A NEW PROCEDURE FOR RESERVOIR FLUID CHARACTERIZATION WITH EQUATION OF STATE (EOS)

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ABSTRACT

A new procedure for reservoir fluid characterization through equation of state (EOS) is proposed. It is applied in a selecting the most appropriate fluid composition for the purpose of reservoir fluid characterization. A Hoffman-Crump-Hocott plot is used to determine whether or not the streams are genuine equilibrium fluids. With the aid of phase diagram and saturation pressure from RFT, the most appropriate fluid sample was chosen for fitting an equation of state to experimental data through regression. Based on data analysis and quality control of all PVT data suggested that fluid from UP-1 DST-3 is the best representative of XYZ field. The PR3-EOS and LBC correlation are applied to the UP-1 DST-3 data sets under conditions of predictions and regression. Agreement between laboratory data and regressed EOS results is generally good to excellent. The results show that that regression on critical properties of components is sufficient for good data matches. In this work, a good agreement with experimental data was obtained with grouping (lumping) 15 to 7 components.

Keywords: fluid characterization, equation of state, regression, pesudoization

I. INTRODUCTION

Samples of reservoir fluid were collected from UP wells (UP-1, UP-North, and UP-West) of XYZ field by direct subsurface sampling and surface recombination of the oil and gas phases. The reservoir fluid data of XYZ field consist of 4 (four) pressurized surface and 3 (three) bottom hole samples. All fluid samples were analyzed through laboratory tests. The PVT analysis measurements include: validity check of separator fluid sample; hydrocarbon compositional analysis of separator fluids; physical recombination of separator fluids; pressure-volume relationships; differential vapourization test; single stage separator test; and viscosity of recombined fluid. A summary of PVT analysis of each sample are shown in Table 1. Figures 1 and 2 show solution GOR and *Z*-factor of each fluid sample.

The objective of this study is to review 7 (seven) different PVT analyses and to identify the most likely PVT results that are representative of the fluid in the formation. In general, reservoir fluid characterization by EOS will be conducted. This includes data analysis and quality control all PVT data and fitting an equation of state to experimental data through regression. Pseudoization will be performed to provide 7 (seven) pseudo components EOS model for compositional reservoir simulation. Then the output of PVT modelling can be converted into the format of reservoir simulation inputs, both for black and compositional modelling.

II. EQUATION OF STATE (EOS) AND PVTi

Equations of State (EOS) offer the advantage of providing a single and consistent source of *K*-value predictions, phase densities and compositions at reservoir conditions. Many forms of Equations of State have been proposed since Van der Waals. The EOS types used in this study are Redlich-Kwong (1949) (R-K EOS), Soave-Redlich-Kwong (1972) (S-R-K

Table 1
Oil DST Summary of XYZ Field

Well	DST-PVT	Test Interval (ft)		GOR Sampling (SCF/STB)	T res (F)	P res (psig	Well Stream Composition (%)				C+	
							N_2-CO_2	C_1	C_2-C+	C+	MW	SG
UP-I	DTS-3	-4965	-5000	844.0	148.0	2159.0	0.89	5.04	23.08	70.99	201.2	0.8749
UP-N	DTS-1 PVT-2	-5511	-5566	391.0	189.8	2143.0	2.43	30.33	55.05	12.28	289.51	0.9579
UP-N	DTS-1 PVT-4	-5511	-5566	645.8	189.8	2143.0	2.61	31.4	62.38	3.61	289.51	10.214
UP-N	DTS-1 BHS-1	-5511	-5566		189.8	2091.7	2.49	32.24	57.72	7.56	322.62	0.9909
UP-W	DTS-1 PVT-1	-5460	-5509	578.0	189.9	2143.0	2.15	24.02	71.28	2.54	335.98	10.424
UP-W	DTS-1 BHS-1	-5460	-5509		189.9	2143.0	2.04	23.73	69.79	4.44	345.52	10.218
UP-W	DTS-1 BHS-2	-5460	-5509		189.9	2143.0	1.74	19.70	71.81	6.75	342.94	10.063

EOS), Zudkevitch-Jofffe-Redlich-Kwong (1970) (ZJRK) and Peng-Robinson (1976)(P-R EOS). Many authors generalised the EOS in general forms (e.g., Martin, 1979; Schmidt & Wenzel, 1980; Coats, 1982).

Due to semi-empirical nature of EOS, the prediction of liquid properties, especially liquid densities and volumes are usually poor. In the S-R-K EOS, for example, the critical compressibility factor takes on the unrealistic universal critical compressibility of 0.333 (at the critical point) for all substances. As a result, the molar volumes are typically overestimated, *i.e.*, densities are underestimated. The concept of volume translation had been introduced after Soave's modification of the Redlich-Kwong equation. Volume translation attempts to alleviate one of the major deficiencies of the Redlich-Kwong EOS, i.e., poor liquid volumetric prediction. Peneloux, Rauzy & Freze (1982) proposed a procedure for improving the volumetric predictions of the S-R-K EOS by introducing a volume correction parameter, into the equation. This parameter does not change the vapour-liquid equilibrium conditions determined by the unmodified S-R-K equation, but modifies the liquid and gas volumes by effecting the following translation along the volume axis. In this study, a volume correction parameter is tied into Equation of States.

Also in this study, a combination of a successive substitution method (Nghiem, Aziz & Li, 1983) and a Minimum Variable Newton-Raphson method (Fussell & Yanosik, 1978) are used to calculate flash composition and saturation points. The successive substitution methods can be used to detect the single phase

Table 2
Separator Condition During Recombination

Sampel	GOR (SCF/STB)	Pressure (psig)	Temperature (°F)
UP-1 DTS-3	676	135.0	94.0
UP-N DTS-1 PVT-2	398	96.8	99.7
UP-N DTS-1 PVT-4	349	292.8	118.9
UP-N DTS-1 BHS-1		2045.0	189.8
UP-W DTS-1 PVT-1	346	208.0	84.0
UP-W DTS-1 BHS-1		2040.0	189.9
UP-W DTS-1 BHS-2		1375.0	189.9

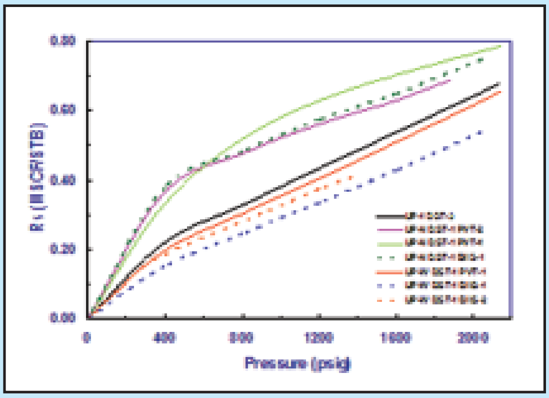


Figure 1
Solution GOR vs Pressure

region without having to compute the saturation pressure. However, this method converges very slowly (or not at all) near the critical region. In this study, when the successive substitution method is converging slowly, the computer program automatically switches to the more robust technique of Minimum Variable Newton-Raphson (MVNR). The MVNR method is a robust algorithm for solving the non-linear system of equations describing thermodynamic equilibrium.

PVTi is pressure-volume-temperature software program based on the equation of state (Schlumberger, PVTi, 2004). It is used in this study to perform phase-equilibrium and property calculations. It is a general-purpose program that uses a generalized cubic EOS. The program may be used to calculate fluid behaviour solely on the basis of the predictive capabilities of any of generalized EOS. More important, however, is the capability to use a nonlinear regression calculation that performs an automatic adjustment of EOS parameter to match a variety of laboratory PVT measurements. The resulting tuned EOS is then used in a compositional reservoir simulator.

III. DATA ANALISYS AND QUALITY CONTROL

Data analysis and quality control of all PVT samples were carried out before simulation of fluid samples with an equation of state is conducted. As a first step, before any regression is considered, as many tests as possible should be performed to test the consistency and quality of the measured data. Clearly it is not possible to match to an inconsistent PVT report caused by poor sampling and/ or collection; bad laboratory procedures, and simple typing mistakes in reporting (for example a composition does not add up to 100). It is most likely to be a combination of all these effects.

The reported well stream composition resulted from fluid recombination was flashed at separator pressure and temperature and the liquid and vapour mole fractions were compared with the observed data. Then, Hoffman-Crump-Hocott test (Alani and Kennedy, 1960) for separator

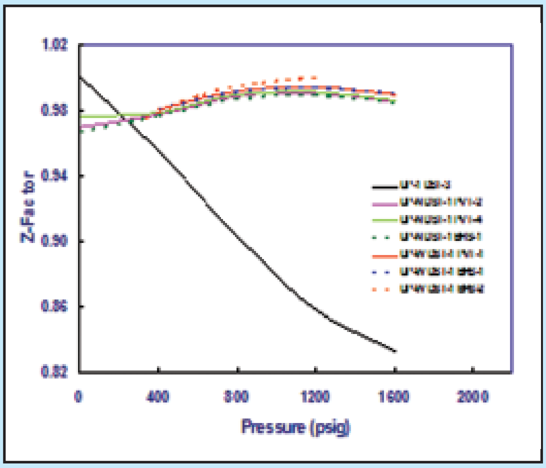


Figure 2
***Z*-factor vs Pressure**

Table 3
Bubble Point Pressure Calculation (7 components)

<table>
<tr><td colspan="3">Specified temperature</td><td>Deg F</td><td colspan="2">184.0000</td></tr>
<tr><td colspan="3">Calculated bubble point pressure</td><td>PSIG</td><td colspan="2">2136.4046</td></tr>
<tr><td colspan="3">Observed bubble point pressure</td><td>PSIG</td><td colspan="2">2135.0000</td></tr>
<tr><td colspan="3" rowspan="2">Fuid Properties</td><td colspan="2">Liquid</td><td>Vaqour</td></tr>
<tr><td>Observed</td><td>calculated</td><td>calculated</td></tr>
<tr><td colspan="3">Mole Weight</td><td></td><td>98.5658</td><td>19.5935</td></tr>
<tr><td colspan="3">Z-factor</td><td></td><td>0.6953</td><td>0.8754</td></tr>
<tr><td colspan="3">Viscosity</td><td></td><td>0.6472</td><td>0.0166</td></tr>
<tr><td colspan="3">Density LB/FT3</td><td>441.1491</td><td>44.145</td><td>6.9704</td></tr>
<tr><td colspan="3">Molar Vol CF/LB-ML</td><td></td><td>2.2328</td><td>2.811</td></tr>
<tr><td colspan="6">Molar Distributions</td></tr>
<tr><td>Components</td><td>Number</td><td>Total,Z Measured</td><td>Liquid, X Calculated</td><td>Vaqour, Y Calculated</td><td>K-Values Calculated</td></tr>
<tr><td>CO_2</td><td>1</td><td>0.4926</td><td>0.4926</td><td>2.5319</td><td>5.1399</td></tr>
<tr><td>N_2</td><td>2</td><td>1.6797</td><td>1.6797</td><td>2.5710</td><td>1.5306</td></tr>
<tr><td>C_1</td><td>3</td><td>30.9650</td><td>30.9650</td><td>86.6605</td><td>2.7987</td></tr>
<tr><td>C_2+</td><td>4</td><td>93.993</td><td>9.3993</td><td>6.1723</td><td>0.6567</td></tr>
<tr><td>C_4+</td><td>5</td><td>13.7265</td><td>13.7265</td><td>1.8936</td><td>0.1380</td></tr>
<tr><td>C_7+</td><td>6</td><td>8.9596</td><td>8.9596</td><td>0.1709</td><td>0.0191</td></tr>
<tr><td>$C_{15}+$</td><td>7</td><td>34.7773</td><td>34.7773</td><td>0.0027</td><td>0.0001</td></tr>
<tr><td colspan="2">Total</td><td>100.0000</td><td>100.0000</td><td>100.0029</td><td></td></tr>
</table>

gas and oil samples were conducted in order to determine whether or not the streams are genuine equilibrium fluids. The Hoffmann-Crump-Hocott (HCH) technique consists of plotting the logarithm of the product of the *K*-value and the pressure against a characterization factor for each component. A typical Hoffman-Crump-Hocott plot shows the actual data and the Standing estimates of *K*-values. They are used as a consistency check and, if the estimated *K*-values and observed are close each other, then the initial feed stream composition is in equilibrium.

This following paragraph explains a typical workflow for PVTi in its role as a data analysis tool:

- Well stream composition was flashed at pressure and temperature of separator during recombination. Table 2 shows the condition of each PVT sample at separator pressure and temperature. Vapor and liquid mole fractions were compared with the observed data. As an illustration here for UP-1 DST-3 sample, Figures 3 and 4 show the comparison between observed and calculated data.
- Then, the well stream compositions were checked whether or not they are genuine equilibrium fluids with the aid of Hoffman-Crump-Hocott plot. Fig-

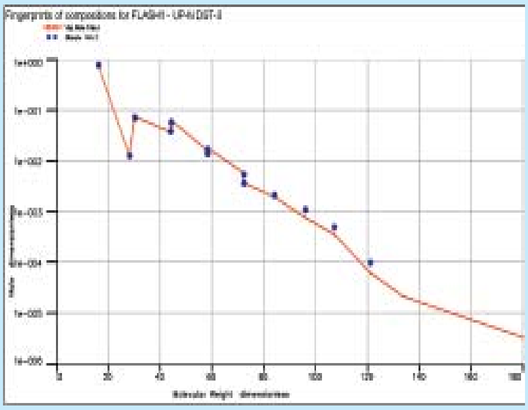


Figure 3
Fingerprints of Composition for Flashing Well Stream at P&T Separator – Vapor Mole Fraction of UP-1 DST-3

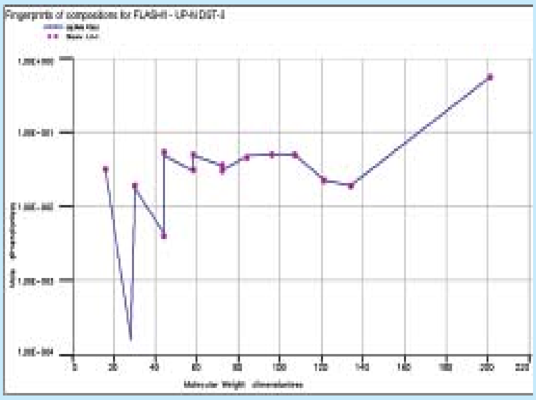


Figure 4
Fingerprints of Composition for Flashing Well Stream at P&T Separator – Liquid Mole Fraction of UP-1 DST-3

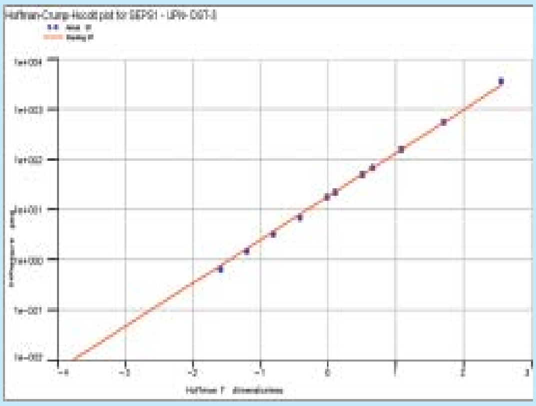


Figure 5
Hoffman-Crump-Hocott Plot for P & T Separator of UP-1 DST-3

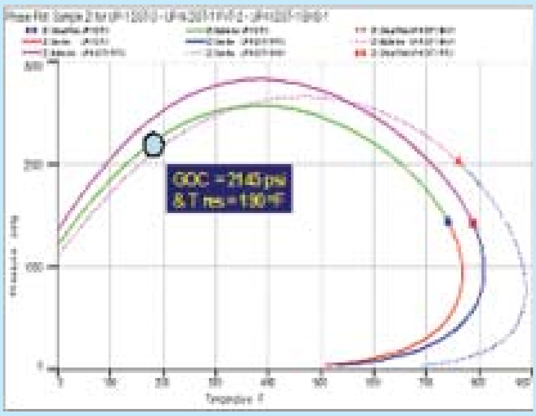


Figure 6
Phase Plot and RFT Data

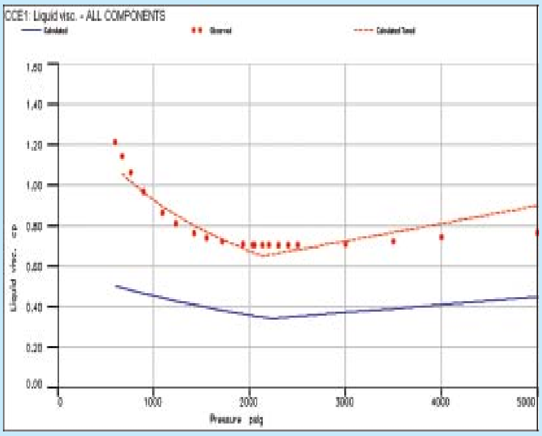


Figure 7
Simulation results and Fitting an EOS To Experimental Results by Regression for CCE: Liquid Viscosity (15 Components)

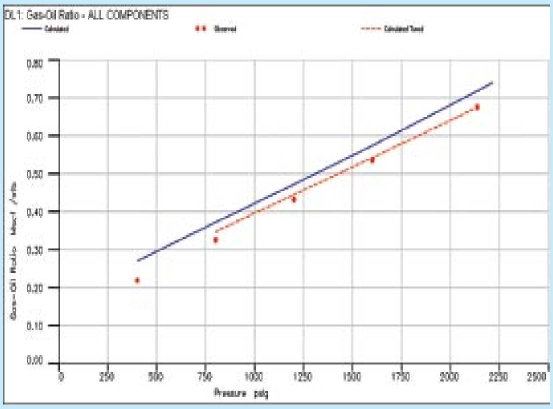


Figure 8
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Gas Oil Ratio (15 Components)

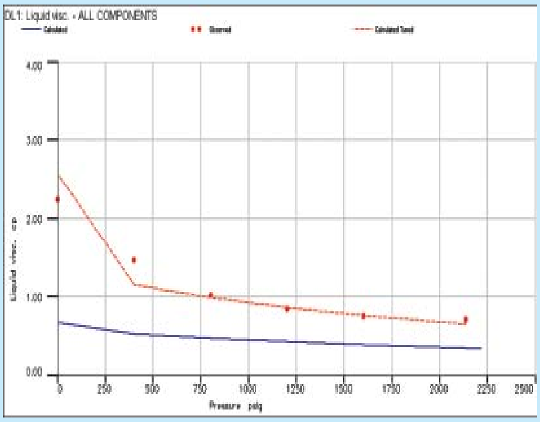


Figure 9
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Liquid Viscosity (15 Components)

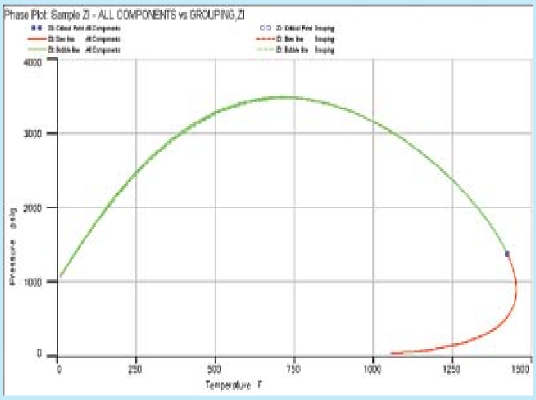


Figure 10
Phase Plot Comparison for 15 and 7 Components

ure 5 shows the observed and the Standing estimates of *K*-values from UP-1 DST-3 sample. It can be seen that both observed and calculated data are in good agreement, and give further evidence that the initial feed stream composition is correct.

- The same procedures were applied for other PVT samples.

Results of flashing well stream composition and Hoffman-Crump-Hocott plot indicated that PVT samples of UP-1 DST-3, UP-N DST-1 PVT-2, UP-N DST-1 PVT-4, UP-N DST-1 BHS-1 and UP-W DST-1 PVT-1 are correct for further analysis. In addition to the data analysis above, however, an RFT data from XYZ wells revealed that estimated Gas Oil Contact (GOC) was found at 4865 ft with saturation pressure of 2145 psia. With average reservoir temperature of 190 °F and the aid of phase diagram (Figure 6) and saturation pressure from RFT, samples of UP-1 DST-3 and UP-1 DST-1 BHS-1 were chosen for further analysis.

Investigating of relationship between *Z*-factor and pressure of UP-1 DST-3 and UP-1 DST-1 BHS-1 samples as shown in Figure 2, the vapour *Z*-factor for UP-1 DST-1 BHS-1 increase and decrease again

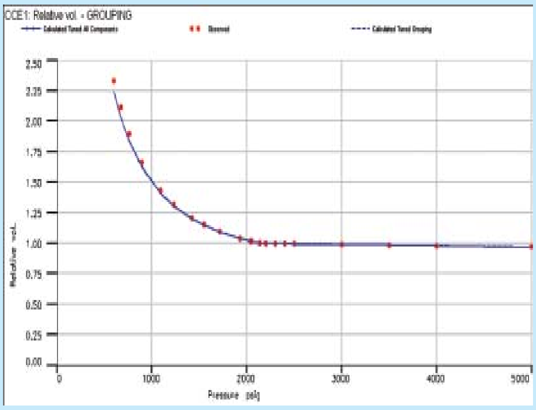


Figure 11
Simulation results and Fitting an EOS To Experimental Results by Regression for CCE: Relative Volumes (7 Components)

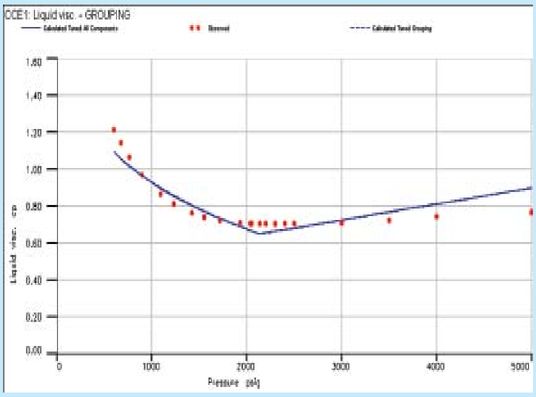


Figure 12
Simulation results and Fitting an EOS To Experimental Results by Regression for CCE: Liquid Viscosity (7 Components)

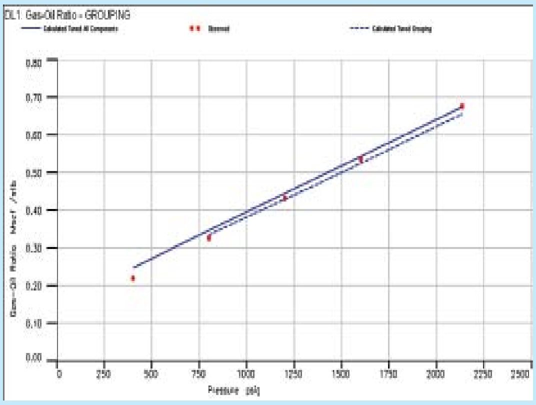


Figure 13
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Gas Oil Ratio (7 Components)

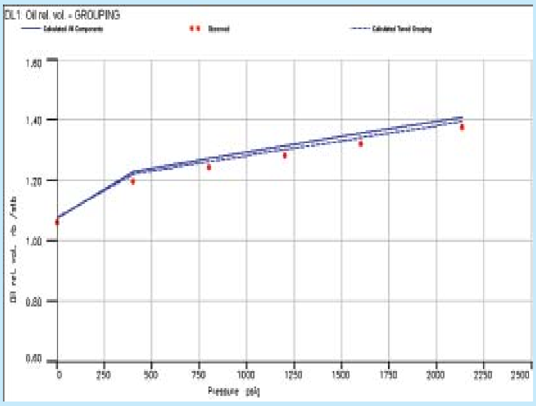


Figure 14
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Oil Relative Volume (7 Components)

as pressure drops in the experiment, probably indicates data error. Therefore, sample of UP-1 DST-3 was appropriate to be further analyzed for fine tuning through EOS.

IV. FITTING AN EQUATION OF STATE TO EXPERIMENTAL RESULTS

A. *PVT Simulation without Regression*

Three-parameter of EOS from Pang-Robinson (PR3-EOS) is used in this study for PVT modelling. The PR3 of EOS has been applied in oil industry for better PVT modelling than the traditional two-parameter of EOS such as PR2. Better prediction of liquid properties, especially liquid densities and saturations can be obtained through PR3-EOS. Lohrenz-Bray-Clark (LBC) correlations is used in this study for determining the viscosity of the saturated oil from composition since it has been enjoying great acceptance and application by engineers in the petroleum industry (Lohrenz *et al*., 1964).

All the experimental observations from UP-1 DST-3 were entered into PVTi. The experiments data contain the following:

- A fluid description (component properties and a sample defined by mole fractions of components).
- A Bubble Point experiment at 184 °F with observations of bubble point pressure and liquid density.
- A Constant Composition Expansion (CCE) experiment with observations of relative volume and liquid viscosity.
- A Differential Liberation (DL) experiment with observations of: relative oil volume, solution gas-oil ratio, *Z*-factors, oil density, gas gravity, gas formation volume factor, liquid viscosity and vapour viscosity.
- The multi-stage separator (SEPS) experiments or can also be called a separation with observations of liquid density, gas-oil ratio and vapour mole fraction.

All of the experiments above were simulated using the PR3-EOS and LBC correlations without interfere the original data. The results can be seen from Figures 7 to 9. The calculated properties were represented by a blue line on those figures. It can be seen from the figures how far the simulated results (blue line) deviated with the observed data (represented

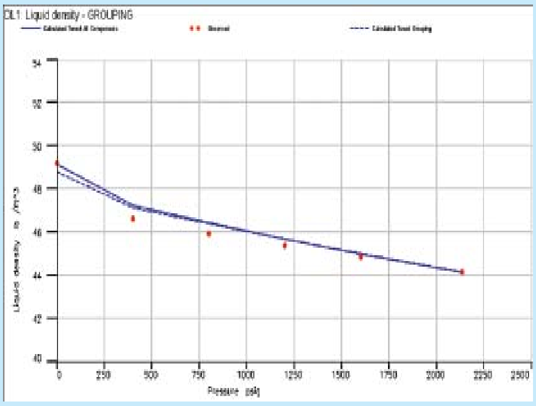


Figure 15
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Liquid Density (7 Components)

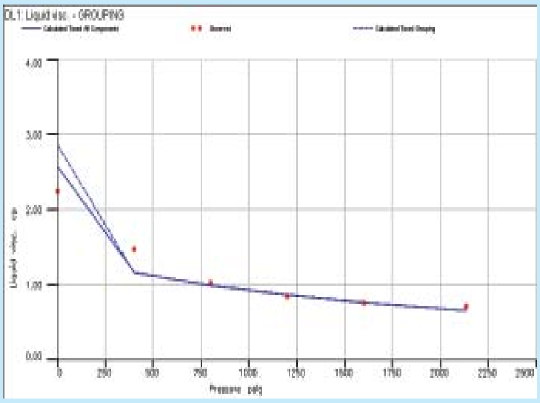


Figure 16
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Liquid Viscosity (7 Components)

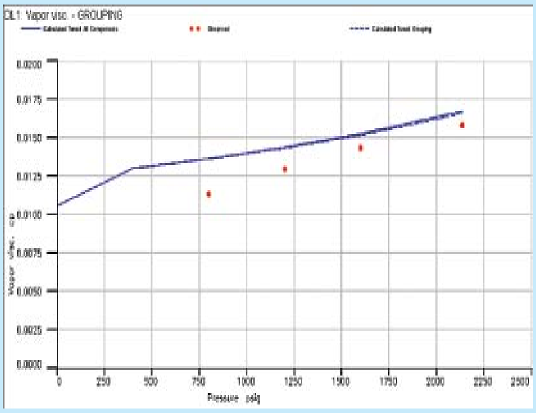


Figure 17
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: Vapor Viscosity (7 Components)

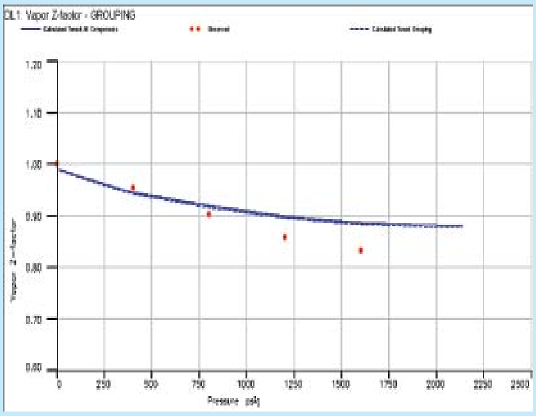


Figure 18
Simulation results and Fitting an EOS To Experimental Results by Regression for DL: *Z*-Factor (7 Components)

by points). The most important deviations between the simulated and observed data are:

- Saturation point at 184 °F is simulated to 2215.6 psig, which is 80.6 psi higher than measured data of 2135 psig. Calculated liquid density is 43.73 lb/ft^3, which is lower than measured of 44.15 lb/ft^3.
- Simulated constant composition expansion shows the simulated and observed data of relative volumes are in good agreement. However, simulated of liquid viscosity are significantly lower than the observed data.
- Simulated differential liberation and separator GOR's are slightly higher than measured.
- Simulated oil viscosities are somewhat lower than measured; meanwhile simulated gas viscosities are higher than measured.

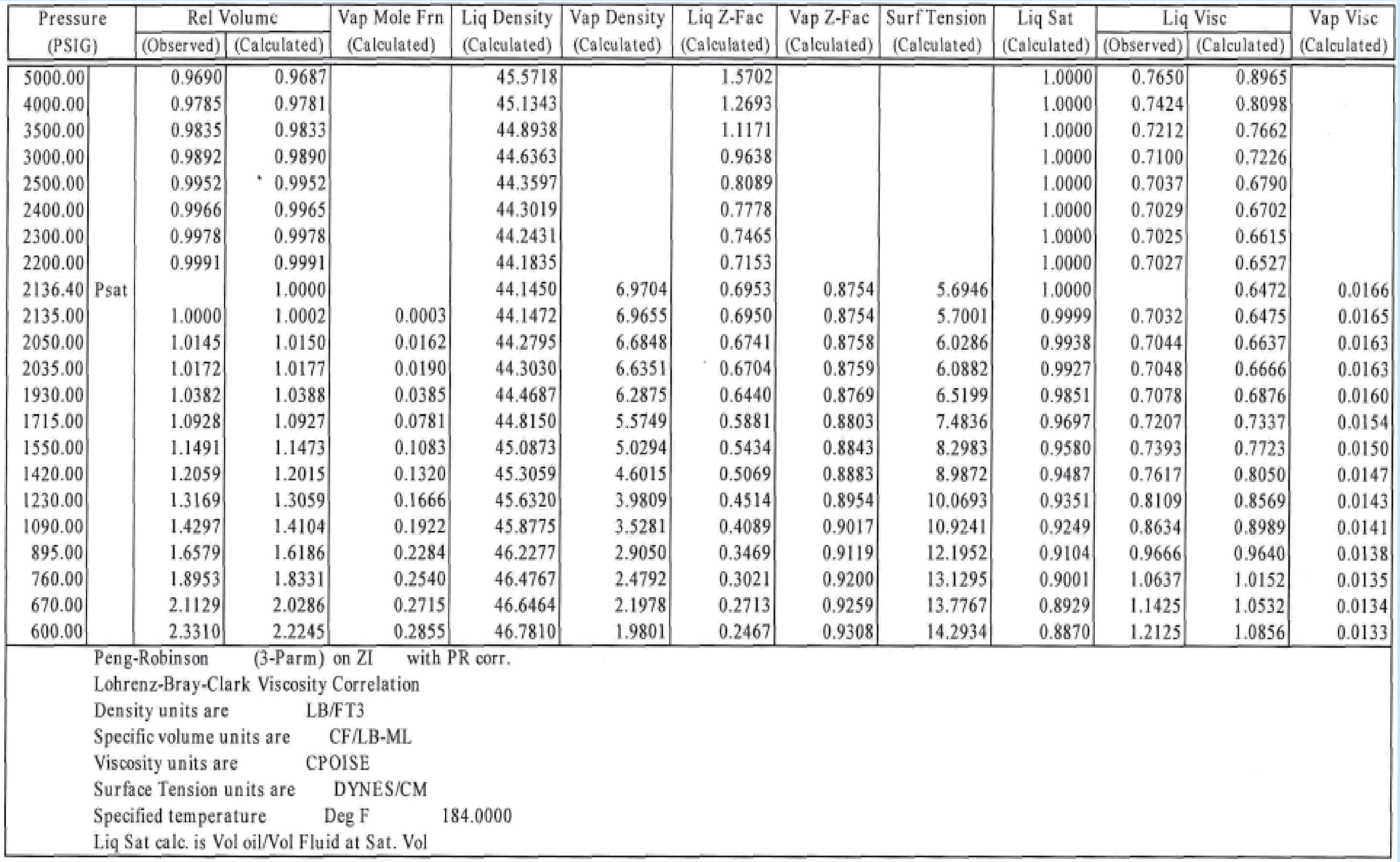
B. *PVT Simulation with Regression*

The main objective of this study is to fit the equation of state through regression to observation data in order to produce a better representation of UP-1 DST-3 sample. A regression based on EOS is essentially an optimization problem, which involve minimizing a function of several variables. In the equation of state, the prediction quantities, such as densities and saturation pressure are called dependent parameters. The dependent parameters are calculated using independent quantities, such as critical state data, Ω_a and Ω_b values, interaction coefficients, and volume shift parameters. These independent quantities may be selected as adjustable independent parameters and the objective of regression is to obtain satisfactory agreement between the experimental values and the prediction.

The repetitive use of equation of state can make the regression based on EOS PVT approach a computationally expensive process as well as a time consuming. Therefore, selecting the independent parameters to which the EOS is the most sensitive is very important in order to reduce the computational time. In addition to that, a sensitivity analysis should be carried out to determine which attributes of the fluid components improve the solution by the smallest change. The most sensitive attributes are then adjusted slightly by regression to improve the equation of state model of the fluid.

This following paragraph explains a workflow for fitting an equation of state with regression to experimental results of UP-1 DST-3, and this procedure is called as normal regression:

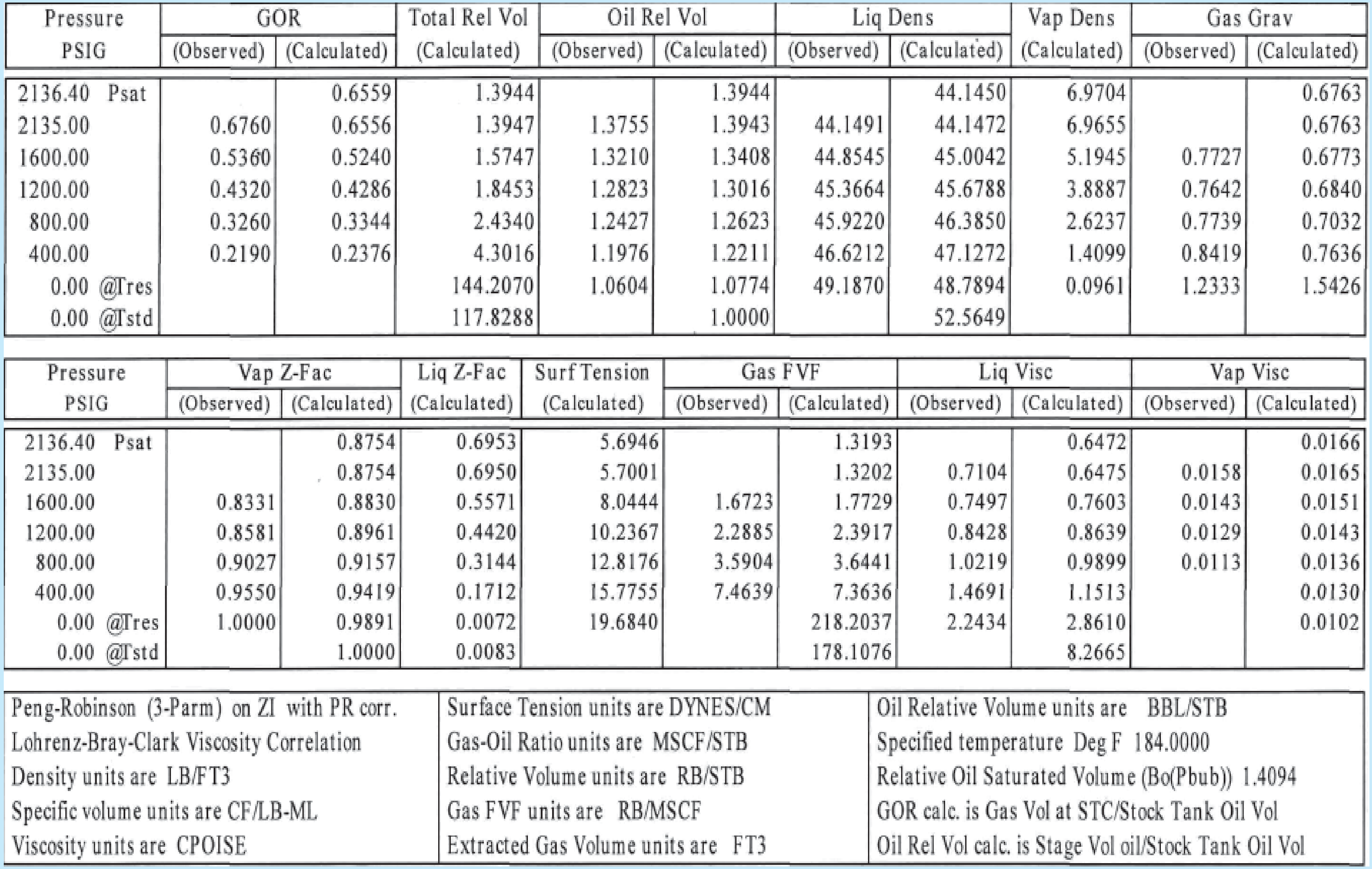
- The first step in designing any regression is to determine the parameter set that will be used. The first step is to try to make all regression variables have similar sizes. This is done to prevent a minor constituent of the fluid having its properties varied extensively to achieve a mathematical fit, which is not a reasonable physical solution.
- The idea here is to look for consecutive components that have small mole fractions. The properties of CO_2, N_2, C_1 and C_2 are well known and generally do not differ significantly from the library properties. These can be grouped together and treated as a single regression variable, forcing the solution to be physically realistic. This group is selected as first regression variable. Grouping the C_3 through C_{10} components into a single regression variable preserves monotonicity between the components, in addition to creating a variable that accounts for 28.2% of the total composition. This group is chosen as second regression variable. The plus fraction (C_{11}^+) contains a mixture of components C_{11}^+ and higher, so its properties may not be so well-determined. This makes the plus fraction an ideal candidate for regression to fit the equation of state to the experimental results. It is therefore, the C_{11}^+ is chosen as second regression variable.
- Sensitivity analysis is used to establish which fluid properties most affect the difference between the observed and simulated values. The sensitivities are calculated for critical temperature and pressure for each experiment, for three regression variables. The most sensitive properties will be selected for use in the regression. In this case, the sensitivities for the first P_{crit} and T_{crit} parameters are generally lower than for second and third regression variables. Therefore, the first regression variable is removed before the next regression is started.
- Next is to reduce the regression variables into 2 (two) variables, *i.e.*, group of C_3 through C_{10} and C_{11}^+. Regression process was continued with the aid of applying weighting observations for getting the desired fit. The results can be seen from Figures 7 to 9. The calculated properties were represented by a red dotted-lines those figures. It can be seen that fitting EOS through regression im-



Pressure (PSIG)		Rel Volume		Vap Mole Frn	Liq Density	Vap Density	Liq Z-Fac	Vap Z-Fac	Surf Tension	Liq Sat	Liq Visc		Vap Visc
		(Observed)	(Calculated)	(Calculated)	(Calculated)	(Calculated)	(Calculated)	(Calculated)	(Calculated)	(Calculated)	(Observed)	(Calculated)	(Calculated)
5000.00		0.9690	0.9687		45.5718		1.5702			1.0000	0.7650	0.8965	
4000.00		0.9785	0.9781		45.1343		1.2693			1.0000	0.7424	0.8098	
3500.00		0.9835	0.9833		44.8938		1.1171			1.0000	0.7212	0.7662	
3000.00		0.9892	0.9890		44.6363		0.9638			1.0000	0.7100	0.7226	
2500.00		0.9952	0.9952		44.3597		0.8089			1.0000	0.7037	0.6790	
2400.00		0.9966	0.9965		44.3019		0.7778			1.0000	0.7029	0.6702	
2300.00		0.9978	0.9978		44.2431		0.7465			1.0000	0.7025	0.6615	
2200.00		0.9991	0.9991		44.1835		0.7153			1.0000	0.7027	0.6527	
2136.40	Psat		1.0000		44.1450	6.9704	0.6953	0.8754	5.6946	1.0000		0.6472	0.0166
2135.00		1.0000	1.0002	0.0003	44.1472	6.9655	0.6950	0.8754	5.7001	0.9999	0.7032	0.6475	0.0165
2050.00		1.0145	1.0150	0.0162	44.2795	6.6848	0.6741	0.8758	6.0286	0.9938	0.7044	0.6637	0.0163
2035.00		1.0172	1.0177	0.0190	44.3030	6.6351	0.6704	0.8759	6.0882	0.9927	0.7048	0.6666	0.0163
1930.00		1.0382	1.0388	0.0385	44.4687	6.2875	0.6440	0.8769	6.5199	0.9851	0.7078	0.6876	0.0160
1715.00		1.0928	1.0927	0.0781	44.8150	5.5749	0.5881	0.8803	7.4836	0.9697	0.7207	0.7337	0.0154
1550.00		1.1491	1.1473	0.1083	45.0873	5.0294	0.5434	0.8843	8.2983	0.9580	0.7393	0.7723	0.0150
1420.00		1.2059	1.2015	0.1320	45.3059	4.6015	0.5069	0.8883	8.9872	0.9487	0.7617	0.8050	0.0147
1230.00		1.3169	1.3059	0.1666	45.6320	3.9809	0.4514	0.8954	10.0693	0.9351	0.8109	0.8569	0.0143
1090.00		1.4297	1.4104	0.1922	45.8775	3.5281	0.4089	0.9017	10.9241	0.9249	0.8634	0.8989	0.0141
895.00		1.6579	1.6186	0.2284	46.2277	2.9050	0.3469	0.9119	12.1952	0.9104	0.9666	0.9640	0.0138
760.00		1.8953	1.8331	0.2540	46.4767	2.4792	0.3021	0.9200	13.1295	0.9001	1.0637	1.0152	0.0135
670.00		2.1129	2.0286	0.2715	46.6464	2.1978	0.2713	0.9259	13.7767	0.8929	1.1425	1.0532	0.0134
600.00		2.3310	2.2245	0.2855	46.7810	1.9801	0.2467	0.9308	14.2934	0.8870	1.2125	1.0856	0.0133

Peng-Robinson (3-Parm) on ZI with PR corr.
Lohrenz-Bray-Clark Viscosity Correlation
Density units are LB/FT3
Specific volume units are CF/LB-ML
Viscosity units are CPOISE
Surface Tension units are DYNES/CM
Specified temperature Deg F 184.0000
Liq Sat calc. is Vol oil/Vol Fluid at Sat. Vol

Table 4
Constant Composition Expansion Calculation (7 components)



Pressure	GOR		Total Rel Vol	Oil Rel Vol		Liq Dens		Vap Dens	Gas Grav	
PSIG	(Observed)	(Calculated)	(Calculated)	(Observed)	(Calculated)	(Observed)	(Calculated)	(Calculated)	(Observed)	(Calculated)
2136.40 Psat		0.6559	1.3944		1.3944		44.1450	6.9704		0.6763
2135.00	0.6760	0.6556	1.3947	1.3755	1.3943	44.1491	44.1472	6.9655		0.6763
1600.00	0.5360	0.5240	1.5747	1.3210	1.3408	44.8545	45.0042	5.1945	0.7727	0.6773
1200.00	0.4320	0.4286	1.8453	1.2823	1.3016	45.3664	45.6788	3.8887	0.7642	0.6840
800.00	0.3260	0.3344	2.4340	1.2427	1.2623	45.9220	46.3850	2.6237	0.7739	0.7032
400.00	0.2190	0.2376	4.3016	1.1976	1.2211	46.6212	47.1272	1.4099	0.8419	0.7636
0.00 @Tres			144.2070	1.0604	1.0774	49.1870	48.7894	0.0961	1.2333	1.5426
0.00 @Tstd			117.8288		1.0000		52.5649			

Pressure	Vap Z-Fac		Liq Z-Fac	Surf Tension	Gas FVF		Liq Visc		Vap Visc	
PSIG	(Observed)	(Calculated)	(Calculated)	(Calculated)	(Observed)	(Calculated)	(Observed)	(Calculated)	(Observed)	(Calculated)
2136.40 Psat		0.8754	0.6953	5.6946		1.3193		0.6472		0.0166
2135.00		0.8754	0.6950	5.7001		1.3202	0.7104	0.6475	0.0158	0.0165
1600.00	0.8331	0.8830	0.5571	8.0444	1.6723	1.7729	0.7497	0.7603	0.0143	0.0151
1200.00	0.8581	0.8961	0.4420	10.2367	2.2885	2.3917	0.8428	0.8639	0.0129	0.0143
800.00	0.9027	0.9157	0.3144	12.8176	3.5904	3.6441	1.0219	0.9899	0.0113	0.0136
400.00	0.9550	0.9419	0.1712	15.7755	7.4639	7.3636	1.4691	1.1513		0.0130
0.00 @Tres	1.0000	0.9891	0.0072	19.6840		218.2037	2.2434	2.8610		0.0102
0.00 @Tstd		1.0000	0.0083			178.1076		8.2665		

Peng-Robinson (3-Parm) on ZI with PR corr.	Surface Tension units are DYNES/CM	Oil Relative Volume units are BBL/STB
Lohrenz-Bray-Clark Viscosity Correlation	Gas-Oil Ratio units are MSCF/STB	Specified temperature Deg F 184.0000
Density units are LB/FT3	Relative Volume units are RB/STB	Relative Oil Saturated Volume (Bo(Pbub)) 1.4094
Specific volume units are CF/LB-ML	Gas FVF units are RB/MSCF	GOR calc. is Gas Vol at STC/Stock Tank Oil Vol
Viscosity units are CPOISE	Extracted Gas Volume units are FT3	Oil Rel Vol calc. is Stage Vol oil/Stock Tank Oil Vol

Table 5
Differential Liberation Calculation (7 components)

proves the prediction of fluid properties better than the simulation without regression. The most important match here to note is the calculated saturation pressure of 2136.8 psig is in very good agreement with measured data of 2135 psig. Also, the calculated liquid density of 44.14 lb/ft^3 is similar with the measured data of 44.15 lb/ft^3. Both simulated constant composition expansion and differential liberation were improved through the regression.

The other procedures to characterize the reservoir fluid are through splitting and grouping (pseudoization) techniques. Splitting the plus fraction (C_{11}^+) into two or more pseudo-components and then regress them. The process for fitting an equation of state to experimental data had been carried in order to investigate if the fluid properties prediction can be improved. However, the trial and error processes with the splitting procedure did not improve the prediction.

C. *Pseudoization*

The high computational cost of the compositional simulation approach is due to the use of the EOS and it is proportional to the number of components used to characterize a given hydrocarbon fluid. Therefore, it is desirable to minimize the number of the components used in an Equation of State without destroying the thermodynamic consistency of the predictions.

In this study, the original components of UP-1 DST-3 sample have to be lumped or pseudoized into a smaller number of new pseudo-components. This following paragraph explains a workflow for fitting an equation of state with regression by lumping (pseudoized) technique of UP-1 DST-3:

- Group the 15 components into 7 components, with the rules for grouping a fluid like this are as follows:
  - Keep CO_2, N_2 and C_1 as a pure component
  - Group $C_2 – C_3$ as C_2^+
  - Group $C_4 – C_6$ as C_4^+
  - Group $C_7 – C_{14}$ as C_7^+
  - Group C_{11}^+ as C_{15}^+
- With the new 7 components, the reservoir fluid compositions were updated. A phase diagram with the new 7 components was constructed, and then it was superimposed with the phase diagram of 15 components. Figure 10 shows a phase plot comparison between 15 and 7 components. It can be seen that the phase diagram of 7 components is in a good agreement with 15 components, and this indicates a good grouping.
- The same step procedures as normal regression were applied. The next step is to determine the parameter set that will be used. This is done by making regression variables have similar sizes. Then, a sensitivity analysis was carried out in order to investigate which fluid properties most affect the difference between the observed and simulated values. The results indicated that grouping C_4^+ - C_7^+ and C_{15}^+ as the first and second regression parameters are the most sensitive compositions.
- With the aid of weighting observation, the best fitting EOS to experimental data were shown in Figures 11 through 18. Tables 3 to 5 shows the results of saturation pressure, constant composition expansion and differential liberation calculations respectively.

D. *Regression to Match Viscosities*

After a match of the phase behaviour, then we need to match the viscosity observations. Lohrenz-Bray-Clark viscosity correlation (LBC) is used for the regression of liquid and vapour viscosities. The LBC correlation is a fourth order polynomial in density. Consequently it is very sensitive to the density of the fluid. In PVTi, there is an option to regress on the critical volume (V_{crit}) or *Z*-factor used in calculating each component's contribution to the total viscosity.

During the regression process of liquid and vapour viscosities, all other experiments that do not have viscosity data were removed. This is done by setting the viscosity observations weights to 1 and the other observations to 0.

The regression process was carried out by choosing the critical volume (V_{crit}) as regression variables. Initially, the all components were set with the same the critical volume (V_{crit}) and weight factors. This is called as the first iteration and the results were compared with the observed data. As the first match was still far from the observations, the process was continued with the second iteration. This iteration was done by setting the critical volume (V_{crit}) of each component and the weight factors. The results are indicated by red-dotted line in Figures 7 and 9. It is clear that the new match as much better than the simulation without regression. The phase matching process is now complete and ready to export the PVT properties or characterization for input in reservoir simulations.

V. CONCLUSIONS

- Based on data analysis and quality control of all PVT data suggested that fluid from UP-1 DST-3 is the best representative of XYZ field.
- The use of regression variables was minimized and only the critical properties were chosen as regression variables.
- The PR3-EOS and LBC correlation are applied to the UP-1 DST-3 data sets under conditions of predictions and regression. Agreement between laboratory data and regressed EOS results is generally good to excellent.
- This study indicates that regression on critical properties of components is sufficient for good data matches. In this work, a good agreement with experimental data was obtained with grouping (lumping) 15 to 7 components.
- All PVT data generated on PVTi and the results of fine tuning UP-1 DST-3 data can be converted into the format of reservoir simulation inputs, both for black and compositional modeling.

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