ANALYSIS OF EQUATION OF STATE (EOS) CHARACTERIZATION ON OIL RECOVERY

By

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FINAL REPORT

Submitted to the Petroleum Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

Mr Iskandar Dzulkarnain
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD HAFIZUDDIN BIN MOHD NOR

TABLE OF CONTENTS

CHAPTER

PAGE

LIST OF FIGURE AND TABLE

CHAPTER 1: INTRODUCTION

1.1 Background of Study

An equation of state (EOS) is an analytical expression relating the pressure P to the temperature T and the volume V. A proper description of this PVT relationship for real hydrocarbon fluids is essential in determining the volumetric and phase behavior of petroleum reservoir fluids and in predicting the performance of surface separation facilities.

The best known and the simplest example of an equation of state is the ideal gas equation, expressed mathematically by the expression: $P = RT/V$, where V = gas volume in cubic feet per 1 mol of gas. This PVT relationship is only used to describe the volumetric behavior of real hydrocarbon gases at pressures close to the atmospheric pressure for which it was experimentally derived [1]. The extreme limitations of the applicability of this equation prompted numerous attempts to develop an equation of state (EOS) suitable for describing the behavior of real fluids at extended ranges of pressures and temperatures.

Currently there are 4 EOS that engineers commonly use to predict reservoir fluids behaviour.
They are:

1. Redlich-Kwong (RK)
2. Soave-Redlich-Kwong (SRK)
3. Peng-Robinson (PR)
4. Zudkevitch-Joffe (ZJ)

The equations of state listed above are implemented using the formulation presented by Martin, and Coats[2].

The equation of state for a real fluid is:

$$PV = nRTZ$$

Where is P the pressure, V the volume, n the number of moles, R the universal gas constant, T the temperature and z is obtained from the solution of the cubic equation:

$$Z^3 + E_2Z^2 + E_1Z + E_0 = 0$$

With

$$E_2 = (m_1 + m_2 - 1)B - 1$$

$$E_1 = A - (2(m_1 + m_2) - 1)B^2 - (m_1 + m_2)B$$

And

$$E_0 = -[AB + m_1m_2B^2(B + 1)]$$

The coefficients m_1 and m_2 depend upon the equation used.

Mnemonic	Equation of state	m_1 value	m_2 value
RK	Redlich-Kwong	0	1
SRK	Soave-Redlich-Kwong	0	1
ZJ	Zudkevitch-Joffe	0	1
PR	Peng-Robinson	$1+\sqrt{2}$	$1-\sqrt{2}$

Table 1.0 EOS coefficients

The cubic equation for the z -factors may be solved to obtain z -factors for liquid and vapor phases. Generally three solutions are obtained. The distinction between the liquid and vapor phase is then made by choosing the smallest root as the z -factor for the liquid phase and the largest root as the z -factor for the vapor phase.

Fugacity coefficients are calculated using:

$$\ln\left(\frac{f_i}{px_i}\right) = -\ln(Z-B) + \frac{A}{(m_1-m_2)B}\left[\frac{2S_i}{A} - \frac{B_i}{B}\right]\ln\left[\frac{(Z+m_2B)}{(Z+m_1B)}\right] + \frac{B_i}{B}(Z-1)$$

where

$$S_i = \sum A_{ij}x_j$$

$$B = \sum_{j=1}^{n} (x_jB_j)$$

$$A_{jk} = (1-k_{jk})(A_jA_k)^{\frac{1}{2}}$$

and *kjk* are binary interaction coefficients, normally between hydrocarbons and nonhydrocarbons. These four equations express the mixing laws used in all the equations of state. The variables *Aj* and *Bj* are defined by the following equations:

$$A_j = \Omega_A(T,j)\frac{P_{rj}}{T_{rj}^2}$$

and

$$B_j = \Omega_B(T,j)\frac{P_{rj}}{T_{rj}}$$

$\Omega_A(T,j)$ and $\Omega_B(T,j)$ are functions of acentric factor and reduced temperature.

For Redlich-Kwong

$\Omega_A(T,j) = \Omega_{A_0} T_{rj}^{-\frac{1}{2}}$

$\Omega_B(T,j) = \Omega_{B_0}$

For Soave-Redlich-Kwong

$$\Omega_A(T,j) = \Omega_{A_0}\left[1 + (0.48 + 1.57\omega_j - 0.17\omega_j^2)\left(1 - T_{rj}^{\frac{1}{2}}\right)\right]^2$$

$\Omega_B(T,j) = \Omega_{B_0}$.

For Zudkevitch-Joffe

$\Omega_A(T,j) = \Omega_{A_0} F_{aj}(T) T_{rj}^{-\frac{1}{2}}$

$\Omega_B(T,j) = \Omega_{B_0} F_{bj}(T)$

For Peng-Robinson

$$\Omega_A(T,j) = \Omega_{A_0}\left[1 + (0.37464 + 1.54226\omega_j - 0.2669\omega_j^2)\left(1 - T_{rj}^{\frac{1}{2}}\right)\right]^2$$

$\Omega_B(T,j) = \Omega_{B_0}$

Equation	Ω_{A_0}	Ω_{B_0}
RK, SRK, ZJ	0.4274802	0.086640350
PR	0.457235529	0.077796074

Table 1.1 EOS constant

The traditional weakness of the so-called two-parameter equation of state, such as the Peng- Robinson, Redlich-Kwong, etc., above, is their poor prediction of liquid properties, especially liquid densities and saturations. Peneloux et al, proposed a molar volume correction for the SRK Equation of State, which is also applicable to any cubic Equation of State [3]. This technique, referred to as volume translation, adds a third parameter to the Equation of State, which greatly improves liquid properties estimations.

1.2 Problem Statement

PVT properties such as oil bubble point pressure, oil formation volume factor, solution gas-oil ratio, gas formation volume factor, and gas and oil viscosities are required for reservoir studies. However, they are not always available or only an incomplete data set may be available. Hence, engineers have to use either an equation of state (EOS) method or a set of correlations to complete the data set to conduct the particular study. The goal of PVT analysis is to provide a tuned Equation of State that can model the reservoir fluid in simulations. The selection of regression parameters is crucial in determining the quality of the tuned fluid model. The use of EOS is for characterizing the reservoir a set of fluid samples for further use for studies and simulation software.

The problem arises as engineers need to choose the right EOS to tune the calculated results to match with the measured results done in laboratory. Each EOS has its own characters and cannot be applied to all fluid samples especially composition reservoir model that required to perform the analysis. Wrong selection of EOS may resulted incorrect oil recovery when simulation was done to predict the oil recovery. In this studies, different PVT fluid model are created to compare what are the effects to the oil recovery when the simulation works is done. The expected result is the most common EOS used which is Peng – Robinson will give the most accurate result for the oil recovery.

1.3 Objective and Scope of Study

The ultimate purpose of this project is to study the effect of different EOS used during the PVT analysis to the oil recovery. In order to complete the study, following objectives are expected to be achieved:

i. To study the characteristic of different EOS
ii. To perform PVT analysis using PVTi
iii. To simulate composition reservoir model using ECLIPSE 300
iv. To perform analysis on oil recovery based on different EOS used
v. To measure the effectiveness of selected EOS used for the simulation

The scope of study will evolve around building a complete PVT fluid model as the input for reservoir simulation. The mechanisms of different EOS regression technique will be studied from the previous works by other researchers. The study also covers the approaches that have been applied in tuning the laboratory data to act similarly with the model predictions by the EOS. Last but not least, the influence of different EOS to the hydrocarbon recovery will be measured and observed through reservoir simulation results later on.

1.4 The Relevancy of the Project

This project is relevance to all petroleum engineers especially reservoir engineers since the major simulation tasks is to perform data gathering and one of them is PVT analysis. Without the knowledge of EOS usage, the simulation tasks may gave incorrect result due to wrong selection of EOS during PVT analysis.

1.5 Feasibility of the Project within the Scope and Time frame

This research is feasible to be conducted through reservoir simulation lab available in Petroleum Engineering Department. The scope of study will be mainly on EOS and PVT analysis as data input for the simulation on oil recovery. This research is feasible to be conducted within the given time frame due to following factors:

1. **Availability of reservoir data**

   The study requires several reservoir data such as laboratory fluid data, reservoir grid

   data and reservoir core samples data.

2. **Availability of softwares**

   The required softwares for this study are PVTi and E300 by Schlumberger

CHAPTER 2: LITERATURE REVIEW

2.1 Representative Sample Collections

The accuracy of any EOS model depends on the quality of the laboratory PVT data and procedures used to obtain the EOS parameters. The value of the PVT data depends on the quality of the fluid samples. They must be representative of the reservoir fluid. Three common methods are used to sample the reservoir fluids [4].

Downhole Sampling : A sample collector with a capacity of several hundred cubic centimeters is used to obtain a fluid sample from within the wellbore. The downhole flowing pressure at the sampling point must be greater than the saturation pressure of the fluid so that the sample is a single phase. At least three fluid samples should be collected to determine the appropriate fluid sample for the PVT measurements.

Wellhead Sampling : A fluid sample can be collected directly from the wellhead. The fluid needs to be in the single-phase region at wellhead flowing conditions. Normally, the sample needs to be taken at a pressure of at least 100 psi greater than the bubble point to be valid. Again, taking multiple samples is recommended.

Separator Sampling : A fluid sample is obtained by recombining the gas and liquid taken at a surface separator at the measured gas/oil ratio (GOR). Usually, GOR's are measured at stock-tank conditions and need to be corrected to separator conditions to be consistent with the gas and liquid collected. The separator gas and liquid sometimes are recombined to a known reservoir bubble point pressure rather than to the measured GOR.

Because of difficulties associated with the accurate measurement of GOR, the downhole or wellhead sampling approach for oil reservoirs is recommended when conditions are favorable. When large volumes of oil are required for slim-tube or coreflood experiments, separator sampling may be the only practical alternative.

However, for gas condensates, the separator-sampling approach is recommended because liquid condensation can occur in the wellbore during the well cleanup, even though the reservoir pressure remains greater than the dew point pressure. The sampling well needs to produce fluid steadily for a long enough period of time and at a rate sufficiently high to carry any condensate in the wellbore to the surface.

2.2 Laboratory PVT Experiments

The appropriate PVT experiments are related closely to the processes implemented in the field. The primary purpose of conducting PVT experiments is to generate reliable fluid properties for use in reservoir simulation and the evaluation of the fluid properties. The most commonly available PVT experiments are the following :

- **Constant-mass expansion (CME)** : A series of volume measurements performed on the reservoir fluid at different pressures starting at the saturation pressure. CME approximates the behavior of black oil and some volatile oil reservoirs. It is used to measure the fluid volume and compressibility over a range of pressures from above the initial reservoir pressure to pressures below the anticipated separator pressures at a constant temperature (usually reservoir temperature). The gas and the liquid phases below the bubble point will stay in equilibrium with the liquid throughout the procedure. This test it is non-destructive.

  For black oils and volatile oils it is also used to determine the saturation pressure at reservoir conditions. The Pressure and Volume values are plotted. For black oil or a volatile oil, the transition from single to a two-phase system is easily determined from the plot. For gas condensates the separation of the liquid phase must be determined visually. The CME experiment may also be carried out at other temperatures in addition to the reservoir temperature. The data resulted from the experiment are saturation pressures, relative volumes, compressibility, density at various pressures and reservoir temperature.

- **Differential liberation (DL)** : Approximation of fluid-property changes with pressure for oil during a natural depletion. This analysis is carried out at reservoir temperature to simulate the volumetric and compositional changes in the reservoir during production. The fluid is charged to a cell at reservoir conditions and is expanded stepwise down to atmospheric conditions, with the gas liberated at every step, to simulate the differential mechanism of reservoirs producing oil.

  The use of PVT cell and the embedded camera allows the operator to control visually the displacement of the gas right to the oil meniscus. Gas volumes, compositions, liquid volume are measured at each step. The oil remaining at reservoir temperature and 0 psig is the residual oil. The residual oil ambient properties (mole weight, density and composition) are subsequently measured. The final data include GOR, Relative Oil Volume, FVF, gas gravity, gas compressibility factor and liquid density.

- **Constant-volume depletion (CVD):** Approximation of gas/condensate depletion when condensate is immobile. This experiment approximates the behavior of gas condensates fluids. The analysis is carried out for gas condensate and sometimes also for volatile oils, considering the large amount of gas produced and the significant liquid shrinkage. The sample from the previous constant mass expansion is depressurized to the dew point with the volume measured at dew point. Then the pressure is reduced stepwise with the gas removed until the depressurized sample volumes returns to the volume at dew point.

At each pressure step, the removed gas and the condensate volume and Z are measured together with the liquid buildup volume in the cell. The fluid produced at each stage can be converted into moles and is used to calculate the fluid remaining in the cell. The final data include the retrograde liquid volume, fluid compositions for every stage, Z, gas viscosity and fluid density.

- **Separator test** : A series of flashes with the liquid from one flash becoming the feed for the next flash at different conditions. A reservoir fluid is flashed at various pressures and temperatures to simulate the well surface conditions: separator and stock tank. Separator tests are used to predict optimum separator conditions. The fluid at working pressure is charged to the cell or separator unit, and then the pressure and temperature are adjusted to the conditions of the first stage. Once the sample is stable, the gas is removed from the cell. The gas and oil volume remaining in the cell, cell and ambient temperatures and pressures are recorded. The gas composition is measured. The process is repeated at the conditions of the subsequent stages. The last stage reproduces stock tank conditions and the residue of the composition is measured as well.

- **Swelling test** : Measurement of oil-property variation with the amount of injection gas added. These properties might include saturation pressure, oil-volume expansion,
  oil viscosity, and oil density.

- **Multicontact test (forward and backward)** : Simulation of the dynamic phase behavior during a gas-injection process. The forward process mimics the mixing of rich gas at the gas front with the original oil. The backward process mimics the continuous contact of the injected gas with the oil left behind the gas front. The experimental data include interfacial tension (IFT), viscosity, and gas and oil composition at each contact. The minimum miscibility pressure (MMP) might also be determined from such a test.

- **Slim-tube test :** A dynamic phase-behavior test where the injection gas displaces oil from uniform sand or glass beads packed in a small-diameter tube to minimize non- ideal effects such as fingering. The MMP is determined from the recovery curve. The effluent composition vs.pressure is provided also.

Fluid density, molecular weight (MW), IFT, and viscosity are measured in some of the above experiments. Often, the composition (component mole fractions) of the sample fluid is obtained from the compositions of gas and liquid at standard conditions weighted by the GOR. The composition of gas is measured by use of a gas chromatograph. The measurements for oils often provide mass fraction rather than mole fraction. To convert these measurements into mole fractions, the molecular weight of each fraction must be used, which can be measured or computed from a correlation.

For gas condensates, the mole fractions of components up to at least C11 should be measured because the component mole fractions often increase with carbon number for components up to C11. For oil reservoirs with a potential for solvent injection, extended compositional analysis might be needed for components up to C30 or even heavier [5]. Mass transfer of these components between the gas and oil dominates the displacement characteristics of miscible or near-miscible floods.

Data from these experiments can be used as input for a black-oil model or to calibrate an EOS for a compositional model. Depending on the simulation model and the field development, only some of these experiments are needed. For a waterflood, the CME, differential liberation, and separator tests are adequate. For gas/condensate reservoirs, CME, CVD, and separator-test data are adequate [6]. These experiments describe the fluid-property change during pressure depletion. For solvent injection, data from the swelling test also are needed. For miscible or near-miscible processes, multicontact and slim-tube tests are needed.

2.3 Developing PVT Fluid Model

Usually, petroleum-reservoir fluids contain several hundred distinct components, which make it impossible to model the fluids rigorously as a mixture of these pure components. Therefore, "pseudocomponents" are used in EOS models, especially for the heavier components. During simulations with an EOS compositional model, two families of chemical compounds represent a reservoir fluid: individual chemical compounds with well-defined physical properties and several groups of heavy components (pseudocomponents) that are identified by use of a single carbon number.

An EOS requires the critical temperature (*Tc*), critical pressure (*Pc*), and acentric factor (ω) for each component. However, the physical properties available for the heavy groups usually are only the mole fraction, MW, and specific gravity (SG). The critical properties of the heavy pseudocomponents are difficult, if not impossible, to obtain experimentally. A practical number of components to use in large compositional reservoir simulations typically are between 6 and 15. The following are steps usually involves to construct the PVT fluid model based on EOS :

1. Develop pseudocomponents for the heavy fraction.
    - *Split the heavy fraction into many pseudocomponents by use of a distribution function that honors the measured MW and SG* [7]*. The MW and SG of each split pseudocomponent are obtained.*
    - *Estimate the Tc, Pc, and ω for these split pseudocomponents by use of an empirical correlation* [8]
    - *Lump these split pseudocomponents into a few groups.*
    - *Compute the Tc, Pc, and ω for these lumped groups by use of mixing rules.*

2. Validate this EOS model against experimental PVT data and determine if tuning of the EOS parameters is needed.

3. Tune the EOS parameters.

- *Select suitable experimental data to tune the EOS.*
- *Choose the adjustable EOS parameters that will be used to match these data.*
- *Perform tuning by use of an optimization technique.*

4. Evaluate the predictive capability of this EOS model.

2.4 Number of Pseudocomponents

The following guidelines can be used to select the number of pseudocomponent :

1. At least two, often three or more, pseudocomponents are needed for the C7+ fraction. Also, the intermediate components between C2 and C6 can be grouped into two pseudocomponents unless surface separation requires detailed knowledge about them.

2. To adequately describe mass transfer between phases for vaporized- and condensed-gas drives and their combined processes, more intermediate components (C5 through C15) may be required [9].

A recent practice in the industry [10] is to start with more components (e.g., 15 to 20), then successively reduce the number of components until the EOS loses its acceptable representation of the measured PVT data. Often, this process requires extended analysis of fluid composition during the laboratory tests and targets complicated solvent-injection displacements. **Figs. 1 and 2** show typical effects of the number of components on phase envelope and liquid dropout of gas condensates.

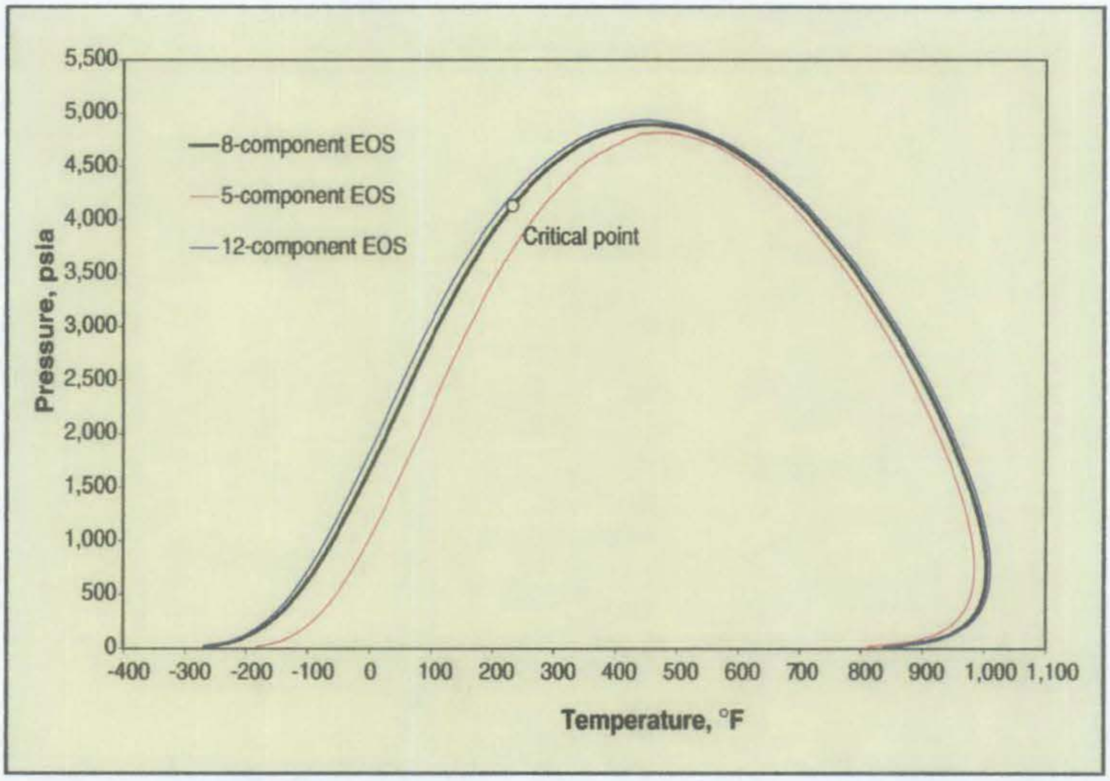


Figure 1.0 Effects of number of components on phase envelope of an actual gas condensate

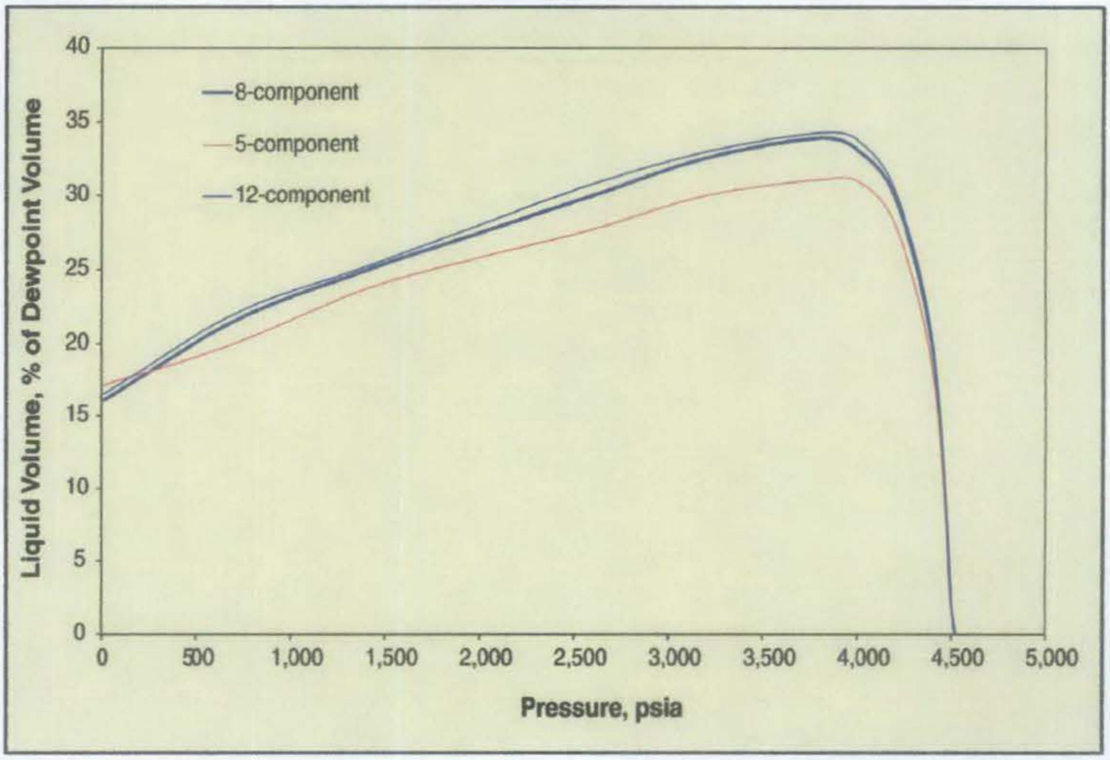


Figure 2.0 Effects of number of components on liquid dropout.

2.4 Tuning EOS Parameters

As discussed in the previous section, a link is needed between the measurable properties, such as MW and SG, and the EOS parameters, such as *Tc*, *Pc*, and ω for the heavy groups. Often, such a link is provided in the form of empirical correlations, which inevitably involve some uncertainties.

Additionally, the well-defined compounds used to generalize the parameters of the original cubic EOS are usually lighter than C15 [11]. Extension of the EOS to heavier components existing in the petroleum fluids relies on the extrapolation of the EOS parameters. The vapor pressure and the conditions at the critical point have been used to develop two-parameter cubic EOS's, while the volumetric properties typically are not used. As a result, a fixed critical compressibility factor (0.303 for the Peng-Robinson EOS and 0.333 for the Soave EOS) is used [12]. Therefore, these EOS's are not expected to provide accurate estimates of density, especially for the liquid phase or when a large fraction of heavy components is in the mixture. To improve the accuracy of the liquid-density predictions, a volume-shift parameter was added to two-parameter cubic EOS's [13, 14]. Three-parameter cubic EOS's, such as that developed by Patel and Teja [15] also can be used to improve volumetric accuracy, but these EOS's commonly are not used in reservoir simulators.

Tuning the heavy-group properties that relate to EOS parameters requires the following:

- Selection of tuning parameters and the ranges in which the selected parameters may vary.
- Selection of experimental data for matching the tuned EOS parameters.
- Judgment regarding the predictive capability of the tuned EOS model.

2.5 Relationship between EOS-PVT and Compositional Simulation

Reservoir simulators are built on the basis of mass or molar balances of each component. Such a balance is assumed at any moment during the fluid flow. Because different phases flow at different velocities in the direction that leads to a decrease in the flow potential of each phase, the equilibrium between phases changes with time [4]. To achieve this new equilibrium, mass transfer of these components between phases needs to take place constantly. An EOS is used to solve this equilibrium part of the equations governing the multiphase and multicomponent flow at a given pressure and overall composition. After the solution of the equilibrium equations is reached, the EOS provides the number of phases, phase molar and mass densities, phase saturations, and the composition of each phase. Subsequently, phase viscosities and interfacial tension between phases can be determined by use of correlations.

2.6 Future development in EOS

It is worth noting that many improved EOS's have been developed in recent years. Orbey and Sandler [16] discuss and illustrate some of these developments. In particular, they show how liquid-activity-coefficient models can be used with new mixing rules in the EOS formalism. Such models greatly improve the accuracy of calculations for mixtures containing polar components, such as water, as well as greatly increase the predictive power of the EOS [17]. These new mixing rules can be combined easily with familiar cubic EOS's, such as the Peng-Robinson EOS. Software for volumetric and phase-behavior calculations that use the Wong-Sandler approach are readily available. It seems likely that such improvements will gradually be incorporated into at least some compositional reservoir simulators.

CHAPTER 3 : METHODOLOGY

3.1 Research Methodology

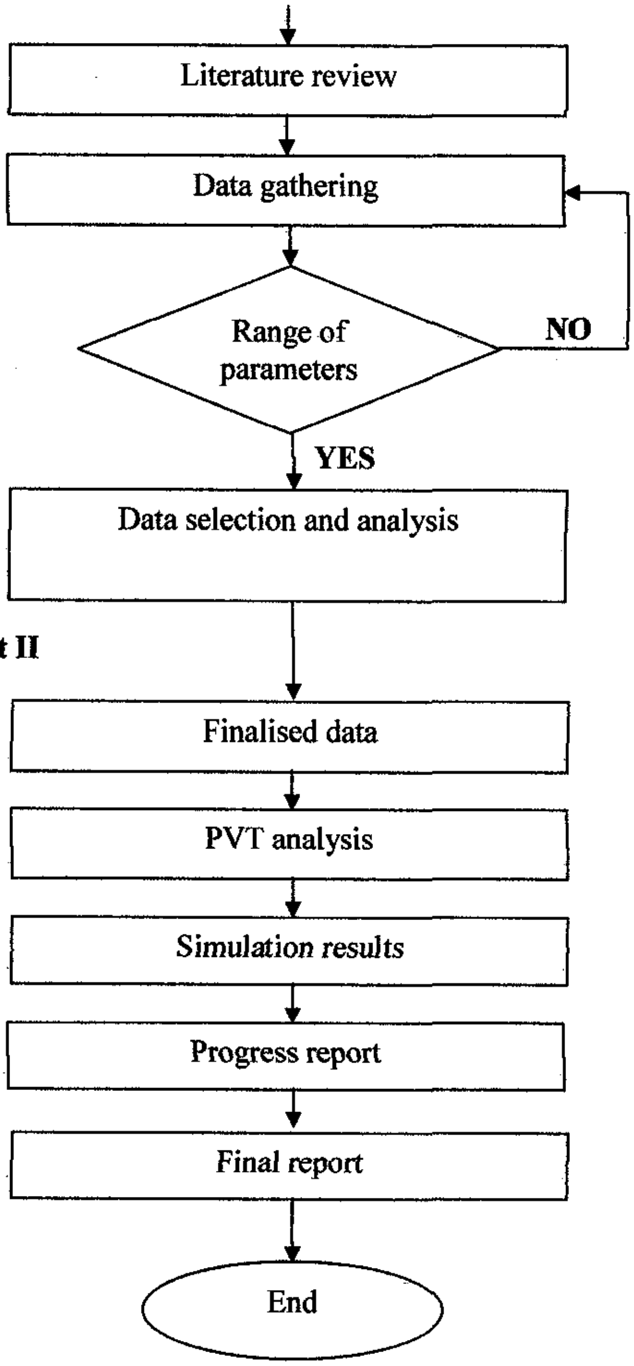
1. Identify Equation of State that available in PVT analysis software
2. Study and understand the concept of EOS and its behaviour
3. Understand the concept of PVT analysis and its usage in reservoir simulation
4. Evaluate the effect of different EOS used to the oil recovery in reservoir simulation
5. Create a reservoir simulation model to be used for EOS analysis
6. Simulate the reservoir simulation model using different EOS
7. Identify the effect of EOS characterization towards oil recovery

3.2 Key Milestone

No.	Activities	Date/Week
1.	Gathering information	W1-W2
2.	Simulation	W3-W5
3.	Result interpretation and data analysis	W6-W8
4.	*Submission of progress report*	W8
5.	Pre EDX, seminar, poster exhibition and submission of final report	W11
6.	Engineering design exhibition	W12
7.	Final oral presentation	W13
8.	Evaluation by external examiners	W14
9.	Submission of hardbound copies of report	W16

3.3 Procedure Identification

Final Year Project I



3.4 *Gantt Chart*

		Week															
No	Task Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Data Selection	■	■														
2	PVT Analysis			■	■	■											
3	Result interpretation and data analysis						■		■	■							
4	Submission of progress report								■	■							
5	Pre EDX, seminar, poster exhibition and submission of finale report										■	■					
6	Engineering design exhibition												■				
7	Final oral presentation													■			
8	Evaluation by external examiners														■		
9	Submission of hardbound copies of report															■	■

3.5 *Tools (eg. Equipment, hardware, etc.) required.*

Several tools especially softwares are required for the project :

1. PVTi software - PVT*i* is a compositional PVT equation-of-state based program used for characterizing a set of fluid samples for use in our ECLIPSE simulators.

2. ECLIPSE E300 - The ECLIPSE Compositional simulator is useful when an equation of state is required to describe reservoir fluid phase behavior or compositional changes associated with depth.

CHAPTER 4 : RESULTS AND DISCUSSION

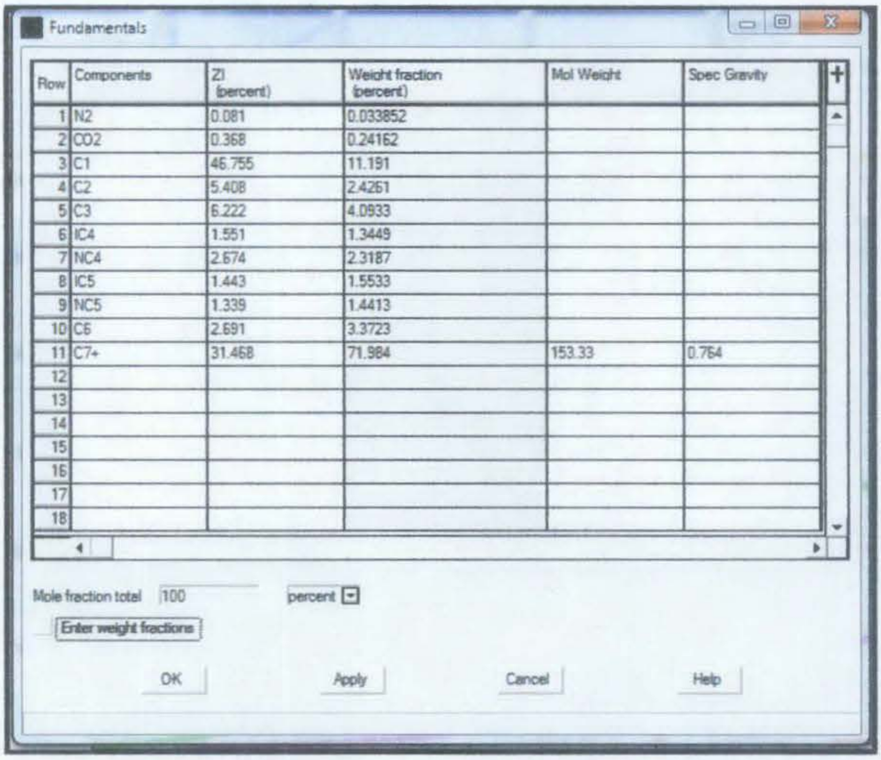
The following discussion is by no means a comprehensive study of the different Equation of State (EOS) such as splitting, lumping and regression techniques as applied to complex multicomponent hydrocarbon systems using PVTi. Rather, the predictive capabilities of selected equations have been tested and documented when used to predict PVT system of oil fluids.

4.1 Data Availability

For this study, the input data are obtained from the PVT lab data of real reservoir fluid studies. From the composition, the fluid is identify to be black oil with reservoir temperature of 194 °F and bubble point of 3300 psig. For the experiments data, 3 experiments were performed to the fluid which were Constant Composition Expansion (CCE), Differential Vaporisation Test (DV) and Viscosity Test. Composition from separator gas and separator oil are recombined at Gas Oil Ratio (GOR) of 1042 scf/bbl and 899 scf/bbl. The dynamic model used in this study is compositional model with 231 MMstb of Stock Tank Oil In Place (STOIIP).

4.2 Data Input

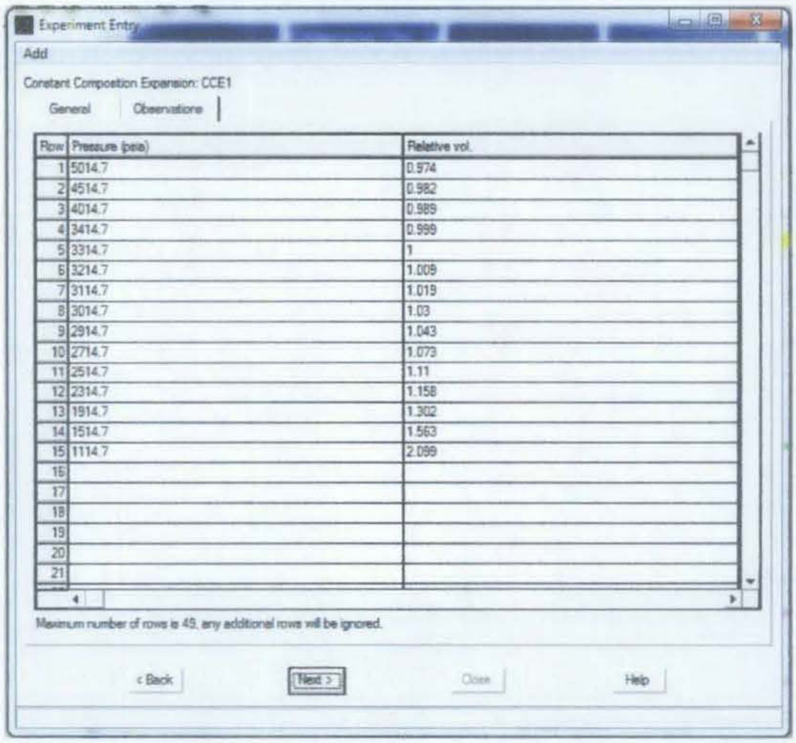
The recombined composition at wellstream of GOR = 899 scf/bbl was selected for further analysis since the reported GOR of the real reservoir is 900 scf/bbl. In the fundamentals section of PVTi, only eleven components are considered to be the input for this study given limited data availability. Besides compositions at the recombined well stream, the data from CCE and DV experiments are also be the data input in the PVTi for further studies. Equation of State (EOS) of 3-Parameter Peng-Robinson (PR3) is used for this initial phase. Later, several EOS will be used to compare the results.



Row	Components	ZI (percent)	Weight fraction (percent)	Mol Weight	Spec Gravity
1	N2	0.081	0.033852		
2	CO2	0.368	0.24162		
3	C1	46.755	11.191		
4	C2	5.408	2.4261		
5	C3	6.222	4.0933		
6	IC4	1.551	1.3449		
7	NC4	2.674	2.3187		
8	IC5	1.443	1.5533		
9	NC5	1.339	1.4413		
10	C6	2.691	3.3723		
11	C7+	31.468	71.984	153.33	0.764
12					
13					
14					
15					
16					
17					
18					

Mole fraction total 100 percent

Figure 3.0 Composition input in PVTi fundamental window

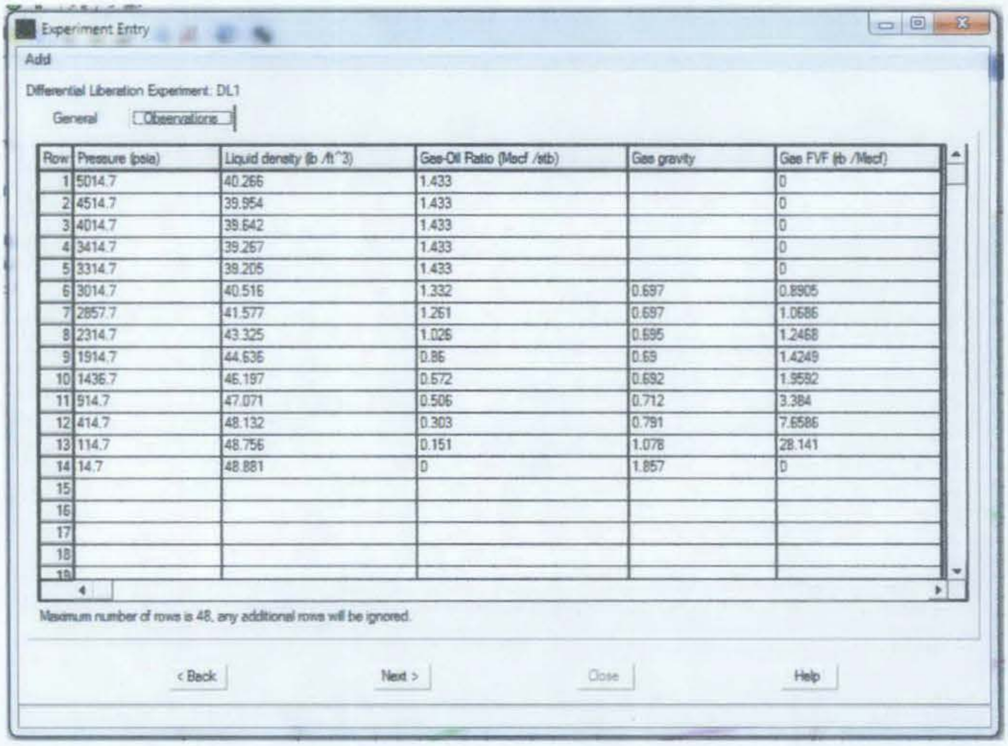


Constant Composition Expansion: CCE1

Row	Pressure (psia)	Relative vol.
1	5014.7	0.974
2	4514.7	0.982
3	4014.7	0.989
4	3414.7	0.999
5	3314.7	1
6	3214.7	1.009
7	3114.7	1.019
8	3014.7	1.03
9	2914.7	1.043
10	2714.7	1.073
11	2514.7	1.11
12	2314.7	1.158
13	1914.7	1.302
14	1514.7	1.563
15	1114.7	2.099
16		
17		
18		
19		
20		
21		

Maximum number of rows is 49, any additional rows will be ignored.

Figure 4.0 CCE experiment input in PVTi

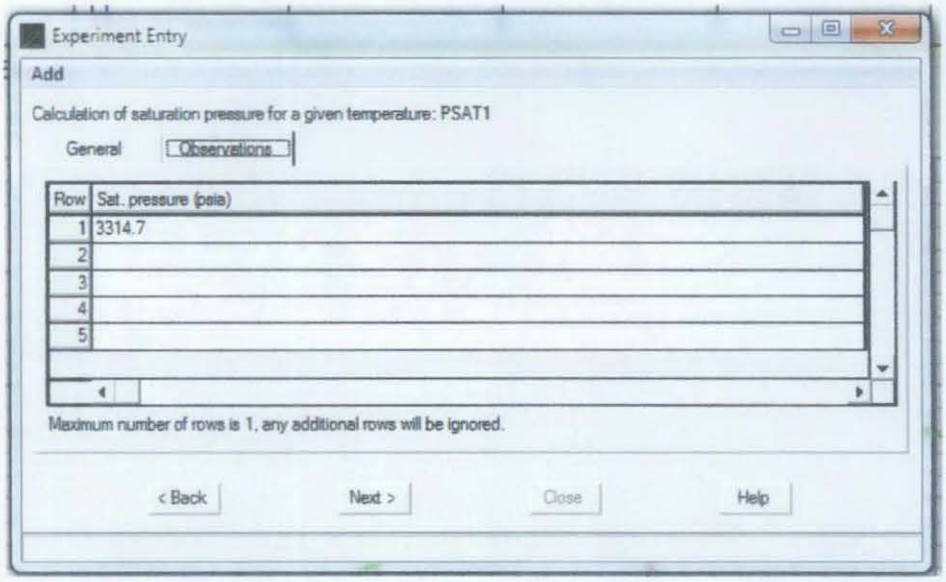


Differential Liberation Experiment: DL1

Row	Pressure (psia)	Liquid density (lb /ft^3)	Gas-Oil Ratio (Mscf /stb)	Gas gravity	Gas FVF (rb /Mscf)
1	5014.7	40.266	1.433		0
2	4514.7	39.954	1.433		0
3	4014.7	39.642	1.433		0
4	3414.7	39.267	1.433		0
5	3314.7	39.205	1.433		0
6	3014.7	40.516	1.332	0.697	0.8905
7	2857.7	41.577	1.261	0.697	1.0686
8	2314.7	43.325	1.026	0.695	1.2468
9	1914.7	44.636	0.86	0.69	1.4249
10	1436.7	46.197	0.672	0.692	1.9592
11	914.7	47.071	0.506	0.712	3.384
12	414.7	48.132	0.303	0.791	7.6586
13	114.7	48.756	0.151	1.078	28.141
14	14.7	48.881	0	1.857	0
15					
16					
17					
18					

Maximum number of rows is 48, any additional rows will be ignored.

Figure 5.0 DL experiment input in PVTi



Calculation of saturation pressure for a given temperature: PSAT1

Row	Sat. pressure (psia)
1	3314.7
2	
3	
4	
5	

Maximum number of rows is 1, any additional rows will be ignored.

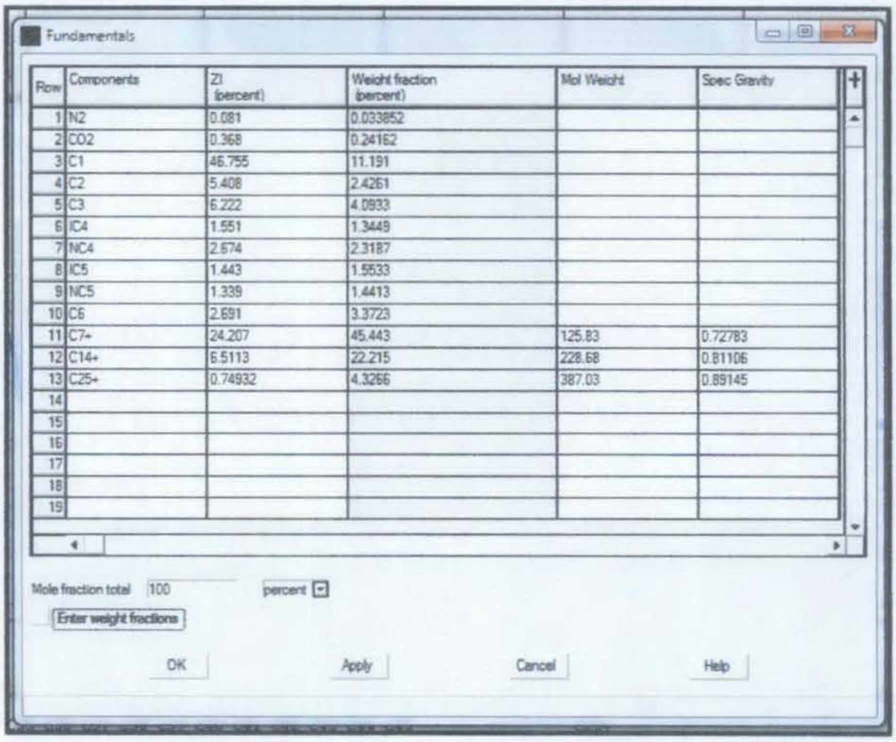
Figure 6.0 Saturation pressure input in PVTi

4.3 Splitting and Grouping

Many people have invested a lot of time and effort to obtain fluid samples, and analyze them to determine their PVT behaviour. Unfortunately, the way the data is presented to us in a laboratory report is not always suitable for use in an EOS model. Two additional steps must often be performed – splitting the residual hydrocarbon plus fraction and grouping with similar hydrocarbons.

There are basically three reasons why splitting should be done : insufficient description for heavier hydrocarbons reduces the accuracy of PVT predictions, condensate and volatile oils are particularly sensitive to plus fraction composition and properties, laboratories tend to give very limited analysis to the plus fraction.

For this study, Whitson splitting technique was used in order to split the plus fraction into sub-fractions. Graphs below shows fingerprint plot for the sample before and after splitting. Notice the difference in plus fractions where the mole percent of the composition is decreasing towards the plus fractions.



Row	Components	ZI (percent)	Weight fraction (percent)	Mol Weight	Spec Gravity
1	N2	0.081	0.033852		
2	CO2	0.368	0.24162		
3	C1	46.755	11.191		
4	C2	5.408	2.4261		
5	C3	6.222	4.0933		
6	IC4	1.551	1.3449		
7	NC4	2.674	2.3187		
8	IC5	1.443	1.5533		
9	NC5	1.339	1.4413		
10	C6	2.691	3.3723		
11	C7+	24.207	45.443	125.83	0.72783
12	C14+	6.5113	22.215	228.68	0.81106
13	C25+	0.74932	4.3266	387.03	0.89145
14					
15					
16					
17					
18					
19					

Mole fraction total 100 percent

Figure 7.0 Composition after splitting

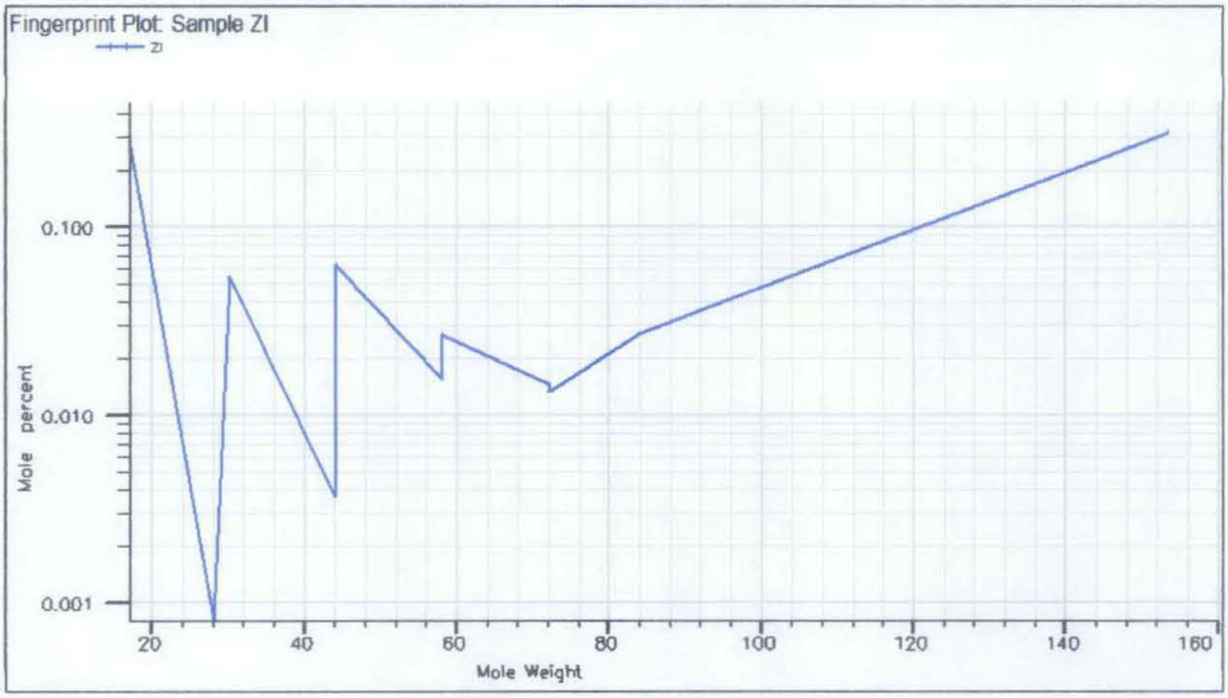


Figure 8.0 Fingerprint plot before splitting

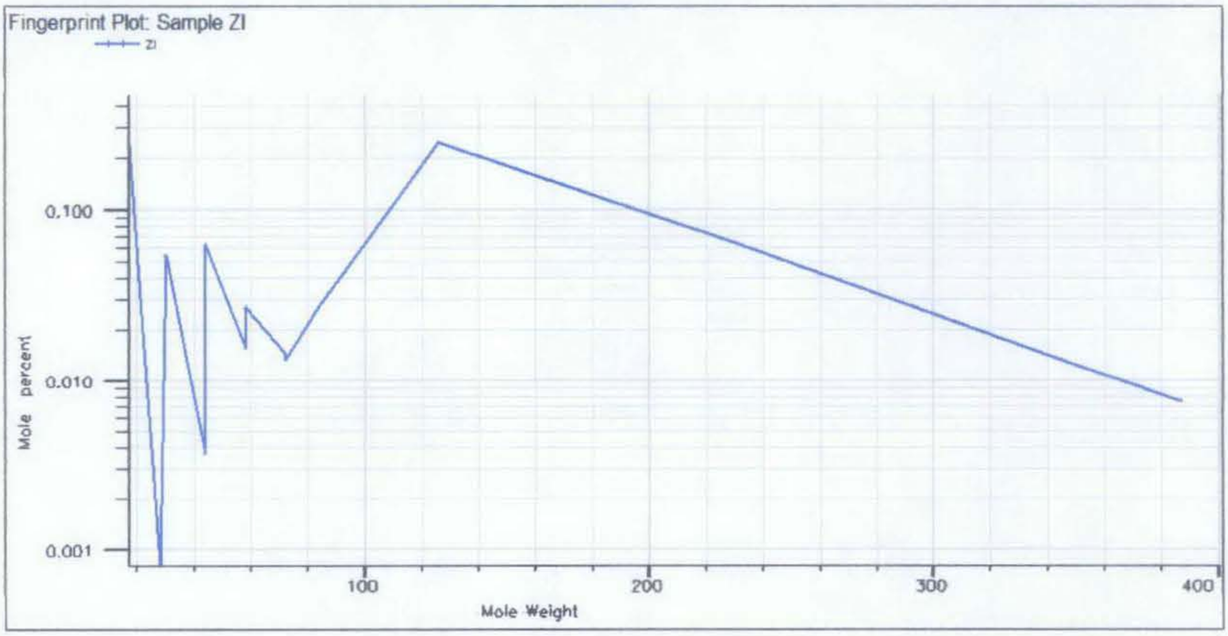
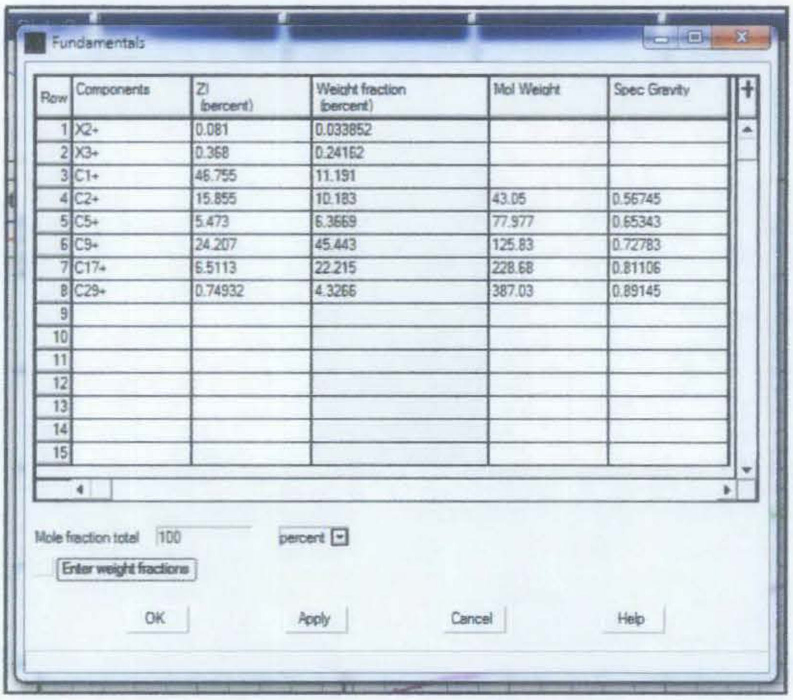


Figure 9.0 Fingerprint plot after splitting

The main reason for grouping components is to reduce computing time of a compositional simulator. This time increases rapidly with an increasing number of components. As example, for large number of components, the computing time needed to solve the flash equations may be as the time needed to solve the flow equations. Also, if there are Nc hydrocarbon components, the number of equations to be solved per grid block is Nc + 2. It shows that more equations will need more time. In most cases, between 4 and 10 components should be enough to describe a compositional simulation process.

The main issue for grouping is to group components with similar molecular weights. For example, C7 should rather group with C8 rather than with C2, as properties of C7 and C8 expected to be similar, while the properties of C7 and C2 would be very different. An exception to this rule is that N2 is usually added to C1 and CO2 is usually added to C2. The reasons why we group the components based on their molecular weight is because the components are expected to have similar properties. Hydrocarbon molecules with similar molecular weights will have similar properties, but this will not apply to non-hydrocarbon molecules such as N2 or CO2.

Figures below show comparison of before and after grouping process to the components. Notice the differences of the components after the grouping and the similarity of the phase diagrams.



Row	Components	ZI (percent)	Weight fraction (percent)	Mol Weight	Spec Gravity
1	X2+	0.081	0.033852		
2	X3+	0.368	0.24162		
3	C1+	46.755	11.191		
4	C2+	15.855	10.183	43.05	0.56745
5	C5+	5.473	6.3669	77.977	0.65343
6	C9+	24.207	45.443	125.83	0.72783
7	C17+	6.5113	22.215	228.68	0.81106
8	C29+	0.74932	4.3266	387.03	0.89145
9					
10					
11					
12					
13					
14					
15					

Mole fraction total 100 percent

Figure 10.0 Composition after grouping

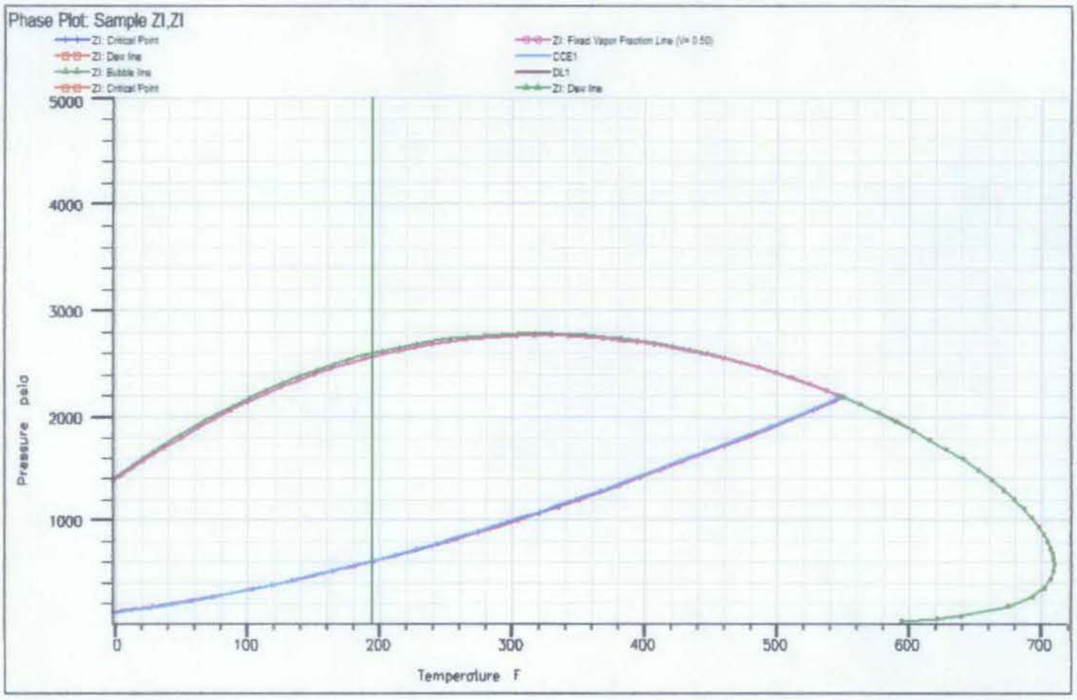


Figure 11 Phase diagram after grouping

4.4 Regression

Since the simple bubble point experiment had been defined, we need to compare the experimental value with the calculated value from PVTi based on the EOS. The comparison was poor to start with but changing the properties of the C7+ will give a better results. The equation of state model may be tuned by regression. The critical state data, *Omega* A *and Omega* B *values, interaction coefficients, and volume shift* parameters (for the three-parameter volume shift equations of state), may be matched to experimental data from the experiments mentioned in the previous paragraph. Additionally, depending on the use of certain facilities and options, five special regression parameters are also available. These are the *A* coefficient in the Cheuh-Prausnitz Bids, the thermal expansion coefficient in the modified Peneloux et al. volume shift method, and three variables associated with the Modified Whitson splitting technique (denoted Semi-Continuous-Thermodynamics), being the mole weight and distribution skewness parameter (on a sample-by-sample basis) and the characterization factor of the plus fraction.

Before regression

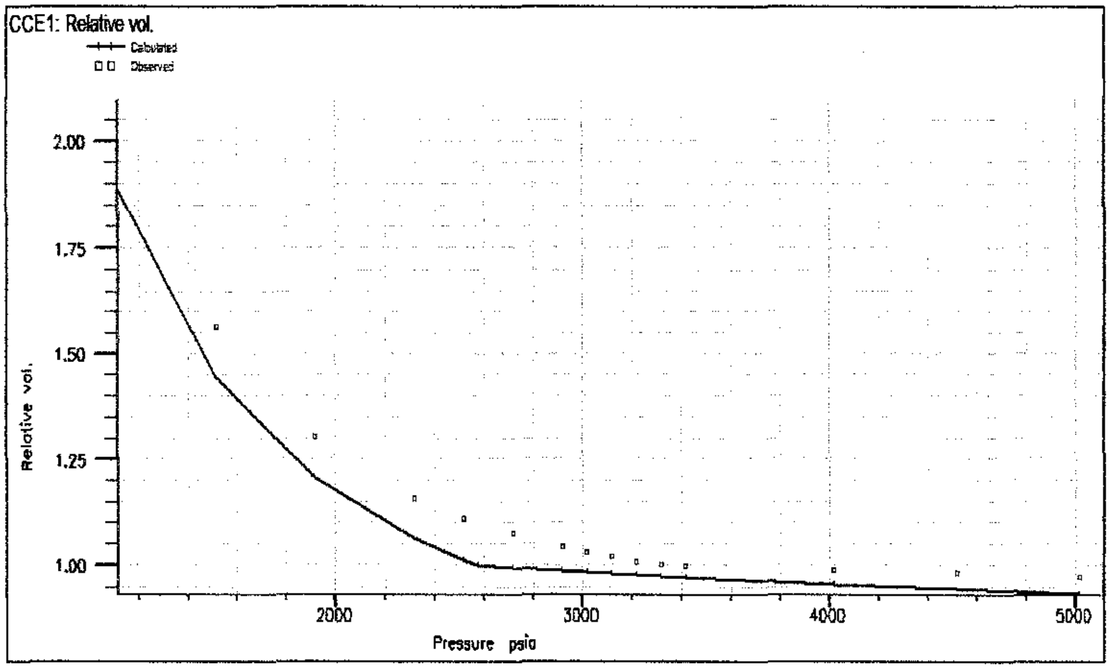


Figure 12 Relative volume before regression

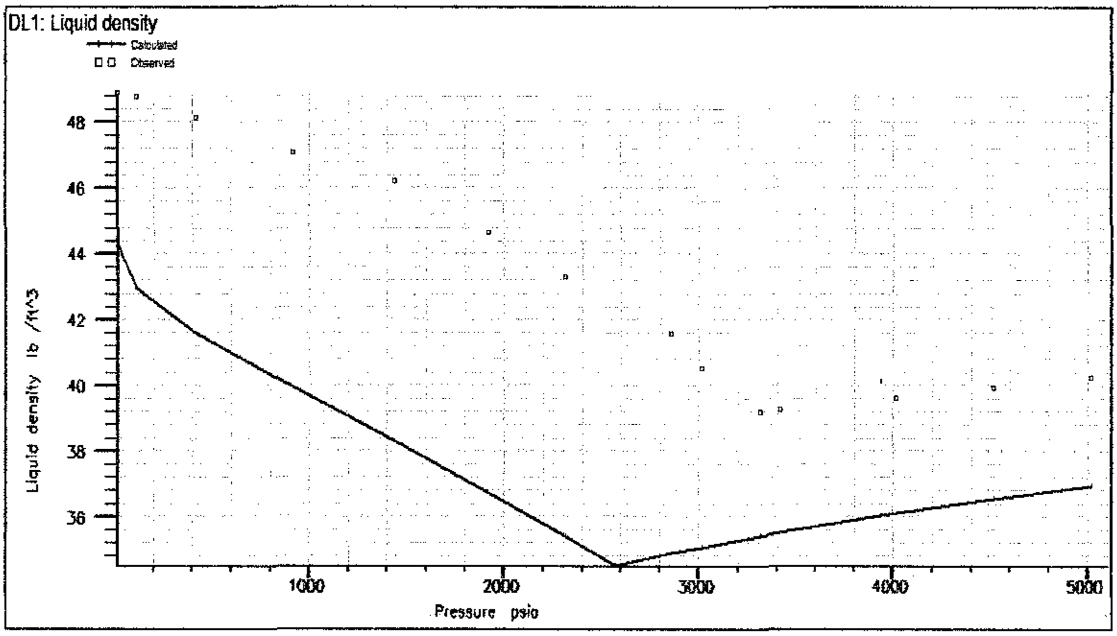


Figure 13 Liquid density before regression

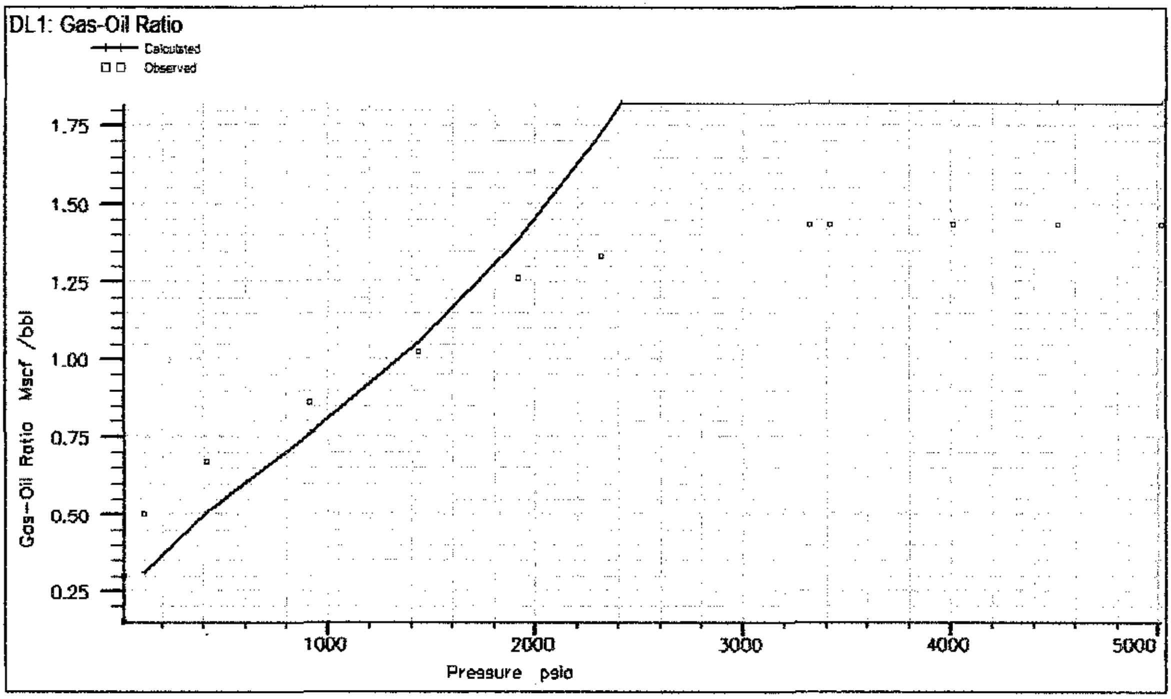


Figure 14 Gas-Oil ratio before regression

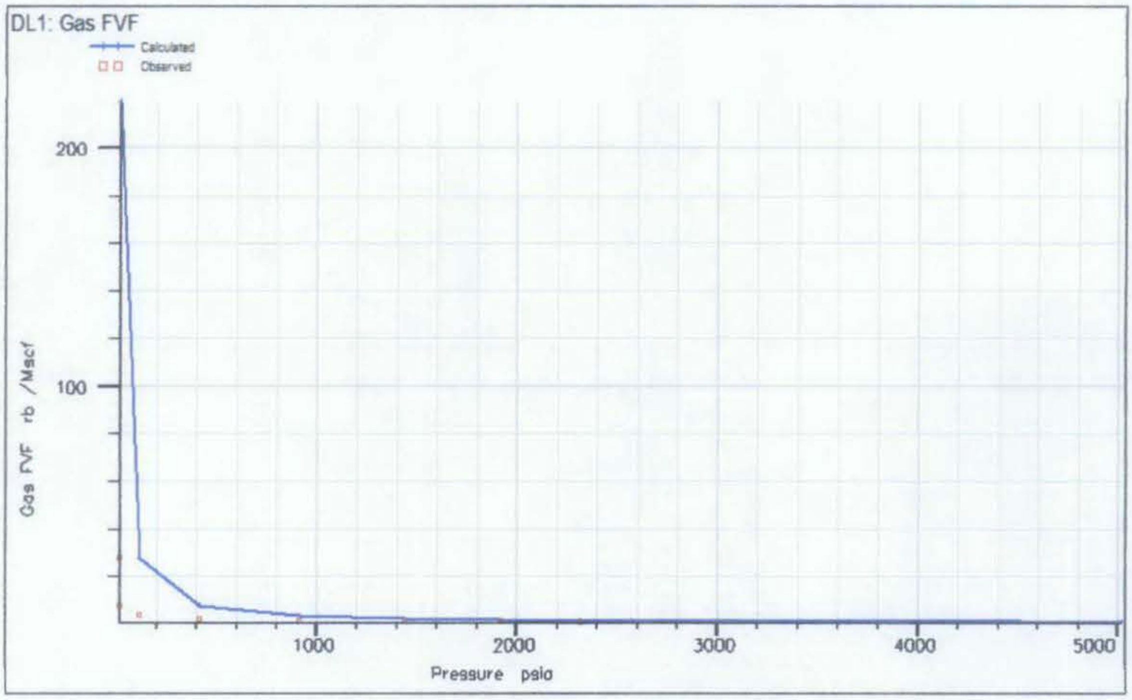
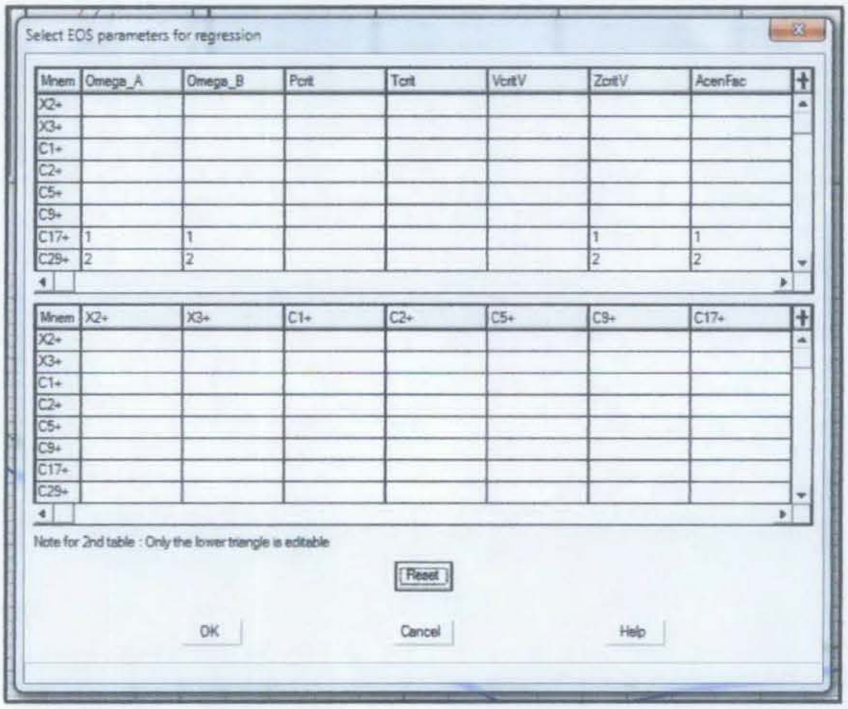


Figure 15 Gas FVF before regression

After regression



Mnem	Omega_A	Omega_B	Pcrit	Tcrit	VcritV	ZcritV	AcenFac
X2+							
X3+							
C1+							
C2+							
C5+							
C9+							
C17+	1	1				1	1
C29+	2	2				2	2

Mnem	X2+	X3+	C1+	C2+	C5+	C9+	C17+
X2+							
X3+							
C1+							
C2+							
C5+							
C9+							
C17+							
C29+							

Note for 2nd table : Only the lower triangle is editable

Figure 16 Tuning parameter

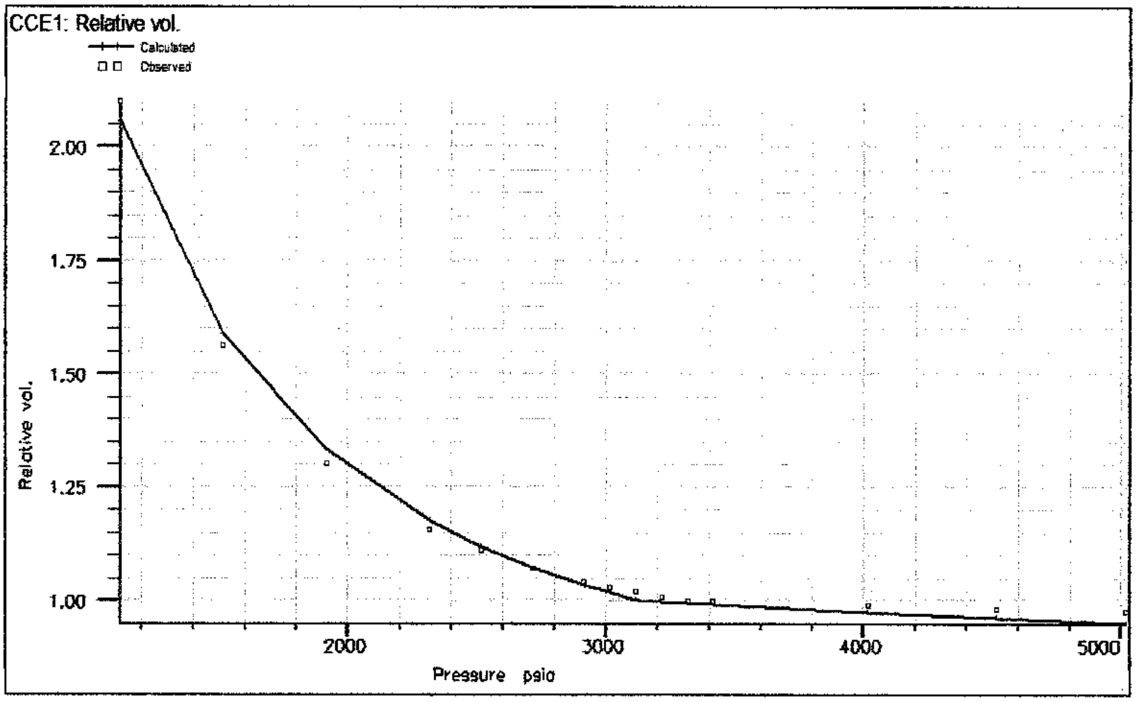


Figure 17 Relative volume after regression

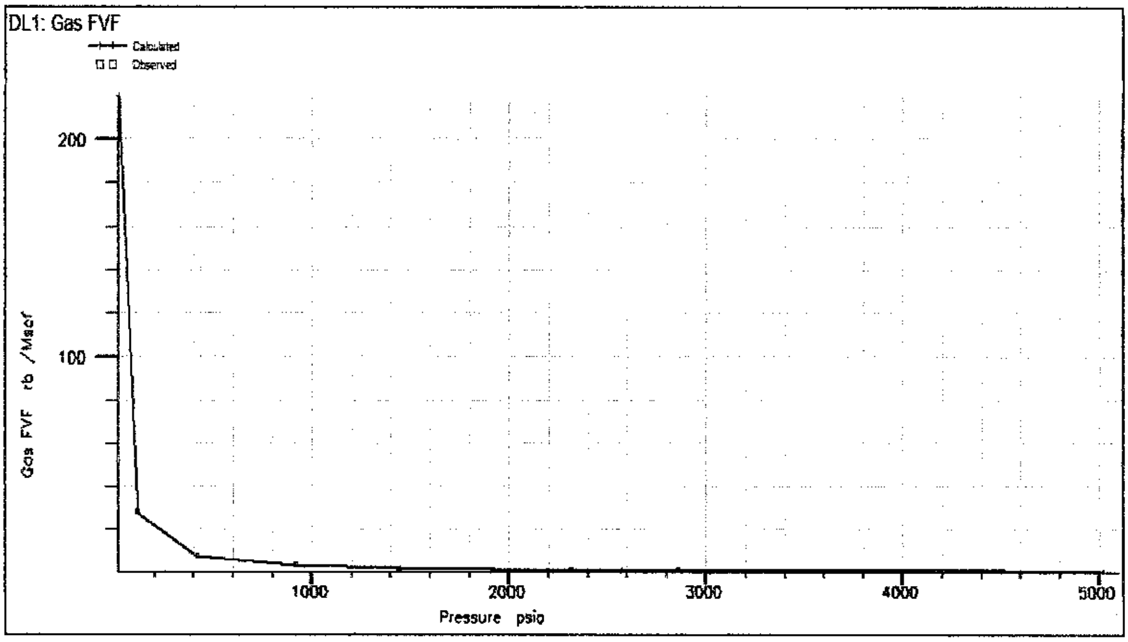


Figure 18 Gas FVF after regression

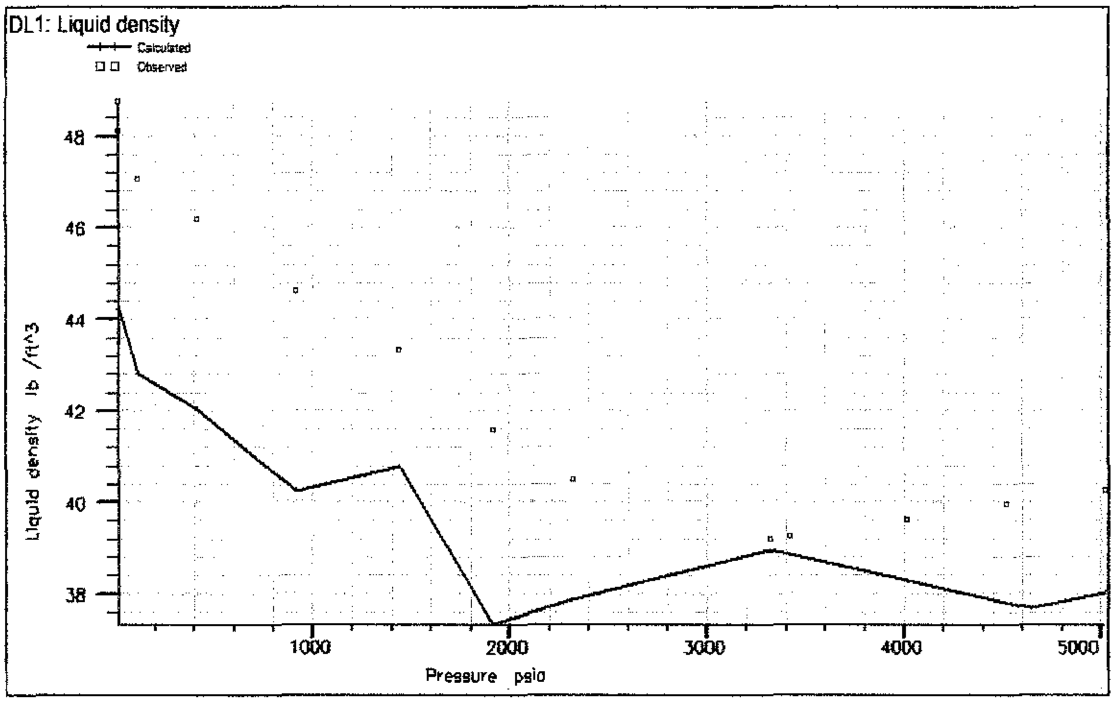


Figure 19. Liquid density after regression

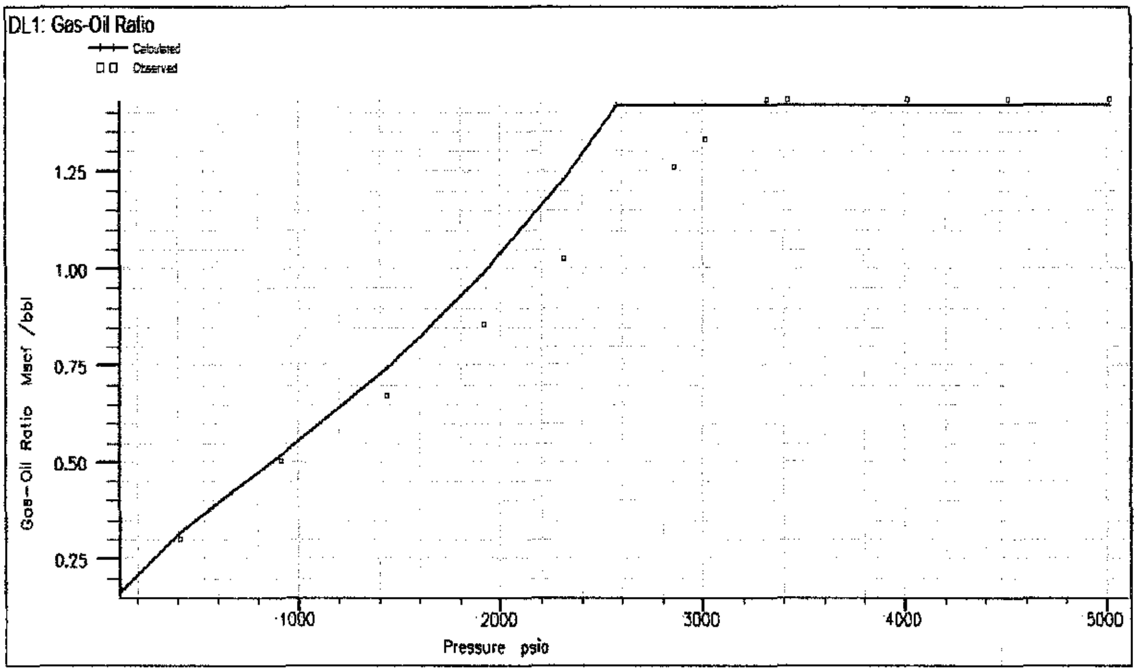
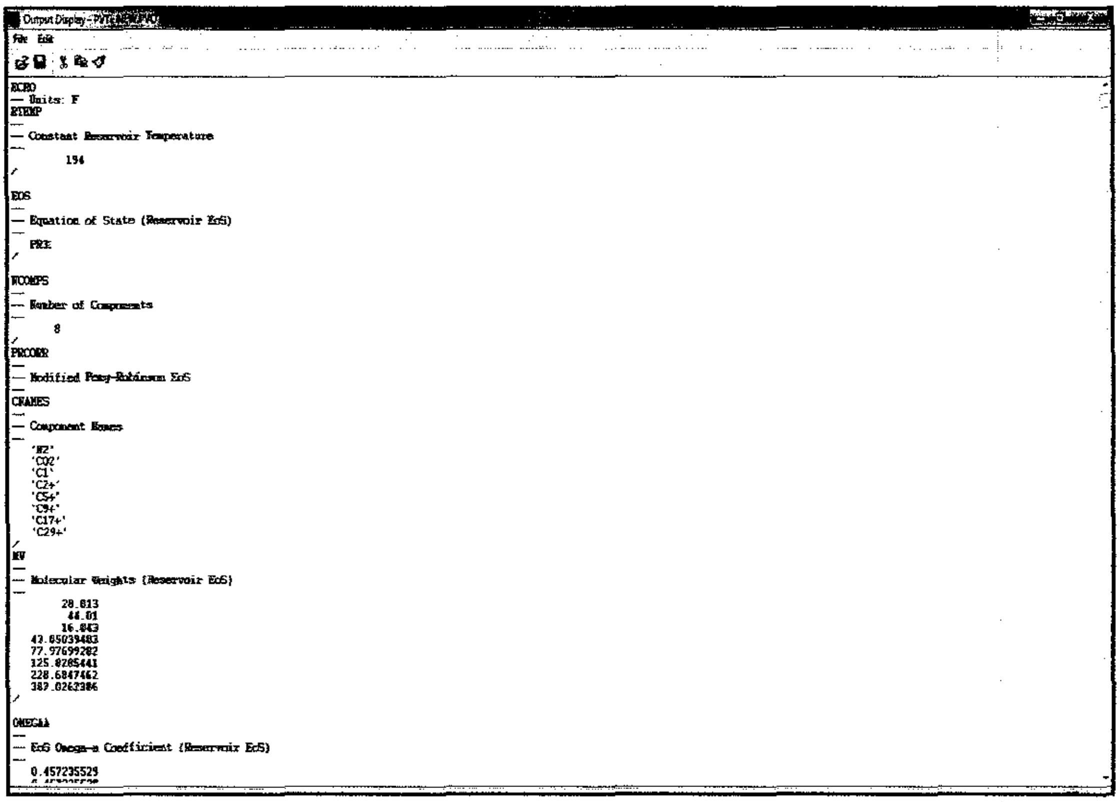


Figure 20 Gas-Oil ratio after regression

4.5 Creating PVT Fluid Model

After completing the PVT fluid model for 3-Parameter Peng-Robinson EOS(PR3), different fluid characterizations were created and applied to the fluid model during regression process. Then different EOS were used to create the PVT fluid model and again, different fluid characterizations were applied to the fluid during regression. The EOS that are used during the process are PR3, 3-Parameter Soave-Redlich-Kwong (SRK3) and Zudkevitch-Joffe (ZJ) EOS. Due to limited time and resources, only these EOS are used and more time and further studies need to be done to compare more EOS affect to the oil recovery. Finally, the entire PVT fluid models are exported to the ECLIPSE E300 to see the effect of using different EOS to the oil recovery. Simple dynamic model with 2 wells is used during the simulation.

4.6 Simulation Input



```
ECHO
-- Units: F
RTEMP
--
-- Constant Reservoir Temperature
--
       194
/

EOS
--
-- Equation of State (Reservoir EoS)
--
   PR3
/

NCOMPS
--
-- Number of Components
--
      8
/
PRCORR
--
-- Modified Peng-Robinson EoS
--
CNAMES
--
-- Component Names
--
   'N2'
   'CO2'
   'C1'
   'C2+'
   'C5+'
   'C9+'
   'C17+'
   'C29+'
/
MW
--
-- Molecular Weights (Reservoir EoS)
--
        28.013
         44.01
        16.043
   42.65039483
   77.97699282
   125.8285441
   228.6847462
   387.0262386
/

OMEGAA
--
-- EoS Omega-a Coefficient (Reservoir EoS)
--
   0.457235529
```

Figure 21 Output Display for Simulation Input

PVT simulation input is performed after we tune the calculated results to match with the observed results. It is observed that PVT keyword for compositional simulation is different from the black oil simulation where it contains more information since each component in fluid are treated individually rather than assumed as one fluid. The exported keyword then inserted to the .DATA file in the PROPS section to complete the model. This complete model is simulated using E300 since we want to track more details on each component of the fluid. These steps are repeated using different PVT fluid model that have been created before using different EOS selected.

4.7 Simulation Results

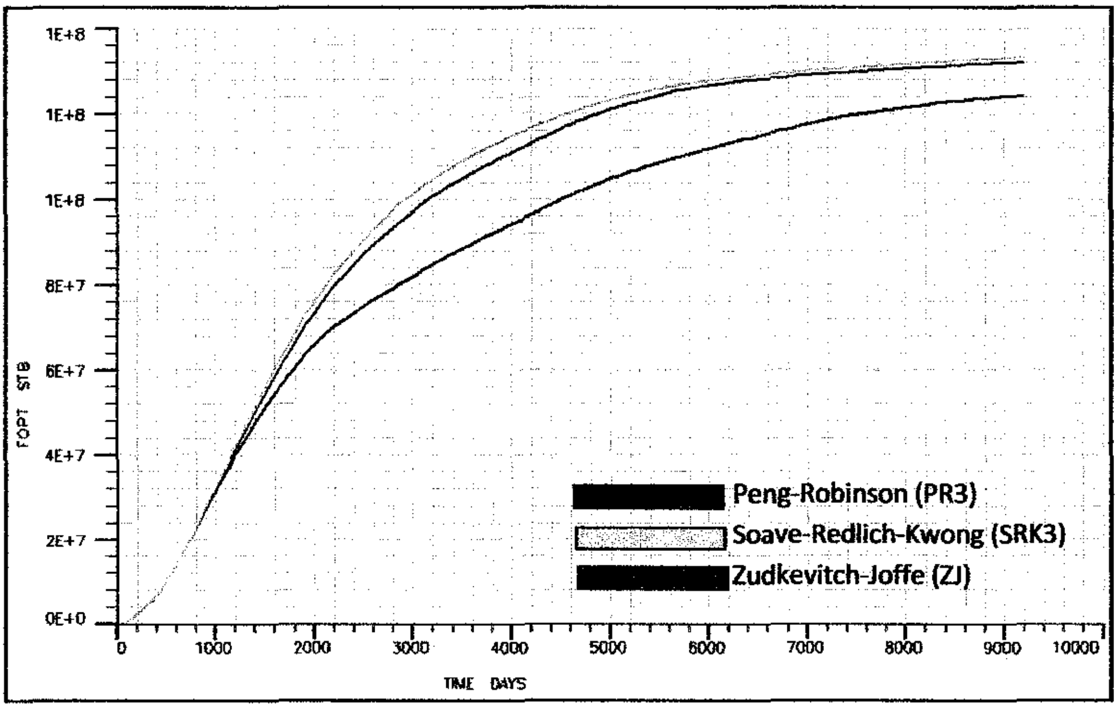


Figure 22 Field Oil Production Total Simulation Result

Based on the oil recovery results stated before, we can see that different EOS will yield different oil recovery results. In figure 22, the simulated Field Oil Production Total (FOPT) for EOS of PR3, SRK3 and ZJ are totally different. Total oil production for PR3 is around 132 MMstb (57% recovery) which is 0.75 % difference from total production from SRK3 which is 133 MMstb (57.6% recovery). Even though the difference is only 1 MMstb, it can affect the economic analysis of the entire field production life. Meanwhile, compared to total oil production from ZJ EOS, which is 123 MMstb (53% recovery), the differences is quite significant, about 7.724 % and around 10 MMstb compared to PR3 and SRK3. The reason why total oil recovery from PR3 and SRK3 is quite similar because the EOS of PR is developed to improve SRK equation back in 1978. By adding some parameter to SRK, the equation has improved and become more accurate in predicting the liquid density and vapour pressure.

CHAPTER 5 : CONCLUSION & RECOMMENDATIONS

A procedure is presented for comparing oil recovery simulated based on different equation of state parameters from the available PVT experiment data. The procedure is based on a fluid characterization which includes splitting, grouping and regressing which the main objective is to match/ tune the calculated data with the observed data in the laboratory. It is shown that it is possible to almost perfectly match experimental PVT data without loosing the predictive ability at conditions or for properties not covered by the regression. This is accomplished by a step wise regression procedure, first critically evaluating the composition data, and secondly adjusting the tuning parameter to match experimental phase densities. For many fluids these adjustments will be sufficient to obtain satisfactory PVT simulation results and will usually give the desired agreement between experimental and calculated PVT data.

Based on final results of this study which are the simulated oil recoveries, it is very clear that by using different EOS to create and develop PVT fluid model that will be exported to the simulator, the end results of the simulation will be based on the EOS selected and will be not the same regardless of what EOS chosen. More studies need to be done before choosing the EOS based on several research papers since there is no up until now a proper guidelines to choose the EOS. This selection criteria may based on the type of reservoir fluid, reservoir pressure, composition of the fluids and etc. For future study, the recovery results for different EOS can be compared on different reservoir fluid types such as black oil, gas condensate and dry gas so that we can see the effects of selecting different EOS in different fluid types.

CHAPTER 6 : REFERENCES

1. **Martin, J.** : *"Cubic Equations of State - Which?*, IEC Fundamentals, Vol. 18, Page 81 , May, (1979)

2. **Coats, H.** : *"Simulation of Gas Condensate Reservoir Performance"*, SPE paper no. 10512, presented at the Sixth SPE Symposium on Reservoir Simulation, New Orleans, January 31st - February 3rd, (1982)

3. **Peneloux, A., Rauzy, E., and Freze, F.** : *"A Consistent Correction for Soave-Redlich-Kwong Volumes"*, Fluid Phase Equilibria 8 , *Page 7-23,* (1982)

4. **Peng Wang and Gary A. Pope** : "Proper Use of Equations of State for Compositional Reservoir Simulation", SPE, U. of Texas at Austin, Page 74, July (2001)

5. **Pedersen, K.S., Thomassen, P., and Fredenslund, A.**: "Characterization of Gas Condensate Mixtures," paper presented at the 1988 AIChE Spring National Meeting, New Orleans, 16–19 March.

6. **Pedersen, K.S., Fredenslund, A., and Thomassen, P.** : *Properties of Oils and Natural Gases,* Gulf Publishing Co., Houston, Texas (1989).

7. **Whitson, C.H. and Brulé, M.R.**: *Phase Behavior,* Monograph Series, SPE, Richardson, Texas (2000)

8. **Whitson, C.H., Anderson, T.F., and Soreide, I.**: "C7+ Characterization of Related Equilibrium Fluids Using the Gamma Distribution," paper presented at the 1988 AIChE Spring National Meeting, New Orleans, 16–19 March.

9. **Barker, J.W. and Leibovici, C.F.**: "Delumping Compositional Reservoir Simulation Results:Theory and Applications," paper SPE 51896 presented at the 1999 SPE Reservoir Simulation Symposium, Houston, 14–17 February

10. **Jerauld, G.R.:** "Timing of Miscible Hydrocarbon Gas Injection After Waterflooding," paper SPE 59341 presented at the 2000 SPE/DOE Improved Oil Recovery Symposium, Tulsa, Oklahoma, 3–5 April.

11. **Peng, D.-Y. and Robinson, D.B.:** "A New Two-Constant Equation of State," *Ind. Eng. Chem Fund.* (1976) 15, 59–64.

12. **Soave, G.:** "Equilibrium Constants From a Modified Redlich- Kwong Equation of State," *Chem. Eng. Sci.*, 27 (1972) 1197

13. **Peneloux, A., Rauzy, E., and Freze, R.**: "A Consistent Correction for Redlich-Kwong- Soave Volumes," *Fluid Phase Equilibria* (1982) 8, 7–23.

14. **Jhaverl, B.S. and Youngren, G.K.**: "Three-Parameter Modification of the Peng-Robinson Equation of State to Improve Volumetric Predictions," *SPERE* (August 1988) 1033

15. **Patel, N.C. and Teja, A.S.**: "A New Cubic Equation of State for Fluids and Fluid Mixtures," *Chem. Eng. Sci.*, Vol. 37, No. 3 (1982) 463

16. **Orbey, H. and Sandler, S.I.**: *Modeling Vapor-Liquid Equilibria: Cubic Equations of State and Their Mixing Rules*, Cambridge U. Press, New York City (1998)

17. **Sandler, S.I.**: *Chemical and Engineering Thermodynamics*, third edition, John Wiley & Sons Inc., New York City (1999)

18. **D.I. O'Reilly** : *"Comparative PVT Simulation : An Application to Australasian Fluid Samples"*, Australian School of Petroleum, SPE, (2009)