THE STUDY OF INTERCHANGEABILITY IN LIQUEFIED NATURAL GAS (LNG) IN COMPARISON TO OTHER FUELS

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ABSTRACT

Natural gas interchangeability is the key subject in the industry today and most recently Liquefied Natural Gas (LNG) has emerged as a major source and differs substantially from domestically produced gas. Interchangeability means the characteristics of a design that allow direct placement of one item without requiring any modification. This research was a challenge, as it is difficult to find the suitable equipment and available equipment in the lab is limited to a lab scale only as the objective is to investigate to what degree LNG in its gaseous form is interchangeable and to show Wobbe Index (WI) is a measure of the fuel interchangeability. From the research that has been conducted, the key parameters used to investigate the interchangeability of a fuel gas WI, Calorific Value (CV), Air Fuel Ratio (A/F) and CARI (Combustion Air Requirement). This research is conducted by experiment, studying the methane as LNG and LPG (at different composition) using Boys calorimeter to find the CV and WI. Then, the Flame Propagation and Stability Unit are used to measure each fuel gases A/F and CARI index. As expected, the result showed that LNG has higher WI value that is 304.787 Btu/Ft^3 when compared to LPG with the value of 238.08 Btu/Ft^3, followed with Propane with the value 228.51 Btu/Ft^3 and Butane with the value of WI 210.816 Btu/Ft^3. As a conclusion, LNG has much better characteristics in interchangeability factor and higher heating value meaning higher Wobbe Index which is better performance in terms of interchangeability when compared to other fuel. It is safe to say LNG provides higher energy to the burner and provides much efficient as well as safer combustion process. The accuracy and the efficiency of this research could be improved by using a metered or digitalizing the Boy's Calorimeter and well as customizing the flame properties for the flame propagation and stability unit at a constant flame color and rate.

ABSTRAK

Kebolehsalingtukaran gas asli ialah subjek utama dalam industri hari ini dan Liquefied Natural Gas (LNG) muncul sebagai satu sumber utama dan berbeza dari gas yang dihasilkan secara domestik. Kebolehsalingtukaran bererti ciri-ciri satu rekaan yang membenarkan pengantian alatan tanpa memerlukan sebarang pengubahsuaian. Penyelidikan ini merupakan satu cabaran, kerana ia agak sukar untuk mencari alat yang sesuai dan peralatan yang sedia ada dalam makmal terhad kepada skala makmal kerana objektif penyelidikan ini ialah untuk menyiasat darjah LNG dalam bentuk gasnya mampu saling bertukar dan menunjukkan Wobbe Index (WI) ialah satu langkah kebolehsalingtukaran bahan api. Dari kajian, parameter utama yang digunakan untuk menyiasat pertukaran dari bahan bakar gas adalah WI, Nilai Kalori (CV), Air Fuel Ratio (A / F) dan CARI (Keperluan Pembakaran Udara). Penyelidikan ini dilakukan melalui percubaan, mempelajari metana sebagai LNG dan LPG (pada komposisi yang berbeza) menggunakan kalorimeter Boys untuk mencari CV dan WI. Kemudian,Unit propagasi api dan kestabilan digunakan untuk mengukur bahan bakar bagi setiap gas untuk A/F dan indeks CARI. Seperti yang diharapkan, hasilnya menunjukkan bahawa LNG mempunyai WI nilai yang lebih tinggi iaitu 304,787 Btu/Ft^3 bila dibandingkan ke LPG dengan nilai 238,08 Btu/Ft^3, diikuti dengan Propane dengan 228,51 Btu/Ft^3 nilai dan Butana dengan nilai 210,816 Btu WI/ ft^3.Sebagai kesimpulan, LNG mempunyai ciri-ciri yang jauh lebih baik dalam faktor saling pertukaran dan nilai pemanasan yang lebih tinggi bermakna lebih tinggi Indeks Wobbe yang prestasi yang lebih baik bila dibandingkan dengan bahan bakar yang lain. Adalah selamat untuk dikatakan, LNG memberikan lebih tenaga dan lebih cekap serta selamat. Ketepatan dan kecekapan kajian ini dapat dipertingkatkan dengan menggunakan kilometer Boy’s yang bermeter atau berbentuk digital dan juga mengubah sifat api untuk unit propagasi api dan kestabilan pada warna nyalaan konstan dan stabil.

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LIST OF ABBREVIATIONS

A/F	: Air to Fuel Ratio
Btu	: British thermal unit
Btu/lb	: Pound per British thermal unit
Btu/Ft^3	: Cubic foot per British thermal unit
C	: Carbon
CARI	: Combustion Air Requirement Index
CH_4	: Methane
C_2H_6	: Ethane
C_2H_8	: Propane
C_4H_{10}	: Butane
C_5H_{12}	: Pentane
C_6H_{14}	: Hexane
C_7H_{16}	: Heptane
C_8H_{18}	: Octane
CO	: Carbon Monoxide
CO_2	: Carbon Dioxide
CV	: Calorific Value
F	: Fahrenheit
GVF	: Gas Volume Factor

H	: Hydrogen
H_2O	: Water
HGV	: Heavy Good Vehicles
lb /US gal	: Pound per gallon
LNG	: Liquefied Natural Gas.
LPG	: Liquefied Petroleum Gas.
LFL	: Lower Flammability Limit.
M – 85	: Methanol
m^2	: Meter square
m^3	: meter cubic
MJ/kg	: Mega joule per kilogram
MJ/m^3	: Mega joule per meter cubic
mL	: milliliter
Nm^3	: Newton meter cube
NO_x	: Nitrogen Oxide
O_2	: Oxygen
Kg /m^3	: kilogram per meter cube
N_2	: Nitrogen
Revs	: Revolution
UFL	: Upper Flammability Limit.
US	: United States

W	: Weight
WI	: Wobbe Index

LIST OF SYMBOLS

°C	: Celsius
ΔT	: Temperature difference

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Liquefied natural gas (LNG) is natural gas (predominantly methane, CH_4) that has been converted temporarily to liquid form for ease of storage or transport. The main advantage of liquefaction process is the reduction by about 600 times of the total volume required for natural gas storage and transportation (Rafael Rosal et al., 2008). It is odorless, colorless, non-toxic and non-corrosive. Hazards include flammability, freezing and asphyxia. The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water, and heavy hydrocarbons, which could cause difficulty downstream. The natural gas is then condensed into a liquid at close to atmospheric pressure (maximum transport pressure set at around 25kPa or 3.6psi) by cooling it to approximately −162°C (−260 F). The reduction in volume makes it much more cost efficient to transport over long distances where pipelines do not exist. Where moving natural gas by pipelines is not possible or economical, it can be transported by specially designed cryogenic sea vessels (LNG carriers) or cryogenic road tankers. Figure 1 shows the typical LNG composition.

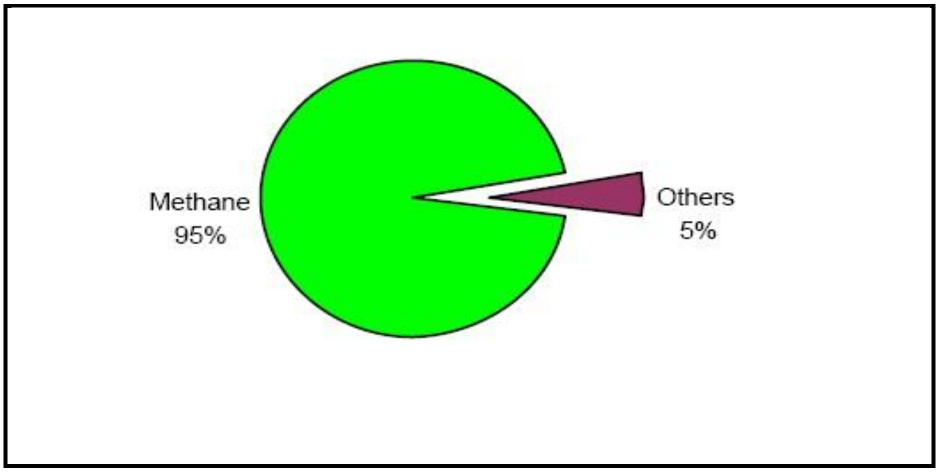

Figure 1.1: Typical LNG Composition

(Source: Center for Energy Economics, et al., 2007)

Natural Gas liquefaction dates back to the 19^{th} century when British Chemist and Physicist Michael Faraday experimented with liquefying different types of gases including natural gas. German engineer Karl Von Linde built the first practical compressor refrigeration machine in Munich in 1873. The first NG plant was built in West Virginia in 1912 and began operation in 1917. The first commercial liquefaction plant was built in Cleveland, Ohio, in 1941. The LNG was stored in tanks at atmospheric pressure.

The liquefaction of natural gas raised the possibility of its transportation to distant destinations. In January 1959, the world's first LNG tanker, The Methane Pioneer, a converted World War II liberty freighter containing five, 7000 barrel equivalent aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, carried in LNG cargo from Lake Charles, Louisiana to Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean (Michelle Michot Foss, 2007). Figure 2 shows the liquefied natural gas production and refueling option diagram.

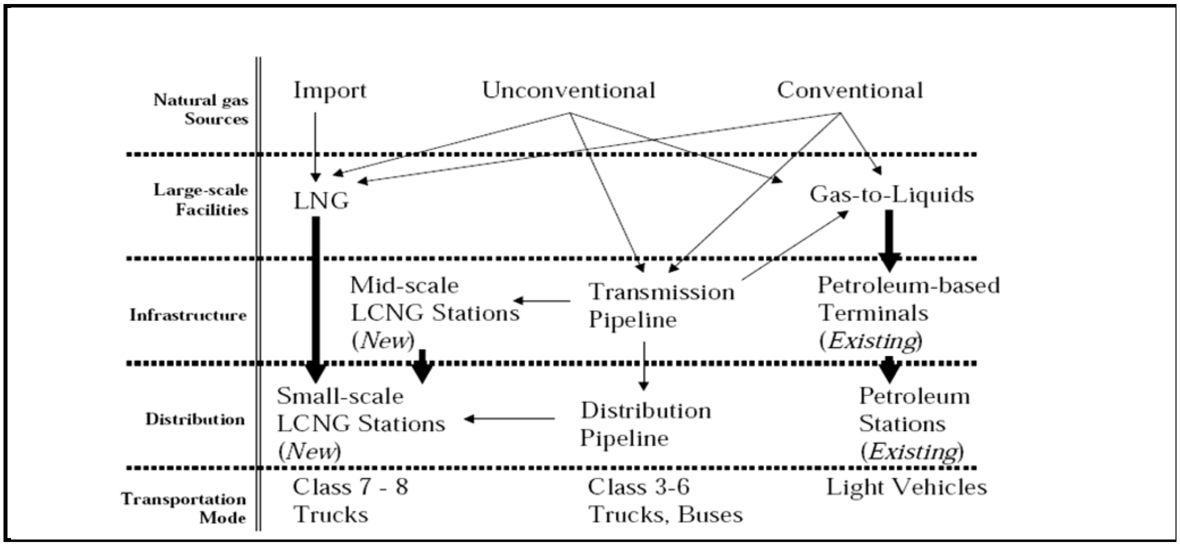

Figure 1.2: Liquefied Natural Gas Production and Refueling Options

(Source: Wegrzyn, J, et.al., 1998)

The LNG must be stored and transported permanently at around this temperature and this is accomplished by super insulation in a pressurized, double tank system, similar in principle to a thermos flask, together with a venting system to take away vapor. The storage pressure of about 8 bar (8 x atmospheric) is not regarded as very high but because of the insulation requirements the tanks are large, the fuel is only suited to large, heavy diesel vehicles such as trucks, buses and HGV's (Envocare et al., 2007). LNG is the liquid form of natural gas people use in their homes for cooking and heating. Natural gas is also used as fuel for generating electricity. Natural gas and its component are used as raw material to manufacture a wide variety of products, from fibers for clothing, to plastics for healthcare, computing and furnishing (Center for Energy Economics et al., 2007).

1.1.1 LNG Industry in Malaysia

Malaysia LNG operates the world's largest LNG production facility in a single location; it has eight production units in three integrated plants and a total production capacity of 23 million tons per year. The country is the world's third largest exporter of LNG. Malaysia LNG is keen to maintain its position as a world-class operator and embarked on a project to review and improve its energy usage in 2005 (Shell Global Solution).

LNG is simply a natural gas that has been treated to remove impurities, and then condensed to a liquid form. The unique economics of the LNG industry usually dictate that heavier ethane-plus components are not removed down to the levels commonly found in US domestic pipeline gas. At the same time, LNGs usually contain little or no carbon dioxide or nitrogen both commonly present in domestic natural gases (Gas Technology Institute et al., 2003).The benefits of LNG include low pressure storage and greater energy density per volume. As a result LNG has the greatest potential for medium-heavy duty applications where users require low-cost, low-weight fuel storage options with increased driving range.

1.2 PROBLEM STATEMENT

The limitation in this research are, first, is to find out what are the other equipment that are available in the gas engineering lab to conduct the interchangeability test that are done mostly with big or industrial scale equipment. Second, the research is to compare the interchangeability of Liquefied Natural Gas, LNG (99.5% of purity) with Liquefied Petroleum Gas (LPG) at different composition (pure propane 96% purity, pure butane 96% and the composition of 70% propane and 30% butane). The next problem is to find out what is the basic parameter can used in measuring interchangeability of the fuel.

1.3 OBJECTIVES

The objective of this project is to investigate to what degree LNG in its gaseous form is interchangeable or compatible with existing utilization equipment. The next objective is to run, analyze different kind of fuel for different kind criteria of the fuel experimentally. Then, the physical terms of LNG and LPG is compared. Lastly, the objective is to show Wobbe index is a measure of the fuel interchangeability with respect to its energy content and metered air fuel ratio (A/F ratio).

1.4 SCOPE OF STUDY

The scope of study in this research is to investigate experimentally the alternate ways to find the key parameter that can be used to measure the interchangeability of LNG and LPG. In the industry, most of the interchangeability test is conducted using industrial scale equipment such as gas turbine and knock engines, and the equipment available in the laboratory is limited only to the industrial scale unit, so we are to find what are the equipment available for the research.

1.5 RATIONALE AND SIGNIFICANCE

This research is conducted to determine interchangeability of LNG to other conventional fuel and to find out experimentally whether LNG is efficient, cleaner, safer and economical in the performance value.

CHAPTER 2

LITERATURE REVIEW

2.1 LIQUEFIED NATURAL GAS (LNG)

LNG is natural gas which has been converted to liquid form for ease of storage or transport. LNG takes up about 1/600th of the volume of natural gas. Depending upon its exact composition, natural gas becomes a liquid at approximately -162°C (-259°F) at atmospheric pressure. LNG's extremely low temperature makes it a cryogenic liquid. Generally, substances which are -100°C (-48°F) or less are considered cryogenic and involve special technologies for handling. In comparison, the coldest recorded natural temperatures on earth are -89.4°C (-129°F) at the height of winter in Antarctica and the coldest reported temperature in a town was recorded in Oymayakon (Sakha Republic) during Siberian winter (-71.2°C; -96.16°F). To remain a liquid, LNG must be kept in containers which function like thermos bottles they keep the cold in and the heat out. The cryogenic temperature of LNG means it will freeze any tissue (plant or animal) upon contact and can cause other materials to become brittle and lose their strength or functionality. This is why the selection of materials used to contain LNG is so important.

2.1.1 Chemical Composition of LNG

Natural gas is a fossil fuel, meaning it has been created by organic material deposited and buried in the earth millions of years ago. Crude oil and natural gas constitute types of fossil fuel known as "hydrocarbons" because these fuels contain chemical combinations of hydrogen and carbon atoms. The chemical composition of natural gas is a function of the gas source and type of processing. It is a mixture of methane, ethane, propane and butane with small amounts of heavier hydrocarbons and some impurities, notably nitrogen and complex sulphur compounds, water, carbon dioxide and hydrogen sulphide which may exist in the feed gas but are removed before liquefaction. Methane is by far the major component, usually, though not always, over 85% by volume. Table 2.1 displays the chemical compositions of the hydrocarbon compounds which make up natural gas, and the volume ranges in which they may be present in LNG. Pipeline natural gas may contain small amounts of water vapor.

Table 2.1: Typical chemical composition of LNG

Chemical	Chemical Formula	Low	High
Methane	CH_4	87%	99%
Ethane	C_2H_6	<1%	10%
Propane	C_3H_8	>1%	5%
Butane	C_4H_{10}	>1%	>1%
Nitrogen	N_2	0.1%	1%
Other Hydrocarbons	Various	Trace	Trace

(Source: Center for Energy Economics)

2.1.2 Boling Point of Liquefied Natural Gas (LNG)

The boiling point of LNG varies with its basic composition, but typically is -162°C (-259°F).

Figure 2.1: LNG “boiling” at atmospheric pressure and temperature.

(Source: Osaka Gas Co. Ltd)

When cold LNG comes in contact with warmer air, water, or the environment, it begins to “boil” at that interface because the surrounding temperatures are warmer than the LNG’s boiling point, as shown in Figure 2.1. Table 2.2 shows the boiling points of water and common gases.

Table 2.2: Boiling points of water and some common gases.

Fahrenheit(°F)	Celsius (°C)	Occurrence
212	100	Water Boils
31	-0.5	Butane Boils
-27	-33	Ammonia Boils
-44	-42	Propane Boils
-259	-162	LNG Boils
-298	-183	Oxygen Boils
-319	-195	Nitrogen Boils
-422	-252	Hydrogen Boils
-454	-270	Helium Boils
-460	-273	Absolute Zero

(Source: Adapted from the Engineering Toolbox)

Note: Absolute zero is the coldest temperature theoretically possible, and cannot be reached by artificial or natural means. By international agreement, absolute zero is defined as precisely 0 K on the Kelvin scale and is equivalent to -273.15°C/-459.67°F.

2.1.3 Density and Specific Gravity of Liquefied Natural Gas (LNG)

Density is a measurement of mass per unit of volume and is an absolute quantity. Because LNG is not a pure substance, the density of LNG varies slightly with its actual composition. The density of LNG falls between 430 kg/m3 and 470 kg/m^3 (3.5 to 4 lb/US gal). LNG is less than half the density of water; therefore, as a liquid, LNG will float if spilled on water.

Specific gravity is a relative quantity. The specific gravity of a liquid is the ratio of density of that liquid to density of water (at 15.6°C/60°F). The specific gravity of a gas is the ratio of the density of that gas to the density of air (at 15.6°C). Any gas with a specific gravity of less than 1.0 is lighter than air (buoyant). When specific gravity or relative density is significantly less than air, a gas will easily disperse in open or well-ventilated areas. On the other hand, any gas with a specific gravity of greater than 1.0 is heavier than air (negatively buoyant). The specific gravity of methane at ambient temperature is 0.554; therefore it is lighter than air and buoyant.

Under ambient conditions, LNG will become a vapor because there is no place on earth with a temperature of -162°C (-259°F). As LNG vaporizes, the cold vapors will condense the moisture in the air, often causing the formation of a white vapor cloud until the gas warms, dilutes, and disperses as shown in Figure 2.2.

Figure 2.2: LNG vapor cloud created for training at Texas A & M in the LNG Live Fire Training Workshop, 2005

(Source: Photograph by A.H. Walker)

For a relative humidity higher than 55%, the flammable cloud is totally included in the visible vapor cloud. If the relative humidity is less than 55%, the flammable cloud can be partially or completely outside of the visible cloud, which means that the vapors could be ignited even though the ignition source is distant from the visible vapor cloud. The size of the vapor cloud will depend on wind speed, direction, and other weather conditions and can easily be predicted by the appropriate related calculations. These very cold vapors will rise as they are sufficiently warmed by ambient air.

LNG vapors at the boiling point temperature (-162°C/ -259°F) and atmospheric pressure have a relative density of about 1.8, which means that when initially released, the LNG vapors are heavier than air and will remain near the ground. However as methane vapors begin to rapidly warm and reach temperatures of approximately -110°C/-166°F, the relative density of the natural gas will become less than 1 and the vapors become buoyant.

At ambient temperatures, natural gas has a specific gravity of about 0.6, which means that natural gas vapors are much lighter than air and will rise quickly. Cold LNG vapors (below -110°C/-166°F) are negatively buoyant and more likely to accumulate in low areas until the vapors warm. Therefore, a release of LNG that occurs in an enclosed space or low spot will tend to replace the air (and oxygen) and make the area a hazard for breathing.

The rate of LNG vapor ascent depends upon the quantity of LNG released, ambient weather conditions, and where the LNG is released, e.g., confined or unconfined, low or elevated area, on land or on water. One strategy to manage the vapors is to create a downwind water curtain which helps block and/or divert the vapors away from possible ignition sources until the vapors warm and become buoyant, and/or dilute to a lesser concentration outside the flammable limits, which are discussed in the next section.

Heat input to LNG in any form will enhance vaporization and dispersion. Such heat may be transferred from passive sources such as atmospheric humidity (which is a significant source), the ground or spill catchment areas, impoundments, pits and structures. LNG vaporizes five times more quickly on water than on land, depending