Feasibility Study on Possibility of Using Flare Gas as a Source of Energy

by

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the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
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Approved by,

(Mr Rahmat Iskandar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD AFIQ BIN MOHD ABD GHAFAR

ABSTRACT

Gas is usually flared because it is thought to be waste. In the oil and gas industry, flare is an essential safety system, used for the safe disposal of flows from pressure safety valves and depressurization of processing equipment. Researches and studies show that flare has the potential to be a source of energy. It is proven by the development of the technologies that reuse and recover the flare gas and use it as source of energy. In the early stage of this project, the characteristic of the flare gas will be analysed. The characteristics that need to be studied are the compositions of the flare gas, the heating value for the flare gas. Afterwards, this project evaluate each option that available that can be use to maximize the usage of flare gas. Every option is evaluated referring to the practicability, efficiency, economically and effect to environment. This project will bring up the best solution on how to maximize the usage of flare gas. The results from the analysis of the gas show that flare gas has the similarity of the composition of the natural gas which has referred as the fuel gas for the equipment on the platform. Even though the composition of the flare gas has the similarity of the natural gas, but the value for the heating value differs from the heating value of the flare gas. This is because the difference in the composition of the other component gas in the flare gas has made the difference. To apply the recovery system for flare gas currently is not economical since flare the gas is the cheapest way of handling ~~flare-gas.~~ But then, referring to the trend of the carbon dioxide (CO_2) emission in Malaysia, it is possible that in the future, Malaysia may need to apply the CO_2 tax scheme to control the CO_2 emission. This study will be a good reference for the petroleum sector to refer to for the flare gas recovery.

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ABBREVIATIONS AND NOMENCLATURES

NEDO	New Energy and Industrial Technology Development Organization
Scf	Square Cubic Feet
LPG	Liquefied Petroleum Gas
UNFCCC	United Nations Framework Convention on Climate Change
GHG	Greenhouse Gases
UN	United Nation
CDIAC	US Department of Energy's Carbon Dioxide Information Analysis Center
WRI	World Resources Institute
EPA	US Environmental Protection Agency
HHV	Higher heating value
LHV	Lower heating value
VRU	Vapor Recovery Unit
DEA	Diethanol Amine
P&ID	Piping and Instrument Diagram
PFD	Process Flow Diagram
FYP	Final Year Project
UTP	Universiti Teknologi PETRONAS

CHAPTER 1
INTRODUCTION

1.2 Background of the Study

In oil and gas industry, oil wells often produce natural gas as a by-product but often cannot transport it to the market. A common approach of disposal these gases are by flaring. Flare also in the oil and gas industry is an essential safety system that use for safe disposal of flows from pressure safety valves and depressurization of processing equipments.[1] Gas flares are the choice disposal option for handling waste hydrocarbon gases because of their ability to burn efficiently. [2][3]

Researches and studies have shown that the flare gas is a valuable "waste" that can be turned into source of energy or can be use recovered and reused to be fuel gas. Currently, there are existing technologies that available that gives solutions that provide economic gain and eliminates environmental exposure with these valuable resources.

Currently, there are technologies that actually utilize flare gas and use it as a source of energy. For instance, there is technology that reused these wasted gases to make electricity and provide the electricity for the utility system for the platform as an example. [2]

1.2 Problem Statement

This project will be concentrating on the possibility of using flare gas as a source of energy by studying the characterisation of the gas itself first. The characteristic of the gas that will be study is on the heating values of the gas and the composition of the gas. Then the result obtained will be compare to the characteristic of the fuel gas that use on the equipment on the platform and the further analysis of the flare gas characteristics will be done to verify that the flare gas is compatible to be use as fuel gas.

Then, this project will evaluate each option available to identify the option that is practical to be apply on the platform. The option available will be evaluate on the practicability, efficiency, space consumption and economical advantages of the system to be apply on the platform. In the end of this project, a proposal on a flexible technical solution that will be usable at various fields will be propose.

1.3 Objectives and Scope of Study

The objectives to be achieved by the end of this project are to verify that the flare gas is compatible to be use as fuel gas and also to identify the available option that can maximize the usage of flare gas from various platforms. By the end of this study, a flexible technical solution that will be usable at various fields will be proposed.

This study will focused on the local oil and gas field which is Sabah and Terengganu. Besides that, this study will concentrate on the composition of flare gas and the heating value of flare gas as the study on the characteristic of flare gas study. The study then will compare the characteristic obtained with the natural gas characteristic as the natural gas is made as the reference as fuel gas. The available methods of handling and recover flare gas will be studied throughout the study.

CHAPTER 2
LITERATURE REVIEW / THEORY

2.1 Background of the Study

For a record, according to a study done by Rafael Lastra and Ikouwem Johnson, the estimated volume of associated gas flared daily in Nigeria is to be about 2 billion scf, which is amounting to about $6.8 MM loss in revenue everyday. [4] With a proper study on the flare gas, this valuable "waste" is possible to be recover and can be use as a source of energy, which means we optimized the usage of the limited source that we get from the earth. [5]

Regarding to the amount of energy that we have wasted on the flare gas, several bodies and engineering companies have came out with ideas on how to use the flare gas as a source of energy. For example, New Energy and Industrial Technology Development Organization (NEDO) of Jakarta, Indonesia has came out with the model project that can recover the flare gas by compress, liquefy and recover the wasted gas to be Liquefied Petroleum Gas (LPG).[6] This shows that flare gas is possible to use as a source of energy. Besides that, a generation services company, Marson Energy, has come out with a solution by using the flare gas to be burned to make electricity. [2]

2.3 Kyoto Protocol

Concerning the increasing of the emission of carbon dioxide, under the United Nations Framework Convention on Climate Change (UNFCCC), Kyoto Protocol has been made. This protocol is made with the objective of reducing greenhouse gases that cause climate change. The countries that ratify this protocol commit to reducing their emissions of carbon dioxide and five other greenhouse gases (GHG), or engaging in emissions trading if they maintain or increase emissions of these gases. [7][8][9]

Kyoto Protocol is underwritten by governments and is managed by global legislation enacted under the UN's aegis. Generally, governments are divided into two general groups: developed countries which referred to as Annex I countries (who have accepted GHG reduction obligations and must submit an annual GHG inventory), and developing countries which referred to as Non-Annex I countries (who have no GHG emission reduction obligations but may participate in the Clean Development Mechanism). [10]

Under the Kyoto Protocol, Non-Annex I economies have no GHG emission restrictions, but when a GHG emission reduction project (a "Greenhouse Gas Project") is implemented in these countries, the project will receive Carbon Credits, which can then be sold to Annex I buyers. [7]

2.2.1 Kyoto Objectives

Generally, Kyoto Protocol is meant to reduce the global emissions of greenhouse gases. The objective is to achieve "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."[9][11][12]

2.3 Carbon Credit

Carbon credits are a key component of the emission trading schemes that been implemented to mitigate global warming. The credits reduce the greenhouse effect emissions on an industrial scale by capping total annual emission and letting the market assign a monetary value to any deficit through trading. The credits can be used to finance carbon reduction schemes between trading partners and around the world. [13] [14]

2.3.1 Carbon Credit Backgrounds

As a result of increasing awareness of the need for controlling emissions, the concept of carbon credits is introduced. [15] The Kyoto Protocol formalized the mechanism and through the subsequent Marrakesh Accords the market mechanisms were agreed. The mechanism adopted was similar to the successful US Acid Rain Program to reduce some industrial pollutants. [13]

2.4 Malaysia's Carbon Dioxide Emission

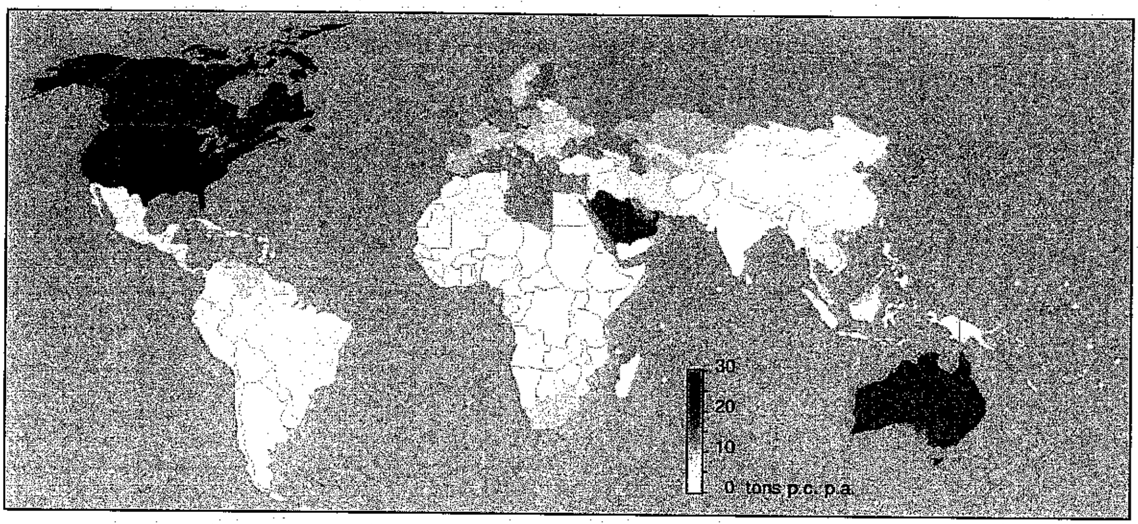


Figure 2.1: CO_2 emission per capita per year per country [17]
(Source: United Nations Millennium Development Goals Indicators, accessed 12 September 2007)

A list of countries by carbon dioxide emissions per capita from 1990 through 2004 has been made (refer to Appendix A). The data was collected in by the US Department of Energy's Carbon Dioxide Information Analysis Center (CDIAC) for the United Nations Statistics Division. [17] Countries are ranked by their metric tons of carbon dioxide emissions per capita in 2004.

From the list, Malaysia's CO_2 emission per capita is increasing from year 1999 to 2004. Until 2004, Malaysia ranked at number 54 world wide in terms of CO_2 emission per capita.

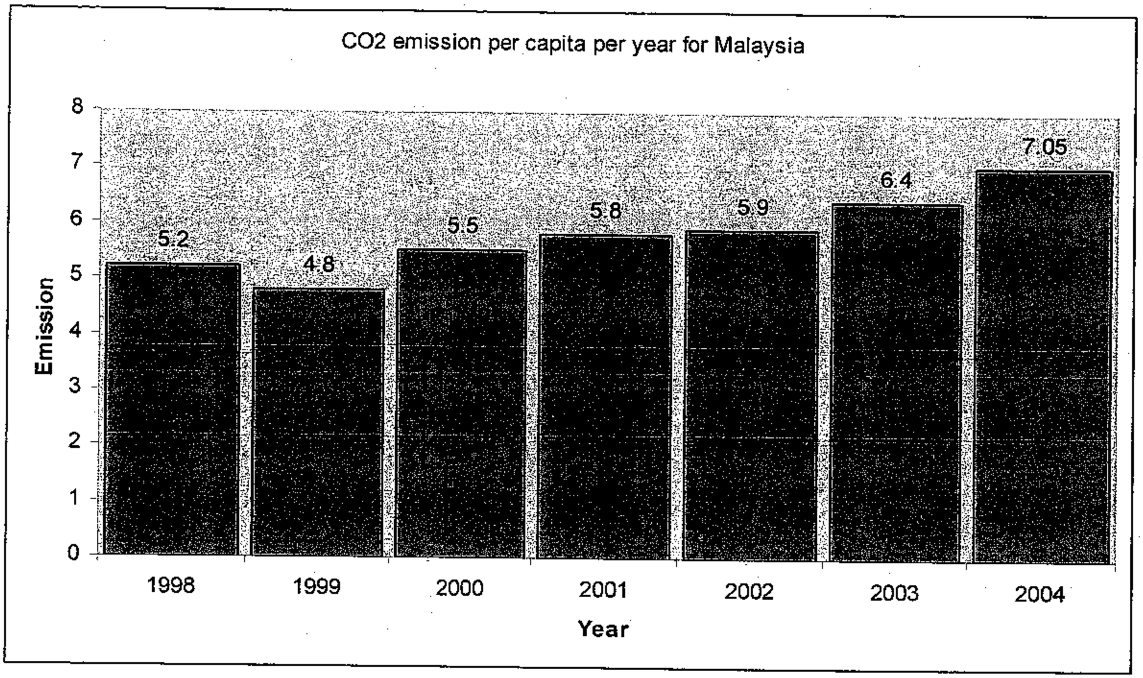


Figure 2.2: CO_2 emission per capita per year for Malaysia

Besides that, from a list of countries ranked by greenhouse-gas emissions per capita in 2000, Malaysia ranked at number 5 world wide (CO_2 emission with land-use change). The list is based on data for carbon dioxide, methane, nitrous oxide, perfluorocarbon, hydrofluorocarbon and sulfur hexafluoride emissions compiled by the World Resources Institute (WRI) from a variety of sources, including CDIAC and the US Environmental Protection Agency. [18]

The list has two sets of per capita emissions are given, one with an estimate of the effects of land-use change (for example, cutting down forests) and one without.

Rank	Country	Tonnes of CO2e
1	Belize	93.9
2	Qatar	54.7
3	Guyana	52.5
4	Malaysia	37.2
5	United Arab Emirates	36.8

Table 2.1: Per capita greenhouse gas emissions in 2000[18]
(Source: www.wikipedia.com/List_of_countries_by_greenhouse_gas_emissions_per_capita)

From data provided in Figure 2.1, Figure 2.2 and Table 2.1, the trend of the CO_2 emission in Malaysia is increasing yearly from 1999 and getting critical. With the increasing trend of the CO_2 and GHG emission in Malaysia, it is possible in the future that the international community will ask Malaysia to consider implementing the Carbon Tax to control the CO_2 and GHG emission.

2.5 Gas Composition

Flare gas on the platform is flared for the safety reason. The gas is originally is product from the wells, which is flared to overcome the over-pressure problems in the equipments such as scrubbers and production separators. Theoretically, the flare gas usually has the composition that nearly similar to the natural gas which is the produced from the wells. Regarding to the similarity of the composition of the flare gas and the natural gas, this project will make a study of the composition of the gas to ensure the similarity between the gases.

James G. Speight (1999) stated that the major element of natural gas is methane (CH_4). Other elements are paraffin hydrocarbons such as ethane, propane ant the butanes. Besides that, many natural gases consist of nitrogen as well carbon dioxide and hydrogen sulphide. Trace quantities of argon, hydrogen, and helium also may present in the gases. Generally, the hydrocarbons having a higher molecular weight than methane, carbon dioxide, and hydrogen sulphide are removed from natural gas before its use as fuel. [19]

Constituents	Composition (vol%)		
	Wet	Range	Dry
Hydrocarbon			
Methane	84.60		96.00
Ethane	6.40		2.00
Propane	5.30		0.60
Isobutane	1.20		0.18
n-Butane	1.40		0.12
Isopentane	0.40		0.14
n-Pentane	0.20		0.06
Hexanes	0.40		0.10
Heptanes	0.10		0.80
Non-hydrocarbon			
Carbon Dioxide		0-5	
Helium		0-0.5	
Hydrogen Sulfide		0-5	
Nitrogen		0-10	
Argon		0-0.05	
Radon,krypton,xenon		Traces	

Table 2.2: General Composition of Wet and Dry Natural Gas
(adapted from Speight, 1999)[19]

2.6 Heating Values

All fuels contain energy. To harness this energy for productive purposes, however, the fuel must undergo a chemical reaction. The most common reaction is the heat liberating process of combustion. Combustion is the rapid combination of oxygen with a fuel in the presence of a source of ignition, resulting in the release of heat. The heating value of the fuel is a measure of the amount of heat liberated during combustion. The heating value of the fuel must be known in order to perform thermodynamic and cost analyses of any energy system. The heating values are calculated based on the chemical constituents of the fuels – usually fossil fuel. [20]

According Neil Petchers (2003), the heating value of any fuel depends on its specific chemical composition. At one time, heating value was empirically determined by reacting a known quantity of fuel in a calorimeter with enough oxygen to ensure its complete combustion and measuring the heat quantity generated during the combustion. The amount of information available on the chemical compounds comprising the various fuels today allows the heating values to be calculated from fuel composition. [20]

The results of such calculations for liquids generally are expressed on energy per unit mass or energy per unit volume basis — Btu/lbm (kJ/kg) or Btu/gallon (kJ/liter). For gaseous fuels, values are expressed on volume basis, and the reference conditions for the fuel volume measurements (pressure, temperature, and degree saturation with water vapor), as well as test conditions, have to be stated explicitly. The alternative "shortcut" to such measurement is to use the criteria established in various national standards as much as possible.

Hence, the ideal energy density for methane is about 1,012 Btu/cf (37,710 kJ/m3) of dry gas. This is based on the volume determined at 14.73 psia (101.6 kPa) and 60°F (15.55°C) through application of the ideal gas law.[20][21] The water produced during combustion is condensed to liquid state, and all combustion products are cooled to the initial temperature of 60°F at the start of the test. Real energy density takes into account the large number of methane molecules in the real volume and differs slightly from the ideal density. The real energy density of methane, which compensates for the compressibility factor, is 1,014 Btu per standard cf (37,784 kJ/Nm3) on dry volume basis. [20]

In addition to the compressibility of gas, there is one more important factor. Most fuels, in addition to carbon, contain hydrogen and are known as hydrocarbons. During the combustion of such fuels, oxygen is combined with carbon, forming carbon dioxide, and with hydrogen, forming water vapor. While the carbon dioxide remains in the gaseous state at normal ambient temperatures, the water vapor in the flue products may leave the combustion device either in vapor or condensed to liquid state. Condensation takes place when the finite quantity of heat, known as the latent heat of vaporization, is extracted from the water formed during condensation.

When this additional amount of energy is extracted from the flue products, causing the water to become liquid, the fuel's energy density is identified as higher heating value (HHV). When the equipment used allows the water to remain in the vapor state, the energy density is identified as lower heating value (LHV). Thus,

$$\mathbf{LHV = HHV - h_{fg}\, mH_2 0} \qquad (2\text{-}1)$$

Where:

h_{fg} = Heat of vaporization of water per unit mass

$mH_2 0$ = Mass of water

The relationship between HHV and LHV can be derived from the basic combustion equation. The combustion equation for pure methane (CH_4), which is the primary constituent of natural gas, is:

$$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_20} \qquad (2\text{-}2)$$

This formula states that one molecule of methane combined with two molecules of oxygen forms one molecule of carbon dioxide and two molecules of water. Since the number of moles of a substance is identical to the number of molecules, the above equation can be expressed in molar mass as well. A mole is defined as the mass equal in numerical amount to the molecular weight of a substance. Thus, one mole of CH_4 equals 16.04 lbm (7.28 kg). Equation 5-2 now has the following form in English system mass units:

$$\mathbf{16.04\ lbm\ (CH_4) + 64.00\ lbm\ (O_2) = 44.01\ lbm\ (CO_2) + 36.03\ lbm\ (H_20)} \qquad (2\text{-}3)$$

Dividing both sides by molar mass of methane (16.04 lbm), the Equation yields all quantities on a mass per unit mass of methane basis:

$$\mathbf{1\ (CH_4) + 3.990\ (O_2) = 2.744\ (CO_2) + 2.246\ (H_20)} \qquad (2\text{-}4)$$

Thus, 2.246 lbm (kg) of water is produced for each lbm (kg) of methane burned. If, for example, methane is at the standard reference conditions of 14.73 psia and 60°F applicable to natural gas per ANSI Z132.1, it will have an ideal density of 0.04237 lbm/cf. The mass of water per unit volume of methane is 0.09516 lbm/cf. Steam tables give the latent heat of vaporization, in English system units, as 1059.8 Btu/lbm for water at 60°F and 14.73 psia. Therefore, ideal LHV for methane on standard volume basis is given by Equation 2-1 as:

$$\mathbf{LHV = HHV - h_{fg}\ mH_20 = 1012.0 - 1059.8 \times 0.09516 = 911.14\ Btu} \qquad (2\text{-}5)$$

As noted earlier, natural gas consists primarily of methane, with various but small amounts of ethane, butane, pentane, and other inert gases, such as carbon dioxide and nitrogen. Although the energy density of such mixtures may vary significantly, the LHV/HHV ratio remains reasonably close to 0.901 for most pipeline gases in the United States. For example, the above results for methane show LHV/HHV = 911.14/1012 = 0.9003. In calculations used for most applications, an average factor such as this affects the accuracy of the results very little and, therefore, is acceptable. In most commercial transactions, the energy density of a fuel is specified using its HHV. LHV is accounted for by the test procedures employed. For example, combustion efficiency of a boiler is generally computed by measuring losses and net output is determined by subtracting losses from the input calculated on HHV. One notable exception is internal combustion in which the net output is determined by direct measurement of torque at the flywheel, rather than subtraction of losses. For this reason, the performance of engines and other similar equipment is defined on an LHV basis, as this provides more reliable fuel consumption data. The reference temperature for the natural gas industry uses 60°F (15.55°C). The difference in values will be minor on a LHV basis, but can be significant on an HHV basis. [20]

CHAPTER 3

METHODOLOGY / PROJECT WORK

3.1 Methodology

3.1.1 Data Acquisition

An extensive data on flare gas compositions and other engineering parameters related to flare gas from as many local oil fields as possible is essential for this project. The data is use to be study the flare gas composition as the fact that different oil fields give different composition of flare gas. This study is important to this project as one of the project's objectives is to propose a flexible technical solution that will be usable at various fields.

This project will be concentrating on the local oil field to narrow the scope of work of this project. Yet, journals, paper works and technical articles about the flare gas from the other country will be as references for this project. The references are important for this project, as the references will be the information sources for this project to progress.

Meeting with the person who actually involve directly with the industry related the flare gas would be significant. This will help this project to improve time by time. From the discussion that will be done, many things about the process of flaring gas will be known. It will help this project to get a clearer picture of what is flare gas is all about and enhancing the knowledge of the flare gas.

3.1.3 Analysis Data

3.1.2.1 Gas Composition

The composition of the flare gas needs to be study. It is important to ensure the composition of the gas is possible to be a source of energy.

The composition of every platform differs from each another. Different composition means different approach in the ways of handling the gas. For example, in some places where the composition of H_2S is high, sweetening process takes place to sweet the sour gas while in other place there is no H_2S content in the gas. [19]

3.1.2.2 Heating Value

The next step for this project is calculating the heating value for the flare gas. The heating value of fuel gas is the amount of heat released during the combustion of a specified amount of it. The heating value is a characteristic for each substance. It is measured in units of energy per unit of the substance, usually mass, such as: kcal/kg, kJ/kg, J/mol, Btu/m^3.

The quantity known as is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. The quantity known as lower heating value (LHV) is determined by subtracting the heat of vaporization of the water produced by combustion from the higher heating value (HHV).[20]

Most applications which burn fuel produce water vapour which is not used, and thus wasting its heat content. In such applications, the lower heating value is the applicable measure. This is particularly relevant for natural gas, whose high hydrogen content produces much water.

$$\mathbf{LHV = HHV - h_{fg}\, mH_20}$$

Where:

h_{fg} = Heat of vaporization of water per unit mass

mH_20 = Mass of water

3.1.3 Evaluating Option

Existing technology has many approach of handling the flare gas. The best way of handling the gas should be consider in terms of economical benefits, engineering practicability, and the efficiency of the method and the effects of the method to the environment.

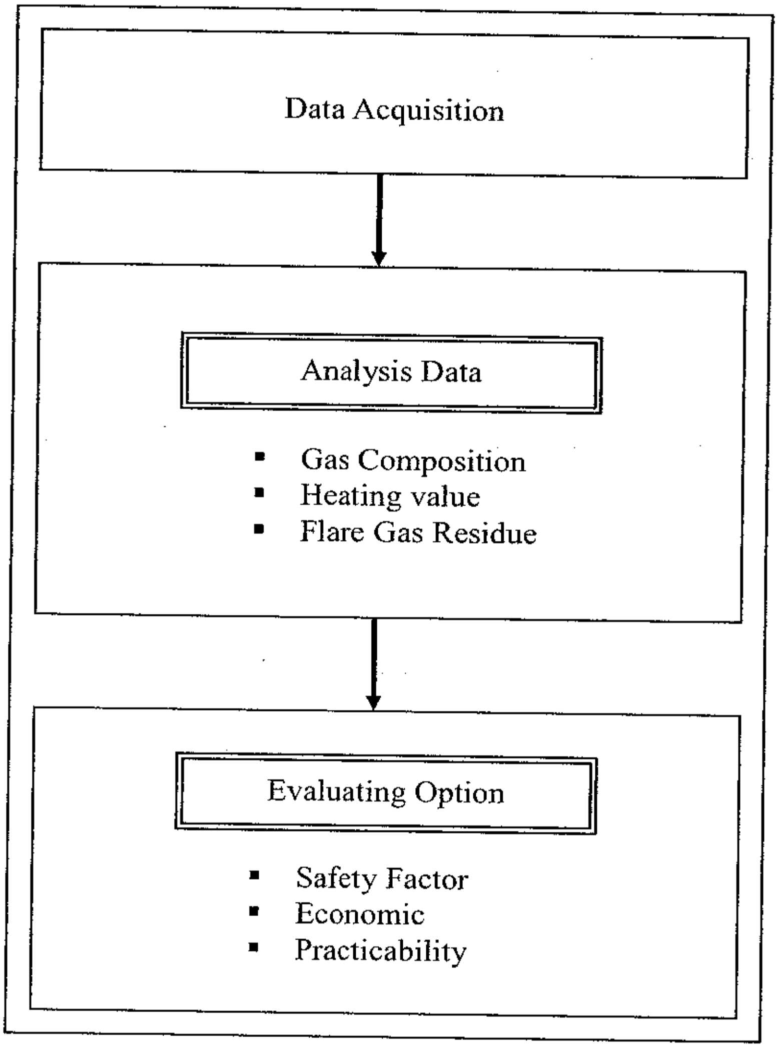


Figure 3.1: Flow Diagram of the Project Methodology

3.2 Project Work

3.2.2 Data

Flow units: mmscfd				
Maximum Flow Rate		1.69	1.02	41.00
Proces Type		Intermittent	Intermittent	Intermittent
Gas Composition : Mole%		Max Oil 200	Max Liq 100	Gas Blow By
Nitrogen	N_2	1.74	3.67	4.60
Carbon Dioxide	CO_2	4.55	4.29	2.35
Methane	CH_4	70.81	73.60	86.14
Ethane	C_2H_6	13.92	11.20	5.36
Propane	C_3H_8	2.75	2.05	0.61
I-Butane	C_4H_{10}	0.48	0.44	0.09
N-Butane	C_4H_{10}	0.52	0.51	0.09
I-Pentane	C_5H_{12}	0.13	0.13	0.02
N-Pentane	C_5H_{12}	0.10	0.10	0.02
Hexane	C_6H_{14}	0.10	0.09	0.02
Cyclohexane	C_6H_{12}	0.05	0.02	0.00
Mcyclopentane	C_6H_{12}	0.05	0.02	0.00
Benzene	C_6H_6	0.02	0.00	0.00
Heptane	C_7H_{15}	0.22	0.18	0.04
Cycloheptane	C_7H_{14}	0.02	0.00	0.00
Toluene	C_7H_8	0.00	0.00	0.00
n-Octane	C_8H_{18}	0.13	0.10	0.02
n-Nonane	C_9H_{20}	0.04	0.03	0.00
N-Decane	$C_{10}H_{22}$	0.02	0.02	0.00
Water	H_2O	4.35	3.55	0.64
		100	100	100

Table 3.1: Flare Gas Composition from Platform A in Sabah, Malaysia (LP Flare Tip)

Flow units: mmscfd			
Maximum Flow Rate		58.01	70.00
Proces Type		Intermittent	Intermittent
Gas Composition : Mole%			
Nitrogen	N_2	4.56	4.66
Carbon Dioxide	CO_2	4.55	2.31
Methane	CH_4	83.44	86.39
Ethane	C_2H_6	5.66	5.22
Propane	C_3H_8	4.72	0.57
I-Butane	C_4H_{10}	1.01	0.08
N-Butane	C_4H_{10}	1.34	0.02
I-Pentane	C_5H_{12}	0.50	0.02
N-Pentane	C_5H_{12}	0.10	0.02
Hexane	C_6H_{14}	0.17	0.02
Cyclohexane	C_6H_{12}	0.05	0.02
Mcyclopentane	C_6H_{12}	0.05	0.01
Benzene	C_6H_6	0.00	0.00
Heptane	C_7H_{15}	0.16	0.04
Cycloheptane	C_7H_{14}	0.02	0.00
Toluene	C_7H_8	0.00	0.00
n-Octane	C_8H_{18}	0.06	0.02
n-Nonane	C_9H_{20}	0.01	0.03
N-Decane	$C_{10}H_{22}$	0.00	0.03
Water	H_2O	0.14	0.54
		100	100

Table 3.2: Flare Gas Composition from Platform B in Sabah, Malaysia (HP Flare Tip)

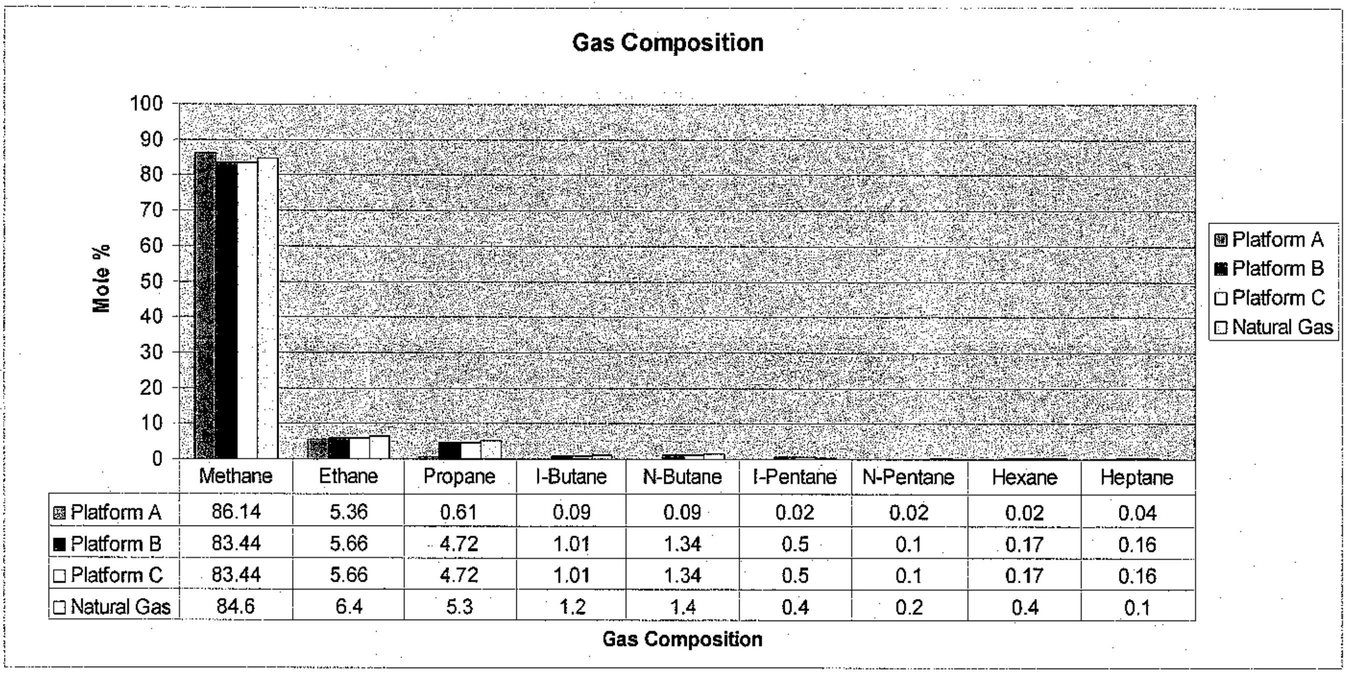
Flow units: kg/hr		
Maximum Flow Rate		4.12
Gas Composition : Mole%		
Nitrogen	N_2	0.08
Carbon Dioxide	CO_2	4.55
Methane	CH_4	83.44
Ethane	C_2H_6	5.66
Propane	C_3H_8	4.72
I-Butane	C_4H_{10}	1.01
N-Butane	C_4H_{10}	1.34
I-Pentane	C_5H_{12}	0.50
N-Pentane	C_5H_{12}	0.10
Hexane	C_6H_{14}	0.17
Cyclohexane	C_6H_{12}	0.05
Mcyclopentane	C_6H_{12}	0.05
Benzene	C_6H_6	0.00
Heptane	C_7H_{15}	0.16
Cycloheptane	C_7H_{14}	0.02
Toluene	C_7H_8	0.00
n-Octane	C_8H_{18}	0.06
n-Nonane	C_9H_{20}	0.01
N-Decane	$C_{10}H_{22}$	0.00
Water	H_2O	0.14
		100

Table 3.3: Flare Gas Composition from Platform C in Sabah, Malaysia

Category	**Component**		**Amount (%)**
Paraffinic	Methane	CH_4	70-98
	Ethane	C_2H_6	10-Jan
	Propane	C_3H_8	Trace-5
	Butane	C_4H_{10}	Trace-2
	Pentane	C_5H_{12}	Trace-1
	Hexane	C_6H_{14}	Trace-0.5
	Heptane and higher	C_7^+	None-trace
Cyclic	Cyclopropane	C_3H_6	Traces
	Cyclohexane	C_6H_{12}	Traces
Aromatic	Benzene,others	C_6H_6	Traces
Non-hydrocarbon	Nitrogen	N_2	Trace-15
	Carbon Dioxide	CO_2	Trace-1
	Hydrogen Sulfide	H_2S	Trace-occasionally
	Helium	He	Trace-5
	Other sulfur and nitrogen compounds		Trace-occasionally
	Water	H_2O	Trace-5

Table 3.4: Composition of Associated Natural Gas from a Petroleum Well
(adapted from Speight, 1999)[19]

3.2.3 Data Discussion



	Methane	Ethane	Propane	I-Butane	N-Butane	I-Pentane	N-Pentane	Hexane	Heptane
▨ Platform A	86.14	5.36	0.61	0.09	0.09	0.02	0.02	0.02	0.04
■ Platform B	83.44	5.66	4.72	1.01	1.34	0.5	0.1	0.17	0.16
☐ Platform C	83.44	5.66	4.72	1.01	1.34	0.5	0.1	0.17	0.16
☐ Natural Gas	84.6	6.4	5.3	1.2	1.4	0.4	0.2	0.4	0.1

Figure 3.2: Comparison Gas Composition

3.2.2.1 Discussion

From the figure above, the composition of the flare gas from the 3 set of data are almost the same with the composition of natural gas. The main component's composition, which is methane from the 3 sets of data are range from 85- 87 mole percent which is almost the same with the composition of methane.

Table 3.1, 3.2 and 3.3 show the composition of flare gas from 3 platforms in Sabah, Malaysia. From the tables, methane is the major component in the flare gas composition. The data has the same composition of the associated natural gas as shown in Table 3.4, which describes the composition of the associated natural gas from petroleum well.

According to James G. Speight (2002), natural gas is the gaseous mixture associated with petroleum reservoir and is predominantly methane. Besides methane, other paraffin hydrocarbons contain in the natural gas are ethane, propane and butane. Usually, these natural gases consist of nitrogen, carbon dioxide and hydrogen sulphide. [19]

The composition of natural gas varies from other wells. Type of natural gas differs from one another according to the composition of the gas. Generally, there are six type of natural gas, which are:

a) Dry Gas

   Dry gas also known as lean gas. Mostly consist of methane

b) Wet Gas

   Wet gas contains considerable amount of higher-molecular-weight and higher-boiling hydrocarbons.

c) Sour Gas

   This gas contains high proportions of hydrogen sulphide.

d) Sweet Gas

   Compare to sour gas, sweet gas contains little or no hydrogen sulphide.

e) Residue Gas

   Residue gas is the gas remaining, which is mostly methane, after the extraction of higher-molecular-weight paraffin.

f) Casinghead Gas

   This gas derived from an oil well by extraction at the surface.

Generally, natural gas main use is for fuel, but it also be used to make chemicals and liquefied petroleum gas.

Referring to the Table 3.1, 3.2 and 3.3, the composition of the flare gas from platform in Sabah, Malaysia is almost the same with composition of the associated natural gas in the Table 3.4. Besides that, Figure 3.2 shows that the composition of flare gas from platform A, B and C has the similarity with the natural gas composition. This shows that flare gas has the prospect to be turn into fuel, a source of energy.

3.2.4 Heating Value Calculation

Referring to Kenneth R. Hall and James C. Holste, the heating value of a natural gas is the absolute value of its enthalpy of combustion in an ideal combustion reaction. The heating value is, therefore, an ideal gas property that can be calculated unambiguously from tables of pure component values and it has no pressure dependence. [21]

An ideal combustion reaction with fuel and air in the ideal gas state and the possibility of water in the fuel and air is

$$\begin{aligned}
& C_\alpha H_\beta S_\gamma(id) + (\alpha + \beta/4 + \gamma)(1 + \epsilon)O_2(id) \\
&\quad + 0.04383(\alpha + \beta/4 + \gamma)(1 + \epsilon)Ar(id) \\
&\quad + [0.00162(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_C/(1 - x_N - x_C)]CO_2(id) \\
&\quad + [3.72873(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_N/(1 - x_N - x_C)]N_2(id) + (n_w^g \\
&\quad + n_w^a)H_2O(id) \\
&= [\alpha + 0.00162(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_C/(1 - x_N - x_C)]CO_2(id) \\
&\quad + n_w^v H_2O(id) + n_w^\ell H_2O(\ell) + \gamma SO_2(id) \\
&\quad + [3.72873(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_N/(1 - x_N - x_C)]N_2(id) \\
& + 0.04383(\alpha + \beta/4 + \gamma)(1 + \epsilon)Ar(id) + \\
&\qquad (\alpha + \beta/4 + \gamma)\epsilon O_2(id) \quad (1)
\end{aligned}$$

Where:

'id' : The ideal gas state
α : Stoichiometric coefficients
β : Stoichiometric coefficients
γ : Stoichiometric coefficients
ϵ : The fraction of excess air
n_w^g : Moles of water contained in the gas
n_w^a : Moles of water contained in the air
n_w^v : Moles of water contained in the product gas mixture
n_w^ℓ : Moles of gas which actually condense
x_c : Mole fraction of CO_2 in the gas
x_N : Mole fraction of N_2 in the gas

If the water formed in the reaction is assumed to be remained in the ideal gas state; the heating value is termed 'net'. If the water formed in the reaction condenses totally to the liquid state is assumed, the heating value is termed 'gross'. The gross heating value is greater than the net heating value by the ideal enthalpy of vaporization [21]

$$\textbf{Heating value (gross) - Heating value (net)} = \mathbf{H_w\,(id) - H_w\,(l)} \qquad \textbf{(2)}$$

For reporting, the heating value is measured on a mass or molar basis and converted to the ideal gas state. Therefore, at any given temperature the heating value is

$$Hn^{id} = \sum_{i=1}^{N} x_i Hn_i^{id} \qquad (3)$$

$$Hm^{id} = \sum_{i=1}^{N} x_i M_i Hm_i^{id} / \sum_{i=1}^{N} x_i M_i \qquad (4)$$

Where

Hn^{id} : Heating value in energy per mole
x : Mole fraction
N : The number of components in the mixture
Hm^{id} : Heating value in energy per mass
M : Molar mass.

Component	Mole Fraction
N_2	0.78102
O_2	0.20946
Ar	0.00918
CO_2	0.00034
	1.0000

Table 3.5: Assumed Composition of Air. [21]
(adapted from Jones, 1978)

In the natural gas industry, the heating value with dimensions of energy per volume is used in its calculations. These dimensions result from multiplying, Hn^{id} or, Hm^{id} by density or mass density of the ideal gas,

$$Hv^{id} = (P/RT)Hn^{id} = (MP/RT)Hm^{id} = \sum_{i=1}^{N} x_i Hv_i^{id} \qquad (5)$$

Where

Hv^{id} : Heating value in energy per volume
P : Absolute pressure
T : Absolute temperature
R : The gas constant (= 8.314471 J mol^{-1}.K = 10.7316 psia. ft^3Ibmol. °R).

The heating value in energy per volume depends upon temperature, composition and pressure. Table 3.6 includes the values for Hv^{id} at 15°C and 101.325 kPa. These values are only valid at the specified T and P. To convert to another pressure is by multiplying the ratio of the new P and 101.325 kPa. [21]

$$Hv^{id} = Hv^{id}(\text{Table2})[P/101.325]. \qquad (6)$$

The heating value data exist at 25°C based upon the reaction

$$C_{\alpha}H_{\beta}S_{\gamma}(id) + (\alpha + \beta/4 + \gamma)O_2(id) = \alpha CO_2(id) + (\beta/2)H_2O(\ell) + \gamma SO_2(id) \qquad (7)$$

The sensible heat effects to arrive at a different temperature is necessary to be corrected

$$Hn^{id}(T) = Hn^{id}(25) + \int_{25}^{T} \left[\sum_{p} C_{p}^{id} - \sum_{r} C_{p}^{id} \right] dT \qquad (8)$$

Where

$$\sum_{p} C_{p}^{id} = \alpha C_{p,CO_2}^{id} + (\beta/2) C_{p,H_2O}^{id} + \gamma C_{p,SO_2}^{id} \qquad (9)$$

Component	Formula	G^{id}	$>b/kPa^{-2}$	$Hv^{id}/kJ.m^{-3}$
Water	H_2O	0.6220	0.0237	18
Nitrogen	N_2	0.9672	0.0017	0
Carbon Dioxide	CO_2	1.5196	0.0075	0
Air		1.0000	0.0019	0
Methane	CH_4	0.5539	0.0044	37706
Ethane	C_2H_6	1.0382	0.0131	66067
Propane	C_3H_8	1.5226	0.0174	93936
i-Butane	C_4H_{10}	2.0068	0.0182	121404
Butane	C_4H_{10}	2.4912	0.0221	121792
i-Pentane	C_5H_{12}	2.4912	0.024	149363
Pentane	C_5H_{12}	2.9755	0.0305	149656
Hexane	C_6H_{14}			177554

Table 3.6: Properties of Natural Gas Components at 15°C and 101.325kPa [21]
(adapted from Jones, 1978)

$$\sum_{r} C_{p}^{id} = C_{p,C_\alpha H_\beta S_\gamma}^{id} + (\alpha + \beta/4 + \gamma) C_{p,O_2}^{id} \qquad (10)$$

Where

C_{p}^{id} : The ideal specific heat at constant pressure
r : Reactants
p : Products.

The cost of gas comes from the simple accounting equation

$$c = \dot{Q}^{id}p^{id}\Delta t \qquad (11)$$

Where

c : The cost

$\dot{Q}^{id}$: The ideal rate of energy transfer

p^{id} : The price of gas per ideal energy unit

Δt : The accounting period.

Using real gas rate of energy transfer merely requires a price of gas per real energy unit which would differ from that in equation (11) in exact proportion to the ratio of $\dot{Q}^{id}$ and $\dot{Q}$.

$$\dot{Q}^{id}p^{id} = \dot{Q}p \qquad (12)$$

$\dot{Q}^{id}$ results from multiplication of heating value by gas flow-rate.

$$\dot{Q}^{id} = \dot{n}Hn^{id} = \dot{m}Hm^{id} = \dot{V}^{id}Hv^{id} \qquad (13)$$

Where

$\dot{n}$, : Molar of ideal gas

$\dot{m}$: Mass of ideal gas

$\dot{V}^{id}$: Ideal gas flow-rates

To convert the real gas flow-rate into an ideal gas flow-rate to use in equation (13)

$$\dot{V} = \dot{V}^{id}Z \qquad (14)$$

Where Z is the compression factor (which is defined as the ratio of real gas volume to ideal gas volume). Thus, energy flow rate becomes

$$\dot{Q}^{id} = (\dot{V}/Z)Hv^{id} \qquad (15)$$

The factor 1/Z in equation (15) converts the real gas flow-rate into an ideal gas flow-rate.

The truncated virial equation of state satisfactorily represents Z at pressures near ambient

$$Z = 1 + BP/RT \qquad (16)$$

where B is the second virial coefficient which is a function only of temperature and composition.

$$-B/RT = \left[\sum_{i=1}^{N} x_i b_i\right]^2 \qquad (17)$$

$$b_i = \sqrt{\frac{-B_i}{RT}} \qquad (18)$$

Where the b_i are 'summation factors'. Table 3.6 lists values for b_i.

The molar mass of the gas from measurements of the gas relative density which is the mass density of gas divided by the mass density of air

$$G = d/d_a = MPT_aZ_a/M_aP_aTZ \qquad (19)$$

Where d is mass density and subscript a refers to air. If the P and T of gas and air are identical,

$$G = (M/M_a)(Z_a/Z) = G^{id}Z_a/Z \qquad (20)$$

Where G^{id} is ideal relative density and the molar mass ratio of gas to air. The molar mass of air for the assumed composition is 28.9625 g. mol^{-1}. G^{id} is a simple function of composition

$$G^{id} = \sum_{i=i}^{N} x_i G_i^{id} \qquad (21)$$

Table 3.6 lists values for G_i^{id}.

Accounting for water

If the gas contains water but the compositional analysis is on a dry basis, it is necessary to adjust the mole fractions to account for the fact that water has displaced some gas, thus lowering the heating value. [21] The mole fraction of water in the gas results from the definition of relative humidity

$$x_w = h^g P^{\sigma}_w / P = n_w/(1 + n_w) \qquad (22)$$

(Based upon one mole of the fuel $C_\alpha H_\beta S_\gamma$) where h^g is the relative humidity of the gas, P^{σ}_w is the vapour pressure of water and n_w denotes moles of water. For saturated gas h^g is unity. Rearranging equation (22) gives the moles of water

$$n_w = x_w/(1 - x_w) \qquad (23)$$

The corrected mole fractions then become

$$x_w(cor) = x_i\left[\frac{1}{1 + n_w}\right] = x_i\left[\frac{1}{1 + x_w/(1 - x_w}\right] = (1 - x_w)x_i \qquad (24)$$

and the heating value becomes

$$Hv^{id} = (1 - x_w)\sum_{i=1}^{N} x_i^{dry} Hv_i^{id} \qquad (25)$$

where water is not included in the n components of the summation. If the composited analysis determines x_w and water is included in the n components of the summation

$$Hv^{id} = \sum_{i=1}^{N} x_i^{wet} Hv_i^{id} - x_w Hv_w^{id} \qquad (26)$$

components	x	α	β	G^{id}	b	Hv^{id}	xα	xβ	xG^{id}	xb	xHv^{id}
CH_4	0.8344	1	4	0.5539	0.0044	37706	0.8344	3.3378	0.4622	0.0037	31464
C_2H_6	0.0566	2	6	1.0382	0.0091	66067	0.1132	0.3396	0.0588	0.0005	3740
C_3H_8	0.0472	3	8	1.5226	0.0131	93936	0.1417	0.3778	0.0719	0.0006	4436
iC_4H_{10}	0.0101	4	10	2.0068	0.0174	121404	0.0403	0.1007	0.0202	0.0002	1223
C_4H_{10}	0.0134	4	10	2.0068	0.0182	121792	0.0536	0.1339	0.0269	0.0002	1631
iC_5H_{12}	0.0050	5	12	2.4912	0.0221	149363	0.0250	0.0599	0.0124	0.0001	746
C_5H_{12}	0.0032	5	12	2.4912	0.0240	149656	0.0162	0.0389	0.0081	0.0001	485
C_6H_{14}	0.0017	6	14	2.9755	0.0305	177554	0.0101	0.0235	0.0050	0.0001	298
N_2	0.0008	0	0	0.9672	0.0017	0	0.0000	0.0000	0.0008	0.0000	0
CO_2	0.0239	0	0	1.5196	0.0075	0	0.0000	0.0000	0.0363	0.0002	0
sum	1.0000						1.2344	4.4121	0.7025	0.0056	44021

Table 3.7: Example calculation for data in Table 3.3 (gas analysis on dry basis)

Equation 22 : x^g = 0.0050
Equation 22 : x^a_w = 0.0086
Equation 21 : G^{id} = 0.7025
Equation 16 and 17 : Z = 0.9967
Equation 16 and 17 : Z_a = 0.9996
Equation 20 : G = 0.7045
Equation 25 : Hv^{id} = 43799 $kJ.m^{-3}$

From the calculation, the heating value for flare gas from table 3.3 is 43799$kJ.m^{-3}$. Below are the heating values from the other 2 sets of data:

- Flare Gas Composition from Platform A in Sabah, Malaysia (LP Flare Tip)
  - Case 1: 38360 $kJ.m^{-3}$
  - Case 2: 36020 $kJ.m^{-3}$
  - Case 3: 33580 $kJ.m^{-3}$
- Flare Gas Composition from Platform B in Sabah, Malaysia (HP Flare Tip)
  - Case 1: 33460 $kJ.m^{-3}$
  - Case 2: 33500 $kJ.m^{-3}$

Fuels	Lower Heating Value (LHV)			Higher Heating Value (HHV)			Density
Gaseous Fuels @ 32 F and 1 atm	Btu/ft3	Btu/lb	MJ/kg	Btu/ft3	Btu/lb	MJ/kg	grams/ft3
Natural gas	983	20,267	47.141	1089	22,453	52.225	22
Hydrogen	290	51,682	120.21	343	61,127	142.18	2.55
Still gas (in refineries)	1458	20,163	46.898	1,584	21,905	50.951	32.8

Table 3.8: LHV and HHV for gaseous fuels @ 32 F and 1 atm [22]

(Source: eia.doe.gov)

Comparing the data calculated for LHV for flare gas for 3 sets of data from the local oil and gas field with the standard value LHV for Natural gas, the differences between the calculated are obvious. Even though there are similarities in the composition of gas, but the value for LHV are significant. The differences of percentage mole of the other components such as ethane, propane and butane may result the differences in LHV. Besides that, the differences approach of calculating the LHV also may contribute to the differences of the value.

3.3 Option Available

Currently, there are a lot of ways to recover the flare gas to be reused again. This study will concentrating on the way of using the recovered flare gas as a source of energy by using the gas as fuel gas on the platform. Besides the flare gas recovery system, this study also will cover the acid gas removal system which is very important for the field that has the sour gas content.

3.3.1 Flare Gas Recovery

Generally, flare gas recovery system is must able to open quickly enough to avoid back pressuring equipment and systems connected to the flare header. Besides that, the system also must have the reliability that complies with relevant safety standards. A reliable method for re-ignition of the gas must in place for the recovery system and the flare gas recovery system should be simple and reliable.

3.3.1.1 Flare Gas Compressor by Aibel Gas Technology

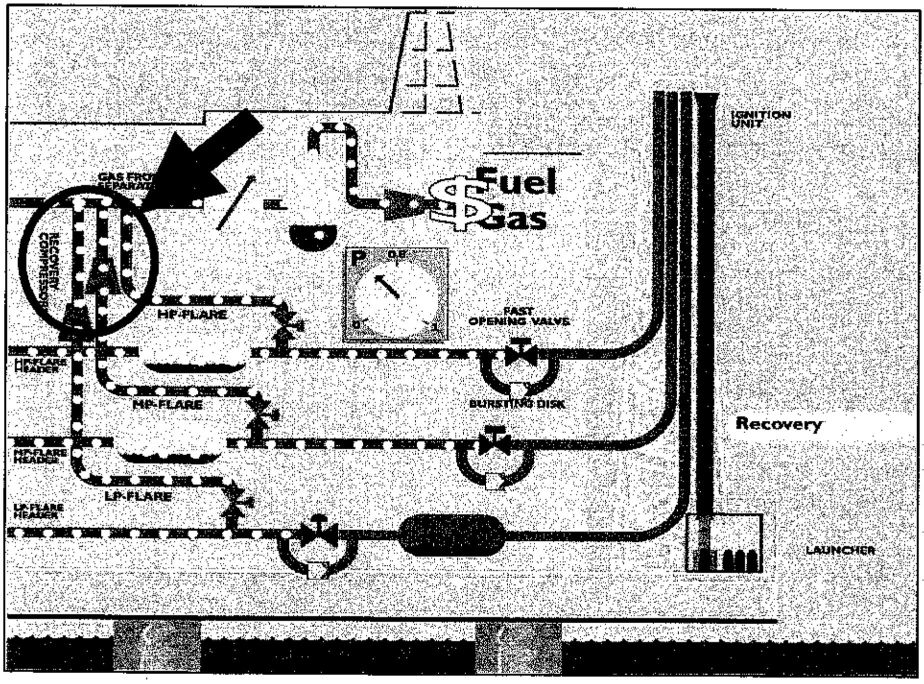


Figure 3.3: Flare gas recovery system [23]

(source: http://vgt.no/default.asp?k=46&id=81)

Aibel Gas Technology has introduced a flare gas recovery system that eliminates the need for continuous flaring of gas. The system compresses, and recovers these wasted gases and to be reused as fuel gas. [23]

- **System description**

The system installed a fast opening valve in the flare header and a bursting disc is fitted in parallel as a secondary protection. The system should capture the underlying flare gas that continuously leaks into the flare header during the normal operation and re-route it back into the gas processing facilities. [23] The fast opening valve opens if a process upset occurs and the gas will diverted to the flare.

3.3.1.2 Vapor Recovery Units (VRU)

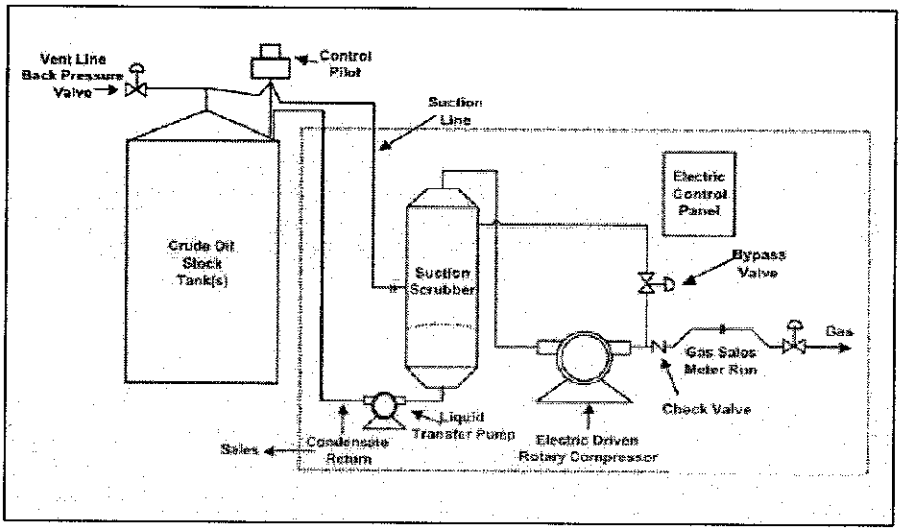


Figure 3.4: Vapor Recovery Units [24]
(Source: EPA Natural Gas STAR Partners)

VRU provides significant environmental and economic benefits for oil and gas producers. The gases flashed from crude oil and captured by VRUs can be used in facility operations. VRU is one of the options to prevent emissions of flare gas and yield significant economic savings. [24]

VRUs are relatively simple systems and have the ability to capture about 95 percent of the Btu-rich vapors for sale or for use onsite as fuel. These vapors that are supposed to be either vented, flared, or recovered by VRUs. The 95 percent of the recovered hydrocarbon emissions that has been capture will be stored in storage tanks.

3.3.3 Acid Gas Removal System

3.3.3.2. Neutralizer

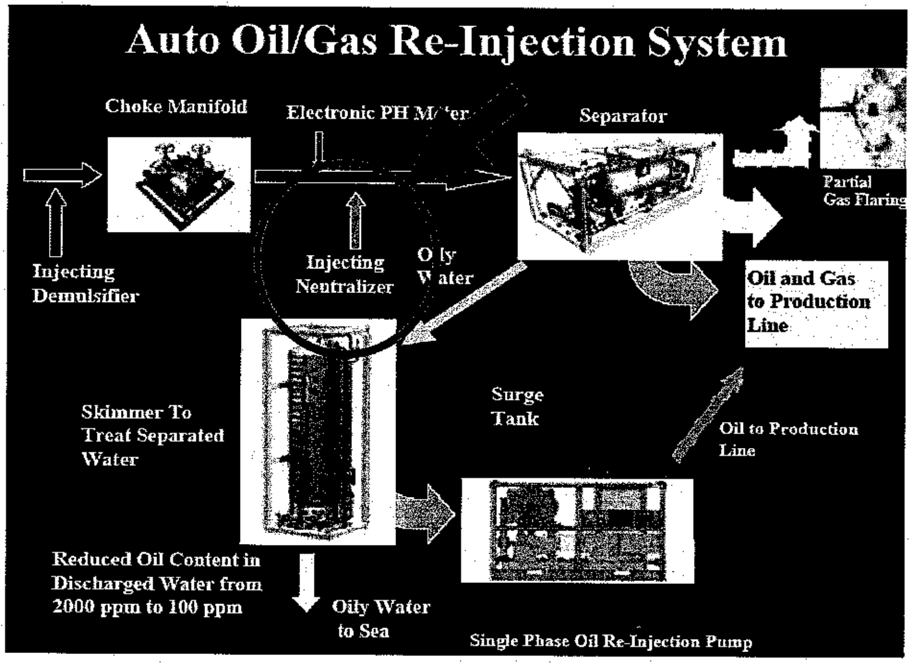


Figure 3.5: Auto Oil/Gas Re-injection System [25]

(Source: S. Kikuchi, A. F. Abu Sharkh, R. Manabe, Teiji Saito, Hassan I Khalil. 2004)

Referring to the Figure 3.5, compact acid neutralization unit was introduced to neutralize spend acid to obtain complete zero in flaring. 2% dilution of soda ash (Na2CO3) injected has been successfully neutralized the spent acid. An electrical PH meter has been introduced to measure the original fluid PH before passing through the acid neutralization system. [25]

3.3.3.2. Acid Gas Removal (Kvaerner process)

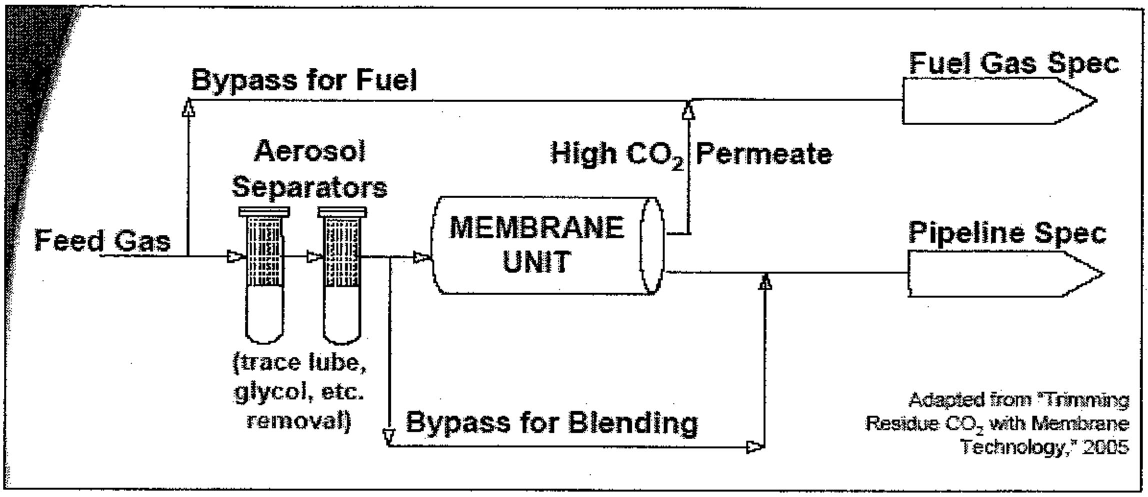


Figure 3.6: System for Acid Gas Removal (Kvaerner process) [26] (adapted from "Trimming Residue CO_2 with Membrane Technology," 2005)

The acid gas removal system above applies Diethanol Amine (DEA) units to absorb CO_2 and H_2S which are corrosive to pipelines, compressors, and other equipment. This system installs a Kvaerner membrane to ensure CO2 is separated from methane.

3.4 Economic Evaluation

There are 3 cases that had been set for economic evaluation for this study. The cases are:

i. **Economic Evaluation for Carbon Tax**

For this case, the value for carbon tax is referred to Appendix C and there is no flare gas recovery. The CO_2 production from the flaring is obtain from the calculation on Appendix D.

ii. **Economic Evaluation for Compressor**

For this case, the purchasing cost for the compressor is included (refer to Table 3.10) and the gas prices is set to be USD 8.29/Mscf (natural gas price on March 2008). [22] 95% of the flare gas is assumed to be recovered for this case.

iii. **Economic Evaluation for Vapor Recovery Unit (VRU)**

For this case, the price for VRU is obtained from Appendix E which capacity is set to be 100Mcfd. The gas prices is set to be USD 8.29/Mscf (natural gas price on March 2008) [22] and 95% of the flare gas is assumed to be recovered for this case. Besides that the price for compressor is include in this cases for the compression system of the recovered gas.

For the economic analysis, the value for the revenue is taken from the recovered flare gas and the price for the recovered flare gas is referred to the natural gas price on March 2008 [22]. This is because the recovered flare gas is assumed to replace the use of natural gas from gas sales pipeline for fuel gas on the platform.

3.4.1 Economic Evaluation for Carbon Tax

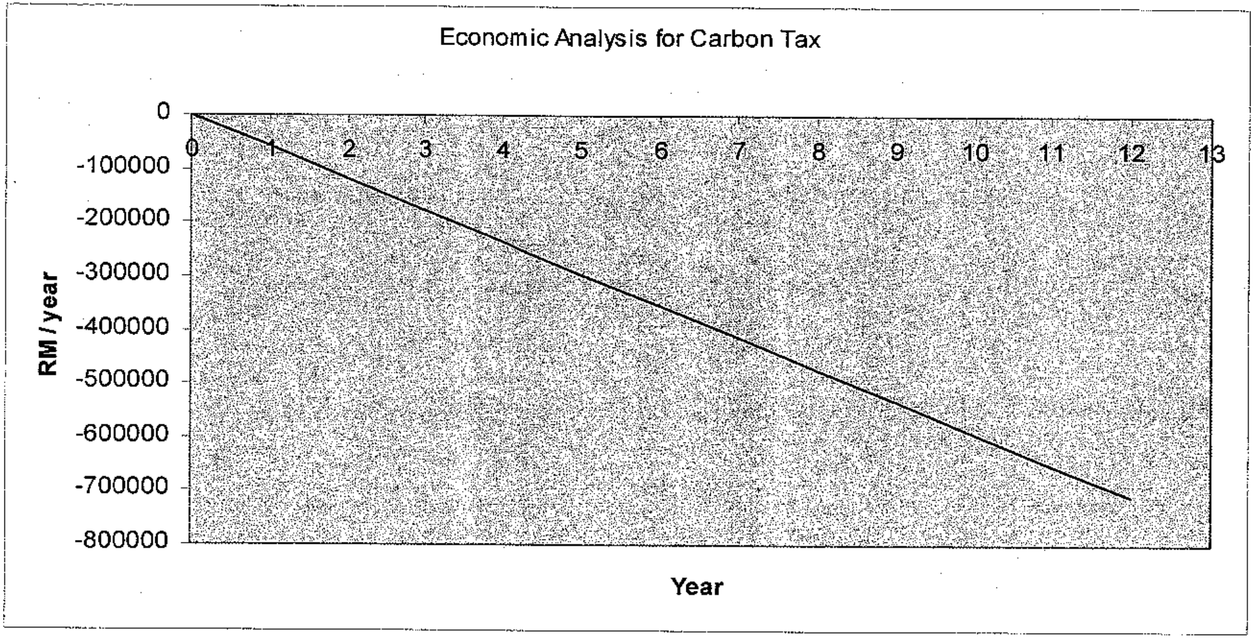


Figure 3.7: Economic Analysis for Carbon Tax

3.4.2 Economic Evaluation for Compressor

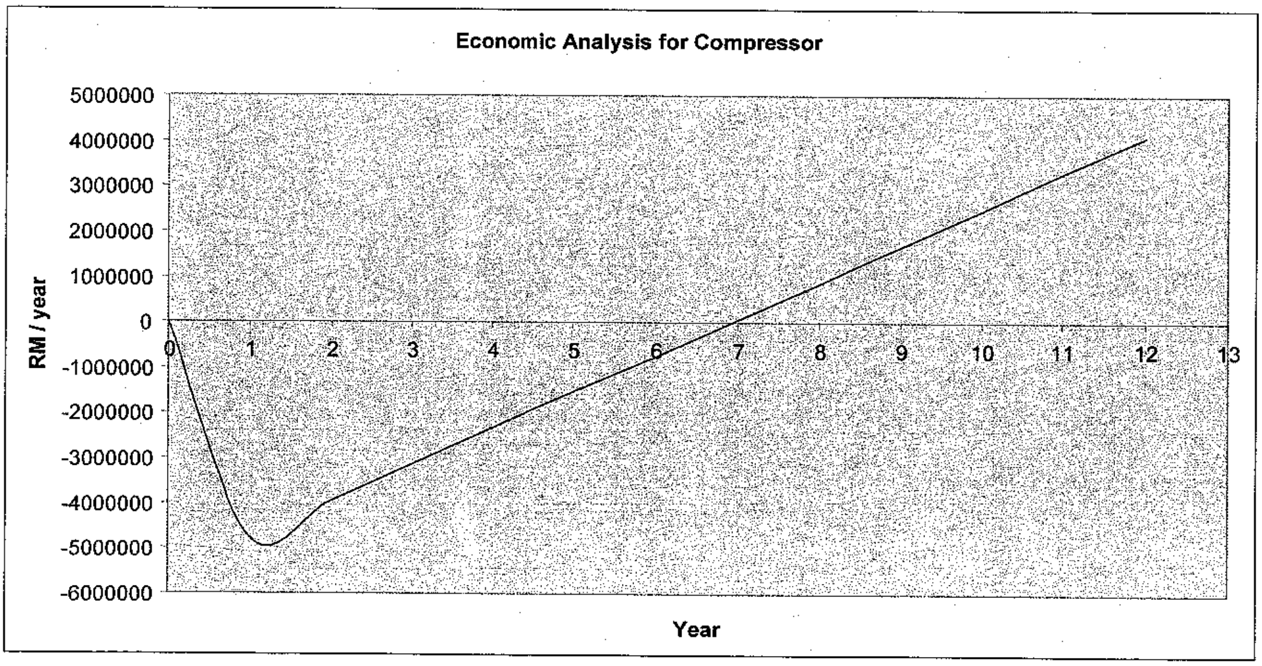


Figure 3.8: Economic Analysis for Compressor.

3.4.3 Economic Evaluation for Vapor Recovery Unit (VRU)

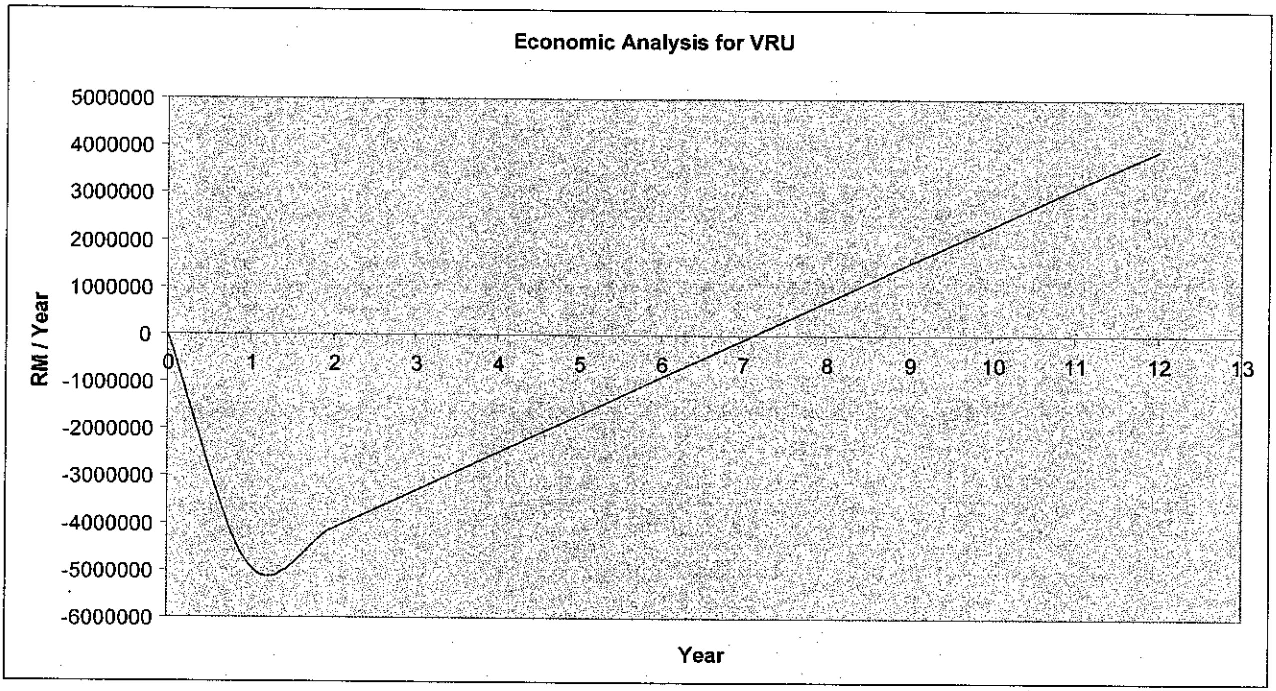


Figure 3.9: Economic Analysis Vapor Recovery Unit (VRU)

3.4.4 Economic Evaluation Discussion

From the Figure 3.7, the Carbon Tax is included in the analysis. By the end of 12th year of the implementation of the carbon tax, the cumulative value for the tax that has been paid is RM 710529.60 per platform.

For case 2, the payback period for the installation of the compressor is in the end of year 6. By the end of 12th year, the cumulative value gained from the installation of recovery compressor is RM4087919.10.

For case 3, the payback period for the installation of the VRU should be in the first quarter of the first year after the installation (refer to Figure 3.10). However, the system need to be installed with a compressor to compress the recovered gas from the VRU to route back the gas to the fuel gas system.

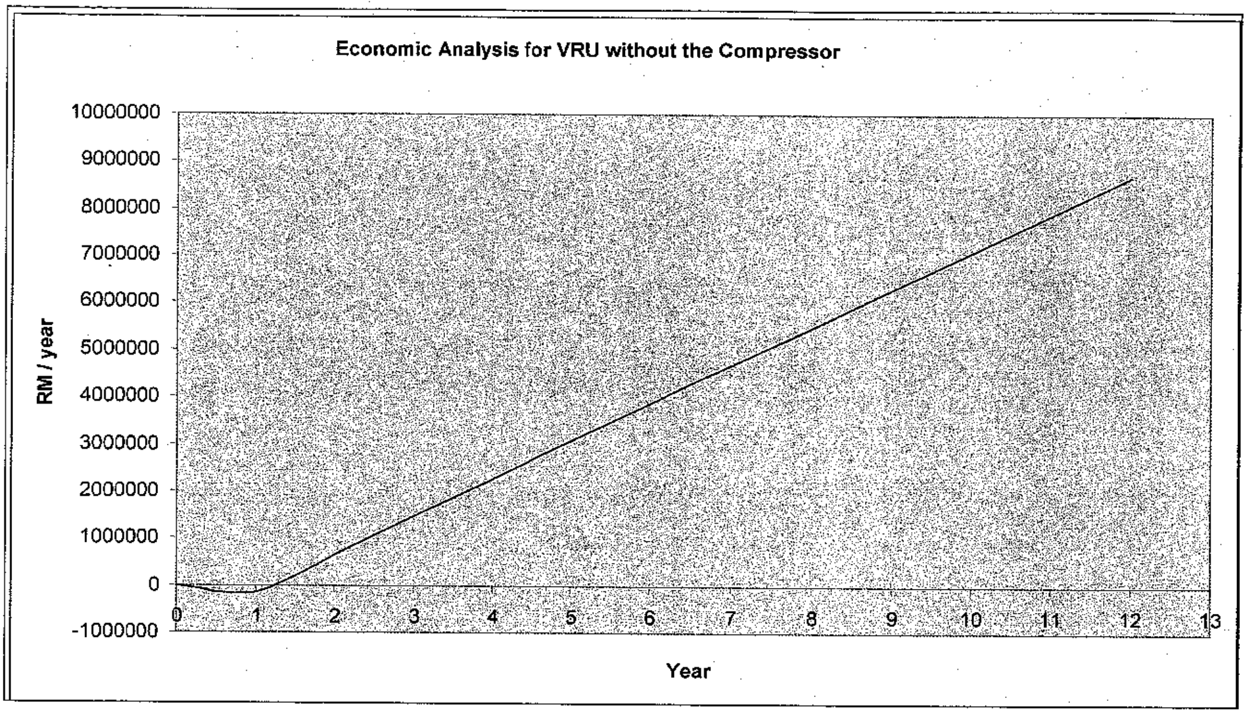


Figure 3.10: Economic Analysis Vapor Recovery Unit (VRU) without the Compressor

From Figure 3.9, the payback period for the installation of the VRU including the installation of recovery compressor is in the early of 7th year after the installation. By the end of the 12th year, the cumulative value regained for case 3 is RM 3931644.10.

In general, the carbon tax cost only RM 59210.80 yearly per platform for flaring. But then, in the long run, installing the recovery compressor will give profit as in the 12th year (refer to Figure 3.8), the value gained from the flare gas recovery will be RM 4087919.10. Compare to the case 3, installing the VRU will need the recovery compressor to be installed. The payback period for the case 3 is slightly late compare to the case 2. Moreover, installing the VRU will consume more space and consume more power for the equipments for the system. The space is critical because the platform has limited space. As a result, case 2 is recommended to be selected if the carbon tax is applied in this country.

3.5 Equipment Design

3.4.3 Compressor

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume.

Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. As gases are compressible, the compressor also reduces the volume of a gas. Liquids are relatively incompressible, so the main action of a pump is to transport liquids.

The main types of gas compressors are illustrated below:

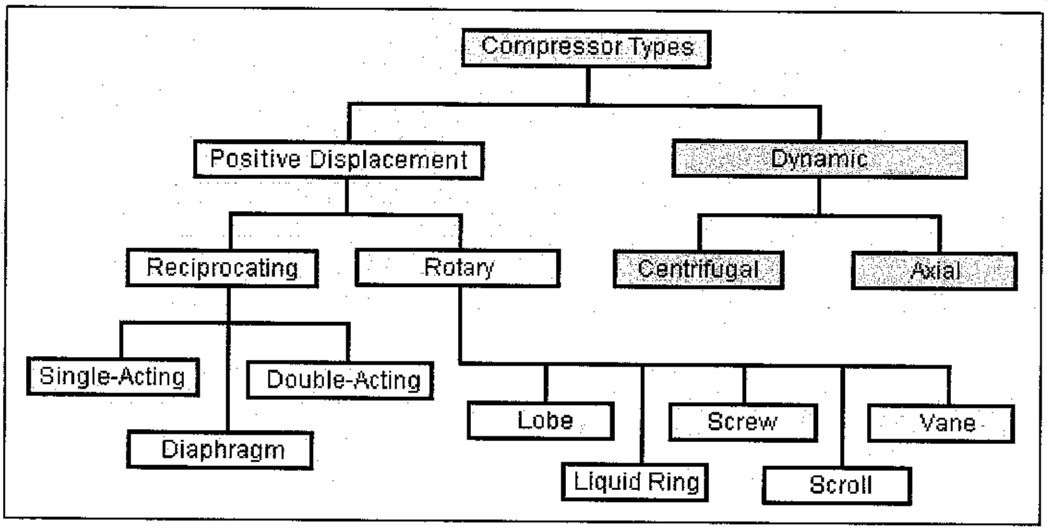


Figure 3.11: Types of compressors.

3.4.2 Process Design

Selection of Compressor

Centrifugal compressors are used throughout industry because they have fewer rubbing parts, are relatively energy efficient, and give higher airflow than a similarly sized reciprocating compressor (i.e. positive-displacement). Their primary drawback is that they cannot achieve the high compression ratio of reciprocating compressors without multiple stages. Centrifugal fan/blowers are more suited to continuous-duty applications such as ventilation fans, air movers, cooling units, and other uses that require high volume with little or no pressure increase.

In the centrifugal compressor, the fluid is fed into the pump at the center of a rotating impeller and is thrown outward by centrifugal force. The fluid at the outer periphery of the impeller attains a high velocity and consequently a high kinetic energy. The conversion of this kinetic energy to pressure energy supplies the pressure difference between the suction side and the delivery side of the pump.

Compressor Sizing Data (From HYSYS)

Parameter	Value
Molar Gas Flow Rate	854.2 kgmol/hr
Cp / Cv,	1.291
Gas Constant, R	8.314 kJ/kmol.K
Inlet Temperature, T_o	338.15 K
Outlet Pressure, P_2	4.400 bar
Inlet Pressure, P_1	1.135 bar

Table 3.9: Data for compressor calculation from HYSYS

Compressor Work Requirement

$$\boxed{Ws = \mu * \left(\frac{\gamma}{\gamma - 1}\right) RT_o \left[\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

$$\boxed{Ws = 854.2 * \left(\frac{1.291}{1.291 - 1}\right) 8.314 * 338.15 \left[\left(\frac{4.4}{1.135}\right)^{\frac{1.291-1}{1.291}} - 1\right]}$$

Ws = 3805546 kJ/hr
Ws = 1057.096 kW

For Actual Work,

$$\boxed{W_a = \left[\frac{W_s}{\eta_c \times \eta_m}\right]}$$

Assumption,

i. η_c = 0.8

ii. η_m = 0.9

So, actual work for Compressor is **1468.19kW** or **1968.87 hp**.

Compressor

Compressor Data Sheet	Equipment No.: K-002	
Compressor Type	Centrifugal	
Driver Type	Shaft-driven Electric Motor	
Material of construction	Carbon Steel	
No. of Stages, N	1	
Operating Data		
Work (kW)	1057	
Actual work (kW)	**kW**	**hp**
	1468.19	1968.87
Purchased Cost	**RM**	
	4765718	
Installed Cost	**RM**	
	14821383	
Total Installed Cost for Compressor	**RM**	
	19587101	

Table 3.10: Specification for compressor [29-31]

CHAPTER 4
CONCLUSION & RECOMMENDATION

4.1 RECOMMENDATION

To be able to do a proper feasibility study, more extensive data such as the Piping and Instrument Diagram (P&ID), Process Flow Diagram (PFD) and other related drawing will be needed to enhance the outcome of the project and also enhanced the understanding of the concept of the gas flaring system on certain platform.

Proper guides from the experienced person that related to the topic will be useful for this project. Even though this project has collaboration with the Group Technology and R&D Management from Research & Technology Division (R&T), PETRONAS, this project will produce a better result if this study can be done with other person from the process field. This will make the progress of the project going smoothly.

4.2 CONCLUSION

The data that was obtained through out the study shows that even though the composition of the flare gas similar to the composition of natural gas, but the LHV value for the flare gas differ a lot from the LHV value from the natural gas which has been set as a reference for the fuel gas.

The differences happened because of the differences approach of calculating the LHV for the gas. Besides that, the composition for the other components besides methane may affect the LHV value for the gas

Regarding the current situation in Malaysia, the recovery system for the flare is not economical. But, as the emission rate of CO_2 increasing year by year, it is not impossible that one day the oil and gas company that operates the platform will need to apply the recovery system for the flare to be use as source of energy. This may happened when the Carbon Tax starts to be implementing in this country. If this happened, the installation of the recovery compressor is recommended as the solution to the carbon tax as the recovery compressor has slightly quick payback period compare to the VRU with compressor and also consume less space compare to the VRU.

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APPENDICES

Appendix A: List of countries by carbon dioxide emissions per capita [17]

Rank	Country	1998	1999	2000	2001	2002	2003	2004
1	Qatar	60.3	56.9	60.1	66.3	67.4	63.1	69.2
2	Kuwait	33.8	32.6	31.7	28.8	27.1	31.1	38
3	United Arab Emirates	36.4	36	35.6	33.5	33.7	33.6	37.8
4	Luxembourg	17.4	17.9	18.9	19.5	21.1	22	24.9
5	Trinidad and Tobago	15.8	18.7	19.7	20.1	21.5	22.1	24.7
6	Brunei	10.7	13.3	17.2	16.1	15.1	12.7	24.1
7	Bahrain	28.8	27.4	27.8	26.4	30.6	31	23.9
8	Netherlands Antilles	19	18.3	18.7	19	19.2	22.7	22.2
9	Aruba	18.9	18.8	22.7	22.4	22.5	22.3	21.3
10	United States	19.8	19.9	20.4	20.1	20	19.8	20.4
11	Canada	15.3	15.6	16.2	16	17.1	17.9	20
12	Norway	9.4	10.1	9.9	11.6	15.8	18	19.01
13	Australia	17.8	18.4	18.3	19.1	18.2	18	16.3
14	Falkland Islands	13.6	13.1	12.7	13.9	13.8	15.1	14.8
15	Nauru	11.9	11.3	11.1	11	10.8	10.8	14.2
16	Estonia	12.6	11.6	11.7	12.1	11.8	13.6	14.1
17	Faroe Islands	14.4	14.4	14.2	14.1	14.1	14.2	13.8
18	Saudi Arabia	10.9	11.1	12.7	12.8	12.7	13	13.4
19	Kazakhstan	8	7.4	8.1	8.4	10.6	10.7	13.3
20	Gibraltar	11.3	11.7	12.1	12.4	12.6	13	13
21	Finland	10.9	10.7	10	10.9	11.8	13	12.6
22	Oman	7.1	8.7	9	9.9	12.2	12.9	12.5
23	Singapore	14.8	14.3	14.1	13.8	13.4	11.3	12.2
24	Palau	13	12.8	12.6	12	11.9	12.3	11.9
25	Montserrat	8.4	10.1	12.6	14.1	15.7	16	11.7
26	Czech Republic	11.5	10.6	11.6	11.6	11.2	11.4	11.48
27	Equatorial Guinea	0.6	0.6	0.6	0.6	9.7	9.4	11.47
28	New Caledonia	8.7	9.6	8.4	8.3	8.1	8.2	11.2
29	Israel	10.2	9.8	10.6	10.3	10.8	10.6	10.8
30	Russia	9.5	9.7	9.9	9.9	9.9	10.3	10.5
50	New Zealand	8.1	8.4	8.7	9.1	8.9	8.8	7.8
51	Spain	6.3	6.8	6.9	6.9	7.3	7.3	7.72
52	Italy	7.3	7.3	7.4	7.4	7.5	7.7	7.69
53	Iceland	7.6	7.4	7.7	7.4	7.7	7.6	7.6
54	Malaysia	5.2	4.8	5.5	5.8	5.9	6.4	7.05
55	Ukraine	6.3	6.4	6.2	6.3	6.4	6.6	6.98
56	Cayman Islands	7.6	7.3	7.1	6.9	6.9	7.1	6.98
57	Slovakia	7.4	7.2	6.6	6.9	6.9	7	6.7
58	Belarus	5.9	5.8	5.9	5.9	6	6.4	6.6
59	Venezuela	7	6.8	6.7	6.4	5.4	5.6	6.57
60	Seychelles	5.7	6.7	7.3	8.3	6.9	6.9	6.4

Table A-1: List of countries by carbon dioxide emissions per capita
(source: www.wikipedia.com/List_of_countries_by_carbon_dioxide_emissions_per_capita)

Appendix B: List of countries by GHG emissions per capita [18]

Rank	Country	Tonnes of CO2e (with land-use change)
1	Belize	93.9
2	Qatar	54.7
3	Guyana	52.5
4	Malaysia	37.2
5	United Arab Emirates	36.8
6	Kuwait	30.4
7	Papua New Guinea	29.2
8	Brunei	25.9
9	Australia	25.9
10	Antigua & Barbuda	25.3
11	Zambia	24.6
12	Canada	24.3
13	Bahrain	23.9
14	USA	22.9
15	Trinidad & Tobago	22.1
16	Luxembourg	21.2
17	Panama	19.7
18	New Zealand	19.3
19	Estonia	18.2
20	Botswana	17.8
21	Ireland	16.8
22	Saudi Arabia	16.5
23	Venezuela	15.8
24	Indonesia	14.9
25	Bolivia	14.8
26	Equatorial Guinea	14.5
27	Belgium	14.3
28	Turkmenistan	14.2
29	Singapore	14.1
30	Czech Republic	13.9
31	Liberia	13.9
32	Netherlands	13.5
33	Russia	13.5
34	Nicaragua	13.4
35	Finland	13.1
36	Oman	12.9
37	Palau	12.8
38	Brazil	12.8
39	Denmark	12.5
40	Germany	12.3
41	Mongolia	11.8
42	Israel	11.8
43	Nauru	11.7
44	Norway	11.4
45	South Korea	11.1
46	Kazakhstan	11
47	UK	11
48	Libya	10.8

Table A-2: List of countries by GHG emissions per capita

(source: www.wikipedia.com/ List_of_countries_by_greenhouse_gas_emissions_per_capita)

Appendix C: CO$_2$ tax rates for petroleum products

	Basic Tax	CO$_2$ Tax	SO$_2$ Tax	Total	CO$_2$ tax per tonne CO$_2$ emitted
Unleaded petrol	4.02	0.87		4.89	376
Leaded petrol content below 0,05g/l	4.26	0.87		5.13	376
Leaded petrol content above 0,05g/l	4.76	0.87		5.63	376
Autodiesel	3.35	0.435		3.785	164
Light mineral oil	0	0,435	0-0.07[1]	0.435-0.505	164
Heavy mineral oil	0	0.435	0.14-0.70[1]	0.575-1.135	140
Diesel, North Sea	0	0.87		0.87	328
Gas, North Sea	0	0.87		0.87	373
Coal	0	0.435		0.435	179
Coke	0	0.435		0.435	136

Table A-3: Tax rates for petroleum products (NOK/1), gas (NOK/Sm3) and coal and coke (NOK/kg) [31]

(source: Norway's second national communication under the Framework Convention on Climate Change, 1997)

Appendix D: CO_2 production calculation

Components	α	β	CO_2 (mole percent)
CH_4	1	4	1.0288807
C_2H_6	2	6	2.0319182
C_3H_8	3	8	3.0349557
iC_4H_{10}	4	10	4.0379932
C_4H_{10}	4	10	4.0379932
C_5H_{12}	5	12	5.0410307
iC_5H_{12}	5	12	5.0410307
C_6H_{14}	6	14	6.0440682
			30.2978706

Table A-4: CO_2 production calculation from data from Table 3.3

$$
\begin{aligned}
& \mathrm{C}_\alpha\mathrm{H}_\beta\mathrm{S}_\gamma(\mathrm{id}) + (\alpha + \beta/4 + \gamma)(1 + \epsilon)\mathrm{O}_2(\mathrm{id}) \\
&\qquad + 0.04383(\alpha + \beta/4 + \gamma)(1 + \epsilon)\mathrm{Ar}(\mathrm{id}) \\
&\qquad + [0.00162(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\qquad + x_C/(1 - x_N - x_C)]\mathrm{CO}_2(\mathrm{id}) \\
&\qquad + [3.72873(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\qquad + x_N/(1 - x_N - x_C)]\mathrm{N}_2(\mathrm{id}) + (n_w^g \\
&\qquad + n_w^a)\mathrm{H}_2\mathrm{O}(\mathrm{id}) \\
& = [\alpha + 0.00162(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_C/(1 - x_N - x_C)]\mathrm{CO}_2(\mathrm{id}) \\
&\quad + n_w^v\mathrm{H}_2\mathrm{O}(\mathrm{id}) + n_w^\ell\mathrm{H}_2\mathrm{O}(\ell) + \gamma\mathrm{SO}_2(\mathrm{id}) \\
&\quad + [3.72873(\alpha + \beta/4 + \gamma)(1 + \epsilon) \\
&\quad + x_N/(1 - x_N - x_C)]\mathrm{N}_2(\mathrm{id}) \\
& + 0.04383(\alpha + \beta/4 + \gamma)(1 + \epsilon)\mathrm{Ar}(\mathrm{id}) + \\
&\qquad\qquad (\alpha + \beta/4 + \gamma)\epsilon\mathrm{O}_2(\mathrm{id}) \qquad (1)
\end{aligned}
$$

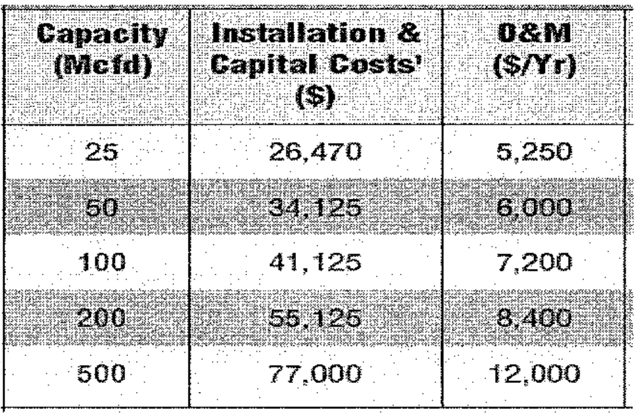
Referring to the above equation, by using the data from Table 3.3, the mole percent of CO_2 can be determined as in Table A- 4.

Molar Mass for CO_2	44.01	kg/kmol
MassFlow	4.12	kg/hr
MoleFlow	0.22123	kmol/hr

Production CO_2 for	1 day	70.7976327 kg
	1 year	25841.1359 kg

Carbon Tax	RM 59210.8025

Appendix E: Cost Analysis for VRU



Capacity (Mcfd)	Installation & Capital Costs' ($)	O&M ($/Yr)
25	26,470	5,250
50	34,125	6,000
100	41,125	7,200
200	55,125	8,400
500	77,000	12,000

Table A-5: Cost Analysis for VRU [24]
(Source: EPA Natural Gas STAR Partners)