APPROXIMATION OF INTERFACIAL TENSION FOR ASPHALTENIC CRUDE OIL AND CO2 USING PARACHOR METHOD

By

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Dissertation submitted in partial fulfillment of

The requirements for the

Bachelor of Engineering (Hons)

(Petroleum Engineering)

MAY 2011

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CERTIFICATION OF APPROVAL

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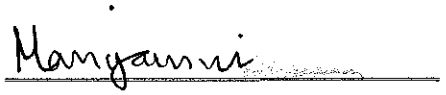
Approved by,



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May 2011

CERTIFICATION OF ORIGINALITY

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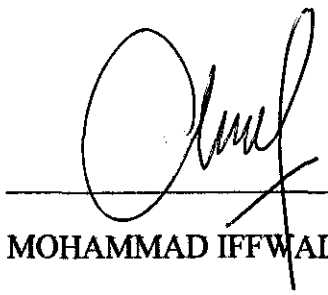

MOHAMMAD IFFWAD B AHMAD NAZRI

ABSTRACT

In this study, new way to handle the determination of interfacial tension for asphaltenic crude oil and CO2 using parachor method is proposed. Parachor is one empirical method that can be use to predict interfacial tension and is widely used in the industry. Parachor method is dependent on the phase density, molecular weight, parachor value for each components and the scaling exponent. Early studies defined the value of the scaling exponent to be 3.67, 3.88,3.91 and 4.00. However, these proposed values are not design to predict the IFT for crude oil that contain asphaltenes more than 0.01%. As a result, the predicted IFT gave an error when comparing the results with the laboratory determination. This paper used four types of asphaltenic crude oil that contain different percentage of asphalt. The samples are Dulang Crude Oil, Iraq Ratawi Crude Oil, and mixture of 80% Dulang Crude and 20% Iraq Ratawi Crude, and 20% Dulang Crude and 80% Iraq Ratawi Crude. To compare the empirical method, this project implemented IFT pendant drop experiment as the main laboratory work. This paper compared the IFT value from the experiment and the empirical method in order to come up with a method to encounter the error.

ACKNOWLEDGEMENT

First and foremost, my highest appreciation goes to my Final Year Project (FYP) supervisor, Prof Dr Mariyamni bt Awang. She has been very dedicated to coach and is willing to share her valuable knowledge whenever I ask her questions regarding the project. I could have not completed this project alone without the kind help and her guidance from the very beginning.

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study. To all individuals who helped me in any way but whose names are not mentioned here, I sincerely thank you all for the endless support, guidance and patience.

Last but not the least, my family and the one above all of us, the omnipresent God, for answering my prayers for giving me the strength to plod on despite my constitution wanting to give up and throw in the towel, thank you so much Dear Lord.

I hope all the things that I learned here will be useful in my education and life in the future at large.

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Chapter 1

Introduction

1.1.Background Study

Interfacial tension is an important property that must be considered in a process that involves two phases in contact. The unbalance force created between the phases will form tension within the surface. For asphaltenic crude oil, the interfacial tension value will increase due to the presence of asphaltenes material in the crude[5,6]. Thus, the expected production from Enhanced Oil Recovery (EOR) is lesser if the crude contains higher asphaltenes contain compare to a free asphalt-crude. For IFT measurement, one of the empirical methods to predict interfacial tension is Parachor method[3]. However, it has been found that prediction of IFT from Parachor is not accurate for crude oil with more than 0.01% asphaltenes. The principal theory of this empirical method is the parachor value for each component in the crude and also the scaling exponent values that were used to predict interfacial tension value. The samples that were used for this project are Dulang Crude Oil, Iraq Ratawi Crude Oil and Synthetic Crude C. This project proposed a modified scaling exponent that is applicable for empirical Parachor method so it can give high accuracy of IFT prediction.

1.2.Problem Statement

1.2.1. Problem Identification

The presence of asphaltenes material in the crude oil in early studies shows that the accuracy of IFT prediction using empirical parachor method is low (error of 8% - 10%) . For parachor method, one variable in the equation is the scaling exponent, *n*. Base from studies, scaling exponent,*n*, values that widely used are 3.67, 3.91 and 4.00[3]. However, there is no specific exponent value that will result accurate IFT prediction if the crude oil contain more than 0.01 % of asphaltenes.

1.2.2. Significance of the Project

To be able to describe the empirical parachor method in determining the interfacial tension value of asphaltenic crude oil and CO2 with high accuracy and small error. This can be achieved through better understanding of interfacial tension effect to a two phase flow, the importance of IFT by quantifying effect of different asphaltenes contain and percentage to IFT value.

1.3.Objective and Scope of Study

1.3.1. Objectives

A. To examine and illustrate the changes of interfacial tension value with different quantity or percentage of asphaltenes

Asphaltenes material affected the density of the crude. The relationship between asphaltenes and density were analyzed.

B. To determine the error percentage from parachor method prediction if it is asphaltenic crude oil

In low asphaltenes content, it is believe from study that the accuracy of parachor method is high and the results have very small to zero error percentage. Thus, thorough calculations were illustrated to examine the dependency level of accuracy and the asphaltenes content.

C. **To get the new scaling exponent value that will result a high accuracy of IFT prediction**

Asphaltenic crude oil produced high error percentage (>8%) when parachor method is applied. Thus, new variables value was suggested and explained in order to come up with the highest accuracy of interfacial tension value. Alteration of this new value is required in order to develop the highest accuracy of IFT prediction that can encounter the effect of asphaltenes.

1.3.2. Scope Of Study

- Dulang Crude oil, Ratawi Crude oil and synthetic crude c sample will be used for experimental and result analysis.
- Interfacial tension experiments to measure the IFT value with either low or high asphaltenes content, with CO2 as second fluid in contact.

1.4.Relevance of Project

The findings from this research enhanced the applicability of empirical parachor method in determining the interfacial tension for crude oil with high asphaltenic percentage. Through lab experiments, it provided the method to examine IFT value for different asphaltenic percentage. With this result, the empirical parachor method is hoped to be applicable and accurate for asphaltenic crude oil IFT prediction.

Chapter 2

Literature Review

2.1. Interfacial Tension

The occurrence of interfacial tension is possible when two fluids in contact with each other. Here, there will be an unbalance molecular force created at the interface between the two phases. The main cause of this unbalance force is the physical contact created between the two molecules of the fluids and is known as interfacial tension [2,6].

Consider two immiscible fluids in contact, (air – water /oil – water /oil – gas), the liquid molecule which is not located at the interface is surrounded by other same liquid molecules. This will result to a net attractive force of zero. However, for the liquid molecules that are located at the surface, there will be imbalance forces acting on the molecules. This is because; there is force acting on the liquid from the air (gas) molecules lying immediately above the interface to form a physical contact. The unbalance attraction force will create a membrane and give rise to the surface tension [3].

The attraction between molecules is inversely proportional to the distance. Besides, the attraction is directly proportional to the mass of molecules. In other words, the interface between two fluids will encounter interfacial tension due to difference in mass and the distance. Interfacial tension has the unit of force per unit of length, dynes/cm, and denoted with the symbol σ. It can be thought as force required preventing destruction of the surface in contacts. Interfacial tension is equal to the boundary energy. Boundary energy defined as the work required to create one square centimeter of surface.

Interfacial tension only exists when two phases are present. This can occurs along the vapor pressure line for pure substances. The interfacial tension for pure substances decreases as temperature increases and becomes zero at critical point. Interfacial tension of hydrocarbon liquid and gas at equilibrium may be estimated with:

$$\sigma = [\sum pi(xi\frac{\rho l}{Ml} - yi\frac{\rho v}{Mv})]^4$$

Where ρ is the density for liquid and gas, g/cm³, M is the apparent molecular weight of the equilibrium liquid. P is defined as parachor, and the value for the components of hydrocarbon mixture are obtained through studies. In petroleum industry, most of the processes involved more than one fluid in contact. The physical behavior of this interface is quantified by values of the interfacial tension between the fluids. Some of the petroleum processes that use interfacial tension as one of its property are enhance oil recovery, oil and gas production and drilling fluid injection.

2.1.1 *Prediction of Interfacial Tension*

The interfacial tension between reservoir fluids can be measured using several methods. The first method is from experimental work and the second method is the empirical or theoretical. The first method is the measurement methods that require experimental work to accomplish. This measurement is called pendant drop experiment. This apparatus is suitable at high pressure and high temperature. In this widely applied experiment, there will be two sections where fluids are stored. The first one is called the accumulator and the second is the cell. Generally, this experiment will allow a liquid droplet to hang from the tip of a capillary tube in a high pressure visual cell. In the cell, the second fluid will be injected and it will create a physical contact and create interfacial tension[5,6].

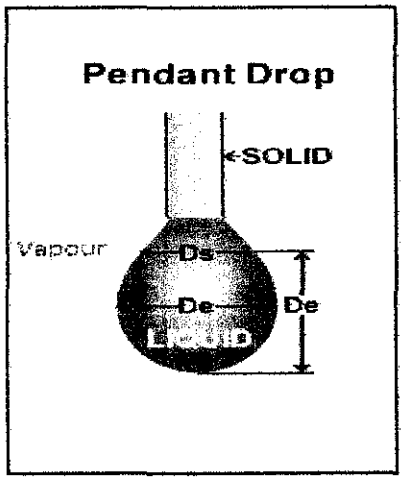

Figure 2.1: IFT measurements by pendant drop method

For pendant drop experiment, user can have the option to change the temperature from 0°C to 130° and pressure of 0 psia to 2000 psia. However, the higher temperature of the liquid injected, the harder for the user to form a droplet since the molecular energy is high thus increase the kinetic energy and thus lower the bonding energy between the molecules.

Besides from experiment pendant drop method, one of the methods that are widely used in petroleum industry is the parachor method. At first, from the basis of experimental observations, *Macleod* suggested the following relation between surface tension and densities.

$$\frac{\sigma}{(\rho l - \rho v)^4} = C \quad \text{..... (1)}$$

Where σ = surface tension, ρl and ρv = liquid and vapor density respectively and C = constant. Later, *Sugden* related the C to the chemical composition of the substance. From his study, he defined the parameter by,

$$p = \frac{M}{(\rho l - \rho v)} \sigma^{1/4} \quad \text{..... (2)}$$

From this modified equation, M is the molecular weight and P is called parachor. Each of the components will have parachor value. From Sugden first study, it is believed that parachor is a measure of the molecular volume and chemical composition[3,6].

Since there are limitations of the usage of parachors, Weinaug and Katz used produced an equation that they used for multicomponent systems.

$$\sigma = [\sum pi(xi\frac{\rho l}{Ml} - yi\frac{\rho v}{Mv})]^4 \quad \text{..... (3)}$$

This equation is suitable and essentially a linear combination of equations for pure substance with mole – fraction weighting. X_i and y_i = mole fractions of component I in both liquid and vapor phase[3,5].

2.2 Scaling Exponent Value Applicability

The main problem in the literature regarding the parachor method in determining the interfacial tension is the lack of clarity concerning the scaling exponent and parachor derived from varies exponent value. From the evolvement of the interfacial tension equation, the value of scaling exponent is identified to be different with each other:

$$\sigma = [\sum pi(xi\frac{\rho l}{Ml} - yi\frac{\rho v}{Mv})]^4 \quad \text{..... (4)}$$

$$\sigma = [\sum pi(xi\frac{\rho l}{Ml} - yi\frac{\rho v}{Mv})]^{3.67} \quad \text{..... (5)}$$

$$\sigma = [\sum pi(xi\frac{\rho l}{Ml} - yi\frac{\rho v}{Mv})]^{3.91} \quad \text{..... (6)}$$

Equation 4, 5 and 6 are the three equations widely used for parachor method proposed by *Weinaug and Katz, Hough and Stegemeir* and *Lee and Chien* respectively. As we can see from these equations, the exponent value differs from 4, 3.67 , 3.88 and 3.91. To further study the suitable value of the scaling exponent, the project will look at each of the value and the reason behind it[2,3].

A) Scaling Exponent Value : 4

At first, *Weinaug and Katz* used the scaling exponent of 4. The value of 4 for scaling exponent was taken based from Van der Walls theory and equation. This theory explained the attractive forces between molecules. Van der Waals equation stated that:

$$\left(p + \frac{n^2 a}{V^2}\right)(V - nb) = nRT \quad \text{..... (7)}$$

Where,

a is a measure of the strength of attraction between particles

b is the volume excluded from one mole of particle

R is the gas constant that depends on the Boltzmann constant and Avogadro's constant

One of the major assumptions to the Van der Waals equation is that the force will drop or falls if the distance between the molecules reaches to the 4th power. From here, *Weinaug and Katz* stated that 4 should be the scaling exponent value [3].

B) Scaling Exponent Value: 3.67 and 3.91

The exponents 3.67 and 3.91 originated from the relationship between IFT and density difference:

$$\sigma = c(\Delta\rho)^{\alpha/\beta}$$

Constant C is related to parachor and the exponent value refers to □ / β. *Hough and Stegemier* proposed the value of 0.33 for β and 1.22 for □ based on empirical relations. The ratio of this value will yield 3.696969 or equivalent to 3.67. The empirical relation was studied first by *Guggenheim*'s in 1945. The resultant value based from the limited measurements of eight fluid densities and IFT's which is (Ne, Ar, Kr, Xe, N_2, O_2, CO, and CH_4) [3].

From there, *Lee and Chien* determine the □ and β value from different source. They used 1.22 for □ and 0.3125 for β. From this value, they come out with the value of scaling exponent of 3.91.

Origin	β	□	□/β
Van der Waals equation	1.5	1.5	3.0
2-D Ising model	0.125	1.0	8.0
3-D Ising mode	0.325	1.26	3.88
Currently accepted values	0.325	1.26	3.88

Table 2.1: Theoretical Values of the Critical Exponents [3]

C) Scaling exponent value: 3.88

In proving the applicability of exponent value of 3.88, first, we will look into *Macleod's* study. He gathered the data of 8 different components (shown in figure 2.2), and calculated the interfacial tension value and density difference. The slope of the data shows the value of 3.88. However, the value *Macleod* demonstrated shows theoretical derived critical exponent (3.88) can be applied to a wide range of conditions.

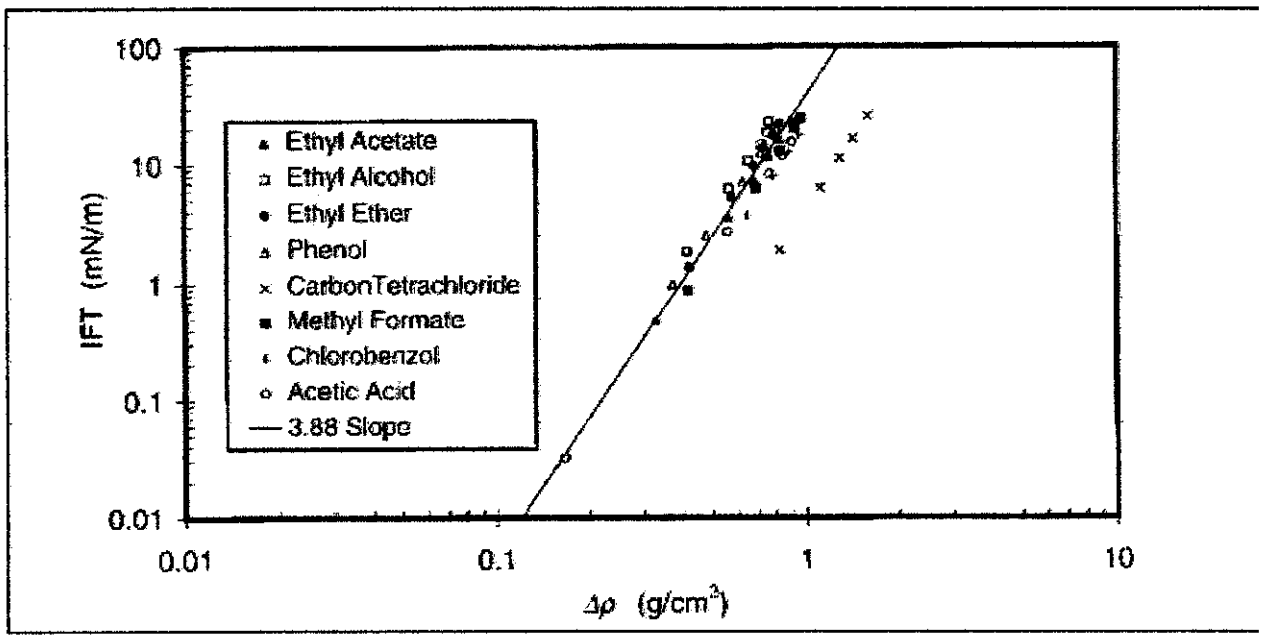

Figure 2.2: IFT vs Density difference measurement by *Macleod*[3]

To explain further the scaling exponent value of 3.88, first plot IFT vs reduced temperature (1-T/Tc) in low IFT region for methyl ether and CO2. The slope from this experiment yield the value of 1.26.By using the value of β suggested from earlier study which is 0.325, *Weinaug and Katz* summarise that the scaling exponent value for parachor method is equal to 3.88.

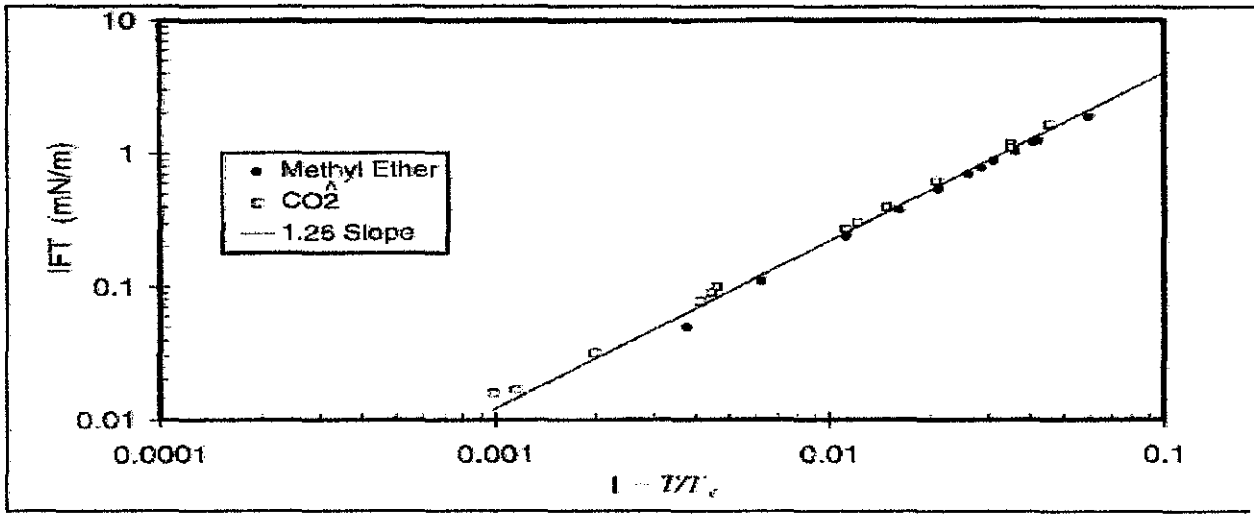

Figure 2.3: IFT vs Reduced Temperature for Methyl Ether and CO2 [3]

To further strengthen this value, he repeated the experiment with 57 pure components and again he get the theoretical slope from the experiment. Figure below summarized the slope produced from the experiment.

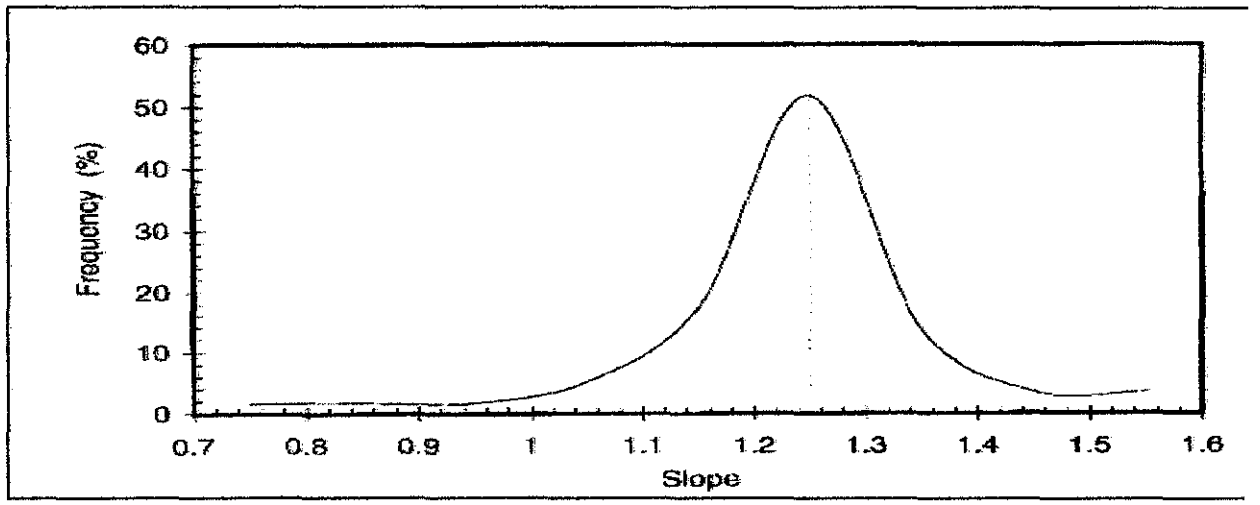

Figure 2.4: Slope Distribution of IFT for 57 Pure Components vs 1-(T/Tc) [3]

From this slope, *Weinaug and Katz* again summarized that the slope produced from the experiment is 1.26 and thus strengthen the earlier study that the scaling exponent value is equal to 3.88.

2.3 Asphaltenic crude oil

Similar to the resins, the asphaltenes crude oil can be defined as solubility class of the fraction of crude oil precipitating in light alkanes. Some of the examples of light alkanes are pentane, hexane and heptanes. However, this precipitate is soluble in aromatic solvents like toluene and benzene. The fraction of asphaltenes contains the largest percentage of organumetallic constituents (Ni and Fe) and Heteroatoms (O, S, N) in the crude oil [6,7].

The structure of the asphaltenes has been the subject of several investigations, but current studies showed that it is believed to consist of polycyclic aromatic clusters, substituted with varies alkyl side chains. Figure 2.5 shows a typical example of asphaltene monomer molecule. Besides, the molecular weight of asphaltenes crude oil molecules has been difficult to measure due to the tendency of asphaltenes to selfaggregate. However, it is stated that molecular weight in the range of 500 – 2000g/mole is reasonable. Asphaltene monomer molecular size is in the range 12-24Å [3]

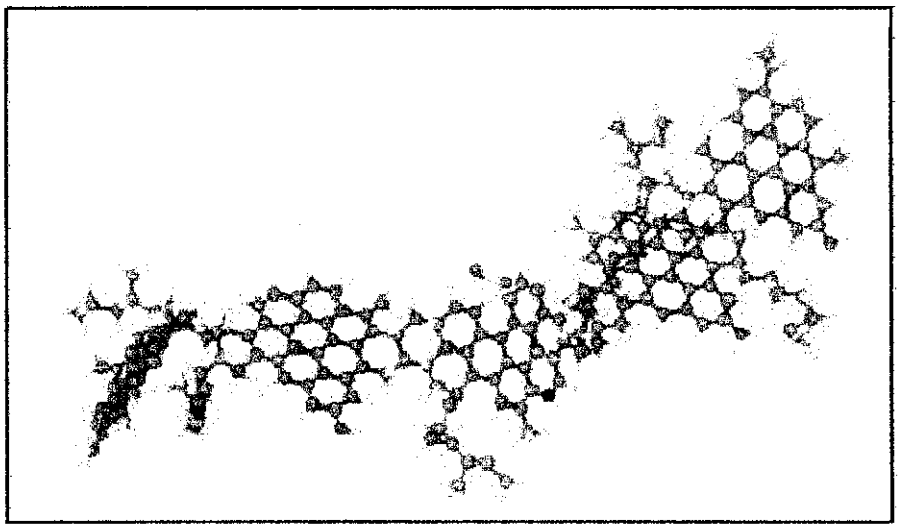

Figure 2.5: Typical asphaltenes molecular structure

The asphalt materials that form asphaltenic crude oil have its influence on liquid/gas equilibrium and interfacial tension. Experiments show that direct current and crude oil separation in a centrifuge may cause black asphaltic materials plated out of crude oil[5]. Besides, asphaltic particles might appear in oils when passing through cores. Asphalt particles also adsorb on dry sand turning it into oil wet[6,7].

At reservoir condition, asphalt is not known to vaporize. In general phase behavior calculation of reservoir fluids, light hydrocarbon and other constituent properties showed continuity in the properties behavior. However, discontinuity occurs for properties calculation with the heavy fraction components. This phenomenon is believed to be a result of the presence of asphalt material. It shows that asphalt properties are not continuous with the properties of lighter fractions[7].

2.4 Parachor

Parachor is a value that needed to quantify in order to obtain the interfacial tension value. Parachor, *P,* has been extensively treated as a parameter representing the molecular volume of a compound under conditions where there is no effect of temperature. *P* is considered to have a unique value for each compound independent of pressure and temperature. It is convenient to split hydrocarbon components when analyzing hydrocarbon fraction. The C_{7+} fractions contain indefinite number of components that contain carbon number of seven and higher. It is shown that for the plus fractions, parachor value must dependent on their molecular weights[1,3].

Figure 2.6 below shows a plot of Parachor vs Molecular weight data. This graphical presentation can conclude that there exists a good linear relationship for a variety of hydrocarbons. This linear relationship can be expressed as $P = aM + b$

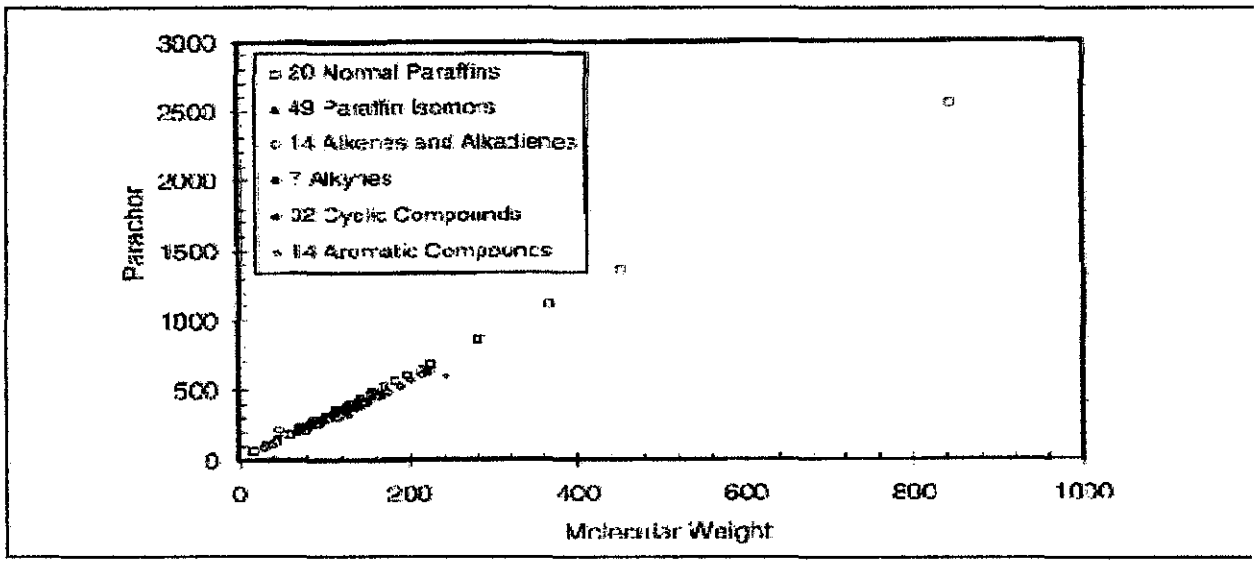

Figure 2.6: Parachor vs Molecular Weight for selected Hydrocarbon [3]

The average parachor value was computed for each cut on the basis of the high pressure measurements. The parachor value was excluded when at the atmospheric pressure from the ring method due to lack of efficiency and reproducibility. With the exception of any residue, the value of parachor of various crude cuts correlate well compare with the molecular weight. The relationship of parachor value and the components are near to a straight line correlation [8].

Chapter 3

Research Methodology

For this project, three main phase of research has been completed. (1) Density measurement (2) Interfacial tension measurement,(3) IFT from parachor method.

3.1 Density Measurement

This experiment used to determine the density of the samples required for this project. The equipment used was densitometer and temperature of 60°C was applied. The important chemicals and apparatus for this experiment were Ethanol 50ml, Toluene 50ml, Dulang Crude oil 20 ml, Iraq Ratawi Crude 20ml, Dulang Crude 80% Iraq Ratawi Crude 20% 20 ml, Iraq Ratawi Crude 80% Dulang Crude 20% 20 ml ,50 ml waste bottle and 10 ml syringe. The procedures for this experiment were:

1. The density was set within the range of 0.000 – 0.001 g/cm^3.
2. 20 ml of dulang crude was added into the accumulator tube using syringe(make sure there was no bubble trapped inside the tube)
3. The temperature was set to 60°C and pushed the start button.
4. The equipment was heated for 30 minutes. Run the density measurement for four times and the results were recorded.
5. 20 ml of toluene was injected to displace the previous sample.
6. 20 ml of ethanol was injected to cleanse the tube from any unwanted fluid in the tubing.
7. Gas was injected to make sure there is no fluid stuck in the accumulator.
8. The density was set within the range of 0.000 – 0.0001 g/cm^3.
9. Step two was repeated with the other samples.
10. The results were recorded 4 – 5 times to ensure the density from the experiment is accurate.

3.2 Interfacial Tension Measurement

The measurement was carried out with reference to American Standard Testing Measurements 974 (ASTM 974). This experiment determined the IFT of the samples required for this project. Operating temperature was 60°C and applied pressure of 1000 psia, 1500 psia and 1820 psia. The important chemicals and apparatus for this experiment were Ethanol 100ml, Toluene 100ml, Dulang Crude oil 30 ml, Iraq Ratawi Crude 30ml, Dulang Crude 80% Iraq Ratawi Crude 20% 30 ml, Iraq Ratawi Crude 80% Dulang Crude 20% 30 ml , CO2, 50 ml waste bottle and 10 ml syringe. The procedures for this experiment were:

1. Prepare the solutions or samples to be injected as listed above.
2. Water was injected to ensure there is no earlier sample stuck in the equipment. This may affect the IFT results.
3. The fluid chamber and injection needles were assembled.
4. Turn on the PC and startup device, check the camera and fluid chamber.
5. The IFT software in the PC was turn on and ready for the experiment.
6. The setting of the experiment was set up using the Da Vincci software from the PC.
7. The accumulator was filled with Dulang Crude oil. Temperature was set to 60°C while pressure was set to 1000 psia. (repeat procedure with 1500 and 1820 psia)
8. CO2 was injected into the chamber using the piston chamber.
9. Crude drop was set at the tip of the needle. This bubble shape was controlled using the injection pump while monitored from the camera.
10. Run the software and the results were recorded.
11. The results was saved in Microsoft work format
12. Procedure was repeated with the other samples.
13. The device was cleaned by injecting ethanol and toluene into the accumulator and the cell heater.

3.3 Project Workflow

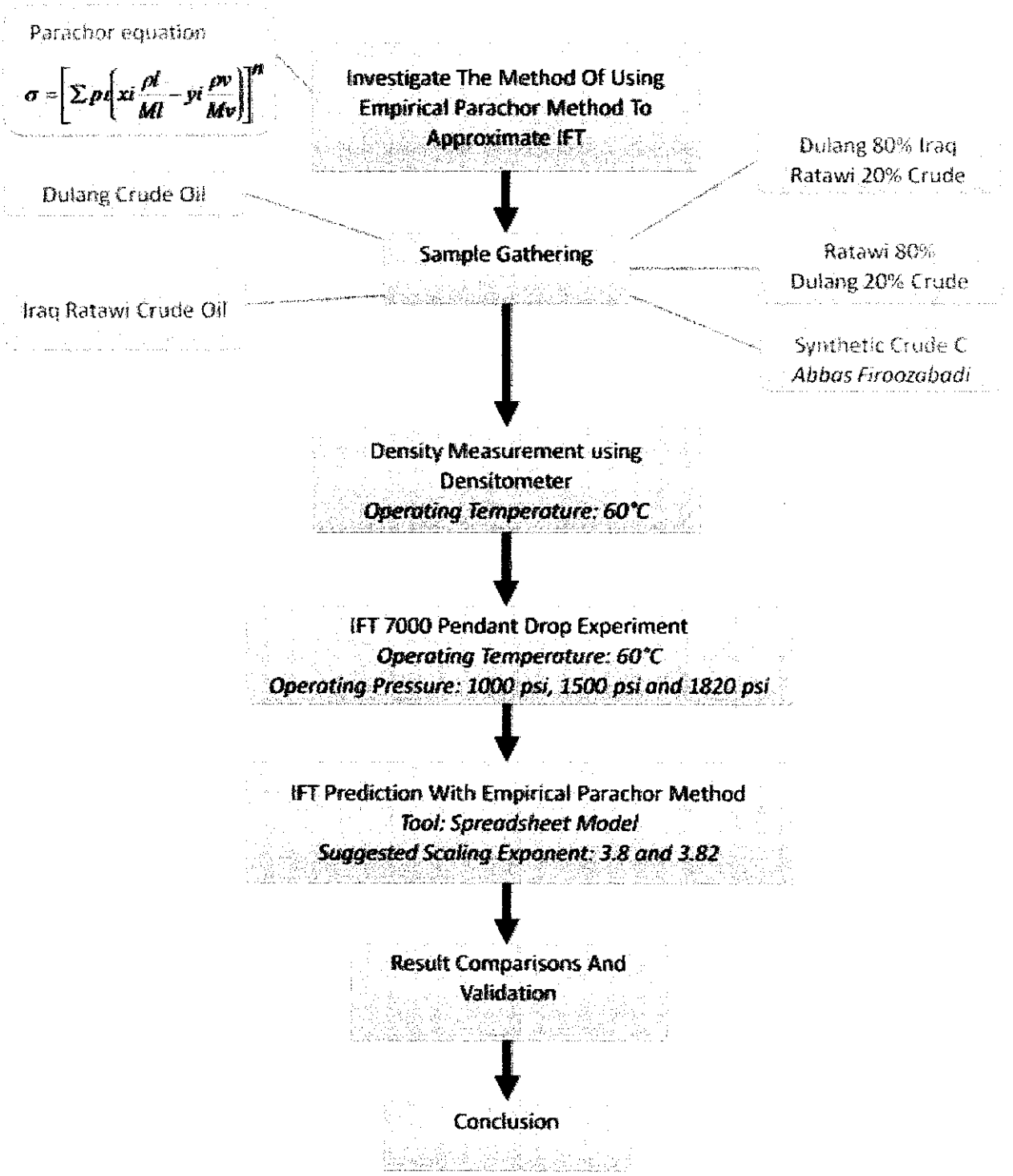

Figure 3.1: Project Workflow

3.4 Gantt Chart

For more details reagarding the project timeline and plan, a reference Gantt chart is provided.

Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13
Sample Preparation													
Density Measurement													
IFT Measurement													
Spreadsheet Modelling													
Progress Report													
Shell Paper													
Data Analysis													
Poster Submission & Presentation													
Interim Report													
Final Presentation													

Table 3.1: Final Year Project II Gantt Chart and guidelines

3.6 Tools Required

The following tools required for this project:

1. IFT 7000 Pendant drop
2. Densitometer
3. Microsoft Excel

Chapter 4

Results & Discussions

4.1 Laboratory Work

This paper completed to experiments which are IFT and density experiment. The equipment used was densitometer and IFT 7000 Pendant drop. Below are the summaries of the results obtained from each experimental phases.

4.1.1 Densitometer Experiment

Sample	Density, g/cm³
Dulang Crude Oil	0.81504
Iraq Ratawi Crude Oil	0.92587
Dulang Crude 80% + Iraq Ratawi Crude 20%	0.83721
Iraq Ratawi Crude 80% + Dulang Crude 20%	0.90370

Table 4.1: Density measurement results

4.1.2 *Interfacial Tension Experiment*

Sample	IFT (dynes/cm) P: 1000psia	IFT (dynes/cm) P: 1500psia	IFT (dynes/cm) P: 1820psia
Dulang Crude Oil	11.33	8.60	2.52
Iraq Ratawi Crude Oil	14.56	10.10	5.20
80% Dulang Crude + 20% Iraq Ratawi Crude	12.05	8.90	3.05
80% Iraq Ratawi Crude + 20% Dulang Crude	13.87	9.80	4.60

Table 4.2: IFT measurement results

4.2 Empirical / Modelling Work

Empirical method used Microsoft excels as the calculation tool. Below are the summaries of the results obtained from each modeling phase.

Scaling Exponent Value, n	IFT (Dynes/cm) from empirical parachor method	IFT (Dynes/cm) from experimental method	Error Percentage ,%
4	7.58	6.90	9.89
3.91	7.24	6.90	4.99
3.88	7.14	6.90	3.41
3.82	6.92	6.90	0.31
3.67	6.10	6.90	7.03

Table 4.3: Dulang Crude Oil IFT from Experiment and Empirical Comparisons

Scaling Exponent Value, n	IFT (Dynes/cm) from empirical parachor method P: 2315 psia	IFT (Dynes/cm) from experimental method P: 2315 psia	Error Percentage ,%
4	4.95	4.60	7.57
3.91	4.77	4.60	3.77
3.88	4.72	4.60	2.53
3.82	4.58	4.60	0.42
3.67	4.34	4.60	5.72

Table 4.4: Synthetic Crude C IFT from Experiment and Empirical Comparisons (P: 2315 psia)

Scaling Exponent Value, n	IFT (Dynes/cm) from empirical parachor method P: 2815 psia	IFT (Dynes/cm) from experimental method P: 2815 psia	Error Percentage ,%
4	3.34	3.19	4.69
3.91	3.25	3.19	1.89
3.88	3.24	3.19	1.56
3.82	3.16	3.19	0.84
3.67	3.02	3.19	5.23

Table 4.5: Synthetic Crude C IFT from Experiment and Empirical Comparisons (P: 2815 psia)

4.3 Discussions

4.3.1 Sample Density Measurement

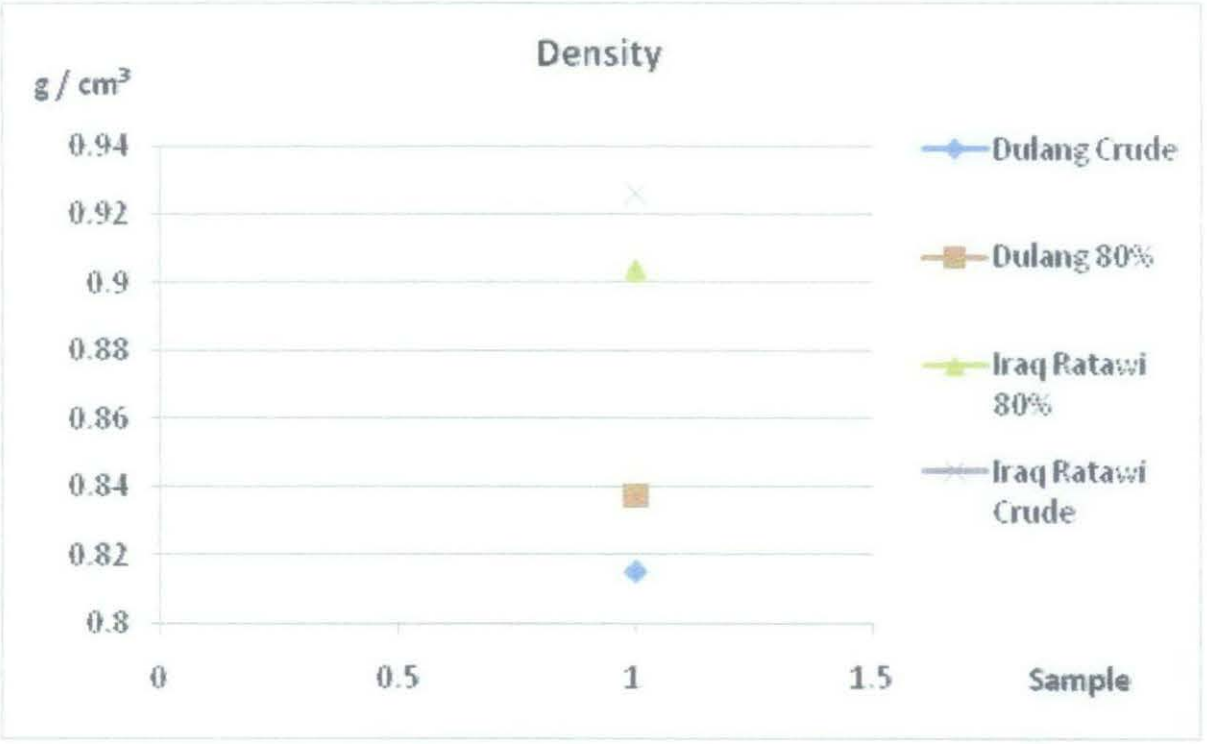

Figure 4.1: Density Comparisons of Crude Used

From figure 4.1, it shows that Iraq Ratawi Crude oil have the highest density compare to Dulang Crude oil. This shows that Iraq Ratawi have the highest percentage of asphaltenes compare to the other samples. Iraq Ratawi has 6-8% of asphaltenes while the lowest is Dulang crude that contain 0.4 – 1% asphaltenes.

4.3.2 Interfacial Tension Measurements

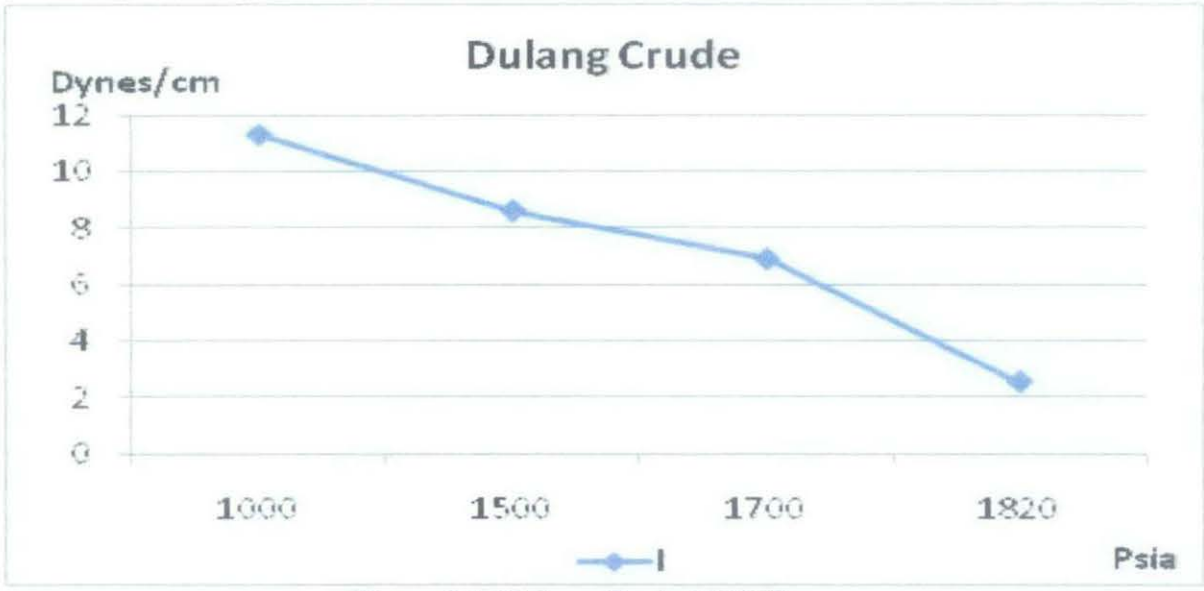

Figure 4.2: Dulang Crude Oil IFT

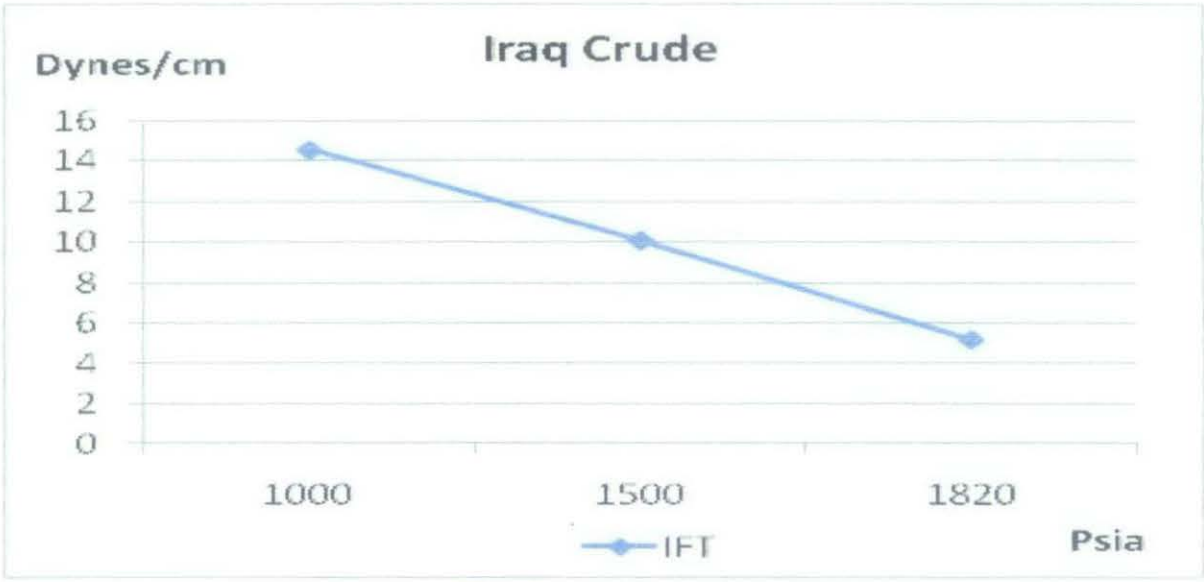

Figure 4.3: Iraq Ratawi Crude Oil IFT

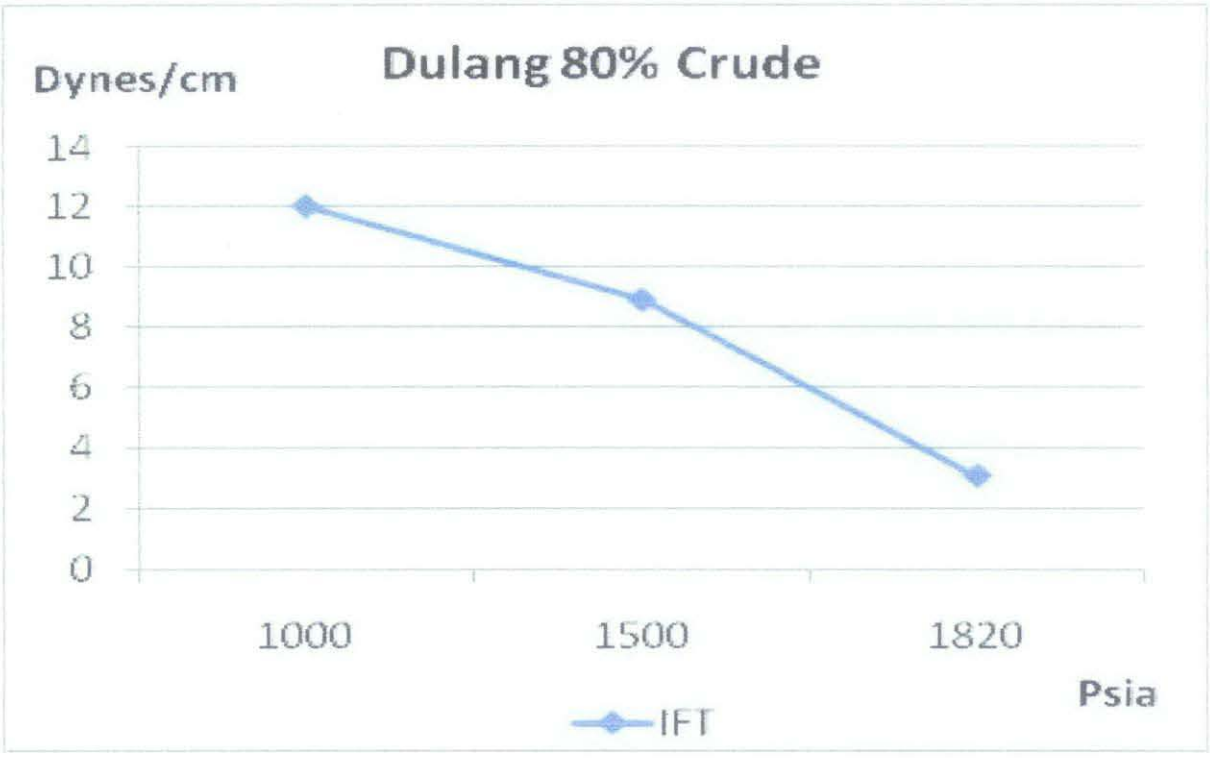

Figure 4.4: Dulang Crude Oil 80% IraqRatawi Crude 20% IFT

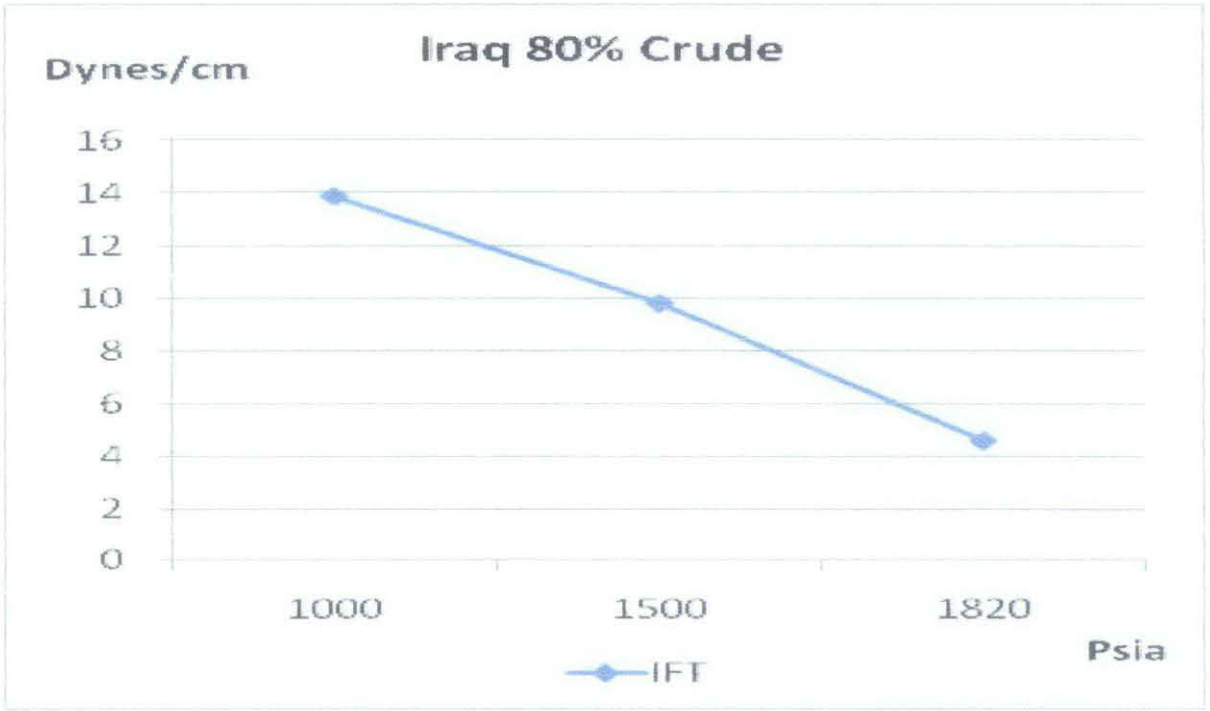

Figure 4.5: Dulang Crude Oil 20% Iraq Ratawi Crude 80% IFT

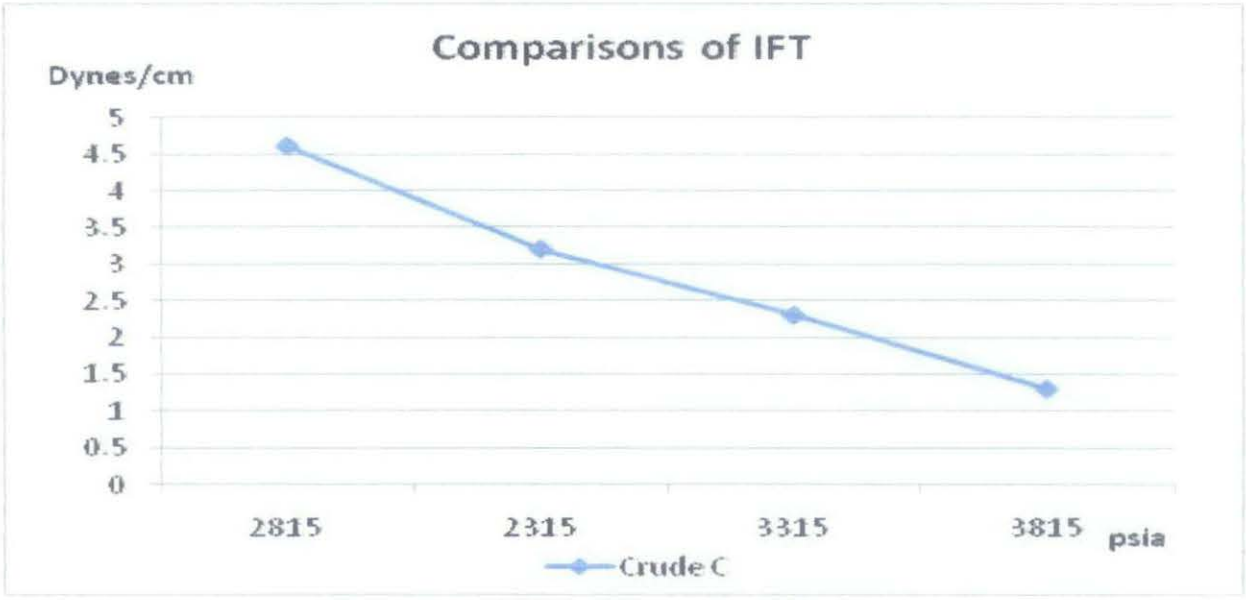

Figure 4.6: Synthetic Crude C IFT [3]

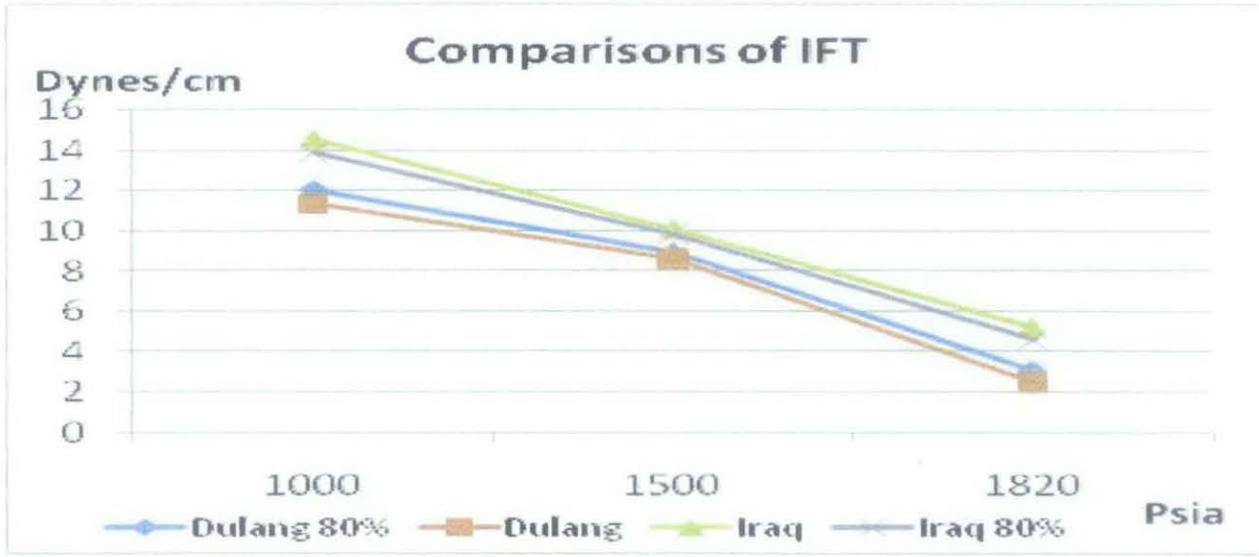

Figure 4.7: Comparisons between IFT

From the graphical presentation of figure 4.2 –4.5, it has been found that the interfacial tension values of the samples will decrease when the pressure increase. This relationship also resulted from Firoozabadi.s study in figure 4.6 [3]. In addition, figure 4.7 shows the comparisons between the samples' IFT. Here it has been found that Iraq Ratawi crude have the highest IFT, followed by Iraq Ratawi 80%, Dulang Crude 80% and lastly Dulang Crude 100%.

4.3.3 Parachor Scaling Exponent Value IFT

As mention in previous sections, this paper will study the error percentage results from the widely used scaling exponent values. The values are 4.00, 3.91,3.88 and 3.67. If the IFT predicted from parachor method from these values produce an unacceptable percentage of error for asphaltenic crude oil, this paper will suggest a new value that will encounter this problem.

Figure 4.8: Error Percentage Comparisons between Scaling Exponent Value of Dulang Crude Oil

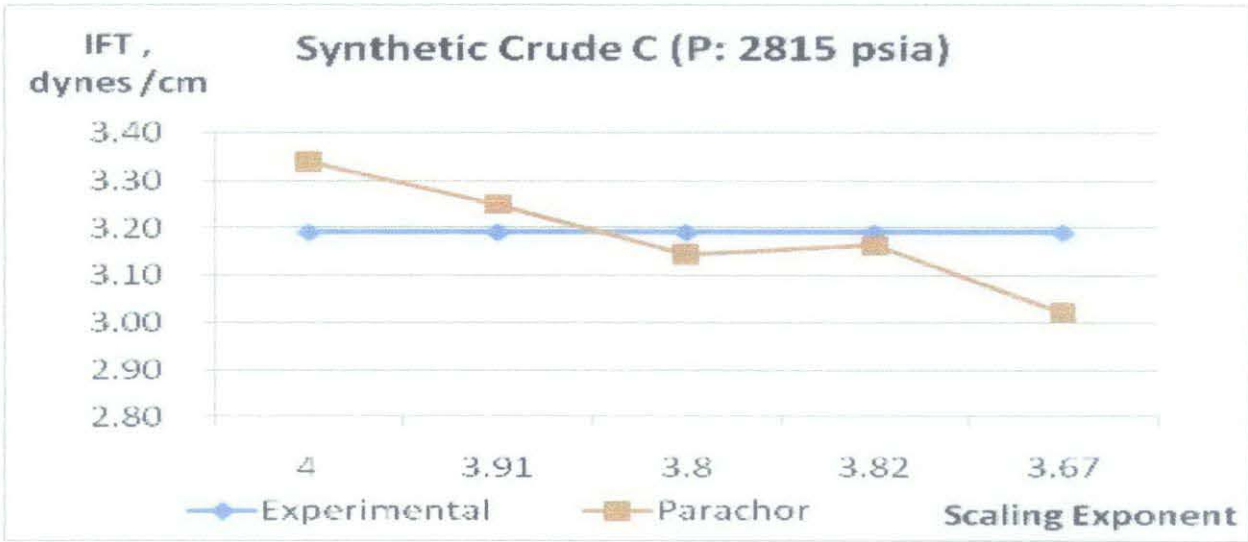

Figure 4.9: Error Percentage Comparisons between Scaling Exponent Value of Synthetic Crude Oil C (P: 2815 psia)

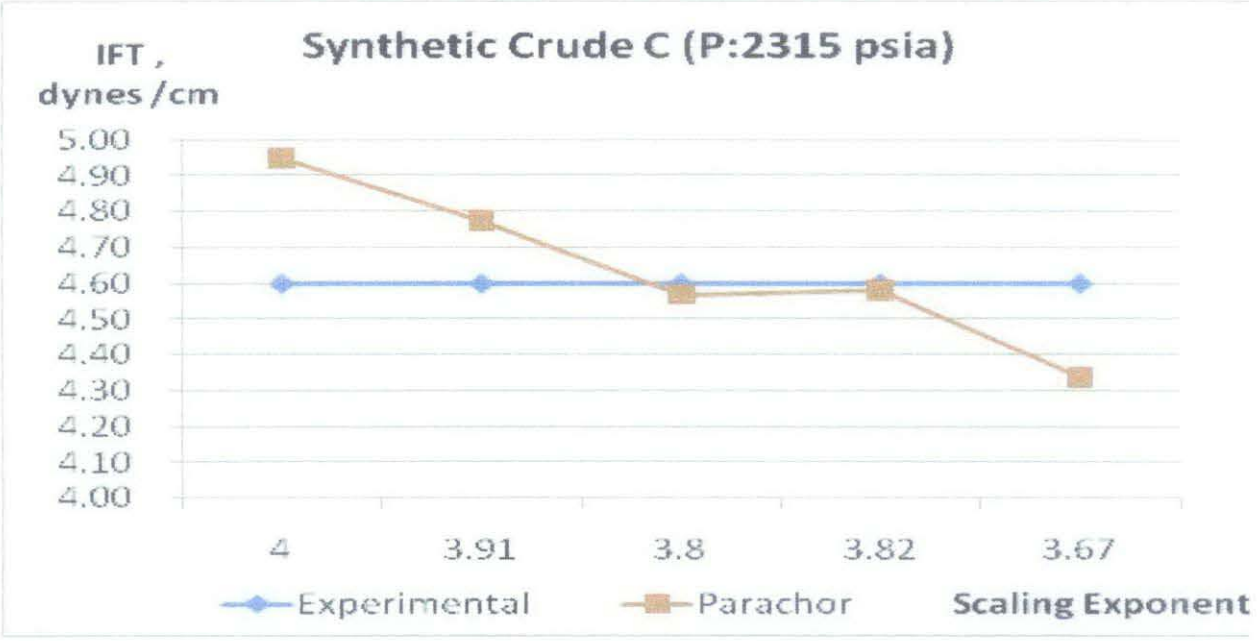

Figure 4.10: Error Percentage Comparisons between Scaling Exponent Value of Synthetic Crude

This paper has found that this widely used scaling exponent value is not applicable when predicting IFT for asphaltenic crude oil. For crude that contains more than 0.01% of asphaltenes contain, the parachor method will not be accurate. Thus, this paper has suggested and tries new scaling exponent values to encounter this problem.

Figure 4.8 – figure 4.10 shows the comparisons between IFT values with different scaling exponent values. From this project, it has been found that the suggested scaling exponent values from earlier studies will result to a high percentage of error when applied to asphaltenic crude oil. The further study about this errors are as per below.

4.3.4 Scaling Exponent Value Error Percentage Comparisons

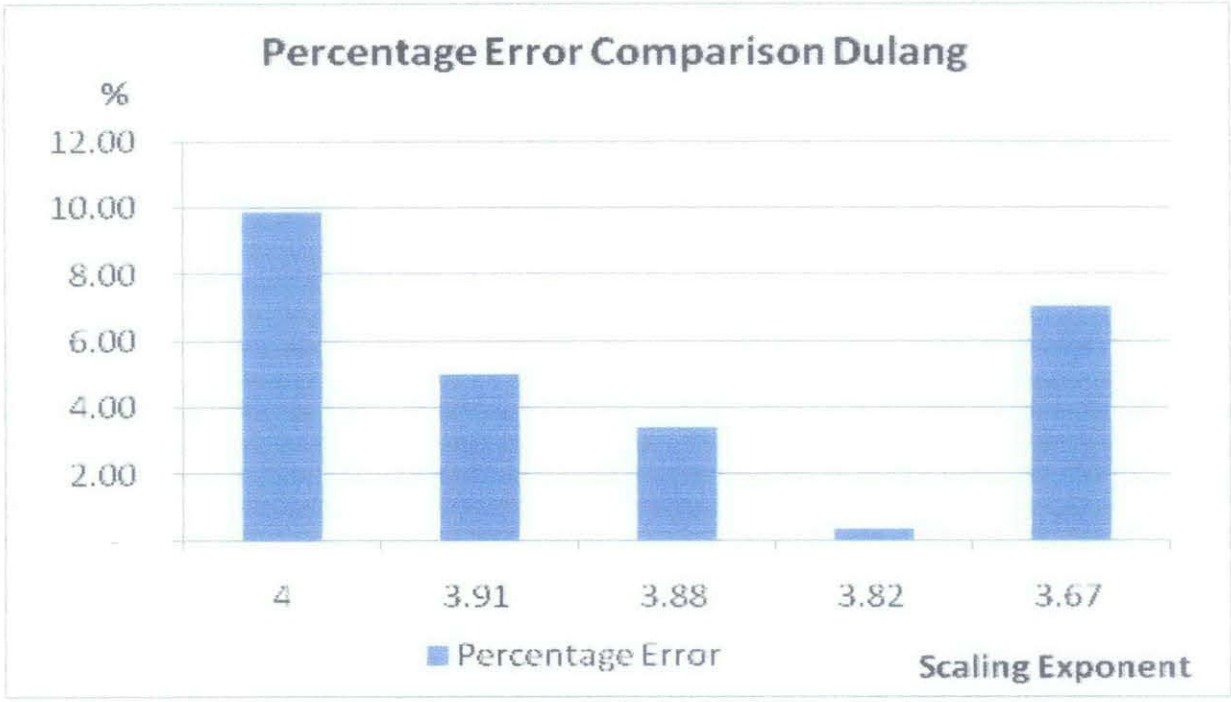

Figure 4.11: Error Percentage of each Scaling Exponent Values Used for Dulang Crude

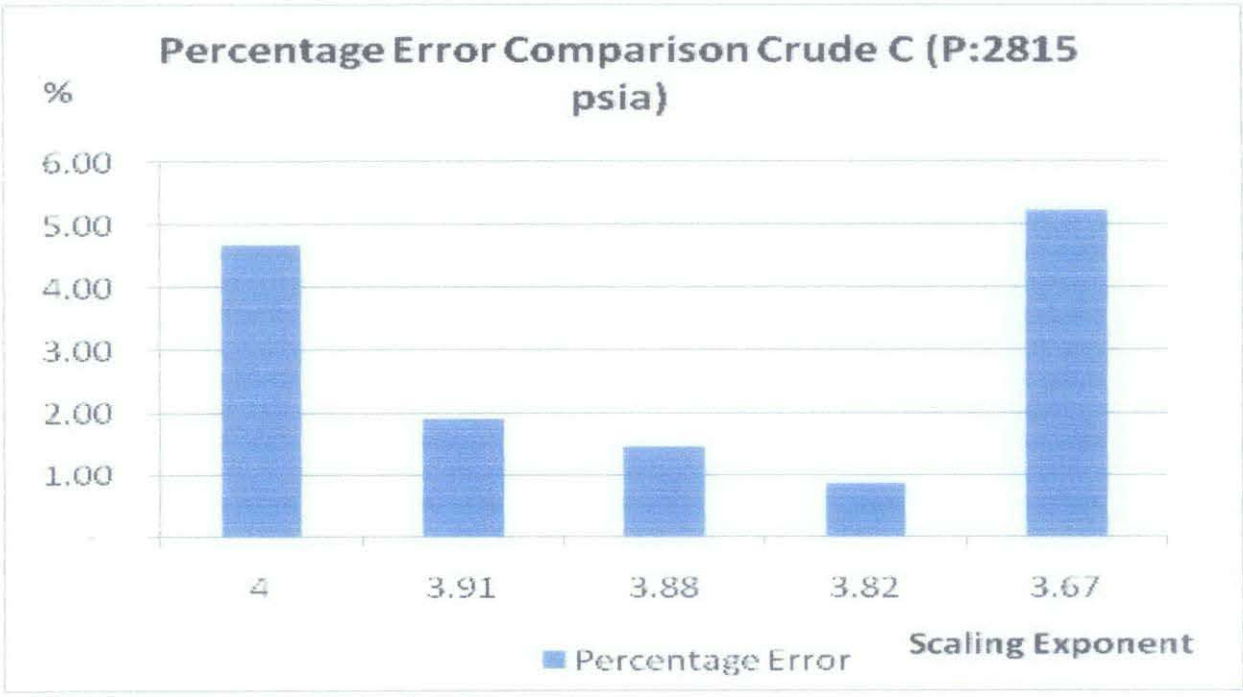

Figure 4.12: Error Percentage of Each Scaling Exponent Values Used for Crude C (P: 2815 psia)

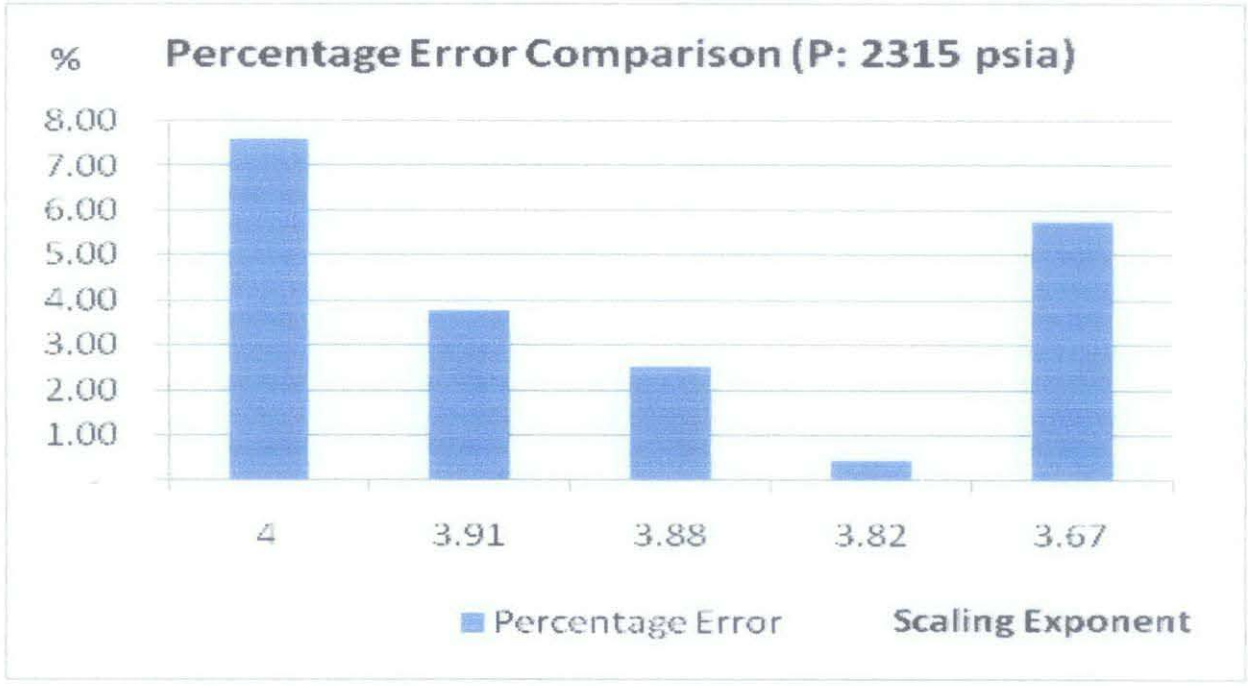

Figure 4.13: Error Percentage of Each Scaling Exponent Values Used for Crude C (P: 2315 psia)

Figure 4.11 – 4.13 shows the detail of error percentage produced from each of the scaling exponent values used in this project. This is the extended study of previous section. Here, it has been found that scaling exponent value of 4[3] gave the highest error percentage for asphaltenic crude oil. While, scaling exponent value of 3.82 suggested from this paper produced the lowest error percentage when applying parachor method to predict the IFT of asphaltenic crude oil.

Chapter 6

Conclusions & Recommendations

6.1 Conclusion

From this paper, asphaltenes presence in crude proves to be one of the major factors in determining interfacial tension values. In summary:

1. Higher asphaltenes content produced a higher interfacial tension value. IFT for Dulang crude with 0.4% of asphaltenes is lower compare to Iraq Ratawi Crude with 6-8% asphaltenes.
2. The suggested new scaling exponent value decreased the error resulted from parachor method 10% to less than 1%. The scaling exponent value of 4 from the study of Macleod gives good prediction of IFT for crude oil that has low asphaltenic (<0.1%). However, it gave the highest error percentage when predicting asphaltenic crude oil.
3. This paper suggests the scaling exponent value for asphaltenic crude oil to be 3.82. This new scaling exponent value decreased the error resulted for IFT prediction to <1%. Thus, the parachor method equation for asphaltenic crude oil is:

$$\sigma = \left[\sum pi \left(xi \frac{\rho l}{Ml} - yi \frac{\rho v}{Mv} \right) \right]^{3.82}$$

6.2 Recommendation

One of the major problems for this project is the lack of equipment. There are some properties that the author cannot determine because of this problem. Thus, it is highly recommended for this project to continue with the availability of gas chromatography that can determine dead oil fluid composition. With this, this project can come up with a better data and result analysis and further propose a more accurate scaling exponent value.

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6. Chapter 8, Interfacial Tension, " *PVT and Phase Behavior of Petroleum Reservoir Fluids*", Ali Danesh, pp 281-297
7. Narve Aske, "*Characterization of Crude Oil Components, Asphaltenes aggregation and emulsion stability by means of near infrared spectroscopy and multivariate analysis*", Norwegian University of Science and Technology, Trondheim.
8. Chang-Yu Sun and Guang- Jin Chen, "Measurement of Interfacial Tension for the CO2 Injected Crude Oil and Reservoir Water System", Technical Paper, University of Petroleum, Beijing.

Appendixes

Reading	Density (g/cm³)
1	0.814967
2	0.815241
3	0.813922
Average	0.815043

Table 1: Dulang Crude Oil Density

Reading	Density (g/cm³)
1	0.92419
2	0.92267
3	0.93075
Average	0.92587

Table 2: Iraq Ratawi Crude Oil Density

Reading	Density (g/cm³)
1	0.83681
2	0.83672
3	0.83809
Average	0.83721

Table 3: Dulang Crude Oil 80% Iraq Ratawi Crude Oil 20%

Reading	Density (g/cm³)
1	0.902345
2	0.901184
3	0.907584
Average	0.903704

Table 4: Dulang Crude Oil 20% Iraq Ratawi Crude Oil 80%

Reading	IFT (Dynes/cm) P: 1000 psia	IFT (Dynes/cm) P: 1500 psia	IFT (Dynes/cm) P: 1700 psia	IFT (Dynes/cm) P: 1820 psia
1	10.52	8.71	7.21	2.42
2	11.72	8.59	6.59	2.71
3	11.47	8.62	6.8	2.31
4	11.61	8.64	7.0	2.62
Average	11.33	8.60	6.9	2.52

Table 5: Dulang Crude Oil IFT

Reading	IFT (Dynes/cm) P: 1000 psia	IFT (Dynes/cm) P: 1500 psia	IFT (Dynes/cm) P: 1820 psia
1	14.87	10.50	5.10
2	15.21	9.70	5.87
3	13.92	10.19	4.95
4	14.25	10.01	4.89
Average	14.56	10.10	5.20

Table 6: Iraq Ratawi Crude Oil IFT

Reading	IFT (Dynes/cm) P: 1000 psia	IFT (Dynes/cm) P: 1500 psia	IFT (Dynes/cm) P: 1820 psia
1	11.52	9.12	3.10
2	12.25	8.71	3.32
3	12.10	9.06	2.78
4	12.31	9.21	3.01
Average	12.05	8.90	3.05

Table 7: Dulang Crude Oil 80% Iraq Ratawi Crude 20% IFT

Reading	IFT (Dynes/cm) P: 1000 psia	IFT (Dynes/cm) P: 1500 psia	IFT (Dynes/cm) P: 1820 psia
1	13.86	9.61	4.44
2	14.26	10.02	5.16
3	13.56	9.77	4.51
4	13.81	9.88	4.28
Average	13.87	9.80	4.60

Table 8: Dulang Crude Oil 20% Iraq Ratawi Crude 80% IFT

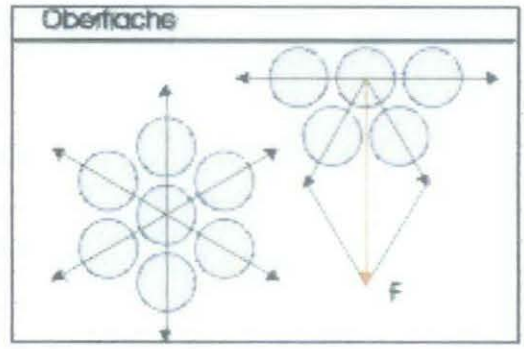

Figure 1: Attractions between Molecules

Figure 2: IFT 7000 Equipment