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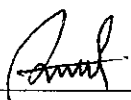3. This thesis is classified as

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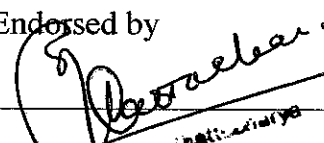Remarks on disclosure:

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UNIVERSITI TEKNOLOGI PETRONAS

TESTING MODIFIED EVAPORATIVE FRACTIONATION IN A CLOSED
SYSTEM FOR SELECTED OILS

by

SYAZAILA WASLI

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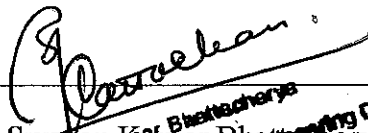
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TESTING MODIFIED EVAPORATIVE FRACTIONATION IN A CLOSED SYSTEM FOR SELECTED MALAY BASIN OILS

by

SYAZAILA WASLI

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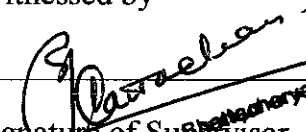
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ABSTRACT

The study areas that have been chosen are Malay Basin and Sabah Basin. Malay Basin is situated in the southern part of the Gulf of Thailand, between Vietnam and Peninsular Malaysia. Sabah Basin is situated in the northern part of the island of Borneo and has a complex structural history. The primary objectives of this study are to study the characteristics of oil in reservoir rock with geochemical evaluation of the oil characters and to test the alteration of reservoir oil by modified evaporative fractionation technique.

Erb West crude oil in Sabah Basin generally is slightly waxy, light, contents of low sulphur and the API gravity value is about 28^0 while the gas constituent is 92% methane. The Erb West structure is an elongated hydrocarbon bearing sand layer, and it lies in a north-easterly by south westerly direction. As for oil in Dulang field, it has a large oil accumulation and account for a majority of the Group E oils in the basin. Mostly, oils in this group are immature over much of the basin except only in the lowest part of E reaches the oil window in some areas. A majority of Group E oils are moderately waxy to waxy and condensates are more common, and the gas produced is known to be high in CO_2. Angsi predominantly has Pre-group I oils in Malay basin. The geochemical characteristics vary only little in Pre-group I and this variation is considered to be due to a combination of differing maturity of the oils and of post-accumulation processes such as evaporative fractionation.

The crude oil sample from each of basin was carried out using modified evaporative fractionation technique in a closed system. In this process, instead of injecting gas, the oil were heated at certain temperature and allowed adequate vapour pressure to build up over oil in a closed system. The first analysis of the vapour and residual oil samples from Erb West, Dulang and Angsi oil at the desired pressure suggested increasing in aromaticity and decreasing in paraffinicity. All data from Erb West, Dulang and Angsi show the same pattern for each of the graph data (show by the similarity from the value) because they remained in equilibrium state (both

residual oil and vapour samples). Residual oil and vapour samples were taken from the same oil with the same temperature and pressure during each stage of the experiment. The flow of heat in the first experiment for modified evaporative fractionation in closed system is based on thermodynamic cycle. So, the results for first experiment cannot show the whole effect of modified fractionation technique.

Due to this situation, a second test of modified evaporative fractionation technique (second test) has been done only for Angsi. Angsi oil is chosen to show how modified fractionation can effect the changes of characteristics of crude oil. The vapour sample was collected at 90 psi (pressure) of $250^{0}C$ (maximum temperature) and residual oil sample was taken out after a cooling process of fractionation. The results (second experiment) show the value of aromaticity is decreasing in residual sample and rich in vapour sample while the value of paraffinicity is rich in residual sample and decreasing in vapour sample. The result in second test is different and vice versa from the first experiment because the technique for collecting oil samples for both residual oil and vapour samples are different.

The effect of temperature and pressure can change the characteristics of crude oil. Evaporative fractionation becomes a method of changing original crude oil to paraffin rich in the original reservoir and aromatic rich fractionated oil in shallower reservoir. Thus, it appears to be one of the major mechanisms of generation of gas-condensate fluids.

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LIST OF ABBREVIATIONS

μL	Microlitre
μm	Micrometre
^{0}C	Celsius
^{0}F	Fahrenheit
API	American Petroleum Institute
C_{20} - C_{40}	Molecular weight biomarker
C_{22}	Hastelloy
C_5H_{12} - C_8H_{18}	molecular formula in gasoline range
C_7 "Mango"	Mango parameter
C-H bond	carbon-hydrogen bond
CH_2	Methylene
C_nH_{2n+2}	Paraffin
C_nH_{2n6}	Aromatic
CO_2	carbon dioxide
DRU	Deep regional unconformity
Ft	Feet
GC	Gas chromatography
GC - MS	Gas chromatography - Mass spectrometry
H/C	Atomic hydrogen to carbon ratio
HC/g	hydrocarbon/gram
Km	Kilometre
km^2	kilometre per square
M	Metre
m/z	mass to charge ratio
MCH	Methylcyclohexane
Mg	Milligram
Ml	Millimetre
M	Millimetre

MS	Mass spectrometry
n	Normal
n-C$_7$	Toluene
NSO	nitrogen-sulphur-oxygen
OPEC	Organization of the Petroleum Exporting Countries
pH	an potential hydrogen ion
PID	Proportional integral derivative
Pr/Ph	pristane to phytane ratio
psi	pressure-sensing instrument
SRU	Shallow regional unconformity
TOC	Total organic carbon
WEC	World energy conference
wt%	weight percentage

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter covers the introduction for the entire work process. It includes the study of background, problem statement, objectives and the scope of study in evaporative fractionation for this research.

1.2 Background of Study

Evaporative fractionation as a mode of reservoir alteration of trapped hydrocarbon was established by Thompson (1987) whereby fractionation was carried out using gas influx over reservoir oil. "Under this condition, evaporative fractionation can also result in generated aromatic rich residual oil in the original reservoir and paraffin rich fractionated oils in the upper shallower reservoir. This occurs when the parent oil undergone repeated gas washing episodes, such that no saturated compounds are left to be stripped by migrating gas, and then a subsequent migrating gas is forced to pick up a very aromatic-rich residue from the parent oil, and delivers that material to a shallower reservoir where it condenses out as an aromatic-hydrocarbon-rich condensate", Thomson (1987). Such fractionation leads to variable compositions depending on the composition of gas because solubility of the liquid components in gas depending on the pressure-temperature and also the composition of the gas. In University Technology Petronas (UTP), a technique of evaporative fractionation had been developed in a closed system. In this process, instead of injecting the gas, the oil had been heated at certain temperature and allowed an adequate vapour pressure to build up over oil in a closed system.

out. The analysis of the vapour and residual oil samples at the desired temperature and pressure suggest an increased in aromaticity and decreased in paraffinicity. Both residual oil and vapour show same pattern because they remain in equilibrium. Logically, it was inferred that when aromaticity increases in the vapour, the residual oil should be correspondingly rich with paraffins. Thus, it became a method of changing original crude to paraffin rich oil in the original reservoir and aromatic rich fractionated oils in shallower reservoirs. For first experiment, the modified technique has been tested by using Sabah oil. Then, the experiment was continued with Dulang and Angsi oil. Original oil was heated up to 100^0C, 150^0C, 200^0C and 250^0C in different stages at each temperature and 20psi, 40psi, 60psi and 80psi pressures stages were attained. For every temperature-pressure stage, samples from vapour and liquid were collected and analysed. Results indicate that the paraffinicity decreases and aromaticity increases at every stage. The results suggested this process of closed system fractionation causes high paraffin in residual oil and corresponding fractionated oil gets more aromatic. The results of corroborate analysis was made by Yarborough (1972).

1.3 Problem Statement

Generally, the changes in oil composition were ascribed to the organic facies variation. However, evaporative fractionation also can change oil characters by redistribution of compounds in distillates and residues. The change follows pressure – temperature conditions in the basin and is unique for each basin conditions. It is necessary to experimentally verify the nature of distributed hydrocarbons in the selected oils using modified evaporative fractionation technique.

1.4 Research Objectives

In this study, the interpretations of geochemical analysis were the convenient way to justify the characteristics of crude oil. This research will enable the researcher to achieve the following objectives:

1. To study the characteristics of oil in reservoir rock / detailed geochemical evaluation of the oil characteristics.
2. To test alteration of reservoir oil by modified evaporative fractionation technique.

1.5 Scope of study

The selected areas were chosen based on the occurrences and the production of oils in the field. Samples of oil for the experiment were collected in Sabah basin and Malay basin. Malay basin is located in the Peninsular Malaysia while Sabah basin is located at the East Malaysia. Malay basin and Sabah basin are different from the geography location, reservoir characteristics and also the composition of oil in the field. Both of the basins were chosen to make a comparison due to the changes of characteristics and the composition of oil. A comprehensive distillation test using modified evaporative fractionation technique was planned to be carried out to test hydrocarbon occurrences in selected Malay Basin (Dulang and Angsi) and Sabah basin (Erb West) area. Malay basin is the largest petroliferous basin in Sunda Shelf. It is also one of the deepest continental extensional basins in the region. In Malay Basin, the natures of accumulated hydrocarbons are variable both laterally and vertically.

As for Sabah basin, it is known with a complex geological history and lying adjacent to actively moving plates in the Southeast Asian region compared to Peninsular Malaysia. Most of the hydrocarbons occurred in complex wrench-induced faulted anticlines, rollover anticlines associated with deltaic growth faults, and other fault-related closures. Oils from different reservoirs and same reservoirs were not uniform in a particular field and also in different fields. These variations of the composition of oil can be ascribed to variation of organic facies in the source rock or

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it can be possibly by in-reservoir alteration. So far it has been justified by assuming facies variation in source rocks. However, reservoir alteration associated with compositional change can also occur by evaporative fractionation in which injected gas over oil can dissolve some compounds of oil and remove as the gas escapes. The vaporization process of gas carrying oil components in the gas phase through permeable pathways has been investigated by several workers (Zhuze et al., 1962; Silverman, 1965; Thompson, 1987).

Thompson (1987) defined that the process as evaporative fractionation in which a charge of dry gas enters an existing oil accumulation. The gas then equilibrates with light components of the reservoir oil. The gas vented from the accumulation and taking with it the dissolved components that originally is part of oil accumulation. The migrating gas may then condense out a liquid (or "retrograde condensate") in a shallower reservoir. Therefore, this process is the cause of two new fluids: (1) More paraffinicity condensate in a shallower reservoir, and (2) More aromatic residual oil (in the original reservoir) depleted in the light paraffin and enriched in the other fractions and this process known as fractionation as shown in Figure 1.1. At lower temperature, the rate of decrease of paraffinicity in liquid is uniform and linear with pressure whereas at higher temperature the rate of decrease is polynomial of power two. However, the decrease is faster at lower pressures and with higher pressure the rate of decrease of paraffinicity is reduced. Compositions of oil in terms of aromatic and paraffin fractions are to be compared using gasoline range known as 'Mango Parameters'. This was because only the gasoline range compounds are mobile between vapour and liquid phases during fractionation.

Crude oil is a complex mixture of many different components in chemical systems. The fluids contain from hundreds to thousands of individual components in the range of simple molecular weight n-alkanes to the high molecular weight waxes and asphaltenes. Due to the content of these high molecular weight substances, crude oils are somewhat colloidal in nature. Reservoir crude oils were very close to the thermodynamic equilibrium, but during the production the changes of pressure and temperature can cause a disturbance of the equilibrium and phases separation may result. Crude oil is an example of supersaturated solution because the concentration of

dissolved solute is higher than the saturated solution. In crude oil system, light hydrocarbon components such as methane and ethane act as a solvents to the supersaturated solution and the saturation depends on the temperature.
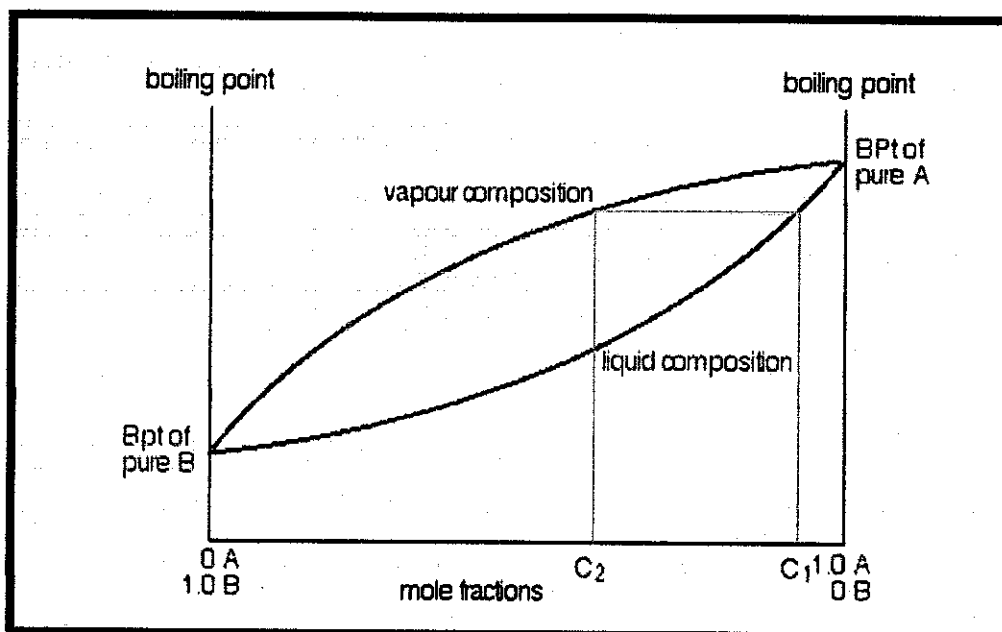
Figure 1.1: Shows phase behavior of a mixture of two ideal liquids at 1atm. Pressure
(Source: Raoult's Law)

Crude oils were often being processed or transported at conditions where fluid temperature may decrease due to greater heat loss to the surrounding. When the crude oil was cooled, a transition from none equilibrium to the equilibrium is accompanied by crystallization. The conditions under which supersaturated crude oils were formed and the properties of the crude oils govern. This will affect the nature of waxing or crystallization. The separations of these components into usable products are known as refining. Refineries must be designed to handle the type of crude oil that is going to be process. The amount of gasoline and fuels that were produced or distilled was relatively small, and in some conditions were by-products of the refining process. From the analysis of the crude oil, it can be determined what the basic composition of the crude is and what applications it is suited for.

As example as crude oil comes out of the ground, it can be the American Petroleum Institute (API) gravity methodology that can determines these differences. The oil portion of cylinder stock is a heavy lubricant base stock that used in heavy

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duty gear oil applications and many industrial lubricants. The refining of crude oil was complex and involved operations that generate many different components that we use in our daily lives. The proposed research was carried out in a selected field (Malay basin and Sabah basin). Both basins were chosen to test the compositional variation of oil composition with modified evaporative fractionation process under different temperature and pressure. In this research it was proposed to generate vapour by heating oil and allow the vapour to build pressure on oil. The vapour generated was allowed to equilibrate with oil at a definite temperature and pressure. Then the sample of vapour and original oil were analysed for comparison.

The first experiment was tested with the oil composition in the Sabah Basin. Oil samples from Sabah Basin were carried out and completed using the test of compositional variation with modified evaporative fractionation process under different temperature and pressure stage. The technique was tested using Sabah oil basically was heated to 100^0C, 150^0C, 200^0C and 250^0C in different stages and at each temperature stage 20psi, 40psi, 60psi and 80psi pressures were attained. The change in composition will ultimately be compared with distribution of hydrocarbons in the reservoirs to understand their genesis. Experiment for Dulang and Angsi also were carried out using the same method as in Sabah oil.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter covers the literature related to this study. It is mainly focussed on evaporative fractionation and distillation process. This topic is divided into three sections mainly which are history, function and the effect that are related to evaporative fractionation and distillation process.

2.2 History of Fractional Distillation Process

Distillation is the principal method for separating crude oil into useful products. Fractional distillation was developed by Tadeo Alderotti in the 13th century. Both alembics and retorts are forms of glassware with long necks pointing to the side at a downward angle which acted as air-cooled condensers to condense the distillate and let it drip downward for collection. Later, copper alembics were invented. Riveted joints were often kept tight by using various mixtures, for instance dough made of rye flour. These alembics often featured a cooling system around the beak, using cold water for instance, which made the condensation of alcohol more efficient. These were called pot stills. Today, the retorts and pot stills have been largely supplanted by more efficient distillation methods in most industrial processes. Early forms of distillation were batch processes using one vaporization and one condensation. Purity was improved by further distillation of the condensate.

Greater volumes were processed by simply repeating the distillation. Chemists were reported to carry out as many as 500 to 600 distillations in order to obtain a pure

compound. In the early 19th century, the basic of modern techniques including pre-heating and reflux were developed, particularly by the French.

2.3 Function of evaporative fractionation

Evaporative fractionation is defined as the vaporization process of gas-carrying oil in the gas phase vertically through faults, fractures, and other permeable pathways and being trapped as condensate in the shallower reservoir. In order to emphasize, it involves a fractionation process that can form aromatic condensates. It is also known as geologic process of reservoir alteration of crudes during which lighter fraction of oil is evaporated and condensed in the shallower reservoirs (Thompson, 1987). The process involves (i) a charge of gas (generally dry) entering an existing oil accumulation, (ii) the gas then equilibrates with the light components of the reservoir oil, and then (iii) the gas is vented from the accumulation, taking with it dissolved components that originally were part of the oil accumulation. The migrating gas may then condense out a liquid (or "retrograde condensate") in a shallower reservoir. Therefore, this process is the cause of two new fluids: (1) High-gravity retrograde condensate in a shallower reservoir, and (2) Lower gravity, more aromatic residual oil (in the original reservoir) depleted in the light paraffin and enriched in the other fractions in which the process known as fractionation. An experiment were carried out as many as eleven successive equilibration steps of oil supersaturated with methane at 6000 psi and 127^0C (260^0F).

Respectively, the experiment shows the increase in aromaticity and decrease in paraffinicity. Aromaticity is measured as the ratio of toluene to n-heptane and paraffinicity as n-heptane to methylcyclohexane. In the experiment, the first two condensates are slightly less aromatic than parent oil, succeeding condensate become highly aromatic and naphthenic (less paraffinic) and this situation are called evaporative condensates (Thompson, 1987). In evaporative fractionation, the original reservoir oil may be supersaturated with methane by either thermal alteration of conventional oil or methane migration through the reservoir from a deeper source (gas stripping). As the gas with dissolved oil migrates upward, hydrocarbons liquefy and

drop out on the way, just as in the distillation tower. Consequently, the shallowest oils and condensates have the highest API gravity (lowest specific gravity) (John M. Hunt, 1979). The highest value of API is more related in quality of hydrocarbons but not all high API gravity crude oils are condensates, especially if they contain little or no methane (Sanudin Hj Tahir, 2003).

2.4 Function of distillation process

Distillation is a method of separating mixtures based on differences in their volatilities in a boiling liquid mixture. Distillation is a unit operation, or a physical separation process, and not a chemical reaction. Commercially, distillation has a number of applications as shown in Figure 2.1. It is used to separate crude oil into more fractions for specific uses such as transport, power generation and heating. Distillation of fermented solutions had been used since ancient times to produce distilled beverages with higher alcohol content. Crude oils form a continuum of chemical species from gas to the heaviest components made up of asphaltenes and the techniques of fractionation is used in the characterization of petroleum as well as the techniques of elemental analysis applied to the fractions obtained. Distillation process is a first step to distillate crude oil and separates the mixture of crude oil that related with its boiling points and hydrocarbon structures.
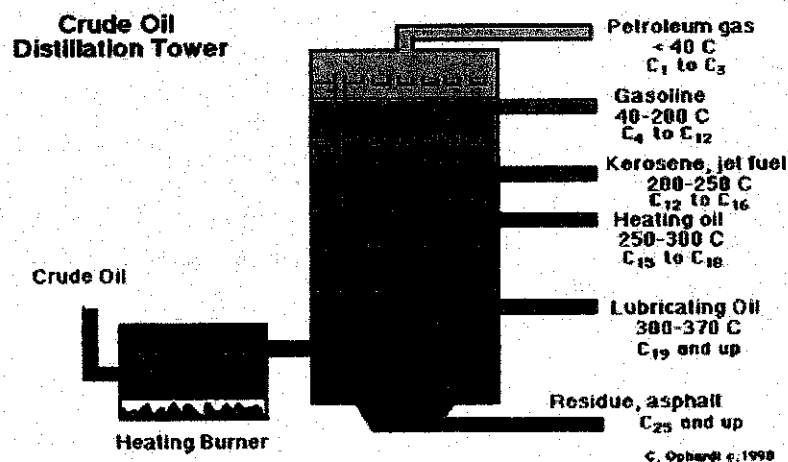
Figure 2.1: The simple crude oil distillation tower (Vasily Simanzhenkov and Raphael Idem, 2003).

Subsequently, these molecules are separated from the liquid forming the gas state. The vapour pressure is caused by a balance between molecules in a gaseous state and molecules in a liquid state that is consider as the beginning of boiling process. The boiling point is a rough measure of the amount of energy required to separate a liquid molecule of their closest neighbours (Vasily Simanzhenkov and Raphael Idem, 2003). A series of alkanes shows the general principle that boiling points will increase with the increasing of molecular weight or length of the string. Focus on oil and fossil fuels; fractional distillation of petroleum (oil refining) is the physical process of separation of the mixtures and compounds present in many crude oil in which the components of a mixture are separated by heating at different temperatures. It is used for separation of complex mixtures and purification of crude oil. The principle used is that the longer the carbon chain, the higher the temperature of these compounds. Crude oil is heated and became gas.

The gases pass through a distillation column cool as altitude increases. When a compound in the gaseous state cools below its boiling point, it condenses into a liquid (M.R.Riazi, 2005). The liquid can be extracted from the distillation column at different heights. Although all fractions of petroleum, the greatest demand is for gasoline. A barrel of crude oil contains only 30-40% gasoline. Transportation demands required that over 50% of crude oil became gasoline. To meet this demand some petroleum fractions must be converted to gasoline. That can be achieved by "cracking." "Cracking" is decomposition of large molecules of heavy heating oil, "reform" that is changing the molecular structures of molecules of low quality gasoline, or "cures" the formation of smaller molecules. For example, if pentane is heated to about 500^0C, the carbon-carbon covalent bonds begin to break during the cracking process. Many types of compounds including alkenes are made during the cracking process as shown in Figure 2.2. Alkenes are formed because there are not enough hydrogen atoms to saturate all membership positions after the carbon-carbon bonds are broken.
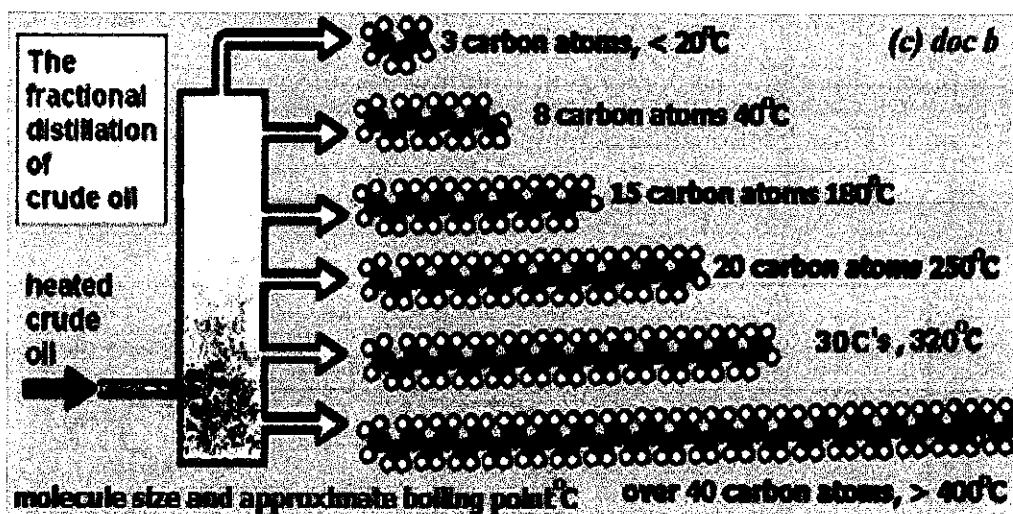
Figure 2.2: Shows the differences of carbon atoms for each type of distillation columns (Vasily Simanzhenkov and Raphael Idem, 2003).

Fractional distillation is a type of distillation that involves the separation of a mixture into its constituent substances based on the differences in their boiling point (volatility). It is practiced for those mixtures, in which the boiling point of the components differs by less than 25°C at one atmospheric pressure. The component with the least boiling point is separated first, while the component with the highest boiling point is drawn off at the last. If the boiling point of the constituents differs by more than 25°C, then simple distillation procedure is implemented for separation (Vasily Simanzhenkov and Raphael Idem, 2003). In the process of fractional distillation, a specific apparatus is used for boiling the mixture and collecting a series of fractions of the components. The laboratory setup for fractional distillation includes a round-bottom boiling flask, condenser, adapter (that connects boiling flask and condenser), fractionating column (within the adapter) and a collection flask.

A thermometer is fixed to the adapter for monitoring the temperature. The fractionating column is usually composed of plates arranged in a horizontal manner, which enhances the separation by allowing condensation, evaporation and re-condensation of the separated components. The vapour of the component substance after passing the fractionating column is passed to the condenser, which is fixed with a water inlet and water outlet pipe. In the water inlet pipe, cold water is constantly supplied to cool down or condense the separated vapour. The warm water is removed via the outlet pipe after being circulated through the condenser. The component had

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undergone condensation in the condenser, which is then collected in the collection flask as a purified liquid. The component with lower boiling point tends to collect at the top portion of the fractionating column, while those with high boiling point settle at the bottom of the column.
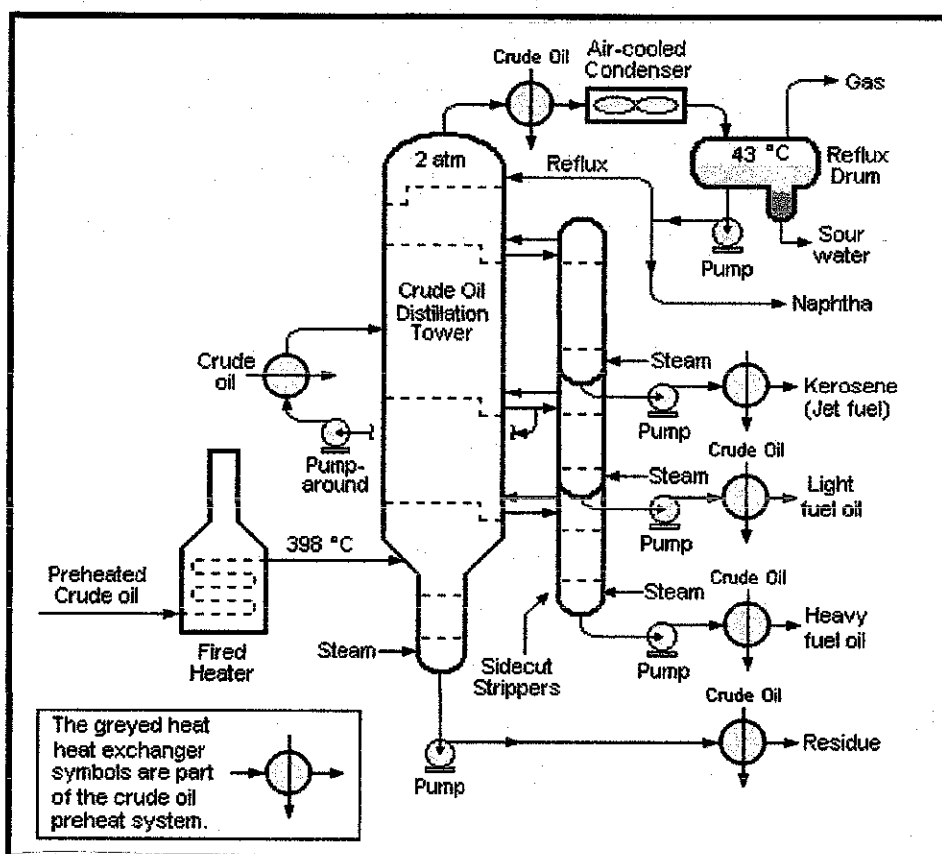
Figure 2.3: Shows petroleum refining in industries (Vasily Simanzhenkov and Raphael Idem, 2003).

Though fractional distillation provides better separation of constituents, it requires more energy and longer time than the usual simple distillation. The more the number of plates, the longer is the distillation. For these reasons, fractional distillation is implemented for purifying complex mixtures with many components. In fact, fractional distillation is the most common procedure followed for separation of mixtures in petroleum refining industries and chemical industries. In petroleum refining, gasoline is separated first followed by kerosene, heating oil and lubricating oil. In industries, large fractionation towers (vertical structures) are used for distillation process. Under controlled conditions of feed (complex mixture),

temperature and condenser, product is being collected continuously. This technology had been implemented in the industries is referred to as continuous fractional distillation.

The main difference between laboratory scale distillation and industrial distillation is that laboratory scale distillation is often performed batch-wise, whereas industrial distillation often occurs continuously. The composition of the source material, the vapours of the distilling compounds and the distillate change during the distillation as shown in Figure 2.3 known as batch distillation. In batch distillation, a charged (supplied) with a batch of feed mixture, which is then separated into its component fractions which are collected sequentially from most volatile to less volatile, with the bottoms (remaining least or non-volatile fraction) removed at the end. The still can then be recharged and the process is repeated. In continuous distillation, the source materials, vapours, and distillate are kept at a constant composition by carefully replenishing the source material and removing fractions from both vapour and liquid in the system. This results in a better control of the separation process.

2.5 Hydrocarbon

Crude oil is a complex mixture of mainly hydrocarbon compound molecules because they consist of atoms of at least two different elements which are not chemically combined. Hydrocarbons occurrences are a combination from carbon and hydrogen which are organic compounds of carbon and hydrogen atoms that may include from one to 60 carbon atoms that vary in both size and type of molecule in crude oil. The properties of hydrocarbons depend on the number and arrangement of the carbon and hydrogen atoms in the molecules. The simplest hydrocarbon molecule is one carbon atom linked with four hydrogen atoms which is methane. All other variations of petroleum hydrocarbons evolve from this molecule. The variations in the distribution of the different sizes and types of hydrocarbons are due to the differences in the physical and chemical properties of petroleum. The chemical property of each substance in the mixture is unchanged. This means crude oil can be separated by

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physical methods, such as fractional distillation, because they have different boiling and condensation points.

The crude oil is heated to vaporise it (evaporated or boiled). The most volatile fraction, i.e. the molecules with the lowest boiling points, boil or evaporate off first and go to the top of the column. The rest separate out according to their boiling/condensation point so that the highest boiling fraction, i.e. the less volatile molecules with higher boiling points, tend to condense more easily lower down the column. The bigger the molecule, the greater the intermolecular attractive forces between the molecules, so the higher the boiling or condensation point. Hydrocarbon molecules are only made of a chemical combination of carbon and hydrogen atoms, (Hunt, 1995) as shown in Figure 2.4.

$$H-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-\overset{\overset{\displaystyle H}{|}}{\underset{\underset{\displaystyle H}{|}}{C}}-H$$
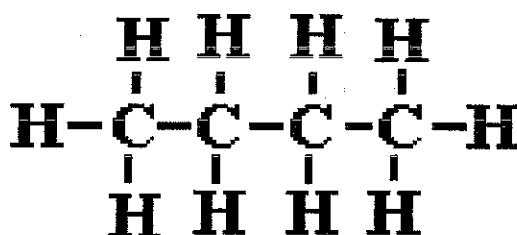
Figure 2.4: Shows hydrocarbon molecules are only made of a chemical combination of carbon and hydrogen atoms (Hunt, 1995).

The percentage of NSO compounds also can be a factor to these differences in petroleum properties. Hunt, (1995) state that the hydrocarbon molecules can occur in different types of structural forms with the different names, for example, open-chain molecules with single bonds between the carbon atoms are known as alkanes. Alkenes contain more or one bond between the carbon atoms, and hydrocarbons with one or more benzene rings known as arenes. Mostly, the petroleum geologists and engineers are familiar with the terms of paraffins for alkanes, naphthenes for cycloalkanes, olefins for alkenes and aromatics for arenes. According to Hunt (1995), the form of hydrocarbons are from the homologous series, that is, the families of molecules whose members have similar properties and differ in size by the CH_2 group. As the molecular size increases, the individual members change from gases to liquids to solid.

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Hydrocarbons containing up to four carbon atoms are usually gases. Those with 5 to 19 carbon atoms are usually liquids and those with 20 or more are solids. The refining process uses chemicals, catalysts, heat, and pressure to separate and combine the basic types of hydrocarbon molecules naturally found in crude oil into groups of similar molecules. The refining processes also rearrange their structures and bonding patterns into different hydrocarbon molecules and compounds. Therefore it is the type of hydrocarbon (paraffinic, naphthenic, or aromatic) rather than its specific chemical compounds that is significant in the refining process.

2.5.1 Paraffin

The paraffin types of hydrocarbons are the second most common constituents of crude oil instead of naphthenes. The word *paraffin* is derived from the Latin *parum affinis*, which means "of slight affinity". Paraffins are the terms for alkane's compound. Molecules in the high boiling range of petroleum frequently contain more than one of the molecular types just described.

Conventional formula   Skeletal formula
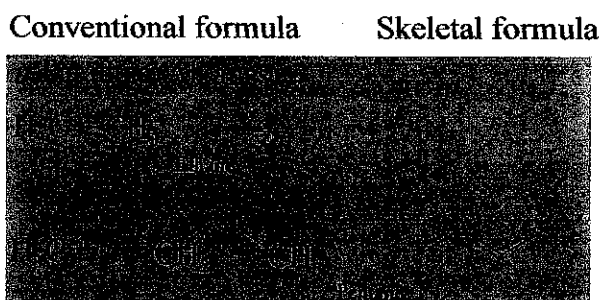
Figure 2.5: Shows hydrocarbon formula for normal alkanes (Hunt, 1995).

In order to avoid a misunderstanding, a molecule that does not contain either an aromatic or a cycloparaffin ring is called *paraffinic*. The formula for the paraffin series is C_nH_{2n+2}, where n is any number from 1 to 100. In the paraffin series, n equals 1 to 4 for gases, 5 to 16 for liquids, and above 16 for solid for the straight-chain paraffins. Paraffins are the principal hydrocarbons in the most deeply buried and oldest reservoirs and dominate the gasoline fraction of crude oil, Hunt (1995). *Saturated* and *aliphatic* hydrocarbons are also used as the terms for this group. Figure 2.5 above shows the straight chain paraffins that are called *normal paraffins* or *n-*

paraffins. The conventional formula and the skeletal formula are shown in Figure 2.5. There are a limited number of value of *n* in crude oil, usually fewer than eighty (*n* = 1 to 80) and this is due to normal paraffin that is defined as a straight chain.

The numbers of *n* value in crude oils are related to the waxy crudes. The lowest value of *n*, very waxy crudes that contain traces of paraffin chains with up to 200 carbon atoms can occur in hydrocarbon. Normal paraffin is the easiest identified compounds in petroleum because all other molecules types contain hundreds of different molecules and make the identification much more difficult. As described earlier, normal paraffins form a homologous series. This condition is due to the differences of each hydrocarbon from the succeeding members by one carbon and two hydrogen atoms. *Homologs* are known as the members of series in hydrocarbon.
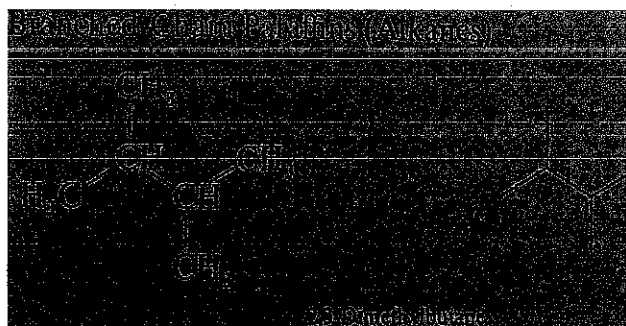
Figure 2.6: Shows branched-chain structures for paraffins (Hunt, 1995).
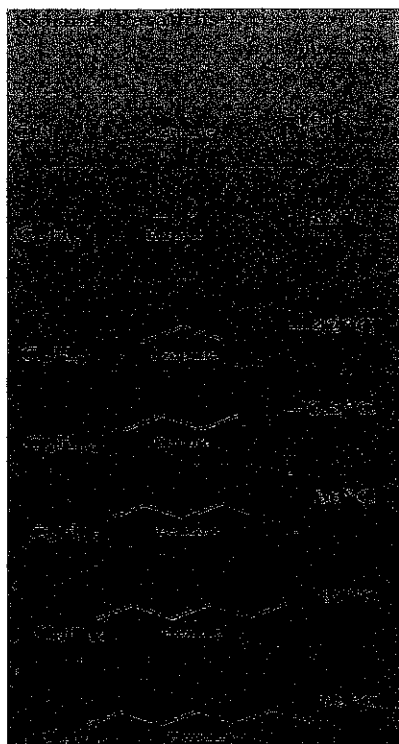
Figure 2.7: Shows the *n*-paraffins form a homologous series in petroleum (Hunt, 1995).

In addition to straight chain, the paraffins can form branched-chain paraffins, as shown in Figure 2.6 above. Figure 2.7 shows the *n*-paraffins form a homologous series. The normal paraffins are relatively inert with strong acids, bases, and oxidizing agents. It is theoretically possible to have more than a million branched-chain structures like as shown in Table 2.1, whereas only about eighty structures of straight-chain normal paraffins that exist in petroleum. The table that shown below list the number of possible isomers representing different kinds of branching and all contain the same number of carbon atoms and corresponding to the formula C_nH_{2n+2}.

Isomers have different compounds with the same molecular formula. Since crude oil derived from a finite numbers of structures in living thing, these isomers can form through the cracking and rearrangement of organic structures and it is obvious that the composition of petroleum is very complex. The boiling point of normal paraffin is slightly higher than any of the branched-chain paraffins with the same molecular formula and the boiling range of paraffin in the fractional distillation of crude oil is about 120^0C to 240^0C. In paraffin hydrocarbons, the covalent bonds of the

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carbon atom are normally at an angle of 109.5^0 and this refer to the angle of C – H bonds in methane.

Table 2.1: Shows the possible number of paraffin isomers for each size of molecule (source: Hunt, 1995)

Size	Isomers
C_1, C_2, C_3	1 each
C_4	2
C_5	3
C_6	5
C_7	9
C_8	18
C_9	35
C_{10}	75
C_{11}	159
C_{12}	355
C_{13}	802
C_{15}	4,347
C_{18}	60,523
C_{25}	36,797,588

2.5.2 Aromatic

The term of *aromatic hydrocarbon* originated when some pleasant-smelling compounds such as cymene were isolated from natural fragrant oils, Hunt (1995). However, most of the hydrocarbons have very little odour in the pure state. The petroleum that has strong odour is due to the non-hydrocarbons. Aromatic is one of the term for arene's compound. The molecular formula for aromatic compound is C_nH_{2n6}. A molecule is called *aromatic* if it contains at least one aromatic ring and a combination of an aromatic ring with other two types would be called an *alkylaromatic* and *cycloalkylaromatic*. All the aromatic hydrocarbons contain at least

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one benzene ring. The top of Figure 2.8 show the flat 6-carbon ring called benzene in aromatic hydrocarbons and, in which the fourth bond of each carbon atom is shared throughout the ring.

The ring is shown with an inner circle, which indicates that the fourth bond's unpaired electrons are delocalized over all carbon atoms in the ring. The aromatics rarely amount to more than 15 percent (%) of a total crude oil and tend to be concentrated in the heavy fractions of petroleum, for example gas oil, lubricating oil, and residuum, in which the quantity often exceed to 50%.
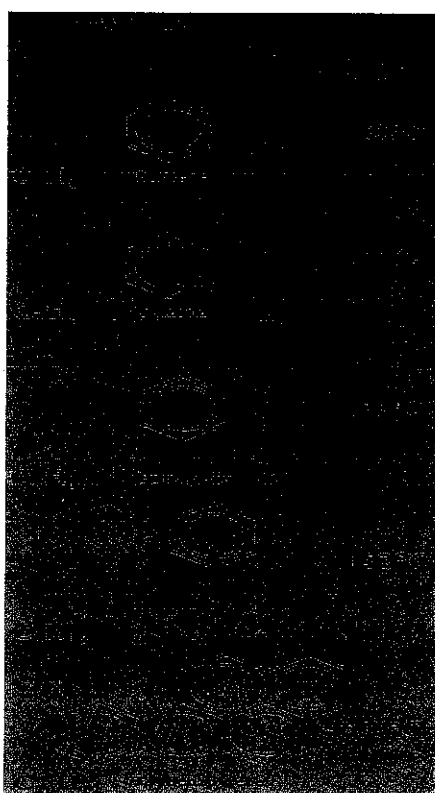
Figure 2.8: Shows the skeletal formula for aromatic hydrocarbons in petroleum (Hunt, 1995).

Aromatics are the unsaturated hydrocarbons that react to add hydrogen or other elements to the ring. The most common aromatic hydrocarbons in petroleum are toluene and metaxylene as shown in Figure 2.8. Aromatics have the highest octane ratings of the hydrocarbon types and they are valuable in the gasoline blends. However, they are undesirable in the lubricating-oil range because they have the highest change in viscosity with temperature of all the hydrocarbons. Polycyclic

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aromatic hydrocarbons in natural products are being studied more intensively because some of them are potent carcinogens and some are being found in coal tars and petroleum. They are a common constituent of the burning of most organic material.

2.6 Uses of crude oil

Crude oils have physical and chemical characteristics that vary widely from one production field to another and even within the same field. The roughest form of characterization, but nevertheless one that has great economic consequence is the classification of "light" and "heavy" crude (Jean-Pierre Wauquier, 1995). The diversity of products derived from petroleum classified according to their distillation range and number of carbon atoms. From one sample of crude to another, the proportions of the recovered fractions vary widely. A good illustration is the gasoline fraction which is one of the most economically attractive. Crude oil is composed essentially of hydrocarbon molecules and its specific gravity (60^0F) varies inversely with its H/C atomic ratio (Vasily Simanzhenkov, 2003; Raphael Idem, 2003).

Specific gravities for various crude oils will range from 0.7 to 1.0; they are often expressed in degrees API (American Petroleum Institute) which will vary between 70 and 5. It is clear that this variable gravity reflects the compositions of chemical families that are very different from each other. All these differences influence the conditions of production, transport, storage and refining adapted to the crude and its derived products; hence the necessity for knowing the composition as precise as possible. The grade of crude oil can be broken down into the following basic fractions, or components: Gasoline, Kerosene and Fuel Oil, Gas Oil, Wax Distillate, and Cylinder Stock or Bottoms.

$$API = [(141.5/ \text{ standard specific gravity}) - 131.5] \qquad (2.1)$$

According to Jean-Pierre Wauquier (1995), the gasoline fraction is further refined. Certain portions of the gasoline fraction are removed and others have their chemical structure changed (isomerised). Some impurities are removed (desulfurized), and others have components added to produce the final product (reformulated gasoline). The kerosene and fuel oil fraction are basically unchanged and used as fuel

for the trucking and construction industry. This fraction can also be processed into some of the specialty solvents used in manufacturing. The gas oil fraction is a heavy, relatively slow burning, non-volatile fuel, or it is frequently used as light lubricating oil. This fraction can be used either as a fuel or as oil. If the gas oil fraction is hydroprocesssed, it can be made into white oil (sewing machine oil) or high quality oils for use in cosmetics and pharmaceuticals.

The wax distillate is a valuable source of lubricating stock and paraffin. By removing the wax or paraffin one of the basic components of lubricant is produced (neutral). Neutrals can be further refined through distillation (fractionation) and hydro processing (catalyzation) to produce a series of specialized components used in the manufacture of engine oils, gear lubricants, and greases. The addition of additives to control oxidation, thermal degradation, and viscosity produce the high quality lubricants used today.

Paraffin is used in many different aspects of our daily life. They are used not only in candles, but in cosmetics, paper coating, inks, fabrics, and even on foods. The Cylinder Stock or Bottoms fraction is what left over after the crude oil has been put through the distillation tower. The wax portion is removed to create new product that has higher melting point than paraffin. The oil portion of the cylinder stock is further processed to remove the resins. These resins are used to create many different products ranging from high temperature insulations to undercoating or fuels for ocean going barges.

Among the more important characteristics are the distillation curve, which leads to a first classification of light crude oils having high distillate yields as opposed to heavy or extra heavy crudes; sulphur content which means the crude having low or high contents; chemical composition, this is used only to characterize particular crudes (paraffinic or naphthenic). Classification of crude oil types by geographical source is generally not a useful classification scheme for response personnel because they offer little information about general toxicity, physical state, and changes that occur with time.

2.7 Mango parameter

The unique character of each oil family has evident from their n-alkane and biomarker signatures which is supported by distinctive gasoline range characteristics in general and C_7 ("Mango") parameters in particular. Emphasis is placed on compositional variations in the gasoline range (C_5H_{12} to C_8H_{18}) to verify the biomarker based on the classification of oil families. Although higher molecular weight biomarkers ($C_{20} - C_{40}$) are considered the best tools for oil-oil correlation studies because they provide much information regarding an oil and its source rock (Peters and Moldown, 1993) but these compounds are unstable under thermal stress and are often absent in high maturity oils/condensates (Van Graas, 1990; ten Haven, 1996).

According to the Benchmark studies (Thompson, 1983; Mango, 1990; BeMent et al, 1995; Halpern, 1995; ten Haven, 1996) have suggested that gasoline range hydrocarbons also carry useful information regarding genetic associations and alteration of oils. It has been documented that the light hydrocarbon ratios have applications for oil-oil correlation studies (Mango parameters, C_7-based star diagrams), provide an indication of the temperature of oil expulsion from its source (2,3-/2,4-dimethylpentane ratio) and reflect the stage of thermal decomposition of oil (paraffin indices).

The application of these light hydrocarbon analysis is an advantageous, not only because they may constitute the only compositional fraction available for analysis in oils/ condensates generated late during catagenesis when sterane and terpane biomarkers are below detection limit, but also because such techniques are relatively rapid and inexpensive. Therefore, they show excellent potential and can be extremely practical for geochemical correlations of low-density crude oil/condensate fractions providing valuable information about differences in source kerogen, depositional paeloenvironment, genetic affinities and petroleum alteration. Data typically can be obtained through more advanced analyses of biomarkers.

Paraffin Indices (Isoheptane and Heptane values, n-C_7/ methylcyclohexane) and aromatic index (toluene/n-C_7) are proved to be successful indicators for characterization of reservoir alteration.

2.8 Gas Chromatography (GC) – Mass Spectrometry (MS)

Gas chromatography ("GC") and mass spectrometry ("MS") make an effective combination for chemical analysis. The GC device is generally a reliable analytical instrument. The GC instrument is effective in separating compounds into their various components. However, the GC instrument cannot be used for reliable identification of specific substances. The MS instrument provides specific results but produces uncertain qualitative results. GC analysis is a common confirmation test and separates all of the components in a sample and provides a representative spectral output. The sample will be injected into the injection port of the GC device. The GC instrument vaporizes the sample and then separates and analyses the various components. Each component ideally produces a specific spectral peak that may be recorded on a paper chart or electronically.

The time elapsed between injection and elution is called the "retention time". The retention time can help to differentiate between some compounds. The retention time should be measured from the sample injection until the compound elutes from the column. However, retention time is not a reliable factor to determine the identity of a compound. If two samples do not have equal retention times, those samples are not the same substance. Identical retention times for two samples only indicate a possibility that the samples are considered as substance. Potentially thousands of chemicals may have the same retention time, peak shape, and detector response. The size of the peaks is proportional to the quantity of the corresponding substances in the specimen analysis. The peak is measured from the baseline to the tip of the peak. A mixture of chemicals present in a specimen can be separated in the GC column.

Some chemical and physical characteristics of the molecules cause them to travel through the column at different speeds. If the molecule has lower mass it may

travel more swiftly. Also, the molecule's shape may affect the time needed to exit the column. Interactions between the sample's molecule and the column surface may cause the molecule to be retained inside the column for a different amount of time than similar molecules that interact with the column differently. The equipment used for gas chromatography generally consists of an injection port at one end of a metal column packed with substrate material and a detector at the other end of the column. A carrier gas propels the sample down the column. Flow meters and pressure gauges are use to maintain a constant gas flow. A gas that does not react with the sample or column is essential for reliable results. For this reason, carrier gases are usually argon, helium, hydrogen, nitrogen, or hydrogen.

Hydrogen usually is a good carrier gas but it may react and convert the sample into another substance. So, many analysts use helium because it does not react. The ultimate choice for a carrier gas may depend on the type of detector used. To ensure proper separation, the sample must enter the column in a discreet, compact packet. Normally the sample is injected into the injection port with a hypodermic needle and syringe capable of measuring the specimen amount. The needle is stuck into a replaceable neoprene or silicone rubber septum that covers the injection port. The injection port is maintained at a temperature at which the sample vaporizes immediately. Ideally, the sample spreads evenly along the cross section of the column, forming a plug. The column is a metal tube, often packed with a sand-like material to promote maximum separation. Columns are commonly obtained pre-packed by vendors.

As the sample moves through the column, the different molecular characteristics determine how each substance in the sample interacts with the column surface and packing. The column allows the various substances to partition themselves. Substances that do not like to stick to the column or packing are impeded but eventually elute from the column. The various components in the sample separate before eluting from the column end. The GC instrument uses a detector to measure the different compounds as they emerge from the column. Among the available detectors are the argon ionization detector, flame ionization detector, flame emission

detector, cross section detector, thermal conductivity detector, and the electron capture detector.

Some considerations are that the flame detectors destroy the sample, the thermal conductivity detector is sensitive, and the argon ionization detector requires argon as a carrier gas. The spectral output is usually stored electronically and displayed on a monitor. The argon ionization detector does not detect water, carbon tetrachloride, nitrogen, oxygen, carbon dioxide, carbon monoxide, ethane, or compounds containing fluorine. The flame ionization detector does not respond to water, nitrogen, oxygen, carbon dioxide, carbon monoxide, helium, or argon. The electron capture detector can not detect simple hydrocarbons but it does detect compounds containing halides, nitrogen, or phosphorus.

2.9 Parr reactor

The reactors are used for multiple processes such as scale up processes, process development and small scale production. Lab reactors are often used as batch reactors. The operation temperature for such reactors can be from − 50°C up to + 250°C. Chemical reactors are used for many different processes. To process many different chemicals, the reactors are built in highly corrosion resistant or inert materials. Due to this fact and due to the reactor's design, they can be used as multiple processes and substances. Glass pressure reactors can be used to a pressure up to 12 bars and offer the advantage to allow visual observation of the reaction.

If higher pressure is needed, the glass reactor can be exchanged for a stainless steel reactor with a sight glass. Other reactor materials such as Hastelloy C22, Titanium, Tantalum, and Zirconium are available. There are 2 ways of temperature control for heating or cooling temperature control: A circulator controls the heating of the heat transfer fluid, which is circulating through the jacket of the jacketed reactors. The alternative is to use PID temperature control system which controls the electric heating, built directly onto the pressure vessel. Inside the reactor, there are accessories that available. Stirrers are to be defined according to the processed media and process.

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The stirrers are driven by magnetic drives or by magnetic couplings, allowing the process to run under high pressure or high vacuum. Accessories such as burettes, sampling devices, condensers, mass flow controller for gas dosing and many others are built into the top of the reactor. Sometimes, dosing of solids or liquids into the pressurized vessel is requested, other requests such as pH control, sampling, catalyst addition, nitrogen purging /blanketing, distillation, reflux distillation are also to be considered. In many cases these reactors are installed in flame proof or hazardous area.

CHAPTER 3

REGIONAL GEOLOGY

3.1 Overview

This section is focus on the geology, the regional geology, and also crude oil characteristics for each of Malay Basin and Sabah Basin.

3.2 Geology of Malay Basin

It has been realised that the petroleum resources are valuable assets to the country. The sedimentary basins have been proven to be petroliferous and currently commercial oil and gas are being produced in the Malay Basin. Sedimentary deposition and subsequent structural overprints in these basins have resulted in a variety of structural and stratigraphic configurations which provide conductivity conditions for petroleum generation, migration and entrapment. Figure 3.1 show that Malay Basin is a northwest-trending elongate basin about 500 km long and 200 km wide. It is situated in the southern part of the Gulf of Thailand, between Vietnam and Peninsular Malaysia. The basin covers an area of about 80,000 km^2 and it contains over 12 km or more of Oligocene to Recent sediments. The Oligocene sediments are generally terrestrial deposits with minor marine influence, whereas the Miocene-Recent sediments are coastal plain to shallow marine deposits. Malay Basin is also underlain by a pre-Tertiary, basement metamorphic rocks. The Malay Basin is separated from the Penyu Basin by the Tenggol Arch which is a shallow basement area.

The Malay Basin strata are subdivided informally into seismo-stratigraphic units and each unit is known as a Group, is bounded by basin-wide seismic reflectors. Some of these reflectors represent major sequence boundaries and are erosional unconformities on the basin flaks. The stratigraphic development of the Malay Basin is directly related to its structural evolution, which occurred in 3 phases: (1) A Pre-Miocene (Oligocene or possibly earlier) extensional or synrift phase, (2) An Early to Middle Miocene thermal/tectonic subsidence phase, which was accompanied by basin inversion, and (3) A Late Miocene-Quaternary subsidence phase, which represents a tectonically quiescent period. According to Mazlan Madon (1997a), the Malay Basin was effectively a narrow seaway or gulf that received sediment from its north-eastern and south-western flanks.
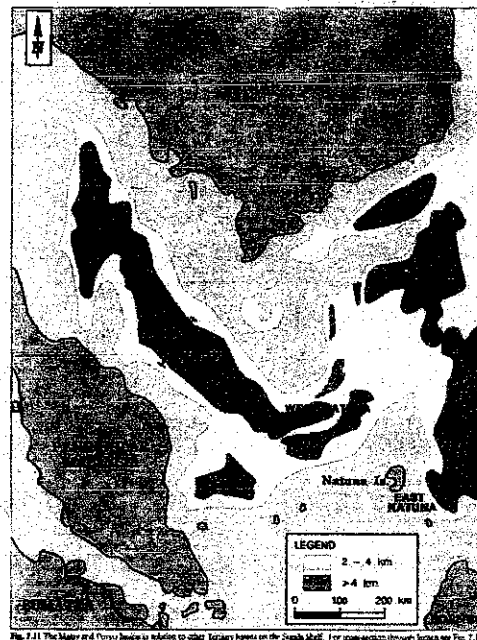
Figure 3.1: Show the location of Malay Basin in the Sunda Shelf (Tjia, 1994).

The geographic and stratigraphic distribution of oil and gas appears to be controlled primarily by basin morphology on a regional scale. The basin is considerably deeper in the north, and has a much thicker, hence more deeply buried, sedimentary succession. Having been buried to greater depths, the sediments would have reached gas-window maturity or greater. There is a great tendency for oil to be flushed out by high-maturity gas. In contrast, the Middle-Late Miocene tectonic uplift in the south has resulted in shallower burial and lower thermal maturities. Energy

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resources are becoming increasingly important to humankind as population growth places increasingly greater demands on Earth's natural resources. Our increased population size also has spurred the growth of both technological development and industrial production, and this growth has in turn created an increased demand for energy supplies. The development of modern societies has spurred a shift in the use of energy resources from wood to coal to oil and, to a certain extent, uranium.

The use of each of these energy sources produces environmental costs; these costs are incurred during harvesting, transporting, and the actual process of releasing the energy contained within each of these materials. Petroleum, one of the world's most important resources, has had a huge effect on the world economy. From this resource, a wide variety of energy-rich products are produced—most importantly, oil and gasoline. Most people are aware that crude oil is pumped from underground sources, mostly from reservoirs in the OPEC member countries, and then it is shipped to oil refineries for processing. But what processing occurs at the oil refinery and how does it produce so many petroleum products will be answered when we explore these questions by modelling the process of fractional distillation and investigating the properties of the crude oil that makes the processing possible. Petroleum chemists have identified this fossil fuel as a complex mixture of many different compounds that developed underground under low-oxygen conditions from marine-deposited organic compounds.

3.2.1 Regional structures of Malay Basin

Malay Basin is originated by extension during Late Eocene-Early Oligocene times which is probably along a major left-lateral shear-zone and, subsequently, by thermal subsidence during the Miocene to Recent as shown in Figure 3.2. It is one of the deepest continental extensional basins in region, and is believed to have formed during early Tertiary times. Sedimentation during the Miocene was accompanied by structural inversion that caused major east-trending anticlines to grow in the axial part of the basin. A major Middle-Upper Miocene unconformity is associated with this inversion event. According to Hamilton (1979) and Mazlan Madon (1997a), the

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anticlines are believed to be the result of right-lateral wrench deformation. The Malay Basin show a variety of structural styles that reflect their tectonic setting and origin and also the extensional basins formed in continental crust.

Their structural styles are typified by basement normal faults, which often have significant strike-slip displacements and these basin are also characterised by high surface heat flow, perhaps because of the thinning of the lithosphere during their formation, which caused a thermal a thermal anomaly beneath the basin (Mazlan Madon, 1997b). Basement structures in the Malay Basin are dominated by pre-existing pre-Cenozoic fault trends that may have been reactivated by Cenozoic tectonic movements (Khalid Ngah et al., 1996) and some changes in the regional stress regime had caused these faults to be reactivated again during the course of basin falling and produced a variety of inversion structures.
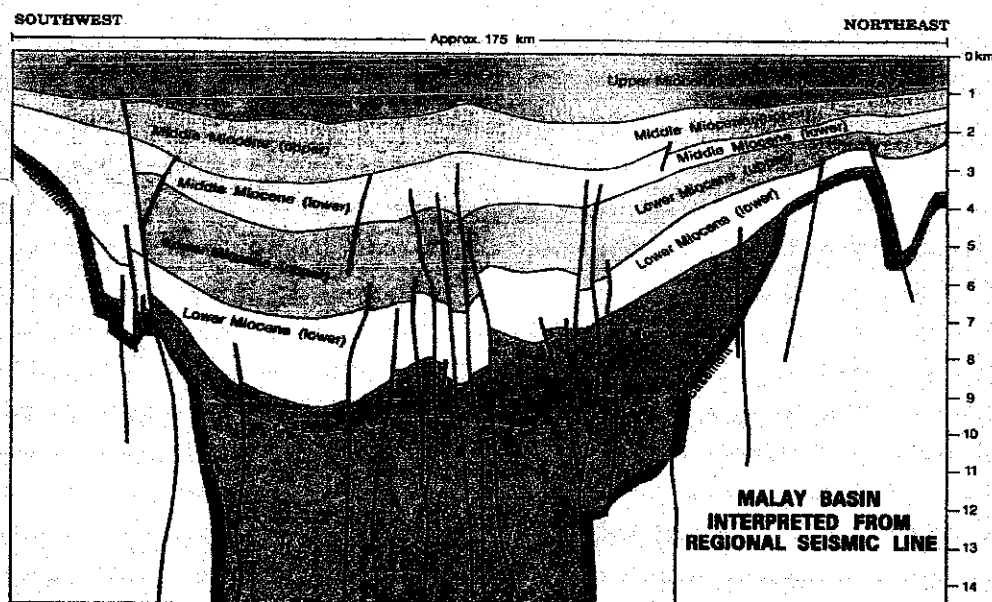
Figure 3.2: Show the interpretation of Malay Basin from regional seismic line (Tjia, 1994).

Others theory that refer Malay Basin as the northern part of the basin is characterised by N-trending faults and half-grabens (Liew, 1994). The axial part of the Malay Basin is characterised by very deep basement, which is poorly imaged by conventional seismic and small pull-apart half-grabens also occur on the flexural margins of the basin (Liew, 1994). The rift-sag basin geometry of the Malay Basin is

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typical of basins formed by lithospheric stretching and the initial basin geometry is that of half-grabens associated with the crustal extension. According to Watts et al., (1982), this synrift basin is overlain by a broad sag basin characterised by stratigraphic on lap onto the basin margins, which is produced by thermal subsidence and sediment loading as in Figure 3.3.

Based on the analyses, the Malay Basin is not a purely extensional basin that has been indicated by the gravity modelling analysis and its development may have involved a significant strike-slip component of extension (Mazlan Madon, 1996; Mazlan Madon and Watts, 1998). "The Malay Basin was subjected to basin inversion during the Middle-Late Miocene, which produced major anticline structures that trap large amounts of oil and gas in the basin" (Tjia, 1994; Mazlan Madon, 1995, 1997a). South-eastern part of the basin was probably uplifted during this time also and the basin inversion is thought to have resulted from a dextral shear regime following a change in the regional stress field (Tjia and Liew, 1996; Mazlan Madon 1997a).

A mantle plume developed beneath the current junction of the Malay-Penyu-West Natuna basins and manifested as the Malay Dome. Intensity of inversion is generally greater at the centre than on the flanks of basin. Inversion also increases in intensity towards the southeast. Hence, in the West Natuna Basin inversion structures are more commonly associated with thrust and reverse faults (Ginger et al., 1993). The inversion structures are growth features formed during deposition, the thickness of the syn-inversion stratigraphic unit's decrease towards the crustal region as the depositional surface is being deformed and eroded.
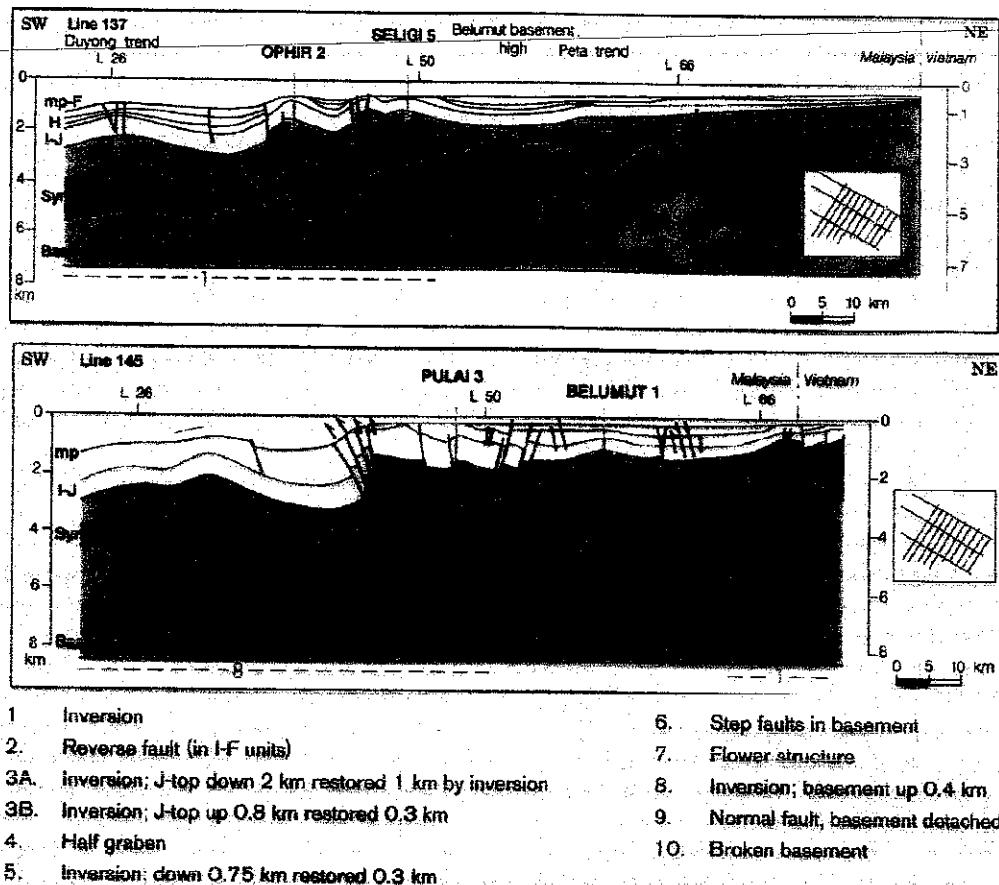
Figure 3.3: Show the structural features in the Malay Basin (Watts et al., 1982).

Although the timing of structural growth is synchronous across the whole basin, the peak fold growth is earlier in the south than in the north. The three named basins originated as rifts on this dome. Hard collision of the Indian sub-plate with the Eurasian plate that begin in the Middle Eocene, differentially extruded elongated crustal slabs of the Southeast Asian lithosphere towards the southeast along three major NW-SE striking wrench fault zones.

3.2.2 Reservoir characterization

Depositional environments and reservoir characteristics in the Malay Basin are divided into "groups" according to the stratigraphy and palaeoenvironments of the Malay Basin. Figure 3.4 show the groups are designated and labelled alphabetically in order of increasing age, A to M from top to bottom. The Recent or Pliocene phase represents Group A that consists of the earlier age of the sediments reservoir while

Group B is in the Upper Miocene. The environment for Group A down to H is in the area of coastal plain and the structural histories are related to the compression of the basin development. According to the stratigraphy and structural history of Malay Basin, Group D down to H are in the Middle Miocene phase, Group I down to K are in Lower Miocene, Group L in Upper Oligocene while the age of the oldest sediment is Group M in Lower Oligocene phase.

However, the environment for basement ages from Cretaceous and older sediments cannot be ruled out. The palaeoenvironments for Group I down to J are subtidal and for Group K down to L is fluvial lacustrine while for Group M is alluvial fan or alluvial plain sediments. The structural histories for Group I down to K are in thermal subsidence and for Group L down to M are extension phase of basin development. In the older groups, Group K, L and M reservoirs are formed, mainly fluvial channels in a non marine-lacustrine setting. The sandstones are predominantly shore face and subtidal shelf sands in the J and younger groups (mostly in J group) while in Group I and younger are fluvial deltaic to estuarine channel complexes. Group K sandstones are mainly deltaic and braided stream deposits whereas those in Group J are mainly shallow marine sediments.

The reservoir sandstones of Groups D and E in the Upper Miocene have been interpreted as tidal, deltaic to lower coastal plain deposits (Khandwala et al., 1984; Thambydurai et al., 1988; Mazlan Madon, 1994). The K reservoirs consist of braided stream sands deposited in alluvial fans and fan delta complexes (Nik Ramli, 1988a). Oligocene sediments were derived from the flanks of the basin via rivers flowing across the steeply faulted basin margins. The reservoirs consist mainly of stacked fluvial channel complexes in a low stand systems tract. The channel complexes are 5-15 m thick, with individual channels measuring about 5-6 m thick. Non-reservoir facies are interpreted as flood plain, tidal flat and lower shore face deposits. The transition from lacustrine (K shale) to marine (J sandstone) is a significant event in the depositional history in the basin.

This Lower Miocene interval consists of coastal plain-estuarine to tidally-dominated shallow marine sandstones deposited in a low stand systems tract (Ramlee

and Beddingfield, 1996). It is about 40% of the total reserves in the basin consists in Group J and the majority of the reservoirs occur in the middle Group J (Ramlee and Beddingfield, 1996) estuarine and high-energy subtidal deposits. The lower and upper J sequences have lower reservoir quality, having been deposited in low to moderate energy subtidal environments. Group J estuarine channel and subtidal sands, with their long axis parallel to the tidal current direction, form the best quality reservoirs. Up-dip of the estuaries, where the depositional energy is lower, poor quality reservoir sands were developed.

Group J reservoir sandstones are mainly subtidal deposits forming east-west trending, moderate-high energy and subtidal bars. Group I fluvial and tidal reservoirs occur at depths of between 1300 and 2500 m. The two main reservoir intervals are a lower fluvial-deltaic facies above a major sequence boundary, and an upper reservoir of sandy tidal estuarine deposits. The fluvial deltaic deposits consist of braided fluvial channels, with sharp-based, blocky log signature, which rest sharply on a coarsening upward, offshore-delta front to stream mouth bar succession. The contact between the two main facies was interpreted as a major sequence boundary which represents a relative sea-level fall. The Group E sandstones form an important group of reservoirs in the central part of the Malay Basin.

According to the researcher, Mazlan Madon (1994), studied the reservoirs in the Jerneh gas field, which occur at depths of 1250 to 2000 m were interpreted the sandstones as deltaic, include distributaries mouth bar, shore face, and channel sediments formed during a Middle-Late Miocene regression. All the differences between each group of reservoir are based on the different reservoir sand bodies characterise between the delta front and delta plain facies association. The former is typified by distributaries mouth bar and shore faces sandstones whereas the latter is associated with the channel point bar deposits. The overlying transgressively deposits are typified by laterally extensive shallow marine sheet sandstones.

Most studies indicate that two main factors that control reservoir quality are depositional environment and burial diagenesis. Compaction during burial is the most important diagenetic factor controlling reservoir quality. Ignoring the burial

diagenetic effects, however, depositional environment has the strongest control on the reservoir quality. The best quality of reservoir is shown by Group J estuarine sandstones, and mid-lower Group K braided stream deposits. Low energy subtidal and tidal flat reservoirs have the poorest quality.

The reservoir properties of the J sandstones are primarily determined by depositional factors which are high-energy facies storm bar sandstones tend to be of better quality than low-energy lower shore face to inner shelf sandstones. In addition, it was noted that meteoric water flushing of the sandstones associated with the Middle-Upper Miocene regional unconformity in the southern Malay Basin has generated secondary porosity. Textural parameters such as sorting and grain size also exert some control on reservoir properties. Coarser grained sandstones tend to have the best reservoir properties.

The reservoirs of group M to K are mostly braided stream deposits, which are very coarse-grained and conglomeratic, whereas the younger groups tend to be fined to very fine grained. This generally fining trend with decreasing stratigraphic age could be the result of decreasing energy of deposition, the coastal plain and tidal settings being dominant in the younger groups.

Chemical diagenesis is thought to have played a minor role in altering reservoir properties, and its effect is usually local (Mazlan Madon, 1994; EPIC, 1994). Apart from the direct impact of burial digenesis on porosity, there is the indirect effect of high geothermal gradients on the rapid destruction of porosity with depth. Reasonable that porosity values (>10%) can still be maintained down to depths of about 3000 m. Besides, the compactional effects during shallow buried that less than 1 km will have resulted in up to 50% reduction of the original porosity into 10 to 25%.

AGE (approximate)	MALAY BASIN					PENYU BASIN	WEST NATUNA BASIN
	EPMI	EPIC	PULAI No. 1	CONOCO	PETRONAS CARIGALI		
RECENT- PLIOCENE	A		PILONG	PILONG	VIII / VII	PILONG	MUDA
	E				Non-deposition		ARANG
	J		BEKOK	UPPER SAND - COAL	IV	PARI	BARAT
		K	TAPIS	LOWER SAND - COAL	III		UDANG
			PULAI	TERENGGANU SHALE		TERENGGANU	GABUS
			SELIGI	TAPIS		PENYU	BELUT
			LEDANG	SOTONG			
			TELUK BUTUN				

Figure 3.4: Show the correlation of the tertiary stratigraphy in Malay Basin (Khalid Ngah et al., 1996).

3.2.3 Crude oil characteristics

In Malay Basin, the geochemical data suggest that the natural hydrocarbon gases (methane, ethane, propane, etc) were derived from either a biogenic or a thermogenic source (Curry, 1992; EPIC, 1994; Wapples and Mahadir Ramly, 1995; McCaffrey et al., 1998). Oil types in Malay Basin maybe classified into three groups which are based on a combination of geochemical characteristics and age of the host reservoir. The three groups are Group E, Group I and also Pre-Group I oils. The naming for oils group and reservoir group are a bit confusing but both of group is different. Hydrocarbons in the Malay Basin are found in sandstone reservoirs of Groups D down to K and the depositional environment of the sandstones vary with the stratigraphy. Geographically, oils in Group E are restricted to the basin centre, with the Dulang and Semangkok fields accounting for the majority of E oils. Group E has a large oil accumulation such as Dulang. Mostly, oils in this group are immature over much of the basin except only in the lowest part of E reaches the oil window in some areas.

Although in the far north of the basin, such as Ular, a majority of Group E oils are moderately waxy to waxy and condensates are more common. This is because of

the thickness of sediment in the north and high maturity of the source sequences. Although the majority of oil tends to have a terrigenous rather than a lacustrine signature, the E oils show some variations in the biomarker distribution. Typically, most of the Group E oils and condensates have high Pr/Ph (Pristane/Phytane) and Pr/nC$_{17}$ (Pristane / n-heptadecane) ratios and suggesting oxidising depositional conditions for the source rock. The low Tm/Ts (Trisnorhopane / Trisnornoehopane) ratio which is less than 1.00, and moderate quantities of diasteranes probably indicate that coal was not a major contributor to the E oils. Group I oils are common in the southern half of the Malay Basin. Mostly, this group was found over much of the width of the basin such as in Tembikai-1 and Meranti-1 in the west. In the deeper northern part of the basin, oils in Group I are restricted to the eastern flank, such as Bunga Kekwa field.

Group I reservoirs host many large accumulations in the southern Malay Basin. In this field, the hydrocarbon reservoirs are mainly in Groups I and J. Group I have high value of API condensates to moderately API waxy oils and also show variable compositions at both bulk and molecular level. The degree of variation observed in Group I source rocks, provided that all the source rocks have been effective. The oils range from very terrigenous, to more lacustrine-influenced. The different source rock facies during Group I times have resulted in mixing the oils they generated. Although there are many similarities between the source rock and oil biomarker distributions, the correlating of any oil to a particular source rock may not be possible. Group I oils were sourced from Group I source rock (EPIC, 1994).

However, on the basin flank (north-eastern flank), Group I oils were probably sourced from stratigraphically deeper levels, such as the Pre-I lacustrine sequences. Pre-I oils occur in reservoir for Groups J, K and L and there are no known occurrences in Group M reservoirs. The Pre-I oils are restricted to the southern end of the basin, with only few exceptions, and primarily on the eastern side. The distribution in this group is consequently caused of the maturity of the Pre-I source rocks. The only parts of the basin where Pre-I source rocks are not over-mature are the marginal areas (being relatively shallow). The Resak and Beranang wells is an example where the Pre-I oils known occur on the western flank but the occurrences is sparse. The Bunga Kekwa field also contains some Pre-I oils that located in the north-

eastern flank of the basin. The Pre-I oils has an interesting feature which is their geochemical characteristics vary only a little, although despite a wide range of bulk properties.

The oils vary from waxy crudes to light condensates and this variation is due to a combination of different maturity of oils and also a post-accumulation process such as evaporative fractionation. As most of the oils appear to have been derived from similar source rocks, source facies is not considered to have been a factor. All the Pre-I oils have common feature in moderately low Pr/Ph ratio which are between 2.0 to 3.0 and low Pr/nC_{17} which are 0.3 to 0.5. Such features are typically of mildly oxidising or non-oxidising depositional conditions. Group J and Group K are suggested to be derived from the same source because of the similarity in the geochemical characteristics. Therefore, according to the earlier researcher, it has been believed that K shale lacustrine sequence has been an effective source over large area of the basin, and has been responsible for charging the J and K reservoir sands.

3.3 Geology of Sabah Basin

Geographically, Sabah is known as a younger basin in Malaysia and the hydrocarbon produced in the field is less than in Peninsular Malaysia. The first offshore producing oil field in Sabah was Tembungo with production commencing in 1974. Crude oil reserves in Sabah represent only about 15% of total reserves compare to Peninsular Malaysia is about 62% total reserves. Figure 3.5 show that Sabah is situated in the northern part of the island of Borneo and tectonic elements in Sabah Basin. The well developed compressive and extensional structures are the manifestation of several regional tectonic events in Sabah since the early Tertiary.
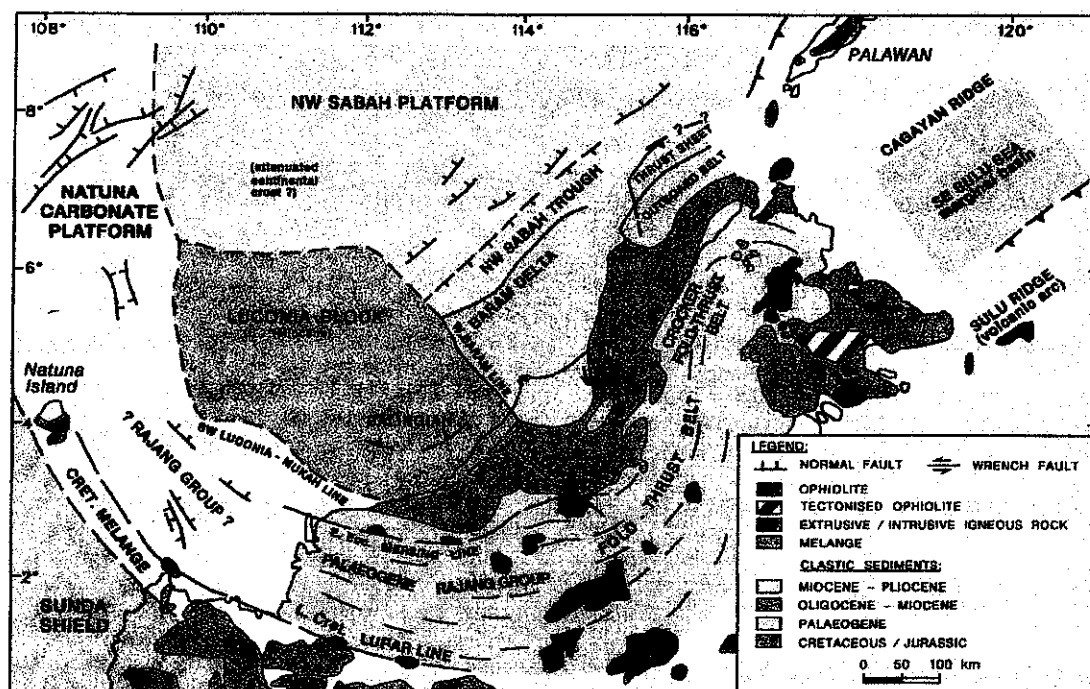
Figure 3.5: Show tectonic elements of Sabah Basin (modified from Hazebroek et al., 1994)

Most of the oil produced in Sabah basin is within the "light oil" category and this is based on the cut-off for medium crude oil quality of between 22 and 31 degrees. Sedimentation in Sabah Basin was punctuated by several tectonic events that resulted in several region unconformities at the basin margin. After an earlier phase of deep marine sedimentation which is West Crocker and Kudat formations, its sedimentation history involved basically the north-westward progradation of siliciclastic shelf sedimentation since the Middle Miocene. According to Levell, 1987, these unconformities have been used as the basis for subdividing the stratigraphy of the Sabah Basin into "stages". Noor Azim Ibrahim (1994) recognised two main phases of deposition in the Sabah Basin, based on the detailed analysis of subsidence history using well data. The first phase is a very rapid subsidence phase during early Middle Miocene to early Late Miocene.

This rapid phase resulted in deltaic aggradation and then followed by the second phase which is a much slower subsidence phase accompanied by westward progradation of shelf-slope system as sediment accumulation rates exceeded the rate of increase in accommodation space. Sabah Trough and NW Sabah Platform are the distinctive geomorphic or tectonic elements in offshore NW Sabah deep waters.

Features with water depths of 2.8 to 3.0 km and extending over 300 km, Sabah Trough is a NE-SW linear bathymetric and its average width is 80 km. Earlier writers has been interpreted Sabah Trough as a Palaeogene subduction trench, underlain by southward dipping oceanic crust (Haile, 1973; Hamilton, 1979; Taylor and Hayes, 1980, 1983).

Geomorphologically, a distinct mountain range comprising Palaeogene Crocker Formation and older rock units occurs near the west coast, and rises to between 3,000 to 4,000 m above sea level, culminating in the Late Neogene Kinabalu granodiorite intrusion, which peaks at 4101 m. The main geological elements of Sabah maybe can be categorized as follows:

a) Pre-Tertiary Core – crystalline basement

- A metamorphic and igneous complex (amphibolites, hornblende, schists and gneisses, granodiorites, tonalites, granites)

- Radiometrically dated in the range of Cretaceous to Triassic (Kirk, 1962; Leong, 1974, 1998; Hutchison, 1997).

b) Cretaceous-Early Palaeogene – ophiolites and indurate deep marine sediments

- Chert-Spilite Formation: a complex of extrusive igneous rocks (basalts, spilites, volcanic breccias, agglomerates) associated with radiolarian cherts, limestones and clastics. The radiolarian cherts are of Early Cretaceous age and limestones are Late Cretaceous (Leong, 1974, 1977; Basir Jasin and Sanudin Tahir, 1988; Basir Jasin, 1992). Associated with ultrabasic and basic igneous intrusives.

- Madai-Baturong Limestone: algal, oolitic and massive limestone of Cretaceous age (Adams and Kirk, 1962; Leong, 1974; Fontaine and Ho, 1989).

- Sapulut, Trusmadi and East Crocker Formation: thick turbiditic clastics; partly metamorphosed to slates and phyllites.

The above rock units occur mostly in central and eastern Sabah. The oldest rocks penetrated offshore northern Sabah consisted of Eocene shales and mudstones, partly conglomeratic, containing smooth, rounded to angular fragments of sandstone, siltstone, chert and serpentinite. The occurrences of Palaeocene to Eocene limestones in all parts of Sabah indicate that the Early Palaeogene and older units were uplifted during this time (Tongkul, 1991a). The pre-Tertiary crust in offshore Sabah is largely unknown. In summary, the acid igneous rocks of the Crystalline Basement probably represent a continental basement and perhaps have a different origin and tectonic history.

c) Palaeogene Basins – mainly N-S elongated basins containing deep marine sediments to the east and west of the Cretaceous-Early Palaeogene deep marine sediments.

d) Neogene Basins – the petroleum producing Sabah Basin to the northwest, northeast (NE) Sabah Basin and southeast (SE) Sabah Basin, flanking the Palaeogene Basins (Leong, 1978a).

There have been many studies describing the geology of Sabah Basin in general and the north-western Sabah continental margin in particular. In summary, Sabah Basin (Figure 3.6) has a structurally complex basin that was formed on the southern margin of a foreland basin that resulted from the collision between the NW Sabah Platform and western Sabah during the early Middle Miocene.
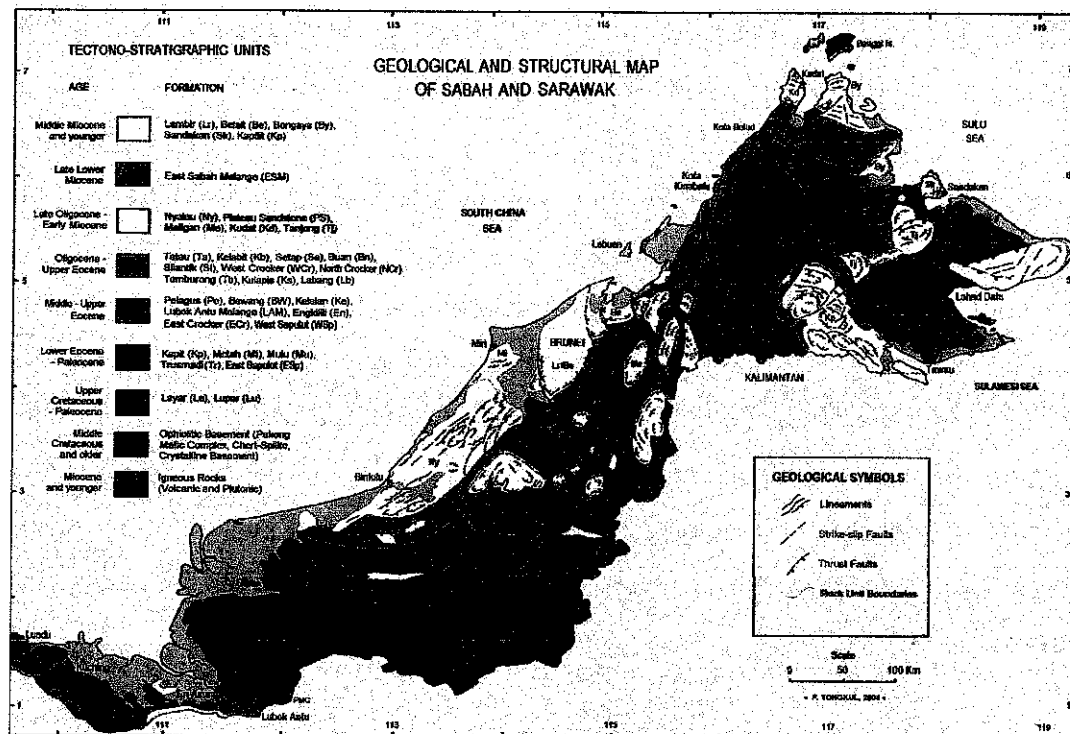
Figure 3.6: Show geological and structural map of Sabah (Hutchison, 1989).

3.3.1 Regional Structures of Sabah Basin

The Sabah Basin is also known as the NW Sabah Basin and a predominantly offshore Middle Miocene sedimentary basin that underlies the continental margin off western Sabah. Sabah Basin (Figure 3.7) is unconformably overlies deformed deepwater sediments that now form the Crocker Formation and Rajang Group rocks in western Sabah. The structure and stratigraphic evolution of the NW Sabah continental margin is described based on seismic data. Several regional tectonic events have occurred in Sabah since early Tertiary. Occasionally, mud volcanoes occur at several localities in eastern, western and northern of Sabah and activated through earth movements (Tjia, 1978; Lee, 1990; Tongkul, 1988). According to Lim (1986), renewed fault activities in Sabah mainly along the north to northeast structural trend were indicate by shallow earthquakes.

42
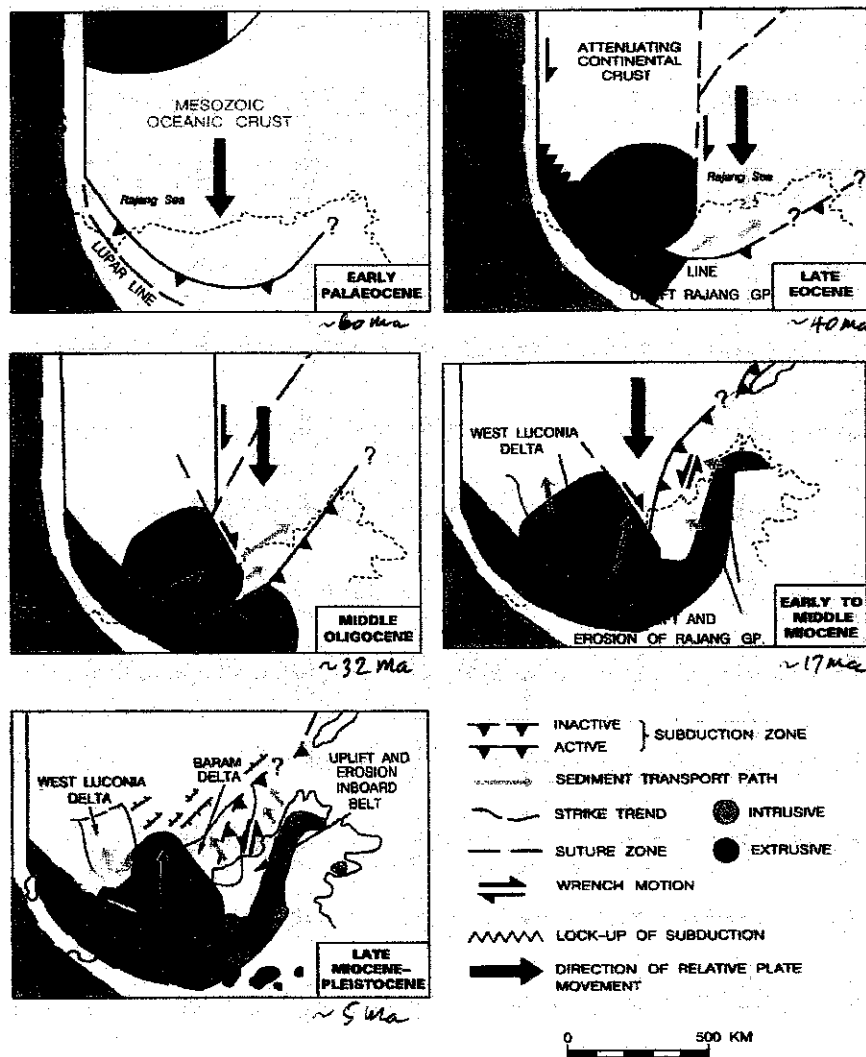
Figure 3.7: Show tectonic evolution of North-West Borneo (Hazebroek, 1993, 1994; Tan 1993).

The Sabah Basin exhibits features indicative of compressional margins characterised by thrusts and wrench tectonics which reflect the strong influence tectonics has had over its structural evolution. According to Tan and Lamy, 1990, the Sabah Basin is subdivided into provinces that are characterised by distinct structural styles and sedimentation histories. Earlier researcher such as Bell and Jessop (1974), Tjia (1988), Hutchison (1993), Clennell (1991) and many more have given the tectonic models for eastern Sabah. However, Tongkul (1991a) gave the first comprehensive and coherent account on the tectonic evaluation for the whole of Sabah, supplemented later by further research work in northern and central Sabah as shown in Figure 3.8.

NW   SE

Dangerous Grounds,
Reed Bank ?   'Rajang Sea'
(Southern China)   Sapulut, East Crocker,   Volcanic arc, ophiolites
                          Trusmadi   Chert - Spilite

Oceanic crust
Continental
crust
(A)   CRETACEOUS
                                                                             - EOCENE

                                   West Crocker   Rajang
                                   Temburong,   (Older Crocker)
                                      Kudat,   Fold–Thrust Belt
                                     Stage III   and imbrication of
                                                 ophiolite complex   Kulapis,
Carbonate   Labang
layer
(B)   OLIGOCENE -
                                                                             EARLY MIOCENE

                             Rajang and Crocker
                             Fold–Thrust Belts,
                             'pop-up' slivers
                               of ub /b   Chaotic   Dent volcanics and
                                            deposits   volcaniclastics
                                   Collision
                                     zone
                               Spreading axis
(C)   EARLY
                                                                             MIOCENE

Neogene
sediments
(Sabah Basin)   (Extensional basin)   Dent volcanics and
                                              volcaniclastics
(D)   EARLY-
                                                                             MIDDLE
                                                                             MIOCENE

                                              Semporna - Tawau - Sulu
                                                     volcanics   Neogene
Neogene   Neogene   sediments
sediments   Kinabalu   sediments
(E)   LATE
                                                                             MIOCENE-
                                                                             PLIOCENE

0   100   200 km

Figure 3.8: Show tectonic evolution of Sabah (modified after Tongkul, 1991a).

According to Tongkul (1991a), the diverse and complex structures in Sabah resulted from at least 5 episodes of deformation that began in the Early Cretaceous. Three major of episodes were at least linked to NW-SE compressions coinciding with the intermittent opening of the South China Sea sub-basins during the Middle Eocene, early Middle Miocene and Late Miocene (Tongkul, 1994, 1997). Based on the study of central Sabah area, Tongkul (1997) concluded that the Middle Eocene deformation episode is characterized by folding and thrusting of basement rock and older Palaeogene sediments trending with associated N-S left lateral horizontal faults. The early Middle Miocene deformation is characterised by imbrication of the basement rock and overlying sediments to the NE, with associated NE-SW left lateral horizontal faults. The Late Miocene deformation is characterised by thrusting earlier deformed basement rock and overlying sediment to the NW.

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The complexity of the structural patterns is further enhanced by extensional tectonics in eastern Sabah in Early Miocene to early Middle Miocene. The continued extension in eastern Sabah probably initiated subduction processes in the southeast to produce the extensive volcanic activity in Late Miocene to Quaternary. A large part of Sabah Basin lies offshore. The complex structural history of the Sabah Basin is the result of multiple phases of structural development that maybe local or regional in nature. Bol and van Hoorn (1980) recognised three major phases of structural deformation in the basin:

I. Late Miocene phase in the central and southern parts of the basin.

II. Early Pliocene phase folding in the northeast.

III. Late Pliocene phase along the westernmost margin of Sabah Basin.

Superimposed upon the basement flexure is the independent movement of crustal blocks, which resulted in contrasting structural styles in the different provinces, particularly between the northwestern and southern areas (Levell, 1987; Tan and Lamy, 1990). The overprinting of several structural events has also produced a complex fault pattern. Furthermore, the obliquity of the compressive forces and the presence of shale within the deltaic depositional system have produced very complex transgressive structural trends. This condition commonly associated with wrench faulting. Subsidence in Sabah Basin has been attributed to wrenching of West Crocker Formation during Oligocene age (Whittle and Short, 1978).

In central Sabah Basin, strike-slip deformation has been associated with younger deformation, and yet there is no evidence of rapid subsidence. Bol and van Hoorn (1980) have noted that a variation in structural style across the continental margin off NW Sabah. Figure 3.9 show the structural styles show generally from southeast to northwest:

i. Dominantly compression with minor early extension.
ii. Dominantly compression with compression in some areas.

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iii. Dominantly compression with thrust belts that could be the result of gravity sliding or subduction or a combination of both.

Shell geologists have subdivided the Oligocene-Recent strata into sedimentary "cycles" for Sarawak Basin. However, this cycle concept is not applicable for Sabah Basin because of the strong influence of tectonics on the stratigraphy during the Neogene.
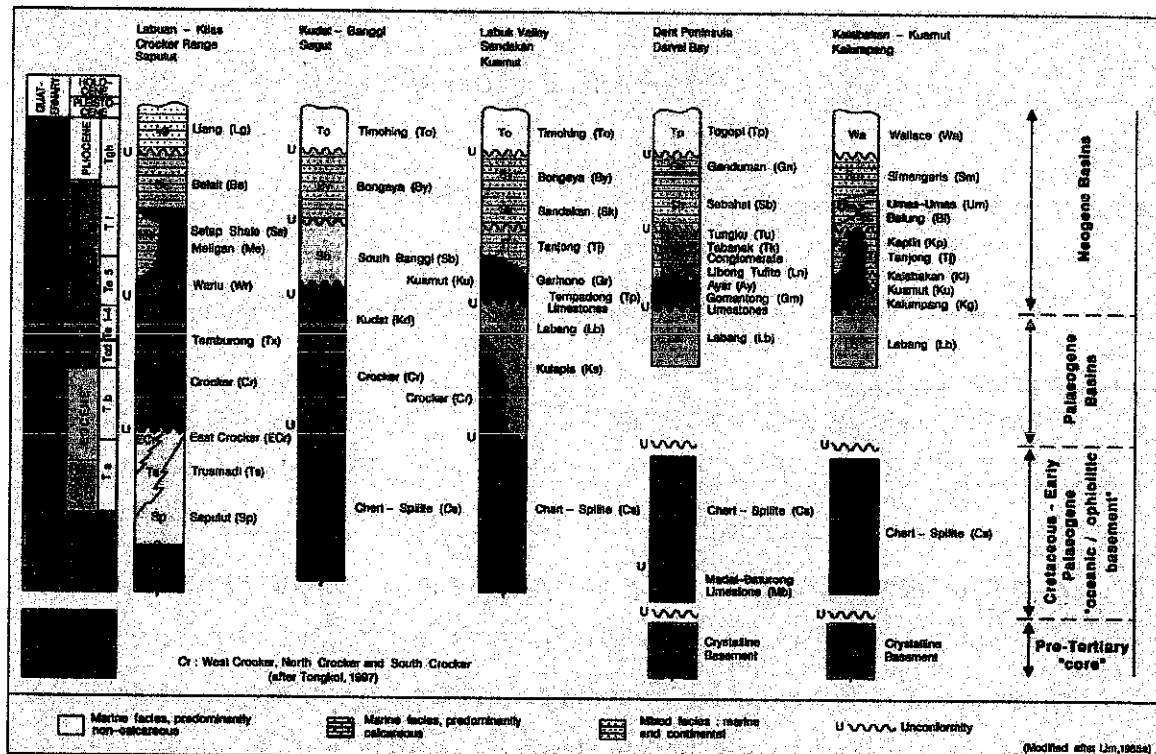
Figure 3.9: Show generalised stratigraphy of Sabah (modified after Lim, 1985a).

3.3.2 Reservoir characterization

Figure 3.10: Show stratigraphic summary of the Northern Sabah province (Levell, 1987).

The unconformities and correlative conformities are used to define several unconformity-bounded stratigraphic unit called "stages". A stage in Sabah Basin (Figure 3.10) is similar in some respects to a "sequence" in sequence stratigraphic terminology. The strongest of the regional unconformities is the Deep Regional Unconformity (DRU), which separates a pre-Middle Miocene succession of deep marine rocks (Stage I to III) from the overlying Middle Miocene to Quaternary prograding shelf-slope sediments. The latter is subdivided into 7 stages which are Stage IVA to Stage IVG in younging order. These stages are bounded by major unconformities produced by tectonic movements and uplift of the south-eastern margin of the basin. Each unconformity passes north-westward into a conformable down lap surface.

The intraformational shale and mudstone units provide effective top and flank seals in many accumulations because there is no major seal horizons in Sabah Basin. The timing of structural trap formation is related to the shallow regional unconformity (SRU) in Late Miocene, Horizon II in Early Pliocene and Horizon I in Late Pliocene. Two types of different ages structures are in Middle Miocene in Horizon II (affected by SRU or Early Pliocene deformations) and also in Late Miocene in Horizon I

(structures affected by Late Pliocene deformation). Stage IVA reservoirs mainly occur in Southern Inboard Belt and deformed during Late Miocene in shallow regional unconformity (SRU) deformation. The small accumulations in this area are maybe due to the loss of hydrocarbon in destruction of earlier formed traps.

The SRU deformation in Northern Inboard Belt is appears less severe. Most of Sabah Basin reservoirs are predominantly siliciclastic and good quality of reservoirs are formed by coastal fluviomarine and stacked shallow marine sandstones in Stage IVA and Stages IVC/IVD. In general, reservoir thicknesses can reach up to 300 m in places. According to Scherer, 1980, lower coastal plain facies have better quality than fluviomarine facies because it has higher permeability and tend to form thicker reservoir, but fluviomarine facies reservoirs have better lateral continuity.

The deep marine turbidites in Stages IVC/IVD, to fluviomarine and shelf deposits also form a thick and high quality reservoirs. Although carbonate reservoirs is a minor component, but have fair to excellent quality of reservoirs. Kudat Platform that located in the Northern Sabah is one of the examples that consist of carbonate reservoir occurrences (Stage IVC and Stages IVE-IVG in Lower and Upper Limestone Units).

Mixed carbonate siliciclastic reservoirs have been assigned to Stage IVB which located in Tiga Papan of Northern Inboard Belt and thought to be equivalent to the onshore of South Banggi Formation. Mohammad Yamin Ali (1992, 1995) studied the detail about diagenetic of these rocks. Figure 3.11 below show the schematic illustration of stratigraphy several east-west tracts for Sabah Basin that based on Shell (1993) exploration in the basin.
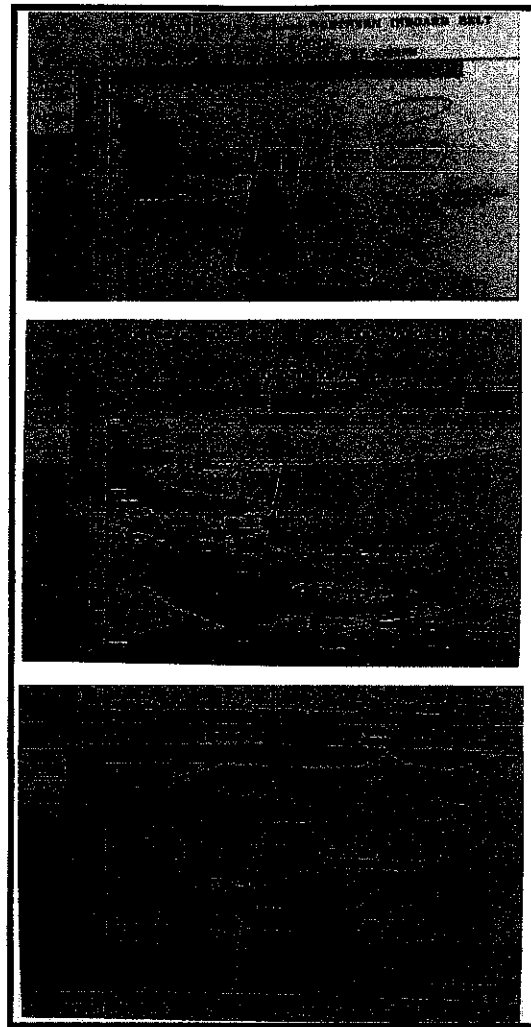
Figure 3.11: Show stratigraphy of several east-west tracts of Sabah Basin (Based on Shell, 1993).

The deposition of source beds that rich in terrigenous organic matter which interbedded with sand prone reservoir facies is resulted by the erosion of NW Sabah margin during Early Middle Miocene and the extensive outbuilding of Stage IV siliciclastic wedge. The palaeogeographic controls on the distribution, preservation, quality and maturity of source rocks based on onshore and offshore data from Sabah Basin areas. Lower coastal plain shales that containing disseminated organic matter derived mainly from land plants with coals occurring as transported fragments is the major source lithology.

These studies concluded invariably that the majority of potential source rock have poor to good organic matter contents which have total organic carbon (TOC) is less than 2 wt% with correspondingly poor to fair hydrocarbon generating potentials

($S_2 < 5$ mg HC/g TOC) while the good quality of source rocks ($S_2 > 5$ mg HC/g TOC) are rare because they are commonly associated with coaly shales. The reservoirs range from coastal or shallow marine sediments to deep marine turbidites. They are found in structural traps including extensional growth fault structures and wrench related compressive anticlines (Figure 3.11).

3.3.3 Crude oil characteristics

Hydrocarbons in Sabah Basin are found and produced from siliciclastic reservoirs mainly in Stages IVA, IVC and IVD. Most of the hydrocarbons occur in complex wrench induced faulted anticlines that associated with deltaic growth faults and other fault, but there are minor occurrences in other stratigraphic units including Stage III. The hydrocarbon plays in the different tectonostratigraphic provinces. Generally, Sabah Basin crude oils are light, slightly waxy, and contents of low sulphur. The API gravity ranges between 25^0 to 50^0 degrees and for normal, non-degraded oils the API averages 35^0 while for degraded oils, the value of API is 25^0. The API value and the variation of wax content maybe are due to the amount of landplant-derived components in source rock and extent of biodegradation of oils. The API gravity value that less than 13.9^0 to 14^0 degrees, low in waxy and have very heavy oils are probably because of the biodegradation of a light condensate due to sub-aerial chemical and biological weathering.

Most of the slightly waxy oils has been observed and found in the north-eastern part of basin while some occur in the southwest. The variations in wax content are related to the source rock depositional environment. Generally, deltaic source rocks generate oils with higher wax contents compared to the source rocks that deposited in marine shelf or slope environment have lower wax content in oils. The source rocks are most likely non-marine, coastal plain deposits because the oils and condensates contain low sulphur content. Carbon isotope ratios that stable in oils and saturated hydrocarbons progressively become heavier with decreasing amounts of saturated hydrocarbons. According to the earlier researcher (Leong, 1978; Mazlan

Madon, 1994; Azlina Anuar, 1994), table 3.1 below shows the bulk properties of hydrocarbons that have been recovered from the offshore in Sabah Basin.

Table 3.1: Shows the properties of hydrocarbons in Sabah Basin (Source: Leong, 1978; Mazlan Madon, 1994; Azlina Anuar, 1994)

Sample	Gravity (^{0}API)	Wax (Wt %)	Sulphur (Wt %)	$\delta^{13}C_{oil}$	$\delta^{13}C_{sat}$	$\delta^{13}C_{aro}$
Bambazon	35	0.7	0.30	-28.0	-28.5	-26.9
Barton	32	0.7	0.36	-27.9	-28.9	-26.8
Bongawan	32	0.4	0.07	-27.7	-28.5	-26.8
Dampier	36	0.3	0.10	-27.8	-28.4	-26.3
Erb South	20	-	0.20	-26.7	-26.8	-26.4
Erb West	28	0.6	0.30	-27.5	-28.0	-26.4
Glayzer	31	0.1	0.10	-28.0	-28.4	-26.8
Kebabangan	29	-	0.10	-27.0	-27.6	-26.5
Ketam	37	0.4	0.05	-27.2	-27.8	-26.3
Kinabalu	37	0.6	0.10	-	-28.7	-29.9
Nosong	47	-	0.10	-	-27.6	-26.6
Lokan	33	0.3	0.30	-27.6	-28.0	-26.6
Pondu	24	-	0.20	-27.5	-28.1	-26.4
Rusa Timur	32	1.0	0.10	-	-28.7	-26.5
Samarang	34	0.4	0.20	-27.6	-28.1	-26.8
Sikuati	14	Low	0.50	-27.1	-	-
South Furious	31	0.8	0.10	-27.6	-28.0	-26.6
St. Joseph	34	0.8	0.20	-28.0	-28.9	-26.7
SE Collins	34	0.4	0.10	-27.9	-28.4	-26.7
Tembungo	40.0	0.3	0.30	-27.4	-27.9	-26.6
Tiga Papan	26-36	4-10	0.10	-27.6	-	-
Titik Terang	50	-	0.05	-	-	-
W. Emerald	20	-	0.20	-26.7	-26.7	-26.4

The table shows that carbon isotope for aromatics remain constant because aromatic probably are more reliable for correlation and not affected by gross composition. Aromatics that have stable carbon isotope values indicate that they were generated from very similar types of organic matter for example from land plants. According to the earlier studies, hydrocarbons in Sabah Basin mostly very similar in

composition because they have originated from source rock that rich in terrigenous organic matter.

As the sediments are generally immature, it is difficult to correlate the oils with their potential source sediments extracts. Sabah Basin oils can be grouped into one family because the oils originated either from different source rock or same source rocks but with similar chemical composition. The source rock for organic matter can be indicated by high triterpane to sterane ratios and the presence of diagnostic landplant derived compounds. The Pr/Ph ratios also can be a good indicator for source rocks deposition environments.

CHAPTER 4

SAMPLES

4.1 Overview

In this chapter, this section discusses and explains the description of each sample that has been collected from oil field in Sabah Basin (Erb West) and Malay Basin (Dulang and Angsi).

4.2 Samples

Figure 4.1: Shows crude oil that collected from Erb West oil field in Sabah Basin area.

Figure 4.1 shows crude oil in Sabah Basin generally is slightly waxy, light and has low content of sulphur. The API gravity value for Sabah oil is about 28^0, and the gas constituent is 92% methane. The oil from Sabah is collected based on its stratigraphy and location area. Sabah oil has collected from the Erb West platform. Erb West platform is situated in 125km offshore Malaysia, in approximately 215ft of

water. The Erb West structure is an elongated hydrocarbon bearing sand layer, and it lies in a north-easterly by south westerly direction. The main faults in the blocks are in the East - West direction, concentrated in the southern half of the structure. It is the entrapped hydrocarbon within these southern blocks that are targeted for the revisit campaign.
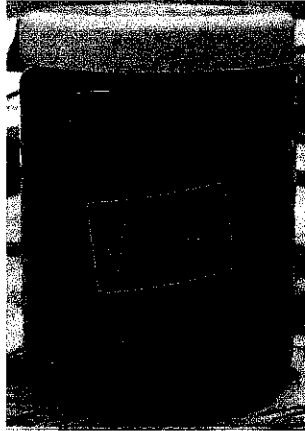
Figure 4.2: Shows crude oil that collected from Dulang oil field in Malay Basin area.

Dulang is geographically restricted to the centre of Malay Basin and the Dulang field has a large oil accumulation and account for a majority of the Group E oils in the basin. Figure 4.2 shows the crude oil that has been collected from Dulang oil field. Mostly, oils in this group are immature over much of the basin except only in the lowest part of E reaches the oil window in some areas. A majority of Group E oils are moderately waxy to waxy and condensates are more common, and the gas produced is known to be high in CO_2.
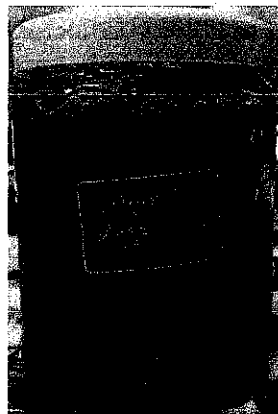
Figure 4.3: Shows crude oil that collected from Angsi oil field in Malay Basin area.

Angsi predominantly has Pre-group I oils in Malay basin. Figure 4.3 shows the crude oil that has been collected from Angsi oil field. Pre-group I oils are common in the eastern side of the Malay Basin. The geochemical characteristics vary only little in Pre-group I and this variation is considered to be due to a combination of differing maturity of the oils and of post-accumulation processes such as evaporative fractionation. Group I have high value of API condensates to moderately API waxy oils and also show variable compositions at both bulk and molecular level. The oils range from very terrigenous, to more lacustrine-influenced. Crude oils are very complex chemical systems. In crude oil system, the fluids contain from hundreds to thousands of individual components in the range of simple molecular weight n-alkanes to the high molecular weight waxes and asphaltenes. As for the light hydrocarbon components such as methane and ethane act as a solvents to the supersaturated solution and the saturation depends on the temperature.

CHAPTER 5

METHODOLOGY

5.1 Overview

This section will discuss and explains the methods that will be used to conduct the study. The first part of the section which is, fieldwork will clarify how the data or the sample (s) will be collected from the field and how the samples are collected for laboratory analysis. The following section is related more to laboratory analysis which will be elaborate more on experimental works.

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┌─────────────────────────────────┐
│ METHODOLOGY                      │
└─────────────────────────────────┘
         │
         │    ┌──────────────────────────────────┐
         ├────│ Fractionation using high pressure │
         │    │           Parr Reactor            │
         │    └──────────────────────────────────┘
         │    ┌──────────────────────────────────┐
         ├────│ Sampling under different pressure │
         │    │          & temperature            │
         │    └──────────────────────────────────┘
         │    ┌──────────────────────────────────┐
         ├────│     Data Analysis using GC - MS   │
         │    └──────────────────────────────────┘
         │    ┌──────────────────────────────────┐
         └────│    Establish trend of variations  │
              └──────────────────────────────────┘
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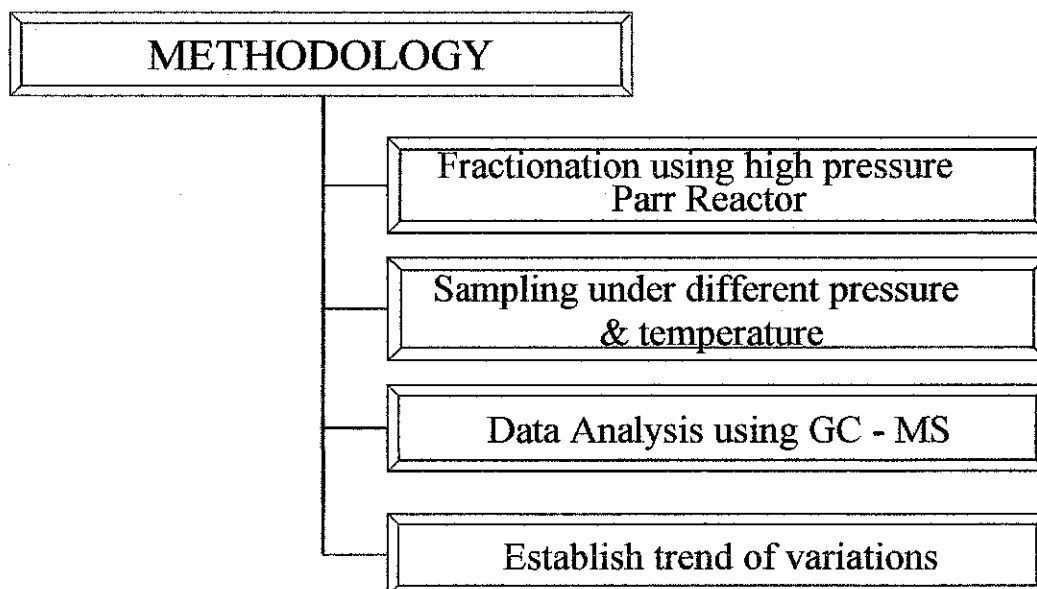
Figure 5.1: Shows the sequences in methodology for the experiment.

In this chapter, the modification technique of fractionation used in the characterization of petroleum as well as the techniques of elemental analysis applied to the fractions obtained will be introduced (modified from Thompson, 1987). The final part after

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fractionation experimental is data analysis using GC-MS analysis. Based on the experiment, all the data can be concluded in Chapter 6 for its results and discussion part as shown in Figure 5.1.

5.2 Modification of the instrument

The instrument (Figure 5.2) that will be used in the experiment is high pressure reactor. The function of this instrument is to heat crude oil samples at a certain temperature up to maximum. The samples are only available in a liquid phase. A modification with this instrument was made by adding a condenser that connected to the vapour valve exit. So, by modified the instrument, a sample in a vapour phase can be collected.
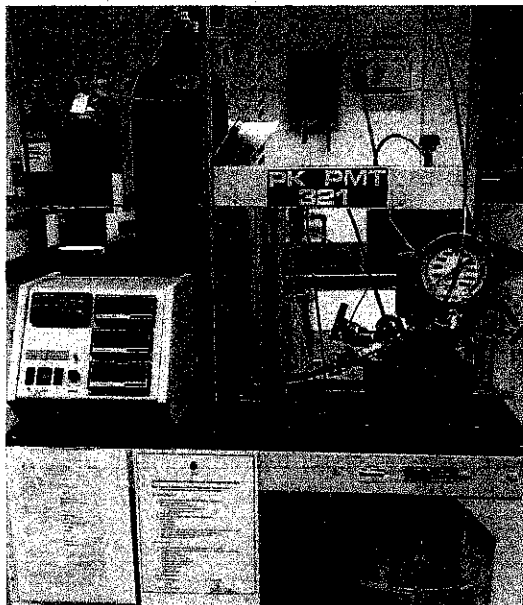
Figure 5.2: Shows instruments for evaporative fractionation experiment called pressure reactor.

The methodology that has been used in this system mostly was according to Thompson, which was evaporative fractionation by heating the oil sample with different temperature and pressure. Thompson had done this experiment in the open system while for this experiment it was in a close system. Evaporative fractionation is done by passing gas over oil.

5.3 Fieldwork

Table 5.1 shows the reservoir and trap characters of oils collected from Erb West oil field in Sabah Basin, Dulang Oil and Angsi Oils from Malay Basin area. The volume of oil that has been collected from Erb West in Sabah Basin is about 700 ml while for Dulang is about 900 ml and for Angsi is about 1000 ml volume of oil.

Table 5.1: Shows the data from each type of oil in Sabah Basin and Malay Basin (source: Mazlan B.H. Madon, 1995)

No	Location	Field	Reservoir	Trap
1	Sabah Basin	Erb West	Stage IV D shallow marine sands and 6 main reservoirs at around 2286m.	Trap is trending from E-W anticline that cut by a normal faults and oil rim with gas cap.
2	Malay Basin	Dulang	Main reservoirs are shallow marine and fluvial sandstones of Group I reservoirs. Sourced are from the interbedded carbonaceous shales and coals	Compressional anticlines – a trend usually comprises a series with major E-trending deep-seated basement fault.
3	Malay Basin	Angsi	Reservoirs are formed by shallow marine sandstones of Group D and Group E reservoirs, interbedded claystone and shale units provide the top seals for reservoirs.	Compressional anticlines – central part of the basin trap are formed by 4-way dip closures in domal structures or asymmetrical anticlines, and normal fault bounded structures.

5.4 Fractionation using High Pressure Parr Reactor

5.4.1 Parr High Pressure Reactor

Evaporative fractionation experiments were carried out using modified Parr High Pressure Reactor as shown in Figure 5.3. The instrument principally comprised pressure pumps in which pressure is recorded using transducers and burst limit is 8000 psi and a steel pressure vessel that are capable of being maintained at constant, elevated temperature.
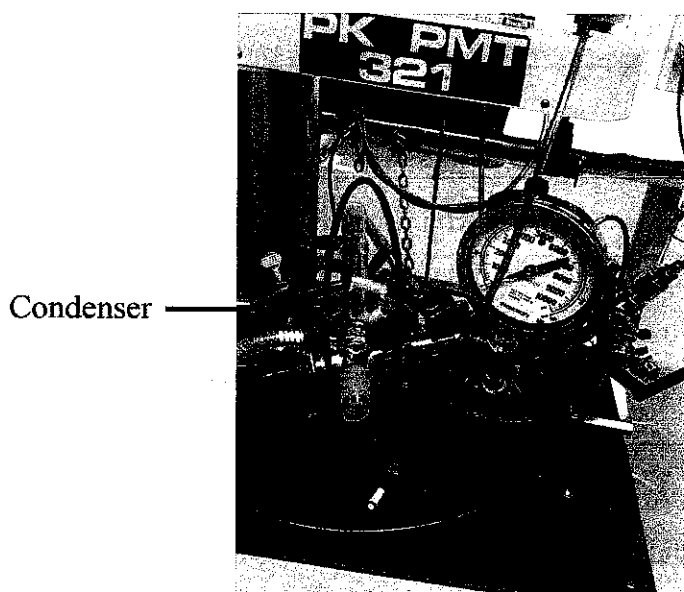
Condenser —

Figure 5.3: Shows the modification by adding condenser into the vapour valve exit.

The first experiment is done with Sabah oil and continuously with Dulang and Angsi oil. This experiment is use to collect liquid and vapour sample and both samples are collected in a liquid phase. There were two steel valve for collecting liquid and vapour sample. However, vapour sample is only available in gas phase. A modification with this instrument is made by adding a condenser that connected to the vapour valve exit.
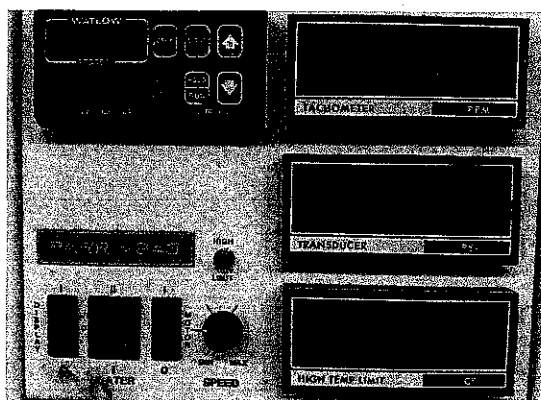
Figure 5.4: Shows switch machine that control the temperature

Figure 5.4 shows the temperature can be control on the switch machine of the instrument while amount of pressure is control by using pressure vessel. The experiment was started by putting the oil samples in the modified fractionating pressure reactor instrument and the oil was heated at different temperature. About 350 ml amount of oil sample were displaced into a glass cylinder before displace it in the fractionating instrument. The oil sample then will be heated at a maximum 250^0C temperature. It takes about more than 2 hours for the instrument to reach the final temperature and this condition will generate excess vapour pressure.

At this extra pressure, vapour will equilibrate with the liquid and some molecules will be withdrawn from the liquid to vapour phase. When this vapour condensed, it generates a different liquid from the original and also changes the composition of the original. If the excess pressure is more than 20 psi for initial experiment, then a pressure valve will be open to maintain the pressure in the fractionating instrument. This vapour then condensed to generate liquid sample for compositional analysis by GC-MS. The Figure 5.5 below shows the sequence of the evaporative fractionation experiment.

Put the crude oils in glass cylinder

Put the glass cylinder in the stainless steel heater

Setup cap closure before heating the crude oils

Setup all the available accessories include heaters, temperature controllers, 1000 ml vessel valves, gage block assemblies, and gas filling hoses.
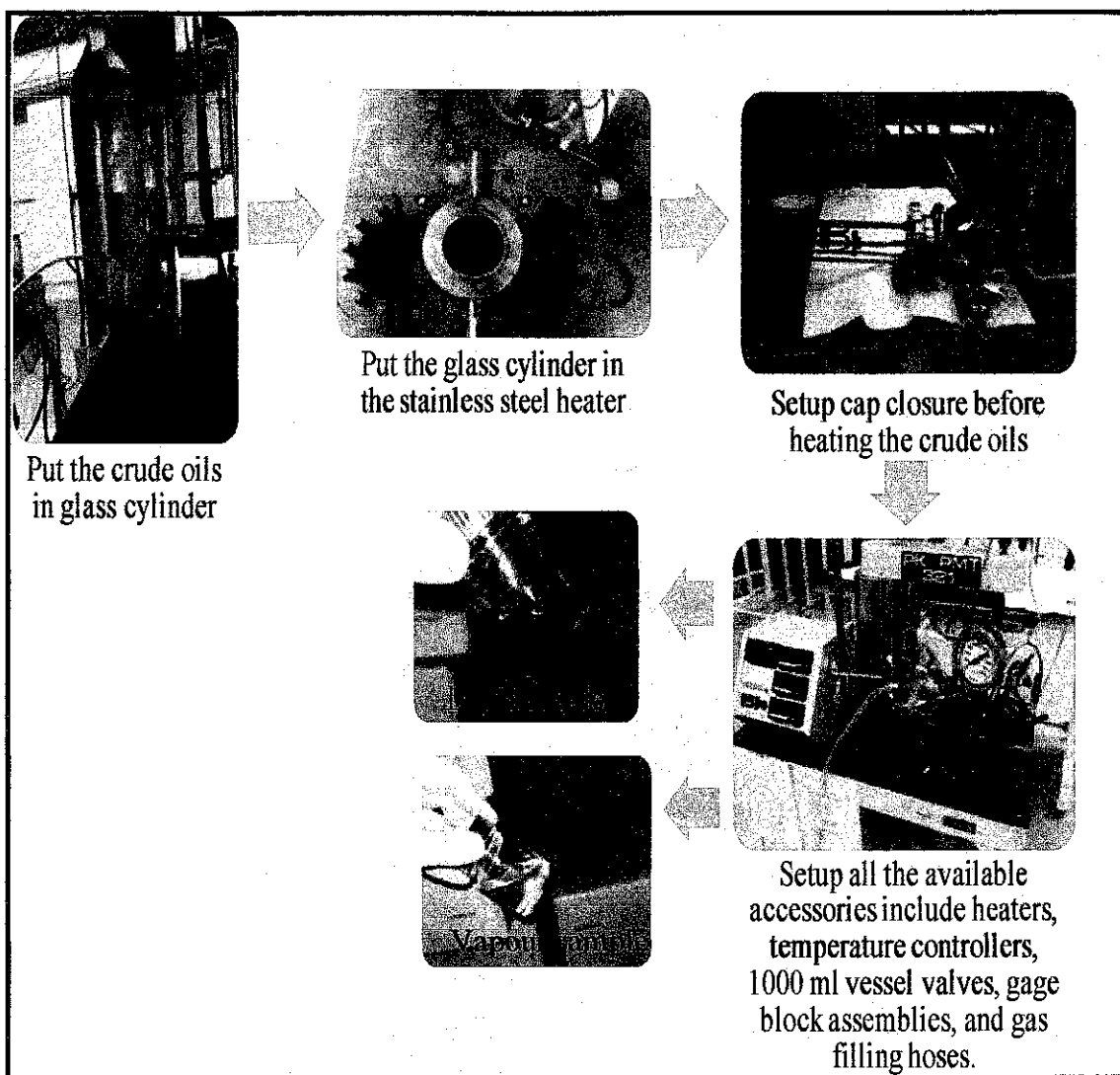
Figure 5.5: Shows the flow of the fractionation experiment using modified instrument.

Vapour valve
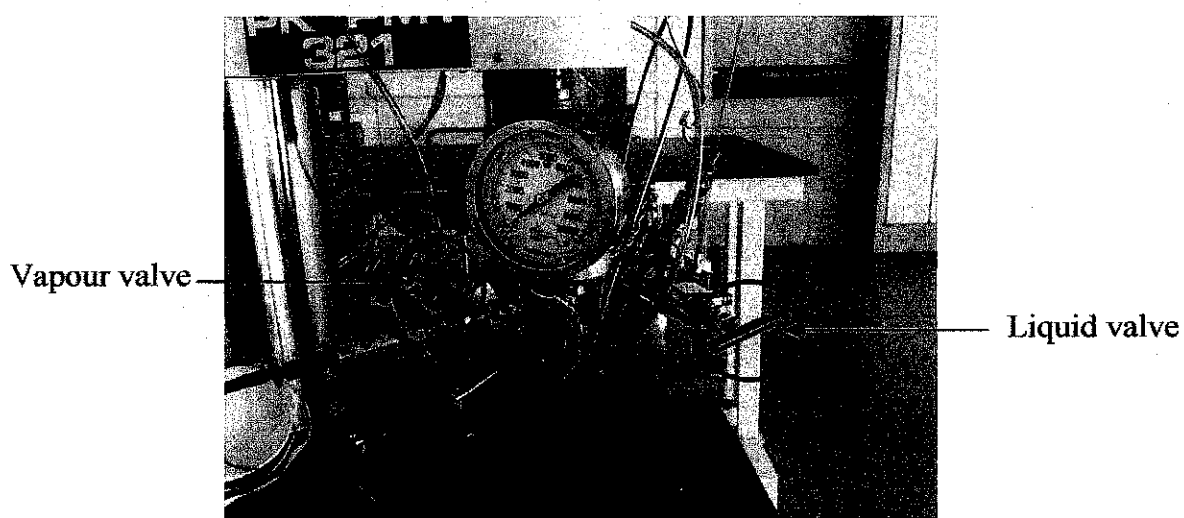
Liquid valve

Figure 5.6: Shows vapour and liquid valve connected with the instrument

After the heat was reached out for temperature and pressure, each of the oil samples will be collected using glass bottle sample by opening vapour and liquid valve. The heating of oil sample were repeated until vapour samples were collected at initial pressure 20 psi, and then it will continue for 40, 60 and 80 psi pressures.

5.5 Sampling under different temperature and pressure

The crude oil samples (Figure 5.7) will be collected in liquid phase and vapour phase with different pressure and temperature.

Figure 5.7: Show samples collected in vapour and liquid phase.

Figure 5.8, 5.9 and 5.10 show each of the vapour samples that have been collected have different colour while for liquid samples, the colour is remain the same but the viscosity is different for each samples.
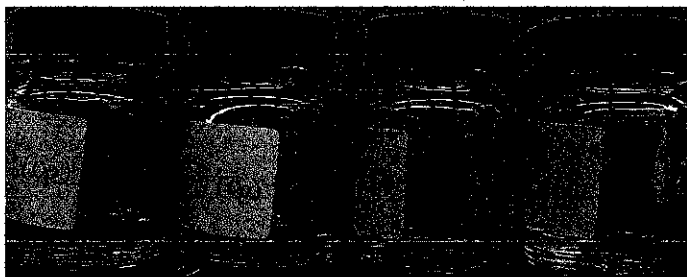
Figure 5.8: Show vapour samples with same temperature but different pressure.
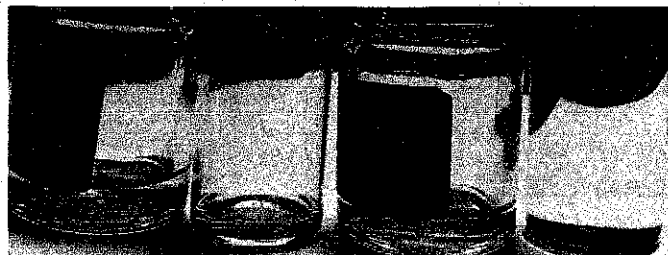
Fig 5.9: Show vapour samples with same pressure but different temperature.

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Figure 5.10: Shows different viscosity in liquid sample with same temperature and different pressure.

5.6 Analysis sample using GC-MS

5.6.1 GC-MS

The results then will be analysed with gas chromatography analysis (GC-MS) as shown in Figure 5.11. Analysis of the samples was carried out using a Hewlett-Packard GC-MS (HP6890 series GC with an HP5973 MS detector) with a capillary column (Agilent: HP-5MS, HP19091S-433) (length, 30 m; internal diameter, 250 mm; film thickness, 0.25 μm).
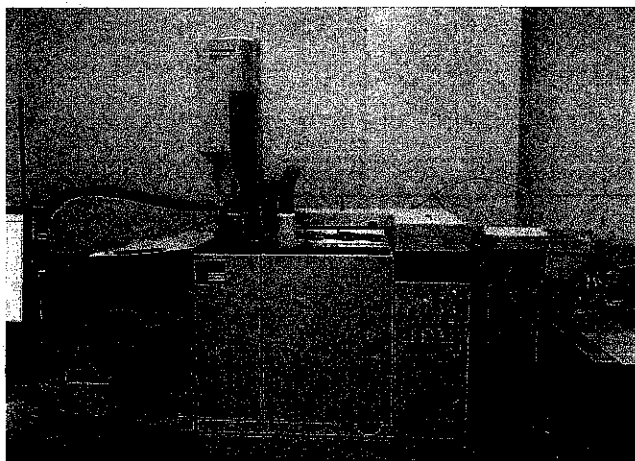
Figure 5.11: Shows gas chromatography (GC-MS) instrument.

Standard solutions covering the concentration range of the samples were used to obtain the calibration curve for calculating concentration of the compounds of interest. It was not possible to obtain standards for all the compounds identified in the

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GC/MS chromatograms. Consequently, signal intensity of the un-calibrated was normalized to compare trend of their concentration versus experimental parameters. The method that had been used during GC-MS analysis was up to C_7 and the column was BPX5 SGE. The size of column was about 30m x 0.25mm x 0.25μm and the temperature for this analysis was basically $35^0C - 70^0C$.

The pressure was mostly in vacuum pressure for about $9.86e^{-06}$ Torr. The purpose of this experiment is to analysis amount of each compound that contain in the oil sample after fractionating process had been done. Each of the collected oil samples were carefully removed from the bottle sample and transferred into labelled small vials which is about 2 ml from each of oil sample (10% from the collected oil sample). Figure 5.12 shows the vials were labelled with unique sample number assigned to the sample. Then the vial will be placed in the GC-MS tray.
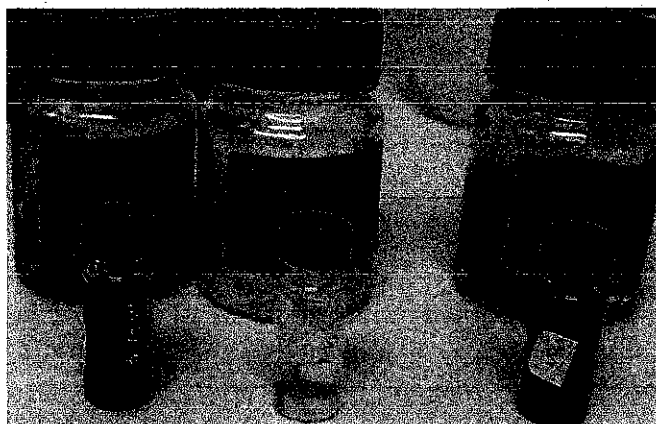
Figure 5.12: Show the samples transfer into 2ml vials to be analyse using GC-MS.

The experiment will take about 30 minutes to analyze each sample. The procedures for detection of the samples are generally as follows. A 1 μL sample was injected into the injection port set at 35°C with a split ratio of 30:1. The column was operated in a constant flow mode using 1.1 ml/min of helium as carrier gas. The column temperature was initially maintained at 40°C for 3 minutes before increasing it to 270°C at a heating rate of 15°C/min. A solvent delay of 1.3 minutes was employed. The identification of each compound was achieved based on the matching mass spectrum in the spectral library.

Gas chromatography mass spectrometer can determined the compound class by passing a saturate or aromatic fraction of oil or extract through a GC column into an MS, which will analyze the individual molecules and whole oil. It can be used in some systems. The parent molecular ions initially formed in MS will have a mass to charge ratio (m/z). Most biomarkers that are used for maturation and correlation elute between the n-paraffins C_{24} and C_{36}. This results in the formation of a major daughter fragment ion plus additional fragment ions.

Moreover, the identification will further be confirmed by comparing the retention time and mass spectrum with the standards. The distribution and relative abundance of fragment ions on the mass spectrum also can be as identification of the original molecule and its class. As for the determination of crude oil, the derivation method was used and the procedure is generally following the literature.

5.7 Establish trend of variations

Subsequent research by Thompson (1987, 1988) described the evaporative fractionation process and listed various hydrocarbon ratios that are useful in characterizing crude oils. According to Thompson (1987), the designations that use to calculate the value of paraffinicity and aromaticity is designation B (toluene/n-heptane) and F (n-heptane/methylcyclohexane). Mostly, light hydrocarbon composition ratios have been used for many years to classified crude oils. As for the analyses of a trend variation, a lower pattern of composition ratios is up to C_7 range. The C_7 alkanes are increasingly being used for oil-oil and oil-source rock correlation based on research by Mango (1990, 1992, and 1994) indicating that the C_7s are generally related. The definitions and significance of Gasoline compositional ratios will be used as parameter for paraffinicity and aromaticity shown as Table 5.2 below.

Table 5.2: The parameter shows the designation to differentiate between aromaticity and paraffinicity according to Thompson, 1987.

Designation	Definition	Property assessed
A	Benzene/n-hexane	Aromaticity (fractionation)
B	Toluene/n-heptane	Aromaticity (fractionation)
X	Xylene (m & p)/n-octane	Aromaticity (fractionation)
C	(n-hexane + n-heptane) / (cyclohexane + methylcyclohexane)	Paraffinicity (maturity)
I (isoheptane value)	(Methylhexanes (2- & 3-)) / (dimethylcyclopentanes (1c3-, 1t3-, & 1t2-))	Paraffinicity (maturity)
F	n-heptane / methylcyclohexane	Paraffinicity (maturity)
H (heptane value)	100 n-heptane/ (Σ cyclohexane through methylcyclohexane)[a]	Paraffinicity (maturity)
R	n-heptane / 2-methylhexane	Extent of branching
U	Cyclohexane / methylcyclopentane	Extent of branching

CHAPTER 6

RESULTS & DISCUSSIONS

6.1 Overview

This section will discuss the results of analysis of parafinicity and aromaticity in condense vapour and the residual liquid. Parafinicity and aromaticity had been analyzed individually with varying temperature and pressure. All the result from each basin (Erb West, Dulang and Angsi – liquid and vapour samples) had been analyzed using Gas Chromatography - Mass Spectrometry (GC-MS). Results are shown graphically as well as in tabular form. The purpose of this graph is to get a trend line of oil in Sabah Basin and Malay Basin. It is also to understand the behavior of oil that was affected from different temperature and pressure.

6.2 Erb West oil in Sabah Basin

Paraffinicity and aromaticity are calculated based on "Thompson Parameters" as follow:

$$\text{Paraffinicity} = \frac{\text{n-heptane}}{\text{Methyl Cyclohexane}} \qquad (6.1)$$

$$\text{Aromaticity} = \frac{\text{Toluene}}{\text{n-heptane}} \qquad (6.2)$$

Table 6.1: Show the results of paraffinicity and aromaticity in the residual oil samples in Erb West (Sabah Basin).

Residual oil Samples	Sample no.	n-heptane, (n-C$_7$) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C$_7$/MCH)	Aromaticity, toluene/n-C$_7$
Original oil	1	3.94	18.22	19.09	220	4.86
Residual 1	2	3.3	20.02	30.82	170	9.34
Residual 2	3	2.82	19.28	33.23	150	11.78
Residual 3	4	2.33	18.13	35.17	130	15.09
Residual 4	5	1.8	16.51	37.04	110	20.58
Residual 5	6	1.26	13.91	36.21	90	28.67
Residual 6	7	0.88	12.32	36.77	71	41.78
Residual 7	8	0.7	10.56	34.47	66	49.24
Residual 8	9	0.59	9.52	33.62	62	56.98
Residual 9	10	0.34	5.92	22.34	57	65.71
Residual 10	11	0.12	4.11	15.45	30	128.75
Residual 11	12	0.16	6.12	24.14	26	150.87
Residual 12	13	0	0	19.1	0	0
Residual 13	14	0	2.01	12.66	0	0
Residual 14	15	0	1.26	11.69	0	0
Residual 15	16	0	0	0	0	0
Residual 16	17	0	0	0	0	0

Note: The code of the sample number is:

No. 1 = Original oil (25^{0}C, 1 atm without any heating process)

No. 2 = Residual oil 1 (100^{0}C, 20 psi)

No. 3 = Residual oil 2 (100^{0}C, 40 psi)

No. 4 = Residual oil 3 (100^{0}C, 60 psi)

No. 5 = Residual oil 4 (100^{0}C, 80 psi)

No. 6 = Residual oil 5 (150^{0}C, 20 psi)

No. 7 = Residual oil 6 (150^{0}C, 40 psi)

No. 8 = Residual oil 7 (150^{0}C, 60 psi)

No. 9 = Residual oil 8 (150^{0}C, 80 psi)

No.10= Residual oil 9 (200^{0}C, 20 psi)

No.11= Residual oil 10 (200^{0}C, 40 psi)

No.12= Residual oil 11 (200^{0}C, 60 psi)

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No.13= Residual oil 12 (200^{0}C, 80 psi)

No.14= Residual oil 13 (250^{0}C, 20 psi)

No.15= Residual oil 14 (250^{0}C, 40 psi)

No.16= Residual oil 15 (250^{0}C, 60 psi)

No.17= Residual oil 16 (250^{0}C, 80 psi)
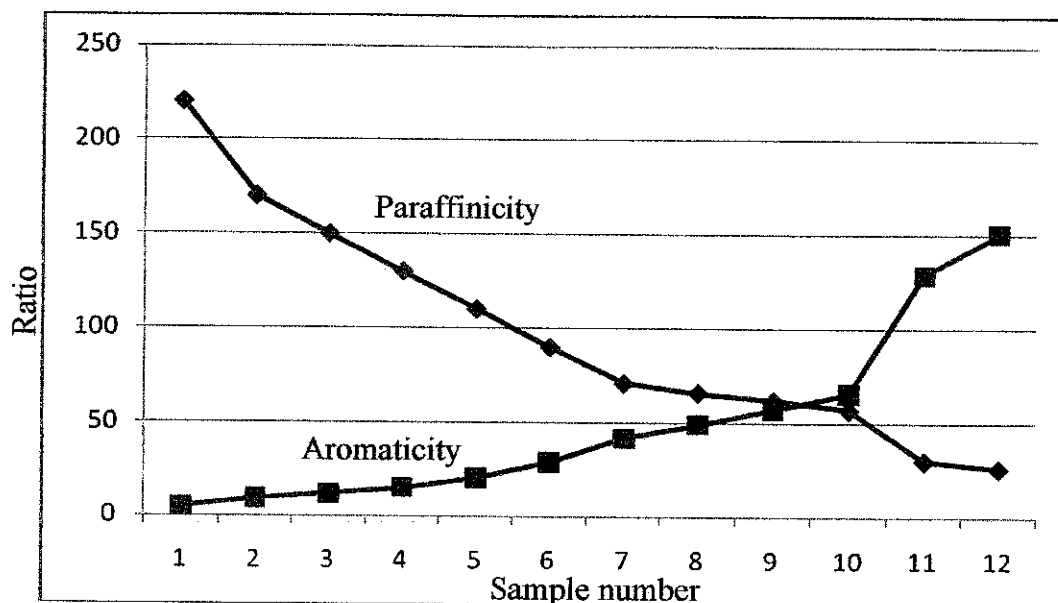
Figure 6.1: Shows paraffinicity decreases and aromaticity increases in residual oil samples in Erb West (Sabah Basin).

The data in the tabular form for paraffinicity and aromaticity in residual oil samples are shown in Table-6.1. The analysis is shown graphically in Figure 6.1 in which blue line represent paraffinicity while red line represents aromaticity. The results show that the value of paraffinicity is decreasing while the value of aromaticity is increasing as the temperature or pressure becomes higher. The individual analysis of the residual oil with effects of pressure and temperature are shown below.

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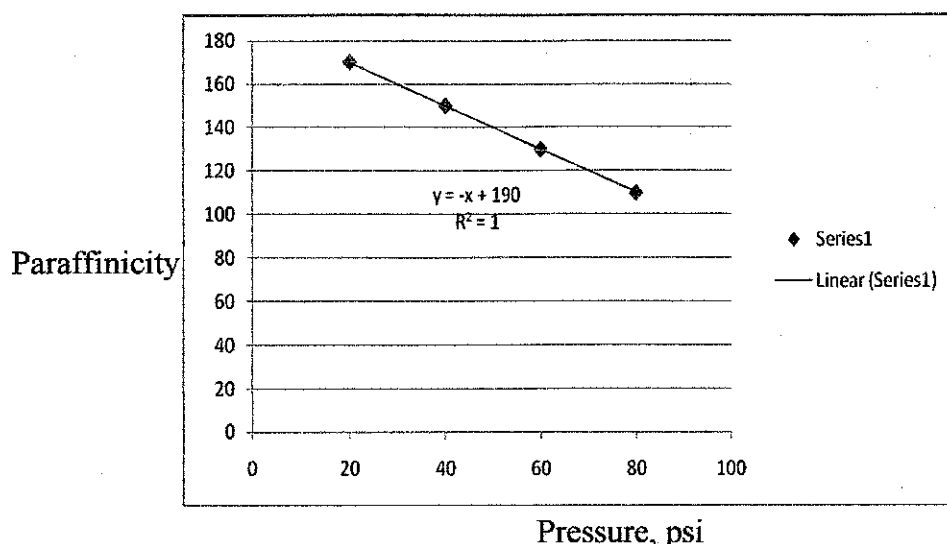
Figure 6.2: Changes of paraffinicity in residual oil samples with increasing pressure at 100^0C (Erb West).
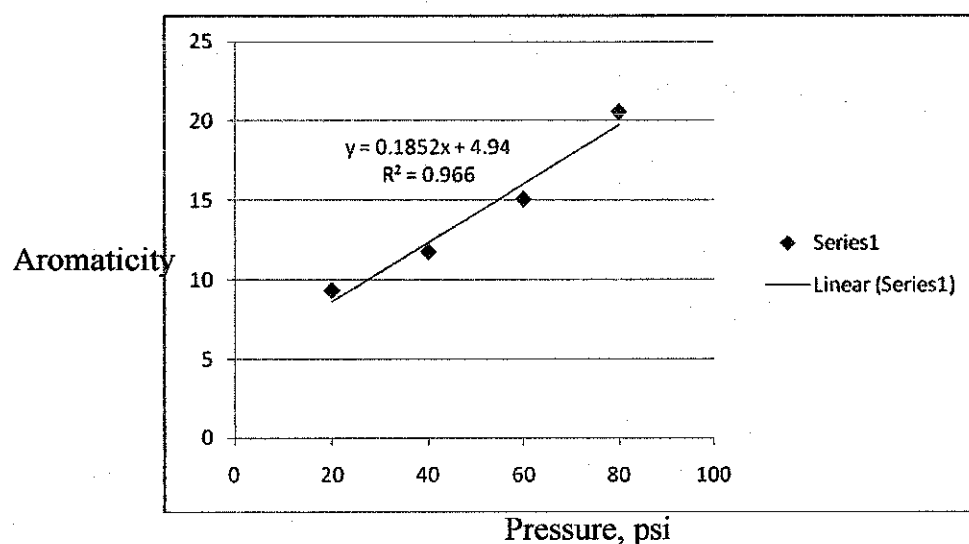
Figure 6.3: Changes of aromaticity in residual oil samples with increasing pressure at 100^0C (Erb West).

Figure 6.2 and Figure 6.3 above show the changes of paraffinicity and aromaticity with changes of pressure at the same temperature of 100^0C for samples in Erb West. Paraffinicity shows the stable decreasing of trend (follow the linear line) while increasing trend of aromaticity is a bit unstable. The value of temperature is constant for the first experiment while value of pressure is changing starting from 20 psi, 40 psi, 60 psi and up to 80 psi. Then the experiments are repeated from 100^0C, 150^0C, 200^0C until it reaches the maximum temperature 250^0C. Each of the

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experiments are repeated with Sabah, Dulang and Angsi crude oil with same value of temperature but different pressure, and same value of pressure but different temperature. Figure 6.4 below shows a flow chart of the samples that had been collected based on the temperature and pressure value.
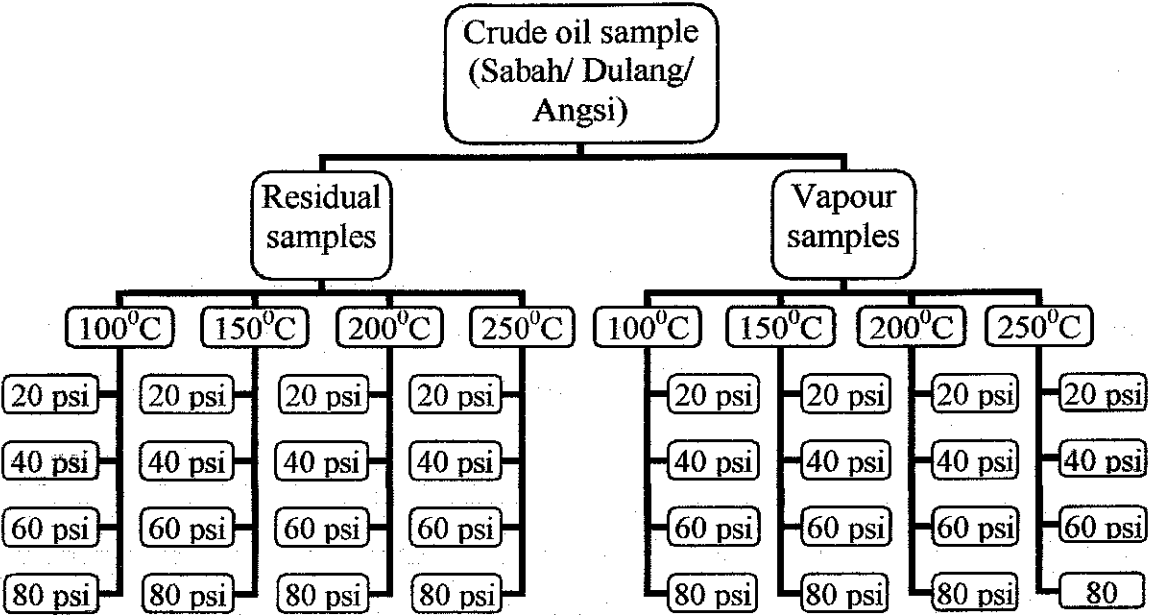
Figure 6.4: Shows flow chart of samples according to temperature and pressure.
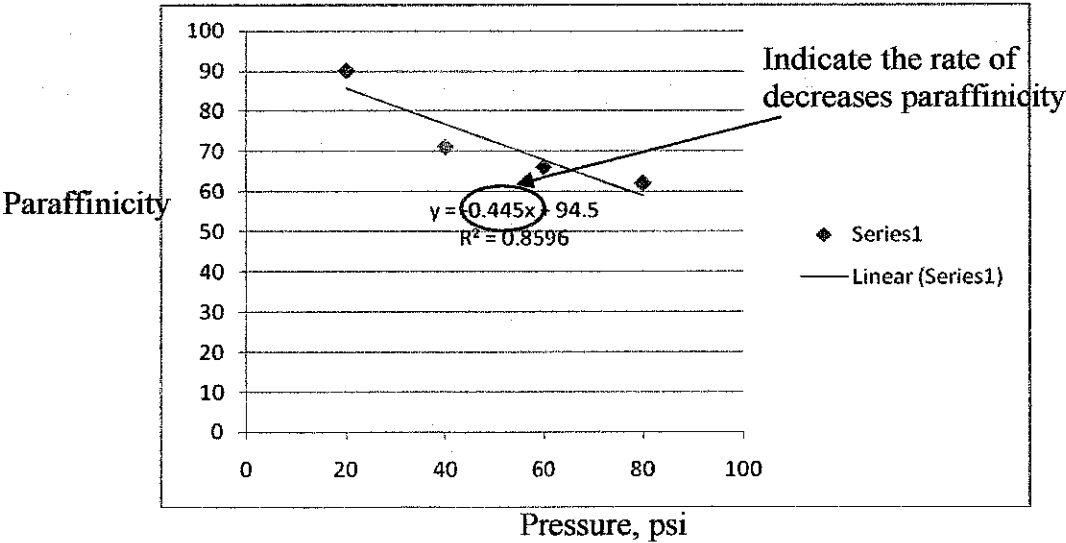
Figure 6.5: Changes of paraffinicity in residual oil samples with increasing pressure at 150^{0}C (Erb West).
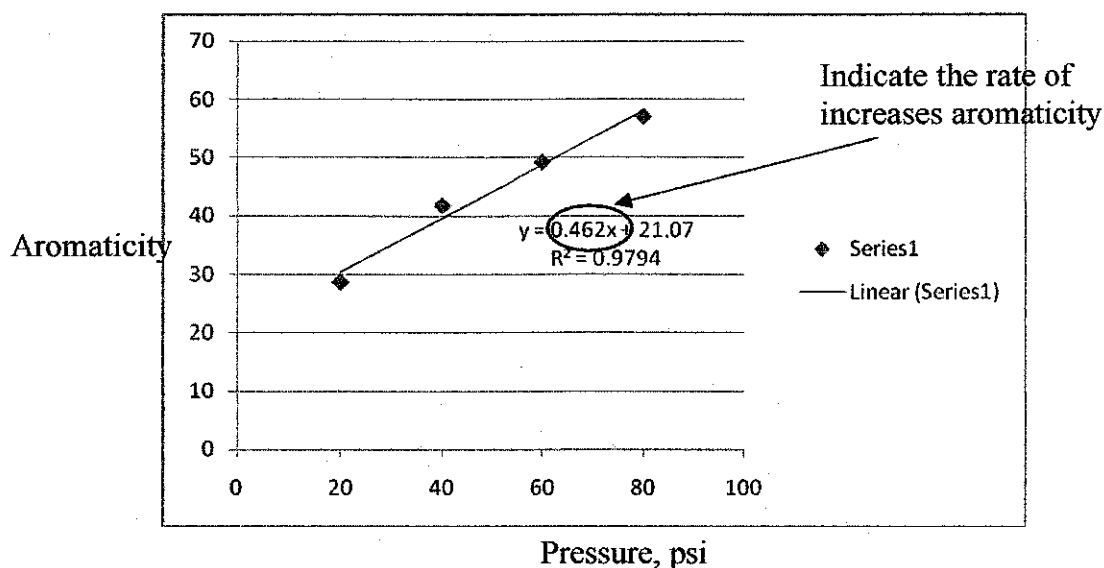
Figure 6.6: Changes of aromaticity in residual oil samples with increasing pressure at 150⁰C (Erb West).

Figure 6.5 and Figure 6.6 show the changes of paraffinicity and aromaticity with changes of pressure but at the same temperature of 150⁰C for samples in Erb West. The aromaticity shows stable increasing trend (follow the linear line) and the decreasing of paraffinicity is a bit unstable. It is not only about stability but also the gradient of the trend line is also changing from -1 to -0.445 for the paraffinicity and from 0.996 to 0.462 for the aromatics. This suggests that both the rate of decreasing for paraffinicity and rate of increasing of aromaticity with pressure fall as the temperature increased.
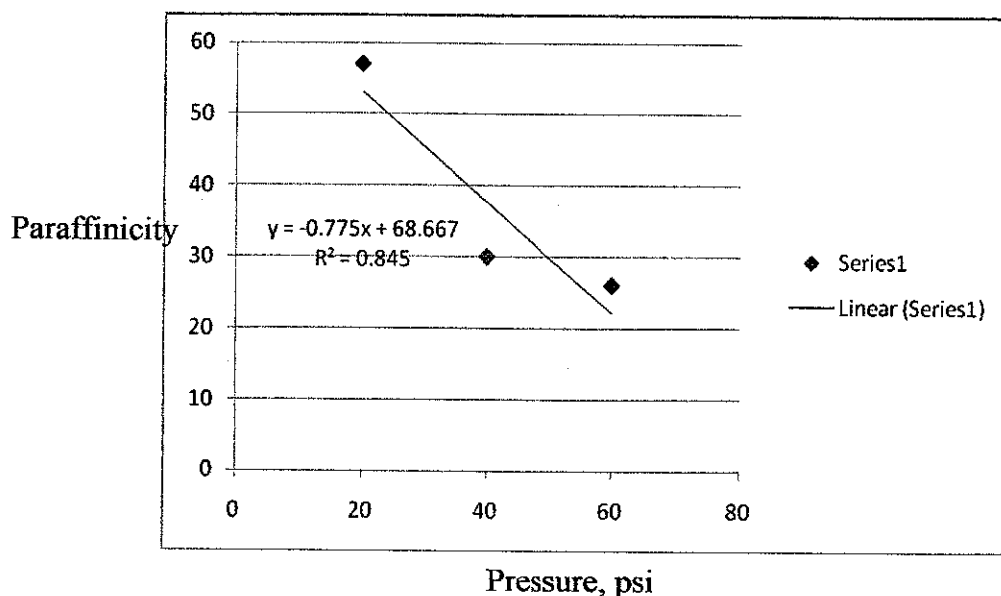
Figure 6.7: Changes of paraffinicity in residual oil samples with increasing pressure at 200°C (Erb West).

Figure 6.8: Changes of aromaticity in residual oil samples with increasing pressure at 200°C (Erb West).

Figure 6.7 and Figure 6.8 show the changes of paraffinicity and aromaticity with changes of pressure at the same temperature of 200°C for samples in Erb West. In this experiment, it is also use the same earlier trend and it was maintained. Paraffinicity show decreasing trend and aromaticity shows increasing trend. However at this temperature the rate of increasing of aromaticity is 2.129 and rate of decreasing

of paraffinicity is -0.775. Both ratios are higher than the previous. The rate of increases in aromaticity and decreases of paraffinicity equals to the gradient of trend line. There is no result or graph data that can be analysed for 200°C temperature with pressure (80 psi) in residual oil samples. This is because the value of n-heptane from condensate 12 until condensate 16 had been evaporated into vapour and cannot be measured through GC-MS (gas chromatography – mass spectrometry) analysis. So that is why the value of paraffinicity and aromaticity at 200°C (80 psi) and 250°C with increasing pressure (20 psi to 80 psi) are not available in the graph.
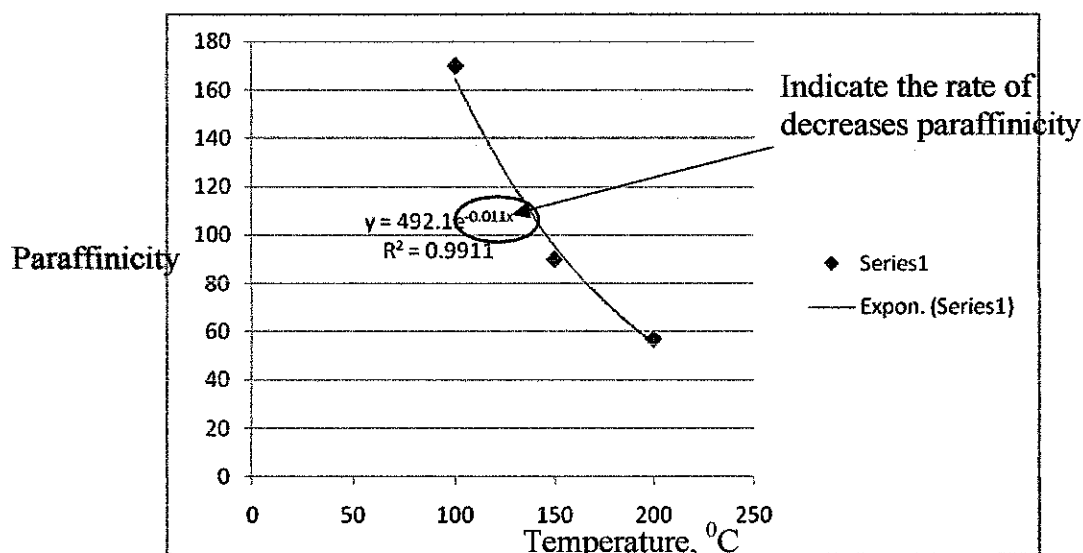
Figure 6.9: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 20 psi (Erb West).
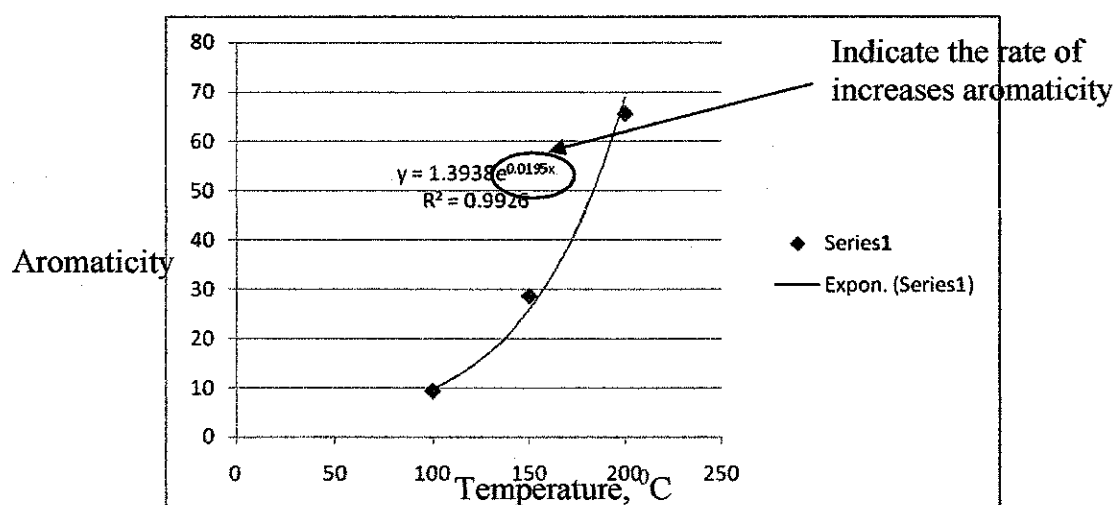
Figure 6.10: Changes of aromaticity in residual oil samples with increasing temperature at pressure of 20 psi (Erb West).

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Figure 6.9 and Figure 6.10 show the changes of paraffinicity and aromaticity with the changes of temperature but at the same pressure (20 psi) for samples in Erb West. Paraffinicity shows more stable decreasing trend and aromaticity shows stable increasing trend. The rate of increasing for aromaticity is 0.0195 and rate of decreasing for paraffinicity is -0.011 with increasing temperature at pressure of 20 psi. The rate of increasing aromaticity and decreasing of paraffinicity equals to the gradient of trend line.
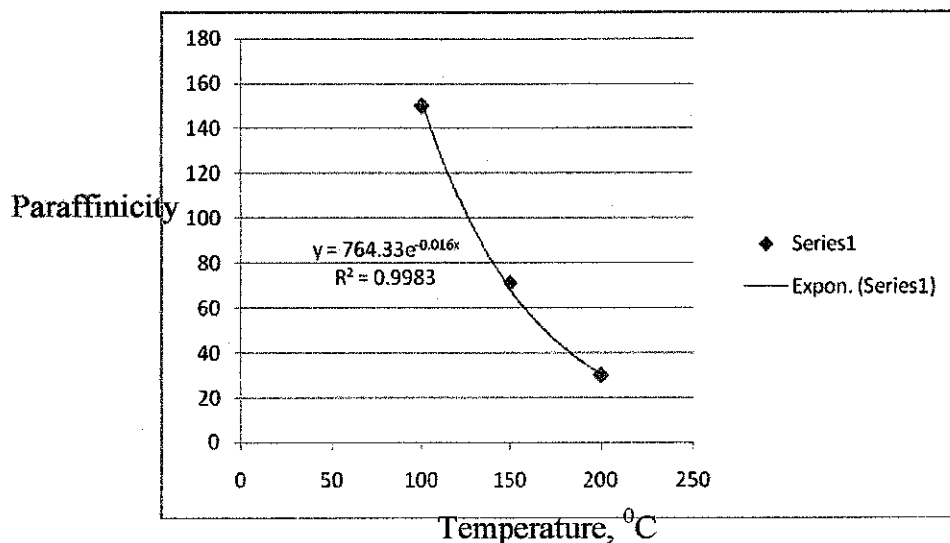
Figure 6.11: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 40 psi (Erb West).
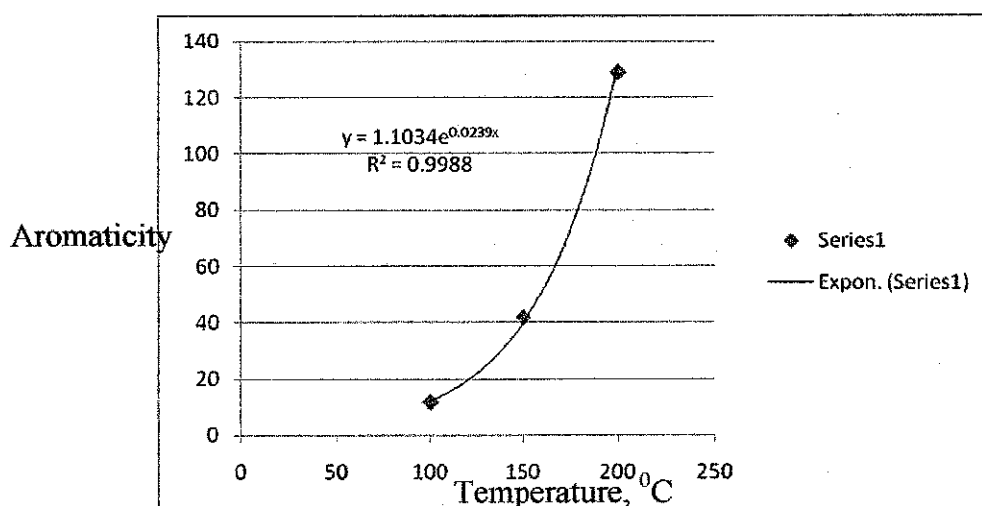
Figure 6.12: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 40 psi (Erb West).

Figure 6.11 and Figure 6.12 show the changes of paraffinicity and aromaticity with the changes of temperature at a fixed pressure of 40 psi for samples in Erb West. The value of aromaticity increases and paraffinicity decreases exponentially as earlier. However, the rate of decreasing of paraffinicity and rate of increasing of aromaticity are observed to be faster than earlier. The rate of increasing of aromaticity is 0.0239 and the rate of decreasing of paraffinicity is -0.016. Both rates are higher than previous graph.

Figure 6.13: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 60 psi (Erb West).

Figure 6.14: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 60 psi (Erb West).

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Figure 6.13 and Figure 6.14 show the changes of paraffinicity and aromaticity with the changes of temperature but same pressure of 60 psi for samples in Erb West. In this experiment, the same earlier trend is maintained. Paraffinicity shows the decreasing trend and aromaticity show the increasing trend. Both of the graphs are stable which follow the exponential line. However, the rate of decreasing of paraffinicity and rate of increasing of aromaticity are observed to be the same as earlier. This shows the rate of increasing of aromaticity is 0.023 and rate of decreasing of paraffinicity is -0.016.

Figure 6.15: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 80 psi (Erb West).

Figure 6.16: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 80 psi (Erb West).

Figure 6.15 and Figure 6.16 show the changes of paraffinicity and aromaticity with the changes of temperature at a fixed pressure of 80 psi for samples in Erb West. In this result, aromaticity is increasing and paraffinicity decreasing exponentially as earlier. This is shown that the rate of increasing of aromaticity is 0.0204 and rate of decreasing of paraffinicity is -0.011. Both rates are lower than the previous (at temperature condition). The analysis data for pressure value in residual oil samples only available up to $150^{0}C$ for this experiment. This is because the value of n-heptane from condensate 12 until condensate 16 had been evaporated into vapour samples and cannot be measured through GC-MS (gas chromatography – mass spectrometry) analysis.

Table 6.2: Show the results of paraffinicity and aromaticity in the vapour samples in Erb West (Sabah Basin).

Vapour Samples	Sample no.	n-heptane, (n-C$_7$) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C$_7$/MCH)	Aromaticity, toluene/n-C$_7$
Original oil	1	3.94	18.22	19.09	220	4.86
Condensate 1	2	3.26	17.31	32.15	190	9.86
Condensate 2	3	1.49	11.4	32.45	130	21.78
Condensate 3	4	2.43	17.07	35.62	140	14.66
Condensate 4	5	0.76	9.77	34.71	80	45.67
Condensate 5	6	1.52	14.07	31.75	110	20.89
Condensate 6	7	0.96	11.16	34.88	90	36.33
Condensate 7	8	0.81	10.11	34.66	80	42.79
Condensate 8	9	0.59	8.15	35.42	72	60.03
Condensate 9	10	0.55	7.8	35.78	71	65.05
Condensate 10	11	0.53	7.59	39.54	70	74.6
Condensate 11	12	0.55	6.49	38.54	80	70.07
Condensate 12	13	0.38	6.23	41.58	60	109.42
Condensate 13	14	0.77	10.25	41.3	75	53.64
Condensate 14	15	0.47	9.14	43.96	50	93.53
Condensate 15	16	0.65	7.7	44.05	80	67.77
Condensate 16	17	0.85	7.74	40.78	110	47.98

The data in the tabular form for paraffinicity and aromaticity in vapour samples are shown in Table-6.2. The analysis is shown graphically in Figure 6.17 in which blue line representing paraffinicity while red line representing aromaticity. The results show the value of paraffinicity is decreasing while the value of aromaticity is increasing as the temperature or pressure rises. The individual analysis of the residual oil with effects of pressure and temperature are shown below.

Note: The code of the sample number is:

No. 1 = Original oil (25^0C, 1 atm without any heating process)

No. 2 = Condensate oil 1 (100^0C, 20 psi)

No. 3 = Condensate oil 2 (100^0C, 40 psi)

No. 4 = Condensate oil 3 (100^0C, 60 psi)

No. 5 = Condensate oil 4 (100^0C, 80 psi)

No. 6 = Condensate oil 5 (150^0C, 20 psi)

No. 7 = Condensate oil 6 (150^0C, 40 psi)

No. 8 = Condensate oil 7 (150^0C, 60 psi)

No. 9 = Condensate oil 8 (150^0C, 80 psi)

No.10= Condensate oil 9 (200^0C, 20 psi)

No.11= Condensate oil 10 (200^0C, 40 psi)

No.12= Condensate oil 11 (200^0C, 60 psi)

No.13= Condensate oil 12 (200^0C, 80 psi)

No.14= Condensate oil 13 (250^0C, 20 psi)

No.15= Condensate oil 14 (250^0C, 40 psi)

No.16= Condensate oil 15 (250^0C, 60 psi)

No.17= Condensate oil 16 (250^0C, 80 psi)
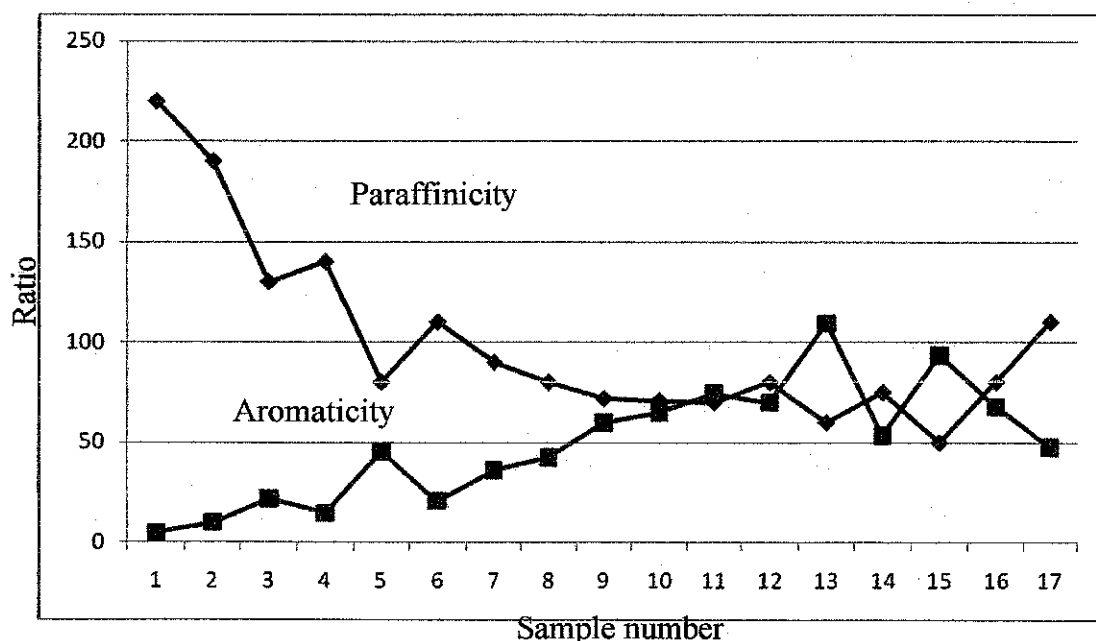
Figure 6.17: Shows the result of indicate paraffinicity decreases and aromaticity increases in vapour samples in Erb West (Sabah Basin).
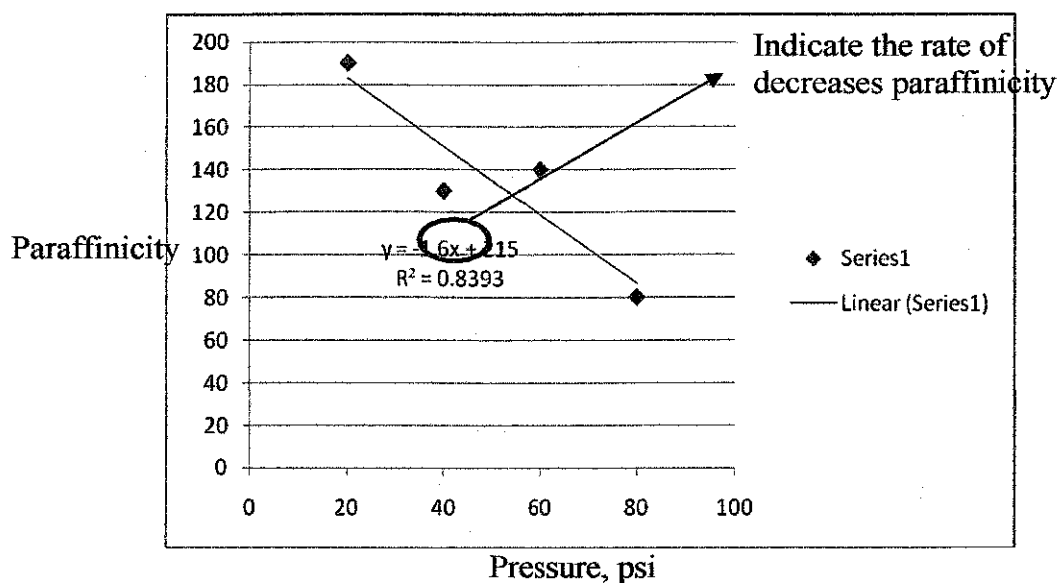
Figure 6.18: Changes of paraffinicity in vapour samples with increasing pressure at 100°C (Erb West).
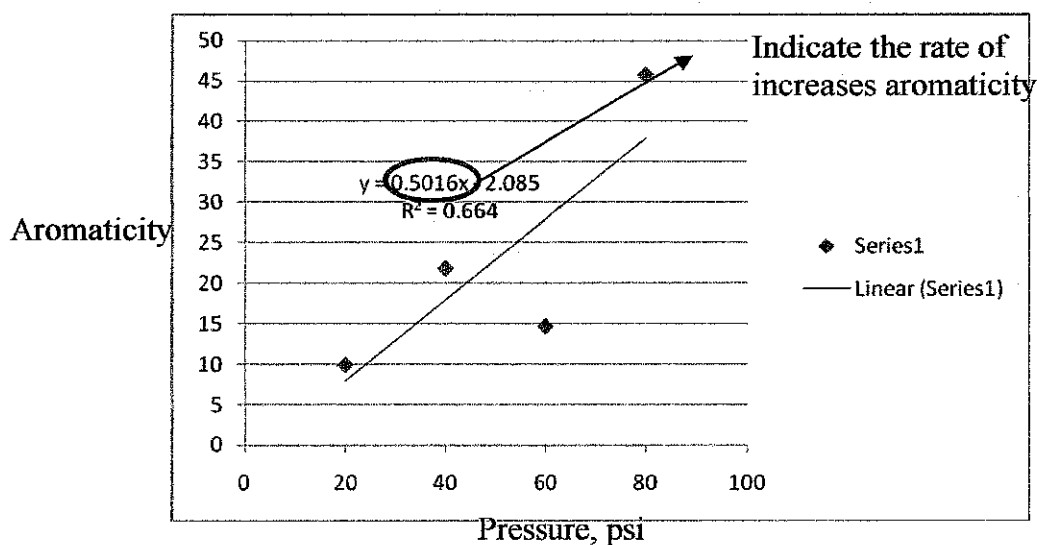
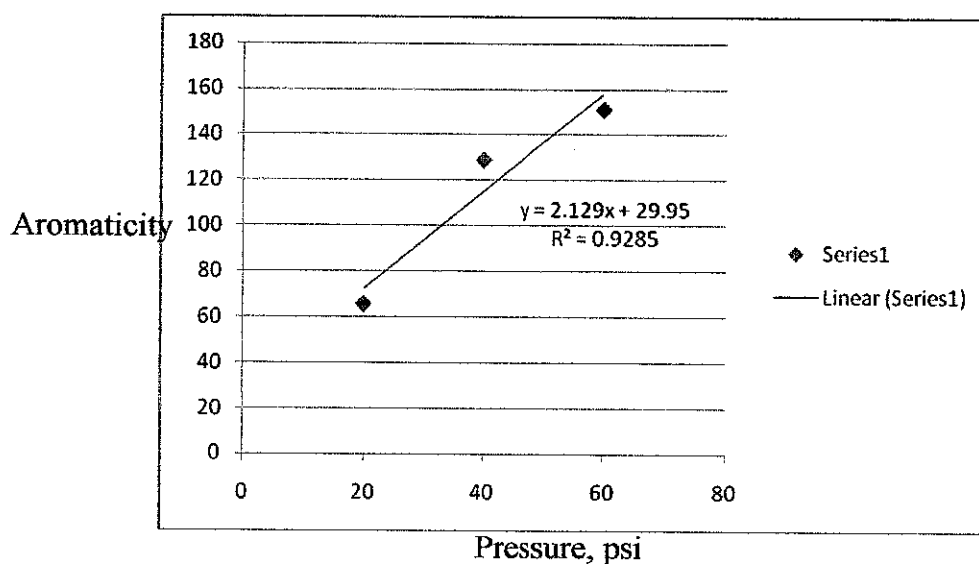
Figure 6.19: Changes of aromaticity in vapour samples with increasing pressure 100°C (Erb West).

Figure 6.18 and Figure 6.19 show the changes of paraffinicity and aromaticity with the changes of pressure at a fixed temperature of 100°C for samples in Erb West. Paraffinicity show the decreasing trend and aromaticity show the increasing trend. The rate of increasing aromaticity and decreasing of paraffinicity equals to the gradient of trending line.

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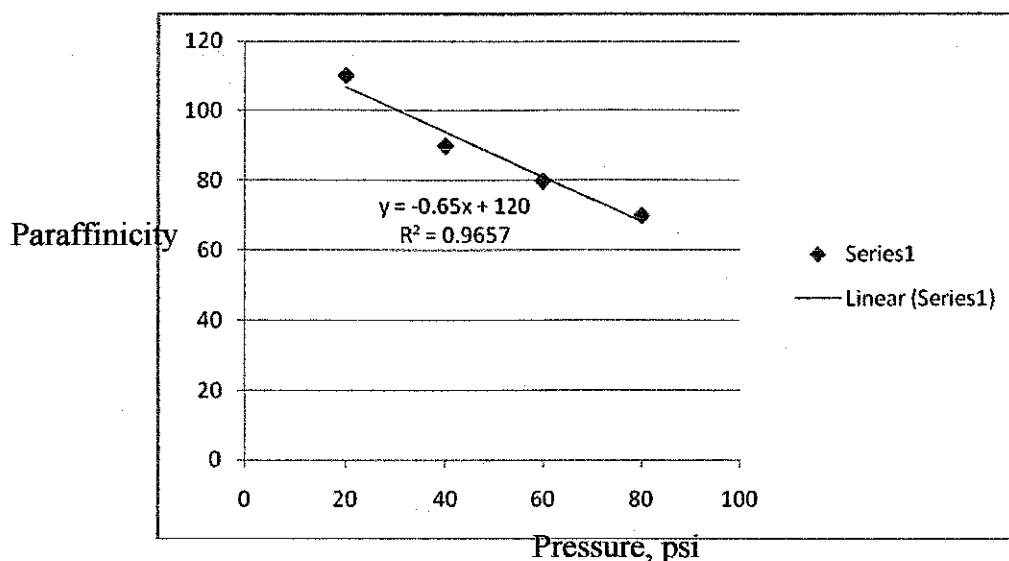
Figure 6.20: Changes of paraffinicity in vapour samples with increasing pressure at 150^0C (Erb West).
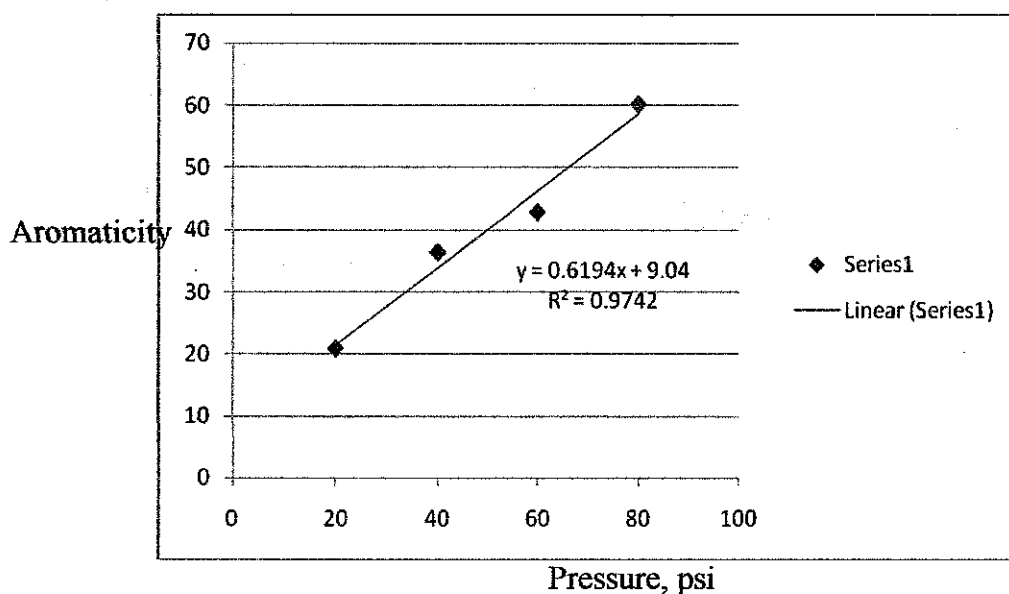
Figure 6.21: Changes of aromaticity in vapour samples with increasing pressure at 150^0C (Erb West).

Figure 6.20 and Figure 6.21 show the changes of paraffinicity and aromaticity with the changes of pressure at the same temperature of 150^0C for samples in Erb West. Both of the graphs of aromaticity and paraffinicity show the increasing of aromaticity and the decreasing of paraffinicity is a bit stable compared to the previous graph. It was not only stability but also the gradient of the trending line is also

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changing from -1.6 to -0.65 for the paraffinicity and from 0.5016 to 0.6194 for the aromatics. This suggests both the rate of decreasing for paraffinicity and rate of increasing of aromaticity with pressure falls and rises as the temperature is increased.
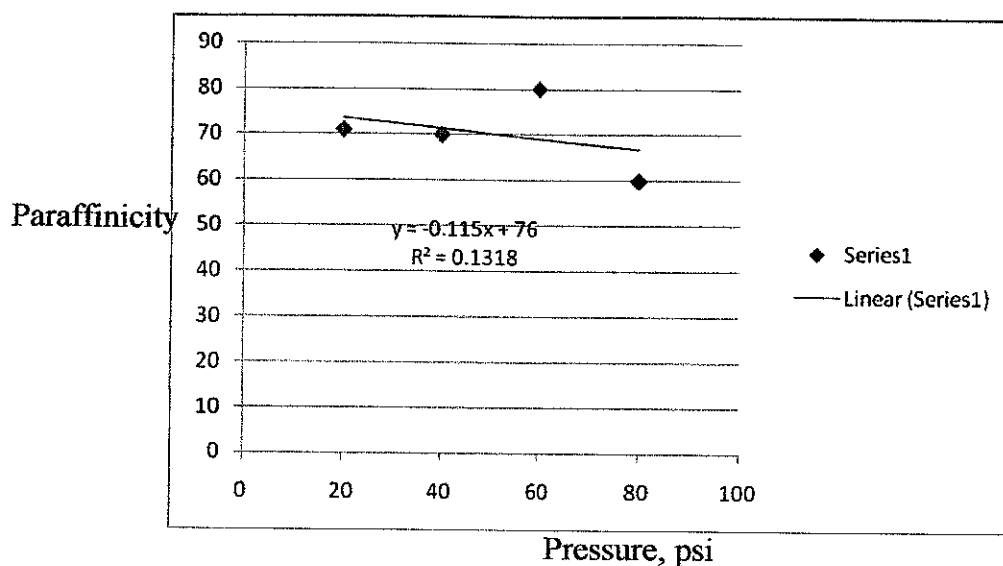
Figure 6.22: Changes of paraffinicity in vapour samples with increasing pressure at 200°C (Erb West).
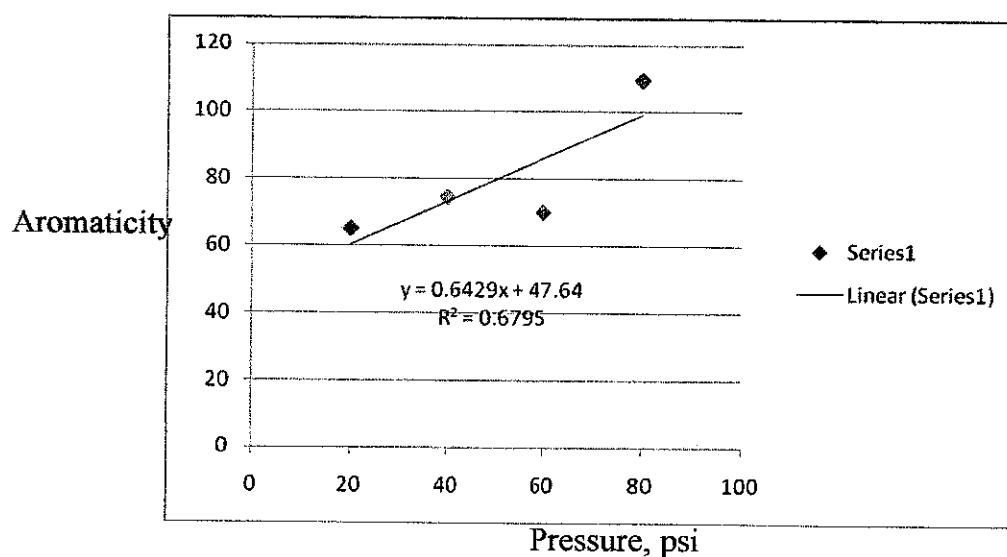
Figure 6.23: Changes of aromaticity in vapour samples with increasing pressure at 200°C (Erb West).

Figure 6.22 and Figure 6.23 show the changes of paraffinicity and aromaticity with the changes of pressure at the same temperature of 200°C for samples in Erb

West. Both of the graphs of aromaticity and paraffinicity show the increasing of aromaticity and the decreasing of paraffinicity is unstable (did not follow the linear line) compare to the previous graph. However at this temperature the rate of increasing of aromaticity is 0.6429 and rate of decreasing of paraffinicity is -0.115.
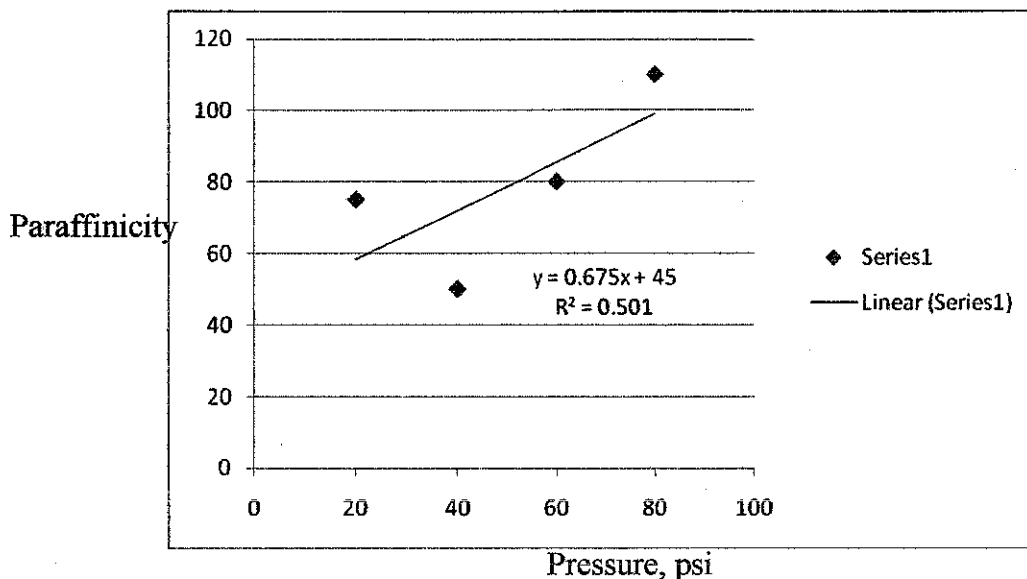
Figure 6.24: Changes of paraffinicity in vapour samples with increasing pressure at 250^{0}C (Erb West).
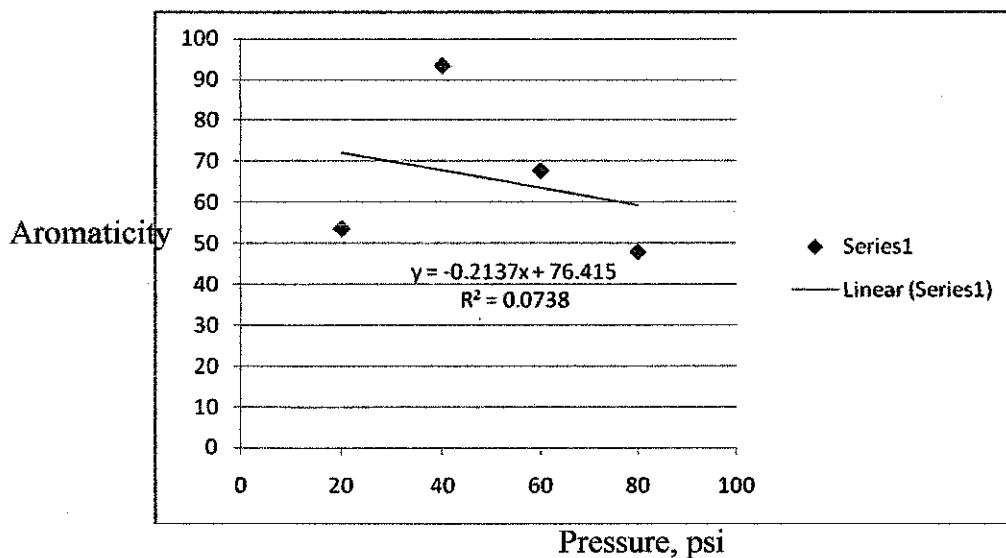
Figure 6.25: Changes of aromaticity in vapour samples with increasing pressure at 250^{0}C (Erb West).

Figure 6.24 and Figure 6.25 show the changes of paraffinicity and aromaticity with the changes of pressure at a fixed temperature of 250^0C for samples in Erb West. In this condition, the paraffinicity is increasing while the aromaticity is decreasing and both values did not follow the linear line. This condition maybe due to the reaction of paraffinicity that has lower boiling point and aromaticity has higher boiling point. So, when the temperature and pressure is increased, the reaction of paraffinicity will be increasing and for aromaticity it will be decreasing.
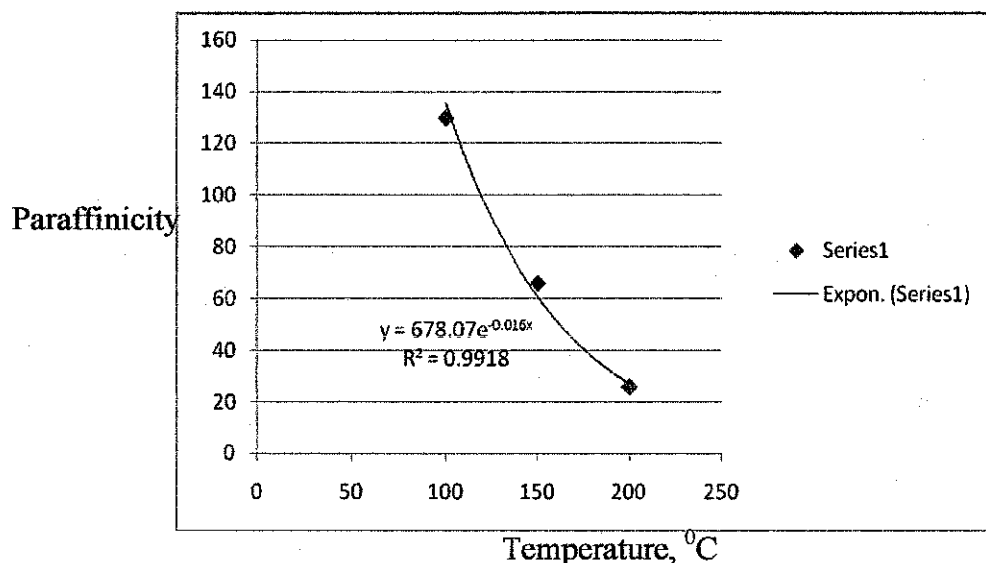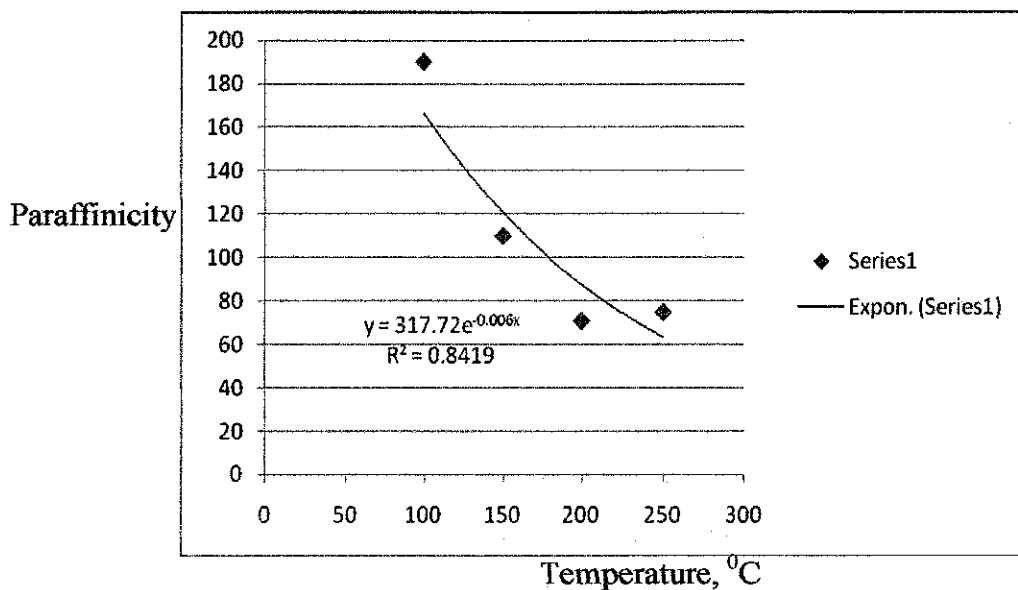

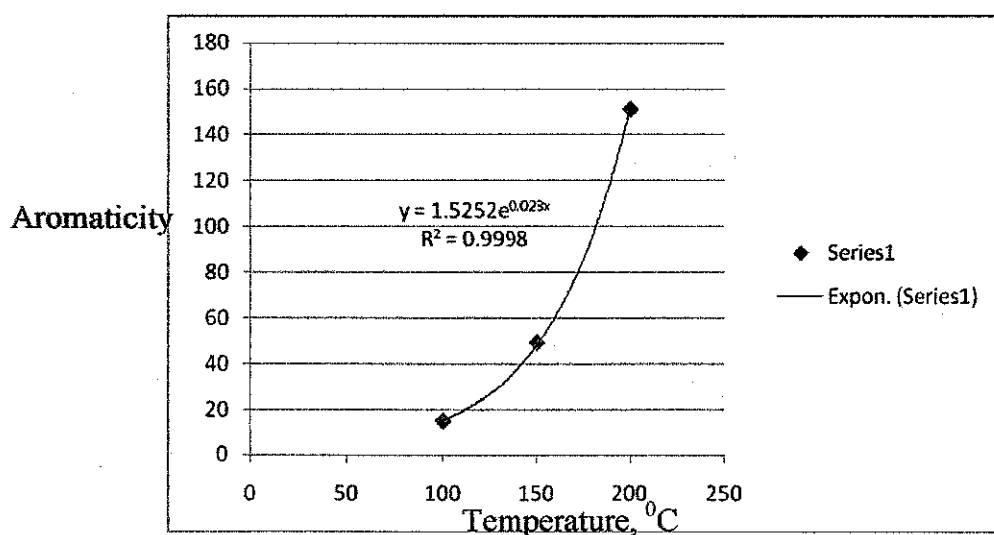Figure 6.26: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 20 psi (Erb West).
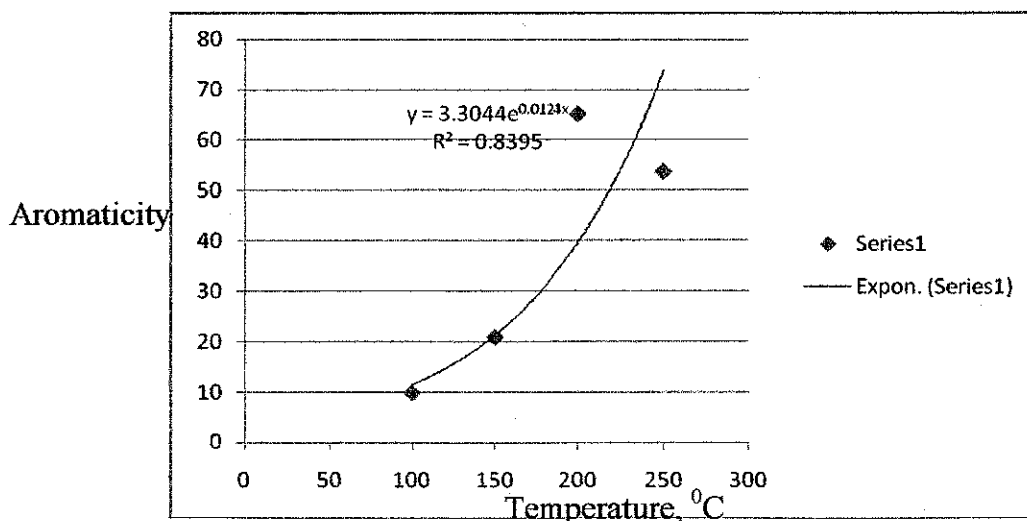
Figure 6.27: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 20 psi (Erb West).

Figure 6.26 and Figure 6.27 show the changes of paraffinicity and aromaticity with the changes of temperature but at the same pressure of 20 psi for samples in Erb West. The graphs of aromaticity show the increasing of aromaticity while graph for paraffinicity shows a decreasing value. The rate of increasing of aromaticity is 0.0124 and the rate of decreasing of paraffinicity is -0.006. The rate of increasing aromaticity and decreasing of paraffinicity are equals to the gradient of trending line.
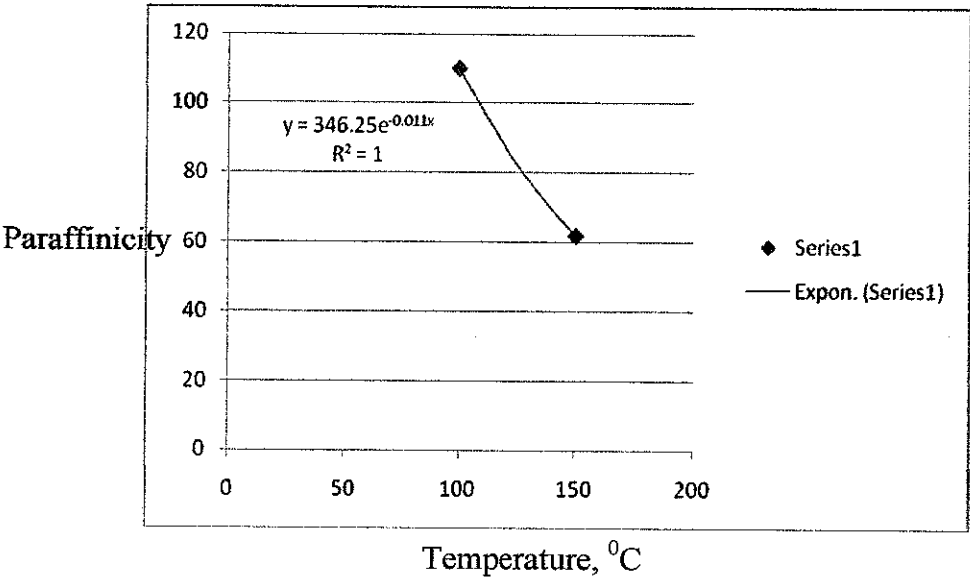

Figure 6.28: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 40 psi (Erb West).
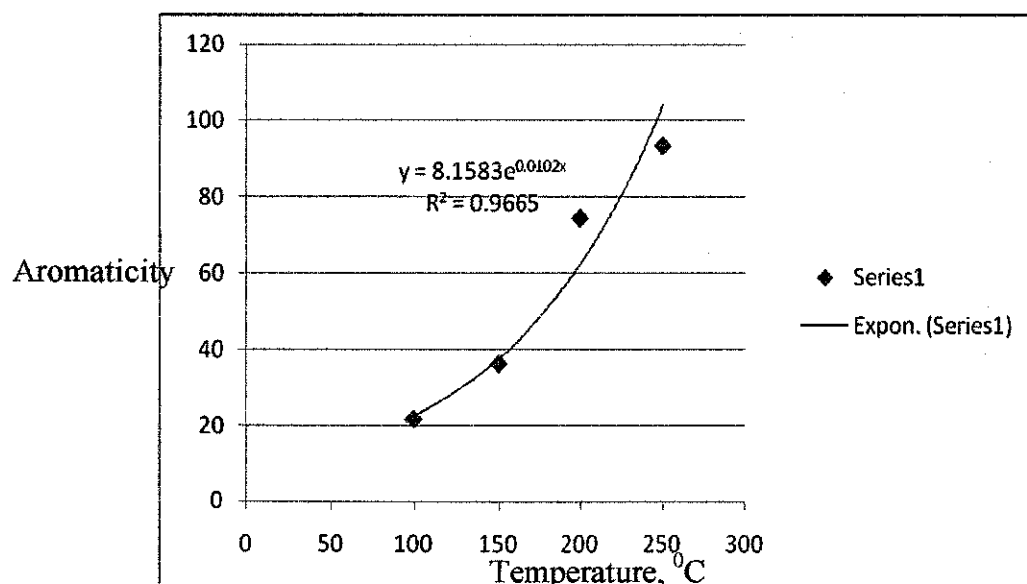
Figure 6.29: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 40 psi (Erb West).

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Figure 6.28 and Figure 6.29 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 40 psi for samples in Erb West. The rate of increasing of aromaticity is 0.0102 and the rate of decreasing of paraffinicity is -0.006.
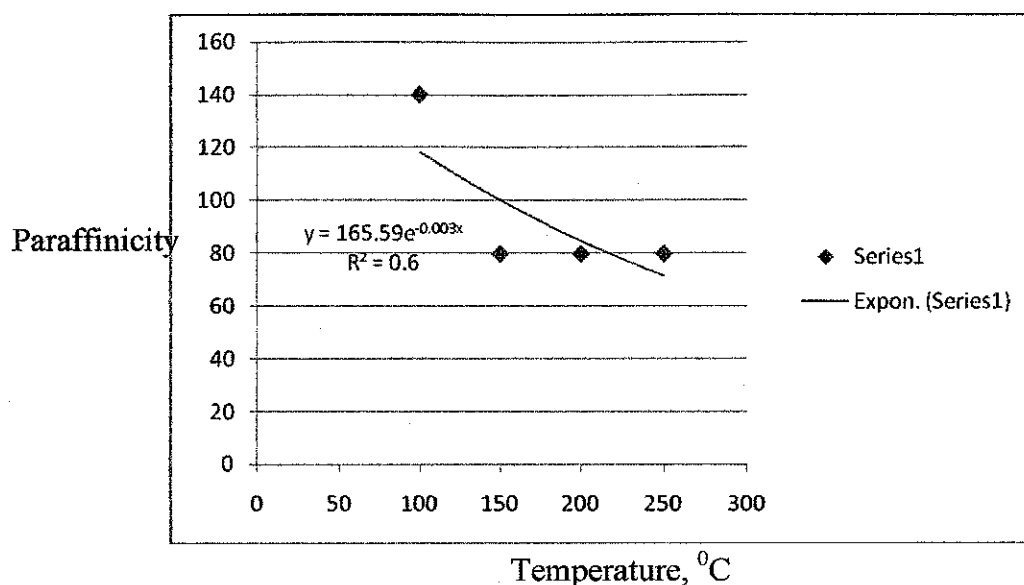
Figure 6.30: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 60 psi (Erb West).
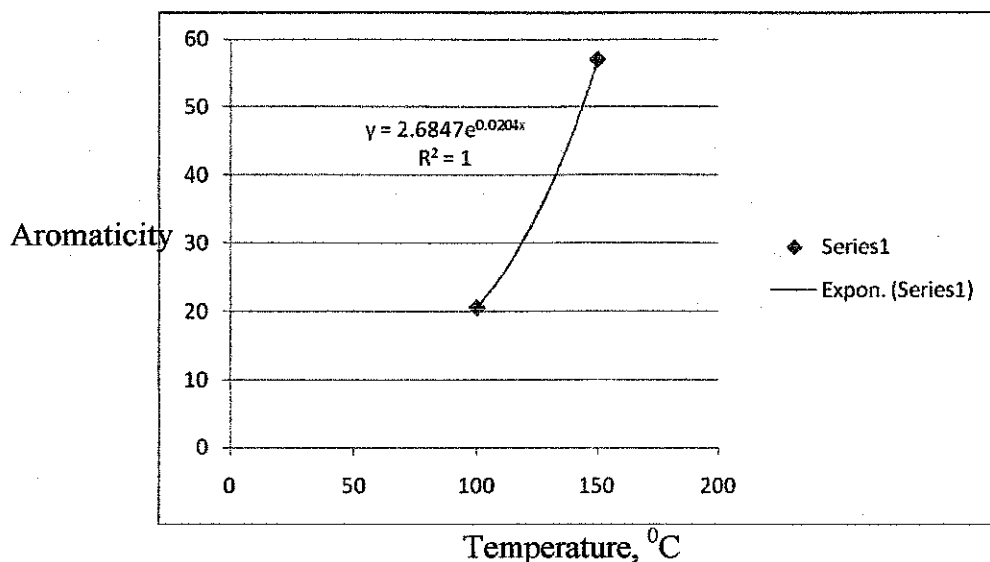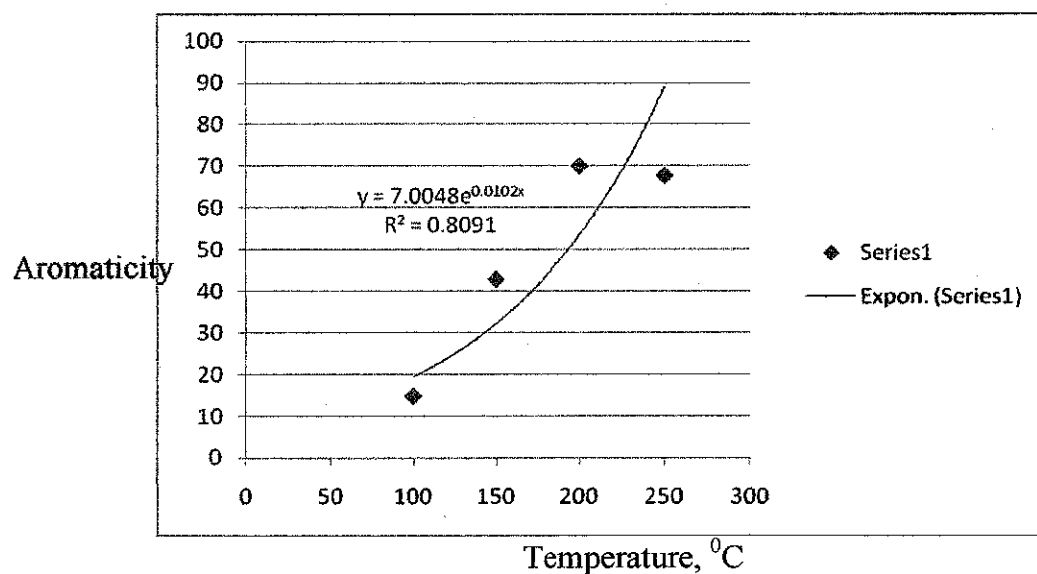

Figure 6.31: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 60 psi (Erb West).

Figure 6.30 and Figure 6.31 show the changes of paraffinicity and aromaticity with the changes of temperature but at the same pressure of 60 psi for samples in Erb West. The graphs show the increasing of aromaticity and the decreasing of paraffinicity. The rate of increasing of aromaticity is 0.0102 and rate of decreasing of paraffinicity is -0.003.
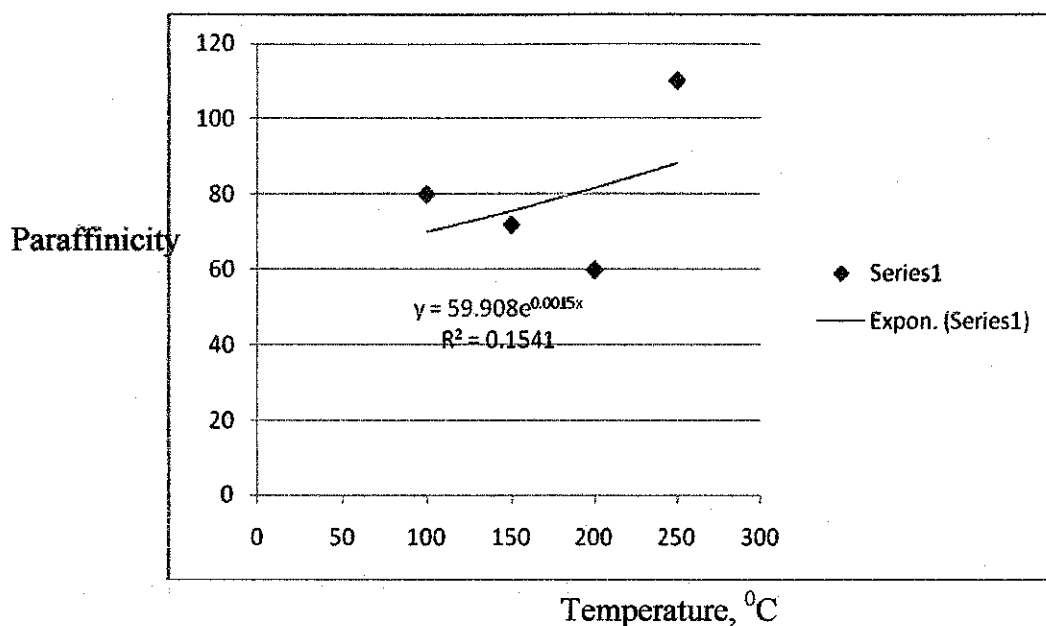
Figure 6.32: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 80 psi (Erb West).

Figure 6.33: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 80 psi (Erb West).

Figure 6.32 and Figure 6.33 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 80 psi for samples in Erb West. However at this temperature, aromaticity shows the decreasing and paraffinicity shows the increasing value. This condition is maybe due to the paraffinicity that has lower boiling point while aromaticity has higher boiling point. The rate of decreasing of aromaticity is 0.0015 and rate of increasing of paraffinicity is 0.0015.

There is no result or graph data that can be analysed from the crude oil sample for 250^0C temperature with a fixed pressure in liquid samples. As shown in Table 6.1, there is no value for paraffinicity and aromaticity starting from condensate 12 until condensate 16. This is because there is no composition of heptane that can be detected in the crude oil starting from condensate 12. This condition is due to the molecules in normal paraffin has lower boiling point compared to the molecules in aromatic compounds that have higher boiling point.

The covalent bonds of the carbon atom in the paraffin are easily to break apart from each other as the temperature is increasing compared to the covalent bonds in aromatic compounds. Paraffin also is a light compound compared to aromatic. Paraffin remains on the top of aromatic compound in the samples. So, when the sample was heated, molecules of paraffin will equilibrate and generate the excess vapour pressure and then the vapour will condensate as a vapour phase. Subsequently, as the temperature is increasing, the covalent bonds will continue to disintegrate to form vapour.

As a result, the value of paraffinicity in liquid will be decreased due to the increasing of temperature. The carbon atom in aromatic compound has strong covalent bond. It takes a lot of energy to break down the bonds in aromatic. So, this might be the answer why the data in liquid samples are not available until the maximum 250^0C temperature. All the concentration for paraffinicity and aromaticity starting from condensate 12 until condensate 16 (Table 6.1) in residual oil samples has been dissolved into the vapour samples.

However, the value of paraffinicity in vapour is decreasing due to the increasing of temperature and pressure, and the value for aromaticity in vapour is increasing as the temperature and pressure are increasing. The result for both residual oil and vapour samples are similar. Paraffinicity is decreasing both in vapour and liquid samples and as for aromaticity; the value is also increasing in vapour and liquid samples. Samples of paraffinicity and aromaticity have similar results because both are in the equilibrium state. In thermodynamic, systems are said to be in thermal equilibrium if they have no net exchange of heat or thermal energy.

As in thermodynamic cycle, the net heat supplied to the system equals the net work done by the system. This also shows that at certain temperature and pressure condition, the modified evaporative fractionation technique can be changed and effected the composition and characteristics of crude oil. Most of the graphs show the stability of result for paraffinicity and aromaticity in liquid samples compared to vapour samples. This is due to the condition of samples in vapour having more kinetic energy compared to liquid samples.

So, the tendency to move freely is higher in vapour phase compared to liquid phase. As the temperature increasing, the reaction for vapour is faster than in liquid phase. This condition is due to the differences of carbon atom in different type of chemical composition in paraffinicity and aromaticity compound. Each of the molecules has different characteristics. Due to the differences characteristics, each of the molecules will react with different temperature and pressure. So, that is why the graph shows the differences in each of the results. Most of the graph of paraffinicity and aromaticity show the same pattern between the liquid samples. It has been analysed that this condition is due to the evaporative fractionation of residual oil is in equilibrium with the vapour samples.

6.3 Dulang oil in Malay Basin

All the analysis samples were analysed using GC-MS and calculated using Thompson parameter as follow in the earlier page. Dulang field has both occurrences

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of oil and gas field. So, the results from Dulang oil in Malay basin maybe a bit different from Sabah Basin oil field. Table 6.3 below shows the result of paraffinicity and aromaticity in the liquid samples from Dulang oil field as the temperature and pressure are increasing.

Table 6.3: Show the results of paraffinicity and aromaticity in the residual oil samples in Dulang (Malay Basin).

Residual oil Samples	Sample no.	n-heptane, (n-C$_7$) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C$_7$/MCH)	Aromaticity, toluene/n-C$_7$
Original oil	1	6.02	15.59	18.14	39	3.01
Residual 1	2	6.2	16.84	19.74	37	3.18
Residual 2	3	6	17.49	20.21	34	3.37
Residual 3	4	5.85	18.39	24.04	32	4.11
Residual 4	5	4.27	15.28	18.41	28	4.31
Residual 5	6	5.32	18.29	24.7	29	4.64
Residual 6	7	2.8	12.91	23.14	22	8.26
Residual 7	8	4.34	16.95	25.97	26	5.98
Residual 8	9	2.84	13.42	23.67	21	8.33
Residual 9	10	1.94	10.29	21.25	19	10.95
Residual 10	11	0.46	2.94	5.38	16	11.7
Residual 11	12	1.59	9.02	15.36	18	9.66
Residual 12	13	2.49	14.44	24.78	17	9.95
Residual 13	14	1.43	8.95	17.7	16	12.38
Residual 14	15	0	12.04	23.47	0	0
Residual 15	16	0	4.95	9.87	0	0
Residual 16	17	0	3.43	6.79	0	0

The data in the tabular form for paraffinicity and aromaticity in residual oil samples are shown in Table-6.3. The code number for residual oil samples in Dulang is similar with Erb West code number. The analysis is shown graphically in Fig.6.34 in which blue line representing paraffinicity while red line representing aromaticity. The results show the value of paraffinicity is decreasing with increasing temperature or pressure while the value of aromaticity is increasing as the temperature or pressure

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is increased. The individual analyze of the residual oil with effects of pressure or temperature is shown below.
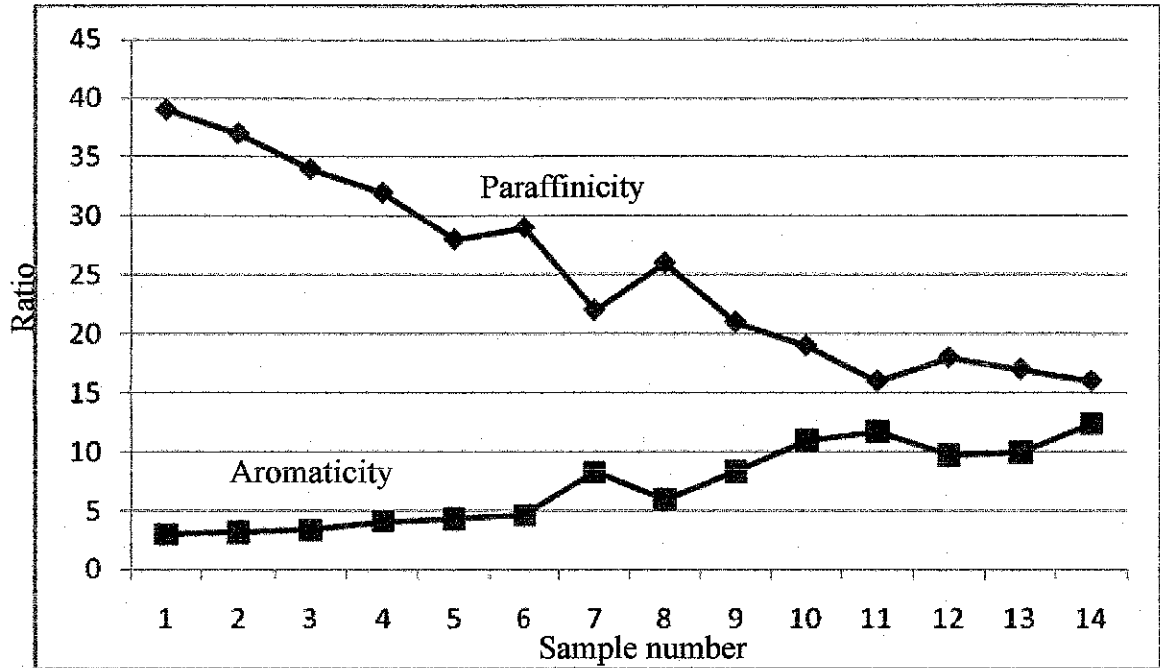
Fig 6.34: Shows the result of indicate paraffinicity decreases and aromaticity increases in residual oil samples in Dulang (Malay Basin).

Figure 6.35: Changes of paraffinicity in residual oil samples with increasing pressure at 100^0C (Dulang).

Figure 6.36: Changes of aromaticity in residual oil samples with increasing pressure at 100^0C (Dulang).

Figure 6.35 and Figure 6.36 show the changes of paraffinicity and aromaticity with the changes of pressure but at the same temperature of 100^0C for samples in Dulang. Paraffinicity shows decreasing trend and aromaticity shows increasing trend. The rate of increasing of aromaticity at this temperature is 0.0207 and the rate of decreasing of paraffinicity is -0.145. The rate of increasing aromaticity and decreasing of paraffinicity are equals to the gradient of trending line.
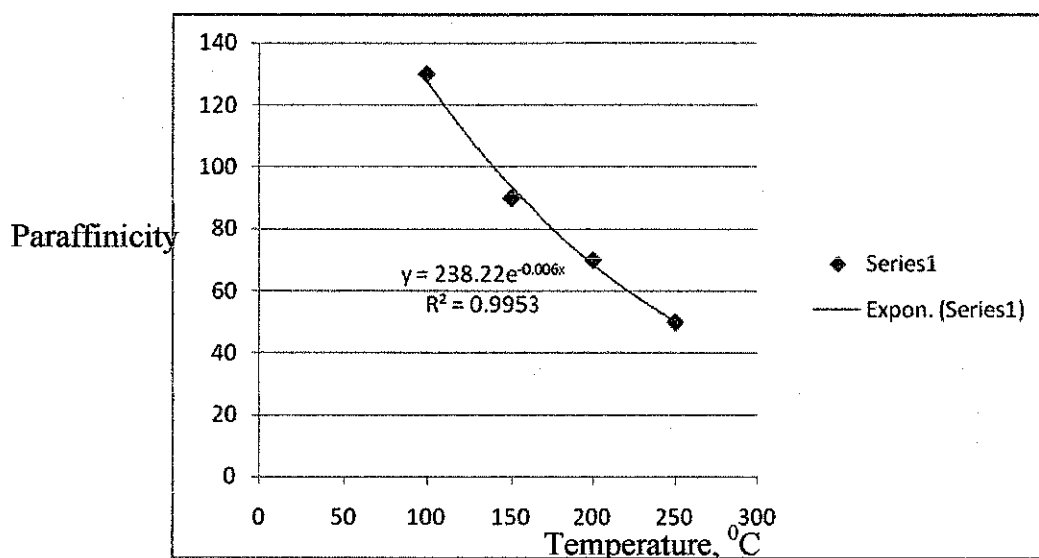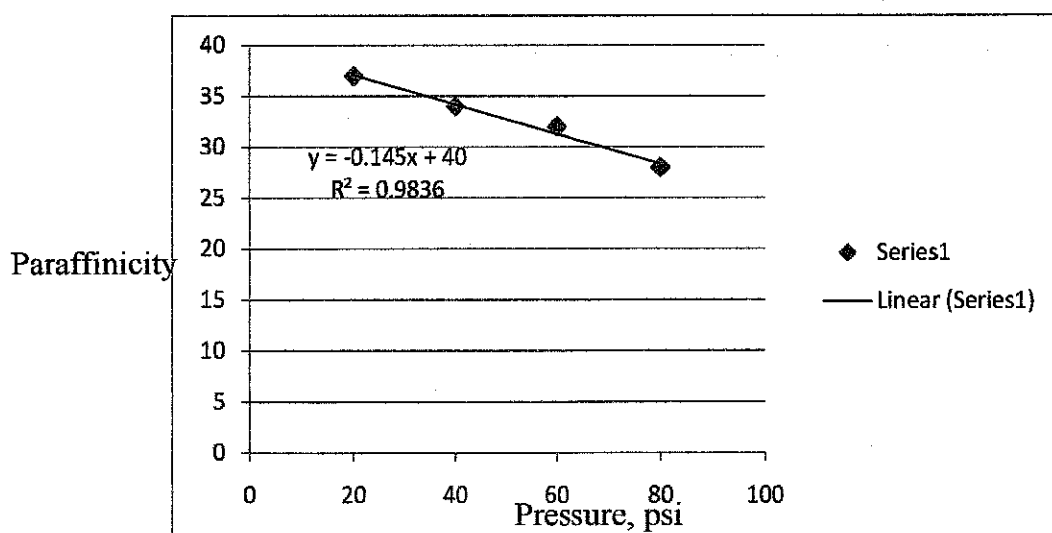

Figure 6.37: Changes of paraffinicity in residual oil samples with increasing pressure at 150^0C (Dulang).

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Figure 6.38: Changes of aromaticity in residual oil samples with increasing pressure at 150^0C (Dulang).

Figure 6.37 and Figure 6.38 show the changes of paraffinicity and aromaticity with increasing of pressure but same temperature of 150^0C for samples in Dulang. Both of the graphs of aromaticity and paraffinicity show the increasing of aromaticity and the decreasing of paraffinicity is unstable compared to the previous graph. It is not only stability but also the gradient of the trending line (rate) is also constant (-0.145) for the paraffinicity and changing from 0.0207 to 0.044 for the aromatics. This suggests both the rate of decreasing for paraffinicity and rate of increasing of aromaticity with increasing pressure are slower as the temperature constant.
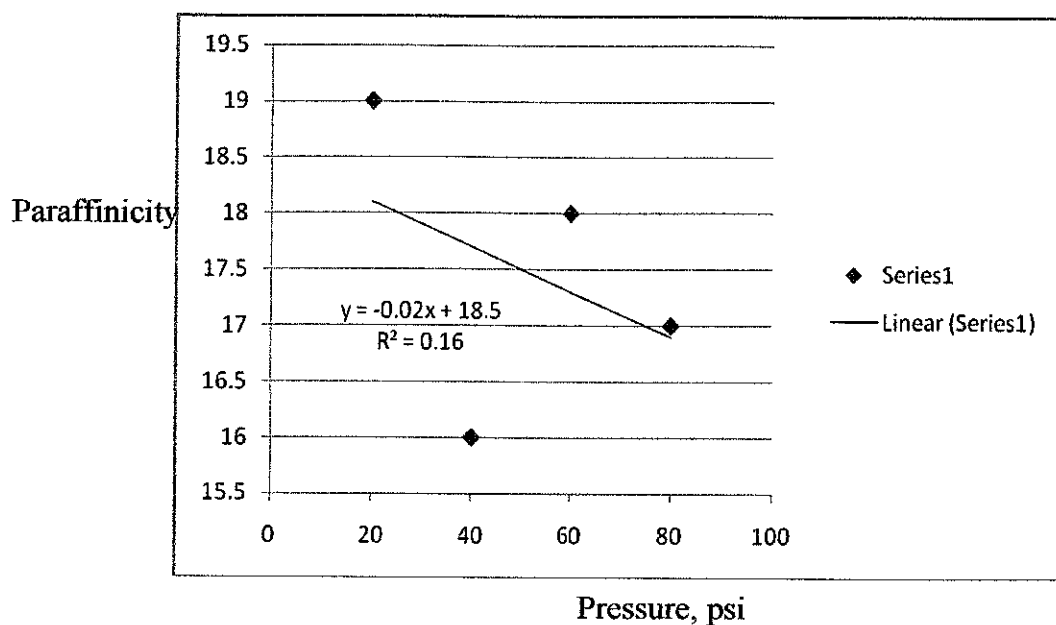
Figure 6.39: Changes of paraffinicity in residual oil samples with increasing pressure at 200°C (Dulang).
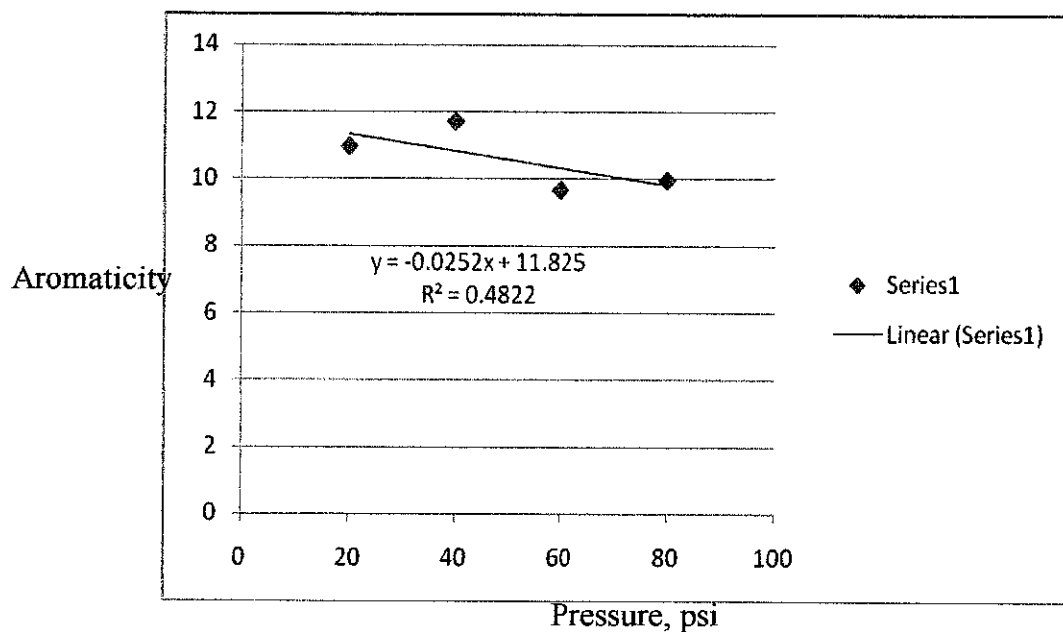
Figure 6.40: Changes of aromaticity in residual oil samples with increasing pressure at 200°C (Dulang).

Figure 6.39 and Figure 6.40 show the changes of paraffinicity and aromaticity with the changes of pressure at fixed temperature of 200°C in residual oil samples in Dulang. Aromaticity is decreasing because at this condition, aromatic has not reached its boiling point. So, due to this situation aromaticity is decreasing. However, the rate

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of decreasing of paraffinicity and aromaticity are observed to be slower than earlier. The rate of decreasing of aromaticity is -0.0252 and rate of decreasing of paraffinicity is -0.02.
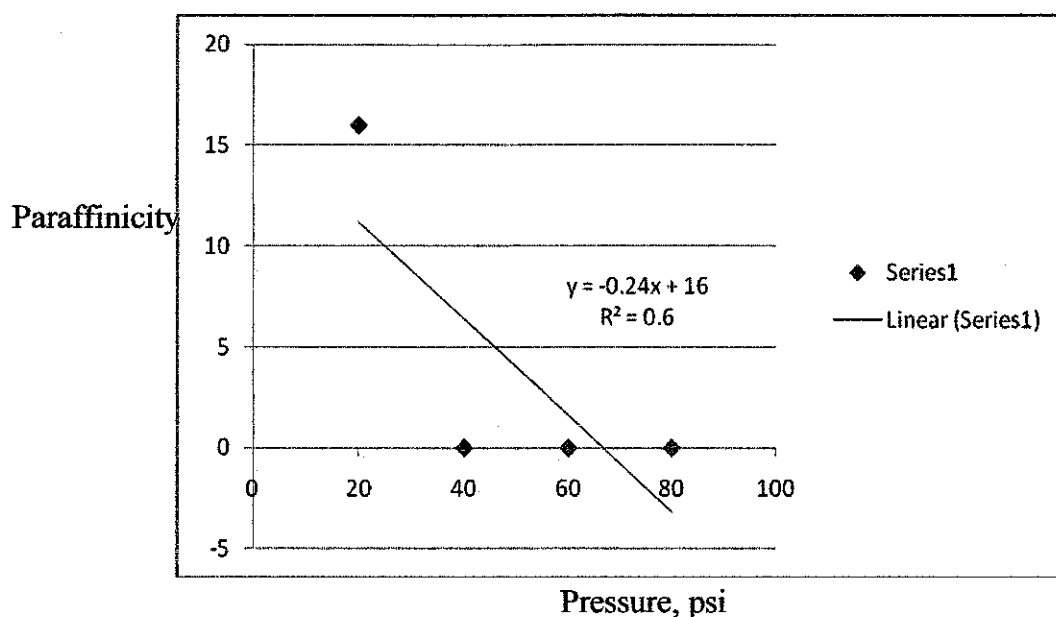
Figure 6.41: Changes of paraffinicity in residual oil samples with increasing pressure at $250^{0}C$ (Dulang).
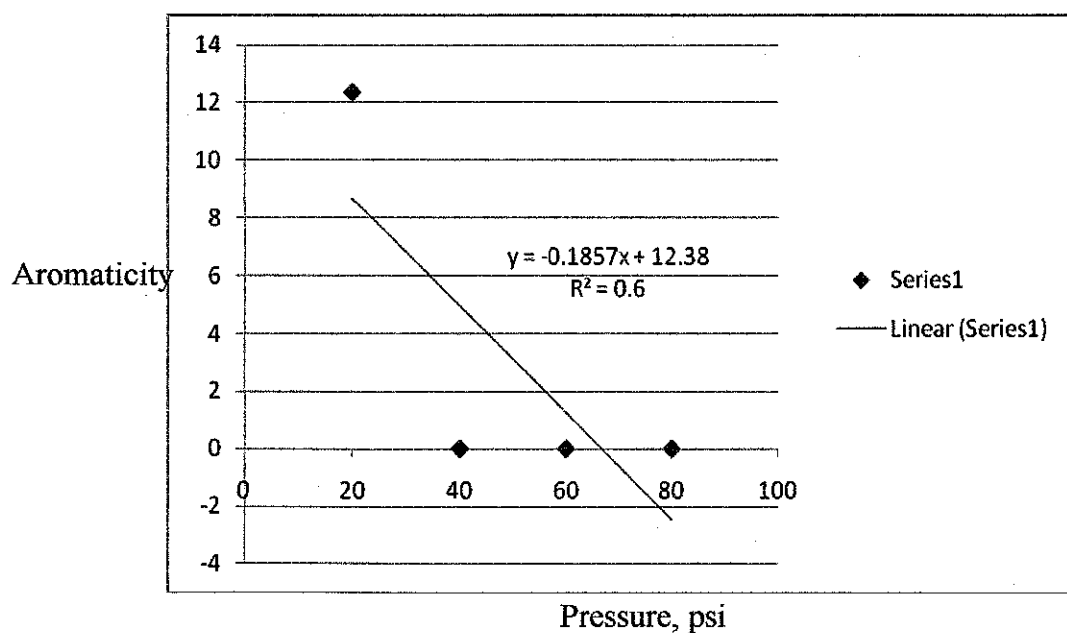
Figure 6.42: Changes of aromaticity in residual oil samples with increasing pressure at $250^{0}C$ (Dulang).

Figure 6.41 and Figure 6.42 show the changes of paraffinicity and aromaticity with the changes of pressure at fixed temperature of 250^0C for samples in Dulang. As we can see, there are no data results up to 40 psi to 80 psi condition. The graph show the value of paraffinicity and aromaticity both are available only at pressure of 20 psi. This condition maybe due to the concentration of n-heptane has been evaporated into vapour.
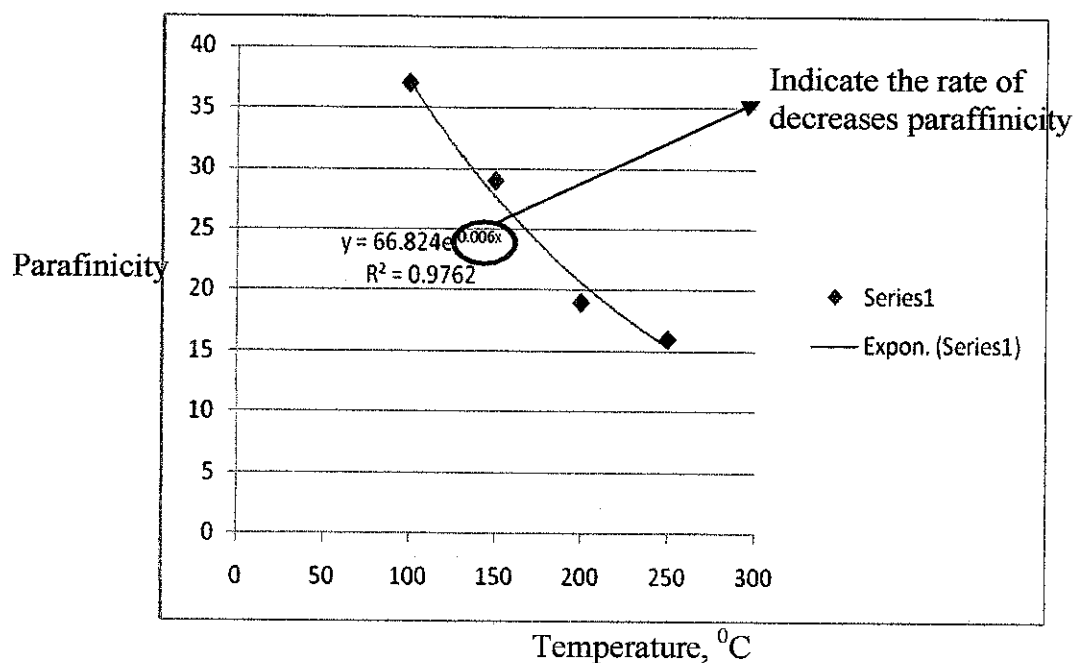
Figure 6.43: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 20 psi (Dulang).
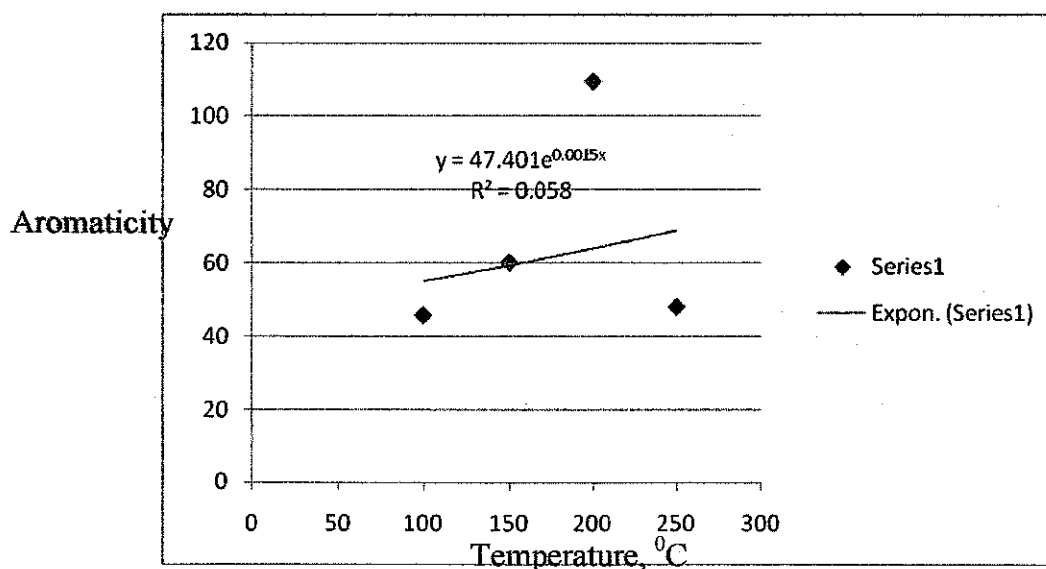
Figure 6.44: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 20 psi (Dulang).

Figure 6.43 and Figure 6.44 show the changes of paraffinicity and aromaticity with the changes of temperature at the same pressure of 20 psi for samples in Dulang. The same earlier trend is maintained in this experiment. Paraffinicity show the decreasing trend and aromaticity shows increasing trend. The rate of increasing of aromaticity is 0.0099 and rate of decreasing of paraffinicity is -0.006. The rate of increasing aromaticity and decreasing of paraffinicity are equals to the gradient of trending line.

Figure 6.45: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 40 psi (Dulang).

Figure 6.46: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 40 psi (Dulang).

Figure 6.45 and Figure 6.46 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 40 psi for samples in Dulang. The rate of increasing of aromaticity at this pressure is 0.0124 and rate of decreasing of paraffinicity is -0.008. There is no result or graph data that can be analysed for

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temperature of 250°C at 40 psi pressure in residual oil samples. This condition maybe due to the concentration of n-heptane at 250°C has been evaporated and dissolved in the vapour samples.
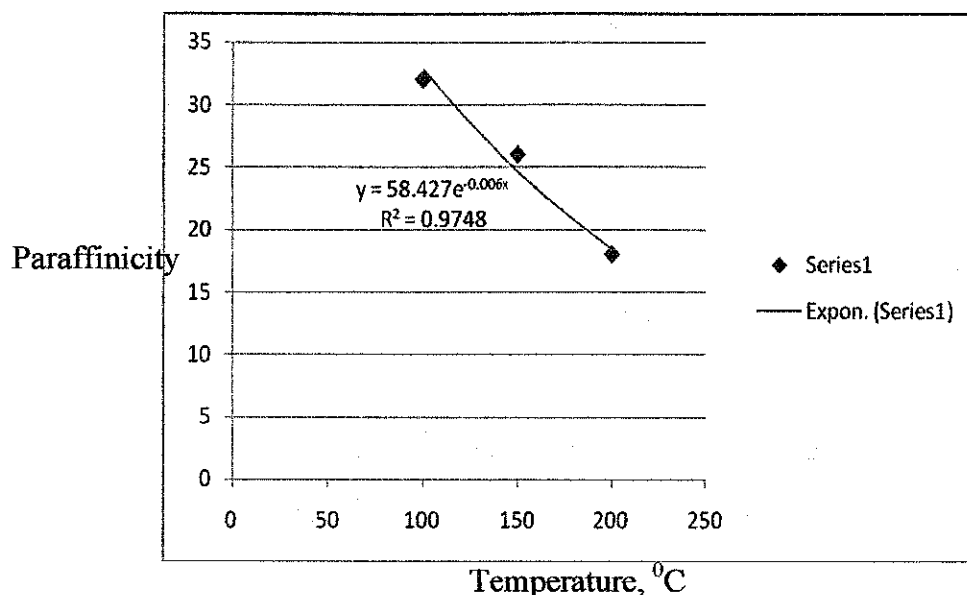
Figure 6.47: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 60 psi (Dulang).
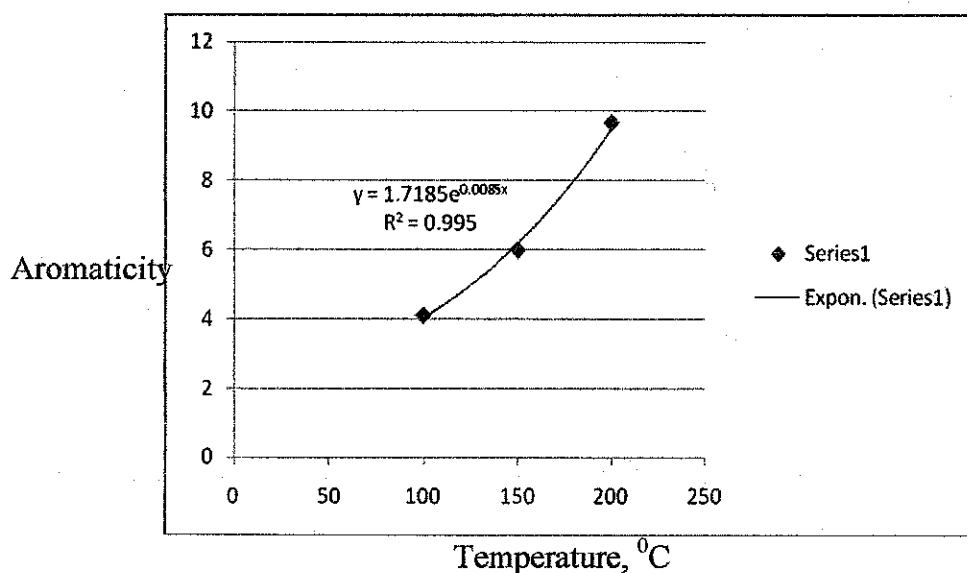
Fig 6.48: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 60 psi (Dulang).

Figure 6.47 and Figure 6.48 show the changes of paraffinicity and aromaticity with the changes of temperature at the same pressure of 60 psi for samples in Dulang. The rate of increasing of aromaticity at this pressure is 0.0085 and rate of decreasing of paraffinicity is -0.006. There is no data that can be analysed for Dulang crude oil samples at temperature of 250^0C and pressure 60 psi.
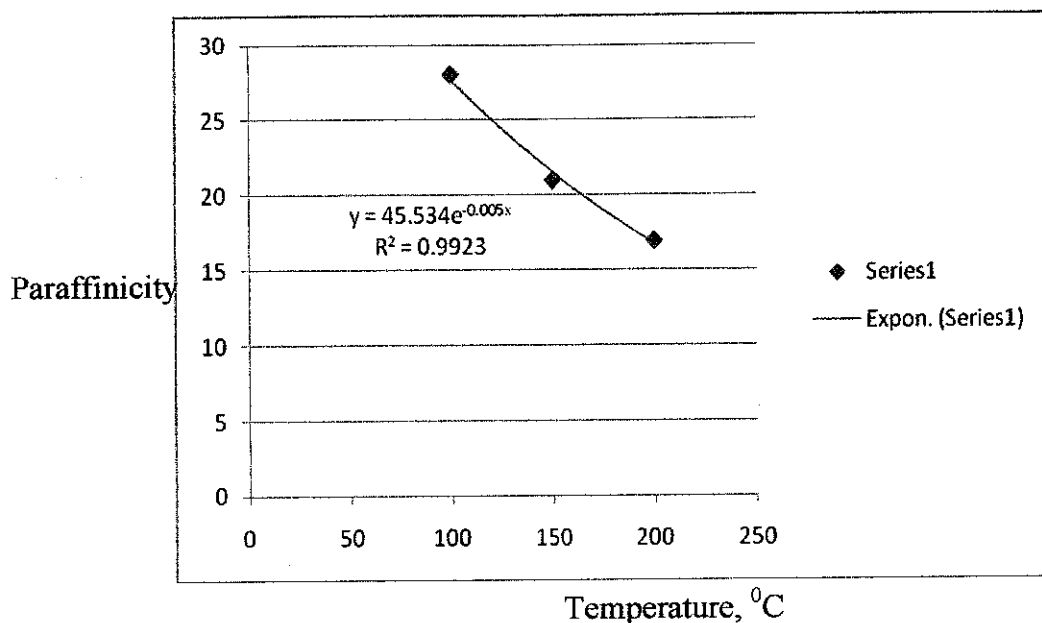
Figure 6.49: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 80 psi (Dulang).
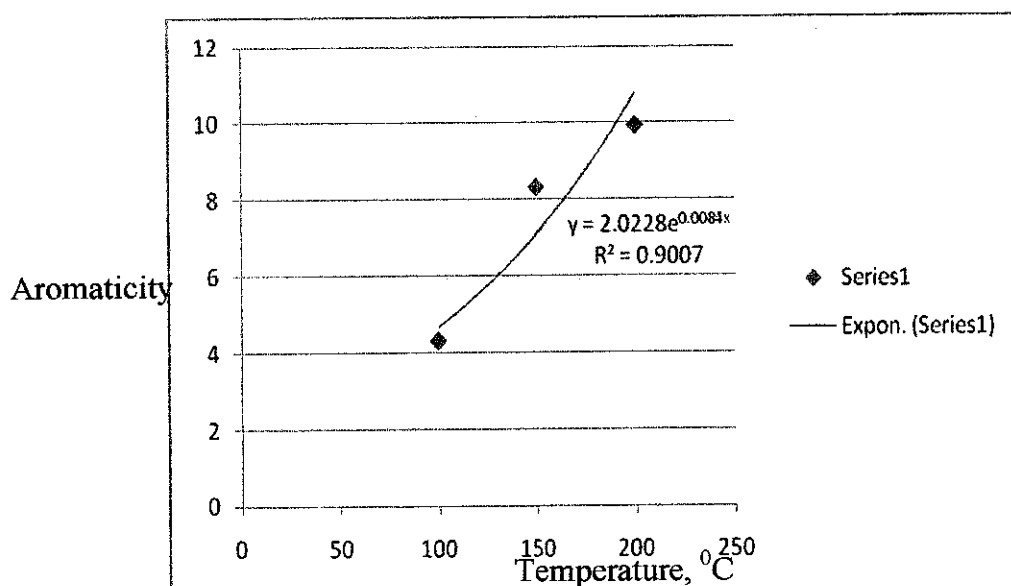
Fig 6.50: Changes of aromaticity in residual oil samples with increasing temperature at a pressure of 80 psi (Dulang).

Figure 6.49 and Figure 6.50 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 80 psi for samples in Dulang. However at this pressure the rate of increasing of aromaticity is 0.0084 and rate of decreasing of paraffinicity is -0.005 are both lower than the previous graph.

Table 6.4: Show the results of paraffinicity and aromaticity in the vapour samples.

Vapour Samples	Sample no.	n-heptane, (n-C₇) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C₇/MCH)	Aromaticity, toluene/n-C₇
Original oil	1	6.02	15.59	18.14	39	3.01
Condensate 1	2	6.56	15.02	21.18	44	3.23
Condensate 2	3	4.06	11.53	21.98	35	5.41
Condensate 3	4	0.89	3.76	16.48	24	18.52
Condensate 4	5	1.69	5.8	20.25	29	11.98
Condensate 5	6	5.07	14.18	22.94	36	4.52
Condensate 6	7	5.71	15.95	22.94	36	4.02
Condensate 7	8	3.8	12.9	23.77	29	6.26
Condensate 8	9	4.24	14.24	24.18	30	5.7
Condensate 9	10	4.56	16.2	24.03	28	5.27
Condensate 10	11	3.42	14.32	24.27	24	7.1
Condensate 11	12	2.15	11.47	23.02	19	10.71
Condensate 12	13	2.94	14.97	24.53	20	8.34
Condensate 13	14	2.49	13.02	26.94	19	10.82
Condensate 14	15	2.11	12.09	26.7	17	12.65
Condensate 15	16	1.83	10.86	25.83	17	14.11
Condensate 16	17	1.52	10.13	27.09	15	17.82

The data in the tabular form for paraffinicity and aromaticity in vapour samples are shown in Table-6.4. The analysis is shown graphically in Figure 6.51 in which blue line representing paraffinicity while red line representing aromaticity. The results show the value of paraffinicity is decreasing with increasing temperature or pressure while the value of aromaticity is increasing as the temperature or pressure are increased.

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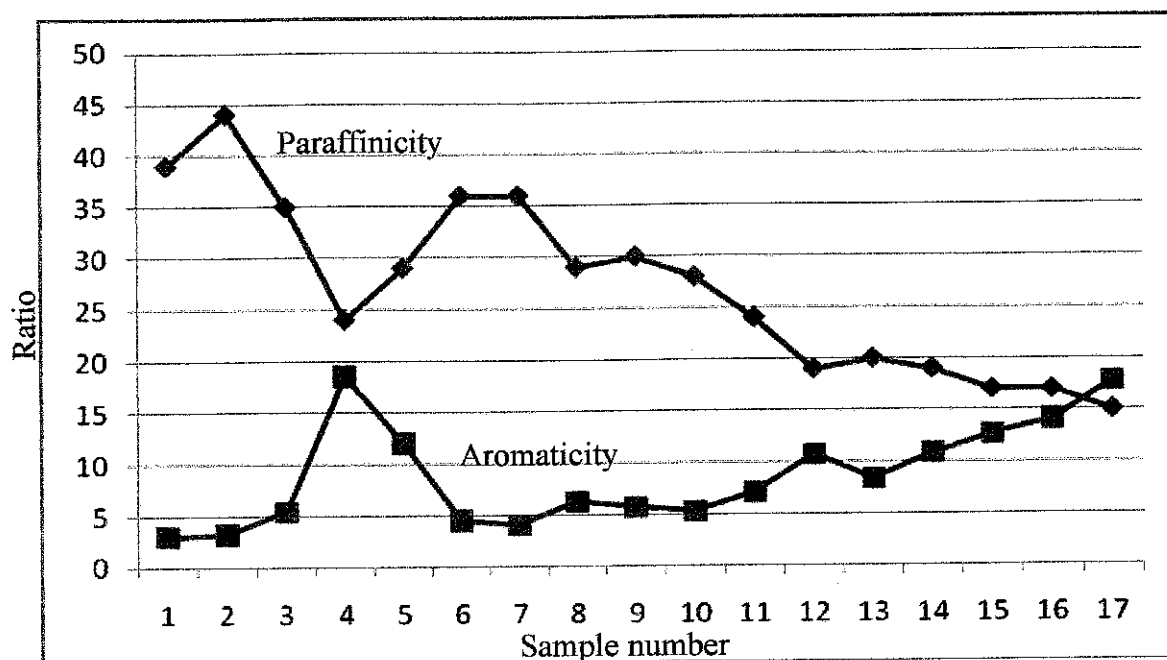
Figure 6.51: Shows the result of indicate paraffinicity decreases and aromaticity increases in vapour samples in Dulang (Malay Basin).

The individual analysis of the vapour samples with effects of pressure or temperature are shown below.
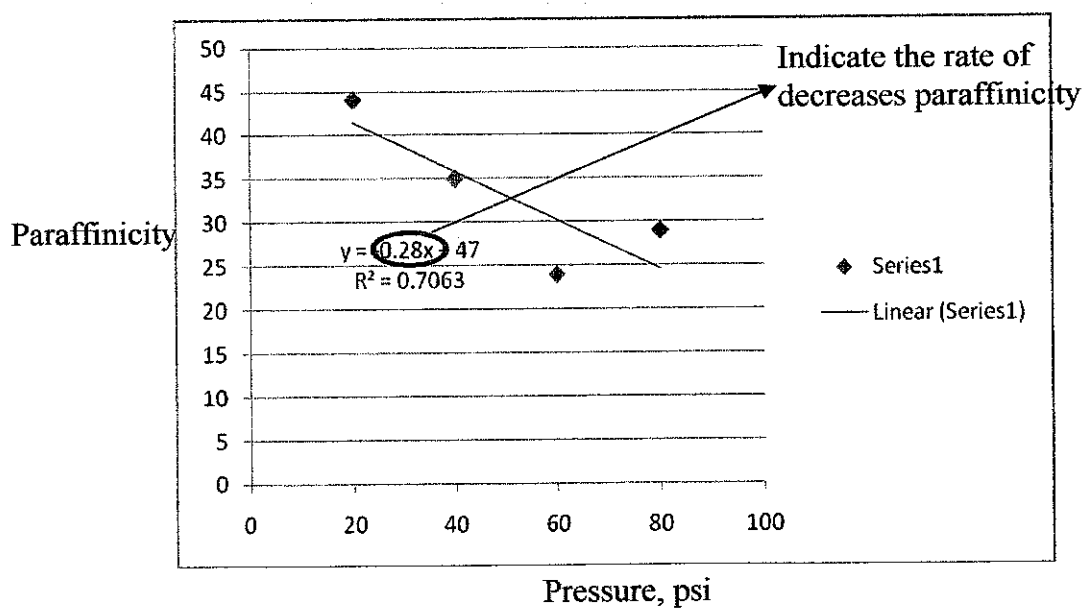
Figure 6.52: Changes of paraffinicity in vapour samples with increasing pressure at 100^0C (Dulang).

Figure 6.53: Changes of aromaticity in vapour samples with increasing pressure at 100°C (Dulang).

Figure 6.52 and Figure 6.53 show the changes of paraffinicity and aromaticity with the changes of pressure at the same temperature of 100°C for samples in Dulang. The same earlier trend is maintained. Paraffinicity show the more unstable decreasing trend and aromaticity shows unstable increasing trend. However at this temperature the rate of increasing of aromaticity is 0.1968 and rate of decreasing of paraffinicity is -0.28.
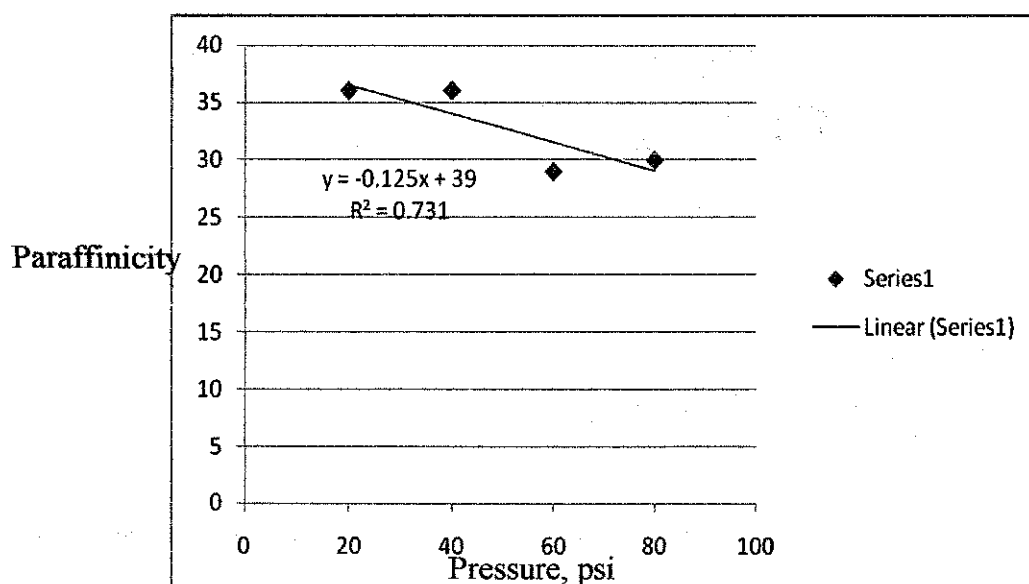
Figure 6.54: Changes of paraffinicity in vapour samples with increasing pressure at 150°C (Dulang).
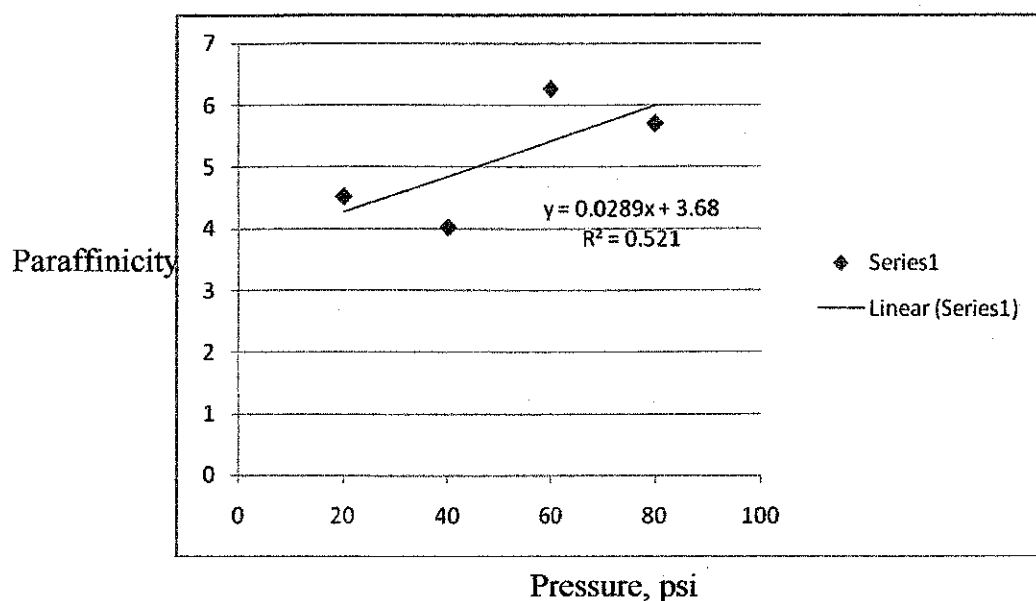
Figure 6.55: Changes of aromaticity in vapour samples with increasing pressure at 150^0C (Dulang).

Figure 6.54 and Figure 6.55 show the changes of paraffinicity and aromaticity with the changes of pressure but at the same temperature of 150^0C for samples in Dulang. The aromaticity show unstable increasing trend and paraffinicity show the unstable decreasing trend. It is not only stability but also the gradient of the trending line is also changed from -0.28 to -0.125 for the paraffinicity and from 0.1968 to 0.0289 for the aromatics. This suggests both the rate of decreasing for paraffinicity and rate of increasing of aromaticity with pressure falls as the temperature is increased.
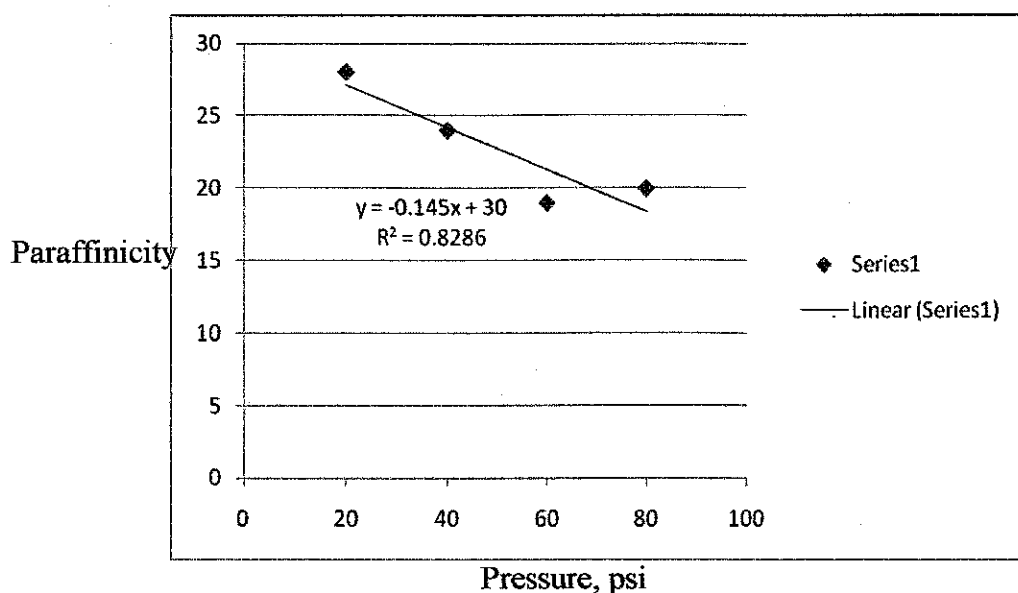
Figure 6.56: Changes of paraffinicity in vapour samples with increasing pressure at 200°C (Dulang).
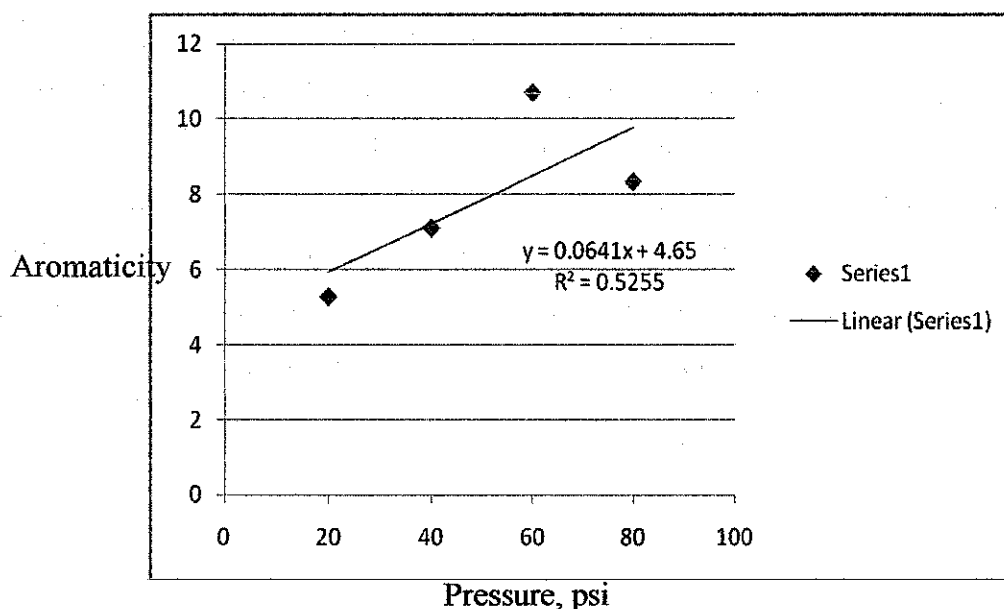
Figure 6.57: Changes of aromaticity in vapour samples with increasing pressure at 200°C (Dulang).

Figure 6.56 and Figure 6.57 show the changes of paraffinicity and aromaticity with the changes of pressure but at the same temperature of 200°C for samples in Dulang. Paraffinicity show the decreasing trend and aromaticity shows increasing trend. However at this temperature the rate of increasing of aromaticity is 0.0641 and rate of decreasing of paraffinicity is -0.145.
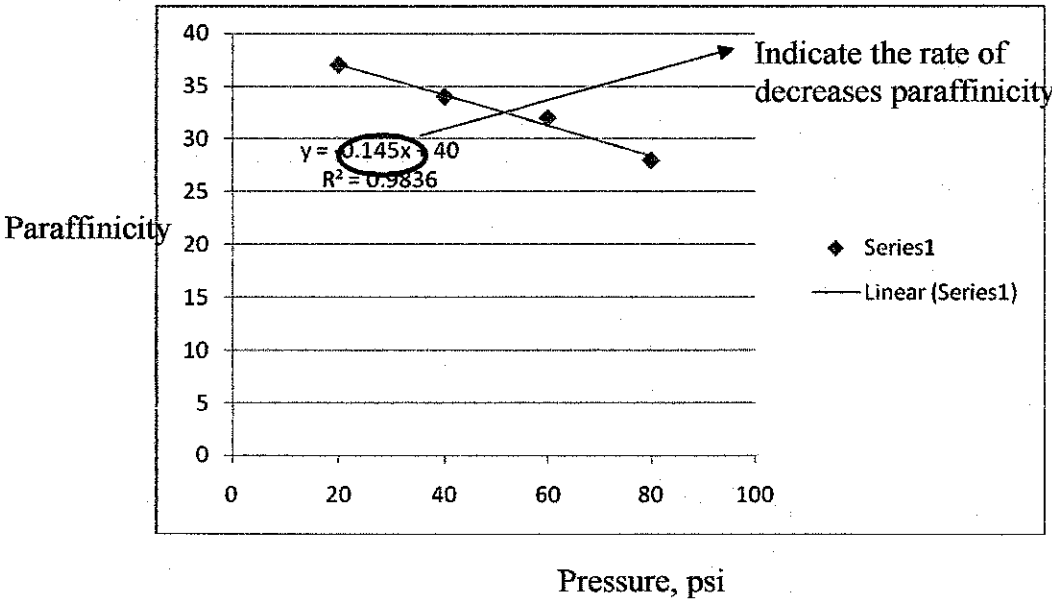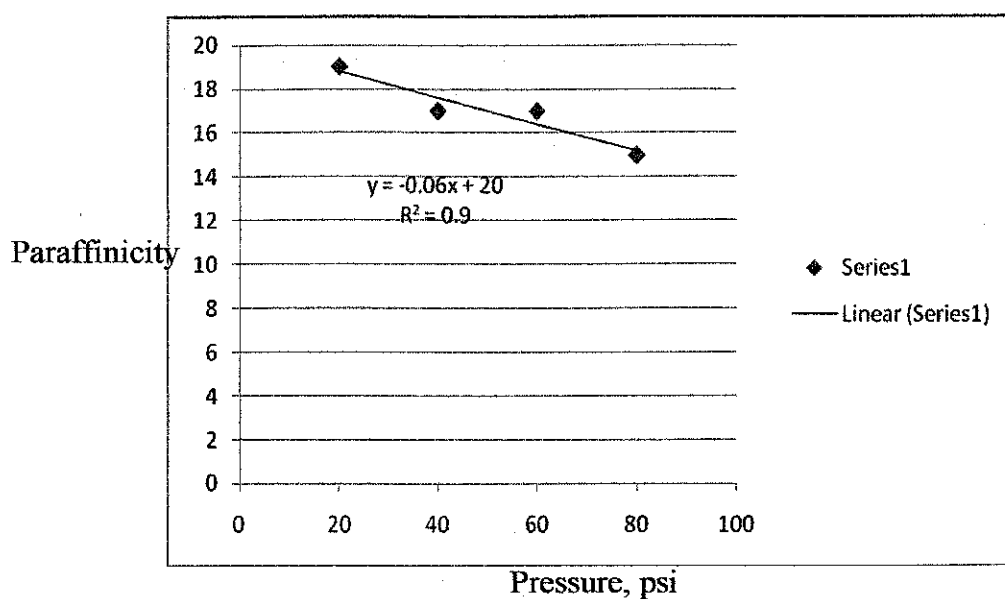
Figure 6.58: Changes of paraffinicity in vapour samples with increasing pressure at 250°C (Dulang).
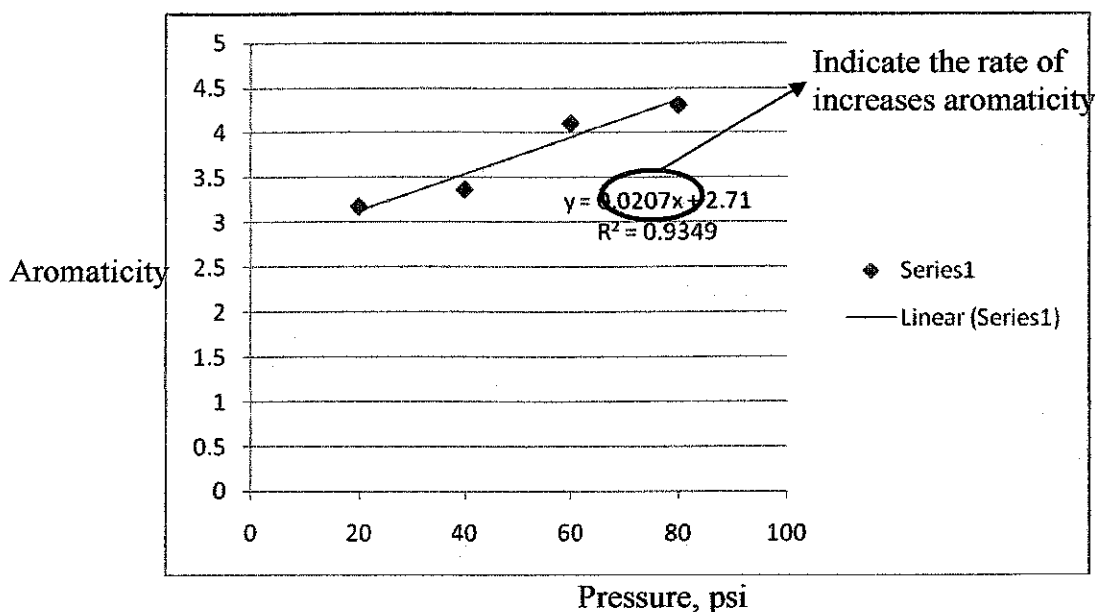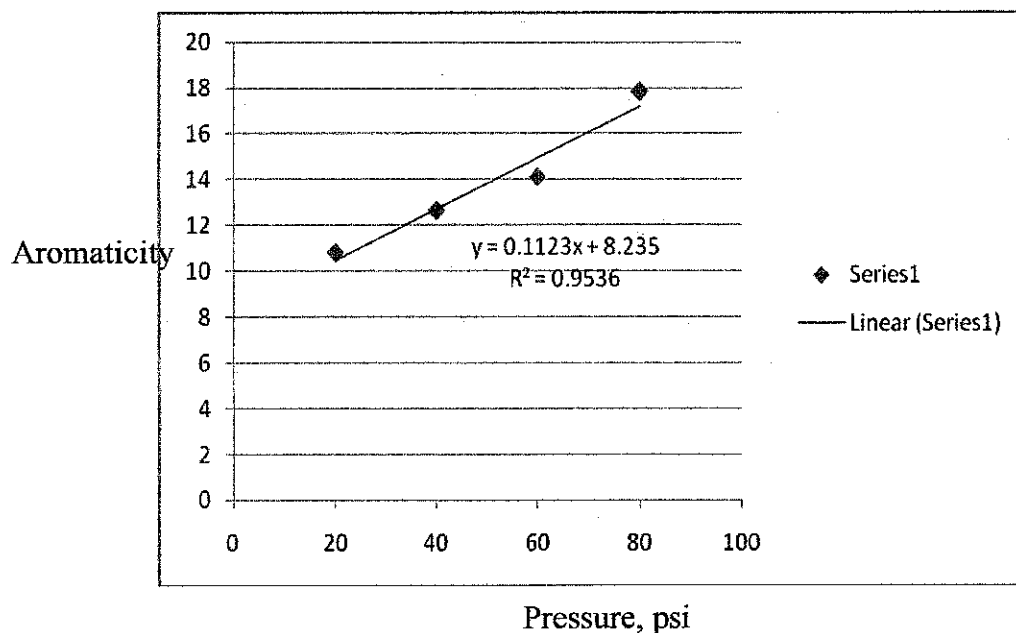

Figure 6.59: Changes of aromaticity in vapour samples with increasing pressure at 250°C (Dulang).

Figure 6.58 and Figure 6.59 above show the changes of paraffinicity and aromaticity with the changes of pressure but at the same temperature of 250°C for samples in Dulang. The rate of increasing of aromaticity is 0.1123 and rate of decreasing of paraffinicity is -0.06 are both higher than the previous.
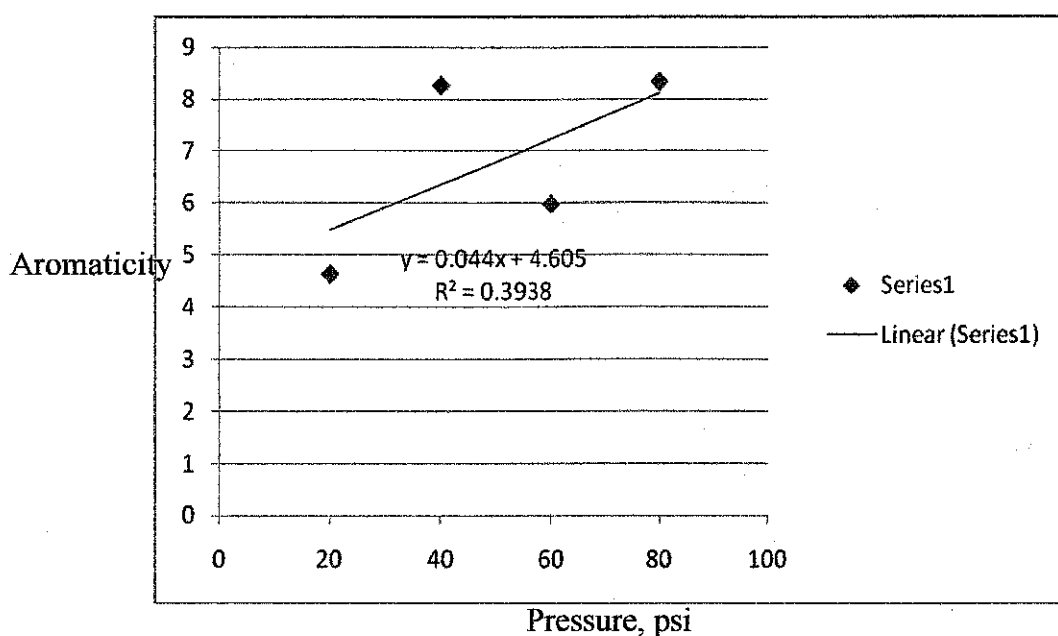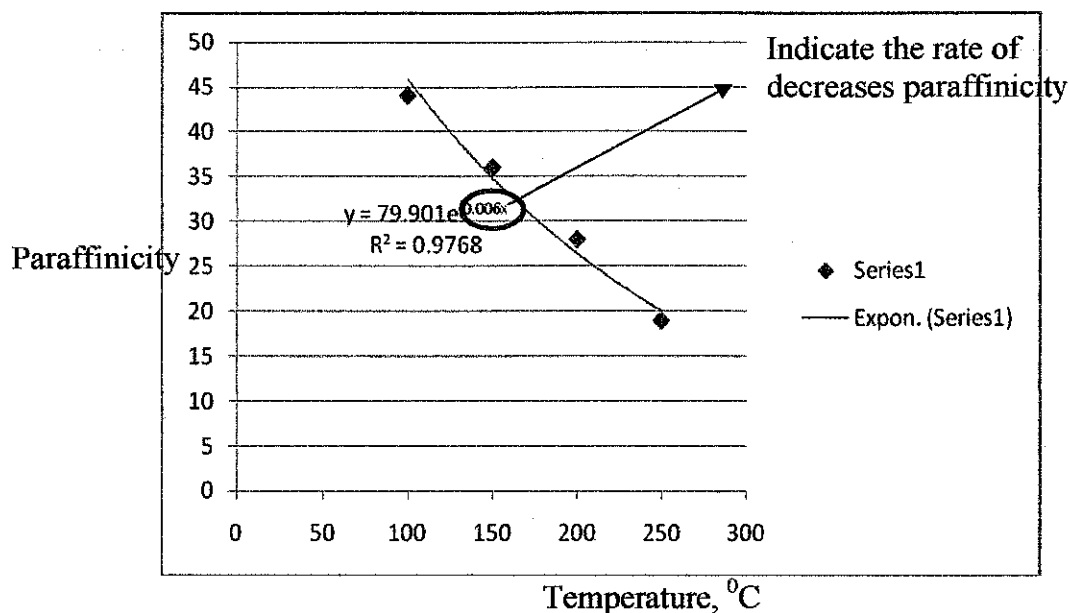
Figure 6.60: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 20 psi (Dulang).
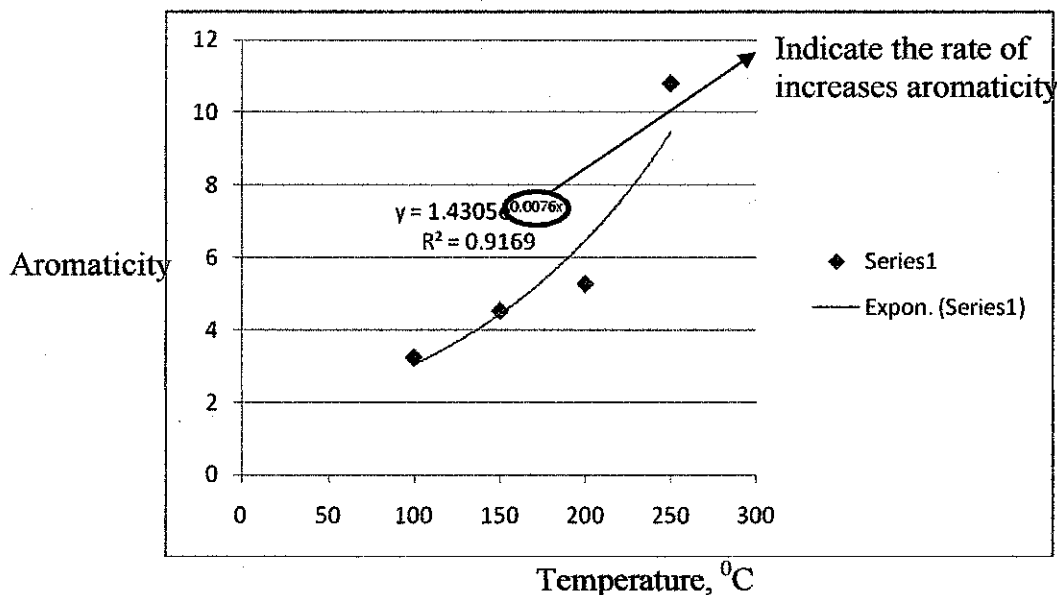
Figure 6.61: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 20 psi (Dulang).

Figure 6.60 and Figure 6.61 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 20 psi for samples in Dulang. In this experiment, aromaticity is increasing and paraffinicity decreasing exponentially as earlier. However, the rate of decreasing of paraffinicity and rate of increasing of

aromaticity are observed to be slower than earlier. The rate of increasing of aromaticity is 0.0076 and rate of decreasing of paraffinicity is -0.006.
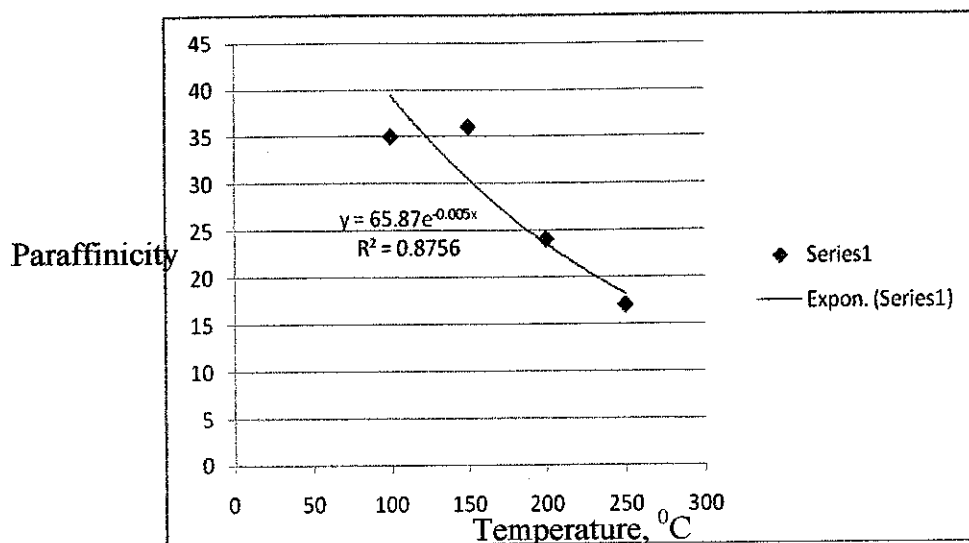
Figure 6.62: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 40 psi (Dulang).
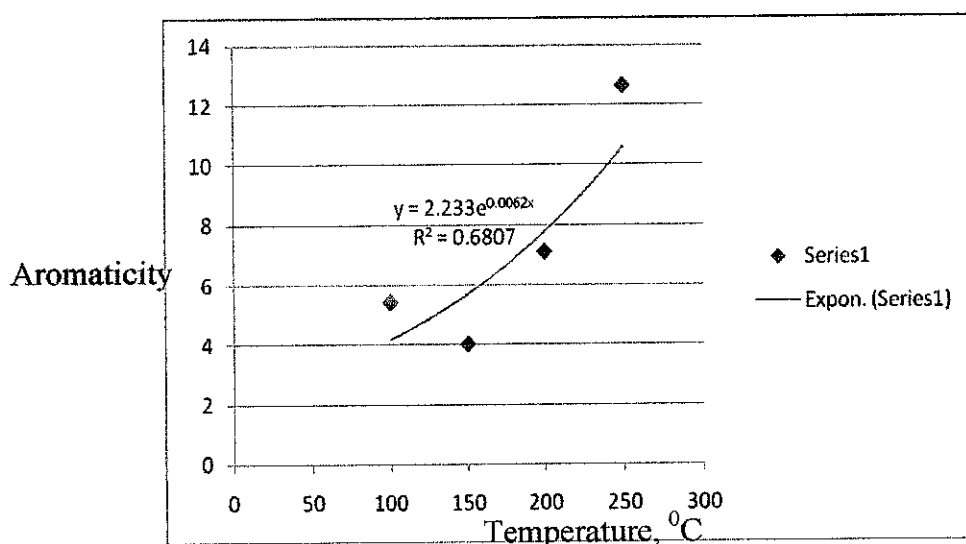
Figure 6.63: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 40 psi (Dulang).

Figure 6.62 and Figure 6.63 show the changes of paraffinicity and aromaticity with the changes of temperature but at the same pressure of 40 psi for samples in Dulang. The rate of increasing of aromaticity is 0.0062 and rate of decreasing of paraffinicity is -0.005.
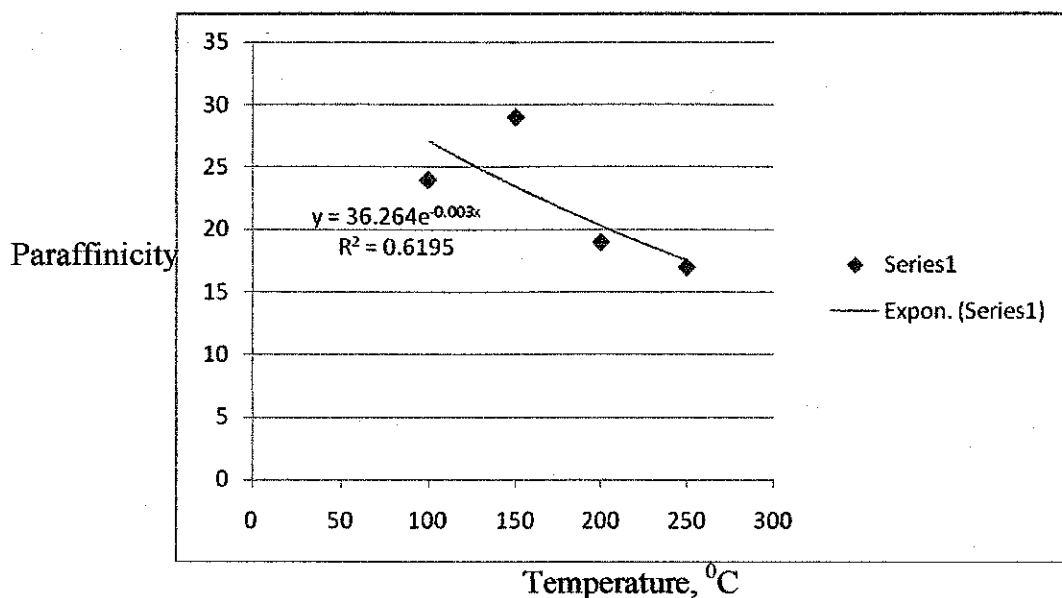
Figure 6.64: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 60 psi (Dulang).
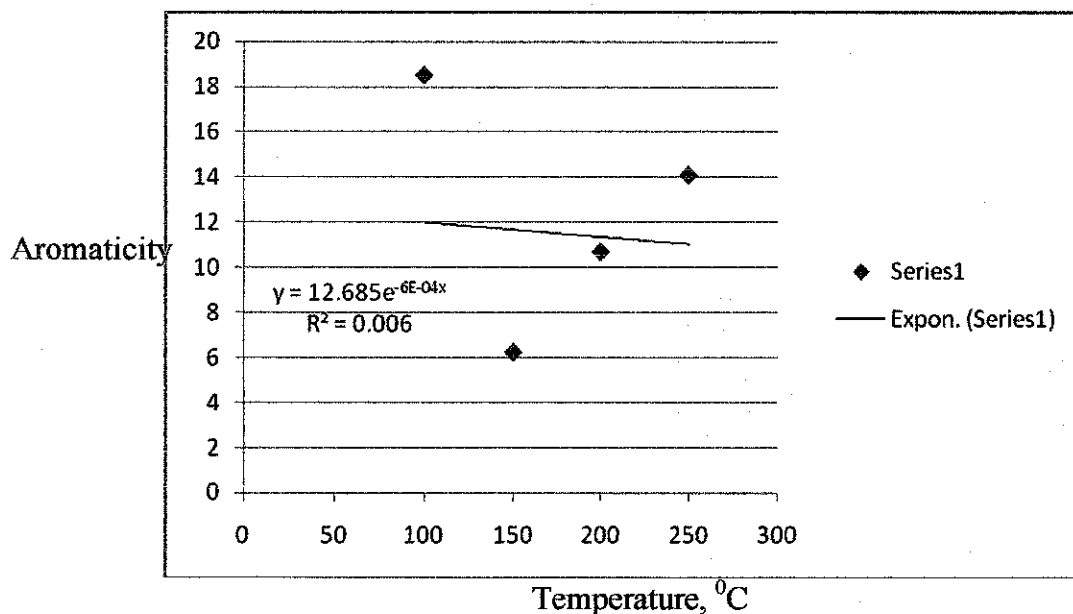
Figure 6.65: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 60 psi (Dulang).

Figure 6.64 and Figure 6.65 show the changes of paraffinicity and aromaticity with the changes of temperature at fixed pressure of 60 psi for samples in Dulang. However, both aromaticity and paraffinicity show the decreasing trend. This condition maybe due to affect of aromatic that has higher boiling point compare to paraffin. So

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the changes of temperature and pressure will affected the stability of aromatic composition.
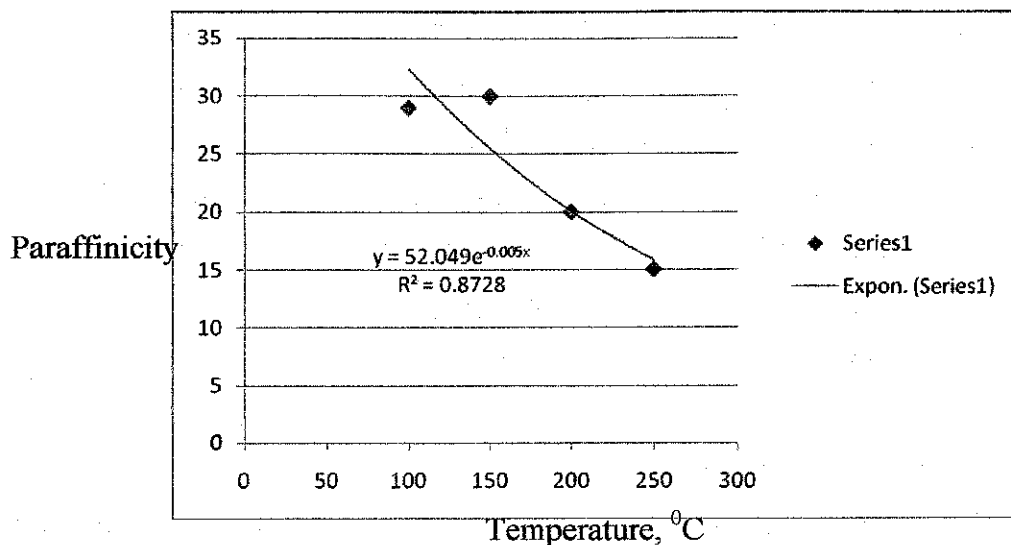
Figure 6.66: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 80 psi (Dulang).
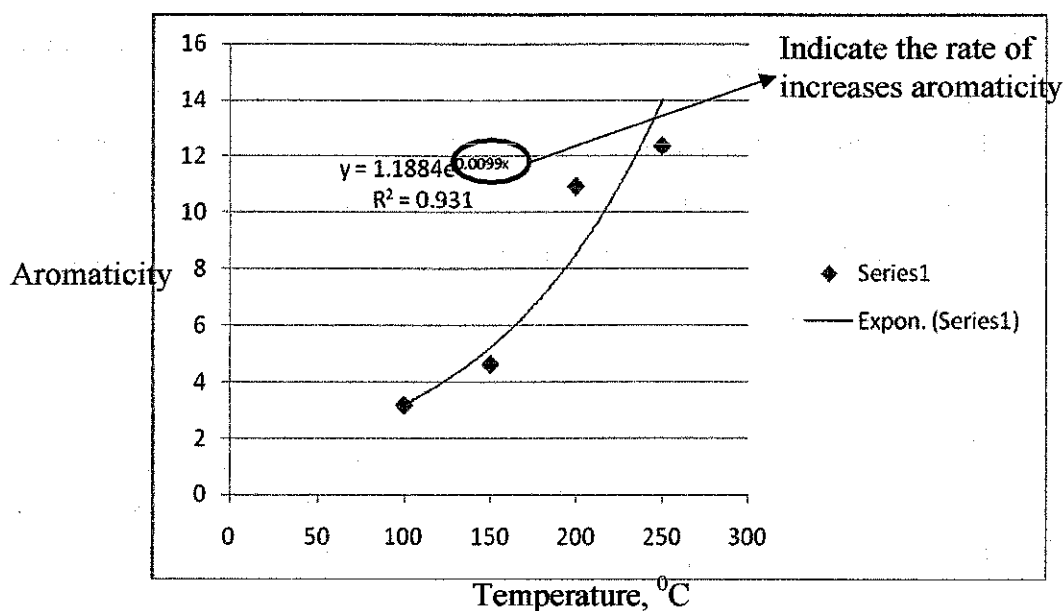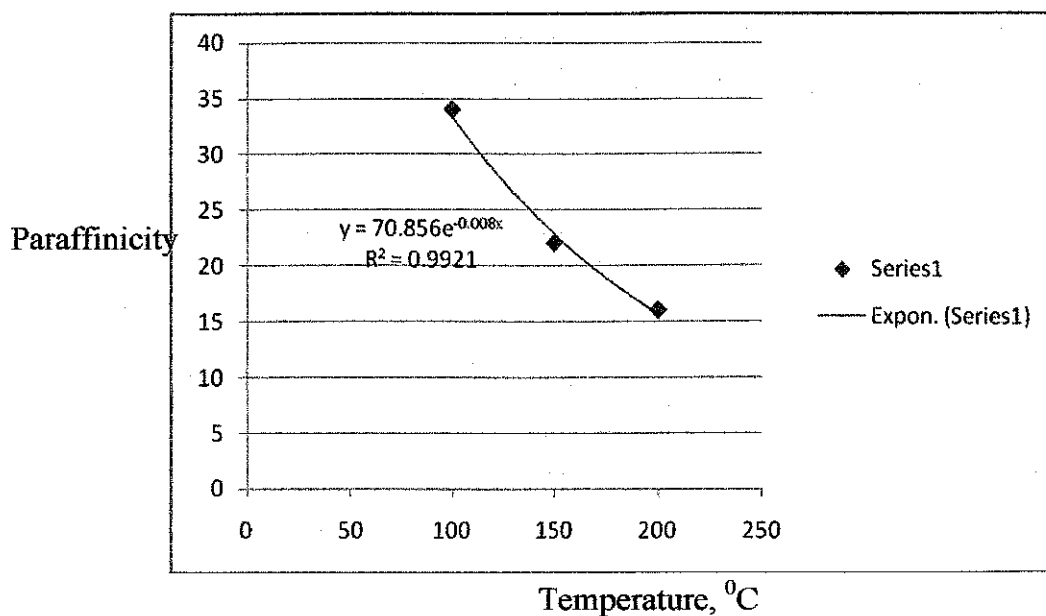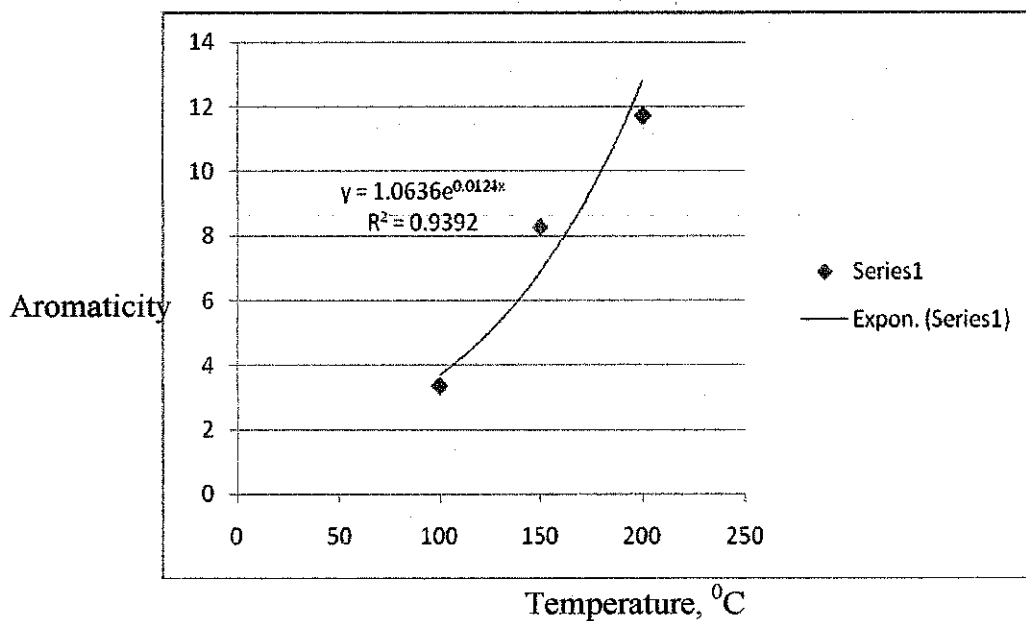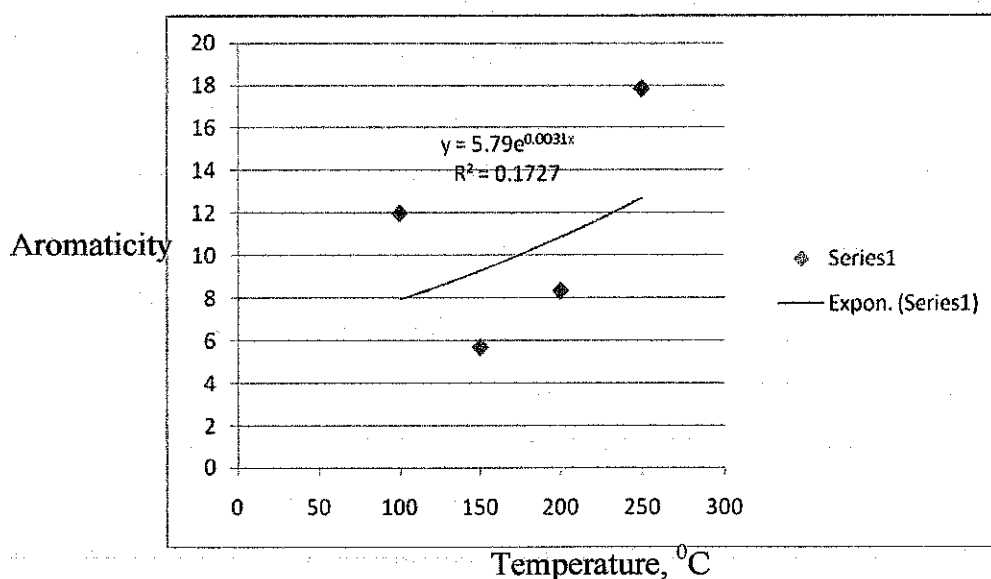

Figure 6.67: Changes of aromaticity in vapour samples with increasing temperature at a pressure of 80 psi (Dulang).

Figure 6.66 and Figure 6.67 show the changes of paraffinicity and aromaticity with the changes of temperature but at the same pressure of 80 psi for samples in Dulang. Paraffinicity show the decreasing trend and aromaticity shows increasing

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trend. However at this pressure the rate of increasing of aromaticity is 0.0031 and rate of decreasing of paraffinicity is -0.005, are both lower than the previous.

The increasing and the decreasing for both paraffinicity and aromaticity value that shows in the graph for liquid samples are constant as the temperature and pressure are increased. As we can see from Table 6.3 above, the analysis data was only available up condensate 13. The concentration of n-heptane in the residual oil samples has been evaporated into the vapour samples. This condition is due to the molecules in normal paraffin has lower boiling point compared to the molecules in aromatic compounds that has higher boiling point.

So, when the crude oil sample is heated, it will generate excess pressure and molecules of paraffin will equilibrate and condensate in a vapour phase. This condition is due to the differences of carbon atom in different type of chemical composition in paraffinicity and aromaticity compound. Each of the molecules has different characteristics. Due to the differences characteristics, each of the molecules will react with different temperature and pressure. Most of the vapour samples are unstable because the vapours samples reacted more exponentially with temperature compare to liquid samples. Subsequently, as the temperature and pressure are increasing, the covalent bonds will continue to disintegrate or atomize and condensate as a vapour.

There is some condition where the value of paraffinicity and aromaticity are both decreasing. At this point, the effect of pressure was linear compare to the effect of temperature is exponential. As the temperature is in a constant condition, the liquid samples maybe are not reacting as the increasing of pressure. So, both of aromaticity and paraffinicity are decreasing because both composition did not react with the increasing pressure.

The increasing and the decreasing for both paraffinicity and aromaticity value that shows in the graph for vapour samples is not constant compare to liquid as the temperature and pressure are increased. As we can see from Table 6.4 above, the analysis data in vapour sample are all available up to 250^0C compare to residual oil

sample. Most of the vapour samples can be analysed until 250^0C for temperature and pressure for 80 psi. The graph in vapour samples showing a spike of aromaticity for Dulang oil while for paraffinicity, the decreasing is declined sharply. At this point (condensate 4 — temperature 100^0C, pressure 80 psi), the reaction for both samples maybe in the optimized state which show the highest point for aromaticity while the decreasing of paraffinicity sharply.

6.4 Angsi oil in Malay Basin

Angsi oil sample also has been analysed using GC-MS and calculated using Thompson parameter same as earlier sample. Angsi is located same as Dulang in Malay Basin. However, Angsi field has occurrences of oil. Even though both of the oil field located in the same basin (Malay Basin), but the results from Angsi oil maybe different from Dulang oil field. It is maybe due to the differences of oil characteristics and oil occurrences in both fields. Table 6.5 below shows the result of paraffinicity and aromaticity in the residual oil samples from Angsi oil field as the temperature and pressure are increased.

Table 6.5: Show the results of paraffinicity and aromaticity in the residual oil samples in Angsi (Malay Basin).

Residual oil Samples	Sample no.	n-heptane, (n-C$_7$) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C$_7$/MCH)	Aromaticity, toluene/n-C$_7$
Original oil	1	5.94	17.98	7.66	33	1.29
Residual 1	2	6.2	20.63	0	30	0
Residual 2	3	5.83	20.7	0	28	0
Residual 3	4	5.26	17.01	0	31	0
Residual 4	5	4.31	17.4	0	25	0
Residual 5	6	3.29	16.24	0	20	0
Residual 6	7	3.1	15.19	0	20	0
Residual 7	8	2.35	13.59	0	17	0
Residual 8	9	2.66	12.82	0	21	0
Residual 9	10	3.85	16.93	0	23	0
Residual 10	11	0.98	6.03	0	16	0
Residual 11	12	0.63	3.85	0	16	0
Residual 12	13	0.36	2.7	0	13	0
Residual 13	14	0.36	2.52	0	14	0
Residual 14	15	0	1.53	0	0	0
Residual 15	16	0	0.97	0	0	0
Residual 16	17	0	1.4	0	0	0

The data in the tabular form for paraffinicity and aromaticity in residual oil samples are shown in Table-6.5. The analysis is shown graphically in Fig.6.68 in which blue line representing paraffinicity. The results show the value of paraffinicity is decreasing as the temperature or pressure rises. The analysis for aromaticity could not be measured. This is because the value of toluene in Angsi is very low which cannot be measured either in residual oil or in vapour samples. The value of toluene that has been analysed was a value of combination with 3-methylheptane value. So, the original value of toluene cannot be measured and was not identified properly because of the combination.
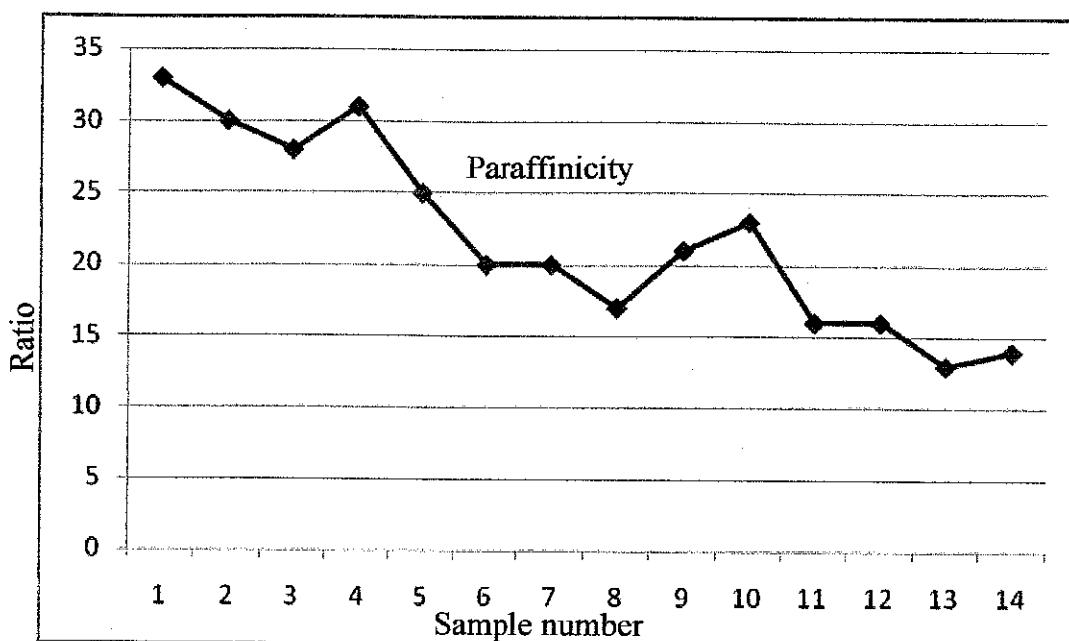
Figure 6.68: Shows the result of indicate paraffinicity decreases in residual oil
samples in Angsi (Malay Basin).

Figure 6.68 shows the result of paraffinicity is decreasing as the temperature
or pressure rises. A residual oil sample 9 (sample no. 10) is increasing abruptly. This
condition is due to characteristics of paraffin that has lower boiling point. At this
condition, paraffin has reached its boiling point. So, when the temperature is higher
and pressure is lower, the value of paraffin will be higher. The individual analysis of
the residual oil with effects of pressure and temperature are shown below.
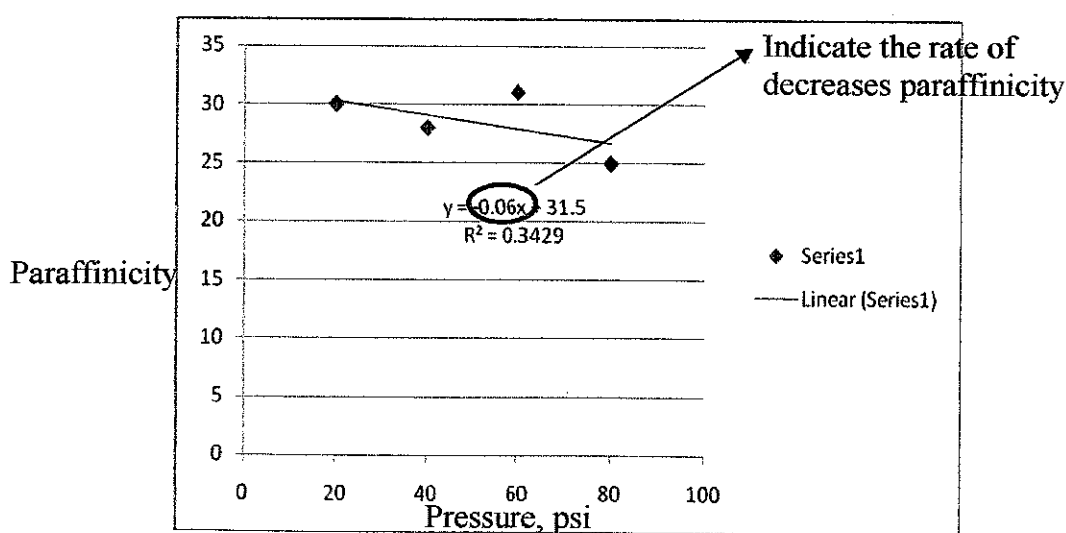
Figure 6.69: Changes of paraffinicity in residual oil samples with increasing pressure
at 100^0C (Angsi).

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Figure 6.69 shows the changes of paraffinicity with the changes of pressure at the same temperature of 100^0C for samples in Angsi. The graph shows the unstable value in the decreasing of paraffinicity as the increasing of pressure. However, at this temperature the rate of decreasing of paraffinicity is -0.06.
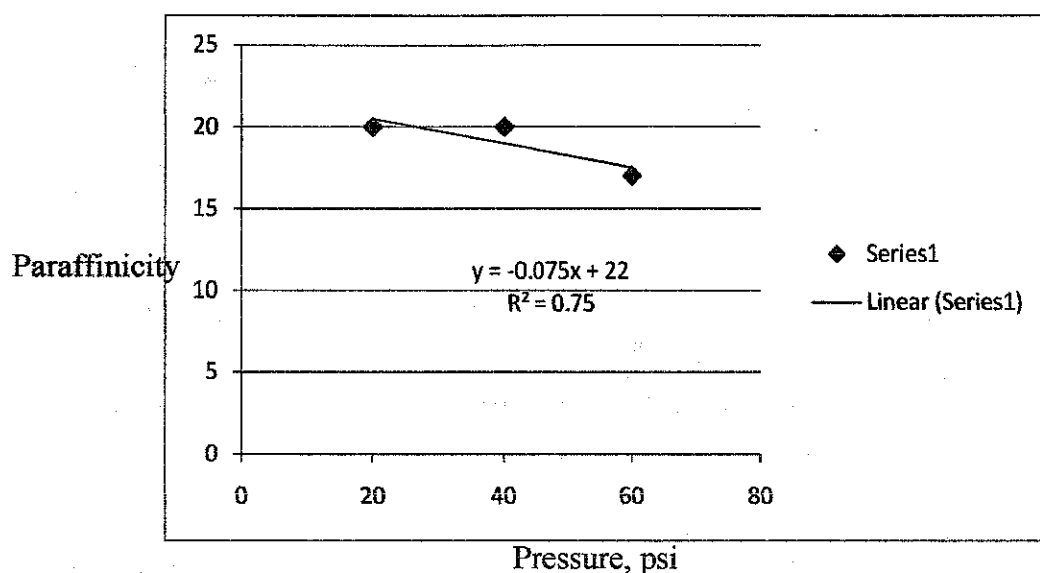
Figure 6.70: Changes of paraffinicity in residual oil samples with increasing pressure at 150^0C (Angsi).

Figure 6.70 shows the changes of paraffinicity with the changes of pressure but at the same temperature of 150^0C for samples in Angsi. The graph shows the decreasing value of paraffinicity. The rate of decreasing of paraffinicity is -0.075 and lowers than the previous. This suggests the rate of decreasing for paraffinicity falls as the pressure is increased.
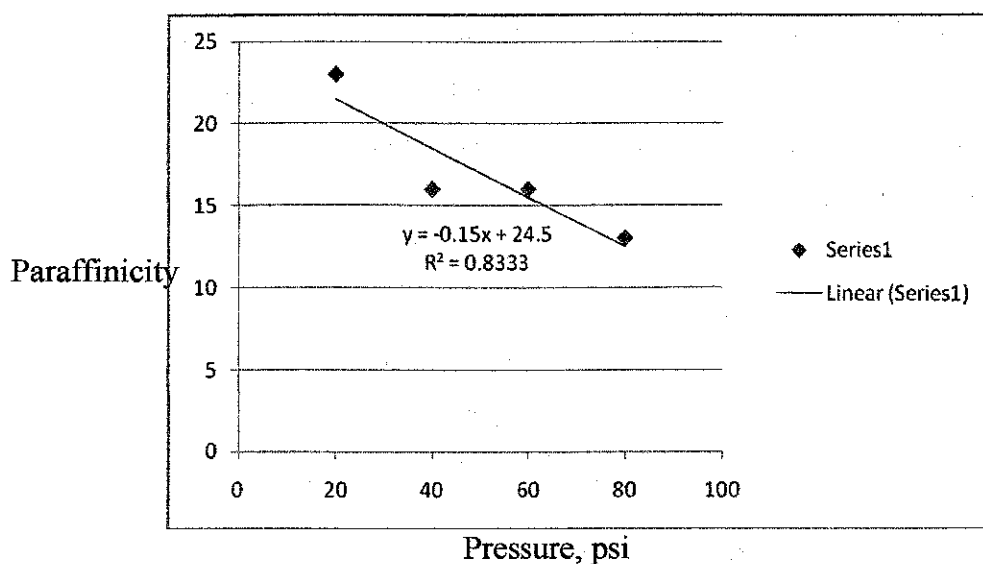
Figure 6.71: Changes of paraffinicity in residual oil samples with increasing pressure at 200^0C (Angsi).

Figure 6.71 shows the changes of paraffinicity with the changes of pressure at fixed temperature of 200^0C for samples in Angsi. The graph shows the unstable value in the decreasing of paraffinicity as the increasing of pressure. However at this temperature the rate of decreasing of paraffinicity is -0.15 and rate for paraffinicity falls as the pressure is increased.
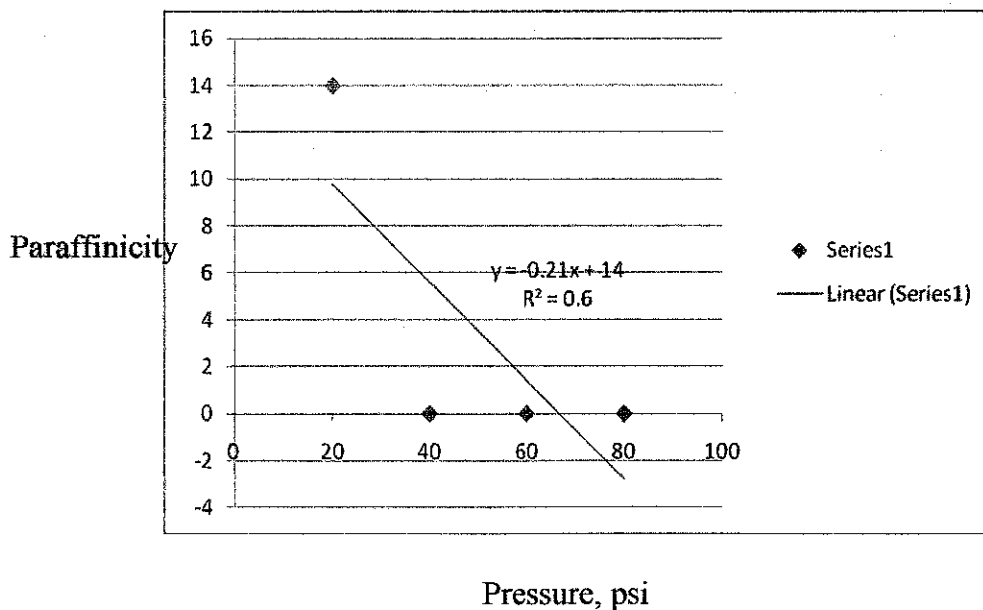
Figure 6.72: Changes of paraffinicity in residual oil samples with increasing pressure at 250^0C (Angsi).

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Figure 6.72 shows the changes of paraffinicity with the changes of pressure at the same temperature of 250^0C for samples in Angsi. The graph show the value of paraffinicity is available only at pressure of 20 psi. This condition maybe due to the concentration of n-heptane has been evaporated into vapour.
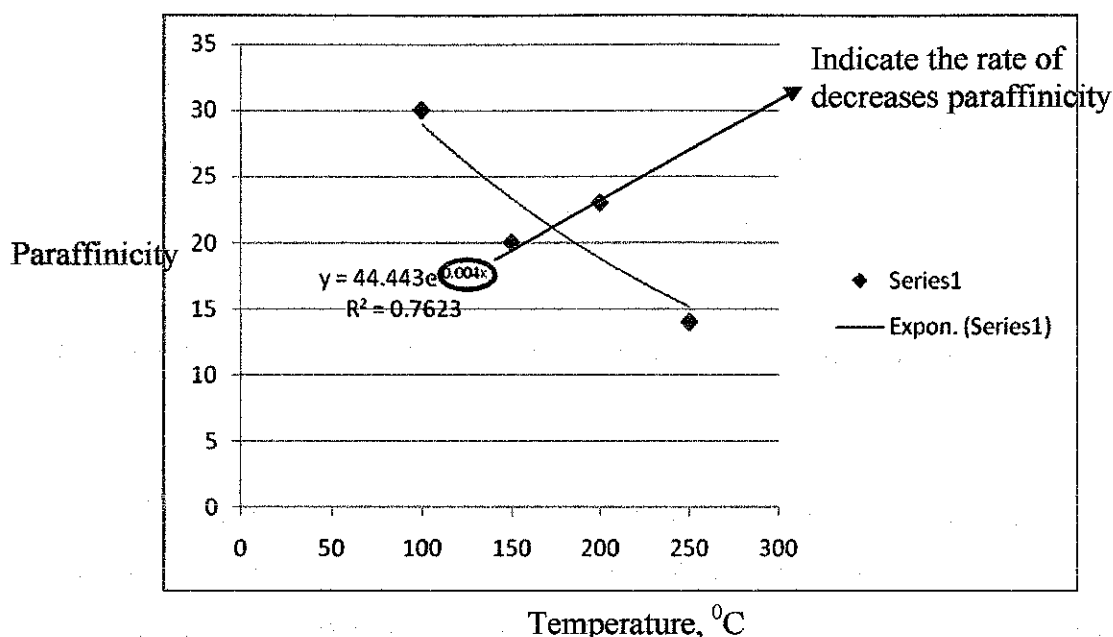
Fig 6.73: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 20 psi (Angsi).

Figure 6.73 shows the changes of paraffinicity with the changes of temperature at fixed pressure of 20 psi for samples in Angsi. The rate of decreasing of paraffinicity is -0.004 and higher than the previous. This suggests the rate of decreasing for paraffinicity rises as the temperature is increased.
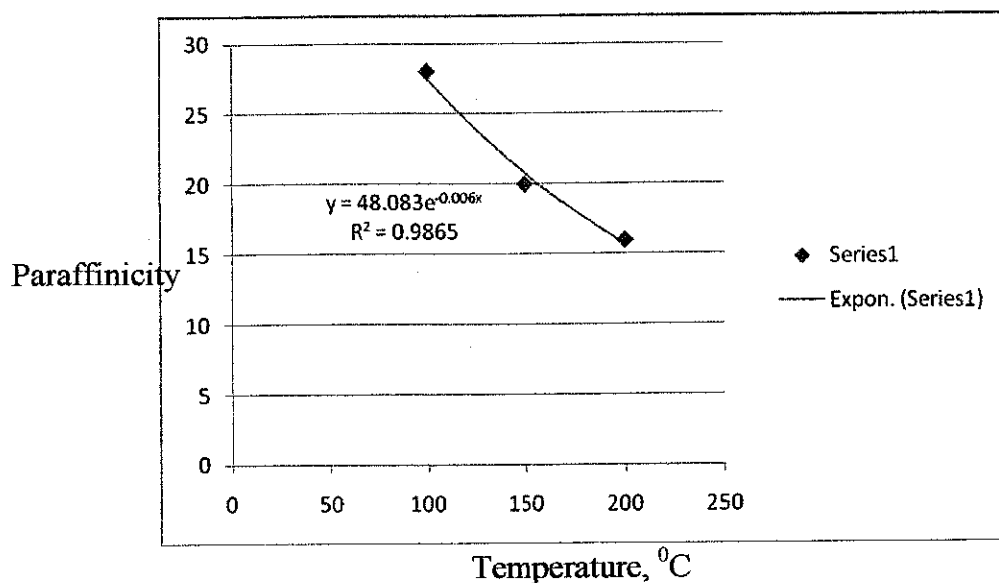
Figure 6.74: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 40 psi (Angsi).

Figure 6.74 shows the changes of paraffinicity with the changes of temperature at the same pressure of 40 psi in residual oil samples in Angsi. However at this temperature the rate of decreasing of paraffinicity is -0.006.
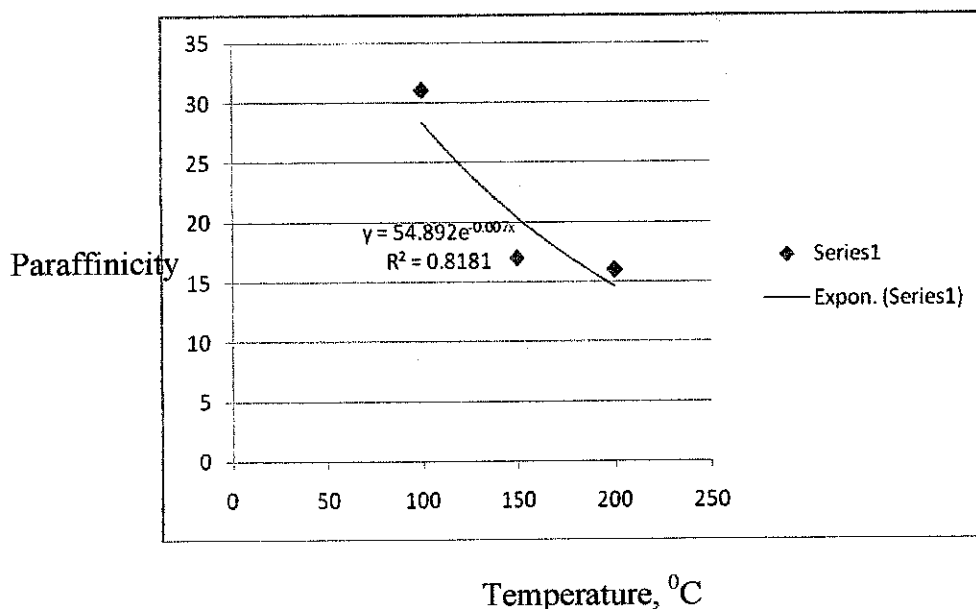
Temperature, ^{0}C

Figure 6.75: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 60 psi (Angsi).

Figure 6.75 shows the changes of paraffinicity with the changes of temperature at the same pressure of 60 psi for samples in Angsi. The rate of decreasing of paraffinicity is -0.007. There is no result or graph data that can be analysed from Angsi crude oil sample at temperature of 250^0C. This condition maybe due to concentration of n-heptane has been evaporated into vapour.
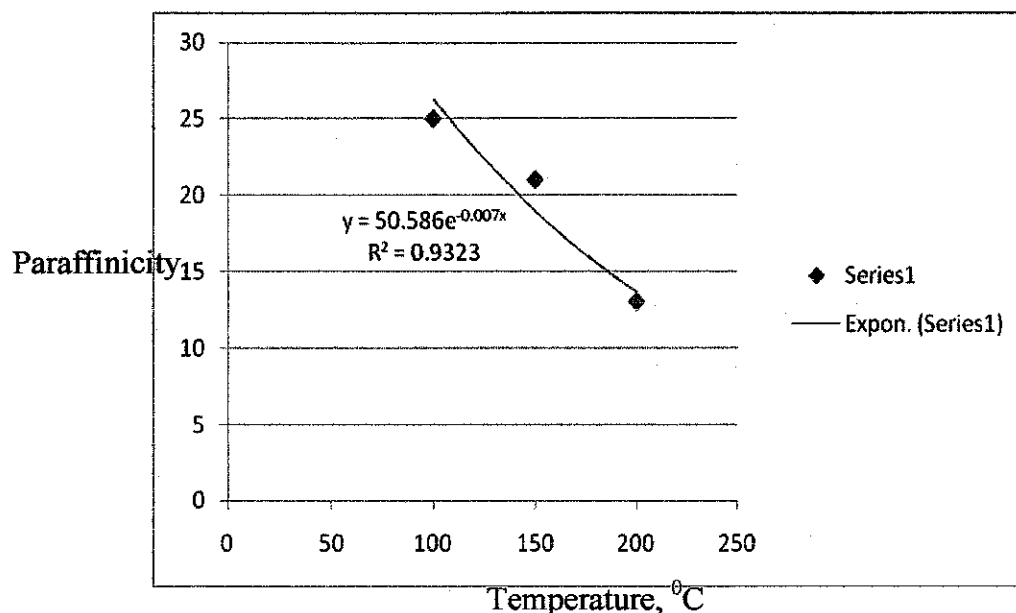
Figure 6.76: Changes of paraffinicity in residual oil samples with increasing temperature at a pressure of 80 psi.

Figure 6.76 shows the changes of paraffinicity with the changes of temperature at fixed pressure of 80 psi from samples in Angsi. The rate of decreasing of paraffinicity is -0.007 and the value are similar as the previous. This suggests the rate of decrease for paraffinicity is constant as the temperature is increased.

Table 6.6: Show the results of paraffinicity and aromaticity in the vapour samples in Angsi (Malay Basin).

Vapour Samples	Sample no.	n-heptane, (n-C₇) %	Methyl-Cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C₇/MCH)	Aromaticity, *toluene*/n-C₇
Original oil	1	5.94	17.98	7.66	33	1.29
Condensate 1	2	3.73	11.25	0	33	0
Condensate 2	3	4.69	12.53	0	37	0
Condensate 3	4	5.33	14.03	0	38	0
Condensate 4	5	3.37	10.26	0	39	0
Condensate 5	6	3.25	10.07	0	32	0
Condensate 6	7	4.04	12.37	0	33	0
Condensate 7	8	1.77	6.44	0	27	0
Condensate 8	9	3.12	11.07	0	28	0
Condensate 9	10	5.16	15.85	0	33	0
Condensate 10	11	4.12	16.28	0	25	0
Condensate 11	12	4.04	16.69	0	24	0
Condensate 12	13	3.36	16.35	0	21	0
Condensate 13	14	2.12	10.85	0	20	0
Condensate 14	15	1.83	10.3	0	18	0
Condensate 15	16	1.54	9.3	0	17	0
Condensate 16	17	2.05	13.39	0	15	0

The data in the tabular form for paraffinicity and aromaticity in vapour samples are shown in Table-6.6. The analysis is shown graphically in Figure 6.77 in which blue line representing paraffinicity. The results show the value of paraffinicity is decreasing as the temperature or pressure rises. In this experiment also, the value of aromaticity could not be measured due to the concentration of toluene in Angsi is lower. As we can see in Figure 6.77, residual oil samples 9 (no. 10) is increasing abruptly. This condition is due to characteristics of paraffin that has lower boiling point. At this condition, paraffin has reached its boiling point. So, when the temperature is higher and pressure is lower, the value of paraffin will be higher.
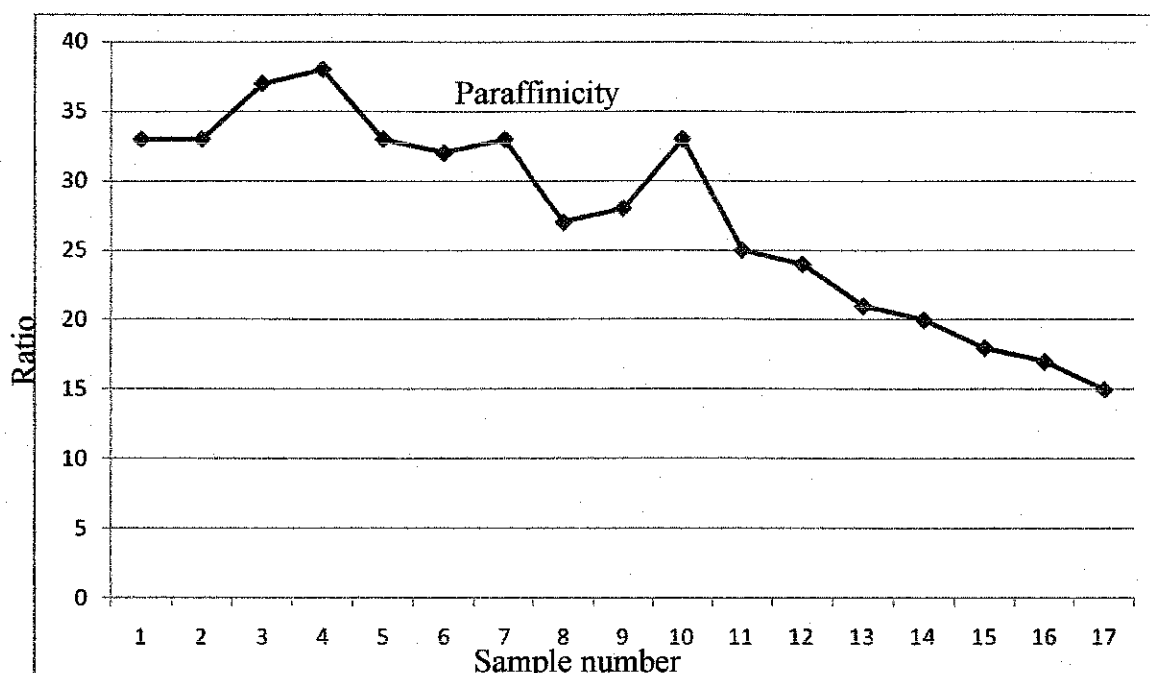
Figure 6.77: Shows the result of indicate paraffinicity decreases and aromaticity increases in vapour samples.

. Concentration of toluene in Angsi oil sample is detected with 3-methylheptane. The value of toluene that has been analysed is a value of combination with the value of 3-methylheptane. The original value of toluene cannot be measured and was not identified properly because of the combination. So, the distribution of toluene in vapour and residual oil became so low that was below measurable contain. The Angsi crude oil sample has been taken from Petroleum Geoscience department in UTP. The individual analysis of the residual oil with effects of pressure and temperature are shown below.
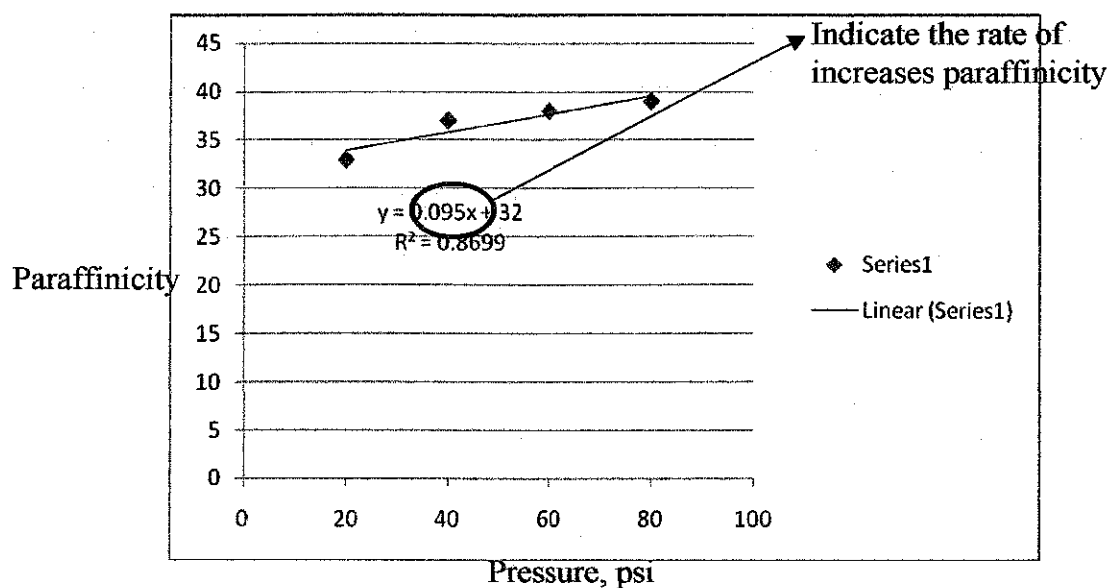
Figure 6.78: Changes of paraffinicity in vapour samples with increasing pressure at 100°C (Angsi).

Figure 6.78 shows the changes of paraffinicity with the changes of pressure at fixed temperature of 100°C for samples in Angsi. The graph shows the stable value of increasing paraffinicity. Paraffinicity is increasing at 100°C with increasing pressure because it is due to paraffin lower boiling point. So at this condition, paraffin has reached boiling point.
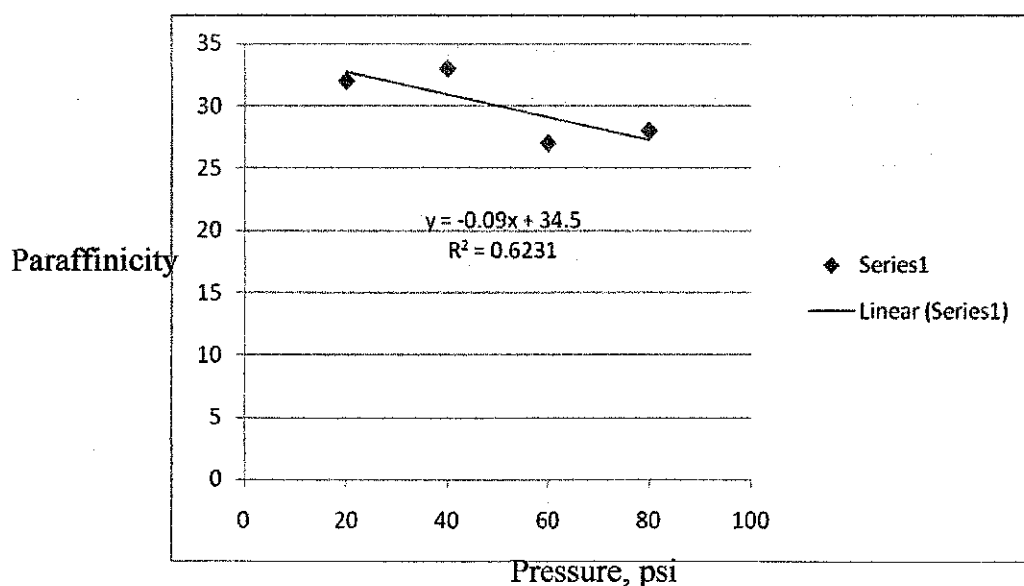
Figure 6.79: Changes of paraffinicity in vapour samples with increasing pressure at 150°C (Angsi).

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Figure 6.79 shows the changes of paraffinicity with the changes of pressure at the same temperature of 150°C in vapour samples for Angsi. The graph shows the unstable value in the decreasing of paraffinicity. At this temperature the rate of decreasing paraffinicity is -0.09 and lower than previous. This suggests the rate of decreasing for paraffinicity falls as the pressure is increased.
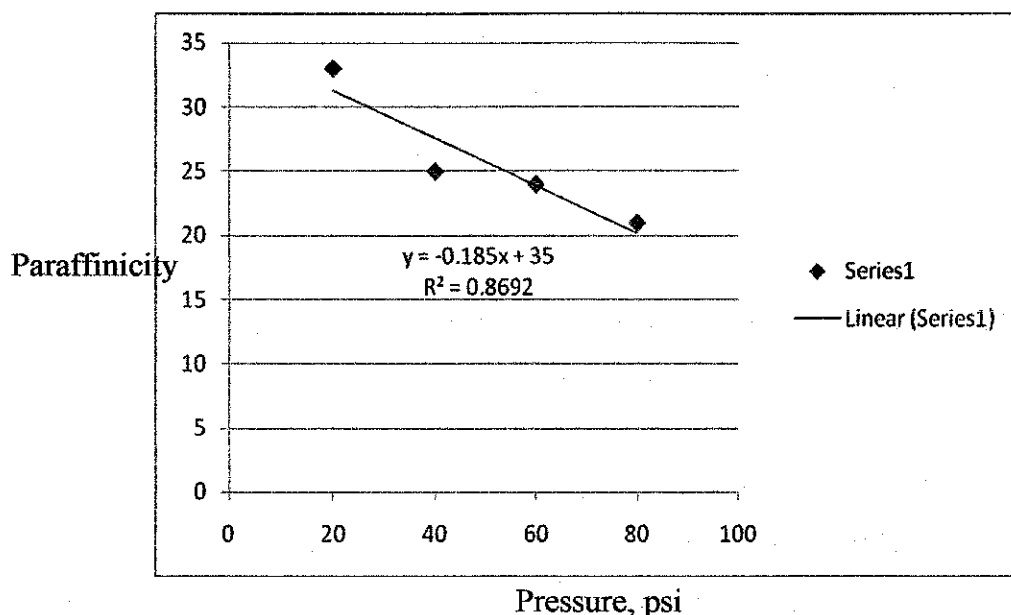
Figure 6.80: Changes of paraffinicity in vapour samples with increasing pressure at 200°C (Angsi).

Figure 6.80 shows the changes of paraffinicity with the changes of pressure but at the same temperature of 200°C in vapour samples for Angsi. The graph shows the paraffinicity is decreasing. The rate of decreasing for paraffinicity is -0.185.

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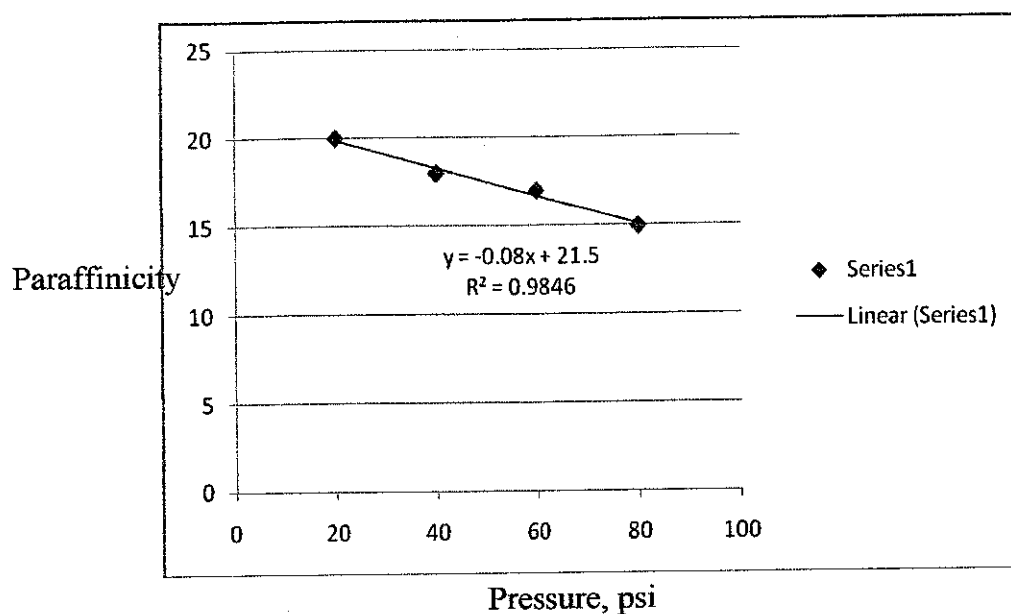
Figure 6.81: Changes of paraffinicity in vapour samples with increasing pressure at
250⁰C
(Angsi).

Figure 6.81 shows the changes of paraffinicity with the changes of pressure at the same temperature of 250⁰C for samples in Angsi. The rate of decreasing of paraffinicity is -0.08 and higher than previous. This suggests the rate of decreasing for paraffinicity rises as the pressure is increased.
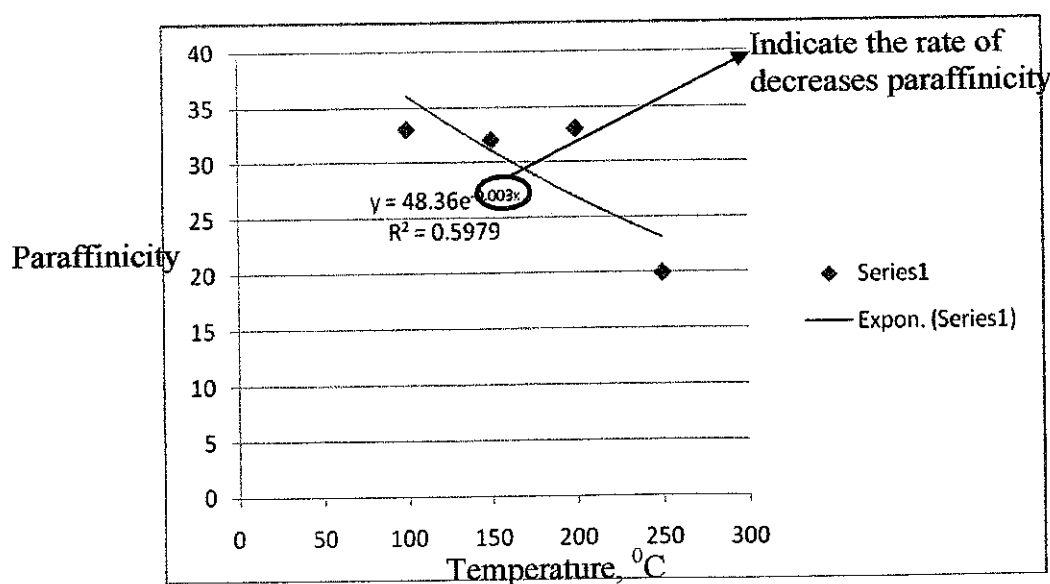
Figure 6.82: Changes of paraffinicity in vapour samples with increasing temperature
at a pressure of 20 psi (Angsi).

Figure 6.82 shows the changes of paraffinicity with the changes of temperature at fixed pressure of 20 psi for samples in Angsi. The graph shows the value of paraffinicity is decreasing. However at this temperature the rate of decreasing paraffinicity is -0.003 and higher than previous. This suggests the rate of decreasing for paraffinicity higher as the temperature is increased.
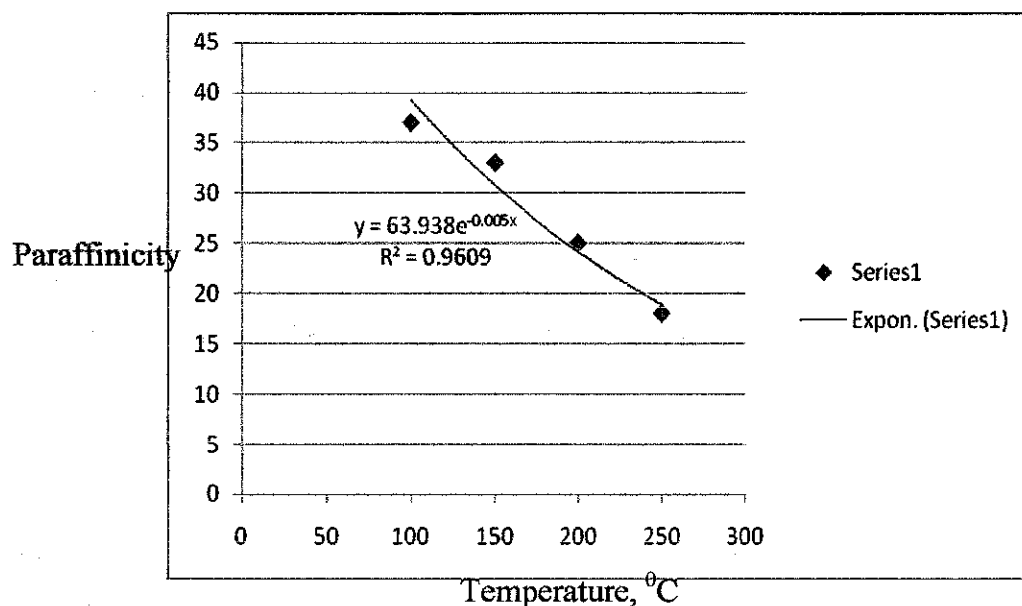
Figure 6.83: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 40 psi (Angsi).

Figure 6.83 shows the changes of paraffinicity with the changes of temperature at fixed pressure of 40 psi in vapour samples for Angsi. The graph shows the decreasing trend of paraffinicity as the increasing temperature. At this temperature, the rate of decreasing of paraffinicity is -0.005.
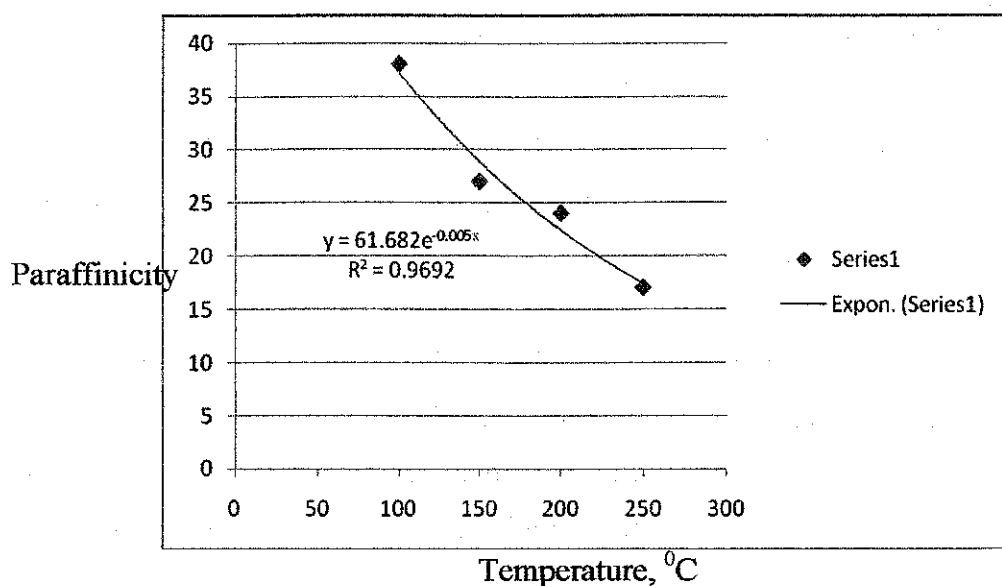
Figure 6.84: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 60 psi (Angsi).

Figure 6.84 shows the changes of paraffinicity with the changes of temperature but at the same pressure at 60 psi in vapour samples for Angsi. At this temperature, the rate of decreasing for paraffinicity is -0.005 and constant as the previous. This suggests the rate of decreasing for paraffinicity with constant temperature is increased.
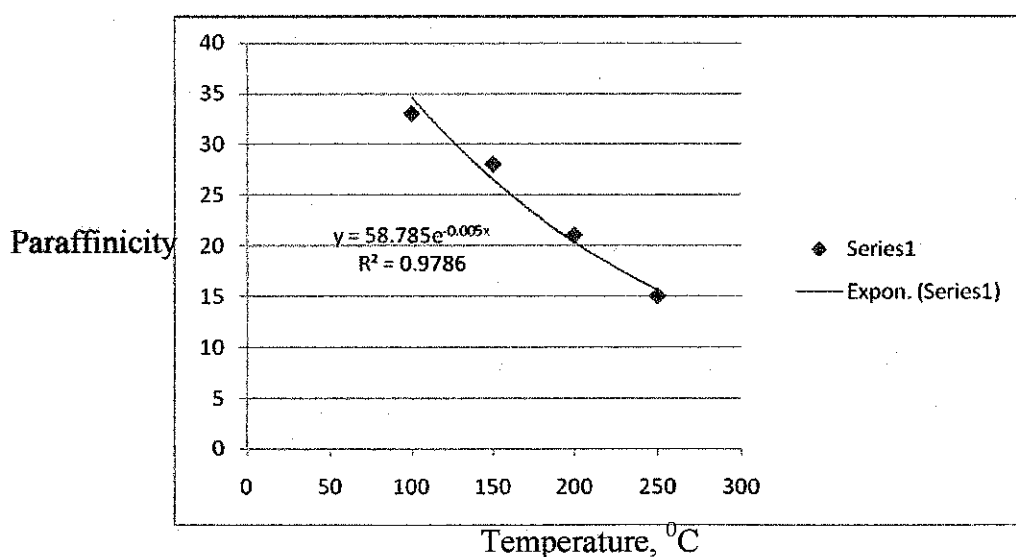
Figure 6.85: Changes of paraffinicity in vapour samples with increasing temperature at a pressure of 80 psi (Angsi).

Figure 6.85 shows the changes of paraffinicity with the changes of temperature but at the same pressure of 80 psi for samples in Angsi. The graph shows the decreasing value for paraffinicity. At this temperature, the rate of decreasing for paraffinicity is -0.005. The rate for decreasing paraffinicity remains constant. This show that at this point, paraffinicity has reached its optimum point.

As we can see in Table 6.5 and Table 6.6, the values of aromaticity remain zero from condensate 1 until condensate 16. There is no reaction for aromaticity in Angsi crude oil as the temperature and pressure is increased. This condition is maybe due to the concentration of toluene in Angsi oil is very low which is not measurable or analysed through GC-MS analysis in the vapour or residual oil afterwards. The value of toluene in the original oil that has been analysed was found out to be a value of combination between toluene and 3-methylheptane. The value of the original toluene is not identify properly because it is mix with 3-methylheptane. So, due to this situation the distribution of toluene in vapour and residual sample became so low that is below measurable contain.

The viscosity of the Angsi oil is maybe higher compare to Dulang and Erb West oil. This situation is due to the concentration in Angsi oil is different from both Sabah and Dulang oil. Even though Angsi is located in Malay Basin same as Dulang, but the characteristics and the concentration of Angsi oil is different from Dulang. This shows from the result analysis and the graph from Dulang and Angsi oil. It is also maybe because of high containing of paraffin in Angsi oil and less aromatic. So, when the crude oil had been analysed, the concentration of aromatic compound cannot be detected in the GC-MS instrument.

As for paraffinicity, the data is only available up to condensate 13. The results for paraffinicity from condensate 14 until condensate 16 are zero. At this situation, the concentration of n-heptane has been dissolved into vapour. This condition is due to the molecules in normal paraffin has lower boiling point compared to the molecules in aromatic compounds that has higher boiling point. The graph for paraffinicity in vapour sample is stable compare to the graph in residual oil samples. This shows that

the characteristics of crude oil can be effect by the increasing of pressure and temperature.

6.5 Second evaporative fractionation test for Angsi oil

As we can see for the previous graph and table above, the value of aromaticity and paraffinicity for both liquid and vapour samples mostly remain same. All data from Dulang and Angsi in Malay Basin and Erb West in Sabah Basin show the same trend or pattern for each of the graph data. The value of paraffinicity is decreasing and the value for aromaticity is increasing. Paraffinicity is decreasing both in vapour and liquid samples and as for aromaticity; the value is also increasing in vapour and liquid samples. This condition is due to the first evaporative fractionation of residual crude oil is in equilibrium state with vapour. This is show by the similarity from the value of both liquid samples and vapour sample. Both of paraffinicity and aromaticity show the same pattern of graph.

In thermodynamic, systems are said to be in thermal equilibrium if they have no net exchange of heat or thermal energy. The net heat supplied to the system equals the net work done by the system. The flow of heat in the closed system evaporative fractionation instrument is based on the thermodynamic cycle. This is also show that at certain temperature and pressure condition, the modified evaporative fractionation technique can change and effect the composition and characteristics of crude oil. Due to this situation, a second test of modified evaporative fractionation technique has been done only for Angsi oil.

Table 6.7: Shows the value of paraffinicity and aromaticity (second test) for Angsi oil.

Sample	Sample no	n-heptane, (n-C$_7$) %	Methyl-cyclohexane, (MCH) %	Toluene, %	1000*Paraffinicity, 1000 (n-C$_7$/MCH)	Aromaticity, toluene/n-C$_7$
Original oil	Angsi	5.94	17.98	7.66	33	1.29
Vapour sample (250^{0}C, 90 psi)	A-vapour	5.85	25.54	11.51	23	1.97
Remain sample (25^{0}C, 1 atm)	A-liquid	4.84	12.34	0	39	0

The first experiment has been done by heating the crude oil using pressure reactor and both vapour and liquid samples will be collected each of the increasing pressure. This process has been done for Sabah, Dulang and Angsi crude oil with the increasing temperature and pressure in the first experiment. In this process, the excess vapour pressure will be controlled by releasing the excess vapour so that the vapour will remain constant for example 20 psi. The heating process will be repeated with 40 psi, 60 psi and up to 80 psi. After that, the sample will be collected in vapour phase at the same time as liquid sample collected. At this point, both of vapour and liquid samples were remain in an equilibrium condition. So the previous results cannot show the whole effect of modified evaporative fractionation technique that can change the composition and characteristics of crude oil because the residual oil and vapour samples were in the equilibrium state.

The second experiment has been done and repeated with Angsi crude oil. Angsi crude oil is chosen to show how modified fractionation can affect the changes of characteristic of crude oil. Compare to the first experiment, the second experiment with Angsi crude oil will be repeated with heated the samples to the maximum temperature of 250^{0}C. The integration of temperature will generate excess vapour pressure and in this case, the pressure is generating naturally without adding any gas up to 90 psi. The vapour sample is collected at this pressure of 90 psi and then the heated crude oil has been cooling down first before the liquid sample was taken out from the glass cylinder.

The liquid sample was taken out after the cooling process of pressure reactor instrument. As we can see in Table 6.7 above, the vapour sample has high pressure and temperature while for residual oil sample; it is under lower temperature and pressure condition. Both residual oil and vapour samples have different pressure and temperature compare to the first experiment. The vapour pressure is generating naturally by the heating process compare to the first experiment, the increasing vapour has to be controlled so it can remain constant.

Based on the Table 6.7, aromaticity is decreasing and rich in vapour sample while paraffinicity is increasing and rich in remain sample. Evidence of evaporative fractionation processes affecting oils and gas condensates in nature are represented in the second experiment for Angsi crude oil. At this certain pressure and temperature, the crude oil will change in terms of its compositions and characteristics.

In the first experiment, we can found out that the residual or remain oil is rich in aromatic while paraffin is rich in vapour. It is found that through second experiment, the result is vice versa with the first experiment which is the residual oil is rich in paraffin instead of aromatic and the vapour is rich in aromatic instead of paraffin. Compare to the first experiment in Angsi crude oil, the value of aromatic is remain zero for both liquid and vapour samples from condensate 1 until condensate 16.

This result is different from the first experiment. It shows that at certain temperature and pressure, modified evaporative fractionation technique can effect the changes of composition and characteristics of crude oil. As we can see for both experiments, at certain temperature and pressure, we can generate new different liquid with different concentration and characteristics using modified evaporative fractionation technique. We can generate crude oil that rich in paraffin or rich in aromatic using this technique at certain pressure and temperature.

CHAPTER 7

CONCLUSION

7.1 Overview

This section will focus on the conclusions for the results that have been done through modified evaporative fractionation experiment. The results were dealt in terms of aromaticity and paraffinicity according to Thompson's parameters.

7.2 Conclusion

This research is based on the study regarding the changes of characteristics and compositions of crude oil using modified evaporative fractionation technique. The following were the conclusion drawn in view of the objectives of this research:

1. The first objective is to study the characteristics of oil in reservoir rock and the detailed geochemical evaluation of the oil characters to develop the related methodology for research findings.

   i) Oils from different reservoirs are not uniform in a particular field and oils in the same reservoir in different fields are also not uniform. This variation of the composition of oil can be ascribed to variation of organic facies in the source rock or it can be possible by in-reservoir alteration. So far it has been justified by assuming facies variation in source rocks.

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ii)   Erb West crude oil in Sabah Basin generally is slightly waxy, light and contents of low sulphur. The API gravity value for Sabah oil is about 28^0, and the gas constituent is 92% methane. The Erb West structure is an elongated hydrocarbon bearing sand layer, and it lies in a north-easterly by south westerly direction. The main faults in the blocks are in the East - West direction, concentrated in the southern half of the structure. It is the entrapped hydrocarbon within these southern blocks that are targeted for the revisit campaign.

iii)   Dulang oil belong to Group E reservoirs in Malay basin that are geographically restricted to the basin centre, with the Dulang fields accounting for the majority of E oils and has a large oil accumulation. Mostly, oils in this group are immature over much of the basin except only in the lowest part of E reaches the oil window in some areas. A majority of Group E oils are moderately waxy to waxy and condensates are more common, and the gas produced is known to be high in CO_2.

iv)   Angsi belongs to Pre-group I oils in Malay basin. Group I oils are common in the southern half of the Malay Basin. The geochemical characteristics vary only little and this variation were considered to be due to a combination of differing maturity of the oils and of post-accumulation processes such as evaporative fractionation.

2. The second objective is to test the alteration of the reservoir oil by modified evaporative fractionation technique.

Results indicate:

i)   In the first experiment of modified evaporative fractionation, paraffinicity was decreasing as the value of temperature and pressure were increased while the value of aromaticity was increasing as the temperature and pressure were increased for both liquid and vapour samples.

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ii)   The second test indicate the ratio of paraffinicity is decreasing in vapour sample and increasing in residual oil sample while the ratio of aromaticity indicate a decreasing in residual oil sample and increasing in vapour sample. The result for second test is vice versa with the first experiment.

Logically, it is inferred that when aromaticity increases in the vapour, the residual oil should be correspondingly rich with paraffins. Thus it becomes a method of changing original crude to paraffin rich oil in the original reservoir and aromatic rich fractionated oils in shallower reservoirs. The phenomena occur in many basins and a key to determine major aspects of petroleum variability and characteristic. The modified technique firstly has been tested using Sabah oil and continued with Dulang and Angsi oil. Original oil was heated gradually to 250^0C in different stages and at each stage 20psi, 40psi, 60psi and 80psi pressures were attained.

For every stage samples from vapour and liquid are collected and analysed. The result was analysed using GC-MS instrument. Results indicate that the paraffinicity decreases and aromaticity increases at every stage. The results suggests this process of closed system fractionation causes high paraffin in residual oil and corresponding fractionated oil gets more aromatic. The effect of temperature and pressure can change the characteristics of crude oil. Thus, evaporative fractionation appears to be one of the major mechanisms of generation of gas-condensate fluids.

7.3 Recommendations

This research was important to identify the changes of crude oil characteristics and compositions. It is also crucial in the comparison between the original crude oil and the fractionated oil. Other recommendations may include:

1) Carry out a research in the original field which contain lot of crude oil in the system and make a comparison analysis in order to confirm modified evaporative fractionation technique as a tool of reservoir alteration.

2) Adding more pressure and temperature to the maximum value as in the original oil field for both small and big amount of oil and make a comparison in order to determine whether the effect of high pressure and temperature can be change the composition of crude oil.

3) It would have been better if the API gravities of the resulting condensates and residual oils were measured and included as part of the results in addition to the paraffinicity and aromaticity parameters.

REFFERENCES

Adams, C.G. and Kirk, H.J.C., 1962. The Madai-Binturong Limestone Member of the Chert-Spilite Formations, North Borneo. Geological Magazine, 44, 289-303.

Azlina Anuar, 1994. Source rock evaluation of Middle-Late Miocene sequences, North Sabah Basin, Malaysia. Unpublished PhD thesis, Imperial College of Science, Technology and Medicine, University of London, 296pp.

Basir Jasin, 1992. Significance of radiolarian chert from the Chert-Spilite Formation, Telupid, Sabah. Bulletin of the Geological Society of Malaysia, 31, 67-84.

Basir Jasin and Sanudin Tahir, 1988. Barremian Radiolaria from Chert-Spilite Formation, Kudat, Sabah. Sains Malaysiana, 17, 67-79.

Bell, R.M. and Jessop, R.G.C., 1974. Exploration and Geology of the West Sulu Basin, Philippines, Australian Petroleum Exploration Association Journal, 1, 21-28.

BeMent, W.O., Levey, R.A., Mango, F.D., 1995. The temperature of oil generation as defined with a C7 chemistry parameter (2,4-DMP/2,3-DMP). In: Grimalt, J.O., Dorronsoro, C. (Eds.), Organic Geochemistry: Developments and Applications to Energy, Climate, Environment and Human History. Pro- ceedings of the 17th International Meeting on Organic Geo- chemistry, San Sebastian, September 1995, pp. 505-507.

(2,4-DMP/2,3-DMP). In: Grimalt, J.O., Dorronsoro, C. (Eds.), Organic Geochemistry: Developments and Applications

to Energy, Climate, Environment and Human History. Pro- ceedings of the 17th International Meeting on Organic Geo- chemistry, San Sebastian, September 1995, pp. 505±507.

Bol, A.J. and van Hoorn, B., 1980. Structural styles in western Sabah offshore. Bulletin of the Geological Society of Malaysia, 12, 1-16.

Clennell, B., 1991. The origin and tectonic significance of melanges of Eastern Sabah, Malaysia. Journal of the Southeast Asian Earth Sciences, 6, 407-425.

Curry, D.J., 1992. Geochemistry and source facies relationships of gases from the Malay Basin. Unpublished Report, Esso Production Malaysia Inc.

EPIC (Esso-PETRONAS Integrated Collaborative Study), 1994. Regional study of the Malay Basin-Final Portfolios. Unpublished report, Esso Production Malaysia Inc.

Fontaine, H. and Ho, W.K., 1989. Note on the Madai-Baturong Limestone, Sabah, East Malaysia; Discovery of Caprinidae (Rudists), CCOP Newsletter, 14, 27-32.

Ginger, D.C., Ardjakusuma, W.O., Hedley, R.J. and Pothecary, J., 1993. Inversion history of the West Natuna Basin: examples from the Cumi-Cumi PSC. Proceedings of the Indonesian Petroleum Association 22nd Annual Convention, Jakarta, October 1993, 635-658.

Haile, N.S., 1973. The recognition of former subduction zones in Southeast Asia. In: Tarling, D.H. and Runcorn, S.K., eds., Implications of Continental Drift to the Earth Sciences, 2. Academic Press, London, 885-892.

Halpern, H.I., 1995. Development and applications of light-hydrocarbon-based star diagrams. American Association of Petroleum Geologists Bulletin 79, 801-815.

Hamilton, W., 1979. Tectonics of the Indonesian region. United States Geological Survey Professional Paper, No. 1078.

Hunt, J.M., 1995, Petroleum Geochemistry and Geology: San Francisco, Freeman, ch.7, pp.93-120

Hutchison, C.S., 1993. Gondwanaland and Cathaysian blocks, Palaeothethys sutures and Cenozoic tectonics in South-East Asia. Geologisches Rundschau, 82, 388-405.

Hutchison, C.S., 1997. Tectonic framework of Neogene basins of Sabah. Abstracts Geological Society of Malaysia Petroleum Geology Conference 1997.

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Jean-Pierre Wauquier., 1995. Petroleum Refining. Institut Français du Pétrole. Gulf Publishing Company, Houston, Texas.

Khalid Ngah, 1990a. Deposition and diagenesis of Oligocene-Lower Miocene sandstones in the southern Malay Basin. Unpublished Ph.D. Thesis, University of London.

Khalid Ngah, Mazlan Madon, and Tjia, H.D., 1996. Role of pre-Tertiary fractures in formation and development of the Malay and Penyu Basins. In: Hall, R. and Blundell, D.J., eds., " Tectonic Evolution of Southeast Asia". Geological Society of London Special Publication, 106, 281-289.

Khandwala, S.M., Abd Malek Abd Rani and M Nasir Abd Rahman, 1984. Field development planning for the Semangkok field, offshore Peninsular Malaysia. 5th Offshore South East Asia Conference, 21-24 February 1984, Singapore, 8.35-8.49.

Kirk, H.J.C., 1962. The geology and mineral resources of the Semporna Peninsula, North Borneo. British Borneo Geological Survey. Memoir 14.

Kugel, Roger W. "Raoult's Law: Binary Liquid-Vapor Phase Diagrams" Journal of Chemical Education 75.9 (1998): 1125.

Lee, D.C.T., 1990. Formation of Pulau Batu Harian and other islands around Pulau Banggi, Northern Sabah. Bulletin of the Geological Society of Malaysia, 26, 71-76.

Leong, K.M., 1978. Sabah. In: ESCAP Atlas of Stratigraphy I. Burma, Malaysia, Thailand, Indonesia, Philippines. United Nations, Mineral Resources Development Series, 44, 26-31.

Leong, K.M., 1974. The geology and mineral resources of the Upper Segama Valley and Darvel Bay area, Sabah, East Malaysia. Geological Survey of Malaysia Memoir 4 (Revised), 354pp.

Leong, K.M., 1977. New ages from radiolarian cherts of the Chert-Spilite Formtion, Sabah. Bulletin of the Geological Survey of Malaysia, 8, 109-111.

Leong, K.M., 1978a. Sabah. In: ESCAP Atlas of Stratigraphy I. Burma, Malaysia, Thailand, Indonesia, Philippines. United Nations, Mineral Resources Development Series, 44, 26-31.

Leong, K.M., 1998. Sabah Crystalline Basement: 'Spurious radiometric ages? Continental?' Warta Geologi, 24, 5-8.

Levell, B.K., 1987. The nature and significance of regional unconformities in the hydrocarbon-bearing Neogene sequence offshore West Sabah. Bulletin of the Geological Society of Malaysia.

Liew, K.K., 1994. Structural development at the west-central margin of the Malay Basin. Bulletin of the Geological Society of Malaysia, 36, 67-80.

Lim, P.S., 1986. Seismic activities in Sabah and their relationship to regional tectonics. Geological Survey of Malaysia Annual Report for 1985, 465-480.

Mazlan B. Hj. Madon, 1994. Depositional and diagenetic histories of reservoir sandstones in the Jerneh Field, central Malay Basin. Bulletin of the Geological Society of Malaysia, 36, 31-53.

Mazlan B. Hj. Madon, 1995. Tectonic evolution of the Malay and Penyu basins, offshore Peninsular Malaysia. Unpublished D.Phil. Thesis, University of Oxford, 325pp.

Mazlan Madon, 1996. Gravity anomalies, isostasy, and the tectonic evolution of the Malay and Penyu basins. Geological Society of Malaysia Petroleum Geological Conference, 9-10 December 1996, Kuala Lumpur. (abstract).

Mazlan B. Hj. Madon, 1997a. The kinematics of extension and inversion in the Malay Basin, offshore Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 41, 127-138.

Mazlan B. Hj. Madon, 1997b. Analysis of tectonic subsidence and heat flow in the Malay Basin (offshore Peninsular Malaysia). Bulletin of the Geological Society of Malaysia, 41, 95-108.

Mazlan B. Madon and Watts, A.B, 1998. Gravity anomalies, subsidence history and the tectonic evolution of the Malay and Penyu basins. Basin Research, 10, 375-392.

Mango, F.D., 1987. An invariance in the isoheptanes of petroleum. Science 237, 514-517.

Mango, F.D., 1990. The origin of light cycloalkanes in petroleum. Geochimica et Cosmochimica Acta 54, 23-27.

Mango, F.D., 1996. The temperature of oil generation as defined with a C7 chemistry parameter (2,4-DMP/2,3-DMP). In: Grimalt, J.O., Dorronsoro, C. (Eds.), Organic Geochemistry: Developments and Applications to Energy, Climate, Environment and Human History. Pro- ceedings of the 17th International Meeting on Organic Geo- chemistry, San Sebastian, September 1995, pp. 505-507.

McCaffrey, M.A., Abolins, P., Mohammad Jamaal Hoesni and Huizinga, B.J., 1998. Geochemical characterisation of Malay Basin oils: some insight into the effective petroleum systems. Ninth Regional Congress on Geology, Mineral and Energy Resources of Southeast Asia – GEOSEA '98, 17-19 August 1998, Kuala Lumpur, Programme and Abstracts, 149.

M.R. Riazi, 2005. Characterization and Properties of Petroleum Fractions. American Society for Testing and Materials, West Conshohocken, PA.

Nik Ramli, 1988a. Development of a humid tropical fan-delta system: the middle Tertiary 'K' sandstone in the southeastern Malay Basin, offshore West Malaysia. In: Nemec, W. and Steel, R.J., eds., Fan Deltas: "Sedimentology and Tectonic Settings". Blackie, Glasgow, 341-353.

Noor Azim Ibrahim, 1994. Major controls on the development of sedimentary sequences Sabah Basin, Northwest Borneo, Malaysia. Unpublished PhD thesis, University of Cambridge, 254pp.

Peters, K.E. & Moldowan, J.M., 1993. In: The Biomarker Guide Interpreting Molecular Fossils In petroleum And Ancient sediments. Englewood Cliffs, NJ, Prentic Hall. 363 p.

Ramlee, A.R. and Bedingfield, J.R., 1996. Mid J Group sequence stratigraphy and reservoir architecture in Block PM-9, Malay Basin PRSS Technology Forum, 12-13 September 1996, Awana Genting, Kuala Lumpur (unpublished proceedings).

Raoult F.M., (1882). General Law of the Vapor Pressure of Solvents. *Comptes Rendus* 104, 1430-3 (May 23, 1887) [as translated and published by Henry M. Leicester & Herbert S. Klickstein, *A Source Book in Chemistry, 1400-1900* (Cambridge, MA: Harvard, 1952)]

Raphael Idem., 2003. Crude Oil Chemistry. University of Regina, Regina Saskatchewan, Canada. Marcel Dekker, Inc.

Sanudin Hj. Tahir, 2003. Geologi Petroleum. Universiti Malaysia Sabah. Utusan Kinabalu Co. Sdn. Bhd. Kota Kinabalu Sabah.

Scherer, F.C., 1980. Exploration in East Malaysia over the past decade. In: Halbouty, M.T., ed., Giant Oil and Gas Fields of the Decade 1968-1978. American Association of Petroleum Geologists Memoir, 30, 423-440.

Silverman, S. R., 1965, Migration and segregation of oil and gas. In A. Young and G. E. Galley (eds.), *Fluids in subsurface environments*. AAPG Memoir 4. Tulsa: American Association of Petroleum Geologist, pp 54-65

Tan, D.N.K and Lamy, J.M., 1990. Tectonic evolution of the NW Sabah continental margin since Late Eocene. Bulletin of the Geological Society of Malaysia, 27, 241-260.

Taylor, B. and Hayes, D.E., 1980. The tectonic evolution of the South China Basin. In: Hayes, D.E., ed., The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands.

Taylor, B. and Hayes, D.E., 1983. Origin and history of the South China Sea Basin. In: Hayes, D.E., ed., The Tectonic and Geologic Evolution of Southeast Asian Seas ans Islands, Part 2.

Ten Haven, H.L., 1996. Applications and limitations of Man- go's light hydrocarbon parameters in petroleum correlation studies. Organic Geochemistry 24, 957-976.

Thambydurai, R., Mustaffa, A.F., Mueller, K.H. and Dixon, M.R., 1988. Jerneh gas field development planning. Proceeding of the 7th Offshore South East Asia Conference, Singapore, 2-5 February 1988, 859-870 (preprint).

Tjia, H.D., 1978. The Lahad Datu (Sabah) earthquakes of 1976: Surface deformation in the epicentral region. Sains Malaysiana, 7, 33-64.

Tjia, H.D., 1988. Accretion tectonics in Sabah: Kinabalu Suture and East Sabah accreted terrane. Bulletin of the Geological Society of Malaysia, 22, 237-251.

Tjia, H.D., 1994a. Origin and tectonic development of Malay-Penyu-West Natuna basins. Paper presented at PRSS Technology Day, 21 June 1994, Kuala Lumpur (unpublished manuscript).

Tjia H.D. and K.K., Liew, 1996. Changes in tectonic stress field in northern Sunda Shelf basins. In: Hall, R. and Blundell, D.J., eds., Tectonic Evolution of Southeast Asia. Geological Society of London Special Publication, 106, 291-306.

Thompson, K.F.M., 1983. Classification and thermal history of petroleum based light hydrocarbons. Geochimica et Cosmo- chimica Acta 47, 303-316.

Thompson, K. F. M., 1987, Fractionated aromatic petroleums and the generation of gas-condensates. Org. Geochem., 11 (6), 573-590.

Tongkul, F., 1988. Geological control on the birth of Pulau Batu Harian mud volcano, Kudat, Sabah. Warta Geologi, 14, 153-165.

Tongkul, F., 1991a. Tectonic evolution of Sabah, Malaysia. In: Nichols, G. and Hall, R. (eds.) Proceedings of the Orogenesis in Action Conference London 1990. Journal of Southeast Asian Earth Sciences, 6, 395-405.

Tongkul, F., 1994. The geology of Northern Sabah, Malaysia : its relationship to the opening of the South China Sea Basin. Tectonophysics, 235, 131-147.

Tongkul, F., 1997. Polyphase development in the Telupid area, Sabah, Malaysia. In: Geosea 1995 Proceedings, Journal of Asian Earth Sciences, 15, 175-184.

Vasily Simanzhenkov, and Raphael Idem, 2003. Crude Oil Chemistry. Marcel Dekker, Inc. United States of America.

Van Graas, G.W., 1990. Biomarker maturity parameters for high maturities: calibration of the working range up to the oil/condensate threshold. In: Durand, B., Behar, F. (Eds.), Advances in Organic Geochemistry 1989, Part II, Molecular Geochemistry. Organic Geochemistry 16, 1025-1032.

Waples, D.W., Leslie, W. and Mahadir Ramly, 1994. A thermal model for the evolution of the Malay Basin. Abstracts of AAPG International Conference & Exhibition, Kuala Lumpur, Malaysia, August 21-24, 1994. American Association of Petroleum Geologists Bulletin, 78, 1169.

Waples, D.W., and Mahadir Ramly, 1995. Geochemistry of gases in the Malay Basin. Abstracts of the Geological Society of Malaysia, Petroleum Geology Conference 1995. Warta Geologi, 21, 413.

Watts, A.B., Karner, G.D. and Steckler, M.S., 1982. Lithospheric flexure and the evolution of sedimentary basins. Philosophical Transactions of the Royal Society of London, A305, 249-281.

Whittle, A.P. and Short, G.A., 1978. The petroleum geology of Tembungo Field, East Malaysia Southeast Asia Petroleum Exploration (SEAPEX) Conference Paper.

Yarborough L. (1972) Vapor-liquid equilibrium data for multicomponent mixtures containing hydrocarbon and non-hydrocarbon components. J. Chem. Eng. Data 17, 129-133.

Zhuze, T. P., G. S. Usakova and G. N. Yushkevitch, 1962, The influence of high temperature and pressure on the content of properties of condensate in the gas phase of gas-oil deposits, *Geochemistry*, 8, 797-806

APPENDICES

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Acq On      : 19 Dec 2011  10:56

Sample      : S180.1 (1)
Data File   : syasaila 101.D
Data Path   : C:\msdchem\CAL 2010\DATA\2011\PG\syasaila\
DataAcq Meth:UP TO C7_M
Misc        :
Operator    : mohdfab

Search Libraries:   C:\Database\NIST05a.L          Minimum Quality:  50

Unknown Spectrum:   Apex minus start of peak
Integration Events: ChemStation Integrator - 2.e
```

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.997	0.09	C:\Database\NIST05a.L			
			Cyclobutanol	646	002919-23-5	10
			2-Methoxy-N-methylethylamine	2171	038256-93-8	9
			Propanamide	713	000079-05-0	9
2	1.031	0.18	C:\Database\NIST05a.L			
			Ammonia	6	007664-41-7	2
			Water	7	007732-18-5	1
3	1.351	0.09	C:\Database\NIST05a.L			
			Methylene Chloride	1497	000075-09-2	95
			Methylene Chloride	1498	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
4	1.446	0.13	C:\Database\NIST05a.L			
			Pentane, 2-methyl-	1795	000107-83-5	58
			Butane, 2,3-dimethyl-	1802	000079-29-8	56
			Pentane, 2-methyl-	1793	000107-83-5	53
5	1.519	0.10	C:\Database\NIST05a.L			
			Pentane, 3-methyl-	1794	000096-14-0	91
			Pentane, 3-methyl-	1797	000096-14-0	86
			Pentane, 2,2,4,4-tetramethyl-	12345	001070-87-7	59
6	1.609	0.28	C:\Database\NIST05a.L			
			Hexane	1791	000110-54-3	91
			Hexane	1792	000110-54-3	83
			Hexane	1790	000110-54-3	58
7	1.806	0.09	C:\Database\NIST05a.L			
			Butane, 1-methoxy-	2069	000628-28-4	47
			Pentane, 2,4-dimethyl-	3897	000108-08-7	42
			Pentane, 2,3-dimethyl-	3899	000565-59-3	38
8	1.845	0.92	C:\Database\NIST05a.L			
			Cyclopentane, methyl-	1467	000096-37-7	91
			Cyclopentane, methyl-	1468	000096-37-7	90
			Cyclohexane	1430	000110-82-7	86
9	2.086	0.42	C:\Database\NIST05a.L			
			Butane, 1-chloro-	2382	000109-69-3	87
			Butane, 1-chloro-	2381	000109-69-3	86
			Butane, 1-chloro-	2377	000109-69-3	86
10	2.193	5.03	C:\Database\NIST05a.L			
			Benzene	1000	000071-43-2	96
			Benzene	1001	000071-43-2	94
			Benzene	998	000071-43-2	93

Note: The symbol ☐ shows the value (area %) of n-heptane, methylcyclohexane and toluene that are used to calculated paraffinicity and aromaticity ratio.

144

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11   2.288   1.55 C:\Database\NIST05a.L
              Hexane, 3-methyl-                            3888 000589-34-4 97
              Hexane, 3-methyl-                            3894 000589-34-4 95
              Hexane, 3-methyl-                            3891 000589-34-4 93

12   2.434   0.89 C:\Database\NIST05a.L
              Cyclopentane, 1,3-dimethyl-                  3325 002453-00-1 74
              Triethylamine                                4052 000121-44-8 60
              Triethylamine                                4054 000121-44-8 58

13   2.513   1.62 C:\Database\NIST05a.L
              Cyclopentane, 1,2-dimethyl-, trans           3346 000822-50-4 96
              Isopropylcyclobutane                         3267 000872-56-0 95
              Cyclopentane, 1,2-dimethyl-, trans           3348 000822-50-4 91

14   2.615   3.30 C:\Database\NIST05a.L
              Heptane                                      3885 000142-82-5 96
              Heptane                                      3886 000142-82-5 95
              Heptane                                      3887 000142-82-5 90

15   2.929   0.23 C:\Database\NIST05a.L
              Hexane, 2,2-dimethyl-                        7451 000590-73-8 83
              Hexane, 2,2-dimethyl-                        7452 000590-73-8 78
              Hexane, 2,2-dimethyl-                        7450 000590-73-8 78

16   3.075  20.02 C:\Database\NIST05a.L
              Cyclohexane, methyl-                         3273 000108-87-2 97
              Cyclohexane, methyl-                         3269 000108-87-2 97
              Cyclohexane, methyl-                         3271 000108-87-2 94

17   3.243   1.11 C:\Database\NIST05a.L
              Cyclopentane, ethyl-                         3268 001640-89-7 96
              Cyclopentane, ethyl-                         3272 001640-89-7 95
              Cyclopentane, 1,2-dimethyl-, cis-            3337 001192-18-3 80

18   3.344   1.05 C:\Database\NIST05a.L
              Cyclopentane, 1,2,4-trimethyl-              6615 002815-58-9 95
              Cyclopentane, 1,2,4-trimethyl-, (1          6653 004850-28-6 94
              .alpha.,2.alpha.,4.beta.)-
              Cyclopentane, 1,2,4-trimethyl-, (1          6652 016883-48-0 91
              .alpha.,2.beta.,4.alpha.)-

19   3.490   0.86 C:\Database\NIST05a.L
              Cyclopentane, 1,2,3-trimethyl-, (1          6655 015890-40-1 94
              .alpha.,2.alpha.,3.beta.)-
              Cyclopentane, 1,2,3-trimethyl-, (1          6654 015890-40-1 94
              .alpha.,2.alpha.,3.beta.)-
              Cyclopentane, 1,2,3-trimethyl-              6613 002815-57-8 83

20   3.692   0.73 C:\Database\NIST05a.L
              Hexane, 2,3-dimethyl-                        7444 000584-94-1 94
              Hexane, 2,3-dimethyl-                        7436 000584-94-1 91
              3,4-Diethyl hexane                          18504 019398-77-7 74

21   3.810   6.03 C:\Database\NIST05a.L
              Heptane, 2-methyl-                           7425 000592-27-8 96
              Heptane, 2-methyl-                           7428 000592-27-8 95
              Heptane, 2-methyl-                           7432 000592-27-8 95

22   3.900   0.17 C:\Database\NIST05a.L
              Hexane, 3,4-dimethyl-                        7448 000583-48-2 91
              Hexane, 3,4-dimethyl-                        7437 000583-48-2 87
              Hexane, 3,4-dimethyl-                        7447 000583-48-2 75

23   3.967  30.82 C:\Database\NIST05a.L
              Toluene                                      2400 000108-88-3 97
              Toluene                                      2395 000108-88-3 93
```

145

Acq On   : 19 Dec 2011 11:38

Sample   : S100.1 (vp)
Data File : syasaila 102.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syasaila\
DataAcq Meth:UP TO C7.M
Misc   :
Operator : mohdfab

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 2.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.997	0.05	C:\Database\NIST05a.L			
			sec-Butylamine	739	013952-84-6	5
			Ethanol, 2-(methylamino)-	880	000109-83-1	5
			1-Propanol, 2-amino-, (S)-	885	002749-11-3	7
2	1.351	0.04	C:\Database\NIST05a.L			
			Methylene Chloride	1498	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
3	1.845	0.08	C:\Database\NIST05a.L			
			Cyclopentane, methyl-	1468	000096-37-7	91
			Cyclopentane, methyl-	1467	000096-37-7	91
			1H-Tetrazole, 5-methyl-	1304	004076-36-2	72
4	2.086	0.07	C:\Database\NIST05a.L			
			Butane, 1-chloro-	2382	000109-69-3	76
			Butane, 1-chloro-	2381	000109-69-3	74
			Butane, 1-chloro-	2377	000109-69-3	72
5	2.188	0.98	C:\Database\NIST05a.L			
			Cyclohexane	1432	000110-82-7	90
			Cyclohexane	1433	000110-82-7	81
			Cyclohexane	1430	000110-82-7	68
6	2.289	0.64	C:\Database\NIST05a.L			
			Hexane, 3-methyl-	3888	000589-34-4	83
			Pentane, 3-ethyl-	3895	000617-78-7	74
			Pentane, 3-ethyl-	3889	000617-78-7	72
7	2.429	0.66	C:\Database\NIST05a.L			
			Triethylamine	4054	000121-44-8	64
			Triethylamine	4052	000121-44-8	60
			Triethylamine	4050	000121-44-8	53
8	2.474	0.32	C:\Database\NIST05a.L			
			Cyclopentane, 1,3-dimethyl-, trans	3347	001759-58-6	95
			Cyclopentane, 1,3-dimethyl-	3325	002453-00-1	94
			Cyclopentane, 1,2-dimethyl-, cis-	3337	001192-18-3	94
9	2.513	0.66	C:\Database\NIST05a.L			
			Cyclopentane, 1,2-dimethyl-, trans	3346	000822-50-4	96
			Cyclopentane, 1,2-dimethyl-	3322	002452-99-5	96
			Isopropylcyclobutane	3267	000872-56-0	95
10	2.614	3.26	C:\Database\NIST05a.L			
			Heptane	3886	000142-82-5	96
			Heptane	3885	000142-82-5	95
			Heptane	3884	000142-82-5	87

```
11   2.929  0.33 C:\Database\NIST05a.L
                 Hexane, 2,2-dimethyl-                  7452 000590-73-8 83
                 Butane, 2,2,3,3-tetramethyl-           7473 000594-82-1 83
                 Pentane, 2,2,4-trimethyl-              7457 000540-84-1 83

12   3.080 17.31 C:\Database\NIST05a.L
                 Cyclohexane, methyl-                   3273 000108-87-2 95
                 Cyclohexane, methyl-                   3271 000108-87-2 95
                 Cyclohexane, methyl-                   3269 000108-87-2 87

13   3.249  1.37 C:\Database\NIST05a.L
                 Cyclopentane, ethyl-                   3268 001640-89-7 93
                 Cyclopentane, ethyl-                   3272 001640-89-7 91
                 Isoxazole                               464 000288-14-2 47

14   3.311  0.14 C:\Database\NIST05a.L
                 Hexane, 3,3-dimethyl-                  7446 000563-16-6 90
                 Hexane, 3,3-dimethyl-                  7445 000563-16-6 86
                 Heptane, 2,4-dimethyl-                12289 002213-23-2 78

15   3.350  0.76 C:\Database\NIST05a.L
                 Cyclopentane, 1,2,4-trimethyl-, {1     6652 016883-48-0 91
                 .alpha.,2.beta.,4.alpha.}-
                 Cyclopentane, 1,2,4-trimethyl-, {1     6653 004850-28-6 91
                 .alpha.,2.alpha.,4.beta.}-
                 Cyclopentane, 1,2,4-trimethyl-         6615 002815-58-9 91

16   3.496  1.39 C:\Database\NIST05a.L
                 Cyclopentane, 1,2,3-trimethyl-, {1     6654 015890-40-1 96
                 .alpha.,2.alpha.,3.beta.}-
                 Cyclopentane, 1,2,3-trimethyl-, {1     6655 015890-40-1 95
                 .alpha.,2.alpha.,3.beta.}-
                 Cyclopentane, 1,2,3-trimethyl-         6612 002815-57-8 80

17   3.631  0.09 C:\Database\NIST05a.L
                 Pentane, 2,3,3-trimethyl-              7454 000560-21-4 83
                 Pentane, 2,3,3-trimethyl-              7458 000560-21-4 74
                 Pentane, 2,3,4-trimethyl-              7460 000565-75-3 59

18   3.698  1.46 C:\Database\NIST05a.L
                 Hexane, 2,3-dimethyl-                  7444 000584-94-1 94
                 Hexane, 2,3-dimethyl-                  7436 000584-94-1 91
                 Octane, 4,5-dimethyl-                 18515 015869-96-2 83

19   3.827 11.51 C:\Database\NIST05a.L
                 Heptane, 2-methyl-                     7432 000592-27-8 95
                 Heptane, 2-methyl-                     7428 000592-27-8 95
                 Heptane, 2-methyl-                     7425 000592-27-8 94

20   3.996 32.15 C:\Database\NIST05a.L
                 Toluene                                2397 000108-88-3 87
                 Toluene                                2395 000108-88-3 80
                 Toluene                                2400 000108-88-3 76

21   4.086  0.18 C:\Database\NIST05a.L
                 Cyclobutane, 1,1,2,3,3-pentamethyl    11261 057905-86-9 78
                 Cyclopentane, 1,2,4-trimethyl-, {1     6653 004850-28-6 64
                 .alpha.,2.alpha.,4.beta.}-
                 Cyclopentane, 1,2,4-trimethyl-, {1     6652 016883-48-0 40
                 .alpha.,2.beta.,4.alpha.}-

22   4.215 14.28 C:\Database\NIST05a.L
                 Cyclohexane, 1,3-dimethyl-, cis-       6632 000638-04-0 95
                 1,3-Dimethylcyclohexane,cis            6577 000591-21-9 94
                 Cyclohexane, 1,3-dimethyl-, cis-       6624 000638-04-0 94
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Acq On   : 19 Dec 2011 12:19

Sample   : 8100.4 (1)
Data File : syaaaila 103.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syaaaila\
DataAcq Meth:UP TO C7.M
Misc   :
Operator : mohdfab

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator ~ 2.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.997	0.26	C:\Database\NIST05a.L			
			1-Adamantanemethylamine, .alpha.-m ethyl-	42410	013392-28-4	9
			1-[.alpha.-(1-Adamantyl)benzyliden e]thiosemicarbazide	132776	1000222-63-3	4
			Acetamide, 2-cyano-	1312	000107-91-5	4
2	1.351	1.19	C:\Database\NIST05a.L			
			Methylene Chloride	1499	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	95
			Methylene Chloride	1500	000075-09-2	91
3	1.845	0.29	C:\Database\NIST05a.L			
			Cyclopentane, methyl-	1467	000096-37-7	91
			1H-Tetrazole, 5-methyl-	1304	004076-36-2	72
			Cyclobutane, ethyl-	1445	004806-61-5	72
4	2.193	1.98	C:\Database\NIST05a.L			
			Benzene	1000	000071-43-2	96
			Benzene	998	000071-43-2	93
			Benzene	1001	000071-43-2	92
5	2.288	0.69	C:\Database\NIST05a.L			
			Hexane, 3-methyl-	3894	000589-34-4	95
			Hexane, 3-methyl-	3888	000589-34-4	94
			Hexane, 3-methyl-	3891	000589-34-4	91
6	2.434	0.32	C:\Database\NIST05a.L			
			Cyclopentane, 1,3-dimethyl-	3325	002453-00-1	95
			Cyclopentane, 1,3-dimethyl-, cis-	3336	002532-58-3	91
			Cyclopentane, 1,3-dimethyl-	3323	002453-00-1	90
7	2.513	0.64	C:\Database\NIST05a.L			
			Cyclopentane, 1,2-dimethyl-, trans	3346	000822-50-4	96
			Cyclopentane, 1,2-dimethyl-	3322	002452-99-5	96
			Isopropylcyclobutane	3267	000872-56-0	95
8	2.614	1.80	C:\Database\NIST05a.L			
			Heptane	3836	000142-82-5	95
			Heptane	3835	000142-82-5	95
			Heptane	3837	000142-82-5	90
9	3.075	16.51	C:\Database\NIST05a.L			
			Cyclohexane, methyl-	3273	000108-87-2	95
			Cyclohexane, methyl-	3269	000108-87-2	95
			Cyclohexane, methyl-	3271	000108-87-2	95
10	3.136	0.32	C:\Database\NIST05a.L			
			Hexane, 2,4-dimethyl-	7443	000589-43-5	83

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		Hexane, 1-(hexyloxy)-2-methyl-	57284	074421-17-3	73
		Heptane, 3-methyl-	7426	000589-81-1	64

11 3.243 0.91 C:\Database\NIST05a.L
		Cyclopentane, ethyl-	3268	001640-89-7	95
		Cyclopentane, ethyl-	3272	001640-89-7	89
		Isoxazole	464	000288-14-2	47

12 3.350 0.56 C:\Database\NIST05a.L
		Cyclopentane, 1,2,4-trimethyl-	6612	002815-58-9	91
		Cyclopentane, 1,2,4-trimethyl-, (1.alpha.,2.beta.,4.alpha.)-	6652	016883-48-0	91
		Cyclopentane, 1,2,4-trimethyl-	6615	002815-58-9	91

13 3.496 0.77 C:\Database\NIST05a.L
		Cyclopentane, 1,2,3-trimethyl-, (1.alpha.,2.alpha.,3.beta.)-	6654	015890-40-1	96
		Cyclopentane, 1,2,3-trimethyl-, (1.alpha.,2.alpha.,3.beta.)-	6655	015890-40-1	93
		1-Heptene, 3-methyl-	6489	004810-09-7	72

14 3.692 0.71 C:\Database\NIST05a.L
		Hexane, 2,3-dimethyl-	7436	000584-94-1	91
		Hexane, 2,3-dimethyl-	7444	000584-94-1	90
		Pentane, 3-ethyl-	3395	000617-78-7	73

15 3.810 6.02 C:\Database\NIST05a.L
		Heptane, 2-methyl-	7425	000592-27-8	96
		Heptane, 2-methyl-	7428	000592-27-8	95
		Heptane, 2-methyl-	7433	000592-27-8	95

16 3.962 37.04 C:\Database\NIST05a.L
		Toluene	2400	000108-88-3	95
		Toluene	2395	000108-88-3	93
		Toluene	2396	000108-88-3	90

17 4.198 11.25 C:\Database\NIST05a.L
		1,3-Dimethylcyclohexane,c&t	6577	000591-21-9	94
		Cyclohexane, 1,3-dimethyl-, cis-	6630	000638-04-0	94
		Cyclohexane, 1,3-dimethyl-, cis-	6632	000638-04-0	94

18 4.259 4.60 C:\Database\NIST05a.L
		Cyclohexane, 1,4-dimethyl-, trans-	6640	002207-04-7	95
		Cyclohexane, 1,4-dimethyl-	6558	000589-90-2	95
		Cyclohexane, 1,4-dimethyl-, trans-	6637	002207-04-7	95

19 4.389 2.31 C:\Database\NIST05a.L
		Cyclohexane, 1,1-dimethyl-	6569	000590-66-9	81
		Cyclohexane, 1,1-dimethyl-	6568	000590-66-9	81
		Cyclohexane, 1,1-dimethyl-	6561	000590-66-9	81

20 4.462 1.46 C:\Database\NIST05a.L
		Cyclopentane, 1-ethyl-2-methyl-	6616	003726-46-3	94
		Cyclopentane, 1-ethyl-2-methyl-, cis-	6649	000930-89-2	94
		Cyclopentane, 1-ethyl-2-methyl-, cis-	6647	000930-89-2	94

21 4.630 10.36 C:\Database\NIST05a.L
		Octane	7421	000111-65-9	91
		Octane	7419	000111-65-9	81
		Heptane, 2,4-dimethyl-	12289	002213-23-2	73

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Acq On   : 19 Dec 2011 13:01

Sample   : 3100.4 (vp)
Data File : syazaila 104.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7.M
Misc   :
Operator : mohdfab

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 2.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.997	0.17	C:\Database\NIST05a.L			
			sec-Butylamine	738	013952-84-6	7
			1-Octanamine, N-methyl-	19634	002439-54-5	5
			Benzenepropanoic acid, .alpha.-(1-	51987	139344-69-7	5
			aminoethyl)-, [R-(R*,R*)]-			
2	1.351	0.21	C:\Database\NIST05a.L			
			Methylene Chloride	1498	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
3	2.193	0.24	C:\Database\NIST05a.L			
			Benzene	1001	000071-43-2	93
			Benzene	998	000071-43-2	86
			1,3-Hexadien-5-yne	1010	010420-90-3	62
4	2.289	0.14	C:\Database\NIST05a.L			
			Hexane, 3-methyl-	3891	000589-34-4	80
			Pentane, 3-ethyl-	3889	000617-78-7	72
			Pentane, 3-ethyl-	3895	000617-78-7	72
5	2.474	0.24	C:\Database\NIST05a.L			
			Cyclopentane, 1,2-dimethyl-, cis-	3340	001192-18-3	95
			Cyclopentane, 1,3-dimethyl-	3325	002453-00-1	78
			Cyclopentane, 1,3-dimethyl-, trans	3347	001759-58-6	78
6	2.614	0.76	C:\Database\NIST05a.L			
			Heptane	3886	000142-82-5	74
			Heptane	3884	000142-82-5	59
			Heptane	3887	000142-82-5	53
7	2.929	0.13	C:\Database\NIST05a.L			
			Hexane, 2,2-dimethyl-	7452	000590-73-8	78
			Hexane, 2,2-dimethyl-	7450	000590-73-8	78
			Pentane, 2,2,4-trimethyl-	7464	000540-84-1	78
8	3.075	9.77	C:\Database\NIST05a.L			
			Cyclohexane, methyl-	3273	000108-87-2	95
			Cyclohexane, methyl-	3269	000108-87-2	95
			Cyclohexane, methyl-	3271	000108-87-2	94
9	3.243	0.65	C:\Database\NIST05a.L			
			Cyclopentane, ethyl-	3268	001640-89-7	96
			Cyclopentane, ethyl-	3272	001640-89-7	94
			Cyclopentane, 1,3-dimethyl-	3323	002453-00-1	46
10	3.344	0.43	C:\Database\NIST05a.L			
			Cyclopentane, 1,2,4-trimethyl-	6612	002815-58-9	91
			Cyclopentane, 1,2,4-trimethyl-, (1	6652	016883-48-0	91

150

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                    .alpha.,2.beta.,4.alpha.)-
                    Cyclopentane, 1,2,4-trimethyl-         6615 002815-56-9 91

11   3.496  0.76 C:\Database\NIST05a.L
                    Cyclopentane, 1,2,3-trimethyl-, (1    6655 015890-40-1 94
                    .alpha.,2.alpha.,3.beta.)-
                    Cyclopentane, 1,2,3-trimethyl-, (1    6654 015890-40-1 93
                    .alpha.,2.alpha.,3.beta.)-
                    Cyclopentane, 1,2,3-trimethyl-         6612 002815-57-8 72

12   3.692  0.89 C:\Database\NIST05a.L
                    Hexane, 2,3-dimethyl-                  7444 000584-94-1 94
                    Hexane, 2,3-dimethyl-                  7436 000584-94-1 91
                    Octane, 4,5-dimethyl-                 18515 015869-96-2 83

13   3.810  8.27 C:\Database\NIST05a.L
                    Heptane, 2-methyl-                     7425 000592-27-8 96
                    Heptane, 2-methyl-                     7428 000592-27-8 95
                    Heptane, 2-methyl-                     7433 000592-27-8 95

14   3.900  0.26 C:\Database\NIST05a.L
                    Hexane, 3,4-dimethyl-                  7448 000583-48-2 94
                    Hexane, 3,4-dimethyl-                  7437 000583-48-2 91
                    Hexane, 3,4-dimethyl-                  7447 000583-48-2 78

15   3.963 34.71 C:\Database\NIST05a.L
                    Toluene                                2400 000108-88-3 94
                    Toluene                                2395 000108-88-3 93
                    Toluene                                2397 000108-88-3 93

16   4.080  0.13 C:\Database\NIST05a.L
                    Undecane, 3-methylene-                35008 071138-64-2  9
                    Cyclobutane, 1,1,2,3,3-pentamethyl    11261 057905-86-9  9
                    Cyclopentane, 1,2,3-trimethyl-, (1    6658 002613-69-6  9
                    .alpha.,2.alpha.,3.alpha.)-

17   4.195 14.00 C:\Database\NIST05a.L
                    1,3-Dimethylcyclohexane,c&t            6577 000591-21-9 94
                    Cyclohexane, 1,3-dimethyl-, cis-       6632 000638-04-0 94
                    Cyclohexane, 1,3-dimethyl-, cis-       6630 000638-04-0 91

18   4.260  5.56 C:\Database\NIST05a.L
                    Cyclohexane, 1,4-dimethyl-             6558 000589-90-2 96
                    Cyclohexane, 1,4-dimethyl-, trans-     6637 002207-04-7 95
                    Cyclohexane, 1,4-dimethyl-, trans-     6640 002207-04-7 95

19   4.394  2.91 C:\Database\NIST05a.L
                    Cycloheptane, methyl-                  6507 004126-78-7 81
                    Cyclohexane, 1,1-dimethyl-             6569 000590-66-9 81
                    Cyclohexane, 1,1-dimethyl-             6561 000590-66-9 81

20   4.462  2.00 C:\Database\NIST05a.L
                    Cyclopentane, 1-ethyl-2-methyl-        6616 003726-46-3 94
                    Cyclopentane, 1-ethyl-2-methyl-, c    6647 000930-89-2 94
                    is-
                    Cyclohexane, ethyl-                    6483 001678-91-7 55

21   4.563  0.23 C:\Database\NIST05a.L
                    Cyclopentane, 1-ethyl-1-methyl-        6619 016747-50-5 94
                    Cyclopentane, 1-ethyl-1-methyl-        6620 016747-50-5 78
                    Hexane, 1-bromo-6-chloro-             56066 006294-17-3 59

22   4.636 17.55 C:\Database\NIST05a.L
                    Octane                                 7421 000111-65-9 91
                    Octane                                 7419 000111-65-9 81
                    Heptane, 2,4-dimethyl-               12289 002213-23-2 78
```

Acq On   : 2 Apr 2012 15:07

Sample   : D-100-1 L
Data File : SYAZAILA85.D
Data Path : C:\medchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (ii).M
Misc   : UP TO C 7
Operator   : HASBULLAH

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 5

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	1.031	0.08	C:\Database\NIST05a.L			
			Benzenepropanoic acid, .alpha.-(1-aminoethyl)-, [R-(R*,R*)]-	51987	139344-69-7	9
			Pyridine-3-carboxamide, 1,2-dihydro-4,6-dimethyl-2-thioxo-	44969	079927-21-2	9
			4-Thia-1-azabicyclo[3.2.0]heptane-2-carboxylic acid, 6-amino-3,3-dimethyl-7-oxo-, [2S-(2.alpha.,5.alpha.,6.beta.)]-	68782	000551-16-6	9
2	1.211	0.52	C:\Database\NIST05a.L			
			Butane, 2-methyl-	700	000078-78-4	95
			Butane, 2-methyl-	698	000078-78-4	91
			Butane, 2-methyl-	699	000078-78-4	91
3	1.267	2.00	C:\Database\NIST05a.L			
			Acetone	212	000067-64-1	80
			Manganese(II) acetate	38574	006156-78-1	64
			Acetone	209	000067-64-1	59
4	1.402	6.54	C:\Database\NIST05a.L			
			Methylene Chloride	1499	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
5	1.497	1.91	C:\Database\NIST05a.L			
			Pentane, 2-methyl-	1795	000107-83-5	91
			Pentane, 2-methyl-	1792	000107-83-5	91
			Butane, 2,3-dimethyl-	1801	000079-29-8	56
6	1.576	0.92	C:\Database\NIST05a.L			
			Pentane, 3-methyl-	1794	000096-14-0	90
			Pentane, 3-methyl-	1796	000096-14-0	83
			Pentane, 3-ethyl-2,2-dimethyl-	12349	016747-32-3	83
7	1.666	2.34	C:\Database\NIST05a.L			
			Hexane	1790	000110-54-3	91
			Hexane	1791	000110-54-3	91
			Hexane	1792	000110-54-3	90
8	1.834	0.16	C:\Database\NIST05a.L			
			Pentane, 2,2-dimethyl-	3910	000590-35-2	90
			Pentane, 2,2-dimethyl-	3908	000590-35-2	83
			Pentane, 2,2-dimethyl-	3900	000590-35-2	83
9	1.873	0.19	C:\Database\NIST05a.L			
			Pentane, 2,4-dimethyl-	3897	000108-08-7	87
			Pentane, 2,4-dimethyl-	3902	000108-08-7	87
			Pentane, 2,4-dimethyl-	3903	000108-08-7	64

```
10    1.913   1.95 C:\Database\NIST05a.L
              Cyclopentane, methyl-                       1468 000096-37-7 87
              Cyclopentane, methyl-                       1465 000096-37-7 78
              Propane, 2-cyclopropyl-                     1479 003638-35-5 64

11    1.963   0.06 C:\Database\NIST05a.L
              Carbonic acid, isobutyl isohexyl e          58227 1000314-60-3 78
              ster
              Pentane, 2,2-dimethyl-                      3908 000590-35-2 64
              Butane, 2,2,3-trimethyl-                    3911 000464-06-2 56

12    2.154   0.19 C:\Database\NIST05a.L
              Pentane, 3,3-dimethyl-                      3905 000562-49-2 78
              Pentane, 3,3-dimethyl-                      3904 000562-49-2 78
              Pentane, 3,3-dimethyl-                      3898 000562-49-2 72

13    2.266   7.84 C:\Database\NIST05a.L
              Benzene                                      998 000071-43-2 96
              Benzene                                     1000 000071-43-2 93
              Benzene                                      999 000071-43-2 64

14    2.368   2.44 C:\Database\NIST05a.L
              Hexane, 3-methyl-                           3894 000589-34-4 95
              Hexane, 3-methyl-                           3891 000589-34-4 95
              Hexane, 3-methyl-                           3888 000589-34-4 90

15    2.514   0.82 C:\Database\NIST05a.L
              Cyclopentane, 1,3-dimethyl-                 3325 002453-00-1 96
              Cyclopentane, 1,3-dimethyl-, cis-           3336 002532-58-3 90
              Cyclopentane, 1,2-dimethyl-, cis-           3340 001192-18-3 76

16    2.558   0.56 C:\Database\NIST05a.L
              Cyclopentane, 1,3-dimethyl-, cis-           3338 002532-58-3 97
              Cyclopentane, 1,2-dimethyl-, cis-           3340 001192-18-3 97
              Cyclopentane, 1,3-dimethyl-                 3325 002453-00-1 96

17    2.595   1.05 C:\Database\NIST05a.L
              Cyclopentane, 1,2-dimethyl-, trans          3346 000822-50-4 96
              Isopropylcyclobutane                        3267 000872-56-0 95
              Cyclopentane, 1,2-dimethyl-                 3322 002452-99-5 95

18    2.704   6.20 C:\Database\NIST05a.L
              Heptane                                     3885 000142-82-5 96
              Heptane                                     3886 000142-82-5 94
              Heptane                                     3887 000142-82-5 93

19    3.019   0.22 C:\Database\NIST05a.L
              Butane, 2,2,3,3-tetramethyl-                7472 000594-82-1 90
              Hexane, 2,2-dimethyl-                       7452 000590-73-8 83
              Butane, 2,2,3,3-tetramethyl-                7473 000594-82-1 78

20    3.271  16.84 C:\Database\NIST05a.L
              Cyclohexane, methyl-                        3273 000108-87-2 97
              Cyclohexane, methyl-                        3269 000108-87-2 96
              Cyclohexane, methyl-                        3271 000108-87-2 95

21    3.345   0.73 C:\Database\NIST05a.L
              Cyclopentane, ethyl-                        3268 001640-89-7 96
              Cyclopentane, ethyl-                        3272 001640-89-7 94
              Cyclopentane, 1,3-dimethyl-                 3323 002453-00-1 46

22    3.412   0.08 C:\Database\NIST05a.L
              Hexane, 3,3-dimethyl-                       7446 000563-16-6 78
              Hexane, 3,3-dimethyl-                       7445 000563-16-6 72
              Pentane, 2,3,4-trimethyl-                   7459 000565-75-3 50
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23   3.446   0.42   C:\Database\NIST05a.L
                    Cyclopentane, 1,2,4-trimethyl-, (1    6652 016883-48-9 91
                    .alpha.,2.beta.,4.alpha.)-
                    Cyclopentane, 1,2,4-trimethyl-, (1    6653 004850-28-6 91
                    .alpha.,2.alpha.,4.beta.)-
                    Cyclopentane, 1,2,4-trimethyl-         6615 002815-58-9 91

24   3.597   0.65   C:\Database\NIST05a.L
                    Cyclopentane, 1,2,3-trimethyl-, (1    6654 015890-40-1 94
                    .alpha.,2.alpha.,3.beta.)-
                    Cyclopentane, 1,2,3-trimethyl-, (1    6655 015890-40-1 86
                    .alpha.,2.alpha.,3.beta.)-
                    1-Heptene, 3-methyl-                   6489 004810-09-7 83

25   3.794   0.53   C:\Database\NIST05a.L
                    Hexane, 2,3-dimethyl-                  7444 000584-94-1 93
                    Hexane, 2,3-dimethyl-                  7436 000584-94-1 91
                    Hexane, 2,3-dimethyl-                  7452 000584-94-1 81

26   3.923   5.04   C:\Database\NIST05a.L
                    Heptane, 2-methyl-                     7433 000592-27-8 96
                    Heptane, 2-methyl-                     7425 000592-27-8 96
                    Heptane, 2-methyl-                     7428 000592-27-8 95

27   4.013   0.11   C:\Database\NIST05a.L
                    Hexane, 3,4-dimethyl-                  7437 000583-48-2 91
                    Hexane, 3,4-dimethyl-                  7447 000583-48-2 86
                    Hexane, 3,4-dimethyl-                  7446 000583-48-2 47

28   4.075  19.74   C:\Database\NIST05a.L
                    Toluene                                2400 000108-88-3 97
                    Toluene                                2395 000108-88-3 94
                    Toluene                                2397 000108-88-3 91

29   4.187   0.07   C:\Database\NIST05a.L
                    Cyclopentane, 1,2,4-trimethyl-         6615 002815-58-9 87
                    Cyclopentane, 1,2,4-trimethyl-, (1    6653 004850-28-6 87
                    .alpha.,2.alpha.,4.beta.)-
                    Cyclopentane, 1,2,3-trimethyl-, (1    6658 002613-69-6 72
                    .alpha.,2.alpha.,3.alpha.)-

30   4.310   5.69   C:\Database\NIST05a.L
                    1,3-Dimethylcyclohexane,c&t            6577 000591-21-9 96
                    Cyclohexane, 1,3-dimethyl-, cis-       6631 000638-04-0 96
                    Cyclohexane, 1,3-dimethyl-, cis-       6632 000638-04-0 96

31   4.378   2.06   C:\Database\NIST05a.L
                    Cyclohexane, 1,4-dimethyl-             6558 000589-90-2 96
                    Cyclohexane, 1,3-dimethyl-, trans-     6639 002207-03-6 95
                    Cyclohexane, 1,4-dimethyl-, trans-     6640 002207-04-7 95

32   4.507   1.17   C:\Database\NIST05a.L
                    Cyclohexane, 1,1-dimethyl-             6569 000590-66-9 81
                    Cyclohexane, 1,1-dimethyl-             6561 000590-66-9 81
                    Cyclohexane, 1,1-dimethyl-             6568 000590-66-9 81

33   4.580   0.64   C:\Database\NIST05a.L
                    Cyclopentane, 1-ethyl-2-methyl-        6616 003726-46-3 94
                    Cyclopentane, 1-ethyl-2-methyl-, c     6649 000930-89-2 94
                    is-
                    Cyclopentane, 1-ethyl-2-methyl-, c     6650 000930-89-2 94
                    is-

34   4.748  10.26   C:\Database\NIST05a.L
                    Octane                                 7419 000111-65-9 94
                    Octane                                 7421 000111-65-9 87
                    Heptane, 2,4-dimethyl-                12302 002213-23-2 81
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Acq On   : 26 Feb 2012 13:11

Sample   : DULANG'S OIL 100.1 (VP)
Data File   : SYAZAILA25.D
Data Path   : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (II).M
Misc   : UP TO C 7
Operator   : HASBULLAH

Search Libraries: C:\Database\NIST08.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.318	0.06	C:\Database\NIST08.L			
			Carbamic acid, (cyanoacetyl)-, ethyl ester	28137	006629-04-5	9
			Acetonitrile, hydroxy-	192	000107-16-4	9
			Hydroperoxide, pentyl	4716	000074-80-6	9
2	0.997	0.03	C:\Database\NIST08.L			
			Dimethyl-(6-methyl-2-thioxo-[1,3,2]oxathiaphosphinan-2-yl)-amine	68022	139575-19-2	9
			Ethanamine, N,N-difluoro-	1102	000758-18-9	7
			dl-3-Aminoisobutyric acid, N-methyl-, methyl ester	13767	1000332-87-9	7
3	1.031	0.03	C:\Database\NIST08.L			
			Ammonia	6	007664-41-7	2
			Water	7	007732-18-5	1
4	1.604	0.10	C:\Database\NIST08.L			
			Hexane	1812	000110-54-3	95
			Hexane	1811	000110-54-3	91
			Hexane	1813	000110-54-3	83
5	1.767	0.05	C:\Database\NIST08.L			
			Pentane, 2,2-dimethyl-	3966	000590-35-2	90
			Pentane, 2,2-dimethyl-	3964	000590-35-2	83
			Pentane, 2,2-dimethyl-	3965	000590-35-2	83
6	1.806	0.06	C:\Database\NIST08.L			
			Pentane, 2,4-dimethyl-	3953	000108-08-7	91
			Pentane, 2,4-dimethyl-	3959	000108-08-7	91
			Pentane, 2,4-dimethyl-	3958	000108-08-7	81
7	1.840	0.14	C:\Database\NIST08.L			
			Cyclopentane, methyl-	1487	000096-37-7	94
			Cyclopentane, methyl-	1486	000096-37-7	91
			Cyclohexane	1452	000110-82-7	83
8	1.890	0.02	C:\Database\NIST08.L			
			Butane, 2,2,3-trimethyl-	3969	000464-06-2	86
			Pentane, 2,2-dimethyl-	3965	000590-35-2	83
			Butane, 2,2,3-trimethyl-	3967	000464-06-2	83
9	2.075	0.07	C:\Database\NIST08.L			
			Undecane, 2,8-dimethyl-	47642	017301-25-6	73
			Pentane, 3,3-dimethyl-	3961	000562-49-2	72
			1-Butanol, 2,2-dimethyl-	4438	001185-33-7	72
10	2.176	1.69	C:\Database\NIST08.L			
			1-Pentene, 4-methyl-	1477	000691-37-2	58

			Cyclobutanone, 2-methyl-	1425	001517-15-3	50
			Hexane, 2-methyl-	3949	000591-76-4	50
11	2.283	1.24	C:\Database\NIST08.L			
			Hexane, 3-methyl-	3950	000589-34-4	95
			Hexane, 3-methyl-	3947	000589-34-4	94
			Hexane, 3-methyl-	3944	000589-34-4	91
12	2.429	0.59	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	95
			Cyclopentane, 1,3-dimethyl-, cis-	3382	002532-58-3	91
			Cyclopentane, 1,3-dimethyl-, cis-	3377	002532-58-3	91
13	2.468	0.42	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-, cis-	3377	002532-58-3	95
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	94
			Cyclopentane, 1,3-dimethyl-, trans	3389	001759-58-6	93
14	2.508	0.84	C:\Database\NIST08.L			
			Isopropylcyclobutane	3308	000872-56-0	95
			Cyclopentane, 1,2-dimethyl-, trans	3388	000822-50-4	95
			Cyclopentane, 1,2-dimethyl-	3363	002452-99-5	95
15	2.614	6.56	C:\Database\NIST08.L			
			Heptane	3940	000142-82-5	95
			Heptane	3941	000142-82-5	91
			Heptane	3942	000142-82-5	91
16	2.777	0.03	C:\Database\NIST08.L			
			Methane	3	000074-82-8	3
			Methane	5	000074-82-8	2
			Methane	4	000074-82-8	2
17	2.923	0.42	C:\Database\NIST08.L			
			Butane, 2,2,3,3-tetramethyl-	7600	000594-82-1	83
			Hexane, 2,2-dimethyl-	7577	000590-73-8	83
			Heptane, 2,2,4,6,6-pentamethyl-	37513	013475-82-6	78
18	3.081	15.02	C:\Database\NIST08.L			
			Cyclohexane, methyl-	3312	000108-87-2	91
			Cyclohexane, methyl-	3310	000108-87-2	80
			Cyclopropane, 1,1,2,3-tetramethyl-	3383	074752-93-5	62
19	3.243	0.96	C:\Database\NIST08.L			
			Cyclopentane, ethyl-	3313	001640-89-7	95
			Cyclopentane, ethyl-	3309	001640-89-7	93
			Isoxazole	475	000288-14-2	47
20	3.305	0.14	C:\Database\NIST08.L			
			Hexane, 3,3-dimethyl-	7573	000563-16-6	90
			Hexane, 3,3-dimethyl-	7572	000563-16-6	64
			Hexane, 3,3-dimethyl-	7562	000563-16-6	64
21	3.344	0.81	C:\Database\NIST08.L			
			Cyclopentane, 1,2,4-trimethyl-, (1 .alpha.,2.beta.,4.alpha.)-	6766	016883-48-0	91
			Cyclopentane, 1,2,4-trimethyl-, (1 .alpha.,2.alpha.,4.beta.)-	6767	004850-28-6	91
			Cyclopentane, 1,2,4-trimethyl-	6729	002815-58-9	91
22	3.490	1.24	C:\Database\NIST08.L			
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6768	015890-40-1	97
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6769	015890-40-1	95
			Cyclopentane, 1,2,3-trimethyl-	6727	002815-57-8	86

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23   3.625   0.07   C:\Database\NIST08.L
             Pentane, 2,3,3-trimethyl-              7581 000560-21-4 90
             Heptane, 4-methyl-                     7558 000589-53-7 64
             Hexane, 3-methyl-                       3944 000589-34-4 64

24   3.693   1.22   C:\Database\NIST08.L
             Hexane, 2,3-dimethyl-                  7571 000584-94-1 94
             Hexane, 2,3-dimethyl-                  7563 000584-94-1 91
             Pyrrolidine                             606 000123-75-1 86

25   3.827  10.97   C:\Database\NIST08.L
             Heptane, 2-methyl-                     7560 000592-27-8 95
             Heptane, 2-methyl-                     7555 000592-27-8 91
             Heptane, 2-methyl-                     7553 000592-27-8 64

26   3.990  21.18   C:\Database\NIST08.L
             Toluene                                2432 000108-88-3 76
             Toluene                                2436 000108-88-3 70
             Toluene                                2434 000108-88-3 64

27   4.080   0.15   C:\Database\NIST08.L
             Cyclopentane, 1,3-dimethyl-, cis-      3377 002532-58-3 40
             Cyclopentane, 1,2,4-trimethyl-, (1     6766 016883-48-0 40
             .alpha.,2.beta.,4.alpha.]-
             1-Hepten-3-one                         6412 002918-13-0 12

28   4.215  10.72   C:\Database\NIST08.L
             Cyclohexane, 1,3-dimethyl-, cis-       6746 000638-04-0 94
             Cyclohexane, 1,4-dimethyl-, cis-       6742 000624-29-3 91
             1,3-Dimethylcyclohexane,c&t            6691 000591-21-9 91

29   4.271   4.06   C:\Database\NIST08.L
             Cyclohexane, 1,4-dimethyl-             6673 000589-90-2 97
             Cyclohexane, 1,4-dimethyl-, trans-     6751 002207-04-7 95
             Cyclohexane, 1,4-dimethyl-, trans-     6754 002207-04-7 95

30   4.394   2.49   C:\Database\NIST08.L
             Cyclohexane, 1,1-dimethyl-             6676 000590-66-9 81
             Cyclohexane, 1,1-dimethyl-             6682 000590-66-9 81
             Cyclohexane, 1,1-dimethyl-             6683 000590-66-9 81

31   4.462   1.50   C:\Database\NIST08.L
             Cyclopentane, 1-ethyl-2-methyl-        6730 003726-46-3 94
             Cyclopentane, 1-ethyl-2-methyl-, c     6764 000930-89-2 91
             is-
             Cyclopentane, 1-ethyl-2-methyl-, c     6761 000930-89-2 90
             is-

32   4.563   0.13   C:\Database\NIST08.L
             Cyclopentane, 1-ethyl-1-methyl-        6733 016747-50-5 95
             Cyclopentane, 1-ethyl-1-methyl-        6734 016747-50-5 86
             3-Heptene, 3-methyl-                   6607 007300-03-0 72

33   4.681  16.98   C:\Database\NIST08.L
             Octane                                 7548 000111-65-9 83
             Heptane, 2,4-dimethyl-                12559 002213-23-2 64
             Heptane, 2,4-dimethyl-                12561 002213-23-2 53
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Acq On   : 2 Apr 2012 15:48

Sample   : D-100-4 L
Data File   : SYAZAILA86.D
Data Path   : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (ii).M
Misc   : UP TO C 7
Operator   : HASBULLAH

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	1.031	0.51	C:\Database\NIST05a.L			
			Methane	5	000074-82-8	2
			Methane	4	000074-82-8	2
			Methane	8	000074-82-8	2
2	1.402	17.54	C:\Database\NIST05a.L			
			Methylene Chloride	1499	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
3	1.497	0.29	C:\Database\NIST05a.L			
			Pentane, 2-methyl-	1793	000107-83-5	83
			Pentane, 2-methyl-	1795	000107-83-5	72
			Pentane	692	000109-66-0	62
4	1.576	0.18	C:\Database\NIST05a.L			
			Pentane, 3-methyl-	1794	000096-14-0	83
			Pentane, 3-methyl-	1797	000096-14-0	80
			Pentane, 3-methyl-	1796	000096-14-0	80
5	1.665	0.45	C:\Database\NIST05a.L			
			Hexane	1791	000110-54-3	91
			Hexane	1792	000110-54-3	74
			Hexane	1790	000110-54-3	70
6	1.913	0.61	C:\Database\NIST05a.L			
			Cyclopentane, methyl-	1468	000096-37-7	91
			Cyclopentane, methyl-	1467	000096-37-7	87
			Cyclohexane	1432	000110-82-7	83
7	2.266	3.54	C:\Database\NIST05a.L			
			Cyclohexane	1433	000110-82-7	64
			Cyclohexane	1432	000110-82-7	64
			Cyclohexane	1431	000110-82-7	64
8	2.367	1.52	C:\Database\NIST05a.L			
			Hexane, 3-methyl-	3891	000589-34-4	95
			Hexane, 3-methyl-	3894	000589-34-4	91
			Hexane, 3-methyl-	3888	000589-34-4	90
9	2.513	0.54	C:\Database\NIST05a.L			
			Cyclopentane, 1,3-dimethyl-	3325	002453-00-1	96
			Cyclopentane, 1,3-dimethyl-, cis-	3336	002532-58-3	91
			Cyclopentane, 1,2-dimethyl-, cis-	3337	001192-18-3	90
10	2.558	0.37	C:\Database\NIST05a.L			
			Cyclopentane, 1,3-dimethyl-	3325	002453-00-1	95
			Cyclopentane, 1,3-dimethyl-	3323	002453-00-1	90
			Cyclopentane, 1,3-dimethyl-, cis-	3336	002532-58-3	83

158

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11    2.598   0.80 C:\Database\NIST05a.L
              Cyclopentane, 1,2-dimethyl-, trans    3346 000822-50-4 96
              Isopropylcyclobutane                  3267 000872-56-0 95
              Cyclopentane, 1,2-dimethyl-, trans    3348 000822-50-4 90

12    2.704   4.27 C:\Database\NIST05a.L
              Heptane                               3885 000142-82-5 96
              Heptane                               3886 000142-82-5 94
              Heptane                               3884 000142-82-5 87

13    3.019   0.21 C:\Database\NIST05a.L
              Hexane, 2,2-dimethyl-                 7451 000590-73-8 72
              Butane, 2,2,3,3-tetramethyl-          7474 000594-82-1 72
              Butane, 2,2,3,3-tetramethyl-          7472 000594-82-1 72

14    3.170  15.28 C:\Database\NIST05a.L
              Cyclohexane, methyl-                  3273 000108-87-2 96
              Cyclohexane, methyl-                  3269 000108-87-2 96
              Cyclohexane, methyl-                  3271 000108-87-2 95

15    3.344   0.67 C:\Database\NIST05a.L
              Cyclopentane, ethyl-                  3268 001640-89-7 96
              Cyclopentane, ethyl-                  3272 001640-89-7 95
              2-Hexene, 3-methyl-, (Z)-             3312 010574-36-4 49

16    3.446   0.51 C:\Database\NIST05a.L
              Cyclopentane, 1,2,4-trimethyl-        6615 002815-58-9 91
              Cyclopentane, 1,2,4-trimethyl-        6612 002815-58-9 91
              Cyclopentane, 1,2,4-trimethyl-, (1    6652 016883-48-0 91
              .alpha.,2.beta.,4.alpha.)-

17    3.597   0.72 C:\Database\NIST05a.L
              Cyclopentane, 1,2,3-trimethyl-, (1    6654 015890-40-1 97
              .alpha.,2.alpha.,3.beta.)-
              Cyclopentane, 1,2,3-trimethyl-, (1    6655 015890-40-1 97
              .alpha.,2.alpha.,3.beta.)-
              1-Heptene, 3-methyl-                  6489 004810-09-7 90

18    3.794   0.66 C:\Database\NIST05a.L
              Hexane, 2,3-dimethyl-                 7436 000584-94-1 91
              Heptane, 4-methyl-                    7431 000589-53-7 72
              Pyrrolidine                           593 000123-75-1 72

19    3.917   6.07 C:\Database\NIST05a.L
              Heptane, 2-methyl-                    7433 000592-27-8 95
              Heptane, 2-methyl-                    7428 000592-27-8 95
              Heptane, 2-methyl-                    7425 000592-27-8 94

20    4.074  18.41 C:\Database\NIST05a.L
              Toluene                               2400 000108-88-3 94
              Toluene                               2395 000108-88-3 93
              Toluene                               2397 000108-88-3 93

21    4.310   7.61 C:\Database\NIST05a.L
              Cyclohexane, 1,3-dimethyl-, cis-      6624 000638-04-0 97
              Cyclohexane, 1,3-dimethyl-, cis-      6632 000638-04-0 96
              Cyclohexane, 1,3-dimethyl-, cis-      6631 000638-04-0 96

22    4.378   2.73 C:\Database\NIST05a.L
              Cyclohexane, 1,4-dimethyl-, cis-      6628 000624-29-3 97
              Cyclohexane, 1,4-dimethyl-           6558 000589-90-2 96
              Cyclohexane, 1,4-dimethyl-, trans-   6640 002207-04-7 95

23    4.507   1.59 C:\Database\NIST05a.L
              Cyclohexane, 1,1-dimethyl-           6568 000590-66-9 81
              Cyclohexane, 1,1-dimethyl-           6561 000590-66-9 81
```

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Acq On   : 26 Feb 2012 11:45

Sample   : DULANG'S OIL 100.4 (VP)
Data File : SYAZAILA23.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (II).M
Misc   : UP TO C 7
Operator : HASBULLAH

Search Libraries: C:\Database\NIST08.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.565	0.06	C:\Database\NIST08.L			
			3-Butyn-1-ol	513	000927-74-2	1
2	1.031	0.24	C:\Database\NIST08.L			
			Ammonia	6	007664-41-7	3
			Water	7	007732-18-5	1
3	1.351	0.07	C:\Database\NIST08.L			
			Methylene Chloride	1516	000075-09-2	97
			Methylene Chloride	1517	000075-09-2	94
			Methylene Chloride	1519	000075-09-2	90
4	2.171	0.12	C:\Database\NIST08.L			
			Hexane, 2-methyl-	3949	000591-76-4	91
			Hexane, 2-methyl-	3948	000591-76-4	91
			Hexane, 2-methyl-	3946	000591-76-4	91
5	2.283	0.17	C:\Database\NIST08.L			
			Hexane, 3-methyl-	3944	000589-34-4	94
			Hexane, 3-methyl-	3947	000589-34-4	94
			Hexane, 3-methyl-	3950	000589-34-4	91
6	2.423	0.05	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	93
			Cyclopentane, 1,3-dimethyl-, cis-	3382	002532-58-3	87
			Cyclopentane, 1,3-dimethyl-	3364	002453-00-1	86
7	2.508	0.11	C:\Database\NIST08.L			
			Isopropylcyclobutane	3308	000872-56-0	95
			Cyclopentane, 1,2-dimethyl-, trans	3358	000822-50-4	95
			Cyclopentane, 1,2-dimethyl-	3363	002452-99-5	95
8	2.609	1.69	C:\Database\NIST08.L			
			Heptane	3942	000142-82-5	96
			Heptane	3941	000142-82-5	95
			Heptane	3943	000142-82-5	87
9	2.923	0.17	C:\Database\NIST08.L			
			Hexane, 2,2-dimethyl-	7578	000590-73-8	83
			Pentane, 2,2,4-trimethyl-	7584	000540-84-1	78
			Butane, 2,2,3,3-tetramethyl-	7601	000594-82-1	78
10	3.064	5.80	C:\Database\NIST08.L			
			Cyclohexane, methyl-	3314	000108-87-2	95
			Cyclohexane, methyl-	3312	000108-87-2	95
			Cyclohexane, methyl-	3310	000108-87-2	94
11	3.131	0.36	C:\Database\NIST08.L			
			Heptane, 3,4,5-trimethyl-	18959	020278-89-1	59

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                    Hexane, 2,4-dimethyl-                    7561 000589-43-5 53
                    Furan, tetrahydro-2,5-dimethyl-, c       3933 002144-41-4 50
                    is-

12   3.238  0.41 C:\Database\NIST08.L
                    Cyclopentane, ethyl-                     3309 001640-89-7 96
                    Cyclopentane, ethyl-                     3313 001640-89-7 94
                    Cyclopentane, 1,3-dimethyl-              3364 002453-00-1 41

13   3.305  0.11 C:\Database\NIST08.L
                    Hexane, 3,3-dimethyl-                    7573 000563-16-6 86
                    Hexane, 3,3-dimethyl-                    7562 000563-16-6 80
                    Hexane, 3,3-dimethyl-                    7572 000563-16-6 59

14   3.335  0.48 C:\Database\NIST08.L
                    Cyclopentane, 1,2,4-trimethyl-, (1       6766 016883-48-0 91
                    .alpha.,2.beta.,4.alpha.)-
                    Cyclopentane, 1,2,4-trimethyl-           6726 002815-58-9 91
                    Cyclopentane, 1,2,4-trimethyl-, (1       6767 004850-28-6 91
                    .alpha.,2.alpha.,4.beta.)-

15   3.485  0.76 C:\Database\NIST08.L
                    Cyclopentane, 1,2,3-trimethyl-, (1       6768 015890-40-1 97
                    .alpha.,2.alpha.,3.beta.)-
                    Cyclopentane, 1,2,3-trimethyl-, (1       6769 015890-40-1 95
                    .alpha.,2.alpha.,3.beta.)-
                    1-Heptene, 3-methyl-                     6605 004810-09-7 83

16   3.687  1.01 C:\Database\NIST08.L
                    Hexane, 2,3-dimethyl-                    7563 000584-94-1 91
                    Octane, 4,5-dimethyl-                   18941 015869-96-2 83
                    Pyrrolidine                               606 000123-75-1 79

17   3.810 11.52 C:\Database\NIST08.L
                    Heptane, 2-methyl-                       7560 000592-27-8 95
                    Heptane, 2-methyl-                       7553 000592-27-8 93
                    Heptane, 2-methyl-                       7555 000592-27-8 91

18   3.895  0.24 C:\Database\NIST08.L
                    Hexane, 3,4-dimethyl-                    7564 000583-48-2 91
                    Hexane, 3,4-dimethyl-                    7574 000583-48-2 91
                    Hexane, 3,4-dimethyl-                    7575 000583-48-2 90

19   3.962  0.25 C:\Database\NIST08.L
                    Toluene                                  2436 000108-88-3 94
                    Toluene                                  2431 000108-88-3 94
                    Toluene                                  2433 000108-88-3 93

20   4.069  0.06 C:\Database\NIST08.L
                    2-Azetidinone, 3,4,4-trimethyl-          6886 022607-01-8  5
                    1-Oxa-3,4-diazacyclopentadiene            494 000282-99-3  4
                    Cyclopentane, 1,3-dimethyl-, cis-        3377 002532-58-3  4

21   4.192 13.01 C:\Database\NIST08.L
                    Cyclohexane, 1,3-dimethyl-, cis-         6746 000638-04-0 94
                    1,3-Dimethylcyclohexane,c&t              6691 000591-21-9 94
                    Cyclohexane, 1,3-dimethyl-, cis-         6745 000638-04-0 94

22   4.254  4.50 C:\Database\NIST08.L
                    Cyclohexane, 1,4-dimethyl-, trans-       6751 002207-04-7 95
                    Cyclohexane, 1,4-dimethyl-               6673 000589-90-2 95
                    Cyclohexane, 1,4-dimethyl-, trans-       6754 002207-04-7 95

23   4.383  2.67 C:\Database\NIST08.L
                    Cyclohexane, 1,1-dimethyl-               6676 000590-66-9 81
                    Cyclohexane, 1,1-dimethyl-               6682 000590-66-9 81
                    Cyclohexane, 1,1-dimethyl-               6683 000590-66-9 64
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Acq On     : 31 Mar 2012  13:31

Sample     : A-100-1-L
Data File  : SYAZAILA58.D
Data Path  : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (ii).M
Misc       : UP TO C 7
Operator   : HASBULLAH

Search Libraries:   C:\Database\NIST05a.L          Minimum Quality:  50

Unknown Spectrum:   Apex minus start of peak
Integration Events: ChemStation Integrator - l.e
```

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	1.037	0.08	C:\Database\NIST05a.L			
			Acetamide, 2-cyano-	1312	000107-91-5	9
			2-Methoxy-N-methylethylamine	2171	038256-93-8	9
			1-Methyldecylamine	37095	013205-56-6	9
2	1.093	0.23	C:\Database\NIST05a.L			
			Isobutane	231	000075-28-5	72
			Isobutane	232	000075-28-5	72
			Isobutane	230	000075-28-5	59
3	1.216	1.17	C:\Database\NIST05a.L			
			Butane, 2-methyl-	700	000078-78-4	94
			Butane, 2-methyl-	698	000078-78-4	91
			Butane, 2-methyl-	699	000078-78-4	90
4	1.267	0.38	C:\Database\NIST05a.L			
			Pentane	691	000109-66-0	91
			Pentane	692	000109-66-0	91
			Pentane	695	000109-66-0	91
5	1.374	0.40	C:\Database\NIST05a.L			
			Butane, 2,2-dimethyl-	1805	000075-83-2	90
			Butane, 2,2-dimethyl-	1799	000075-83-2	83
			Butane, 2,2-dimethyl-	1803	000075-83-2	83
6	1.402	0.76	C:\Database\NIST05a.L			
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
			Methylene Chloride	1498	000075-09-2	91
7	1.497	3.33	C:\Database\NIST05a.L			
			Pentane, 2-methyl-	1795	000107-83-5	91
			Pentane, 2-methyl-	1793	000107-83-5	91
			Pentane	692	000109-66-0	58
8	1.576	1.68	C:\Database\NIST05a.L			
			Pentane, 3-methyl-	1794	000096-14-0	91
			Pentane, 3-ethyl-2,2-dimethyl-	12349	016747-32-3	83
			Pentane, 3-methyl-	1797	000096-14-0	83
9	1.666	1.73	C:\Database\NIST05a.L			
			Hexane	1791	000110-54-3	91
			Hexane	1792	000110-54-3	91
			Hexane	1790	000110-54-3	62
10	1.834	0.44	C:\Database\NIST05a.L			
			Pentane, 2,2-dimethyl-	3910	000590-35-2	90
			Butane, 2,2,3-trimethyl-	3913	000464-06-2	86
			Pentane, 2,2-dimethyl-	3900	000590-35-2	83

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11   1.873   0.52 C:\Database\NIST05a.L
                Pentane, 2,4-dimethyl-                      3897 000108-08-7 91
                Pentane, 2,4-dimethyl-                      3903 000108-08-7 91
                Pentane, 2,4-dimethyl-                      3902 000108-08-7 72

12   1.913   2.29 C:\Database\NIST05a.L
                Cyclopentane, methyl-                       1468 000096-37-7 91
                Cyclopentane, methyl-                       1465 000096-37-7 78
                1-Pentene, 2-methyl-                        1452 000763-29-1 64

13   1.963   0.21 C:\Database\NIST05a.L
                Butane, 2,2,3-trimethyl-                    3911 000464-06-2 83
                Butane, 2,2,3-trimethyl-                    3913 000464-06-2 78
                2,2,6,6-Tetramethylheptane                 27266 040117-45-1 72

14   2.154   0.50 C:\Database\NIST05a.L
                Pentane, 3,3-dimethyl-                      3904 000562-49-2 78
                Pentane, 3,3-dimethyl-                      3898 000562-49-2 78
                Pentane, 3,3-dimethyl-                      3905 000562-49-2 78

15   2.261   4.97 C:\Database\NIST05a.L
                Cyclohexane                                 1432 000110-82-7 90
                Cyclohexane                                 1433 000110-82-7 81
                Cyclohexane                                 1431 000110-82-7 74

16   2.368   1.84 C:\Database\NIST05a.L
                Pentane, 3-ethyl-                           3895 000617-78-7 87
                Hexane, 3-methyl-                           3891 000589-34-4 87
                Pentane, 3-ethyl-                           3889 000617-78-7 80

17   2.514   1.44 C:\Database\NIST05a.L
                Cyclopentane, 1,3-dimethyl-                 3325 002453-00-1 96
                Cyclopentane, 1,3-dimethyl-, cis-           3336 002532-58-3 90
                Cyclopentane, 1,2-dimethyl-, trans          3347 001759-58-6 76

18   2.558   0.81 C:\Database\NIST05a.L
                Cyclopentane, 1,2-dimethyl-, cis-           3340 001192-18-3 95
                Cyclopentane, 1,2-dimethyl-, cis-           3337 001192-18-3 95
                Cyclopentane, 1,3-dimethyl-, cis-           3338 002532-58-3 94

19   2.598   1.88 C:\Database\NIST05a.L
                Cyclopentane, 1,2-dimethyl-, trans          3346 000822-50-4 96
                Isopropylcyclobutane                        3267 000872-56-0 95
                Cyclopentane, 1,2-dimethyl-                 3322 002452-99-5 95

20   2.704  [6.20  ]:\Database\NIST05a.L
                Heptane                                     3885 000142-82-5 96
                Heptane                                     3886 000142-82-5 94
                Heptane                                     3884 000142-82-5 90

21   3.019   0.68 C:\Database\NIST05a.L
                Heptane, 2,2,4,6,6-pentamethyl-            26471 013475-82-6 78
                Hexane, 2,2-dimethyl-                       7452 000590-73-8 78
                Pentane, 2,2,4-trimethyl-                   7457 000540-84-1 78

22   3.171  [20.63 ]:\Database\NIST05a.L
                Cyclohexane, methyl-                        3273 000108-87-2 97
                Cyclohexane, methyl-                        3269 000108-87-2 96
                Cyclohexane, methyl-                        3271 000108-87-2 95

23   3.345   0.83 C:\Database\NIST05a.L
                Cyclopentane, ethyl-                        3268 001640-89-7 97
                Cyclopentane, ethyl-                        3272 001640-89-7 94
                2-Hexene, 4-methyl-, (E)-                   3306 003683-22-5 41

24   3.413   0.21 C:\Database\NIST05a.L
```

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Acq On   : 26 Feb 2012 12:22

Sample   : ANGSI'S OIL 100.1 (V2)
Data File : SYAZAILA24.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (II).M
Misc   : UP TO C 7
Operator   : HASBULLAH

Search Libraries: C:\Database\NIST08.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.442	0.19	C:\Database\NIST08.L			
			2,5-Furandione, dihydro-3-methylene-	6196	002170-03-8	2
			1,2,5-Oxadiazole	493	000288-37-9	1
			2-Ethoxypyrazine	10208	038028-67-0	1
2	0.997	0.02	C:\Database\NIST08.L			
			L-Alanine, methyl ester	4520	010065-72-2	32
			DL-Cystine	90484	000923-32-0	10
			2-Pentanamine	1894	000625-30-9	9
3	1.031	0.05	C:\Database\NIST08.L			
			Ammonia	6	007664-41-7	2
			Water	7	007732-18-5	1
4	1.800	0.02	C:\Database\NIST08.L			
			Pentane, 2,4-dimethyl-	3953	000108-08-7	91
			Pentane, 2,4-dimethyl-	3958	000108-08-7	81
			Oxalic acid, isobutyl hexyl ester	82427	1000309-37-1	59
5	2.076	0.07	C:\Database\NIST08.L			
			Pentane, 3,3-dimethyl-	3961	000562-49-2	83
			1-Hexene, 3,4,5-trimethyl-	11438	056728-10-0	64
			Pentane, 3,3-dimethyl-	3960	000562-49-2	64
6	2.171	0.74	C:\Database\NIST08.L			
			Hexane, 2-methyl-	3946	000591-76-4	90
			Hexane, 2-methyl-	3948	000591-76-4	90
			Hexane, 2-methyl-	3949	000591-76-4	90
7	2.283	0.87	C:\Database\NIST08.L			
			Hexane, 3-methyl-	3950	000589-34-4	95
			Hexane, 3-methyl-	3944	000589-34-4	94
			Hexane, 3-methyl-	3947	000589-34-4	94
8	2.429	0.32	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-, cis-	3377	002532-58-3	93
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	91
			Cyclopentane, 1,3-dimethyl-, trans	3389	001759-58-6	70
9	2.469	0.21	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-, cis-	3379	002532-58-3	97
			Cyclopentane, 1,3-dimethyl-, cis-	3377	002532-58-3	95
			Cyclopentane, 1,2-dimethyl-, cis-	3378	001192-18-3	94
10	2.508	0.52	C:\Database\NIST08.L			
			Cyclopentane, 1,2-dimethyl-, trans	3388	000822-50-4	96
			Isopropylcyclobutane	3308	000872-56-0	95
			Cyclopentane, 1,2-dimethyl-	3363	002452-99-5	95

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11	2.609	3.73	C:\Database\NIST08.L		
			Heptane	3942	000142-82-5 95
			Heptane	3941	000142-82-5 94
			Heptane	3940	000142-82-5 94
12	2.923	0.83	C:\Database\NIST08.L		
			Butane, 2,2,3,3-tetramethyl-	7600	000594-82-1 83
			Hexane, 2,2-dimethyl-	7577	000590-73-8 83
			Pentane, 2,2,4-trimethyl-	7591	000540-84-1 83
13	3.069	11.25	C:\Database\NIST08.L		
			Cyclohexane, methyl-	3312	000108-87-2 96
			Cyclohexane, methyl-	3314	000108-87-2 95
			Cyclohexane, methyl-	3310	000108-87-2 95
14	3.131	1.22	C:\Database\NIST08.L		
			Hexane, 2,4-dimethyl-	7570	000589-43-5 90
			Hexane, 2,4-dimethyl-	7569	000589-43-5 83
			Heptane, 3-methyl-	7552	000589-81-1 58
15	3.187	0.06	C:\Database\NIST08.L		
			Pentane, 2,2,4-trimethyl-	7592	000540-84-1 72
			Pentane, 2,2,3-trimethyl-	7590	000564-02-3 72
			Undecane, 2,2-dimethyl-	47669	017312-64-0 56
16	3.236	0.61	C:\Database\NIST08.L		
			Cyclopentane, ethyl-	3309	001640-89-7 95
			3-Hexene, 2-methyl-, (E)-	3353	000692-24-0 55
			Cyclopentanone, 3-methyl-	3201	001757-42-2 46
17	3.305	0.40	C:\Database\NIST08.L		
			Hexane, 3,3-dimethyl-	7573	000563-16-6 86
			Hexane, 3,3-dimethyl-	7562	000563-16-6 64
			Hexane, 3,3-dimethyl-	7572	000563-16-6 64
18	3.339	1.05	C:\Database\NIST08.L		
			Cyclopentane, 1,2,4-trimethyl-	6729	002815-58-9 91
			Cyclopentane, 1,2,4-trimethyl-, (1 .alpha.,2.beta.,4.alpha.)-	6766	016883-48-0 91
			Cyclopentane, 1,2,4-trimethyl-	6726	002815-58-9 91
19	3.491	1.89	C:\Database\NIST08.L		
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6768	015890-40-1 96
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6769	015890-40-1 94
			1-Heptene, 3-methyl-	6605	004810-09-7 87
20	3.625	0.12	C:\Database\NIST08.L		
			Heptane, 3,3,4-trimethyl-	18958	020278-87-9 64
			Pentane, 2,3,3-trimethyl-	7581	000560-21-4 64
			Hexane, 3,3-dimethyl-	7572	000563-16-6 64
21	3.687	2.28	C:\Database\NIST08.L		
			Hexane, 2,3-dimethyl-	7571	000584-94-1 94
			Hexane, 2,3-dimethyl-	7563	000584-94-1 91
			Pyrrolidine	606	000123-75-1 86
22	3.822	16.36	C:\Database\NIST08.L		
			Heptane, 2-methyl-	7560	000592-27-8 95
			Heptane, 2-methyl-	7555	000592-27-8 91
			Heptane, 2-methyl-	7553	000592-27-8 83
23	3.901	0.61	C:\Database\NIST08.L		
			Hexane, 3,4-dimethyl-	7564	000583-48-2 91
			Hexane, 3,4-dimethyl-	7574	000583-48-2 91

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Acq On   : 1 Apr 2012 11:23

Sample   : A-10G-4-L
Data File : SYAZAILA66.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syazaila\
DataAcq Meth:UP TO C7 (ii).M
Misc   : UP TO C 7
Operator : HASBULLAH

Search Libraries: C:\Database\NIST05a.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	1.037	0.06	C:\Database\NIST05a.L			
			2-Amino-1-(o-methoxyphenyl)propane	32745	015402-84-3	9
			Cyclohexanol, 2-(methylaminomethyl)-, trans-	19618	077612-16-9	9
			Acetamide, 2,2,2-trichloro-	30223	000594-65-0	9
2	1.070	0.24	C:\Database\NIST05a.L			
			Ammonia	6	007664-41-7	2
			Water	7	007732-18-5	1
3	1.402	20.23	C:\Database\NIST05a.L			
			Methylene Chloride	1499	000075-09-2	95
			Methylene Chloride	1497	000075-09-2	94
			Methylene Chloride	1500	000075-09-2	91
4	1.497	1.39	C:\Database\NIST05a.L			
			Pentane, 2-methyl-	1795	000107-83-5	91
			Pentane, 2-methyl-	1793	000107-83-5	80
			Pentane	694	000109-66-0	59
5	1.576	0.78	C:\Database\NIST05a.L			
			Pentane, 3-methyl-	1794	000096-14-0	90
			Pentane, 3-methyl-	1796	000096-14-0	83
			Pentane, 3-methyl-	1797	000096-14-0	83
6	1.666	0.85	C:\Database\NIST05a.L			
			Hexane	1791	000110-54-3	91
			Hexane	1790	000110-54-3	90
			Hexane	1792	000110-54-3	90
7	1.834	0.25	C:\Database\NIST05a.L			
			Pentane, 2,2-dimethyl-	3910	000590-35-2	90
			Pentane, 2,2-dimethyl-	3908	000590-35-2	83
			Butane, 2,2,3-trimethyl-	3911	000464-06-2	83
8	1.873	0.32	C:\Database\NIST05a.L			
			Pentane, 2,4-dimethyl-	3897	000108-08-7	90
			Pentane, 2,4-dimethyl-	3902	000108-08-7	83
			Pentane, 2,4-dimethyl-	3903	000108-08-7	83
9	1.913	1.38	C:\Database\NIST05a.L			
			Cyclopentane, methyl-	1468	000096-37-7	87
			Cyclopropane, propyl-	1464	002415-72-7	64
			Cyclobutane, ethyl-	1445	004806-61-5	64
10	1.963	0.14	C:\Database\NIST05a.L			
			Butane, 2,2,3-trimethyl-	3913	000464-06-2	72
			Hexane	1791	000110-54-3	72
			Pentane, 2,2-dimethyl-	3910	000590-35-2	72

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11    2.154   0.35 C:\Database\NIST05a.L
                Pentane, 3,3-dimethyl-                        3904 000562-49-2 90
                Pentane, 3,3-dimethyl-                        3905 000562-49-2 90
                Sulfurous acid, isobutyl 2-pentyl           63344 1000309-15-2 64
                ester

12    2.261   9.19 C:\Database\NIST05a.L
                Cyclohexane                                  1432 000110-82-7 87
                Cyclohexane                                  1433 000110-82-7 81
                Cyclohexane                                  1430 000110-82-7 74

13    2.367   1.42 C:\Database\NIST05a.L
                Pentane, 3-ethyl-                            3895 000617-78-7 90
                Hexane, 3-methyl-                            3894 000589-34-4 87
                Pentane, 3-ethyl-                            3889 000617-78-7 86

14    2.513   1.03 C:\Database\NIST05a.L
                Cyclopentane, 1,2-dimethyl-                  3325 002453-00-1 96
                Cyclopentane, 1,3-dimethyl-, cis-            3336 002532-58-3 83
                Cyclopentane, 1,3-dimethyl-, trans           3347 001759-58-6 76

15    2.558   0.62 C:\Database\NIST05a.L
                Cyclopentane, 1,2-dimethyl-, cis-            3340 001192-18-3 95
                Cyclopentane, 1,3-dimethyl-                  3325 002453-00-1 93
                Cyclopentane, 1,2-dimethyl-, cis-            3339 001192-18-3 91

16    2.598   1.49 C:\Database\NIST05a.L
                Cyclopentane, 1,2-dimethyl-, trans           3346 000822-50-4 96
                Isopropylcyclobutane                         3267 000872-56-0 95
                Cyclopentane, 1,2-dimethyl-                  3322 002452-99-5 95

17    2.704   4.31 C:\Database\NIST05a.L
                Heptane                                      3885 000142-82-5 96
                Heptane                                      3886 000142-82-5 94
                Heptane                                      3887 000142-82-5 93

18    3.019   0.56 C:\Database\NIST05a.L
                Hexane, 2,2-dimethyl-                        7450 000590-73-8 90
                Butane, 2,2,3,3-tetramethyl-                 7472 000594-82-1 90
                Butane, 2,2,3,3-tetramethyl-                 7473 000594-82-1 83

19    3.170  17.40 C:\Database\NIST05a.L
                Cyclohexane, methyl-                         3273 000108-87-2 97
                Cyclohexane, methyl-                         3269 000108-87-2 96
                Cyclohexane, methyl-                         3271 000108-87-2 95

20    3.232   0.76 C:\Database\NIST05a.L
                Heptane, 3,4,5-trimethyl-                   18533 020278-89-1 78
                Hexane, 2,4-dimethyl-                        7443 000589-43-5 78
                Oxalic acid, diisohexyl ester              97255 1000309-32-9 59

21    3.345   0.69 C:\Database\NIST05a.L
                Cyclopentane, ethyl-                         3268 001640-89-7 97
                Cyclopentane, ethyl-                         3272 001640-89-7 94
                2-Hexene, 3-methyl-, (Z)-                    3312 010574-36-4 45

22    3.412   0.19 C:\Database\NIST05a.L
                Hexane, 3,3-dimethyl-                        7435 000563-16-6 86
                Hexane, 3,3-dimethyl-                        7445 000563-16-6 86
                Hexane, 3,3-dimethyl-                        7446 000563-16-6 86

23    3.446   0.81 C:\Database\NIST05a.L
                Cyclopentane, 1,2,4-trimethyl-, (1           6653 004850-28-6 91
                .alpha.,2.alpha.,4.beta.)-
                Cyclopentane, 1,2,4-trimethyl-, (1           6652 016883-48-0 91
                .alpha.,2.beta.,4.alpha.)-
```

Acq On   : 25 Feb 2012 17:14

Sample   : ANGSI'S OIL 100.4 (VP)
Data File : SYA2AILA17.D
Data Path : C:\msdchem\CAL 2010\DATA\2011\PG\syaaaila\
DataAcq Meth:UP TO C7 (II).M
Misc   : UP TO C 7
Operator : HASBULLAH

Search Libraries: C:\Database\NIST08.L   Minimum Quality: 50

Unknown Spectrum: Apex minus start of peak
Integration Events: ChemStation Integrator - 1.e

Pk#	RT	Area%	Library/ID	Ref#	CAS#	Qual
1	0.441	0.15	C:\Database\NIST08.L			
			Propanal, 2,2-dimethyl-, oxime	4082	000637-91-2	1
			1,2,5-Oxadiazole	492	000288-37-9	1
2	0.666	0.03	C:\Database\NIST08.L			
			Hydrogen sulfide	40	007783-06-4	3
			Methane	5	000074-82-8	2
			Methane	4	000074-82-8	2
3	1.031	0.09	C:\Database\NIST08.L			
			Ammonia	6	007664-41-7	2
			Water	7	007732-18-5	1
4	1.211	0.03	C:\Database\NIST08.L			
			Methane, diazo-	63	000334-88-3	1
			Diazirine	61	1000305-84-1	1
			Ketene	55	000463-51-4	1
5	1.609	0.02	C:\Database\NIST08.L			
			Hexane	1812	000110-54-3	35
			Oxetane, 2,2-dimethyl-	1761	006245-99-4	25
			Ethane-1,2-diimine, N,N'-diamino-	1590	1000197-11-5	23
6	2.076	0.04	C:\Database\NIST08.L			
			Pentane, 3,3-dimethyl-	3961	000562-49-2	83
			Pentane, 3,3-dimethyl-	3954	000562-49-2	83
			Octane, 2,6,6-trimethyl-	27940	054166-32-4	72
7	2.171	0.56	C:\Database\NIST08.L			
			Hexane, 2-methyl-	3948	000591-76-4	91
			Hexane, 2-methyl-	3949	000591-76-4	91
			Hexane, 2-methyl-	3946	000591-76-4	91
8	2.222	0.16	C:\Database\NIST08.L			
			Pentane, 2,3-dimethyl-	3963	000565-59-3	94
			Pentane, 2,3-dimethyl-	3955	000565-59-3	91
			Pentane, 2,3-dimethyl-	3962	000565-59-3	91
9	2.283	0.87	C:\Database\NIST08.L			
			Hexane, 3-methyl-	3950	000589-34-4	95
			Hexane, 3-methyl-	3947	000589-34-4	95
			Hexane, 3-methyl-	3944	000589-34-4	94
10	2.429	0.26	C:\Database\NIST08.L			
			Cyclopentane, 1,3-dimethyl-, cis-	3362	002532-58-3	86
			Cyclopentane, 1,3-dimethyl-, cis-	3379	002532-58-3	64
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	62
11	2.469	0.17	C:\Database\NIST08.L			

			Cyclopentane, 1,3-dimethyl-, cis-	3377	002532-58-3	94
			Cyclopentane, 1,3-dimethyl-	3366	002453-00-1	94
			Cyclopentane, 1,2-dimethyl-, cis-	3378	001192-18-3	91
12	2.508	0.41	C:\Database\NIST08.L			
			Isopropylcyclobutane	3308	000872-56-0	95
			Cyclopentane, 1,2-dimethyl-, trans	3388	000822-50-4	95
			Cyclopentane, 1,2-dimethyl-	3363	002452-99-5	95
13	2.615	3.37	:\Database\NIST08.L			
			Heptane	3942	000142-82-5	94
			Heptane	3940	000142-82-5	91
			Heptane	3941	000142-82-5	91
14	2.761	0.03	C:\Database\NIST08.L			
			Methane	5	000074-82-8	2
			Methane	4	000074-82-8	2
			Methane	3	000074-82-8	2
15	2.923	0.71	C:\Database\NIST08.L			
			Hexane, 2,2-dimethyl-	7577	000590-73-8	83
			Butane, 2,2,3,3-tetramethyl-	7600	000594-82-1	83
			Pentane, 2,2,4-trimethyl-	7584	000540-84-1	83
16	3.075	20.26	:\Database\NIST08.L			
			Cyclohexane, methyl-	3312	000108-87-2	96
			Cyclohexane, methyl-	3314	000108-87-2	95
			Cyclohexane, methyl-	3310	000108-87-2	95
17	3.137	1.08	C:\Database\NIST08.L			
			Heptane, 3,4,5-trimethyl-	18959	020278-89-1	59
			Hexane, 2,4-dimethyl-	7570	000589-43-5	55
			Heptane, 4,4-dimethyl-	12560	001068-19-5	53
18	3.238	0.58	C:\Database\NIST08.L			
			Cyclopentane, ethyl-	3309	001640-89-7	56
			Isoxazole	475	000288-14-2	47
			Cyclopentane, ethyl-	3313	001640-89-7	43
19	3.305	0.29	C:\Database\NIST08.L			
			Hexane, 3,3-dimethyl-	7573	000563-16-6	86
			Hexane, 3,3-dimethyl-	7562	000563-16-6	80
			Heptane, 2,4-dimethyl-	12548	002213-23-2	78
20	3.345	1.01	C:\Database\NIST08.L			
			Cyclopentane, 1,2,4-trimethyl-, (1 .alpha.,2.beta.,4.alpha.)-	6766	016883-48-0	91
			Cyclopentane, 1,2,4-trimethyl-	6726	002815-58-9	91
			Cyclopentane, 1,2,4-trimethyl-, (1 .alpha.,2.alpha.,4.beta.)-	6767	004850-28-6	91
21	3.491	1.81	C:\Database\NIST08.L			
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6768	015890-40-1	95
			Cyclopentane, 1,2,3-trimethyl-, (1 .alpha.,2.alpha.,3.beta.)-	6769	015890-40-1	94
			Cyclopentane, 1,2,3-trimethyl-	6727	002815-57-8	72
22	3.625	0.10	C:\Database\NIST08.L			
			Pentane, 2,3,3-trimethyl-	7581	000560-21-4	90
			Hexane, 3,3-dimethyl-	7562	000563-16-6	72
			Hexane, 3,3-dimethyl-	7573	000563-16-6	64
23	3.693	2.23	C:\Database\NIST08.L			
			Hexane, 2,3-dimethyl-	7571	000584-94-1	94
			Hexane, 2,3-dimethyl-	7563	000584-94-1	91
			Pyrrolidine	606	000123-75-1	86