LIQUEFIED PETROLEUM GAS (LPG) STORAGE DESIGN

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ABSTRACT

Liquefied Petroleum Gas (LPG) is common fuel used for domestics, industrial and commercial appliances in Malaysia. Homes in Malaysia get LPG cylinders in various sizes offered by supplier, but most of them using 14kg cylinder. Generally, LPG composed of volatile low boiling point gases – ethane, propane, propene, *iso*-butane, *n*-butane, but-1-ene, *iso*-butene, *trans*-2-butene, *cis*-2-butene, and also *iso*-pentane and *n*-pentane due to the availability of higher boiling point components. When LPG is used, the low boiling point components will evaporate and the high boiling point components will stay in the cylinder. The research aimes to design an exploratory instrumentation for liquid LPG sampling under pressure, to explore the composition of liquid LPG in the LPG cylinder used in Malaysia and conclude whether some of the product might stay in the cylinder as liquid component after the volatiles are used. When the availability of high boiling point components which in turn will stay in the cylinder after it is empty from low boiling point components was proved, the research aimes to recommend a new idea for LPG cylinder design that is more energy-efficient. The first stage of the research was to design the easy and safe exploratory instrumentation for liquid LPG sampling under pressure and collect a sample. Then, the second stage is to determine the LPG composition using the available gas chromatography (GC) column available in FKKSA laboratory. The composition analysed and the retention time then compared to the reference for each of the expected substances to be exist in the LPG mixtures. The third stage is to propose a new design of LPG cylinder based on the existance of liquid component LPG in the LPG cylinder. The design is proposed based on the existance of the liquid LPG in used up LPG cylinder in Malaysia.

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ABSTRAK

Gas Petroleum Cecair (LPG) adalah ia adalah bahan api yang biasa digunakan untuk perkakas-perkakas yang ada dalam bidang industri, perumahan dan komersil di Malaysia. Secara umumnya, LPG terdiri daripada gas mudah meruap yang mempunyai takat didih rendah seperti – etana, propana, propena, iso-butana, n-butana, butena, iso-butena,trans-2-butena, cis-2-butena, dan juga iso -pentana dan n-pentana disebabkan sedia adanya komponen-kompone yang mempunyai titik didih yang lebih tinggi itu. Apabila LPG digunakan, titik komponen didih yang rendah akan menyejat dan komponen titik yang tinggi mendidih akan kekal di dalam silinder. Penyelidikan bertujuan untuk mereka bentuk peralatan penerokaan untuk pensampelan cecair LPG di bawah tekanan, untuk menentukan sebatian yang terdiri dalam sampel cecair LPG, dalam silinder LPG di Malaysia dan menyimpulkan sama ada sesetengah produk mungkin tinggal di dalam silinder sebagai komponen cecair selepas komponen mudah meruap digunakan. Apabila kehadiran komponen-kompenen yang bertitik didih tinggi yang seterusnya akan tinggal di dalam silinder selepas ia dikosongkan oleh komponen-kompone bertitik didih rendah telah dibuktikan, penyelidikan menyasarkan untuk mencadangkan idea baru bagi reka bentuk silinder LPG yang lebih cekap tenaga. Peringkat pertama kajian adalah mereka bentuk peralatan penerokaan yang mudah dan selamat untuk pensampelan cecair LPG di bawah tekanan dan mengambil sampel. Kemudian, peringkat kedua adalah menentukan komposisi LPG yang menggunakan kolum kromatografi gas (GC) yang disediakan di makmal FKKSA. Komposisi LPG dianalisis dan masa tahanan kemudiannya dibandingkan dengan rujukan untuk setiap bahan-bahan yang dijangka akan wujud dalam campuran LPG. Peringkat ketiga ialah mencadangkan satu reka bentuk baru LPG silinder berdasarkan kewujudan cecair komponen LPG dalam silinder LPG. Reka bentuk yang dicadangkan berdasarkan kewujudan LPG cecair dalam digunakan LPG silinder di Malaysia.

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LIST OF SYMBOLS

°C	degree Celcius
°F	degree Farenheit
Btu/lb	British thermal unit per pound mass\
C10	10 kg LPG cylinder
C14	14kg LPG cylinder
C50	50kg LPG cylinder
F14	14kg LPG cylinder for forklift
ft	feet
kg/L	kilogram per liter
kg/m^3	kilogram per meter cubic
kJ/Kg	kilo Joule per kilogram
kJ/L	kilo Joule per kilogram
kPa	kilo Pascal
lb	pound mass
mJ	mega Joule
mol%	molar percentage
vol%	volume percentage

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LIST OF ABBREVIATIONS

FID	Flame Ionization Detector
GC	Gas Chromatography
IPCS	International Programme on Chemical Safety
LPG	Liquefied Petroleum Gas
MS	Malaysian Standard
NPL	National Physical Laboratory

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Liquefied Petroleum Gas (LPG) is already well-known and well-used fuel for domestic, industrial and commercial appliances in Malaysia. LPG is used as a fuel to produce heat for cooking, heating, drying and many other applications. There are various sizes of LPG cylinders that offered by the supplier, but most homes in Malaysia use the size of 14kg that also known as C14.

Every used up LPG cylinder contains small amount of LPG (high boiling point fraction) suspended as a remainder before sent out to the filling station. The remainder LPG might consist of heavier hydrocarbons that have the properties of liquid form in the ambient temperature and pressure. These liquid cannot escape through the valve that located on the top of the LPG cylinder. This study will help in proving the presence of heavier hydrocarbon that stays in liquid form in the used up LPG cylinder.

Through this study, the liquid identified, and then the new design of the cylinder should be proposed based on the result. Therefore, the better improved design can be proposed to benefit the consumer and supplier in term of application of the flammable liquid in the used up LPG cylinder.

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1.2 PROBLEM STATEMENT

Used up LPG cylinder contains remainder in form of liquid. The liquid inside the cylinder is a waste of sufficient energy. Consumer did not know how much they are losing each time they used a LPG cylinder and sent it out to the filling station after its been used up.

In safety prospective, the liquid, unvaporized LPG is dangerous to handler. Consumer might use their creative thinking to make full use of the left liquid in the LPG cylinder. Their ways might turn the cylinder upside down to allow the liquid to exit, or putting the cylinder in a hot water bath to evaporate the liquid, change it to vapour. These ideas will introduce themselves to the danger as the liquid of LPG is also flammable.

At the filling station, the LPG cylinders that have been sent in might be in dented shape. These cylinders then sent to the manufacturer to be built again. The dented cylinders have to be emptied before they were sent to the manufacturer to make full use of the fuel. There were accidents happened as the LPG cylinder emptied. New design of cylinder can propose a new and safe way to withdraw the remainder LPG of a used up LPG cylinder.

In Malaysia, no research is carried out specifically on the LPG cylinder design yet. LPG cylinders are used in almost every home and commercial buildings. The risk of LPG cylinder mishandling is there as the LPG cylinder consumed.

1.3 RESEARCH OBJECTIVES

The objectives of this research are;

1. To design the easy and safe exploratory instrumentation for liquid LPG sampling under pressure.

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2. To determine the LPG composition and prove the theoretical composition in the LPG cylinder in Malaysia using the available gas chromatography (GC) in FKKSA laboratory.
3. To recommend a new idea for LPG cylinder design that is more energy-efficient.

1.4 SCOPE OF RESEARCH

This research conducted to design exploratory method and instrumentation for liquid LPG sampling under pressure. The research then applies the method to obtain the LPG sample for analysis of composition.

This research conducted to investigate the LPG composition in LPG cylinder manufactured in Malaysia. The experimental result will be compared with the theoretical composition to prove the data.

The research also conducted to recommend a new idea that is more energy effective for LPG cylinder design. By proving the presence of liquid content in it after used up, the design recommend to improve the recent design. The design is a modification of the conventional LPG cylinder in Malaysia.

1.5 SIGNIFICANCE OF RESEARCH

In this research, the LPG composition will be investigated. A new design of LPG cylinder will be recommended based on the LPG composition. Not many people have discovered this specific topic in Malaysia. This study will contribute to new idea to other researches as a reference and source of information to make further research to improve or implement this study.

There are lots of LPG cylinder consumers in Malaysia. Therefore, the quantity of LPG cylinder and the frequency of LPG cylinder handling will be much. The new

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design of LPG cylinder aimed to benefits a lot in terms of cost effective and energy effective to the consumer as well as the manufacturer.

There is a high potential of the study to be commercialize in Malaysia for it make a value idea and provide new idea for the LPG cylinder design.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Liquefied petroleum gas (LPG) is a hydrocarbon gas fuel that extracted from crude oil or natural gas. In the ambient temperature, LPG exists as gases but with applied moderate pressure, it is liquefied, therefore, it's called liquefied petroleum gas. LPG is a mixtures of petroleum gases mainly butane and propane. The mixtures ratio is differ in countries around the world that having LPG (Prima Gas, 2011). In Malaysia, the commercial LPG might contain hydrocarbons mixture of propane, propylene, butane (normal-butane or iso-butane) and butylenes (including isomers) (Malaysian Standard (MS) 830, 2003).

2.2 PROPERTIES OF LPG

LPG is the petroleum product composed predominantly of any of the following hydrocarbons or mixtures which are; propane, propylene, butanes and butylenes (National Institute of Standards and Technology, 2010). The ratio of the LPG mixtures depends on the LPG production in each country. Other country may refer LPG as

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propane for commercial purpose. Commercial LPG is a mixture of LPG products; with the primary component being propane at 70:30 with the other major component – butane (according to Petronas specification in Malaysia at 2011).

Ethyl mercaptan is added as an odourant to odourless LPG to detect it in case of leakage. LPG is a non-toxic, colorless and clean burning gas fuel that easily found available in the market. LPG has made the fuel for stoves in the restaurant, the fuel for heater and cooking appliances at homes, also used as a fuel in the transportations.

LPG is a liquid under pressure but a gas at ambient conditions. Commercial LPG distributed to the customer in form of liquid. The ratio of LPG in liquid to gas phase is 270:1. Therefore, for the handler safety and easiness, the LPG liquefied at moderate temperature and stored in LPG storage tanks. LPG stored in liquid state, and used at the gaseous phase. To change LPG in liquid state into the gas state, the vaporizer needs to be installed. LPG is easily liquefied product (National Institute of Standards and Technology, 2010). The characteristics of LPG in Malaysia are as in Table 2.1.

Table 2.1: Typical Liquefied Petroleum Gas (LPG) Data Characteristics

Typical Liquefied Petroleum Gas (LPG) Data Characteristics		
Description	Unit	Specification
Density @ 15ºC	Kg/l	Minimum 0.547
Composition (Propane + Butane)	% vol	Minimum 97
Copper Corrosion, (1hr @ 37.8ºC)	A	Maximum 1
Vapour Pressure @ 37.8ºC	kPa	380 ~ 830
Free Water	% vol	Nil
Total Sulphur (Stenched)	mg/kg	Maximum 100
Volatility @ 95% evaporation	ºC	Maximum 2.2

Source: Gas Malaysia, 2011

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2.3 LPG SUPPLY CONCEPT

LPG supplied to the consumers in two ways, piped gas system or from the actual storage of gas cylinders is used. LPG is stored using two methods, which are the manifold system and the bulk tank system (Gas Malaysia, 2011).

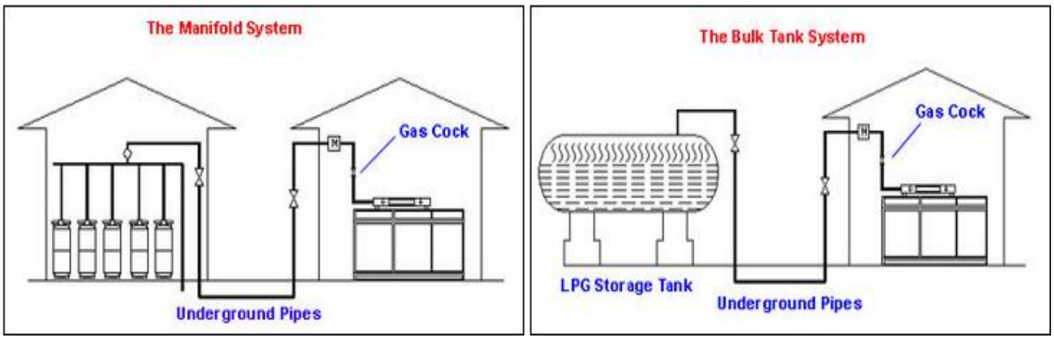

Figure 2.1: LPG Manifold and Bulk Tank System

Source: Gas Malaysia, 2011

LPG storage tanks locate in isolated area from the building. There were also some instalments inside the building with certain mandatory requirement. The internal piping of LPG connected to the meter before used in the buildings appliances.

2.3.1 LPG STORAGE TANK

LPG storage tanks can be categorized into bulk storage and cylinders. LPG bulk storage tanks can be installed either underground or aboveground. For safety and risk prevention cause, the LPG storage tank for above ground should be located in the open air outside of the buildings. According to Gas Supply Act (1993), the storage system is designed by engineers in accordance to gas consumption and safety distance. The

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installations of storage system shall be fenced and locked to prevent unauthorized access and tempering (Gas Supply Act 1993).

2.3.2 LPG CYLINDER

According to Prima Gas (1998-2009), LPG cylinders supplied by the distributors are available in four types of cylinder according to their sizes and function as following.

i. C10 (10 kg LPG cylinder)
ii. C14 (14 kg LPG cylinder)
iii. C50 (50 kg LPG cylinder)
iv. F14 (14 kg LPG cylinder for forklift)

LPG cylinder selection is based on the types of appliances. The common used gas cylinder in homes is C14. The LPG cylinder is made from steel that can stand the LPG internal pressure. F14 differ from the other types because it used as fuel for forklift trucks as well as the fuel withdrawal system. F14 have the modification by adding tubes to the valve for maximum utilization of LPG in liquid state.

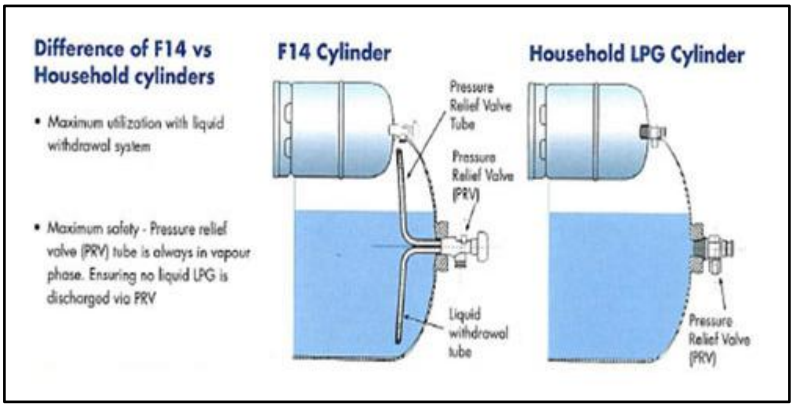

Figure 2.2: Differences of F14 cylinder versus household LPG cylinder

Source: Prima Gas, 1998-2009

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2.4 LPG COMPOSITION

LPG composition in Malaysia is based on butane rich composition. The butane and propane is a mixture of 30:70 ratios respectively.

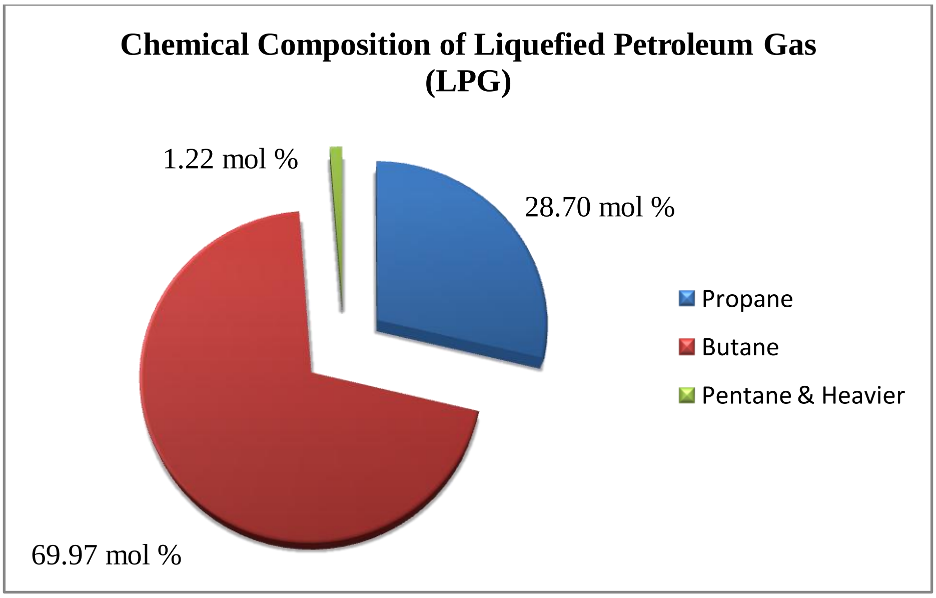

Figure 2.3: Chemical Composition of LPG

Source: Gas Malaysia, 2011

Based on data provided by Gas Malaysia (2011), LPG in Malaysia is butane, C_4 rich and contains 1.22 mol% of pentane and other heavier hydrocarbon. These heavier hydrocarbons might be the liquid remainder in the used up LPG cylinder.

According to data from UK's National Physical Laboratory (NPL) (2011), the hydrocarbons mixture in LPG cylinder are including; ethane, propane, propene, *iso*-butane, *n*-butane, but-1-ene, *iso*-butene, *trans*-2-butene, *cis*-2-butene, *iso*-pentane, *n*-pentane. Each of the components has different properties that may affect the physical appearance.

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Table 2.2: Liquefied Petroleum Gas (LPG) Composition

Component	Amount Fraction (% mol/mol)	
	Liquefied Petroleum Gas (C_3 rich)	**Liquefied Petroleum Gas (C_4 rich)**
Methane	-	-
Ethane	0.5	-
Propane	70	17.5
Propene	15	4.0
iso-Butane	2.0	10
n-Butane	5.0	60
But-1-ene	1.5	2.5
iso-Butene	1.0	2.0
trans-2-Butene	-	1.75
cis-2-Butene	-	1.25
iso-Pentane	-	0.5
n-Pentane	-	0.5
n-Hexane	-	-

Source: UK's National Physical Laboratory (NPL), 2011

The properties of ethane, propane, propene, *iso*-butane, *n*-butane, but-1-ene, *iso*-butene, *trans*-2-butene, *cis*-2-butene, *iso*-pentane, *n*-pentane are as in the following tables.

Table 2.3: General properties of commercial propane

Properties	**Value**
Formula	C_3H_8
Boiling Point at 14.7 psia	-42°C -44°F
Freezing Point, at Atmospheric Pressure	-187.8°C -310°F
Specific Gravity of Liquid at 60°F	0.51
Specific Gravity of Vapour at 60°F (Air=1)	1.52
Mass per US Gallon of Liquid at 60°F (15.5°C)	4.20 lb
Mass per Imperial Gallon of Liquid at 60°F (15.5°C)	5.1 lb

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Table 2.3: Continued

Properties	**Value**
Specific Heat of Liquid at 60°F (15.5°C)	0.590 Btu/lb
Specific Heat of Vapour at 60°F (15.5°C)	0.405 Btu/lb
Vapour per US Gallon at 60°F (15.5°C)	36.38 ft^3
Vapour per Imperial Gallon at 60°F (15.5°C)	44 ft^3
Vapour per Pound at 60°F (15.5°C)	8.5 ft^3
Gross Energy per Litre	24.7 MJ
Density at 15°C	0.51 kg/L
Litres per Tonne	1960
kWh per US Gallon	26.9
Vapourization Rate (Liquid to Vapour)	272:1
Latent Heat of Vapourization at Boiling Point	209 Btu/L
Total Heating Values after Vapourization	24 700 kJ per Litre 49 700 kJ per kg

Source: Canadian Standards Association, Propane Storage and Handling Code, 2005

Table 2.4: General properties of commercial butane

Properties	**Value**
Formula	C_4H_{10}
Boiling Point at 14.7 psia	0°C (32°F)
Freezing Point, at Atmospheric Pressure	-138°C (-260°F)
Specific Gravity of Liquid at 60°F	0.58
Specific Gravity of Vapour at 60°F (Air=1)	2.00
Mass per US Gallon of Liquid at 60°F (15.5°C)	4.81 lb
Mass per Imperial Gallon of Liquid at 60°F (15.5°C)	5.8 lb
Specific Heat of Liquid at 60°F (15.5°C)	0.550 Btu/lb
Specific Heat of Vapour at 60°F (15.5°C)	0.385 Btu/lb
Vapour per US Gallon at 60°F (15.5°C)	31.26 ft^3
Vapour per Imperial Gallon at 60°F (15.5°C)	38 ft^3
Vapour per Pound at 60°F (15.5°C)	6.5 ft^3
Gross Energy per Litre	27.6 MJ
Density at 15°C	0.58 kg/L
Litres per Tonne	1720
Latent Heat of Vapourization at Boiling Point	215 Btu/L
Total Heating Values after Vapourization	27 600 kJ per Litre 49 400 kJ per kg

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Source: Canadian Standards association, Propane Storage and Handling Code, 2005

Table 2.5: Properties of *iso*-butane

Properties	**Value**
Formula	$C_4 H_{10}$
Molecular Weight	58.123 g/mol
Liquid Phase	
Liquid density (1.013 bar at boiling point)	593.4 kg/m^3
Liquid/gas equivalent (1.013 bar and 15°C(59°F))	236 vol/vol
Boiling point (1.013 bar)	-11.7°C
Critical point	
Critical temperature	134.9°C
Critical pressure	36.48 bar
Gaseous phase	
Gas density (1.013 bar at boiling point)	2.82 kg/m^3
Gas density (1.013 bar at 15°C (59°F))	2.51 kg/m^3
Compressibility factor (Z) (1.013 bar and 15°C (59°F))	0.9675
Specific gravity (air=1) (1.013 bar at 21°C (70°F))	2
Specific volume (1.013 bar and 21°C (70°F))	0.406 m^3/kg
Heat capacity at constant pressure (Cp) (1.013 bar and 15°C (59°F))	0.095 kJ/(mol.K)
Heat capacity at constant volume (Cv) (1.013 bar and 15°C (59°F))	0.086 kJ/(mol.K)
Ratio of specific heats (Gamma:Cp/Cv) (1.013 bar and 15°C (59°F))	1.095845
Viscosity (1.013 bar and 0°C (32°F))	0.0000689 Poise
Thermal conductivity (1.013 bar and 0°C (32°F))	13.97 mW/(m.K)
Solubility in water (1.013 bar and 20°C (68°F))	0.0325 vol/vol
Autoignition temperature	460°C

Source: Air Liquide, 2009

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Table 2.6: Gas properties of *n*-butane

Properties	**Value**
Formula	C_4H_{10}
Molecular Weight	58.123 g/mol
Liquid Phase	
Liquid density (1.013 bar at boiling point)	601.4 kg/m^3
Liquid/gas equivalent (1.013 bar and 15°C(59°F))	239 vol/vol
Boiling point (1.013 bar)	-0.5°C
Latent heat of vapourization (1.013 bar at boiling point)	385.6 kJ/kg
Critical point	
Critical temperature	152°C
Critical pressure	37.96 bar
Gaseous phase	
Gas density (1.013 bar at boiling point)	2.7 kg/m^3
Gas density (1.013 bar at 15°C (59°F))	2.52 kg/m^3
Compressibility factor (Z) (1.013 bar and 15°C (59°F))	0.9625
Specific gravity (air=1) (1.013 bar at 21°C (70°F))	2.076
Specific volume (1.013 bar and 21°C (70°F))	0.4 m^3/kg
Heat capacity at constant pressure (Cp) (1.013 bar and 25°C (77°F))	0.096 kJ/(mol.K)
Heat capacity at constant volume (Cv) (1.013 bar and 15.6°C (60°F))	0.088 kJ/(mol.K)
Viscosity (1.013 bar and 0°C (32°F))	0.0000682 Poise
Thermal conductivity (1.013 bar and 0°C (32°F))	13.6 mW/(m.K)
Solubility in water (1.013 bar and 20°C (68°F))	0.0325 vol/vol

Source: Air Liquide, 2009

Table 2.7: Gas Properties of but-1-ene

Properties	**Value**
Formula	C_4H_8
Molecular Weight	56.107 g/mol
Liquid Phase	
Liquid density (1.013 bar at boiling point)	630 kg/m^3
Liquid/gas equivalent (1.013 bar and 15°C(59°F))	261 vol/vol

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Table 2.7: Continued

Properties	**Value**
Boiling point (1.013 bar)	-6.3 °C
Latent heat of vaporization (1.013 bar at boiling point)	390.6 kJ/kg
Vapour pressure (at 21 °C or 70 °F)	2.68 bar
Critical point	
Critical temperature	146.4 °C
Critical pressure	40.2 bar
Gaseous phase	
Gas density (1.013 bar at boiling point)	2.72 kg/m^3
Gas density (1.013 bar at 15°C (59°F))	2.38 kg/m^3
Compressibility factor (Z) (1.013 bar and 15°C (59°F))	0.968
Specific gravity (air=1) (1.013 bar at 21°C (70°F))	1.998
Specific volume (1.013 bar and 21°C (70°F))	0.418 m^3/kg
Heat capacity at constant pressure (Cp) (1.013 bar and 15.6°C (60°F))	0.083 kJ/(mol.K)
Heat capacity at constant volume (Cv) (1.013 bar and 15.6°C (60°F))	0.074 kJ/(mol.K)
Ratio of specific heats (Gamma:Cp/Cv) (1.013 bar and 15.6°C (60°F))	1.110861
Viscosity (1.013 bar and 0°C (32°F))	0.0000708 Poise
Thermal conductivity (1.013 bar and 0°C (32°F))	13.68 mW/(m.K)
Solubility in water (1.013 bar and 20°C (68°F))	0.085 vol/vol
Autoignition temperature	440°C

Source: Air Liquide, 2009

Table 2.8: Gas properties of *iso*-butene

Properties	**Value**
Formula	C_4H_8
Molecular Weight	56.107 g/mol
Liquid Phase	
Liquid density (1.013 bar at boiling point)	626.2 kg/m^3
Liquid/gas equivalent (1.013 bar and 15°C(59°F))	259 vol/vol
Boiling point (1.013 bar)	-7.2°C

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