

**DESIGN OF A PLANT (USING HYSYS PROCESS SIMULATOR)
TO UTILIZE FLARE GAS IN OIL FIELDS**

BY

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2001/11573EH

**Department of Chemical Engineering,
Federal University of Technology Minna, Niger State.**

NOVEMBER, 2007.

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**A Research project submitted to the Department of Chemical
Engineering, School of Engineering and Engineering Technology,
Federal University of Technology Minna, Niger State.**

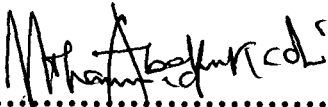
**In partial fulfillment of the Requirement for the Award of Bachelor of
Engineering (B. Eng) Degree in Chemical Engineering.**

NOVEMBER, 2007.

DECLARATION

I, Abdulkadir Mohammed A. (Reg. no 2001/11573EH), hereby declare that this project is a result of my personal research work and has not being, to my knowledge, presented elsewhere for the award of any certificate.

Information derived from published and unpublished works have been duly acknowledged.


.....

STUDENT SIGNATURE

29/11/07
.....

DATE

CERTIFICATION

This is to certify that this research project is the original work of Abdulkadir Mohammed A. (Reg. no. 2001/11573EH), carried out under my supervision.

I found the work adequate both in scope and quality in partial fulfillment of the requirements for the award of Bachelor of Engineering (B.ENG) in Chemical Engineering.

APPROVED BY:



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DEDICATION

This research work is dedicated to my sweet parents for the National Oil
Company of Nigeria.

ACNOWLEDGEMENT

With deepest sense of humility and absolute gratitude to Allah Almighty (Allahu Rabbil aalamyn) for his adventurous LOVE, my infinite appreciation goes to my parents, Alh.M. Abdulkadir Hadejia and my Darling, Haj. Mannira M. A. Hadejia, for their veracious and unequivocal guidance that serves as a basis throughout my rigorous academic periods. Very special appreciation also to Alh. M. Maguwa for his indubitable guardian role and counseling tenacity. Also acknowledged in this respect is Prof. X.Kabouchi of City College of Hong Kong for his stern contributions in concept. I must appreciate Engr. Galadima for his palpable supervision to see that this research work is a success. Finally, it is a pleasure at my leisure to recognize and appreciate the humorous and docile company of my friends for the time we had together.

ABSTRACT

The aim of this project is to design a plant to efficiently utilize (process) the flare gas into potential fuel gas, using least energy possible with high rapid pay-back time, exploring the capabilities of Hysys process simulator to predict the process operating conditions for optimum results.

Assay data from Total Nigeria Plc. For Bonny Light crude was used to characterize the crude oil in the Hysys' oil environment. Light ends compositions were inputted as well (obtained in the assay data), others are API value, density, viscosity, pour point and sulphur content of the crude. The simulation process developed can be used to modify the physical, thermodynamic and transport properties complex mixture with the process unit operations involved to obtain near perfect gas-oil separation.

With assumptions made, the simulation results obtained shows that more oil is recovered by incorporating polymeric membranes system for gas processing to recover condensable hydrocarbons from non-condensable (permanent gases) gases, based on accurate membrane selectivity (permeation) from the gas mixture (i.e. solubility selectivity and diffusivity selectivity). This system was preferred for its significant advantages to conventional simple flash stabilization technologies due to its simple and compact nature, low weight and minimal control needs, well-suited for off-shore applications.

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CHAPTER 1

1.0 INTRODUCTION

Gas flaring: burning associated gas from oil field and discharging it directly to atmosphere. This expends huge energy and causes environmental degradation and disease. Oil has become the center of current industrial developments and economic activities due to industrialization boost and continuous emergence of new scientific and technological discoveries in the 21st century, thus, increased demand for oil and gas for industrial energy consumption.

More gas is flared in Nigeria than anywhere else in the world, due to lack of utilized infrastructure, approximately 76% of associated gas is flared in this country compared to 8% in Alberta Canada. This is a potential threat to the lives of the oil producing communities. This level of flaring is a significant waste of potential fuel which is simultaneously polluting the water, air and the soil in the Niger Delta.

Nigeria accounts for 19.79% of the global flaring as at 2001, more than the second (Iran) and third (Indonesia) countries combined. UNDP/World Bank (2004) estimated Nigeria flaring at close to 2.5 billion ft³ daily (over 70 million m³ daily), about 70 million tons of CO₂. This high level of gas flaring equals approximately one-quarter of current power consumption of African continent equal also about 45% of energy requirement of France, the world fourth largest economy .

1.0.1 Hysys Process Simulation Package

HYSYS is a powerful software for steady and dynamics state simulation Processes. It includes tools for estimation of physical properties and liquid-vapour phase equilibrium, heat and material balances, design, optimization of oil and gas

processes and process equipment. The program is built upon proven technologies, with more than two decades of supplying of process simulation tools to the oil and gas industry. HYSYS is an interactive and flexible process modeling software which allows the engineers to design, monitoring, troubleshooting; perform process operational improvement and asset management. Therefore enhance productivity, reliability, decision making and profitability of the plant life cycle. In HYSYS, all necessary information pertaining to pure components flash and physical properties calculations is contained in the fluid package, choosing the right fluid package for a given component is essential. Proper selection of thermodynamic models during process simulation is also absolutely necessary as a starting point for accurate process modeling. A process that is otherwise fully optimized in terms of equipment selection, configuration, and operation can be rendered worthless if the process simulation is based on inaccurate fluid package and thermodynamics models. For gas-oil separation process simulation, EOSs fluid package and Peng Robinson thermodynamics and non-ideal vapour phase models was found to be more accurate and applicable (Aspen Tech 2003). Once the fluid package and the thermodynamics model equation are selected, it is now possible to enter the simulation environment where the detail process flow diagram of a given plant can be constructed. In HYSYS stream to stream connection is difficult some fictitious units (such as Mixer and Splitters) to produce a satisfactory model is used, though this have little or no effect on the accuracy or optimization results of the process under investigation. Simulation of the built process flow diagram is achieved by supplying some important physical, thermodynamics and transport data of the stream and equipment involves, this is done until all the units and the streams are solved and converged.

HYSYS require minimal input data from the user, the most important input parameters needed for streams to solve are the Temperature, pressure and flow rate of the stream.

HYSYS offers an assortment of utilities which can be attached to process stream and unit operations. The tools interact with the process and provide additional information. For instance the flow sheet within the HYSYS simulation environment can be manipulated by the user to estimate desired out put.

1.1 Aim

To design a plant (using Hysys process Simulation) with optimum operating capacity, definite cost effective installation price, easy and affordable maintenance cost using the least possible energy with at least 99.9% efficiency.

1.2 Objectives

The ultimate objective of this work is to reduce gas flaring to the barest minimum possible level by utilizing the flare gas into potential fuel gas thus saving energy, Niger Deltas and our planet earth.

Others include the determination of:

1. The material balance of the process.
2. The energy balance of the process
3. The equipment specifications of the vessels
4. The process thermodynamic properties profiles.

1.3 Scope of the Project

This research work is limited to design of a plant to utilize flare gas into potential fuel gas adopting the process of compression and membrane separation, as most

suitable to achieve this optimally, considering its efficiency and economic viability. Also in the design work is the determination of material balance, energy balance, and equipment specifications.

CHAPTER 2

2.1 History of Gas Flaring In Nigeria

In order to address the problems of gas flaring, it is necessary to understand why the natural gas is being flared. Because oil and gas are mixed in every oil deposit, the natural gas called “associated gas” must be removed from oil before refining. Gas flaring is simply the burning of this associated gas. Gas flaring in the country (Nigeria) “has contributed more greenhouse gas emissions than all other sources in sub-Saharan Africa combined” according to World Bank. Estimated at close to 2.5billion ft³ daily (about 70million tons of CO₂), leading to gross annual financial loss put at \$2.5billion, (based on LNG values). More gas is flared in Nigeria than anywhere else in the world which amounts to over 19.79% of global flaring index in 2001(latest year) more than the second (Iran) and third (Indonesia) countries combined: www.cedigaz.org.

This high level of gas flaring equal to approximately one-quarter of the power consumption in the African continent, equal also about 45% of energy requirement of France, world’s fourth largest economy (GGFR 2002). Put also at 40% of total gas requirements for Africa. This problem has been produced by range of international oil companies which have been in operation for over four decades (African news service 2003). The economic and environmental ramification of this high level of flaring are serious because this process is a significant waste of potential fuel which is simultaneously polluting the water, air and the soil in the Niger delta. This research work also shows how the reduction of gas flaring could benefit the local economy and the environment in the Niger delta.

Although there are three options to stop gas flaring: by re-injection, utilization for local market, and utilization for export, flaring is the most common practice to dispose of the waste gases that are produced during the conventional oil

exploration in Nigeria. The reason is because for oil companies to gain maximum economic profit, flaring is the most efficient way to dispose of the associated gas. Also, Nigeria has huge deposits, so that it is more economical to use non-associated gas to produce the natural gas as energy source. Indeed associated gas recovery costs four times more than the straight extraction of non-associated gas (ESMAP 2001). Moreover, because the Nigerian government is politically unstable and non-transparent, it is difficult to enforce the proper policies and to make coherent government policies. In addition, oil companies and the government are only willing to gain short term profits than long-term ones. These driving forces have led to keep the oil flowing at minimal costs without considerations of local environment and people. Gas flaring is simply the consequence of cost minimization.

It is shocking watching the endless burning of this gas 24 hours a day. Even though we have grown to be fairly dependent on oil, we rarely consider how oil exploration and exploitation processes create environmental, health and social problems in local communities near the oil fields.

There are various reasons for the continuous flaring. From a political perspective as Michael Watts (2001) said “ In Nigeria, oil became the basis for important forms of political mobilization,” in which petro-capital became the cause of political violence against those advocating environmental justice or compensation for the cost of ecological degradation. The Nigerian government has not effectively enforced environmental regulations because of the overlapping and conflicting jurisdiction of separate governmental agencies governing petroleum and the environment as well as non transparent governance mechanisms (Kaldany 2001. GGFR 2002)

From economic perspective the Nigerian government's main interest in the oil industry is to maximize monetary profits from oil production (ESMAP 2001). Oil Companies find it more economically expedient to flare the natural gas and pay the insignificant fine than to re-inject the gas back into the oil wells. Additionally, because there is insufficient energy market especially in rural areas (GGFR 2002), oil companies do not see an economic incentive to collect the gas. Gas flaring is simply the burning of this associated gas. This is currently illegal in many countries of the world, where gas flaring may only occur in certain circumstances such as emergency shutdowns, non planned maintenance, or disruption to the processing system (Hyne 1999).

International organizations, governments, and major international oil companies have started to pay attention on this routine gas flaring. For example, the Global Gas Flaring Reduction Initiative (GGFR), led by the World Bank group in collaboration with the government of Norway, has just started a project to establish common guidelines and standard for gas flaring and venting on global basis. The GGFR aims to improve the legal and regulatory framework for flaring reductions (GGFR 2002). This is not only because flaring is environmentally unfriendly but also because it is literally destroying valuable natural resources. Since the issue of global warming has become more high profile in the world, there has been more attention paid on gas flaring, which produces enormous amount of greenhouse gases (GHGs) including carbon (IV) oxide (CO_2), methane (CH_4) and propane (Kaldany 2001). In fact, World Bank estimated about 10% of global CO_2 emission come from flaring.

2.2 Effects of flaring

The cocktail of toxic substances emitted in the flares for over 40 years, including benzene and particulates, has exposed the oil producing communities to health risk

and property damage in violation of their human rights. This flares exposed them to an increased risk of pre-mature deaths, child respiratory illnesses, cancer and asthma as well as acid rain. For example, World Bank suggests that gas flaring from just one part of Niger Delta (Bayelsa State) would likely cause annually 49 premature deaths, and 4,960 respiratory illnesses. This level of exposure violets Nigerian constitutional guarantees, including the fundamental rights to life (Article 33) and to dignity (Article 34). It also violets the right guaranteed in the African Charter on Human and Peoples' Rights, including the right of every individual to enjoy the best attainable state of physical and mental health (Article 16) and of all peoples to a general satisfactory environment favorable to their development (Article 24).

Despite the common use of flares in oil industries, remarkably little study of the gas flaring impacts has been conducted in the Niger Delta. Even in such industry intensive region as Alberta Canada. There are not many studies about the emissions of gas flaring conducted because of expense (Johnson, 1999).

2.3 Studies

Economic and environmental studies were conducted.

A workbook created by Global Gas Flaring Report (GGFR), a World Bank initiative, was employed to perform an economic analysis of using the associated gas flared from the oil field. The workbook consists of a financial spreadsheet model capable of evaluating the economic costs and benefits of using associated gas for power production. Industrial gas and LPG production in a 15 year span with fixed 2004 price (GGFR, 2004). Also, it indicates the different options for reducing gas flaring and using associated gas for purposes. The options comprise four scenarios. Scenario 1 is "Use of the associated gas for power production at

the oil field and transmission power to nearest electricity grid.” Scenario 2 is “scenario 1 plus extraction of LPG at the wellhead. Scenario 3 is “Transportation of the associated gas in a new gas pipeline to a site where it can be used by a new or existing power company to power production and or/ by industries.” And lastly, scenario 4 is “scenario 3 and extraction of LPG at the wellhead.” Base on input data, including the amounts of the associated gas, local demand for energy and distance to markets, and financial fuel prices and economic costs of fuels, the workbook identifies which of the four scenarios is more beneficial to the local economy. .

In addition to CO emission, in order to study other emissions of gas flaring, I reviewed the Alberta Research Council (ARC) report released, 2001. This report is one of the most comprehensive academic papers to examine other emissions. In their study the ARC conducted field measurement of product of incomplete combustion downwind the of flare plumes at a low sulphur content gas (called “Sweet gas”) site and other downwind from flares of a higher sulphur content gas (“sour gas”) site. However because Nigerian gas has low sulphur content only the data of sweet site is examined here (Ashton et al, 1999). Table 2 shows other parameters along with the sample collection in ARC study (Stroscher, 1996).

Table 2.1 Conditions for the sample collection measured 5 m
Above a sweet gas flame.

Parameter	sweet Gas Flares
Volume of flares (m ³)	8,600
Stack Height (m)	12.0
Stack Exit Velocity (m/s)	3.2
Wind Speed (m/s)	1.9
Flame Length (m)	4.5
Combustion Efficiency	62.0

Source: (Stroscher, 1996)

2.3.1 Results

In 1996, Nigeria completed its biggest gas project, the West African Gas Pipeline (WAGP) as part of a gas flaring reduction scheme (EIA 2003). The \$400 million, 1,033 km pipeline will transport the gas from the Niger Delta through Benin, and Ghana to be used in those countries (Commerly, 2002). The facility is expected to process 7.15 billion m³ of LNG annually (EIA 2003). Yet, such a large scale project is not designed to directly benefit the local economies. Smaller projects are more effective and efficient for the local community because they are easier to bring to fruition and therefore quicker to achieve efficiency and positive economic returns.

Scenario 1 – Power production at the oil field and transmission of power to the nearest electricity grid.

Scenario 2 – Scenario 1 plus extraction of LPG at the wellhead.

Scenario 3 – Transportation of the Associated Gas in a new Gas pipeline to a site where it can be used by a new or Independent power producer/ power company to power production and/ or by Industries.

Scenario 4 – Scenario 3 plus the extraction of LPG at the Wellhead.

Even though all scenarios are able to earn the profits, scenario 4, which is LPG production and gas transmission to power plant and industries, would be the best method to reduce the gas flaring for local communities. However since this economic analysis counts only the economic benefits, the further considerations such as social and environmental benefits are required. Moreover, further study of the distribution of profits is also needed to address the actual benefits that local communities can obtain.

2.4 Crude Oil and Gas Deposits

Crude oil is found together with dissolved and free gas, called “associated gas (or casing head) buried some 6000-15000 ft down the earth. Formed from thermal decomposition of the remains/ sediments of buried plants and animals’ death bodies by bacterial activities, enormous pressure and cumulative heaps of other organic bodies, due to depths, some 2 billions years ago (cat agensis). The composition of crude oil/ gas is a function of the type of organic material from which it was formed, the pressure and temperature conditions that existed at the time of formation and any changes that occurred as a result of migration or mixing with gas from other sources. Because of the many variables involved in the formation of crude oil/natural gas, it is highly unlikely that gas from two different sources will have identical composition. The “geochemical fingerprint” of oil and gas can, therefore, be used for its identification.

Crude oil/gases from different sources may sometimes be distinguished using standard chemical analyses of the hydrocarbons. The method is complicated, however, because of different size, mass, and solubility of the different chemical constituents, the chemical composition of crude oil/gas can change as it migrates.

"Isotopic analysis" is the definitive method use to distinguish between the different sources.

2.4.1 Oil reservoir

Crude oil is found in a rocky structure called "oil reservoir". It is mainly impervious sedimentary rock, which possesses certain physical and chemical properties suitable for oil bearing. These include age, folds and faults, chemical composition, porosity permeability and thickness. The gas-oil ratio is a reasonable indicator of whether the reservoir contains gas/condensate or crude oil. The gravity and color of the liquid at atmospheric help decide the type of reservoir. Crude oil is darker, green to black, while condensates vary from clear to straw color orange brown.

2.4.2 Drilling operation

Drilling is simply the art and science of making a hole on a solid surface. In oil and gas industry, drilling (in oil & gas industry) is the art of digging the earth crust in search of crude oil deposits by the scientists (Geologists). Classified as percussion (sledge hammering), and rotary (rotating) drilling. After exploration prospects and site located, it is necessary to acquire and obtain legal right for drilling from appropriate authority (i.e. Govt.) or international legal jurisdiction in the case of off-shore operation. After which the land is cleared and a large rectangular shallow hole (cellar) is dug to provide space for rig installation and storing equipment. A well is dug to provide water for flushing where there is no water source nearby. Equipments are conveyed by barge, heavy duty trucks, helicopters and ships (for off-shore) operations. Access road is provided to the site for easy conveyance of equipments. Helicopters are if the site is inaccessible. High

capacity diesel engine is use to provide power to the site. High capacity electric generator is also use to provide electricity by the diesel engine.

2.5 Utilized Flare Gas

This is the product of the utilized associated gas (casing head) which is petroleum gas (C₃₊) and compressed natural gas (methane). Contrary to general perception that propane should be used for Domestic purposes only, more than 200,000 propane fueled vehicles, mostly in fleet, are on the highways today. Applications range from Taxi and school Buses to police cars, and hundreds of other fleet vehicles. Although propane has not been applied to heavy duty vehicles, incorporating the commercial trucking fleet, but light and medium duty vehicles have been in service for more than 60 years (Simmons & CO. Intl.). Methane is also use for power generation for both industrial and domestic use.

2.5.1 Advantages

Propane (LPG) provides a unique combination of driving range, durability and performance for an alternative fuel. Study by Battelle institute found that when total cost was considered on per mile basis, propane was the most economic alternative fuel for fleet vehicle. Maintenance cost for propane fueled vehicles are drastically lower than traditionally fueled engines. Propane's high octane rating (104-112) compared with gasoline (87-92) and low carbon and contamination characteristics results in extended engine life. The National Propane Gas Association has documented that a propane vehicles may enjoy a three times longer engine life over normal gasoline fueled engines.

2.6 Membrane Technology for Gas Processing

Membrane separation is a relatively new technology wherein a polymer membrane module separates gases by selective permeation of one or more gaseous components from one side of the membrane barrier to the other side as shown in the fig. below.

Gas components are transported across the membrane as a result of concentration gradient. The concentration gradient is maintained by a relatively high partial pressure of gas components on the feed (or upstream) side of the membrane barrier and a low partial pressure on the permeate (or downstream) side.

Typical commercial membrane systems (e.g. gas separation, recovery of CH_4 from stream of heavy hydrocarbon gas mixture) are based on stiff-chain rigid glassy polymers (polyvinylchloride, PVC) which exhibit high size (diffusion) selectivity.

In these membranes, small penetrants permeate through faster than the larger penetrants. Recompression of these CH_4 -rich streams is of economic benefit.

Beside size (diffusion) selectivity, other component that contributes to the overall membrane selectivity, and has generally been overlooked by this research effort is solubility selectivity. Gas flux through a membrane barrier depends not only on the rate of penetrants diffusion, but also on the solubility of the penetrants in the polymer. Generally, larger, more condensable penetrants are more condensable than smaller permanent gases. In rubbery polymer (e.g. polydimethylsiloxane, PDMS) these highly soluble penetrants are also more permeable than permanent gases. In the absence of strong polymer-penetrants interaction; the most important factor affecting solubility is relative penetrants condensability. Critical temperature is a property related directly to condensability and is frequently used as scaling factor for penetrants solubility in polymer material.

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2.6.1 Composite membrane

The membrane consists of three layers (shown in figure 2.3.1 below): a support fabric, a micro-porous polymeric support layer, and a selective rubbery/glassy polymer layer. Each layer plays an important part in the overall function of the membrane. The support fabric characteristics are important in

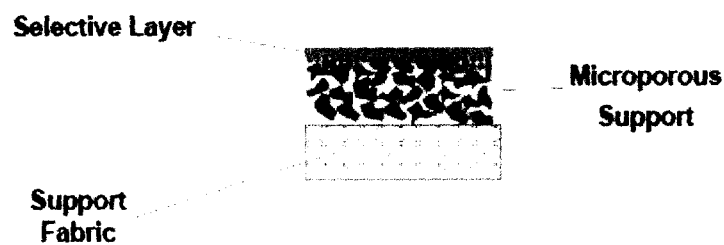


Figure 2.1

Determining the support membrane structure, and together these layers provide the overall mechanical strength of the membrane. The selective layer performs the separation.

2.6.2 Membrane spiral-wound module

The membrane is packaged in a spiral-wound module. The module consists of a series of membrane envelopes. Each envelope contains two sheets of membrane separated by a feed space. The permeate site of the membrane is separated by a permeate spacer. The entire assembly is rolled tightly around the central product

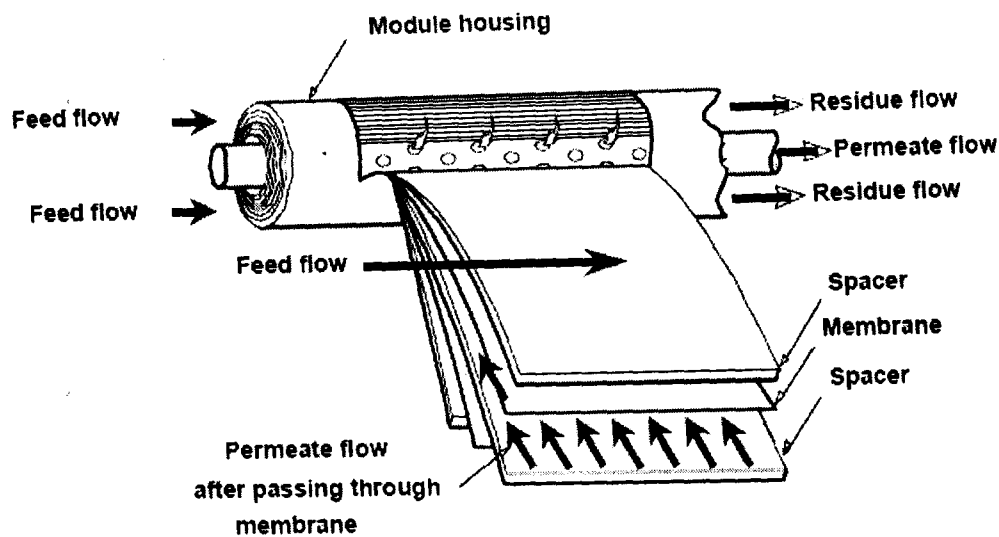


Figure 2.2

The spiral-wound module (shown above) has one inlet and two outlets. One outlet is for the permeate stream, which is enriched in heavy (C_{3+})/(CH_4). The other outlet is for the residue stream, which is depleted in heavy hydrocarbons. The driving force for the separation is the difference in the feed and the permeate pressures.

2.7 Fundamentals of membrane separation

This includes permeabilities that are based on solubility and diffusivity;

2.7.1 Permeability

The permeability of a gas A, P_A through a membrane thickness ℓ is:

$$P_A \equiv N_A \ell / (P_2 - P_1)$$

Where N_A is steady-state gas flux through membrane, ℓ is the membrane thickness, and P_2 , P_1 is the membrane feed (i.e. high) pressure and permeate (i.e. low) pressure, respectively. In a gas mixture, P_2 and P_1 denote the partial pressure of component A on high-and-low pressure sides of the membrane. When the downstream pressure, P_1 , is much lower than the upstream pressure, P_2 , the permeability is often expressed as:

$$P_A = D_A * S_A$$

Where, D_A is the effective concentration-averaged diffusivity. The solubility coefficient, S_A , is defined as C_2/P_2 , where C_2 is the gas concentration in the polymer at the upstream side of the membrane. The ability of the membrane to separate two components is often characterized in terms of ideal selectivity, $\alpha_{A/B}$, which is the ratio of permeabilities of the two components:

$$\alpha_{A/B} \equiv P_A/P_B = D_A/D_B * S_A/S_B$$

Here D_A/D_B is the diffusivity selectivity, which is the ratio of diffusion coefficients of components A and B. The ratio of coefficients of solubility of components A and B, S_A/S_B , is the solubility selectivity. Solubility selectivity is controlled by relative condensability of the penetrants and the relative affinity of the penetrants for the polymer matrix, whereas diffusivity selectivity is governed primarily by the size-difference between the penetrants molecule and the size-sieving ability of the polymer matrix.

Permeability is dependent on either diffusivity or solubility of the gas.

2.7.2 Membrane Selectivity

Selectivity depends on the type of membrane used, in some membranes, selectivity is highly dependent on diffusivity of gases (i.e. PVC), glassy polymer, while some membranes depend on solubility of the gases such as polydimethylsiloxane (PDMS).

2.7.3 Diffusivity Selectivity

D_A/D_B , which is the diffusivity selectivity, is the ratio of diffusion coefficients of components A and B; this is governed primarily by the size difference between the penetrants molecule and the size-sieving ability of the polymer matrix. Here,

smaller penetrants are more permeable than larger penetrants because these polymers have more restricted backbone torsional mobility and, therefore exhibit higher diffusivity selectivity than rubbery polymers. The effects of penetrants size on diffusivity is far greater for poly (vinyl chloride) PVC or glassy polymers, therefore to achieve high diffusivity selectivity, glassy polymers are clearly more useful than rubbery polymers. Hence, glassy polymeric membranes have commercialized for the separation of acidic gases from stream of natural gas, gas pairs such as O_2/N_2 , H_2/CH_4 and CO_2/CH_4 .

2.7.4 Solubility Selectivity

Denoted as S_A/S_B , solubility selectivity is the ratio of solubility coefficients of component A and B, controlled by the relative condensability of the penetrants and the relative affinity of the penetrants for the polymer matrix. The removal of organic vapors and other condensable from super critical gases is also an application of considerable industrial importance and is performed economically using membranes. The removals of higher hydrocarbons from refinery hydrogen purges streams or from methane from natural gas represent promising future applications. Rubbery, Solubility selective polymers such poly (dimethylsiloxane), PDMS, is used for the separation of condensable hydrocarbons from non-condensable ones. Example is the recovery of condensable hydrocarbons (C_{3+}) from non-condensable gases such as methane, nitrogen, ethane and hydrogen as applied in this research work.

2.8 Applications

The following are areas of application of Membrane system.

- a) Associated Gas Processing to Recover Oil Vapors.

- b) Well-head gas conditioning for Btu and dew point control
- c) Fuel gas conditioning for gas engines and turbines.
- d) Turbo-expander gas plant debottlenecks.
- e) Propane refrigeration plant debottleneck

2.9 Methodology

In carrying out this project, HYSYS process simulator was employed to perform the separation of the gas oil mixture

2.9.1 Process Selection

Although there options to stop gas flaring: by re-injection, utilization for local market, and utilization for export. Flaring is still the most common practice to dispose of waste gases in Nigeria, which if otherwise used efficiently and effectively has the potential to fulfill easily and cheaply a requirement for industrialization, and to conserve the environment for local people at the same time.

2.9.2 Re-Injection

Use when the pressure required to push-up crude oil from the reservoir during drilling operation is less. As drilling operation continues, the pressure used in pushing up the oil from the several million meters beneath the earth crust to the wellhead depletes consequently to the extent that additional pressure would be needed to continue the operation that is when gas re-injection is carried out to supply the pressure. Also termed in situ combustion which is not commonly used in drilling operations and therefore not reliable option to stop gas flaring (or utilize associated gas).

2.9.3 Utilization for Export

Associated gas is the gas found together with crude oil in the oil reservoir usually in quantity not enough to transport via transcontinental gas pipelines for market purpose as in the West African Gas Pipeline (WAGP). The gas (associated gas) to oil ratio is too small for transcontinental gas pipeline transport for market purpose and therefore economically not profitable for this option.

2.9.4 Utilization for Local Markets

Utilized associated gas can be transported via local pipelines to the nearest power Generation station to help increase electricity grid for the host communities thereby boosts industrialization, stop youth restiveness bring down poverty level and increase profits to the oil companies. This would go a long way in bringing peace and offer the oil companies with the opportunity of initiating long term plans for their business activities in a secured region. This option is most preferred of the other two options considering its economic viability to both the oil companies and the host communities.

CHAPTER 3

3.0 Process Procedure

The capabilities of HYSYS were explored in carrying out the (or simulating) the process as thus;

3.2 Hysys Simulation Procedures

A base case was established using the following steps; the first step is to select the appropriate fluid package; here Peng Robinson fluid package model is selected as in figure1 below;

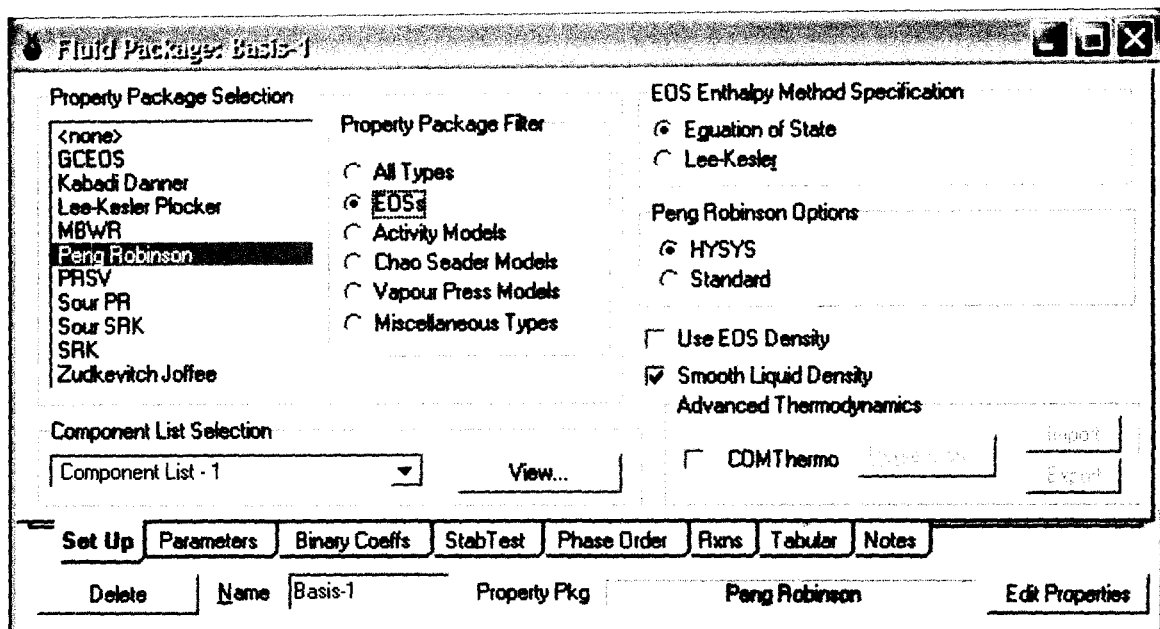


Figure 1 Fluid Package Basis (Peng Robinson Equation of state)

The component selection window is open by selecting view in the component-list shown in fig 1. Figure 2 shows dialog window being used for components selection

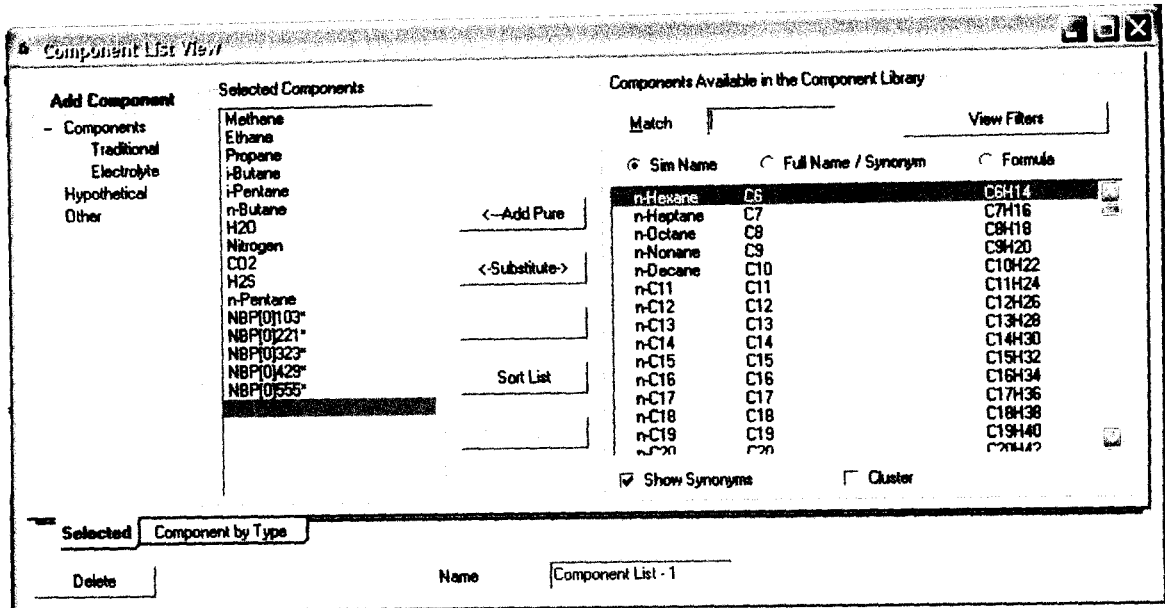


Figure 2 Component selection windows.

Oil Characterization was done by clicking on the oil manager tab where available Assay data were input. Figure 3 shows the oil characterization dialogue box.

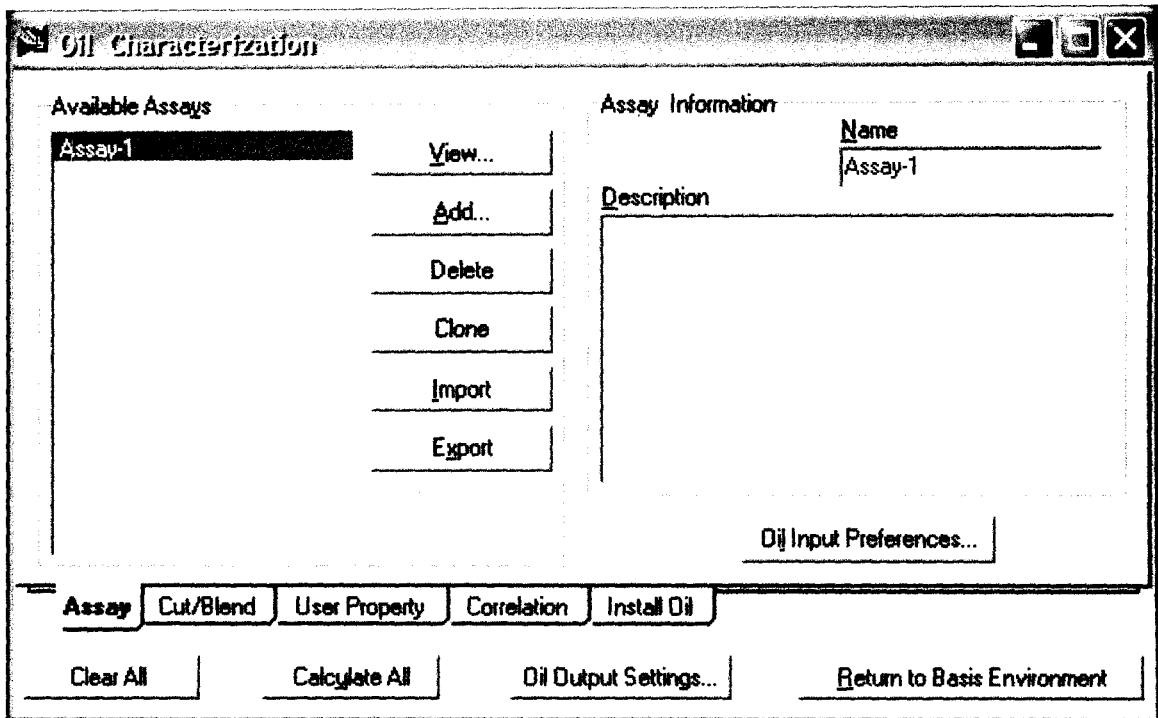


Figure 3 Oil characterization windows.

Clicking on the view tab in Figure 3 above, the following Bulk Properties data of the crude oil sample (Bonny Light) were inputted as shown in figure 4 below.

Assay: Assay-1

Assay Definition

Bulk Properties:

Assay Data Type:

Light Ends:

Molecular Wt. Curve:

Density Curve:

Viscosity Curves:

TBP Distillation Conditions

Atmospheric Vacuum

Input Data

Bulk Props
 Light Ends
 Distillation
 Density

Molecular Weight	<empty>
Standard Density	856.6 kg/m3
Watson UOPK	11.77
Viscosity Type	Kinematic
Viscosity 1 Temp	10.00 C
Viscosity 1	6.900 cSt
Viscosity 2 Temp	50.00 C
Viscosity 2	2.900 cSt

Input Data Calculation Defaults Working Curves Plots Correlations User Curves Notes

Delete Name: Assay-1 Calculate

Figure 4 Bulk Props Data Input windows

Similarly, clicking on the Light Ends radio Button in Figure 4 above, the following Light Ends data of the crude oil sample (Bonny Light) were inputted as shown in figure 5 below.

Assay: Assay-1

Assay Definition

Bulk Properties:

Assay Data Type:

Light Ends:

Molecular Wt. Curve:

Density Curve:

Viscosity Curves:

TBP Distillation Conditions

Atmospheric Vacuum

Input Data

Bulk Props

Light Ends

Distillation

Density

Light Ends Basis:

Light Ends	Composition	NBP [C]
Methane	5.000e-002	-161.5
Ethane	0.1000	-88.60
Propane	0.4900	-42.10
i-Butane	0.5200	-11.73
n-Pentane	0.6700	27.88
n-Butane	1.010	-0.5020
H2O	0.0000	100.0
Nitrogen	0.4800	-195.8
CO2	0.0000	-78.55
H2S	0.0000	-59.65
Pentane	0.7100	36.06

Light Ends Handling & Bulk Fitting Options

Percent of Light Ends in Assay:

Input Data | Calculation Defaults | Working Curves | Plots | Correlations | User Curves | Notes

Delete | Name: Assay-1 | | Calculate

Figure 5 Light Ends Data Input windows.

After all these were done in the Basis manager Environment, one can now enter the simulation environment where the process flow diagram (PFD) is built.

This was done by clicking the Enter Simulation Environment tab. The

Separation Process PFD simulation environment is shown in figure 6

below;

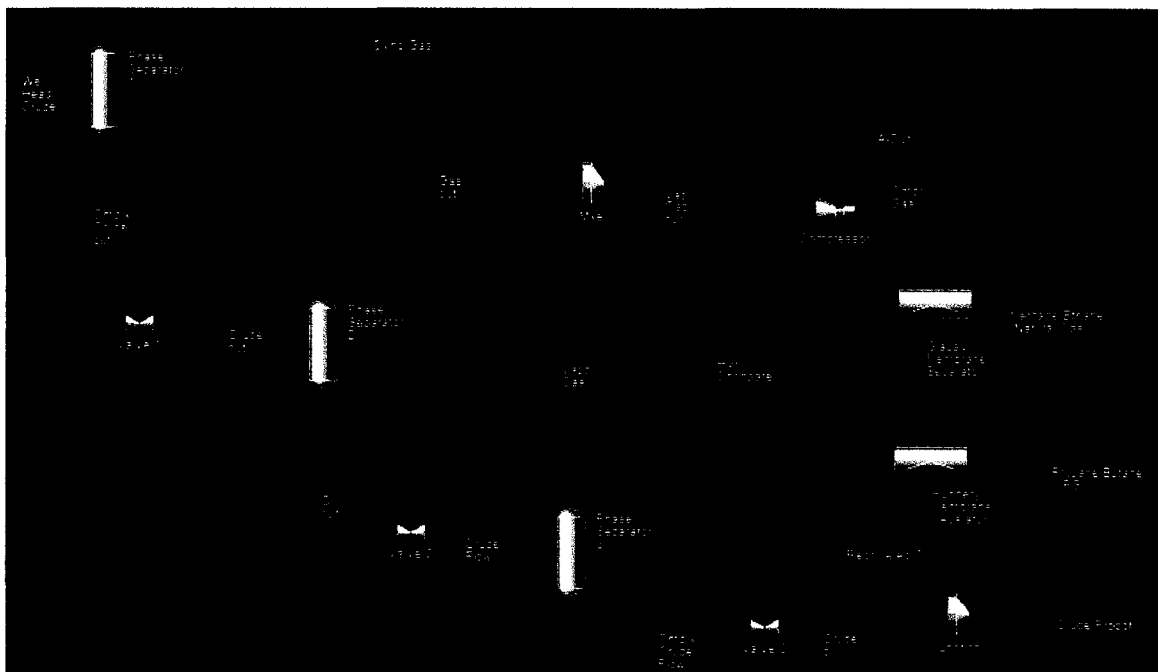


Figure 6 Un-simulated Separation Process Flow Diagrams

The simulation of the process begins with the simulation of the feed Well Head Crude stream by specifying the feed temperature, pressure and flow rate (Blue colours) and HYSYS calculate the remaining parameters (Black colours) as shown in figure 7 below;

Worksheet		Stream Name	Well Head Crude
Conditions	Vapour / Phase Fraction		0.33735
	Temperature [C]		483.50
Properties	Pressure [kPa]		2171.8
	Molar Flow [kgmole/h]		9528.1
Composition	Mass Flow [kg/h]		2.5535e+006
	Std Ideal Liq Vol Flow [m3/h]		2981.0
K Value	Molar Enthalpy [kJ/kgmole]		-2.195e+005
	Molar Entropy [kJ/kgmole-C]		1110.5
User Variables	Heat Flow [kJ/h]		-2.0916e+09
	Liq Vol Flow @Std Cond [m3/h]		2981.0
Notes	Fluid Package		Basis-1
Cost Parameters			

Worksheet Attachments Dynamics

Delete Define from Other Stream... ← →

Figure 7 Well Head Crude specification windows

With the convergence of the various units and streams a complete Light Ends/Oil Separation simulation for the base case was established as shown in figure 8. Detail parameters for the base case and modified parameters are shown in tables of data. The Green colour on the window indicates convergence.

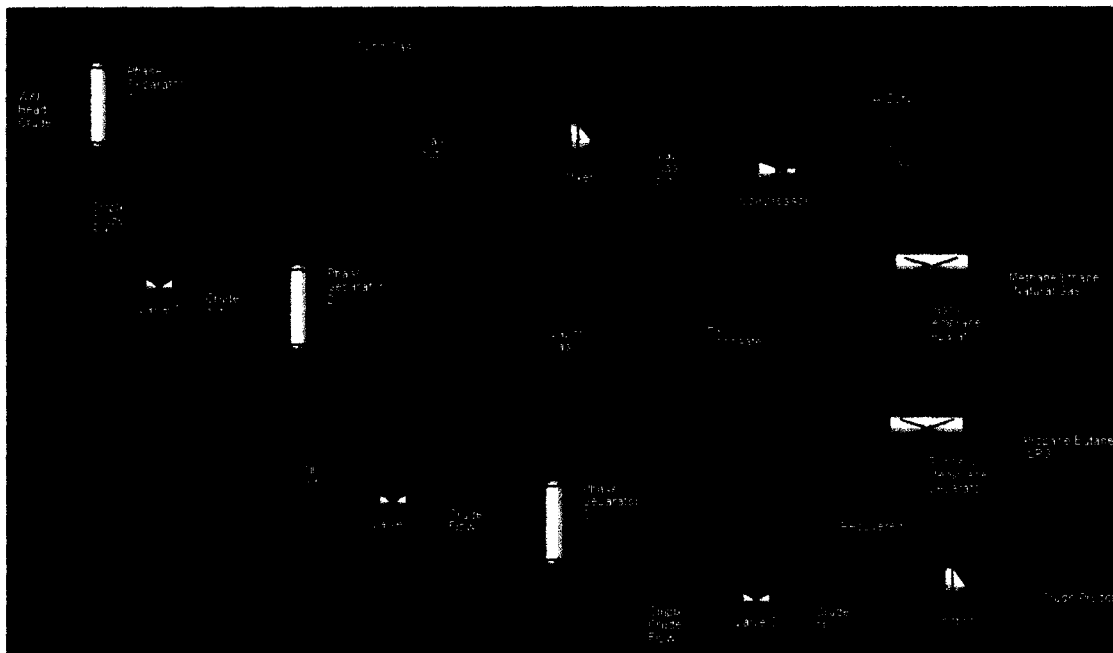


Figure 7 Complete Simulations unit.

3.3 Separation Process Procedure

In the platform processing train for the production of oil and gas from reservoir fluid mixture, the reservoir fluid (Well Head Crude), containing the oil and entrained vapours and gases, enters the first separator vessel in which bulk separation of oil and gases occurs. The pressure of the oil phase is subsequently lowered in a set of separator vessels operating at progressively lower pressures. These pressures from the PFD are 315(psia), 70(psia) and, atmospheric pressure. The pressure reduction releases the lighter entrained gases, and vapours from the heavy oil. The evolved gases are compressed in set of compressor unit to increase

membrane vessels at very high activation energy that best suited permeation of the target gases (i.e. Glassy or Rubbery membrane separation). Glassy membranes allows the permeation of light gases into the downstream side of the membrane rejecting the heavy ones as residues in the upstream side (Diffusivity Selectivity) as shown above, while rubbery membranes permeate the heavy gases into the down stream side rejecting the light ones as residue in the upstream side of the membrane (Solubility Selectivity).

3.2 Justification for the Selected Technology

The modular nature of the membrane offers unique advantages. These advantages include staging the capital investment and operating over a wide range of flow rates (from 40-100% of design). The systems are stable, contain no moving parts, require little or no operator attention, increases oil production by about 870 bpd and are well suited for off-shore applications.

3.3 Equipement List

Phase separators

Glassy membrane separator

Rubbery membrane separator

Compressor & Valves

CHAPTER 4

4.0 RESULTS AND DISCUSSION OF RESULT

After simulation, the following results were obtained and discussed below.

4.1 Simulation results

Detail simulation results are shown in the following lists of tables and chart.

Table 4.1a Material Streams

Name	Well Head Crude	Ovhd Gas	Cmplx Crude out
Vapour Fraction	0.337351863	1	0
Temperature (°C)	483.5	483.5	483.5
Pressure (kPa)	2171.849112	2171.849112	2171.849112
Molar Flow (kgmole/h)	9528.060039	3214.308801	6313.751237
Mass Flow (kg/h)	2553539.095	624182.0839	1929357.011
Liq Volume Flow (m ³ /h)	2981.016884	766.4257066	2214.591178
Heat Flow (kJ/h)	-2091585745	-468733517.4	-1622852227
Name	Vapor Gas	Vap. Gas out	Crude out
Vapour Fraction	1	1	0.696844458
Temperature (°C)	456.0558479	461.7420745	465.3312942
Pressure (kPa)	151.9874949	151.9874949	482.6
Molar Flow (kgmole/h)	593.5239473	4993.226508	6313.751237
Mass Flow (kg/h)	187777.7416	1237238.78	1929357.011
Liq Volume Flow (m ³ /h)	215.3812176	1464.468947	2214.591178
Heat Flow (kJ/h)	-149656285.6	-962518153.3	-1622852227

Name	Gas out	Oil out	Crude Flow
Vapour Fraction	1	0	0.31008822
Temperature (°C)	465.3312942	465.3312942	456.0558479
Pressure (kPa)	482.6	482.6	151.9874949
Molar Flow (kgmole/h)	4399.702561	1914.048677	1914.048677
Mass Flow (kg/h)	1049461.038	879895.9731	879895.9731
Liq Volume Flow (m ³ /h)	1249.087729	965.5034485	965.5034485
Heat Flow (kJ/h)	-812861867.7	-809990359.4	-809990359.4

Name	Methane/Ethane (Natural Gas)	Hvy Cndnsate	Propane/Butane (LPG)
Vapour Fraction	1	0.787651997	1
Temperature (°C)	469	491.7372527	490
Pressure (kPa)	2400	2400	2400
Molar Flow (kgmole/h)	14.29072108	8193.244588	96.21147667
Mass Flow (kg/h)	362.8995976	1861057.964	4937.430511
Liq Volume Flow (m ³ /h)	1.060686275	2229.833967	9.185680811
Heat Flow (kJ/h)	-729447.2122	-1405526075	-5561565.088

Name	Recovered Oil	Crude Prodct
Vapour Fraction	0.773004015	0.989343943
Temperature (°C)	492.1543521	452.2103149
Pressure (kPa)	2400	121.9874949
Molar Flow (kgmole/h)	8097.033111	9417.557841
Mass Flow (kg/h)	1856120.533	2548238.765
Liq Volume Flow (m ³ /h)	2220.648287	2970.770517
Heat Flow (kJ/h)	-1399964510	-2060298584

Table 4.1b Compositions

Name	Well Head Crude	Ovhd Gas	Cmplx Crude out
Comp Mole Frac (Methane)	5.00E-04	1.04E-03	2.27E-04
Comp Mole Frac (Ethane)	1.00E-03	1.98E-03	5.03E-04
Comp Mole Frac (Propane)	4.90E-03	9.30E-03	2.66E-03
Comp Mole Frac (i-Butane)	5.20E-03	9.53E-03	2.99E-03
Comp Mole Frac (n-Butane)	1.01E-02	1.83E-02	5.91E-03
Comp Mole Frac (H2O)	0	0	0
Comp Mole Frac (Nitrogen)	4.80E-03	1.03E-02	2.01E-03
Comp Mole Frac (CO2)	0	0	0
Comp Mole Frac (H2S)	0	0	0
Comp Mole Frac (n-Pentane)	7.10E-03	1.23E-02	4.43E-03
Comp Mole Frac (i-Pentane)	6.70E-03	1.17E-02	4.16E-03
Comp Mole Frac (NBP[0]103*)	0.208079544	0.326180452	0.147954783
Comp Mole Frac (NBP[0]221*)	0.227935265	0.277983481	0.202455892
Comp Mole Frac (NBP[0]323*)	0.270886681	0.232802227	0.290275345
Comp Mole Frac (NBP[0]429*)	0.136661398	6.70E-02	0.172148894
Comp Mole Frac (NBP[0]555*)	0.116137111	2.16E-02	0.164278317

Name	Vapor Gas	Vap. Gas out	Crude out
Comp Mole Frac (Methane)	2.84E-05	2.87E-04	2.27E-04
Comp Mole Frac (Ethane)	8.00E-05	6.36E-04	5.03E-04
Comp Mole Frac (Propane)	5.11E-04	3.36E-03	2.66E-03
Comp Mole Frac (i-Butane)	6.70E-04	3.78E-03	2.99E-03
Comp Mole Frac (n-Butane)	1.37E-03	7.46E-03	5.91E-03
Comp Mole Frac (H2O)	0	0	0
Comp Mole Frac (Nitrogen)	2.09E-04	2.54E-03	2.01E-03
Comp Mole Frac (CO2)	0	0	0
Comp Mole Frac (H2S)	0	0	0
Comp Mole Frac (n-Pentane)	1.22E-03	5.59E-03	4.43E-03
Comp Mole Frac (i-Pentane)	1.14E-03	5.26E-03	4.16E-03
Comp Mole Frac (NBP[0]103*)	5.90E-02	0.186612166	0.147954783
Comp Mole Frac (NBP[0]221*)	0.159781348	0.252826819	0.202455892
Comp Mole Frac (NBP[0]323*)	0.409746584	0.343832738	0.290275345
Comp Mole Frac (NBP[0]429*)	0.286080457	0.14958985	0.172148894
Comp Mole Frac (NBP[0]555*)	8.02E-02	3.82E-02	0.164278317

Name	Gas out	Oil out	Crude Flow
Comp Mole Frac (Methane)	3.22E-04	8.96E-06	8.96E-06
Comp Mole Frac (Ethane)	7.11E-04	2.54E-05	2.54E-05
Comp Mole Frac (Propane)	3.75E-03	1.63E-04	1.63E-04
Comp Mole Frac (i-Butane)	4.20E-03	2.15E-04	2.15E-04
Comp Mole Frac (n-Butane)	8.28E-03	4.41E-04	4.41E-04
Comp Mole Frac (H2O)	0	0	0
Comp Mole Frac (Nitrogen)	2.85E-03	6.56E-05	6.56E-05
Comp Mole Frac (CO2)	0	0	0
Comp Mole Frac (H2S)	0	0	0
Comp Mole Frac (n-Pentane)	6.18E-03	3.96E-04	3.96E-04
Comp Mole Frac (i-Pentane)	5.81E-03	3.67E-04	3.67E-04
Comp Mole Frac (NBP[0]103*)	0.203830335	1.95E-02	1.95E-02
Comp Mole Frac (NBP[0]221*)	0.26537874	5.78E-02	5.78E-02
Comp Mole Frac (NBP[0]323*)	0.3349409	0.18760546	0.18760546
Comp Mole Frac (NBP[0]429*)	0.131177141	0.266328071	0.266328071
Comp Mole Frac (NBP[0]555*)	3.26E-02	0.467048219	0.467048219

Name	Cmplx. Crude Flow	Crude oil	Cmpr. Gas
Comp Mole Frac (Methane)	2.21E-07	2.21E-07	2.87E-04
Comp Mole Frac (Ethane)	8.16E-07	8.16E-07	6.36E-04
Comp Mole Frac (Propane)	6.48E-06	6.48E-06	3.36E-03
Comp Mole Frac (i-Butane)	1.01E-05	1.01E-05	3.78E-03
Comp Mole Frac (n-Butane)	2.17E-05	2.17E-05	7.46E-03
Comp Mole Frac (H2O)	0	0	0
Comp Mole Frac (Nitrogen)	1.32E-06	1.32E-06	2.54E-03
Comp Mole Frac (CO2)	0	0	0
Comp Mole Frac (H2S)	0	0	0
Comp Mole Frac (n-Pentane)	2.38E-05	2.38E-05	5.59E-03
Comp Mole Frac (i-Pentane)	2.17E-05	2.17E-05	5.26E-03
Comp Mole Frac (NBP[0]103*)	1.78E-03	1.78E-03	0.186612166
Comp Mole Frac (NBP[0]221*)	1.20E-02	1.20E-02	0.252826819
Comp Mole Frac (NBP[0]323*)	8.78E-02	8.78E-02	0.343832738
Comp Mole Frac (NBP[0]429*)	0.25745015	0.25745015	0.14958985
Comp Mole Frac (NBP[0]555*)	0.640929021	0.640929021	3.82E-02

Name	Methane/Ethane (Natural Gas)	Hvy Cndnsate	Propane/Butane (LPG)
Comp Mole Frac (Methane)	0.333344873	0	0
Comp Mole Frac (Ethane)	0.666655127	0	0
Comp Mole Frac (Propane)	0	5.70E-03	0.485170112
Comp Mole Frac (i-Butane)	0	6.05E-03	0.514829888
Comp Mole Frac (n-Butane)	0	1.17E-02	0
Comp Mole Frac (H2O)	0	0	0
Comp Mole Frac (Nitrogen)	0	5.58E-03	0
Comp Mole Frac (CO2)	0	0	0
Comp Mole Frac (H2S)	0	0	0
Comp Mole Frac (n-Pentane)	0	8.25E-03	0
Comp Mole Frac (i-Pentane)	0	7.79E-03	0
Comp Mole Frac (NBP[0]103*)	0	0.241691981	0
Comp Mole Frac (NBP[0]221*)	0	0.263137064	0
Comp Mole Frac (NBP[0]323*)	0	0.300873844	0
Comp Mole Frac (NBP[0]429*)	0	0.117431953	0
Comp Mole Frac (NBP[0]555*)	0	3.18E-02	0

Name	Recovered Oil	Crude Prodct
Comp Mole Frac (Methane)	0	3.09E-08
Comp Mole Frac (Ethane)	0	1.14E-07
Comp Mole Frac (Propane)	0	9.09E-07
Comp Mole Frac (i-Butane)	0	1.42E-06
Comp Mole Frac (n-Butane)	1.19E-02	1.02E-02
Comp Mole Frac (H2O)	0	0
Comp Mole Frac (Nitrogen)	5.65E-03	4.86E-03
Comp Mole Frac (CO2)	0	0
Comp Mole Frac (H2S)	0	0
Comp Mole Frac (n-Pentane)	8.35E-03	7.18E-03
Comp Mole Frac (i-Pentane)	7.88E-03	6.78E-03
Comp Mole Frac (NBP[0]103*)	0.24456384	0.210521074
Comp Mole Frac (NBP[0]221*)	0.266263741	0.230609775
Comp Mole Frac (NBP[0]323*)	0.304448921	0.274065167
Comp Mole Frac (NBP[0]429*)	0.118827317	0.138264933
Comp Mole Frac (NBP[0]555*)	3.21E-02	0.117499822

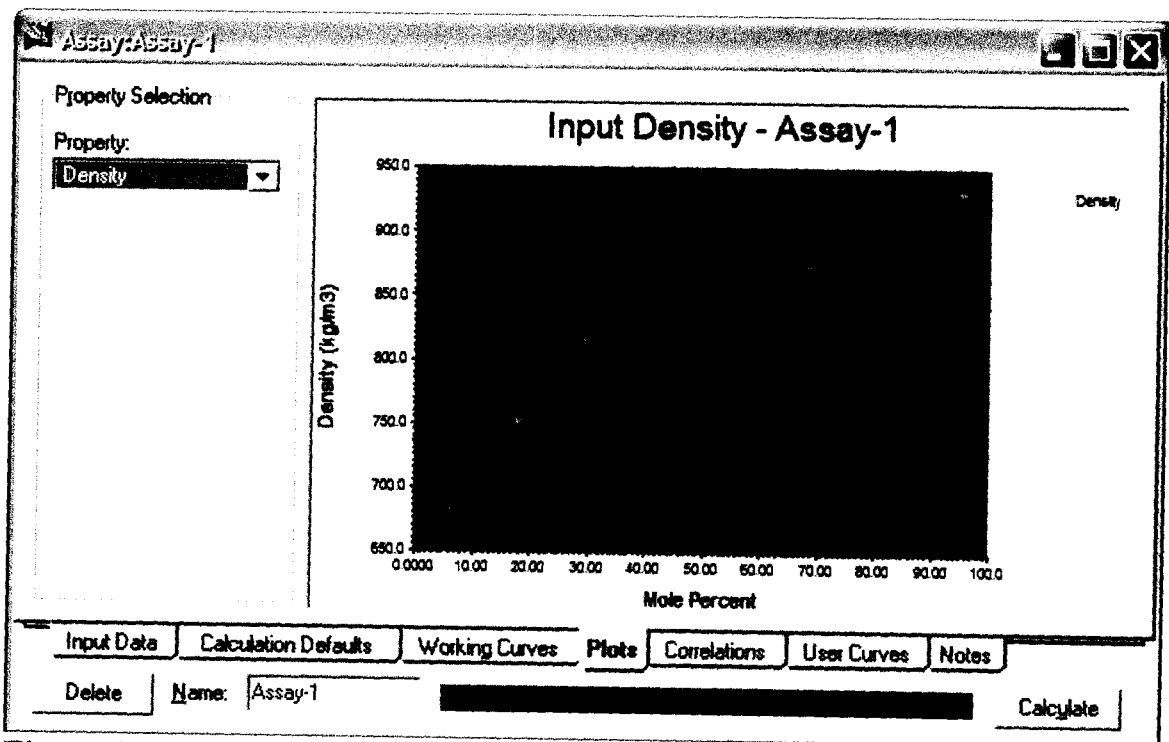


Figure 4.0 Assay Density property plots

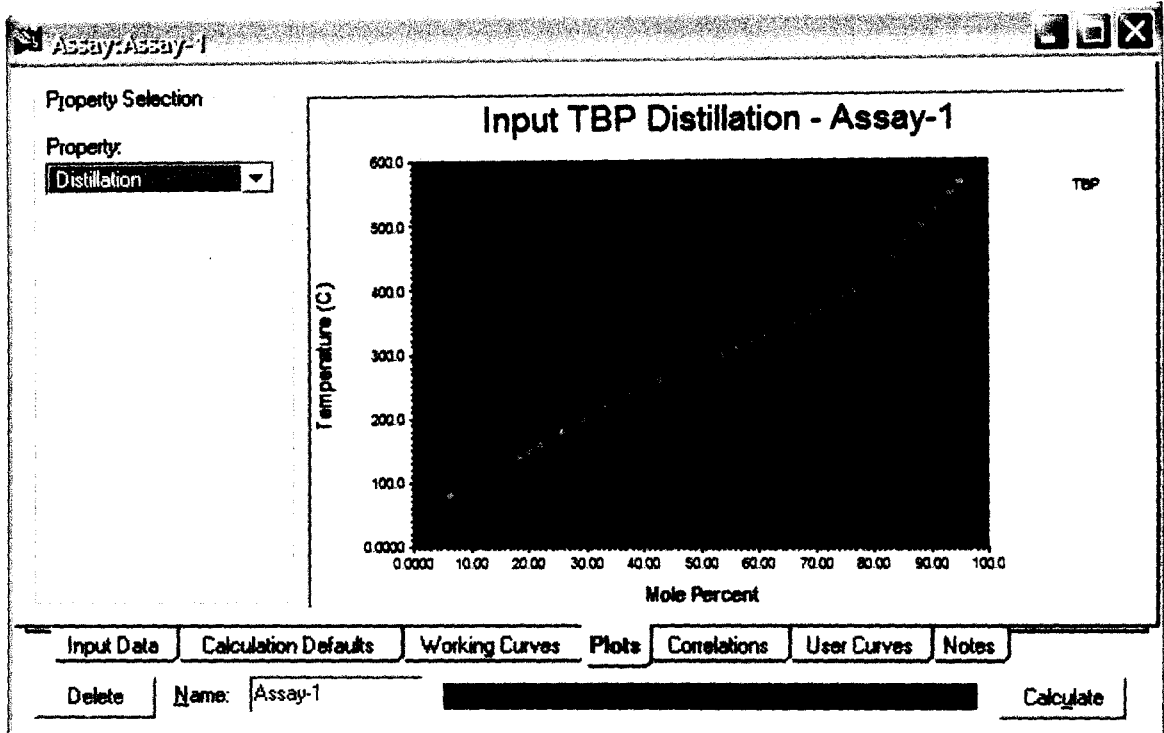


Figure 4.1 Assay Distillation property plots

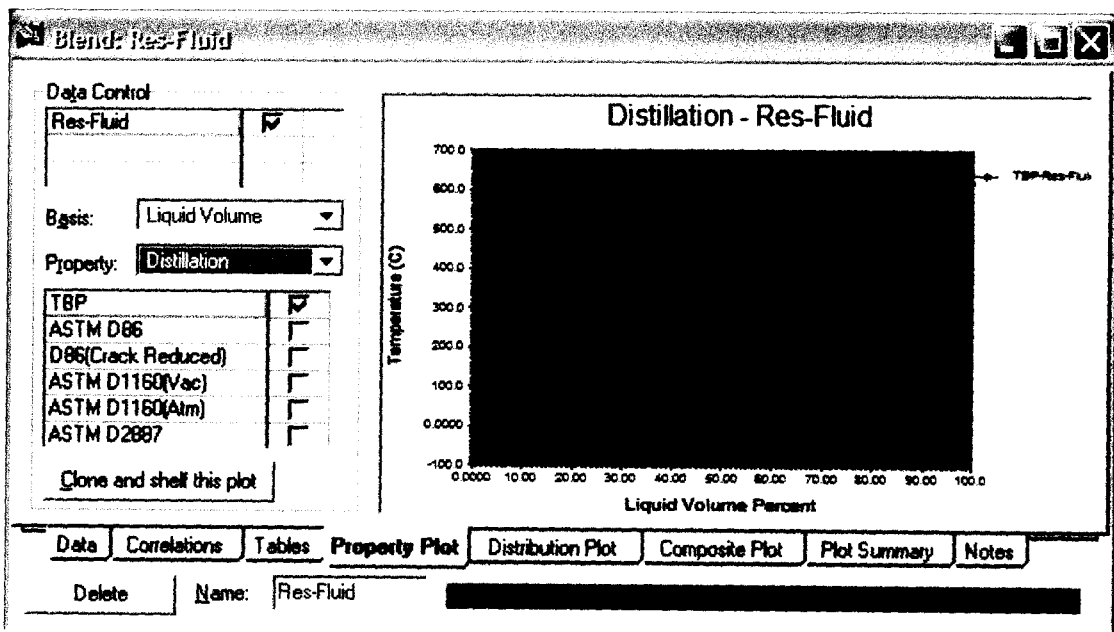


Figure 4.3 Property Plots (Temp vs Liq Vol)

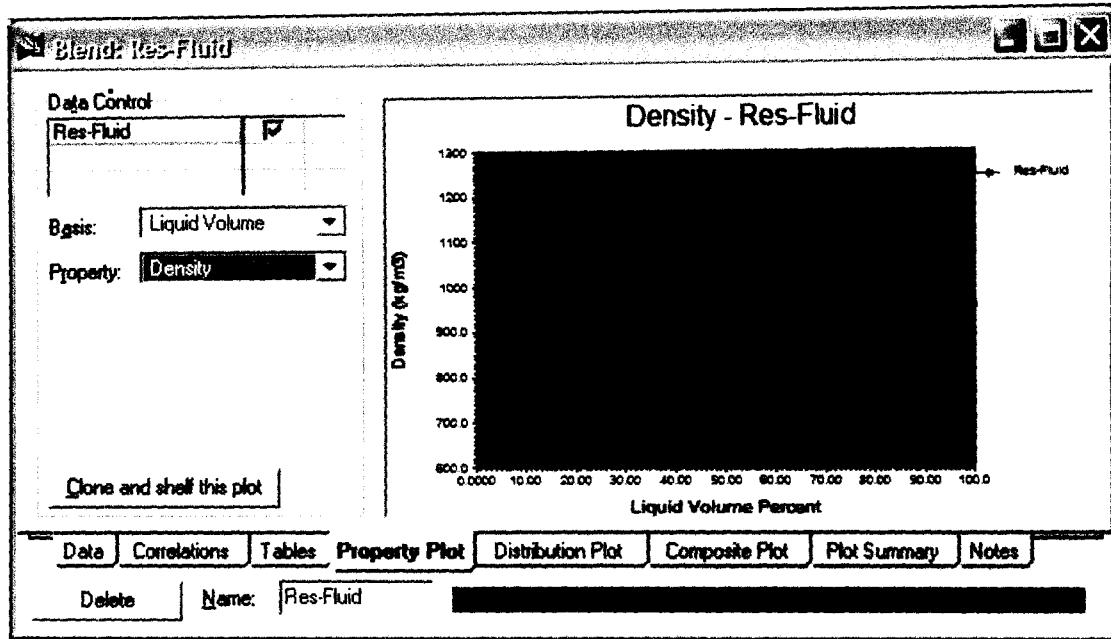


Figure 4.4 Property Plots (Density vs Liq Vol)

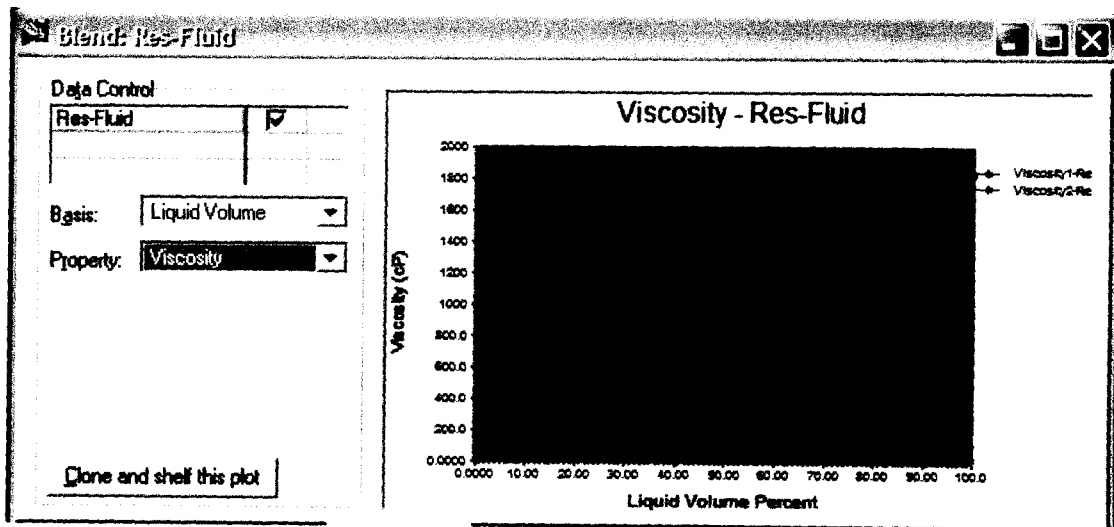


Figure 4.5 Property Plots (Viscosity vs Liq Vol)

4.2 Discussion of results

From the table of material Balances generated, the volumetric flow of the light Natural Gas, the liquefied Petroleum Gas and the Crude Product are $1.060686275\text{m}^3/\text{h}$, $9.185680811\text{m}^3/\text{h}$ and $2970.770517\text{m}^3/\text{h}$. The tables of results generally show both the material and energy balances of the process as well

as other significance thermodynamic properties which include temperature, pressure, and energy balance (heat flow).

Similarly, the table of material Balances generated indicates that the total output mass flow of the light Natural Gas, the liquefied Petroleum Gas and the Crude Product are 362.8995976 kg/h, 4937.430511 kg/h and 2548238.765 kg/h, which amounts to the total material input of 2553539.095 kg/h (i.e. "Well Head Crude" feed stream). Hence, total material balance around the system shows that total material input equals total material output.

In addition, the total energy input (i.e. the "Well Head" stream) is found from the table to be -2091585745kJ/h whereas the energy output of the Natural gas, the LPG, and the Crude product streams are calculated to be -729447.2122kJ/h, -5561565.088kJ/h and -2060298584kJ/h respectively which amounts to a total energy output of -2066589596.3002kJ/h. Thus, the total energy balance around the system is 24996148.6998kJ/h.

The table of compositions shows that high product purity each of Natural gas, LPG and Crude product is obtained at their various outlet streams. The table shows that most of the Natural gas and the LPG are retrieved at the Methane/Ethane and Propane/Butane streams respectively. Nearly 98.7% product purity of the Crude product is obtained at its outlet stream.

Finally, the Plots give the Assay plots of each of Density and Temperature against mole %. The Blended crude property plots each of Temperature, Density and viscosity against liquid volume % are also shown as calculated by hysys after Assay data for the oil characterization were inputted.

CHAPTER 5

5.1 Conclusions

- i. An increased oil output by about 3.9% is achieved as a result of the recovered heavy condensates (condensable hydrocarbons) due to compression.
- ii. Perfect mixed-gas separation is achieved as a result of accurate selectivity of the membrane systems.
- iii. Hysys simulation package can be used to instantly and accurately study the behavior of a chemical process by varying or modifying its thermodynamic properties for research and development.
- iv. With the convergence of the process flow diagram, the plant has proven to be viable.

5.2 Recommendations

- i. It is recommended that feed stream (crude mixture) should be at its flash temperature just before entering any of the flash vessels for efficient separation..
- ii. Operating conditions (i.e. thermodynamics properties) can be changed simultaneously while studying the behavior of the process at different conditions (i.e. flow rate, density, and viscosity)

- iii. Thermal stability of the rubbery membranes should be ensured, maintaining its rubbery and rigid properties to stand various gas dew point temperatures.
- iv. It is also recommended that utilized flare gas be used to improve local economies to better living standards of the oil producing communities by LPG production and gas transmission to power plants and industries.
- v. Hysys simulation package should be put as part of undergraduate academic curriculum in all Chemical/Petrochemical engineering departments in our universities.

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		Crude				TBP								
		Country				DISTILLATION								
		BONNY LIGHT												
		Nigeria												
		Assay Date				21-Sep-03								
Density at 15°C, Kg/m3		856.6				°C	wt%	vol%	°C	wt%	vol%			
		33.61				080	5.16	6.41	450	80.92	83.26			
Viscosity		7.36				140	15.36	18.10	475	83.76	85.88			
Density, cSt at 10 °C		6.9				150	17.22	20.14	500	86.42	88.25			
		37.8 °C				160	18.98	22.08	525	89.16	90.88			
		50 °C				180	22.41	25.78	550	92.19	93.36			
Pour Point, °C		-18				200	25.91	29.45	565	94.16	95.11			
Sulphur wt%						220	29.71	33.35						
Appearance Temperature °C						240	34.07	37.74						
Vapour pressure at 37.8 °C, kPa		31				250	36.47	40.14						
Water vol%						260	38.99	42.85						
Water at 37.8 °C, kPa						300	49.83	53.34						
Sulphur mg/kg						310	52.60	56.06						
Sulphur wt%		0.140				320	55.35	58.75						
Total Sulphur, mg/kg		<1				330	58.06	61.38						
Total Sulphide, mg/Kg		<1				340	60.69	63.94						
Water, mg KOH/g		0.27				350	63.23	66.41						
Water, mg/Kg		3.5				360	65.66	68.75						
Water, mg/Kg		0.4				370	67.93	70.95						
						380	70.05	72.99						
						390	71.99	74.85						
						400	73.78	76.56						

PROPERTIES OF TBP CUTS

Cuts	Yield wt%	Yield vol %	Den 15°C Kg/m3	S wt%	RSH mg/kg	RON clear	RON 0.15 g/l	MON clear	MON 0.15 g/l	Naphth vol%	Aro vol%	RVP kPa					
LIGHT NAPHTHA	15-85																
	15-80	3.80	4.77	683	0.0008		76.3	83.0	73.9	81.0		2.2					
HEAVY NAPHTHA	80-150	12.06	13.73	752	0.0030												
	80-175	16.39	18.45	761	0.0073												
	100-150	6.65	9.83	754	0.0069												
KEROSENE	150-230	14.67	15.41	816	0.051		Smoke Point 22	Acidity mg/g	Cetane calc	Freeze Pt °C	Naphtha vol%	Aro vol%	Saybolt Color	Visc cSt 50°C			Flash Point
	175-230	10.34	10.69	826	0.060					-80.0		14.0					
	150-250	19.25	20.00	824	0.058												
GASOIL	175-400	52.23	51.71	865	0.110		Anilin Point °C	Cetane	Cetane calc	Cloud Pt C	CFPP C	Pour Pt C	Visc cSt 50°C	Visc cSt 100°C	KUOP		Flash Point
	230-400	41.89	41.02	875	0.130				46	-2	-4	-6					
	230-375	37.10	36.43	872	0.120				48	1	-1	-3					
									47	-6	-6	-10					
VACUUM DISTILLATE	375-550	23.20	21.39	929	0.24	Conrad. wt%	Anilin Point °C	Ni mg/kg	V mg/kg	Total N wt%	Bas N mg/kg	Pour Pt C	Visc cSt 100°C	Visc cSt 150°C	KUOP		Asp C7 wt %
	375-565	25.17	23.14	932	0.26	0.20				0.1885	713				11.77		
	375-580																
	400-580																
RESIDUE	> 375	31.01	28.03	948	0.31		AsphC5 wt%	Ni mg/Kg	V mg/kg	Total N wt%	Para	Pour Pt C	Visc cSt 100°C	Visc cSt 150°C			Asp C7 wt%
	> 550	7.81	6.64	1008	0.50	15.6				0.6850		30	22				0.1
	> 565	5.84	4.89	1023	0.54							51	1812				
	> 580												3248				

Estimated value or derived from previous assay

Total DTS/AM Jan-04