CHAPTER 1: INTRODUCTION

1.1 Background studies

Enhanced oil recovery (EOR) has become more popular as oil reservoirs become mature, and easy to produce oil resources dwindle. An established method of EOR is gas injection. In any gas injection design, one of the most important parameters is minimum miscibility pressure (MMP). MMP is the lowest pressure at which gas and oil become miscible at a fixed temperature. MMP is an important parameter that determines the efficiency of oil displacement by gas. The MMP is important because when gas and oil are miscible, the pore scale efficiency (or displacement efficiency) is 100% in the absence of dispersion. Hence, knowledge of MMP is essential in gas flooding designs.

Currently there are three methods to determine MMP which are experimental methods, correlation methods and equation of states methods. Experimental methods include slim tube tests, rising bubble apparatus and vanishing interfacial tension technique. Numerous correlations to estimate MMP based on regression of slim tube data were developed for screening purposes. Some of these correlations were used in predicting MMP's of pure and impure CO2 while others treat the MMP's of all type of gases. EOS methods can be further categorized into numerical approaches and analytical approaches. Numerical approaches involve the application of 1-D compositional simulation. Analytical technique use method of characteristics (MOC) approach to determine MMP. The EOS methods share a common criterion which requires accurate EOS characterization of fluid for MMP prediction.

1.2 Problems statement

The purpose of this work aims to understand the effect fluid characterization in MMP prediction for pure CO2 injection using Mixing Cell Method. This method requires accurate characterization of the reservoir fluid, different selection of EOS, different selection of PVT properties to match and the different selection of EOS variables to adjust may give different prediction of MMP. Furthermore, methods using the same PVT data may come up with very different predictions of MMP values.

1.3 Objectives

The objectives of this study are:

i) To determine MMP prediction by using different EOS which are the Peng Robinson Peneloux (Pederson,1976) and the Soave Redlich Kwong (Soave, 1972)

ii) To determine the effect of tuning parameters based on Critical Temperature, Critical Pressure and Acentric Factor in predicting MMP.

1.4 Scope of studies

This work will focus on researches and findings related to Mixing Cell Method for MMP prediction in order to understand the effect of fluid characterization by using different EOS and the effect of tuning parameters such via software approach by using experimented PVT data.

1.5 Relevancy of project

In terms of the relevancy of this project, it poses a great deal of significance to the oil and gas industry. 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 almost impossible to do the experiment regarding predicting MMP value in UTP due to the unavailability of equipment for the experiment and instead of experiment, the focus move on to EOS. With EOS there are still chances of predicting the value of MMP but the result may be slightly different when it is compared to experimental result. But before we engage more on EOS, it is better if we develop more understanding on the EOS itself. With that, this project is proposed where from this project, we may know whether there is effect on the MMP calculation when EOS with tuned parameters inside the EOS is used to calculate the MMP.

1.6 Feasibility of project

All the objectives stated earlier are achievable and feasible in terms of this project duration and time frame. The whole project is schedule to be completed in 2 semesters.

- 1st semester
  - Understanding theories and concepts
  - Familiarization of software
  - Documentation for the whole idea of the project

- 2nd semester
  - Input data to software
  - Fluid characterization and tuning of EOS parameters to match experimental data
  - Compare the result from EOS approach with the result form experiment approach
  - Analysis of result

CHAPTER 2: LITERATURE REVIEW

2.1 Mixing Cell Method

Mixing cell methods consist of three types which are: i) mixing cell (cell-to-cell) methods, ii) single cell methods and iii) multiple cells (cell-to-cell) methods (Rahmatabadi, 2011). In some cases, MMP can be calculated by mixing cells. The mixing cell method consists of one or a series of virtual PVT cells in which phase equilibrium calculations are performed. The basic idea in these single and multiple mixing cell methods is to mix (analytically) gas and oil in repeated contacts, resulting in new equilibrium compositions.

MMP calculation with a single mixing cell, as the name implies, uses a single virtual PVT cell and an equation-of-state to estimate MMP. These methods are based on the simplifying assumption that the oil or gas tie line controls miscibility (Hutchinson and Braun 1961).

A single PVT cell is then used to make repeated contacts between oil and gas in a forward or a backward manner to converge to the oil or the gas tie line. The criterion for MMP is the pressure at which the converged tie line becomes the critical tie line (i.e., reaches zero length).

Multiple mixing-cell methods are essentially simplified slim-tube simulations in which only phase equilibrium calculation is carried out and solving the flow equation is ignored. There are varieties of published multiple-cell mixing-cells methods (Cook et al. 1969; Jaubert et al. 1998ab; Metcalfe et al. 1973; Pederson et al. 1986; Zhao et al. 2006); however, all are more or less based on the study of Cook et al. Multiple-cell mixing cells consist of a series of PVT cells ranging from 5 to 500 cells that are connected and are initially filled with oil. Typically, gas is mixed in the first cell at a trial pressure and, assuming complete mixing within the cell, the equilibrium phases are calculated. Then the excess volume of the cell (mostly equilibrium gas) is carried to the next cell and mixed with the fluid in the cell. The process continues for a series of cells until some specified volume of gas is injected (typically 1.2 times the total volume). Early multiple mixing cells methods were used to study the development of miscibility rather than calculating the MMP.

Recently (Ahmadi and Johns, 2008) have developed an improved mixing cell method that can mitigate the effect of numerical dispersion yet simple and reasonably fast using variable number of cells and relies on robust P-T flash calculations with any EOS.

2.2 Fluid Characterization

Petroleum reservoir fluids consist of several hundred different components. The components can be divided into two groups which are the well-defined components and the undefined petroleum fractions which are the plus fractions. The fluid need to characterize accurately for the EOS model to be able to simulate and predict the physical properties of the reservoir fluids as it is hard to obtain the critical properties of plus fraction experimentally unlike the well-defined components.

2.2.1 Splitting

Reservoir fluid analysis from the true boiling point distillation will usually give the fluid composition up to C20+. According to Whitson (2000) insufficient description of the plus fractions will undermine the accuracy of the PVT predictions. Therefore, plus fractions in the fluid composition (C20+) are further split into single carbon number (SCN) groups. Some of the techniques for splitting plus fractions into sub fractions are constant mole fraction approach, Whitson approach and semi continuous thermodynamics or modified Whitson. All of these techniques rely on a probability density function to relate mole fraction to mole weight proposed by Whitson (1983).

2.2.2 Lumping

In order to reduce the computational time and storage requirement during simulation, the SCNs are then lumped or grouped together into several pseudo components. Some methods for lumping are based on ranges in molecular weights (Whitson, 1983), component mole fractions (Cotterman and Prausnitz, 1985), mass fractions (Pederson, Rasmussen & Fredenslund, 1985) and K-values (Newley & R.C., 1991). Molar averaging, weight averaging and mixing rule are also suggested by Joergensen and Stenby (1995).

2.2.3 Regression

Variables in the EOS model are tuned in order to achieve satisfactory match with the PVT data as the critical properties of the pseudo components are only estimated by empirical correlations and mixing rule used which may result in uncertainties and errors in the model. PVT data used for the tuning process includes separator test, constant composition expansion test, differential depletion test, constant volume depletion test, swelling test, multiple contact test and others.

There are no set rules for how to do regression of an equation of state model to match to laboratory measurements. Some regression procedures to tune the EOS model are Coats and Smart (1986), Jessen and Stenby (2007) and many more. Tuning to match the PVT is considered more art than science due to a lot of procedures for regression. Excessive tuning is cautioned where it can produce unrealistic results as the variables are tuned beyond the limit of physical behavior (Pederson, Thomassen & Fredenslund, 1988).

CHAPTER 3: METHODOLOGY

3.1 Research Methodology

There are four approaches involves in this researches methodology which are experimental database, fluid F13 characterization, tuning approach and MMP calculation. These approaches will be further discussed below.

3.11 Experimental Database

The availability of comprehensive fluid data especially experimental MMP data is limited. Therefore, Jaubert (2002) published a database of a 13 reservoir oils including their respective injection gases comprising of the full compositional data, standard PVT experiments, swelling tests, and MMP values from slim tube experiments. The data from fluid F13 is used in this research and the injection gas is consists of pure CO2. The reservoir fluid is medium oil with 35.2° API, saturation pressure of 171 bar, reservoir temperature of 377.55 K and MMP of 271 bar.

The compositional analysis is given up to C20+ from the fractional true boiling point (TBP) distillation. Furthermore, the specific gravity, molecular weight and the amount of each heavy components from C7 to C19 including the amounts of TBP residual (C20+) are also tabled.

3.12 Fluid F13 Characterization

There are five step involve in the EOS characterization: 1) Base case fluid models of 13 components are prepared for respective EOS's without tuning; 2) The base case is tuned via regression to match the PVT data; 3) Comparison cases consisting of tuned base cases using tuning variables (critical temperature, critical pressure and acentric factor); 4) Calculation of MMP's using analytical method for each cases; 5) Analysis of models by comparing with PVT data and experimental data.

3.13 Tuning Approach

The EOS model need to be tuned by regression procedure to improve on the accuracy due to the characterized fluid may not be sufficient to represent the experimental data accurately. In this study, the performance of PREOS and SRKEOS are evaluated at two stages; 1) Pure prediction based on default characterizations; 2) After regression of standard PVT measurements such as constant mass expansion experiments and differential depletion experiment.

The tuning parameters used in the regression procedures are; 1) critical temperature of the plus fractions in the characterized fluid description; 2) critical pressure of the plus fractions in the characterized fluid description; and, 3) acentric factor of the plus fractions in the characterized fluid description.

3.14 MMP Calculation

MMP calculation will be performed using the mixing cell simulation and slim tube simulation.

3.2 Project Activities

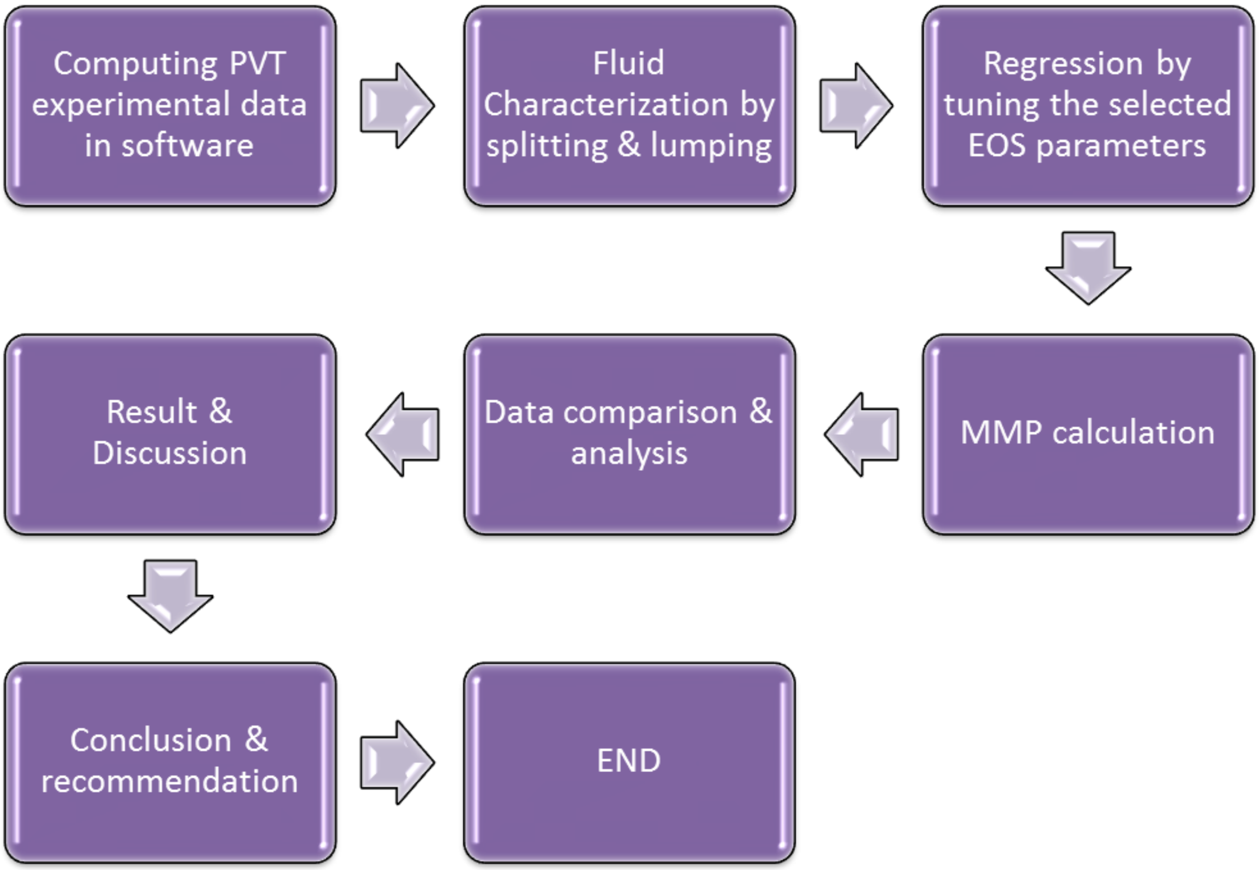

Figure 3.1: Project Activities

3.3 Key milestone

<u>Week 1 to Week 7</u>

- Familiarizing with Eclipse Compositional Simulator and Phazecomp software.
- Practice on the examples given in the software

<u>Week 8</u>

- Submission of Progress Report

<u>Week 9 to Week 10</u>

- Project work continues
- Conduct the simulation works via Eclipse Compositional Simulator and Phazecomp software with actual data
- Comparison of result from the two software
- Analysis of result
- Preparing for Pre-EDX

<u>Week 11</u>

- Pre EDX

<u>Week 12</u>

- EDX
- Delivery of final report to external examiner
- Preparing for Final Oral Presentation

<u>Week 13</u>

- Final Oral Presentation

<u>Week 16</u>

- Submission of hardbound copies

3.4 Gantt Chart

No.	Activities /Week	1	2	3	4	5	6	Mid Semester Break	7	8	9	10	11	12	13
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Proposal Extended Proposal Report Submission														
4	Detail Studies on MMP Prediction Methods														
5	Research Work on Mixing Cell Method														
6	Methodology Studies														
7	Proposal Defense (Oral Presentation)														
8	Studies and Familiarization on Software Required														
9	Data and Results Gathering														
10	Submission of Draft Interim Report														
11	Submission of Interim Report														
7	Proposal Defense (Oral Presentation)														
8	Studies and Familiarization on Software Required														
9	Data and Results Gathering														
10	Submission of Draft Interim Report														
11	Submission of Interim Report														

Figure 3.2: Gantt Chart for FYP 1

No.	Activities /Week	1	2	3	4	5	6		7	8	9	10	11	12	13	16
1	Project work continues							Mid Semester Break								
2	Familiarization of Eclipse Compositional Simulator & Phazecomp software															
3	Practice on examples given in the software															
4	Submission of Progress Report															
5	Conduct simulation with actual data															
6	Comparison of results from Eclipse Compositional Simulator & Phazecomp software															
7	Pre EDX															
8	EDX															
9	Delivery of final report to external examiner															
10	Final Oral Presentation															
11	Submission of hardbound copies															

Figure 3.3: Gantt Chart for FYP 2

3.5 Tools

Software which include:

- **PVTi** is used to characterized the fluid via splitting, lumping and regression
- **Phazecomp** developed by Zick Technologies for simulation and MMP calculation via mixing cell method
- **Eclipse E300** is used to calculate the MMP values via slim tube method.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 EOS Model

Two EOS models were used which are PR and SRK. The base case models without tuning were characterized using the two EOS. The splitting of the models were done using constant mole fractions approach where it splits the 20+ fractions into carbon number fractions from C20 to C45 into 2 pseudo components both with equal compositions. The critical properties and acentric properties correlation were estimated using Kesler-Lee method. The models were then lumped into 13 components by mole fractions approach.

4.2 Regression Strategy

Regression was performed to models in order to match the PVT data. There were 7 defined experiments used consist of 1 separator test, 2 constant mass expansion test (CCE), 1 differential liberation test and 2 multi contact test. However, only 1 experiment applied in the regression due to large errors contributed from other experiments.

The tuning variables used in the regression were critical pressure (Pc), critical temperature (Tc) and acentric factor (AF). All the components were included in the tuning process not only the heavier pseudo components as they contribute low errors. There are 4 regression strategy were implemented.

1) Tuning all the variables at once (Pc, Tc & AF)
2) Tuning the Pc alone
3) Tuning Tc alone
4) Tuning the AF

Table 1, 2 and 3 shows the regression strategy done.

Table 4.1: Tuning on Tc, Pc & AF

Components	Tuning Variables		
	Tc	Pc	AF
N2	1	1	1
CO2	1	1	1
C1	1	1	1
C2	1	1	1
C3	1	1	1
IC4	1	1	1
NC4	1	1	1
IC5	1	1	1
NC5	1	1	1
C6	1	1	1
C7-C19	1	1	1
C20-C32	1	1	1
C33-C45	1	1	1

Table 4.2: Tuning on Tc

Components	Tuning Variables		
	Tc	Pc	AF
N2	1		
CO2	1		
C1	1		
C2	1		
C3	1		
IC4	1		
NC4	1		
IC5	1		
NC5	1		
C6	1		
C7-C19	1		
C20-C32	1		
C33-C45	1		

Table 4.3: Tuning on Pc

Components	Tuning Variables		
	Tc	Pc	AF
N2		1	
CO2		1	
C1		1	
C2		1	
C3		1	
IC4		1	
NC4		1	
IC5		1	
NC5		1	
C6		1	
C7-C19		1	
C20-C32		1	
C33-C45		1	

Table 4.4: Tuning on AF

Components	Tuning Variables		
	Tc	Pc	AF
N2			1
CO2			1
C1			1
C2			1
C3			1
IC4			1
NC4			1
IC5			1
NC5			1
C6			1
C7-C19			1
C20-C32			1
C33-C45			1

Figures 4.1 to 4.4 compare the regression on tuning the variables of PR model while Figures 4.5 to 4.8 compare the regression on tuning the variables. The solid line shows the relative volume before regression, the dotted line shows the relative volume after regression and the line represent by the small red box is the experimental (observed) data.

For the PR model, regression on the all three variables shows the best fit to the observed data which the errors of relative volumes were from 0.35913% to 12.121%. The same situation for the SRK model where tuning on the three variables shows best fit result. The relative volumes errors are were from 0.003214% to 0.9672%.

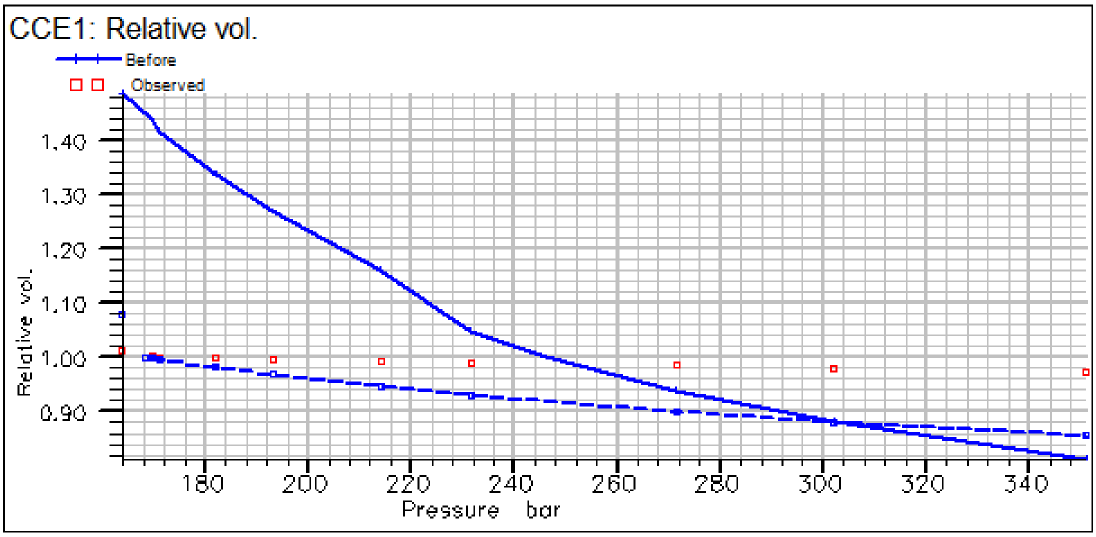

Figure 4.1: Comparison of regression result by tuning of all three variables using PR model

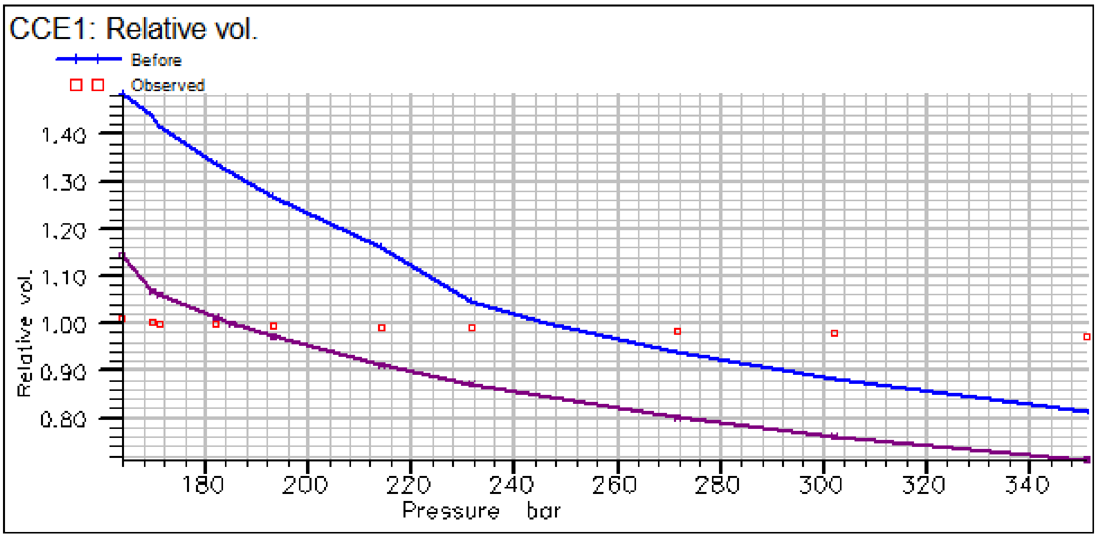

Figure 4.2: Comparison of regression result by tuning of Tc using PR model

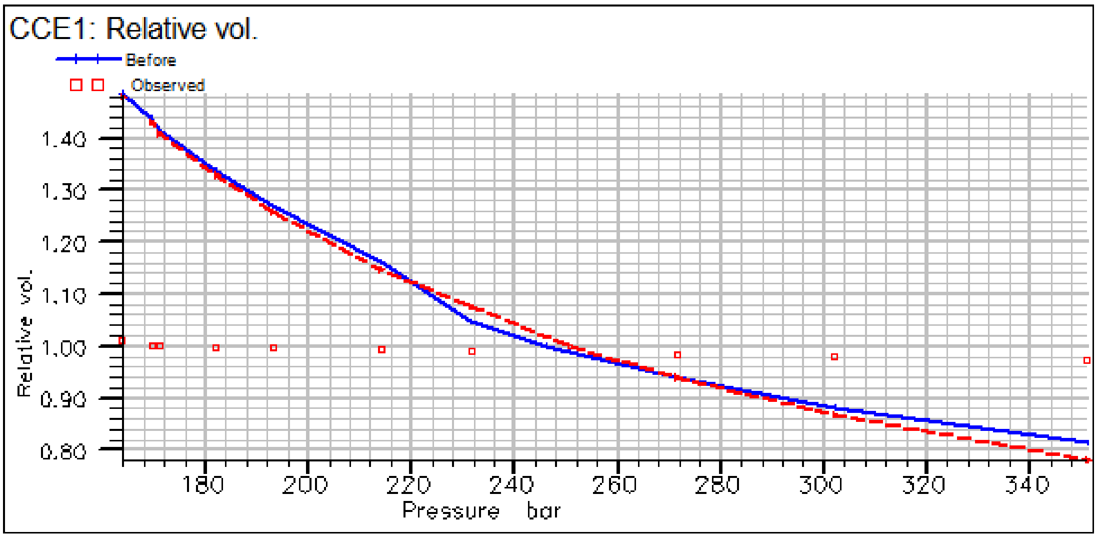

Figure 4.3: Comparison of regression result by tuning of Pc using PR model

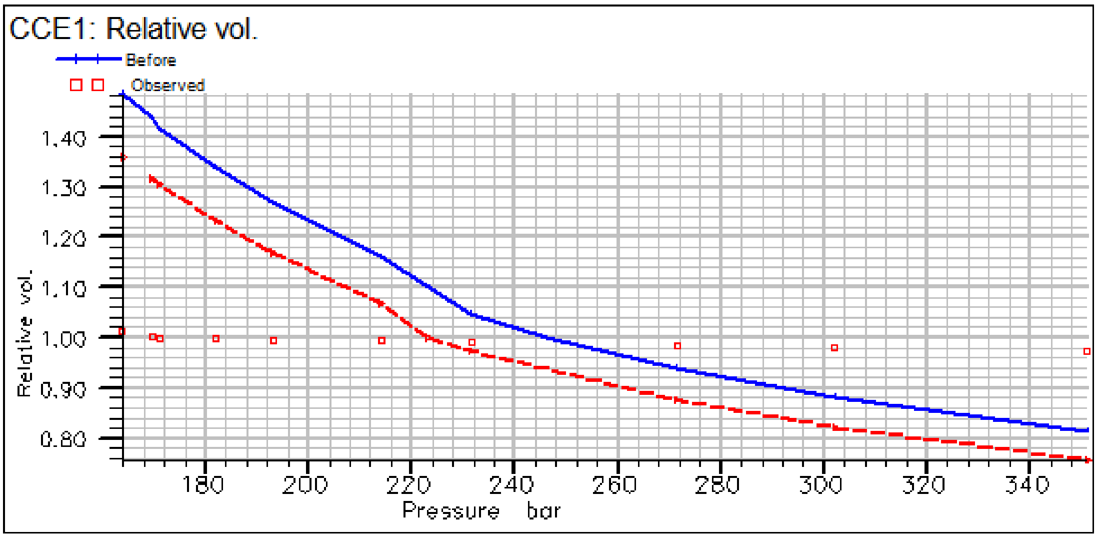

Figure 4.4: Comparison of regression result by tuning of AF using PR model

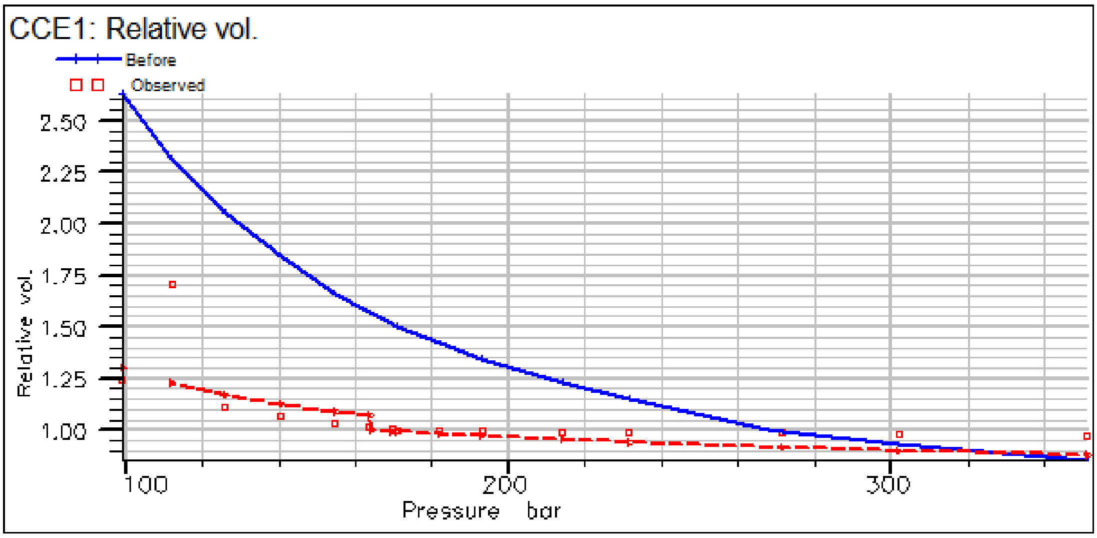

Figure 4.5: Comparison of regression result by tuning of all three variables using SRK model

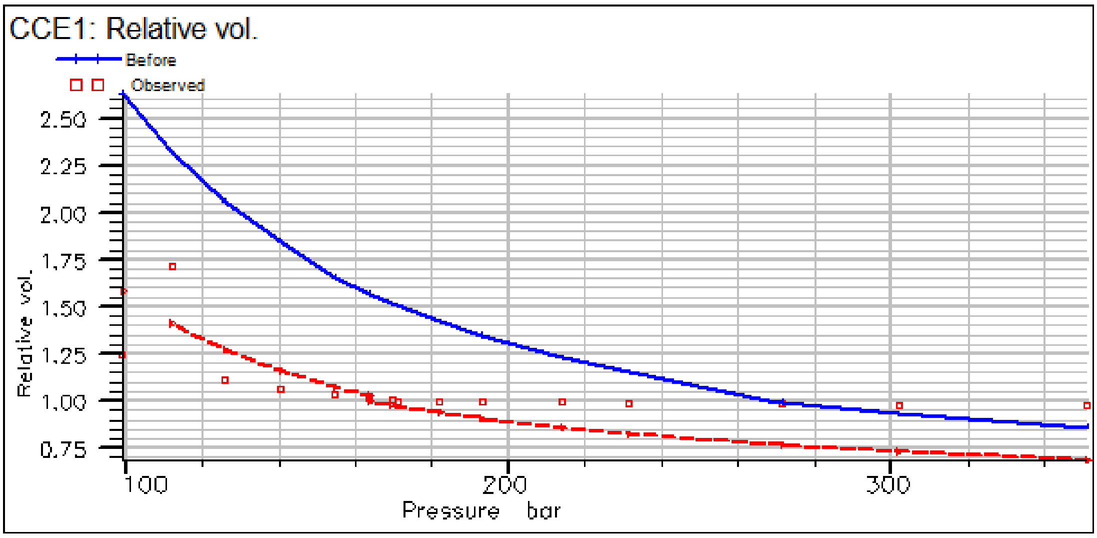

Figure 4.6: Comparison of regression result by tuning of Tc using SRK model

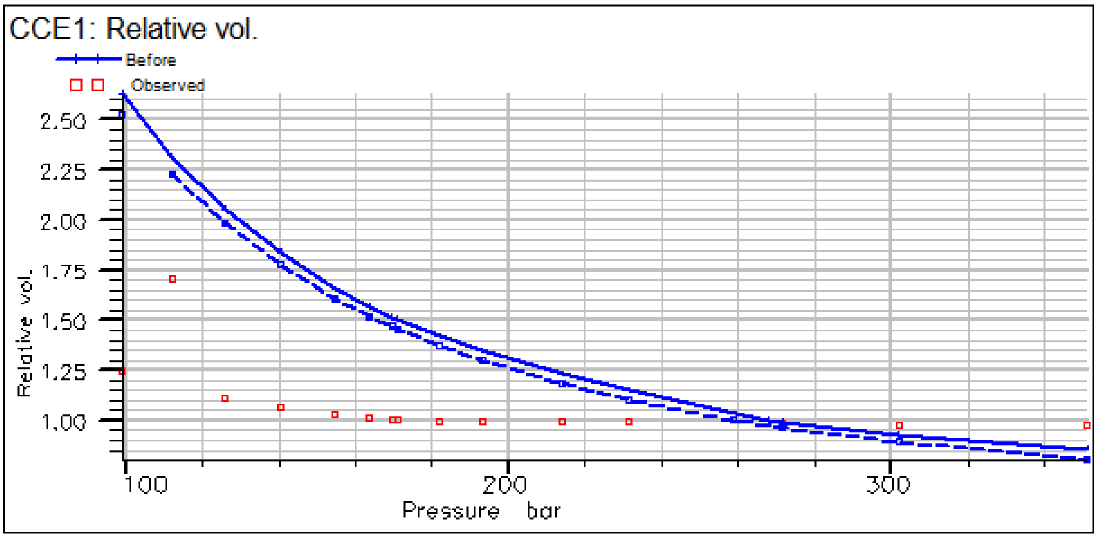

Figure 4.7: Comparison of regression result by tuning of Pc using SRK model

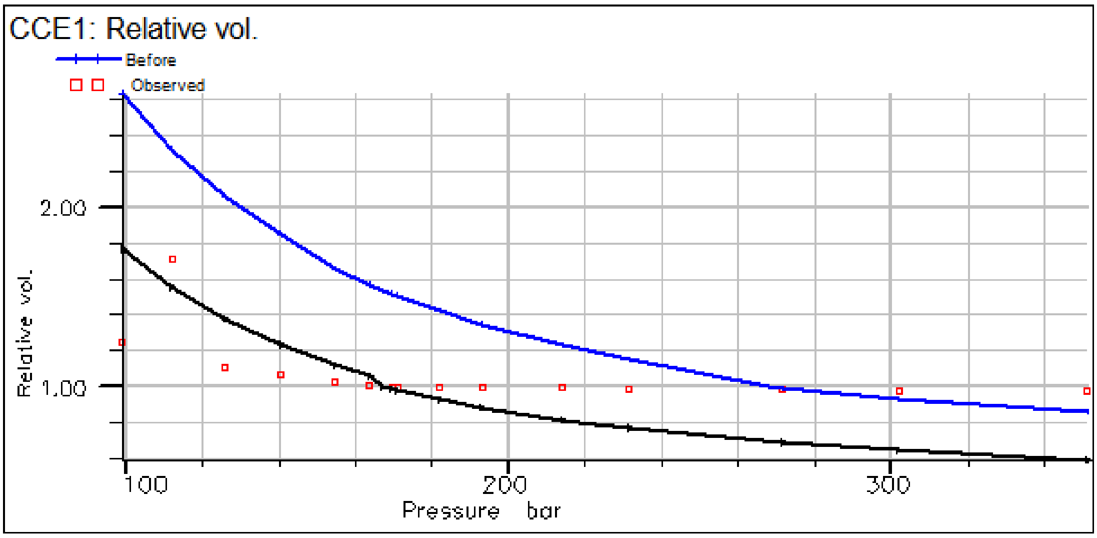

Figure 4.8: Comparison of regression result by tuning of AF using SRK model

4.3 MMP Prediction

The tuned PVT data from regression is then used to compare the MMP values for both mixing cell simulation and slim tube simulation. Table 4.5 shows the comparison of experimental and calculated fluid sample properties comparison of experimental and calculated fluid sample properties of mixing cell simulation which indicates high percentage deviation of errors recorded which are from 89% to 37289.3% for PR model and 84.46% to 37289.3%. The high percentage of error recorded is due to the saturation pressure cannot be calculated as a result of two phase pressure cannot be found.

Both models which tuned with Pc shows the most acceptable MMP values if compare to tuning with other variables. The PR model (percentage deviation -84%) shows better prediction of MMP values compare to SRK model (percentage deviation -89%).

Table 4.5: Comparison of experimental and calculated fluid sample properties of mixing cell simulation

Fluid	EOS	Tuning Parameter	Psat, bar	Deviation, %	MMP, bar	Deviation, %
Experimental	-	-	171.000	0.00	271	0.00
Tuned	PR	All	101325.000	-59154.39	101325	-37289.30
Tuned	PR	Tc	101325.000	-59154.39	101325	-37289.30
Tuned	PR	Pc	275.717	-60.92	42.1086	84.46
Tuned	PR	AF	101325.000	-59154.39	101325	-37289.30
Tuned	SRK	All	101325.000	-59154.39	101325	-37289.30
Tuned	SRK	Tc	222.446	-30.89	10.4836	96.13
Tuned	SRK	Pc	288.281	-68.59	29.8072	89.00
Tuned	SRK	AF	153.232	10.39	101325	-37289.30

On the other hand, MMP values of slim tube simulation shows different results that mixing cell method based on Table 4.6. The percentage deviations of errors are lower than mixing cell simulations which are from 25.22% to 43.92%. The SRK model shows better MMP prediction compares to PR model which is in contrast to mixing cell simulation.

Appendix 1 to 8 shows the fluid data for PR model and SRK Model. Appendix 9 to 16 shows the Pressure vs Recovery data for PR model and SRK model. Indeed, the slim time simulation shows PR model is better in predicting MMP than SRK model but the graphs from Appendix 1 to Appendix 8 are not a smooth graph hence may affect the prediction of MMP.

Furthermore, results of regressions do not tally with the calculated MMP values. The both tuned model with all the variables should get low percentage of deviation errors in MMP values as a result of low percentage of deviation errors in regression. However, the results are in contrast.

Table 4.6: Comparison of experimental and calculated fluid sample properties of slim tube simulation

Fluid	**EOS**	**Tuning Parameter**	**MMP, bar**	**Deviation, %**
Experimental	-	-	271	0.00
Tuned	PR	All	151.99	43.92
Tuned	PR	Tc	151.99	43.92
Tuned	PR	Pc	151.99	43.92
Tuned	PR	AF	151.99	43.92
Tuned	SRK	All	151.99	43.92
Tuned	SRK	Tc	202.65	25.22
Tuned	SRK	Pc	202.65	25.22
Tuned	SRK	AF	202.65	25.22

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was done to help engineers when dealing with the CO2 miscible gas injection process. It is very essential because thorough understanding of miscible gas injection simulation properties calculations can help to avoid extra cost and time incurred to the project. Some conclusions have been made and hopefully it will further help the readers to understand on the effect of the fluid characterization via using miscible gas injection via mixing cell method.

1. Accurate fluid characterization is crucial in predicting MMP. The splitting, lumping and regression are essential steps. Error in these steps may contribute high percentage of deviation errors. In this study the percentage of deviation errors is as high as 37289.3%.

2. The tuning of Tc, Pc and AF give low percentage deviation of errors in regression compare to others but give poor MMP prediction. Tuning of Pc in mixing cell method gives most acceptable result.

3. For pure CO2 miscible displacement, PR model is found to give better prediction of MMP in mixing cell method while SRK model is found to give better prediction of MMP in slim tube simulation.

5.2 Recommendations

The following suggestions for further research are made:

1. Different EOS fluid characterization methods in MMP prediction can also be investigated. This is to determine which characterization method is suitable to predict MMP.

2. The number of fluid samples can be added in this study to give better interpretation of data.

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APPENDICES

Appendix 1: Fluid Data for PR model of tuning Tc, Pc & AF

Component	Tc(K)	Pc(bar)	AF	MW
N2	176.7964764	24.79797834	0.04403801517	28.01300000
CO2	426.8612231	53.96336183	0.24771383530	44.01000000
C1	267.0159144	33.63642197	0.01431235493	16.04300000
C2	427.8838968	35.67947929	0.10855370740	30.07000000
C3	518.0613072	31.01597888	0.16778483780	44.09700000
i-C4	571.7166562	26.64857374	0.20345563010	58.12400000
n-C4	595.6724386	27.73672384	0.22129102620	58.12400000
i-C5	644.9849265	24.76096644	0.24991573610	72.15100000
n-C5	657.8734176	24.62032119	0.27633854520	72.15100000
C6	711.4850038	24.08342496	0.29789211570	86.00000000
C7+	932.0726915	15.97649183	0.60291421910	169.1360659
C30+	1218.861037	5.015404177	1.38903981500	402.7512546
C73+	1693.401616	1.061145908	2.32920574500	953.2487452

Appendix 2: Fluid Data for PR model of tuning Tc

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	126.2000000	25.49427938	0.04	28.01300000
CO2	304.7000000	55.47859601	0.225	44.01000000
C1	190.6000000	34.58089716	0.013	16.04300000
C2	305.4300000	36.68132137	0.0986	30.07000000
C3	369.8000000	31.01597888	0.1524	44.09700000
i-C4	408.1000000	27.39683754	0.1848	58.12400000
n-C4	425.2000000	28.51554174	0.201	58.12400000
i-C5	460.4000000	25.45622821	0.227	72.15100000
n-C5	469.6000000	25.31163379	0.251	72.15100000
C6	507.8687614	24.75966209	0.2705772407	86.00000000
C7+	665.3275907	16.42509484	0.5476306930	169.1360659
C30+	870.0414510	5.156231428	1.2616734060	402.7512546
C73+	1208.775697	1.090941764	2.115631902	953.2487452

Appendix 3: Fluid Data for PR model of tuning Pc

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	104.5095012	33.94387500	0.0400000000	28.01300000
CO2	252.3299922	73.86592500	0.2250000000	44.01000000
C1	157.8408156	46.04208000	0.0130000000	16.04300000
C2	252.9345242	48.83865000	0.0986000000	30.07000000
C3	306.2409948	42.45517500	0.1524000000	44.09700000
i-C4	337.9582206	36.47700000	0.1848000000	58.12400000
n-C4	352.1191752	37.96647750	0.2010000000	58.12400000
i-C5	381.2692104	33.89321250	0.2270000000	72.15100000
n-C5	388.8879696	33.70069500	0.2510000000	72.15100000
C6	420.5793259	32.96578274	0.2705772407	86.00000000
C7+	550.9750764	21.86888117	0.5476306930	169.1360659
C30+	720.5039467	6.865166592	1.2616734060	402.7512546
C73+	1001.018583	1.452513732	2.1156319020	953.2487452

Appendix 4: Fluid Data for PR model of tuning AF

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	126.2000000	33.94387500	0.032015665	28.01300000
CO2	304.7000000	73.86592500	0.1800881156	44.01000000
C1	190.6000000	46.04208000	0.01040509112	16.04300000
C2	305.4300000	48.83865000	0.07891861423	30.07000000
C3	369.8000000	42.45517500	0.1219796837	44.09700000
i-C4	408.1000000	36.47700000	0.1479123723	58.12400000
n-C4	425.2000000	37.96647750	0.1608787166	58.12400000
i-C5	460.4000000	33.89321250	0.1816888989	72.15100000
n-C5	469.6000000	33.70069500	0.2008982979	72.15100000
C6	507.8687614	32.96578274	0.2165677574	86.00000000
C7+	665.3275907	21.86888117	0.4383190203	169.1360659
C30+	870.0414510	6.865166592	1.009832828	402.7512546
C73+	1208.775697	1.452513732	1.693334056	953.2487452

Appendix 5: Fluid Data for SRK model of tuning Tc, Pc & AF

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	189.3000000	23.46202908	0.0600000400	28.01300000
CO2	457.0500000	51.05617671	0.3375002250	44.01000000
C1	285.9000000	31.82431646	0.0195000130	16.04300000
C2	458.1450000	33.75730751	0.1479000986	30.07000000
C3	554.7000000	29.34504533	0.2286001524	44.09700000
i-C4	612.1500000	25.21292677	0.2772001848	58.12400000
n-C4	637.8000000	26.24245461	0.3015002010	58.12400000
i-C5	690.6000000	23.42701112	0.3405002270	72.15100000
n-C5	704.4000000	23.29394290	0.3765002510	72.15100000
C6	761.8031421	22.78597106	0.4058661316	86.00000000
C7+	997.9913860	15.11578528	0.8214465871	169.1360659
C30+	1305.062177	4.745207735	1.8925113710	402.7512546
C73+	1813.163546	1.003978462	3.1734499690	953.2487452

Appendix 6: Fluid Data for SRK model of tuning Tc

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	126.2000000	20.76757407	0.04	28.01300000
CO2	304.7000000	45.19272089	0.225	44.01000000
C1	190.6000000	28.16950943	0.013	16.04300000
C2	305.4300000	29.88050956	0.0986	30.07000000
C3	369.8000000	25.97496578	0.1524	44.09700000
i-C4	408.1000000	22.31739303	0.1848	58.12400000
n-C4	425.2000000	23.22868658	0.201	58.12400000
i-C5	460.4000000	20.73657769	0.227	72.15100000
n-C5	469.6000000	20.61879145	0.251	72.15100000
C6	507.8687614	20.16915673	0.2705772407	86.00000000
C7+	665.3275907	13.3798398	0.547630693	169.1360659
C30+	870.0414510	4.200252791	1.261673406	402.7512546
C73+	1208.775697	0.8886783409	2.115631902	953.2487452

Appendix 7: Fluid Data for SRK model of tuning Pc

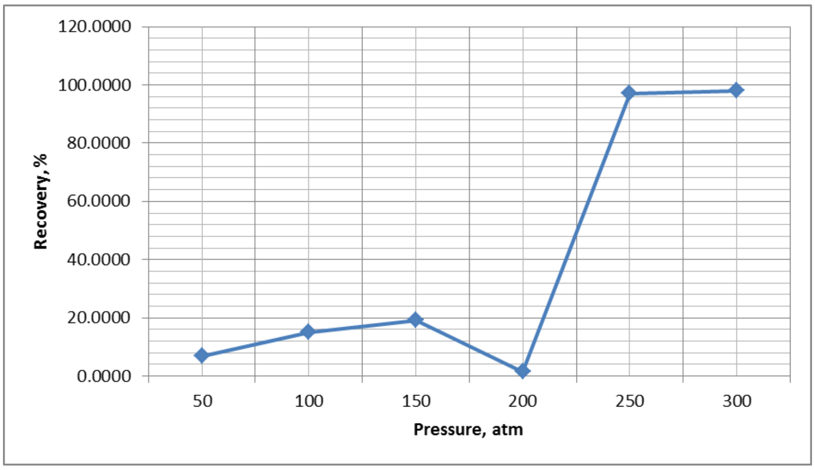
Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	108.8476262	33.943875	0.0400000000	28.01300000
CO2	262.8040547	73.865925	0.2250000000	44.01000000
C1	164.3926906	46.04208	0.0130000000	16.04300000
C2	263.4336804	48.83865	0.0986000000	30.07000000
C3	318.9528698	42.455175	0.1524000000	44.09700000
i-C4	351.9866581	36.477	0.1848000000	58.12400000
n-C4	366.7354252	37.9664775	0.2010000000	58.12400000
i-C5	397.0954604	33.8932125	0.2270000000	72.15100000
n-C5	405.0304696	33.700695	0.2510000000	72.15100000
C6	438.0373146	32.96578274	0.2705772407	86.00000000
C7+	573.8457123	21.86888117	0.5476306930	169.1360659
C30+	750.4116215	6.865166592	1.2616734060	402.7512546
C73+	1042.570247	1.452513732	2.1156319020	953.2487452

Appendix 8: Fluid Data for SRK model of tuning AF

Component	**Tc(K)**	**Pc(bar)**	**AF**	**MW**
N2	126.2000000	33.943875	0.02007372702	28.01300000
CO2	304.7000000	73.865925	0.11291471450	44.01000000
C1	190.6000000	46.04208	0.006523961281	16.04300000
C2	305.4300000	48.83865	0.04948173710	30.07000000
C3	369.8000000	42.455175	0.07648089994	44.09700000
i-C4	408.1000000	36.477	0.09274061882	58.12400000
n-C4	425.2000000	37.9664775	0.10087047830	58.12400000
i-C5	460.4000000	33.8932125	0.11391840080	72.15100000
n-C5	469.6000000	33.700695	0.12596263700	72.15100000
C6	507.8687614	32.96578274	0.13578734170	86.00000000
C7+	665.3275907	21.86888117	0.27482472590	169.1360659
C30+	870.0414510	6.865166592	0.63316218840	402.7512546
C73+	1208.775697	1.452513732	1.06171543200	953.2487452

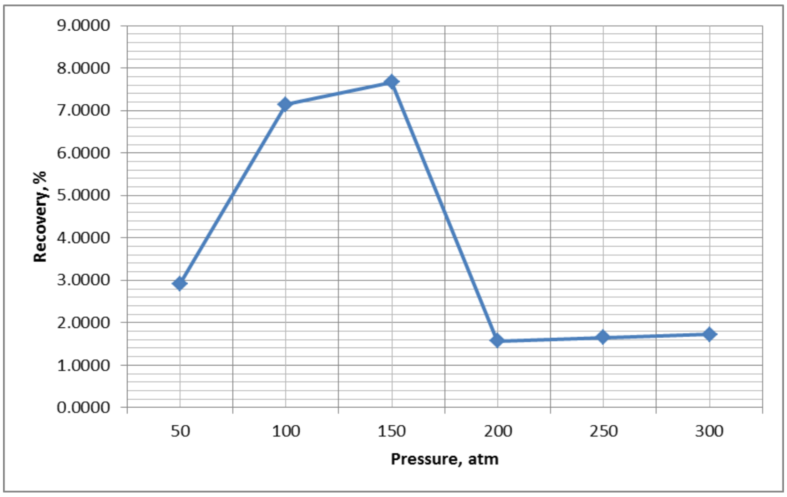
Appendix 9: Pressure vs Recovery Data for PR model of tuning Tc, Pc & AF using 500 grid size

Pressure, atm	Recovery, %
50	6.8760
100	15.0267
150	19.2376
200	1.5151
250	97.0273
300	98.0157



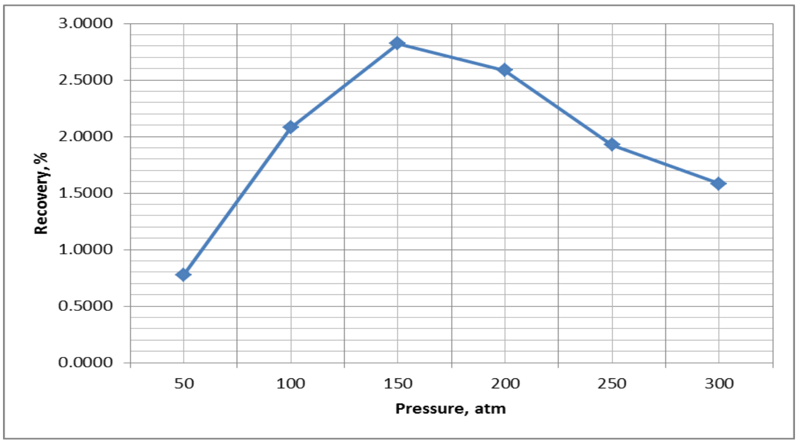
Appendix 10: Pressure vs Recovery Data for PR model of tuning Tc using 500 grid size

Pressure, atm	Recovery, %
50	2.9061
100	7.1447
150	7.6665
200	1.5735
250	1.6564
300	1.7215



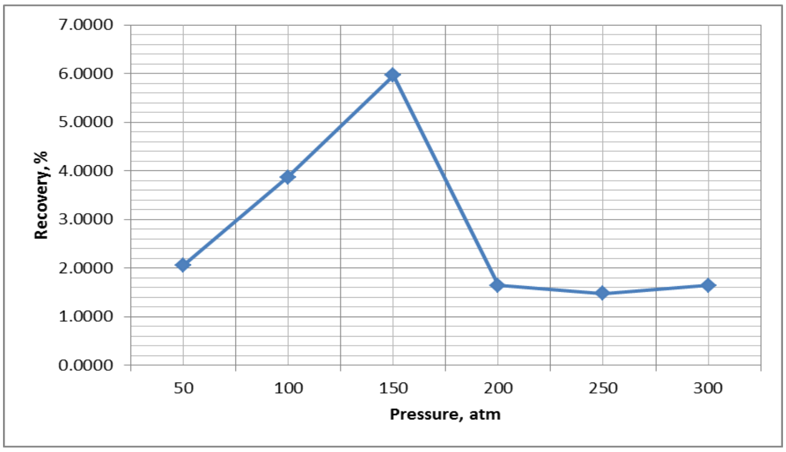
Appendix 11: Pressure vs Recovery Data for PR model of tuning Pc using 500 grid size

Pressure, atm	Recovery, %
50	0.7742
100	2.0787
150	2.8208
200	2.5865
250	1.9257
300	1.5818



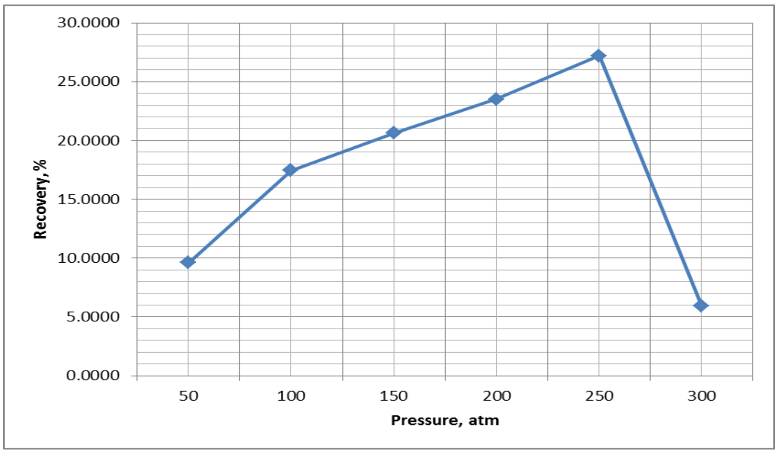
Appendix 12: Pressure vs Recovery Data for PR model of tuning AF using 500 grid size

Pressure, atm	Recovery, %
50	2.0481
100	3.8625
150	5.9592
200	1.6359
250	1.4770
300	1.6410



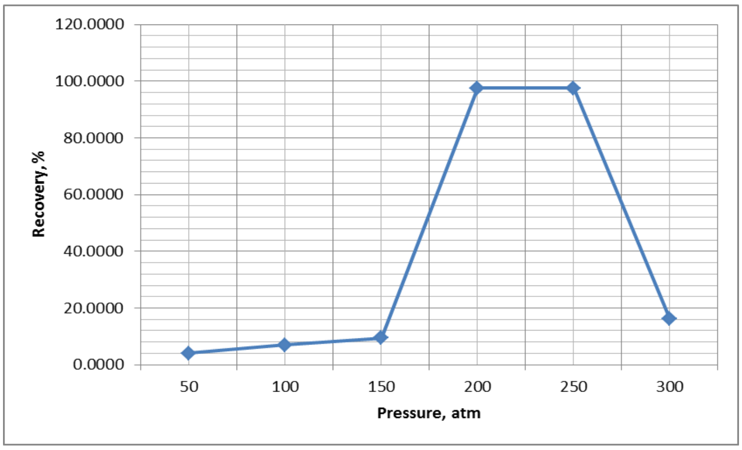
Appendix 13: Pressure vs Recovery Data for SRK model of tuning Tc, Pc & AF using 500 grid size

Pressure, atm	Recovery, %
50	9.6240
100	17.4407
150	20.6261
200	23.5081
250	27.2150
300	5.9153



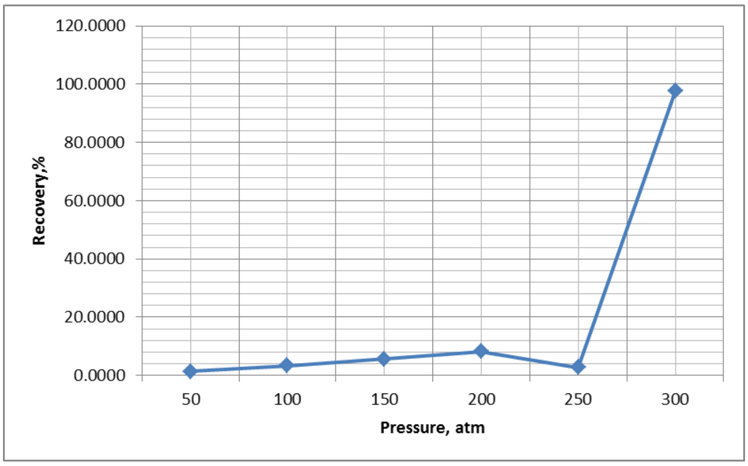
Appendix 14: Pressure vs Recovery Data for SRK model of tuning Tc, using 500 grid size

Pressure, atm	Recovery, %
50	4.0631
100	7.0352
150	9.4383
200	97.6064
250	97.6000
300	16.1821



Appendix 15: Pressure vs Recovery Data for SRK model of tuning Pc using 500 grid size

Pressure, atm	Recovery
50	1.3714
100	3.3771
150	5.6457
200	8.1631
250	2.7416
300	97.6086



Appendix 16: Pressure vs Recovery Data for SRK model of tuning AF using 500 grid size

Pressure, atm	Recovery
50	1.7295
100	4.0242
150	6.2130
200	97.6041
250	97.6000
300	97.6000