The Effect of EOS and Tuning Parameters on Miscibility Pressure Calculation

by

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(Petroleum Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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Approved by,

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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 QAYYUM BIN AHMAD ANI

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ABSTRACT

This project is about the research on the effect of equation of state (EOS) and tuning parameters on the minimum miscibility pressure (MMP). To be exact it is the research about the effect on the MMP value when the parameters inside the EOS that used to predict the MMP value is tuned to match the data from experimental approach. From there we will see whether EOS may able to predict the MMP as good as the experiment or not. Besides that, at the end, there will be analysis on how much does the difference may take in place when the result between the original and tuned EOS is compared. The relevancy of this project is influenced by the factor of the tendency Oil and Gas industry today in using gas injection as their enhance oil recovery process. The relationship between gas injection processes with EOS is that whenever gas injection is used in enhance oil recovery, the purpose will be the same which is to obtain as high as it can in term of monetary. In order to have an economical project, the engineers need to know the MMP value since the project needs to be operated at the pressure on or above MMP. With that MMP determination is affecting the whole operation. Overall of the project will consist of two main stages which are the first stage the project will start with understanding build up and data collection while on the second stage the project will proceed with calculation and simulation for getting the result. At the end of the project, the result that is obtained will be analyzed and documented.

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minimum miscibility pressure (MMP). This so called MMP is important as it will determine whether the EOR process will be economical or not.

1.2 Problem Statement

By focusing on the prediction of MMP for gas injection process, there are already lots of approach that have been developed and by time passes they are getting better in term of prediction. Equation of state as one of the approach to predict MMP has been through lots of modification till it is approved that there is only a small difference of the result between EOS and experiment. Meanwhile in this project, the focus will be the behaviour of the EOS where the project will be focusing on the effect of equation of state (EOS) and tuning parameters on miscibility pressure calculation which we will see the effect of tuned EOS on the MMP predicted value by comparing the MMP value from EOS and experiment. Through this project, we will see the modification on the selected parameter that has been done in order to achieve the best result.

1.3 Objective

As what has been mention above and as the title of this project which is the effect of equation of state (EOS) and tuning parameters on miscibility pressure calculation, the main objective of this project is to see the effect on the value of the MMP when the EOS have been tuned to match the same data from the experimental approach. It is to see whether the EOS able to predict the value of the MMP as good as the experiment.

1.4 Relevancy

As in above discussion, there are about two-third of the original oil in place although after primary recovery and secondary waterflood. Among the EOR processes that have been proposed, gas injection plays a big role in recovering the remaining crude oil inside the reservoir. In order to create an economical gas injection process, the engineers need to do the process on or above the minimum pressure for the miscibility of crude oil with the injected gas to happen and this *minimum* pressure is called as minimum miscibility pressure (MMP). The value of MMP is something that can be predicted only by thorough research and accurate laboratory experiment. However, it is

CHAPTER II: LITERATURE REVIEW

2.1 Methods to Estimate MMP

After few development that have been done on predicting the MMP value, few methods have been proposed into the world and that methods is divided by three main methods which are through experiment, correlation and the other one is through equation of state. Each of the methods has their own ways to estimate the MMP value such under experiment method, there are few ways that have been developed which are slim-tube displacement, rising bubble apparatus and a new method, vanishing interfacial tension (VIT). While under correlation there are lots that have been proposed and some of them are Natl. Petroleum Council's(3) and Holm and Josendal(4) correlation. The same goes to EOS where there are also a few of approaches that have been proposed and some of them that quite famous and widely used around the world are Soave, Redlich and Kwong equation of state (SRKEOS)(5) and Peng and Robinson equation of state (PREOS)(6).

2.1.1 Experiment

2.1.1.1 Slim tube

Slim-tube method is the most common and has been accepted as the standard method to determine MMP. In this method, the miscibility conditions are determined by conducting the displacements process at various pressures or gas enrichment levels while the oil recovery is been monitored. Then, the oil recovery is plotted against the pressure and from this plot, the MMP is defined as the pressure at which the oil recovery vs. pressure curve shows a sharp change in slope. Since this project required extremely low flow rates, long length and smaller diameter tubing to avoid the unfavourable effects of fingering, it is very time consuming and may take several weeks to complete the measurement.

2.1.1.2 Rising bubble apparatus (RBA)

In the rising bubble experiment, the MMP is determined from the observation of changes in shape and appearance of bubble of the injected gas as they rise through a thin column of crude oil. This method is considerably faster and cheaper and requires smaller quantities of fluids, compare to slim-tube. However, there are limitations for this technique which it provide less information where the data regarding changes in composition, interfacial tension and displacement efficiency are not available. Therefore, it is still needed for a development of a laboratory measurement technique that can determine the MMP more accurately, quickly and quantitative in nature.

2.1.1.3 Vanishing interfacial tension (VIT)

To overcome most of the disadvantages on above methods, a new method called vanishing interfacial tension (VIT) has been developed. This method is based on the concept that, at miscibility, the value of interfacial tension between the two phases is zero and it will be a sufficient condition to attain miscibility. In this method, the interfacial tension between the injected gas and crude oil is measured at reservoir temperature while varying in the pressure or enrichment level of gas phase. The MMP is then determined by extrapolating the plot between interfacial tension and pressure. Besides being quantitative in nature, this method is quite rapid and cost effective.

2.1.2 Correlation

Many correlations that relating MMP to the physical properties of the oil and displacing fluid that have been proposed. Few examples such as Holm and Josendal have correlated CO_2 MMP with temperature and the average molecular weight of the C_{5+} fraction of the crude oil on the basis of Benham et al.(7) and also Harmon and Grigg(8) proposed the correlation of the MMP with the pressure at which a dramatic increase in the CO_2-rich phase is gradual, the MMP is the pressure at which the density of the vapor phase is equal to attained after the marked increase in the density at the lower temperature.

2.1.2.1 Correlation criteria

It should:

- account for each parameter that affecting the MMP
- independent of MMP database so that it will not need revision each time a more extensive set of data is acquired
- based on thermodynamic or physical principle that affect miscibility of the fluids
- directly related to multiple contact miscibility (MCM) process

2.1.2.2 Parameters affecting MMP

1) Temperature
2) Oil composition
3) Contaminants present in the CO2 (displacing-fluid composition)

All the correlations account for temperature. Most incorporate C_{5+} oil composition, while only several consider the effects of light and intermediate oil component or CO_2 impurities

2.1.3 Equation of State

Apart from these experimental techniques, an approach based on equations of state calculation is also available to determine minimum miscibility pressures. With the advances in computer systems, the prediction of phase behavior by this approach has become more reliable. However this approach requires the availability of compositional data for the reservoir fluids, which can be obtained from the laboratory PVT measurement.

2.1.3.1 PREOS

Peng and Robinson EOS (PREOS) is one of famous EOS developed for predicting the MMP. It has been tested and resulted with limited success in predicting the phase behaviour and MMP's of simulated reservoir fluids. Firoozabadi and Aziz compared the PREOS prediction results with the one from experimental approach and conclude that the EOS has overestimates the MMP. Lee and Reitzel observed similar trend and conclude that deviation is caused by inaccuracies in establishing the critical point – critical pressure and critical temperature, and due to lack in suitable data for the fine tuning of PREOS.

In order to predict the phase and volumetric behaviour of hydrocarbon mixture by PREOS, one needs to know the critical pressure, Pc, critical temperature, Tc, and acentric factor, ω, for each component that exist in the mixture. For pure compound, these three parameters are well defined but the problem is when there is heavy fraction, C7+ or also called as plus fraction. These three parameters are not well defined for the plus fraction and this plus fraction located at nearly all natural occurring gas and crude oil fluid. This limitation of the PREOS results on the improper procedure for calculating the characterization parameters "a, b and α" for C7+ that quite useful for MMP determination. However with the apparent success of the modified Redlich-Kwong EOS in describing the volumetric behaviour CO2-crude oil systems by Turek et al, it was motivated to implement the modification to PREOS by Tarek Ahmad. In the new approach recommend by Tarek Ahmad, the characterization parameters "a, b and α" for plus fraction is determined from the measured molecular weight and specific gravity of the heptanes-plus fraction.

2.2 Fluid Characterization

The first step in use of a PVT program is to define the components and their associated properties. There are three types of components in the naturally occurring petroleum deposits: pure components (such as CO2, CO, N2, H2S, C1, C2, etc.), mixture components (such as C7, C8, C9, etc), and plus fraction. The properties of pure components are well defined. While the splitting and lumping algorithm is used to define a plus fraction.

sample are determined by reserving the molecular weights of the pseudo components regrouped from the master fluid sample.

Each pseudo component is assumed to have the same properties as those from the master fluid sample. Therefore, the user-input multiple fluid samples are normalized into a unique N-component normalized system which contains all of the components each fluid sample has. The above approximation will be justified from the further automatic regression to match the lab data. If the regression finds that any property has a large uncertainty, it will be adjusted.

2.2.5 Regression

For a given cubic equation of state (PR EOS10, for example), the parameters, which may be tuned, include: EOS parameters Ω_a and Ω_b, critical temperature Tc, acentric factor Ac, volume correction parameter Vcr, molecular weight MW, and binary interaction parameters (BIN). Those parameters are all called EOS parameters for brevity. Those EOS parameters are component dependent. For a 10-component system, there are as many as 105 individual EOS parameters which may be tuned to match the lab data.

The test lab data to be matched may include those from separator test (SEP), constant composition expansion (CCE), constant volume depletion (CVD), differential liberation (DIF), swelling test (SWT), saturation pressure test (SAT), and variety of miscibility tests. Each lab test may run different times at different experimental temperatures for different fluid samples. Therefore, there may be as few as one experimental data (for example, 1 saturation pressure) or as many a hundreds of data points.

Manual regression on such a practical problem proves to be tedious, expensive, and experience-dependent. Therefore, a fully automatic regression program is desired which should automatically and efficiently yield a good match to a given set of lab data points for a given EOS model. User should not be involved in any processes of trying and guessing, such as guessing different number of regression variables, trying different types of regression variables, and so on.

2.2.5.1 Constant Mass Expansion

The reservoir fluid is kept in a cell at reservoir conditions. The pressure is reduced in steps at constant temperature and the change in volume is measured. The saturation point volume, V_{sat}, is used as a reference value and the volumetric results presented are relative volumes, i.e., the volumes divided by V_{sat}.

Gas Condensate Mixtures

For gas condensate systems the primary output for each pressure stage comprises

Rel Vol	V/V_d (V_d is dew point or saturation point volume)
Liq Vol	Liquid vol% of V_d.
Z Factor	(only above saturation point)

Table 1: Gas condensate system primary output

2.2.5.2 Differential Depletion

This experiment is only carried out for oil mixtures. The reservoir fluid is kept in a cell at the reservoir temperature. The experiment is usually started at the saturation pressure. The pressure is reduced stepwise and all the liberated gas is displaced and flashed to standard conditions. This procedure is repeated 6-10 times. The end point is measured at standard conditions.

The primary output consists of

GOR	Volume of gas from the actual stage at standard conditions divided by the volume of the oil from the last stage (atmospheric conditions)
Gas Gravity	Molecular weight of the gas divided by the molecular weight of air (28.964)
FVF	Oil formation volume factor, which is the oil volume at the actual stage divided by the oil volume from the last stage.

Table 3: Separator experiment primary output

Sometimes the separator GOR is seen reported as the standard volume of gas divided by the separator oil volume (oil volume at actual stage

Swelling Experiment

When gas is injected into a reservoir containing undersaturated oil, the gas may dissolve in the oil. The volume of the oil increases, which is called swelling. A swelling test experiment may simulate this process. The cell initially contains reservoir oil. A known molar amount of a gas is added at a constant temperature. The saturation pressure of the swollen mixture and the volume at the saturation point divided by the volume of the original reservoir oil are recorded. More gas is added. The new saturation pressure and saturation point volume are recorded and so on.

The primary output consists of:

Mole%	Cumulative mole% of gas added
GOR	Std. volume of gas added per volume of original reservoir fluid
Sat P	Saturation pressure after gas injection
Swollen volume	Volume of the mixture per volume original reservoir fluid
Density	Density of swollen mixture at saturation point

Table 4: Swelling experiment primary output

It is further indicated in the output whether the saturation point is a bubble point (P_b) or a dew point (P_d).

2.2.6 Lumping

Equation of state calculations is frequently burdened by the large number of components necessary to describe the hydrocarbon mixture for accurate phase behaviour modelling. In the compositional reservoir simulation, the cost and computing time can increase significantly as the number of components increases. Therefore, people usually lump certain components together to form one or more pseudo components. Some practical questions should be reasonably answered before the lumped results could be used to model the phase behaviour of reservoir fluids. Those questions include how the components should be lumped together, what kinds of components should be lumped, how many numbers of components can be lumped, and why those components should be lumped, etc.

Consider a given original system and a lumped system originated from the original system. What people are interested in is how close the fluid properties predicted from the lumped system are to those from the original system. Since there may exist single gas phase, single liquid phase, and/or gas/oil two phase region in normal reservoir development processes, the best lumping scheme determined should be applied to both single phase and two phase regions. If three or more phases coexist in an application, the method developed should be also applied

The procedure to select the best-lumped system is summarized as follows:

1. For a given original fluid system, calculate the bubble point and dew point pressures at the reservoir temperature, or any temperature of interest. Select N pressure points between bubble point and dew point pressures. Select separator conditions if necessary. The bubble point pressure, dew point pressure, N pressure points, reservoir temperature, and separator conditions, if necessary, are named as the reference conditions. If three or more phases coexist in an application, similar reference conditions should also be considered.
2. Calculate the original fluid mixture properties of interest at the reference conditions. Those properties, as well as the bubble point and dew point pressures, are referred to as the base values.

3. For a given lumped system, calculate the component properties of pseudocomponents based on the mixing rule developed above. Calculate the mixture properties of all lumped systems at the same reference conditions. It is not necessary to consider any reference conditions in the common single phase region because the original system and all lumped systems will predict the same mixture properties.
4. Compare the mixture properties of each lumped system from step 3 to the base values from step 2 to generate the lumping error functions. The lumped system with the least error is the best lumped system. In the case of three or more phases, the related phase properties should be also included in the lumping error function.

2.3 Weight factors

Before using any EOS for phase behaviour calculations, it is necessary to calibrate the EOS against the experimental data by adjusting the input values of some uncertain parameters in the EOS so as to minimize the difference between the predicted and measured values. This adjustment which usually takes place via a regression routine is known as EOS tuning. The effectiveness of each experimental property is introduced into the EOS model through its weight factor. Weight factors are assigned to each property based on its accuracy and reliability of measurement. The weakness of EOS towards calculation of some specific properties, the reliability of data and the target for the fluid properties study affects the values of different weight factors. This triggered the need for a fixed set of weight factors to overcome the weakness. As a result, Coats recommended a universal set of weight factors for proper tuning of EOS.

However, if the input parameters of EOS were adjusted widely by assigning weight factors other than those suggested by Coats to match the experimental data, it would lead to unrealistic results. This is known as over tuning of EOS. Pederson et al. discussed the dangers of over tuning of EOS and provided many examples of reliable predictions without any tuning, but only by a proper analysis and characterization of real reservoir fluids. Danesh suggested that, in general, any leading EOS, which predicts the phase behaviour data reasonably well without tuning, would be the most appropriate choice for phase behaviour calculations.

The higher the weight factor, more accurate is the measurement of that data and by that more importance must be given to match that property.

2.4 Tuning Parameters

Cubic equations of state (EoS) have found widespread acceptance as tools which permit the convenient and flexible calculation of the phase behaviour of reservoir fluids. They facilitate calculations of the complex behaviour associated with rich condensates, volatile oils and gas injection processes. Despite their flexibility (or perhaps because of their flexibility) the parameters of a cubic equation of state often need adjusting prior to application to a particular oil field fluid. A priori phase property predictions are difficult because:

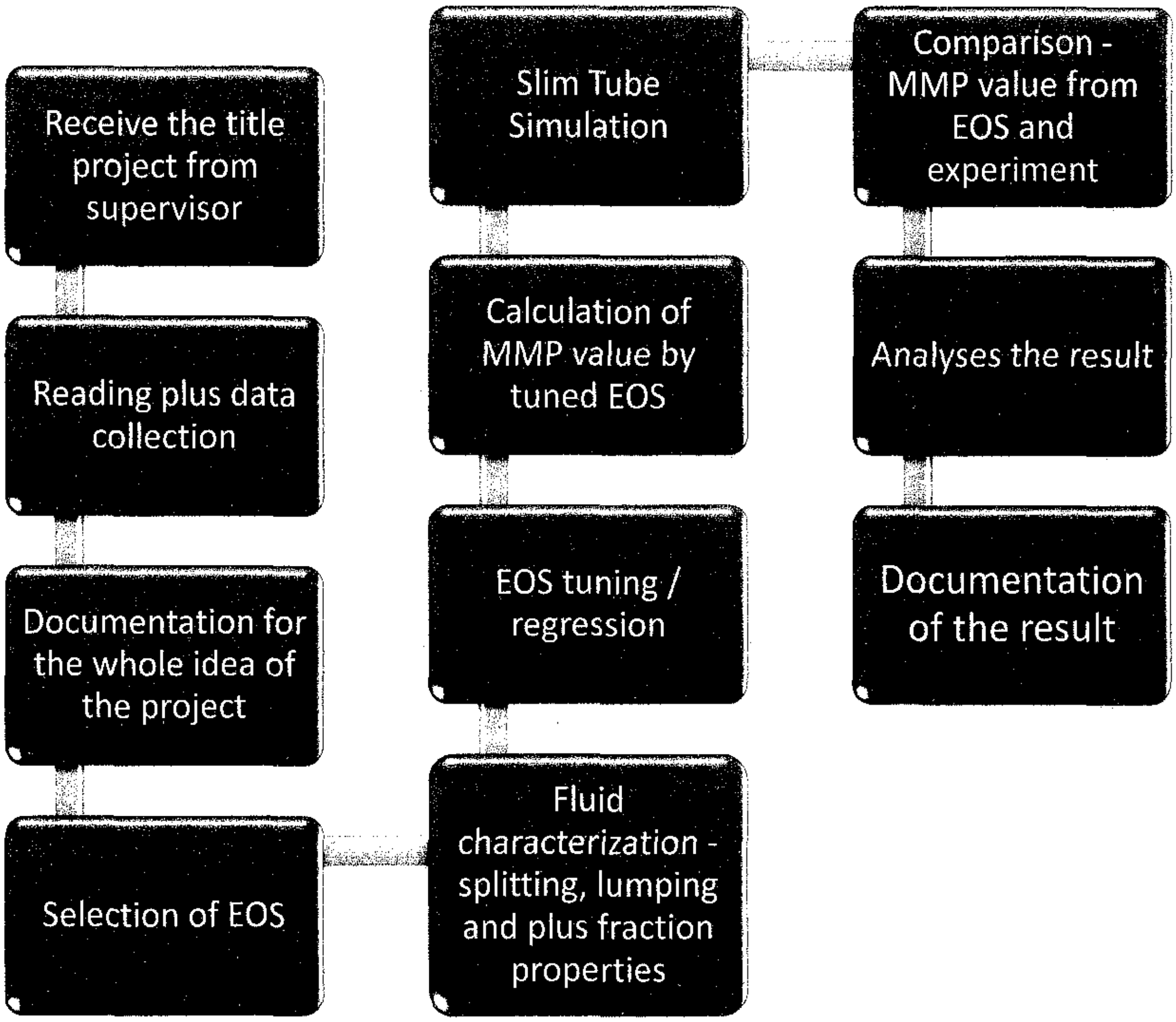
1) The "character" in terms of paraffinic, napthenic and aromatic molecules of the oil is not generally known. It is difficult to assign an appropriate boiling temperature, specific gravity, and molecular weight to components of the "plus" part of the oil.

2) The "flaws" of the simple cubic equation of state also come into play in certain circumstances.
3) Adjusting the parameters to overcome these limitations is called "tuning" or "characterizing" an equation of state

The parameters tuned are:

i) The critical temperature, Tc
ii) The critical pressure, Pc
iii) The acentric factor, ω

CHAPTER III: METHODOLOGY



3.1 Project activities

The whole project is expected to complete in two semesters, so roughly it will be divided by two main operations. In the first semester, the project starts with reading on any paper that seems related to the assigned topic. This is important so that the work afterward will become smoothly. One good examples of journal or paper that seems to relate to the topic is a paper from SPE which titled A Practical Equation of State written by Tarek Ahmed(6). The paper explain on the Peng and Robinson equation of state (PREOS) by briefly describe the reason of its inadequacy to accurately predict the value of MMP and also the modification that need to be done to enhance its prediction ability. Besides reading, supervisor also plays major role during the understanding build up. It is better than lone reading since it short up some time and makes everything clearer. During the reading, the project also proceeds with some data collection. This data will be used in the next semester for the tuning of EOS. Base on the understanding, report is done following the criteria that have been aligned for the student.

While in the second semester, the project will proceed with the selection of any suitable EOS that will be used along the project. It will be whether SRKEOS or PREOS due to their excellent performance in determining the MMP value. After that the project will proceed with fluid characterization. This stage is divided by three work which are splitting, lumping and calculation on the plus fraction properties. The plus fraction needs to be specially treated due to the inability to define the parameters that need to be tuned in order to match the data from experiment. After that, the work proceeds with some correlation and continued by EOS tuning. The purpose of the tuning is to match the PVT data from experiment. By using the tuned EOS, the simulation to calculate the MMP value is done by using few proposed software such as ECLIPSE 300 or PVTSim. With the result that obtained from the simulation, the MMP value between EOS and experiment will be compared in order to see if there is any difference. From here, we will see whether the tuning parameters in the EOS will affect the prediction done on the MMP value. The result of the comparison will be analyzed and documented on a proper documentation.

3.2 Gantt chart

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Software familiarization	🟦	🟦												
2	Data entering		🟦	🟦											
3	Splitting and lumping				🟦										
4	Data regression					🟦	🟦	🟦	🟦						
6	MMP calculation – EOS and slim tube									🟦					
7	Result and data analysis										🟦	🟦			
8	Poster submission												🟨		
9	Technical Report submission													🟨	
10	Draft Final Report Submission													🟨	
11	Submission of Final Report														🟨
12	Oral Presentation														🟨

3.3 Tools

Hardware

- Computer with internet access and compatible with the software mention below (using windows 7 as operating system)

Software

- Microsoft Office 2007
- PVTSim

CHAPTER IV: RESULT AND DISCUSSION

In getting the MMP value through neither EOS calculation nor slim tube simulation, there are few data from the PVT experiments that been calculated by EOS that need to be processed or tuned in order to get the result as close as experimental approach. This tuning that takes place is done in lumping and regression stage.

As what have been explained before, lumping is the process where certain components are lumped together to form one or more pseudo components. This is done in order to avoid the problem that may rise from the large numbers of components to describe the hydrocarbon mixture. The problem is in compositional reservoir simulation, the cost and computing time can increase significantly as the number of components increases.

While for regression, this is where the C7+ components is tuned through the tuning of their critical temperature Tc, critical pressure Pc, acentric factor Ac, EOS parameters Ω_a and $\Omega_{b.}$ These components are tuned so that the PVT data for the EOS calculation may match the experimental approach. The test lab data that need to be matched are from separator test (SEP), constant mass expansion (CME), differential depletion (DD) and swelling test (SWT).

Along the project, there are 5 samples of reservoir fluid that have been used for the MMP's prediction. They are labelled as reservoir 3, 5, 9, 10 and 12. The following data are the results of the tuning that have been done to the test lab data along with the comparison with the experimental value and the EOS calculated value or stated in the table as the value before tuning.

4.1 Saturation Points

Reservoir	Temp °C	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	114.2	255.6	245.754	-3.85211	246.8914	-3.40711
5	121.1	145.8	185.2709	27.07192	149.7099	2.681653
9	121.1	272.6	316.6402	16.1556	258.3951	-5.21091
10	121.1	245.7	326.1065	32.72548	208.8134	-15.0129
12	103.3	270	338.7763	25.47268	282.545	4.646269

Table 5: Saturation point tuning result

The first component that has been tuned is the general saturation point for each of five reservoirs. From the table before we can see the experimental value which act as the base or reference point. The tuning will be better if the tuned parameter value move closer to the experimental value compare to the EOS calculated value or before tuning value. However, the situation will be getting better if the tuned value gets exactly the same as the experimental value. This concept is applied to the entire components which are under compositional mass expansion, differential depletion and swelling test.

4.2 Separator Test

Reservoir	Temp °C	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	89	34	230.5325	578.0368	230.8395	578.9397
9	42.20001	30.6	248.6685	712.6422	190.13	521.3399
10	80	35.8	298.8055	734.6521	189.9895	430.6971

Table 6: Separator test tuning result

In the separator test table, there are only data for reservoir 3, 9 and 10. The absence of the other two which from reservoir 5 and 12 is due to the experiment that been conducted on the both of reservoir does not included the separator test. In the separator test, the value of EOS calculation is so big compare to the experimental value. To tune the value so that it becomes similar with the experimental value, a right regression process needs to be done. However, in this case the regression process was mostly done by try and error process and the result that been looking for is as long as most of the overall PVT data becomes closer to the experimental value, it will be taken as the best regression process. So, for this, separator test after tuned value need to be ignored although the deviation percentage is still so large where it goes beyond 100%.

4.3 Constant Mass Expansion (CME)

Under constant mass expansion, differential depletion and swelling test experiment, there are graphs that are attached base on the data on each component. From the graph, it may even become clearer to see the effect of the tuning. As we can see in each graph after this, in each reservoir there are actually lots of data that transferred into the graph as points but in the table there is only one value that been shown and that selected value is the value at saturation point of each reservoir. As for the graphs, they are taken from reservoir no 3.

For constant mass expansion experiment, the data that been used for the EOS to make its calculation are pressure, relative volume, compressibility, Y-factor and density. However, through PVTSim, it is enough by getting data from only pressure, relative volume and density. The other two types of data can be calculated by the software from the other three data that have been provided.

Saturation

Pressure

Bara

Reservoir	Temp °C	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	114.2	255.6	245.754	-3.85211	246.8914	-3.40711
5	121.1	145.8	185.2709	27.07192	149.7099	2.681653
9	144.7	276.6	327.071	18.24693	270.7402	-2.11851
10	121.1	245.7	326.1065	32.72548	208.8134	-15.0129
12	103.3	270	338.7763	25.47268	282.545	4.646269

Table 7: Saturation pressure tuning result (CME)

Rel Vol

V/Vb

Reservoir	Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	255.6	1	0.996185	-0.38153	0.996801	-0.31987
5	145.8	1	1.091118	9.111826	1.011287	1.128659
9	276.6	1	1.075682	7.568183	0.995976	-0.40239
10	245.7	1	1.116574	11.6574	0.971748	-2.82516
12	270	1	1.072126	7.212551	1.016331	1.633116

Table 8: Relative volume tuning result (CME)

From the simulation that been done in PVTSim, there are few graphs that generated and this is one of the graph. Here we can see the measured in lab (dot) and simulated (drawn line) relative volumes for constant mass expansion experiment. The red line is for the situation before tuning while the green line is for after tuning. We can see that the green line get closer to the point.

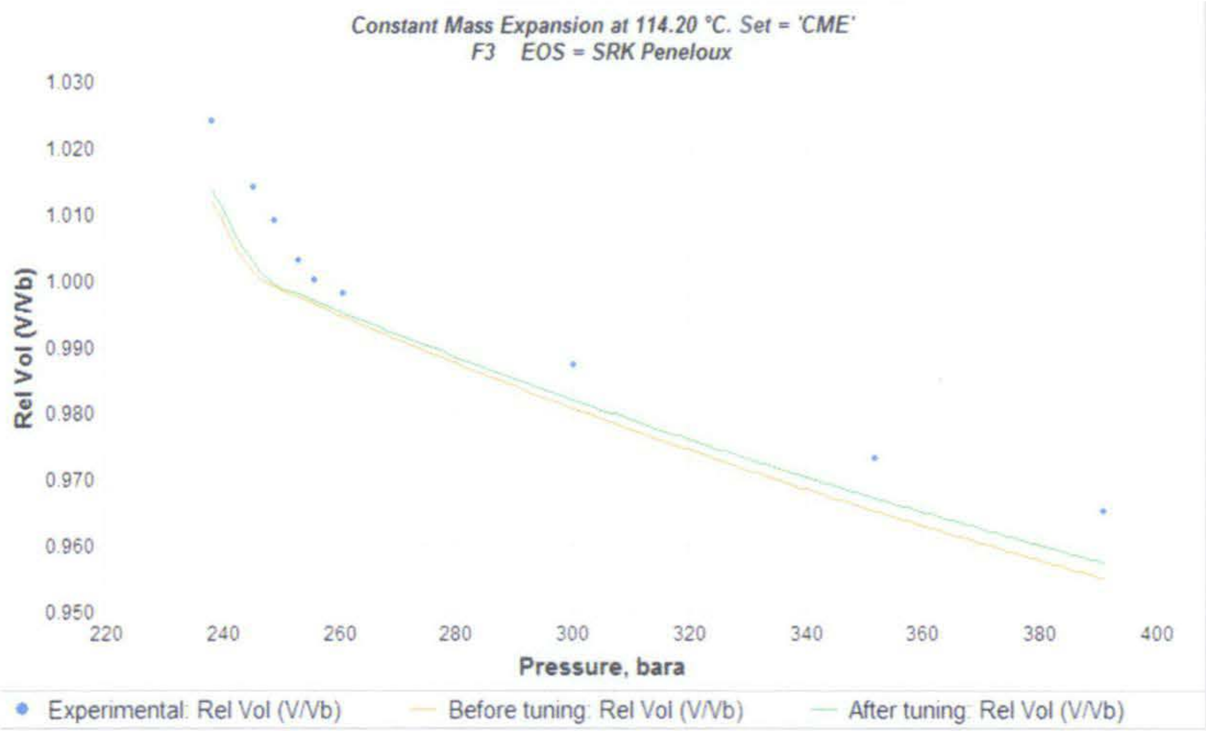


Figure 1: Relative volume vs. Pressure (CME)

Density

g/cm³

Reservoir	Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	255.6	0.617665	0.623411	0.930353	0.615347	-0.37532
5	145.8	0.721501	0.733497	1.662618	0.720334	-0.16174
9	276.6	0.576369	0.554932	-3.71938	0.558408	-3.11621
10	245.7	0.596659	0.594127	-0.42444	0.583524	-2.20139
12	270	0.643915	0.626677	-2.6771	0.618121	-4.00574

Table 9: Density tuning result (CME)

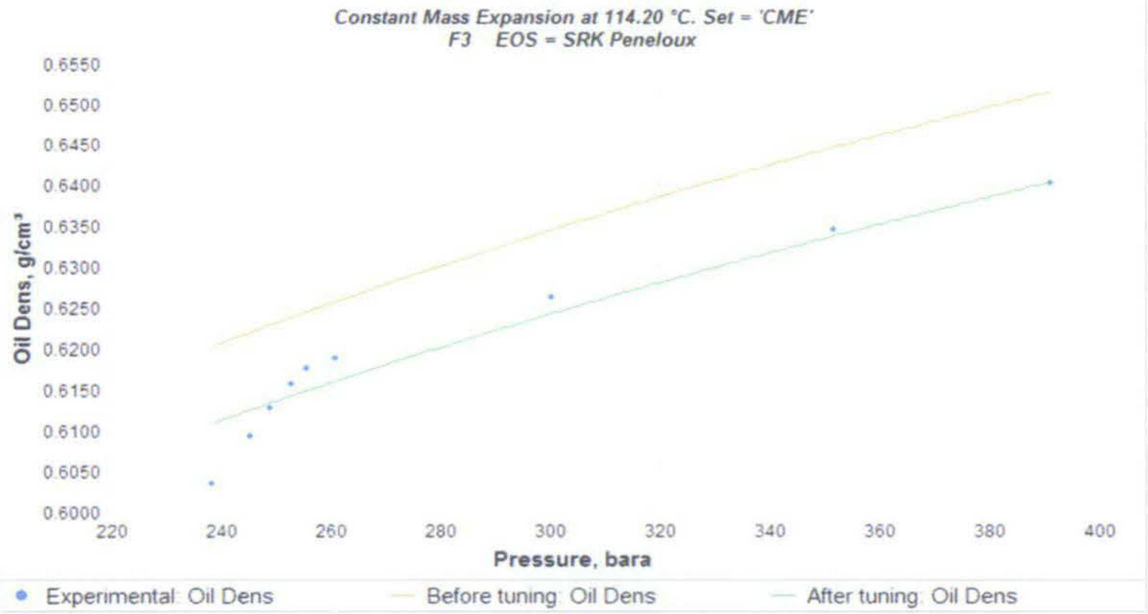


Figure 2: Oil density vs Pressure (CME)

4.4 Differential Depletion

As for EOS to simulate the differential depletion experiment, the data that are needed from the experiment are the pressure, oil formation volume factor, solution gas oil ratio, gas formation volume factor, oil density, Z-factor, gravity, oil viscosity and gas viscosity. However the only needed by PVTSim are the pressure, solution gas oil ratio, oil density and Z-factor. This situation is same as with constant mass expansion where the other missing data are calculated by the PVTSim.

Saturation

Pressure

Bara

Reservoir	**Temp °C**	**Exp value**	**Before tuning**	**%Dev before**	**After tuning**	**%Dev after**
3	114.3	255.6	245.8073	-3.83125	246.9473	-3.38528
5	121.1	145.8	185.2709	27.07192	149.7099	2.681653
9	121.1	272.7	316.6402	16.113	258.3951	-5.24568
12	103.3	270	338.7763	25.47268	282.545	4.646269

Table 10: Saturation pressure tuning result (DD)

Rsd

Sm^3/Sm^3

Reservoir	Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	255.6	229.7	246.4283	7.282681	211.7554	-7.81219
5	145.8	132.9	99.41723	-25.194	118.7203	-10.6695
9	276	1.842251	279.4341	15068.08	366.2794	19782.17
12	270	244.6	220.9667	-9.66201	280.2065	14.55704

Table 11: Solution gas oil ratio tuning result (DD)

For solution gas oil ratio, we can see in the table where the deviation percentage getting larger than before tuning value and the worst was reservoir number 9 where the percentage of deviation comes up till 19782.17% way over the experimental value. This case is same as the separator test where among the PVT data that has been regressed, it resulting with the opposite of expectation. Although that the value getting larger after it has been tuned, this component also is ignored same as the separator test and what value that comes out is taken since this is the best result after regression has been done.

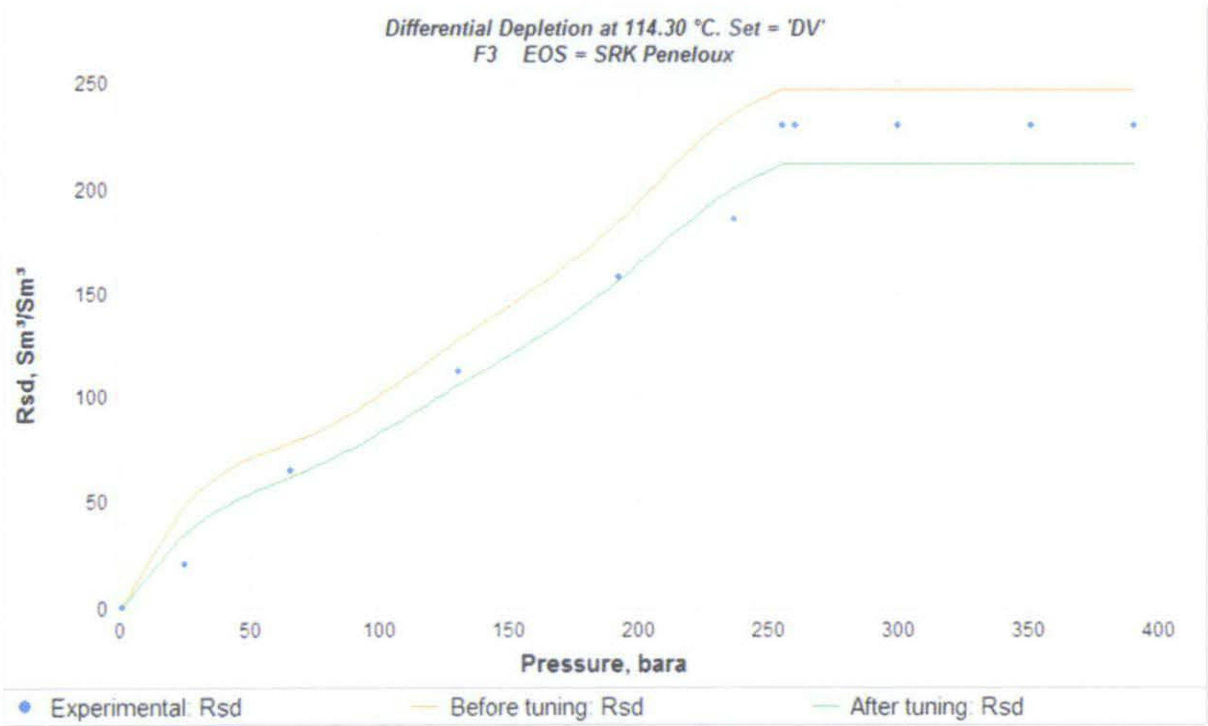


Figure 3: Solution gas-oil ratio vs. Pressure (DD)

Oil Dens

g/cm³

Reservoir	Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	255.6	0.6178	0.623319	0.893333	0.615262	-0.41088
5	145.8	0.7215	0.757867	5.040535	0.7235	0.277175
9	276	0.5963	0.616405	3.371549	0.583434	-2.15758
12	270	0.6441	0.676893	5.091362	0.629286	-2.29997

Table 12: Oil density tuning result (DD)

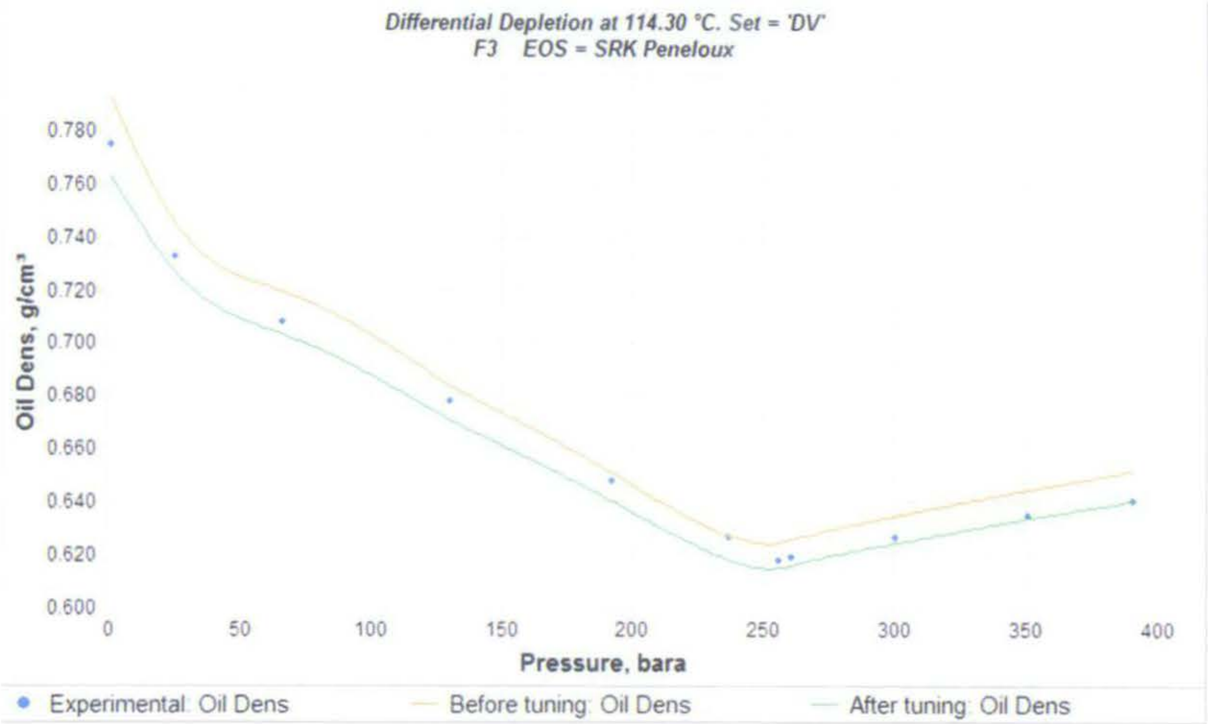


Figure 4: Oil Density vs. Pressure (DD)

Z Factor

Gas

Reservoir	Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	1	1	0.985346	-1.46539	0.990031	-0.99692
5	1	1	0.988481	-1.15185	0.989068	-1.09317
9	1	1	0.993558	-0.64419	0.993914	-0.60861
12	1	0.998	0.990935	-0.70791	0.991262	-0.67512

Table 13: Z-factor tuning result (DD)

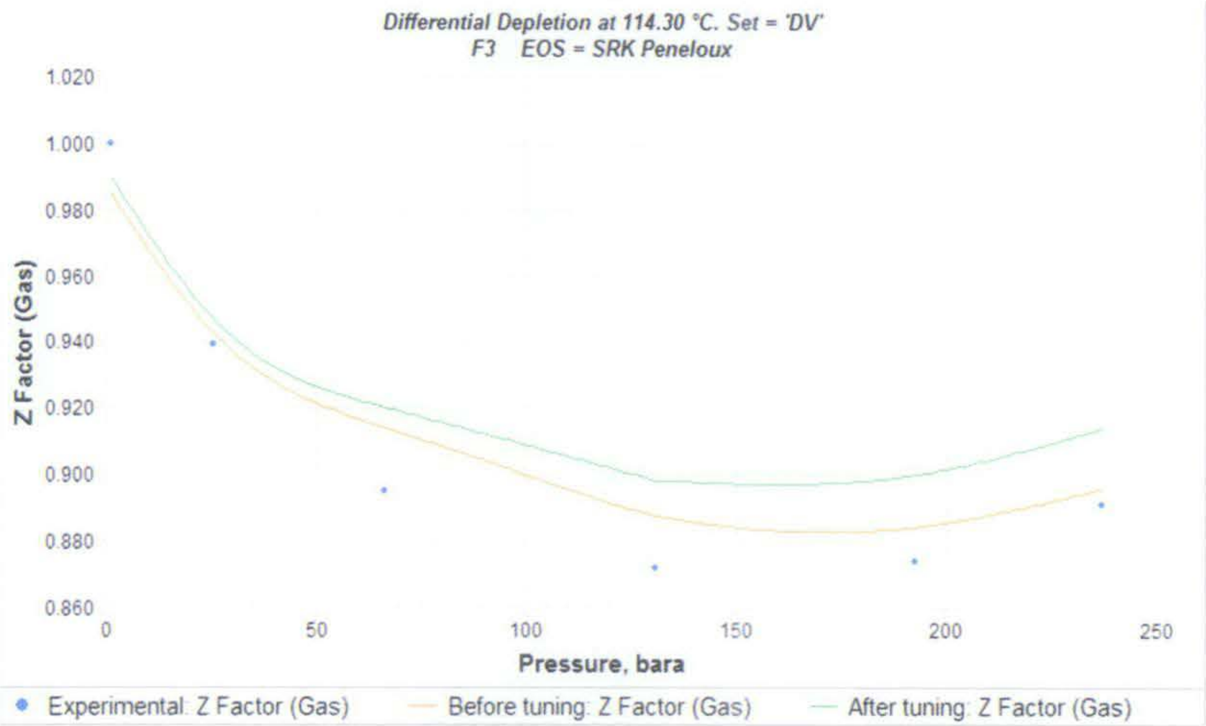


Figure 5: Z-factor vs. Pressure (DD)

4.5 Swelling Test

For the swelling test, the data that needed for EOS to simulate the experiment are percentage of mol gas over initial mol oil, gas-oil-ratio, saturation pressure, swollen volume and density. Same as before, the data that are only few of them where in this experiment, they are only percentage of mol gas over initial mol oil, saturation pressure, swollen volume and density.

Sat P

Bara

Reservoir	Mol% gas/ initial mol oil	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	0	255.6	245.8073	-3.83125	246.9473	-3.38528
5	0	145.8	185.2709	27.07192	149.7099	2.681653
12	0	270	338.7763	25.47268	282.545	4.646269

Table 14: Saturation pressure tuning result (swelling test)

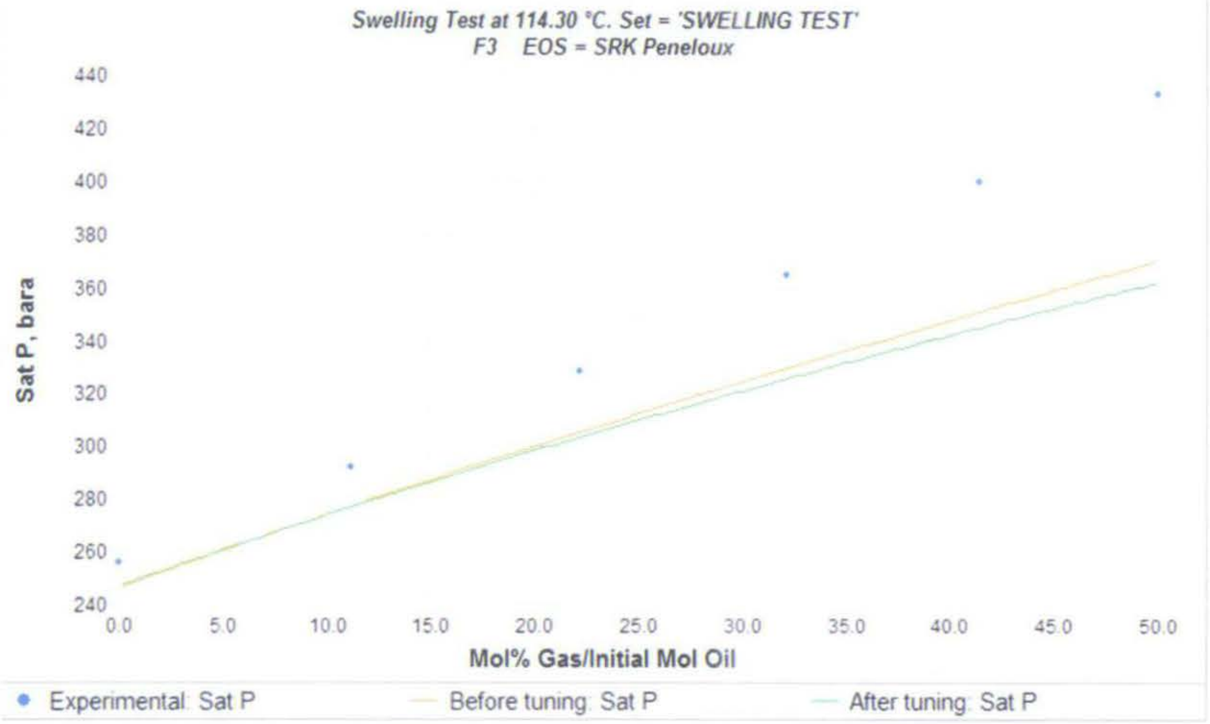


Figure 6: Sat. Pressure vs. Initial Mol Oil (Swelling Test)

Swollen Volume

Reservoir	Mol% gas/ initial mol oil	Exp value	Before tuning	%Dev before	After tuning	%Dev after
3	0	1	1	0	1	0
5	0	1	1	0	1	0
12	0	1	1	0	1	0

Table 15: Swollen volume tuning result (swelling test)

For the swollen volume data, as per table, no changes that happen to the data although after it been calculated by EOS or tuned after that. But the similarity only last with the first data and keep on changes when the swollen volume rise as what we can see in the graph.

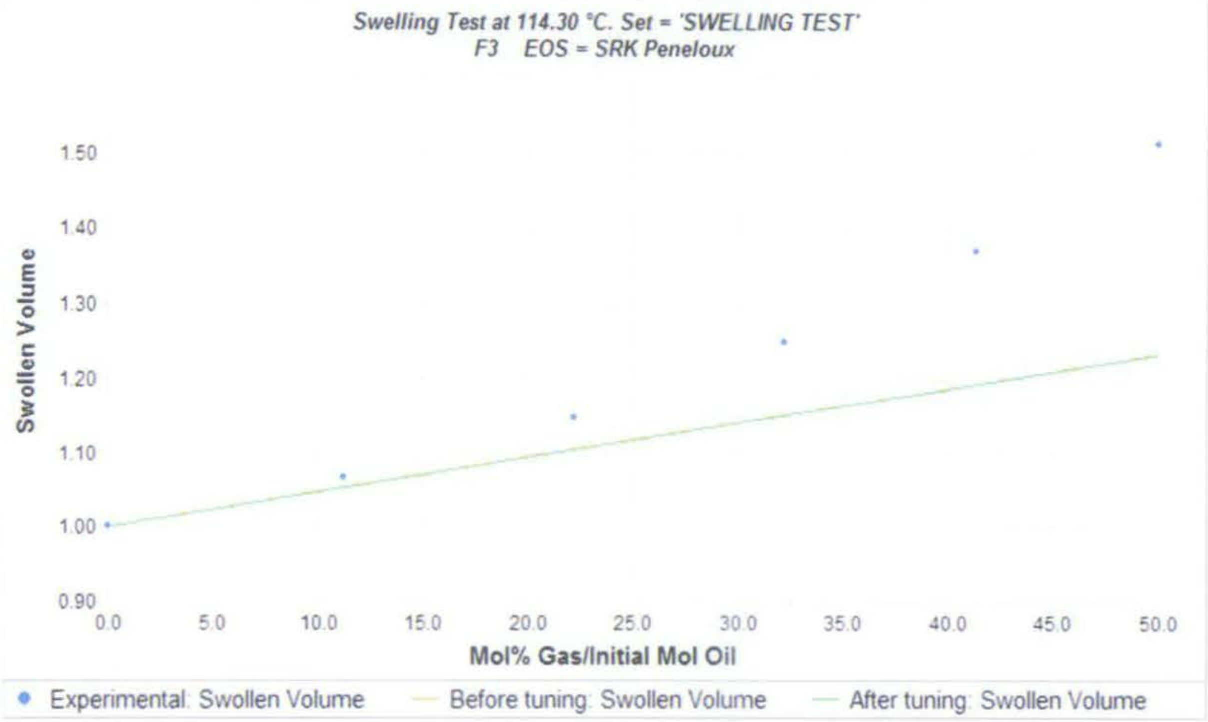


Figure 7: Swollen Volume vs. Initial Mol Oil (Swelling Test)

4.6 EOS calculated MMP value

Below are the sample of the result that generated by PVTSim on the result of MMP value that been predicted through EOS. As per example, from the table of reservoir number 3, by using the Soave- Redlich-Kwong (SRK) EOS, the MMP value is calculated and the value is generated and shown as multi contact misc pressure and in this case, it is 349.6001 bar. This is the pressure predicted by EOS where the miscibility might happen in the targeted reservoir and the crude oil start to move.

F3 EOS = SRK Peneloux			
Injection gas: G3 Gas			
	Combined condensing and vaporizing drive MMP calculation at		
Saturation pressure		255.2114	bara
Critical pressure		472.5433	bara
First contact misc pressure		817.1743	bara
Multi contact misc pressure		349.6001	bara
Drive type		97.8114	% Vaporizing

Table 16: MMP value from tuned EOS

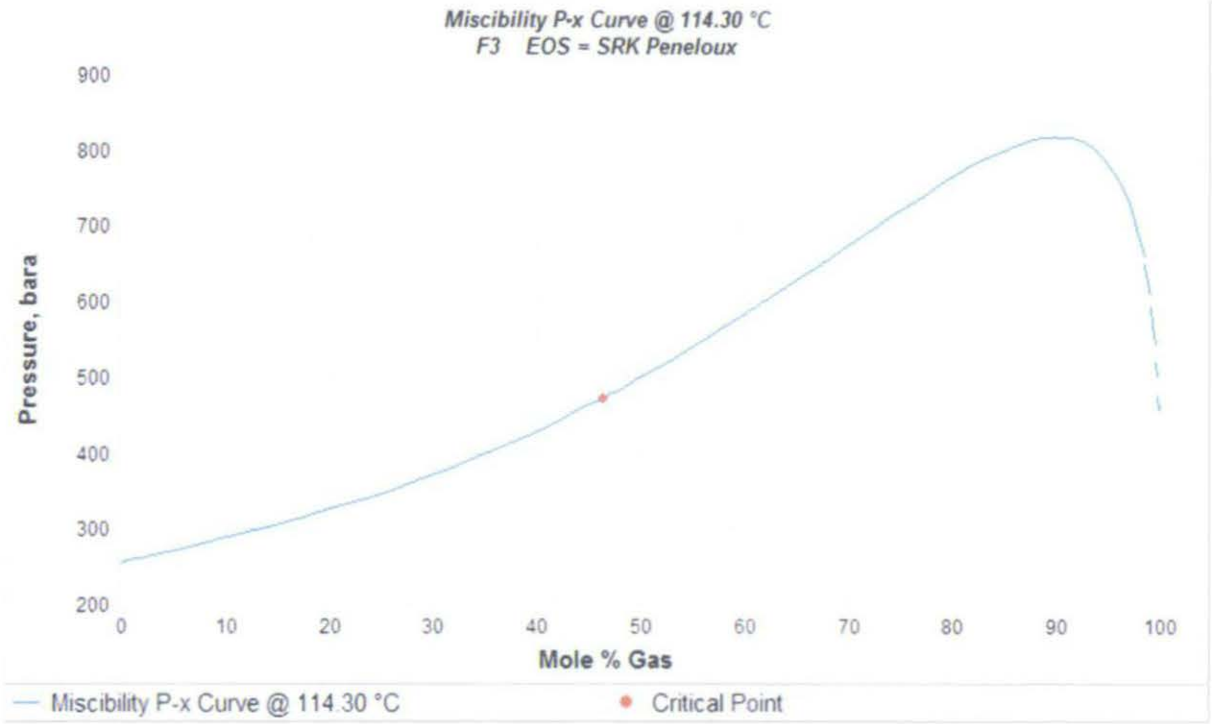


Figure 8: Pressure vs. Mole% gas (EOS calculated MMP value)

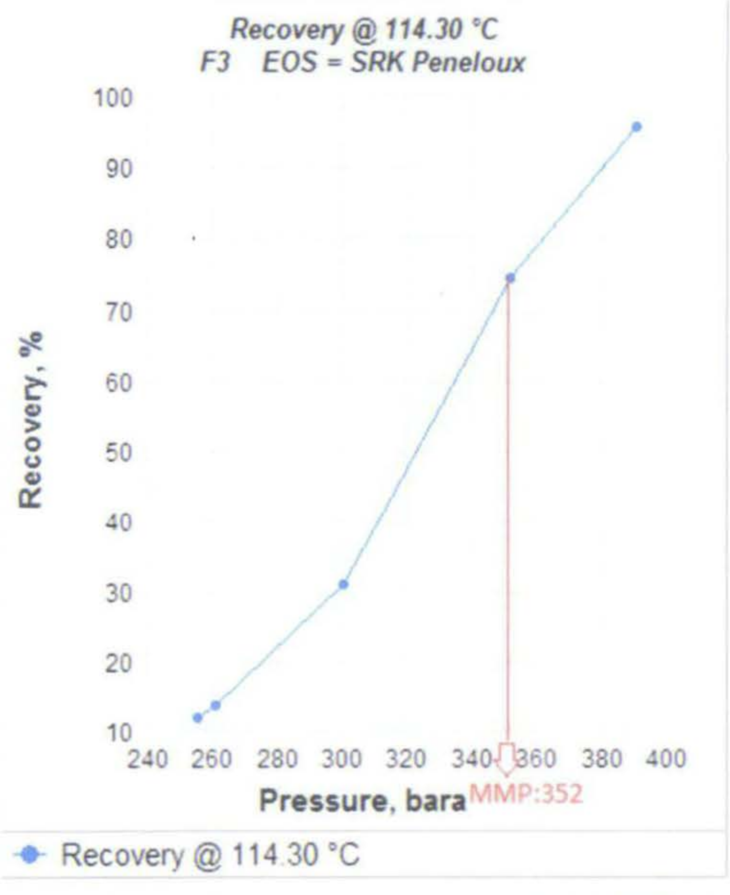


Figure 9: Recovery% vs. pressure (experimental MMP value)

From the above graph which is the simulated slim tube experiment, the MMP value from experimental approach is being generated. From the graph, we are looking at the changes of the line in the graph. The point where there are sudden changes of the slope which is sudden decreasing is the point where MMP is located. So for reservoir number 3, the MMP value that was generated from simulation of slim tube experiment is about 352 bar.

The comparison of MMP calculation by EOS and by slim tube simulation:

Reservoir	MMP calculation by EOS	Slim Tube Simulation
3	349.6000671 bara	352 bara
5	387.2192383 bara	420 bara
9	227.4581451 bara	326 bara
10	203.1754456 bara	276 bara
12	315.33078 bara	335 bara

Table 16: Comparison of MMP value from EOS and slim tube

From the table of comparison, it can be said that not every calculation by EOS is almost the same with the slim tube simulation. However, there are still some reservoirs that are showing good result such as reservoir no 3 and no 12. The deviation from experimental value is smaller where for reservoir no. 3, it is only around 2.4 bar while for reservoir no. 12, it is around 20 bar. This shows that EOS calculation might be almost good as experimental approach in predicting the MMP value.

CHAPTER V: CONCLUSION AND RECOMMENDATION

From the whole project of seeing the effect of equation of state (EOS) and tuning parameters on miscibility pressure calculation, it can be concluded that the raw EOS calculation towards MMP value is not enough to predict the exact value as the experimental approach. However, through tuning which is lumping and regression process, the MMP value that was predicted through EOS calculation just getting better and might reach to "almost similar" with the value from experimental approach.

It is not said that the prediction through EOS calculation might be as good as experimental approach where the value can be exactly the same because through EOS calculation, the regression process might be a bit tricky where sometime the result might just be better after tuning but there are also some of the data that get worst after the tuning. Everything is depending on the regression process. Aside from the good estimation of MMP value such as in reservoir no. 3 and no. 12, there is also calculation that goes way far from the experimental value which is reservoir no. 9. It is almost 100 bar difference in pressure.

As a general conclusion and some recommendation, equation of state calculation can replace the slim tube experiment in predicting the minimum miscibility pressure in the place where it is impossible to get the equipment for slim tube experiment. However, it is still a compulsory to do the slim tube simulation for the check and balance to the prediction that done by EOS. Since that the process that affect the MMP value the most in this project is the tuning process, further time need to be spent for regression or tuning process so that the result can be as similar as the slim tube experiment. Without good regression process, none of the MMP value would appear sufficiently accurate unless just for preliminary MMP calculation purpose.

CHAPTER VI: REFERENCES

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APPENDICES

RESULT DATA FOR RESERVOIR 3

F3 EOS = SRK Peneloux

Saturation Points

SP

Pressure Weight= 1

bara

Temp °C	Exp value	Before tuning	%Dev before	After tuning	%Dev after
114.2	255.6	245.754	-3.85211	246.8914	-3.40711

Separator Test at 89.00 °C

separator test

Saturation Pressure Weight= 50

bara

Temp °C	Exp value	Before tuning	%Dev before	After tuning
89	34	230.5325	578.0368	230.8395

Constant Mass Expansion at 114.20 °C

CME

Saturation Pressure Weight= 100

bara

Temp °C	Exp value	Before tuning	%Dev before	After tuning	%Dev after

114.2	255.6	245.754	-3.85211	246.8914	-3.40711

Rel Vol Weight= 1

V/Vb

Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
391	0.965	0.954787	-1.05834	0.957254	-0.80273
351.8	0.973	0.96504	-0.81807	0.967085	-0.60794
300.3	0.987	0.980475	-0.66109	0.981841	-0.52273
260.7	0.998	0.994263	-0.37445	0.994975	-0.30315
255.6	1	0.996185	-0.38153	0.996801	-0.31987
252.9	1.003	0.997217	-0.57658	0.997782	-0.52023
248.9	1.009	0.998765	-1.01432	0.999253	-0.96599
245.2	1.014	1.000816	-1.30017	1.002575	-1.12669
238.2	1.024	1.011616	-1.20936	1.013774	-0.99867

Density Weight= 50

g/cm³

Pressure bara	Exp value	Before tuning	%Dev before	After tuning	%Dev after
391	0.640205	0.650441	1.598911	0.640769	0.088095
351.8	0.634518	0.643531	1.420392	0.634255	-0.04143
300.3	0.626174	0.6334	1.154002	0.624723	-0.23171
260.7	0.618812	0.624616	0.937976	0.616477	-0.37742
255.6	0.617665	0.623411	0.930353	0.615347	-0.37532
252.9	0.615764	0.622766	1.137149	0.614742	-0.166
248.9	0.612745	0.621801	1.477876	0.613837	0.178204
245.2	0.609385	0.620897	1.889115	0.61299	0.591622
238.2	0.6035	0.619159	2.59474	0.611363	1.302842

Differential Depletion at 114.30 °C

DV

Saturation Pressure Weight= 100

bara

Temp	Exp	Before	%Dev	After	%Dev

°C		value	tuning	before	tuning	after
	114.3	255.6	245.8073	-3.83125	246.9473	-3.38528

Rsd Weight= 50

Sm^3/Sm^3

Pressure		Exp	Before	%Dev	After	%Dev
bara		value	tuning	before	tuning	after
	391	229.7	246.4283	7.282681	211.7554	-7.81219
	351	229.7	246.4283	7.282681	211.7554	-7.81219
	300.3	229.7	246.4283	7.282681	211.7554	-7.81219
	260.7	229.7	246.4283	7.282681	211.7554	-7.81219
	255.6	229.7	246.4283	7.282681	211.7554	-7.81219
	237.2	185.5	235.1873	26.78559	200.7638	8.228476
	192.6	157.2	184.5509	17.39877	156.3743	-0.52525
	130.9	112.3	127.5666	13.59448	105.9299	-5.67244
	66.3	64.2	77.67125	20.98326	61.51353	-4.18452
	25.6	20.3	47.72612	135.104	34.79408	71.39938
	1	0	0		0	

Oil Dens Weight= 100

g/cm^3

Pressure		Exp	Before	%Dev	After	%Dev
bara		value	tuning	before	tuning	after
	391	0.6403	0.650367	1.572162	0.6407	0.062435
	351	0.6347	0.643304	1.355578	0.634043	-0.10354
	300.3	0.6262	0.633314	1.136132	0.624644	-0.24848
	260.7	0.6188	0.624525	0.925139	0.616392	-0.38912
	255.6	0.6178	0.623319	0.893333	0.615262	-0.41088
	237.2	0.6263	0.625598	-0.11201	0.618237	-1.28741
	192.6	0.6479	0.649223	0.204212	0.640419	-1.15472
	130.9	0.6778	0.682015	0.621861	0.670849	-1.02558
	66.3	0.7076	0.717854	1.449126	0.703719	-0.54849
	25.6	0.7326	0.743523	1.490973	0.727051	-0.75738
	1	0.7741	0.790942	2.175679	0.762872	-1.45047

Z Factor Weight= 50

Gas

Pressure		Exp	Before	%Dev	After	%Dev

bara	value	tuning	before	tuning	after
237.2	0.891	0.896196	0.583115	0.915357	2.733723
192.6	0.874	0.88437	1.186545	0.900704	3.05539
130.9	0.872	0.887623	1.791591	0.89851	3.040136
66.3	0.895	0.914188	2.143909	0.920189	2.814383
25.6	0.939	0.942635	0.387137	0.946943	0.845934
1	1	0.985346	-1.46539	0.990031	-0.99692

Swelling Test at 114.30 °C
SWELLING TEST

Injection gas:
G3 Gas EOS = SRK Peneloux

Sat P Weight= 1
bara

Mol% gas/ initial mol oil	Exp value	Before tuning	%Dev before	After tuning	%Dev after
0	255.6	245.8073	-3.83125	246.9473	-3.38528
11.2	291.9	276.6797	-5.21421	276.5036	-5.27452
22.2	328.2	304.6185	-7.18509	302.5753	-7.80766
32.2	364.8	328.4703	-9.95879	324.226	-11.1222
41.4	400	349.442	-12.6395	342.7536	-14.3116
50	433.1	368.4026	-14.9382	359.1055	-17.0848

Swollen volume Weight= 100

Mol% gas/ initial mol oil	Exp value	Before tuning	%Dev before	After tuning	%Dev after
0	1	1	0	1	0
11.2	1.067	1.053425	-1.27226	1.053085	-1.30408
22.2	1.149	1.105262	-3.80658	1.104969	-3.83208
32.2	1.25	1.151775	-7.85799	1.151893	-7.84859
41.4	1.37	1.193993	-12.8472	1.194821	-12.7868
50	1.513	1.232925	-18.5112	1.2347	-18.3939

Density Weight= 100

g/cm³

Mol% gas/ initial mol oil	Exp value	Before tuning	%Dev before	After tuning	%Dev after
0	0.6177	0.620952	0.52645	0.613305	-0.71155
11.2	0.5982	0.60588	1.283936	0.598612	0.068867
22.2	0.575	0.592835	3.101816	0.58569	1.8591
32.2	0.5517	0.582304	5.547214	0.575074	4.236745
41.4	0.5289	0.573615	8.45429	0.566158	7.044456
50	0.5085	0.566275	11.36181	0.558497	9.832266

General Regression Results

Object function before tuning 40.31762

Object function after tuning 38.91613

Corr fac 1: Crit T (°C). Max adjustment: 18.00%.

	Before tuning	After tuning	%Adjustment of Crit T in K
C7	262.1836	343.2999	15.15247
C7-C11	295.1142	381.2203	15.15247

Corr fac 2: Crit T (°C). Max adjustment: 23.00%.

	Before tuning	After tuning	%Adjustment of Crit T in K
C12-C18	399.4469	413.6338	2.109271
C19-C32	529.3865	546.3142	2.109272

Corr fac 3: Crit P (bara). Max adjustment: 18.00%.

	Before tuning	After tuning	%Adjustment
C7	31.95423	31.24523	-2.21879
C7-C11	27.17351	26.57058	-2.21879

Corr fac 4: Crit P (bara). Max adjustment: 23.00%.

	Before tuning	After tuning	%Adjustment
C12-C18	17.936	19.04032	6.157031
C19-C32	13.8032	14.65307	6.157028

Corr fac 5: Acentric factor. Max adjustment: 18.00%.

	Before tuning	After tuning	%Adjustment
C7	0.467898	0.393301	-15.9429
C7-C11	0.527137	0.443096	-15.9429

Corr fac 6: Acentric factor. Max adjustment: 23.00%.

	Before tuning	After tuning	%Adjustment
C12-C18	0.748476	0.576327	-23
C19-C32	1.062546	0.81816	-23

Sensitivity matrix:

Corr fac	d(Obj)/d(Corr fac)
1	-33.6778
2	-15.2036
3	4.606586
4	7.195801
5	-3.15667
6	-1.30061

1st visc correction factor (CSP)

Before tuning	After tuning	%Adjustment
1	1	0

2nd visc correction factor (CSP)

Before tuning	After tuning	%Adjustment
1	1	0

3rd visc correction factor (CSP)

Before tuning	After tuning	%Adjustment

1	1	0

4th visc correction factor (CSP)

Before tuning	After tuning	%Adjustment
1	1	0

Vc correction factor (LBC)

Before tuning	After tuning	%Adjustment
1	1	0

a1 (LBC)

Before tuning	After tuning	%Adjustment
0.1023	0.1023	0

a2 (LBC)

Before tuning	After tuning	%Adjustment
0.023364	0.023364	0

a3 (LBC)

Before tuning	After tuning	%Adjustment
0.058533	0.058533	0

a4 (LBC)

Before tuning	After tuning	%Adjustment
-0.04076	-0.04076	0

a5 (LBC)

Before tuning	After tuning	%Adjustment
0.009332	0.009332	0