S_a and Sr, by evaluating the different correlations for that properties.

Step 4: Use quantitative PVT ranking Screening to rank the correlations

Step 5: Use qualitative Screening to select the best correlation.

Figures 2 to 5 show some of the snapshot of the software output interface.

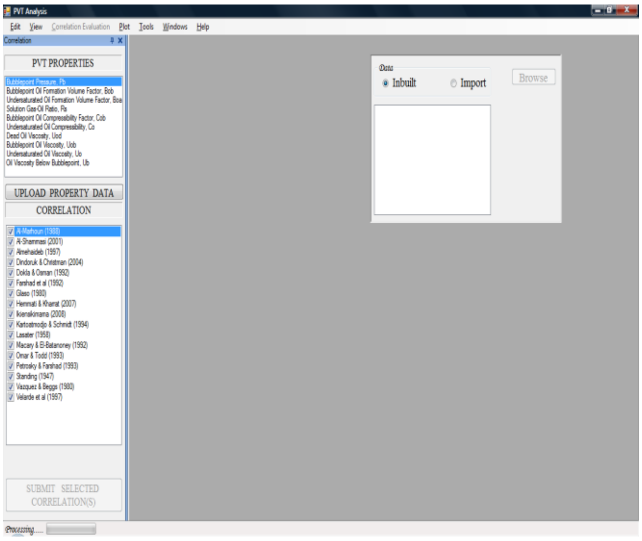


Figure 2. Main Screen Interface

Figure 2 shows the main MDI interface screen. It consist of two main frames. The one on the right contains a small frames that makes data available for process, either data from the inbuilt database, or import from excel worksheet or other compatible formats.

The frame on the left hand consists of two section. The upper section enable the user to select the PVT properties of interest to be evaluated. The lower section makes available the correlations programmed for that fluid property. The command button “submit selected correlation” enable the user to submit the selected correlation(s) for processing. The menu bars consist of drawdown menus such as Edit, view, correlation evaluation, plot, tools, windows and help.

Figure 3 shows the correlation comparative evaluation screen. It is also one of the correlation evaluation menu. This Figure gave the correlation’s statistical parameters evaluated with their respective ranking in the lower right frame.

The lower right frame also shows the strength of the statistical parameter use in the ranking process as stated in section 3. If changes are made to these statistical parameters, “the upload” button uploads these new correlation evaluation. The “summary” button gives the summary of the correlation evaluations (see Figure 4). Figure 4 shows that Ikiensikimama [7] is ranked first with a corresponding value of 7.284 (keeping to 3 decimal places).

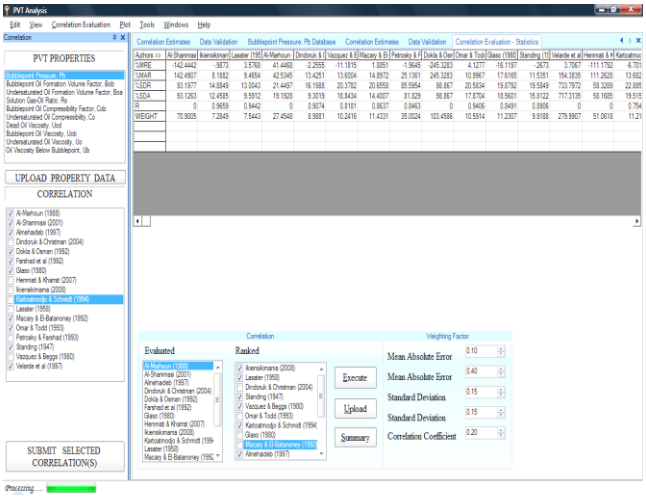
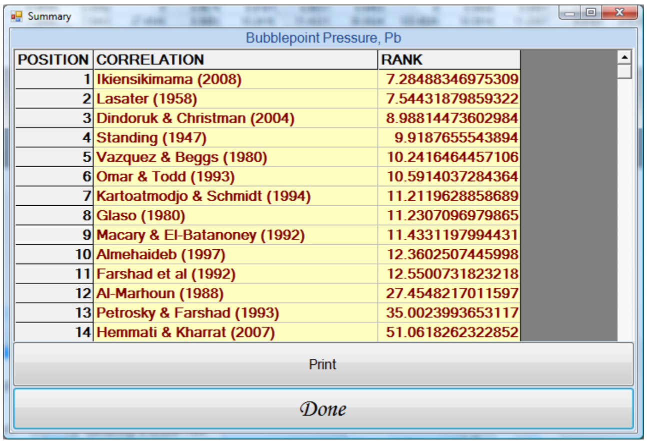


Figure 3. Comparative Evaluation screen



Summary

Bubblepoint Pressure, Pb

POSITION	CORRELATION	RANK
1	Ikiensikimama (2008)	7.28488346975309
2	Lasater (1958)	7.54431879859322
3	Dindoruk & Christman (2004)	8.98814473602984
4	Standing (1947)	9.9187655543894
5	Vazquez & Beggs (1980)	10.2416464457106
6	Omar & Todd (1993)	10.5914037284364
7	Kartoatmodjo & Schmidt (1994)	11.2119628858689
8	Glaso (1980)	11.2307096979865
9	Macary & El-Batanoney (1992)	11.4331197994431
10	Almehaideb (1997)	12.3602507445998
11	Farshad et al (1992)	12.5500731823218
12	Al-Marhoun (1988)	27.4548217011597
13	Petrosky & Farshad (1993)	35.0023993653117
14	Hemmati & Kharrat (2007)	51.0618262322852

Print

Done

Figure 4. Summary Report screen

Figure 5 shows a trimmed date validation screen. The upper part of the middle frame shows the upper and lower bounds and the step by step of the available dataset of interest. The button " trim" trims the data- set required out of the bulk of the data and the button "update" uploads it for processing.

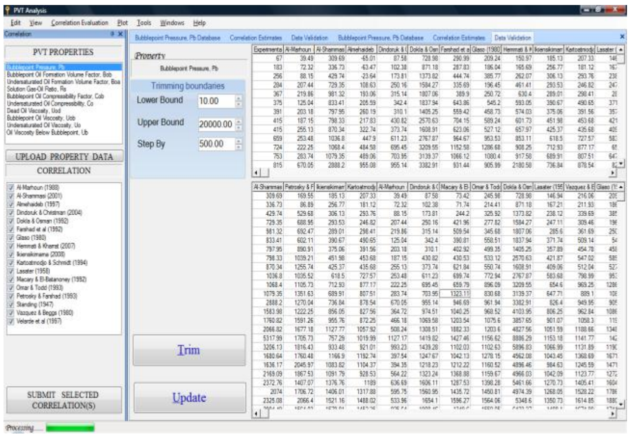


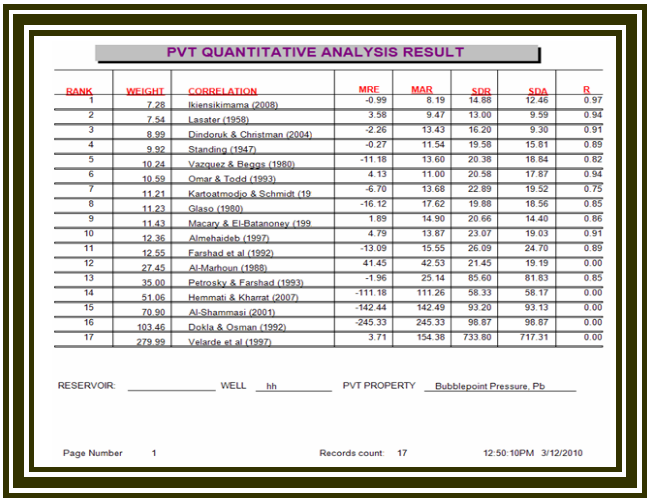
Figure 5. Trimmed Data validation

V. APPLICATIONS OF PVTASOFT 1.2

The PVTASOFT 1.2 can be applied in Reservoir fluids PVT calculation, Validation of reservoir fluid data , Fluid property correlations, Fluid property screening, Fluid property assessment and selection, Crystal report and printing facility, Ranking and selection of PVT data, Comparative evaluation of reservoir fluid property correlations to select correlation of best fit and Conduct PVT study for oil field development.

VI. RESULTS AND DISCUSSION

The bubble point pressure was used to validate the PVTASOFT 1.2 software. The evaluation was made by using seventeen bubble point pressure correlations. The results of the evaluations (as shown in Figures 6 and 7) give the statistical accuracies and the ranking for all the bubble point pressure correlations examined. From Figure 6, Ikiensikimama [7] correlation for Nigerian crude ranked best with E_a of 6.19 and R of 0.97 followed by Lasater [3] correlation for Canada and USA with the rank of 7.54 while Velarde et al. [18] correlation with E_a of 154.36 and without correlation coefficient ranked last for the entire data set used. The impressive performance of Ikiensikimama [7] agrees with the literature since, correlation perform best in a geographical location**.** The results obtained is also consistent, when compared to the result obtained by Ikiensikimama [44]. The author reported that Lasater [3] correlation is the best bubble point pressure correlation followed by Dindoruk and Christain [21] that can be used for Niger-Delta region in the absence of indigenous correlation. The consistency of PVTASOFT 1.2 result with the result obtained by Ikiensikimama [44] shows that the software was properly developed.



PVT QUANTITATIVE ANALYSIS RESULT

RANK	WEIGHT	CORRELATION	MRE	MAR	SDR	SDA	R
1	7.28	Ikiensikimama (2008)	-0.99	8.19	14.88	12.46	0.97
2	7.54	Lasater (1958)	3.58	9.47	13.00	9.59	0.94
3	8.99	Dindoruk & Christman (2004)	-2.26	13.43	16.20	9.30	0.91
4	9.92	Standing (1947)	-0.27	11.54	19.58	15.81	0.89
5	10.24	Vazquez & Beggs (1980)	-11.18	13.60	20.38	18.84	0.82
6	10.59	Omar & Todd (1993)	4.13	11.00	20.58	17.87	0.94
7	11.21	Kartoatmodjo & Schmidt (19	-6.70	13.68	22.89	19.52	0.75
8	11.23	Glaso (1980)	-16.12	17.62	19.88	18.56	0.85
9	11.43	Macary & El-Batanoney (199	1.89	14.90	20.66	14.40	0.86
10	12.36	Almehaideb (1997)	4.79	13.87	23.07	19.03	0.91
11	12.55	Farshad et al (1992)	-13.09	15.55	26.09	24.70	0.89
12	27.45	Al-Marhoun (1988)	41.45	42.53	21.45	19.19	0.00
13	35.00	Petrosky & Farshad (1993)	-1.96	25.14	85.60	81.83	0.85
14	51.06	Hemmati & Kharrat (2007)	-111.18	111.26	58.33	58.17	0.00
15	70.90	Al-Shammasi (2001)	-142.44	142.49	93.20	93.13	0.00
16	103.46	Dokla & Osman (1992)	-245.33	245.33	98.87	98.87	0.00
17	279.99	Velarde et al (1997)	3.71	154.38	733.80	717.31	0.00

RESERVOIR: ______ WELL hh PVT PROPERTY Bubblepoint Pressure, Pb

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Figure 6. Report- PVT Quantitative Analysis Result

Figure 7 shows a snapshot of some performance plot of bubble point pressure correlation. It also shows the capability of PVTASOFT 1.2 to plot and compare the correlations. It can be deduced from Figure 7 that Dindoruk and Christain [21] correlation gave a better performance plot followed by Standing [2], Kartoatmodjo and Schmidt [17] and Glaso [5] which is consistent with the result obtained from Figures 5 and 6. (for the correlations selected for this analysis). From Figure 7, Dindoruk and Christain [21] gives a better performance plots as the points clusters more on the straight line on a slope of 45^0 than every other correlations.

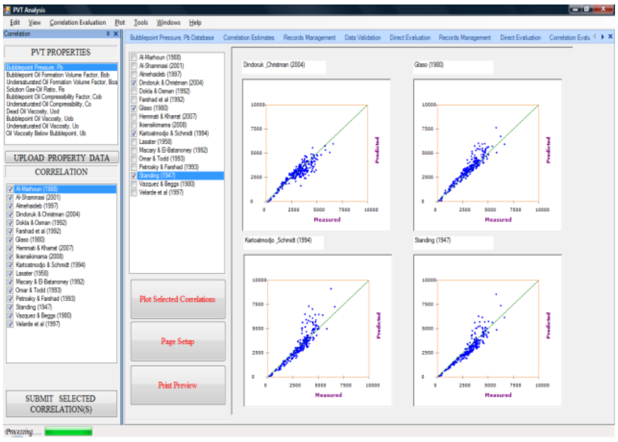

Figure 7. Performance Plot for Bubblepoint Oil

VII. CONCLUSIONS

PVT analysis software called PVTASoft 1.2 has been developed and some of the main features illustrated. It contains a database of the Niger Delta crude for ten different fluid properties with good graphical capability. The software has the capability to upload, validate and evaluate fluid properties data. Data plotting is made easy with the software, performance plots are presented in a more user friendly way and can be easily interpreted. PVTASoft 1.2 maximizes the value of the laboratory PVT studies by minimizing the amount of experiments required, thereby saving cost.

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REFERENCES

[1] S. S. Ikiensikimama and T. Egbe, “Improved PVT Screening Methodology”. Technical Transactions on Software Engineering, **1**, 59-67, IPS Applied Technology Series, University of Port Harcourt, Nigeria ,2006.

[2] M. B. Standing, “A Pressure Volume Temperature Correlation for Mixture of California Oils and Gases,” *Drill.* & Prod. Prac. API, Dallas. 275-87., 1947.

[3] J. A. Lasater, “Bubble point Pressure Correlation,” *Trans.*, AIME **213,** 379-81., 1958.

[4] M. E Vazquez,. and H. D. Beggs, “Correlations for Fluid Physical Property Prediction,” *JPT* (June) 968-70, 1980.

[5] O. Glaso, “Generalized Pressure-Volume Temperature Correlations,” *JPT* (May), 1980 , pp 785-95.

[6] M. A. Al-Marhoun, “PVT Correlations for Middle East Crude Oils, “ *JPT* (May) 650-66, SPE Paper 13718., 1988.

[7] S. S. Ikiensikimama, The performance of Empirical PVT Correlations for Predicting Reservoir Fluid Properties for Some Niger Delta Crude. Ph.D Dissertation, University of Lagos, Lagos – Nigeria. ,2008.

[8] http://www.unicous.com/oilgas/solutions014print.html

[9] http://www.btechsoft.com/Index.aspx

[10] http://www.slb.com/media/services/testing/reservoir/pvt_pro.pdf

[11] N. Varotsis and P. Guieze, “Onsite Reservoir Fluid Properties Evaluation” (SPE paper 18317), *JPT*, August, 1046-1059. 1990

[12] M. Dokla and M. Osman “Correlation of PVT Properties for UAE Crudes,” *SPE Formation Evaluation* (March) 41-46; SPE Paper 21342. 1992.

[13] F. F. Frashad, J. L. Leblance, J. D. Garber and J. D. Osorio, “Empirical Correlation for Columbian Crude Oils,” paper SPE 24538, Unsolicited (1992), Available from SPE book Order Dept. Richardson. TX.1992.

[14] S. M. Macar. and M. H. El-Batanoney “Derivation of PVT Correlations for the Gulf of Suez Crude Oils,” EGPC 11th Pet. Exp & Prod. Conf. 1992.

[15] M. I. Omar. and A. C. Todd, “Development of New Modified Black oil Correlation for Malaysian Crudes,” SPE 25338.1993.

[16] J. Petrosky and F. Farshad, “Pressure Volume Temperature Correlation for the Gulf of Mexico.” 68th Soc. Pet. Eng. Anna. Tech. Con. Houston, TX, Oct 3-6 1993, SPE 26644. 1993.

[17] T. Kartoatmodjo and Z. Schmidt “Large data bank improves crude physical property correlations,” *Oil and Gas Journal*,(July 4), pp 51-55.1994.

[18] J. J. Velarde, T. A. Blasingame, and W. D. McCain, ”Correlation of Black Oil Properties at Pressure Below Bubble Point Pressure – A New Approach,” paper 97-93 presented at the 48th ATM of The Petroleum Society, Calgary, 8-11 June. 1997

[19] R. A. Almehaideb, “Improved PVT Correlations for UAE Crude Oils,” SPE 37691, SPE Middle East Oil Show CONF (Manamah, Bahrain, 3/15-18/97) PROC VI, 1997, pp 109-120.

[20] A. A. Al-Shammasi, “A Review of Bubblepoint Pressure and Oil Formation Volume Factor Correlations, “ SPE paper 71302, 2001.

[21] B. Dindoruk and P. G. Christman, ” PVT Properties and Viscosity Correlations for Gulf of Mexico Oils,” *SPE* Reservoir Engineering, (Dec.), pp 427 – 437, 2004.

[22] M. N. Hemmati and R. Kharrat, “A correlation Approach for Prediction of Crude-Oil PVT Properties,” SPE 15721. 5th Mid East Oil & Gas Show & Conf., Bahrain, March 11-14., 2007.

[23] D. A. Obomanu and G. A. Okpobori “Correlating the PVT Properties of Nigerian Crudes,”Tran ASME Vol. 109**,** pp 214-24, 1987.

[24] E. O. Udegbunam and O. O.Owolabi, ”Correlating the PVT Properties of Nigerian Crudes” SPE NS 215, presented at the NSPE Convention, Port Harcourt, 1987.

[25] G. H. Abdul-Majeed and N. H. Salman “An Empirical Correlation for FVF Prediction” *J Can. Pet. Tech*., 27(6), 118-122., 1988.

[26] M. A. Al-Marhoun, “New Correlation for Formation Volume Factor of oil and gas Mixtures,” *Journal of Canadiann*Petroleum Technology (March) 22-26., 1992.

[27] C. Beal, “The Viscosity of Air, Water, Natural Gas, Crude Oil and Its Associated Gases at Oil Field Temperature and Pressures” (SPE paper 946094), *AIME Chicago Meeting*, February, 94-115., 1946 .

[28] H. D. Beggs and J. R. Robinson, “Estimating the Viscosity of Crude Oil Systems,” *JPT* (Sept.) 1140-41., 1975.

[29] E. O. Egbogah, and T. Jack, “An Improved Temperature-Viscosity Correlation for crude Oil Systems”. Journal of Petroleum Science and Engineering. 5, 1990 pp 197-200.

[30] M. S. Hossain, C. Sarica, , H. Q. Zhang, L. Rhyne, and K. L.Greenhill, "Assessment and Development of Heavy-Oil Viscosity correlations," SPE/PS-CIM/CHOA 97907 PS2005-407 Presented at the 2005 SPE international thermal operations and Heavy Oil Symposium, Calgary, Alberta, Canada, Nov. 1-3., 2005.

[31] J. Chew, and C. A. Connally "A Viscosity Correlation for Gas Saturated Crude Oils," *Trans.,* AIME 216, 23-25.1995.

[32] S. A. Khan, M. O. Al-Marhoun, S. O. Duffuaa, S. A. Abu-Khamain, "Viscosity Correlations for Arabian Crude Oils," SPE paper 15720 presented at the Fifth SPE middle East Oil Show held in Mamama, Bahrain, March 7-10., 1987.

[33] B. Kouzel, :"How Pressure Affects Liquid Viscosity," Hyd. Proc., (March) 120. 1965.

[34] A. H. Al-Khafaji, G. H. Abdul-Majeed, and S. F. Hassoon "Viscosity Correlation for Dead, Live and Undersaturated Crude Oi" *J. Pet. Res.*, December, 1 – 16, 1987.

[35] G. H. Abdul-Majeed, R. R. Kattan, and N. H. Salman "New Correlation for Estimating the Viscosity of Undersaturated Crude Oils" *J. Cdn. Pet. Tech*. (May-June) 80-85., 1990.

[36] D. F. Bergman, and R. P. Sutton, "Undersaturated Oil Viscosity Correlation for Adverse Conditions," SPE 103144. Selected for presentation at the 2006 SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, U. S. A, Sept. 24 - 27., 2006.

[37] W. D. McCain, J. B. Rollins, and A. J. Villena, "The Coefficient of Isothermal Compressibility of Black oils at Pressures Below the Bubblepoint," SPE Formatio Evaluation (Sept.), pp 659-662., 1988.

[38] J. C. Calhoun, *Fundamentals of Reservoir Engineering,* U. of Oklahoma Press, Norman, OK. 1947, P 35.

[39] R. Labedi, "Use of Production Data to Estimate Volume Factor Density and Compressibility of Reservoir Fluids." Jour Pert Scie Eng. **4**, 357-90., 1990.

[40] T. H. Ahmed, *Hydrocarbon Phase Behavior*, Gulf Publishing, Houston, TX. 1988.

[41] G. De Ghetto, F. Paone, and M. Villa, "Reliability Analysis on PVT correlation," SPE 28904, presented at the European Petroleum Conference held in Londom, U. K, 26-27 Oct., 1994.

[42] A. M. Elsharkawy and A. A. Alikhan, "Correlations for Predicting Solution Gas/Oil Ratio, Oil formation Volume Factor, and Undersaturated Oil compressibility," J. Pet. Sci. Eng (May) 291-302., 1997.

[43] M. A. Al-Marhoun, "The Coefficient of Isothermal Compressibility, "SPE Paper 81432. Paper prepared for presentation at the SPE 13th Middle East Oil Show & Conference to be held in Bahrain 5-8 April., 2003.

[44] S. S. Ikiensikimama and O. Ogboja, "Applicability of Bubblepoint Pressure Empirical PVT Correlations for the Niger Delta Crude" Journal of Nigerian Society of Chemical Engineers, **22**, 13-20., 2007.