DETERMINATION OF EXPLOSION PARAMETERS OF LPG-AIR MIXTURES IN THE CLOSED VESSEL

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DETERMINATION OF EXPLOSION PARAMETERS OF LPG-AIR MIXTURES IN THE CLOSED VESSEL

MOHD SAIFOL BIN ISHAK
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A thesis submitted in fulfillment
of the requirements for the award of the degree of
Bachelor of Chemical Engineering
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NOVEMBER 2008

DECLARATION

I declare that this thesis entitled **“**DETERMINATION OF EXPLOSION PARAMETERS OF LPG-AIR MIXTURES IN THE CLOSED VESSEL” is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

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Date : November 2008

DEDICATION

Special Dedication to my beloved parents,
Mr. Ishak Bin Ibrahim and Mrs. Zainab Binti Ismail,
my siblings and my beloved friend, Siti 'Aisyah Binti Yusof
for their love and encouragement.

And,

Special Thanks to my supervisor, Mr. Arman Bin Abdullah
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For all *your Care, Support* and *Best Wishes.*

Thank you

-Mohd Saifol Bin Ishak-

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ABSTRACT

The experimental results of the measurements of the explosion pressure and rate of explosion pressure rise as a function of propane/butane concentration in the mixture with air in the 20 L explosion chamber are tested. The research was aimed at determination of the explosion pressure and limits. The influence of initial temperature of the mixture (changing in the range of 293–473 K) on the fundamental explosion parameters was also investigated. The ignition source was an induction electrical spark. It was stated, that the increase of initial temperature of the LPG-air mixture causes a significant increase of the explosion range. From the experimental result, the concentration of LPG and air mixture just explodes at the range 2% to 10% of LPG in air. The concentration of LPG at 4% gives the highest value of explosion pressure which at this condition, an explosion of LPG becomes very dangerous. The highest of deflagration index for LPG is 29. So, the designing of LPG tank storage should have value of deflagration index more than 29 to resist the over pressure from happen. The change of concentration of the LPG-air mixture causes a significant effect to maximum explosion pressure and maximum rate pressure rise. But it not means that the more concentration of LPG in air will increase the explosion pressure.

ABSTRAK

Daripada hasil eksperimen bagi menentukan tekanan letupan dan kadar kenaikan tekanan letupan sebagai fungsi bagi kepekatan propana dan butana dalam udara di dalam Gas fire explosion. Objektif kajian ini adalah untuk menentukan nilai tekanan letupan dan juga had letupan bagi LPG. Kesan Suhu awal campuran turut dikaji kesannya kepada parameter letupan. Sumber nyalaan adalah daripada induksi percikan elektrik. Semakin bertambah suhu awal LPG dalam udara akan mengakibatkan pertambahan mendadak kepada julat had letupan. Daripada hasil eksperimen, kepekatan LPG dalam udara hanya akan meletup pada julat 2% hingga 10% LPG dalam udara. Pada kepekatan 4% LPG dalam udara akan menghasilkan nilai tekanan letupan yang paling tinggi yang mana pada keadaan ini, letupan LPG adalah sangat merbahaya. Nilai deflagration index yang paling tinggi bagi LPG ialah 29. Oleh sebab itu, dalam pembinaan tangki LPG, tekanan yang lebih tinggi daripada nilai indekx deflagrasi perlulah diambil kira untuk menampung jika berlaku lebihan tekanan. Perubahan kepekatan LPG dalam udara akan menyebabkan kesan yang ketara pada tekanan letupan maksimum dan kadar kenaikan tekanan letupan maksimum. Tetapi ini tidak bermakna lebih besar kepekatan LPG dalam udara akan menyebabkan kenaikan tekanan letupan.

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LIST OF SYMBOLS

K_{max}	-	Deflagration Index
V	-	Volume of Vessel
P_{max}	-	Maximum Explosion Pressure
$(dp/dt)_{max}$	-	Maximum rate pressure rise
LPG	-	Liquefied Petroleum Gas
LEL	-	Lower Explosion Limit
UEL	-	Upper Explosion Limit
U		Burning Velocity
C		Speed of Sound
D		Detonation Velocity
t		Time

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Liquefied Petroleum gas (LPG) has become more popular compared to other liquid fuels based on a few factors i.e. easy to handle, less pollution, minimum space and can produce a high quality product [1]. There are a few concepts of liquefied petroleum gas distribution to the customer and it depends on the categories of customer such as whether it is domestic, commercial and industry. Liquefied petroleum gas will be delivered to the customer either using cylinder bulk storage or pipeline.

Liquefied petroleum gas or commercially known as LPG is a group of hydrocarbons derived from crude petroleum processes or natural gas, which are gases at normal temperatures and atmospheric pressures but which become liquid with either a moderate drop in temperature or pressure, or both. With that characteristic sometimes LPG is known as a ‘hydrocarbon borderline product’. Liquefied petroleum gas is a mixture of petroleum hydrocarbons consisting mainly of propane and butane and it can also exist in its individual components such as pure propane or butane [1]. Besides the main components, other minor components, which may exist in LPG, are propylene, butylenes, and butadiene with these minor components mainly depending on its sources. The difference in the LPG produced in crude petroleum processes is that some of the unsaturated hydrocarbon appears together with the LPG such as propylene and butylenes. Statistically, in the market, 75 percent of LPG is derived from natural gas and 25 percent is from crude petroleum processes. In Malaysia, however, the differential among the two cannot be identified because of the bottling plant design in such a way that the product from the gas processing plant and the refinery come with a commingle line.

An understanding of the behavior of LPG is necessary to assist in the planning and engineering design of process plant, transportation and storage, safety and other applications. LPG can be easily liquefied and vaporized. Propane is liquefied when it is frozen below - 42 ^{o}C under atmospheric pressure or pressurized at above 7 bar (700 kPa) under constant temperature. Butane is more easily liquefied under the conditions of –0.5 ^{o}C and 2 bar (200 kPa). Furthermore, as LPG becomes extremely less voluminous (propane reduced to one over 270, butane one over 240) when liquefied, it is feasible to be safely transported and stored. LPG has a high evaporation heat point, requiring a large quantity of evaporation heat when vaporized. So, installation of separate vaporization facilities is required when a large quantity of LPG is used such as for industrial purpose.

LPG is colorless, odorless and tasteless in liquid and vapor form, yet liquid leaks are often characterized by foggy conditions at ground level as the cooling effect condenses water vapor in the air, and frost may occur at the point of escape. Only a small quantity of odorant is added in order to detect it when leaking. A liquid, LPG is only half of the weight of water yet in gaseous form is twice as heavy as air, so it is difficult to disperse and tends to hug the ground, sliding downhill to accumulate in lower lying areas. It is propane and butane that is the most commonly used and most easily liquefied of these gases. Both have flammability limits between 2 – 4 percent in air, so just 1 liter of split liquid cloud create up to 12.5 m3 of flammable vapor which could be ignited perhaps 50m downwind from the leak point. It is observed that the flammability range of LPG becomes narrow with addition of nitrogen gas. The information of this limit is very much required for prevention of explosive hazards. However, the degree of hazards depend on many factor such as the mass of substances released, physicochemical properties of the substance in the moment of its release, flammability and toxicity of the medium flowing out. Even though LPG is not poison but after expose to LPG it will cause death due to be asphyxia from hypoxia as a result of the exclusion of oxygen by the gas.

Commercial LPG in the market normally consists of propane and butane with 30 percent and 70 percent in composition respectively. However, its composition will vary accordingly and subject to the application, country and surrounding temperatures. Generally, the gas industry will follow the agreement with clients or follow the specification fixed by the Gas Processor Supplier Association (GPSA) about the composition. The specification of GPSA is based on the maximum vapor pressure, minimum vaporization rate and the limitation of the components that will cause corrosion such as water and sulfur. This means that the industry will use both of the cases. However, usually LPG contains certain amount of residue with higher vaporization points falling in the range of lubricant oil. The sources of residue are the LPG processing equipment i.e. pumps, compressors and containers. In industries, there is a routine need to analyze residues in LPG for quality control. Usually, on specific application, residues concentration of LPG must meet industrial codes. For instance, the Australia LPG Association requires the residue concentration below 20 ppm of mass.

1.2 Problem Statement

The problems occur when to design the LPG tank. In this process, the important parameter must be determined to ensure the tank is in safe. LPG kept in the tank has a high pressure. The tank must have special characteristics to hold LPG from explode when exposed to the spark or fire.

When we analyse an internal explosion, we will find that the gas cloud size is the main parameter determining pressure build-up. The geometrical conditions nearly always support flame acceleration and pressure build-up. So, if a large cloud is formed within equipment it is likely that there will be a severe explosion if it ignites. Confined gas explosions are explosions within tanks, process equipment, pipes, in culverts, sewage systems, closed rooms and in underground installations. Confined explosions are also called internal explosions.

An internal explosion may result in loss of containment. The subsequent event can then be strong blast waves from high pressure reservoirs, fires or toxic releases. In the chemical and hydrocarbon process industries, we will find a large variety of cases where internal gas explosions may occur. Such explosions can be caused by uncontrolled leaks, or simply by accidental purging with air (and thereby formation of fuel-air mixtures). There is limited information available in the open literature about these aspects of gas explosions. It is beyond the scope of this chapter to present detailed methods for analysis gas explosions in such systems.

The availability of an explosion model is able to predict accurately and quickly the explosion pressures produced by an ignition of gases or vapors in confined spaces would be great use to many companies and organizations. Obvious areas of application are in the design of enclosures, vessels, etc. to minimize and contain the effects of explosions; in the selection and design of explosion protection measures, for example explosion vents and flame arresters and in undertaking hazard assessments of installations. Two specific examples of the use of an explosion model, which illustrate the potential benefits, are flameproof enclosures and explosion venting.

All flameproof equipment has to be tested and certified that it meets the current standard. Part of the testing involves hydraulic testing of the flameproof enclosure, the hydraulic test pressure being based on the explosion pressures measured in the enclosure. A model capable of predicting the explosion pressures could be used to optimize the layout of the internal components to give the lowest explosion pressure, resulting in an enclosure of lower mechanical strength being required and a consequent saving in cost. In the longer term, the use of such a model might also lead to a reduction in the experimental testing required and thus a saving in the cost of certification.

1.3 Objective

The objective of this study is to find the value of maximum rates of pressure rise and then determine the deflagration index, $K_{G.}$ The research will attempt to overcome the hazard of LPG explosion in the closed vessel

1.4 Scope

The study will focus on how to determine the deflagration index of LPG at the different concentration. This experiment will run at the range of 1% to 10% concentration of LPG mix in the air. It can be easy to determine the range of explosion limit because it is still the same with flammability limit of LPG.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Liquefied petroleum gases (LPG) are substances such as propane and butane, which are transported and stored in the liquid phase in tanks under sufficiently high pressure. It is generated as a by-product either of oil and gas production or refining. At normal temperatures and pressures, but which turn liquid at moderate pressures; its main constituent is propane, and it is sometimes referred to by that name. The composition components of LPG are much simpler than that of gasoline. LPG is thought to be a cleaner fuel because it is has less impact on air quality.

Varieties of LPG bought and sold include mixes that are primarily propane, mixes that are primarily butane, and the more common, mixes including both propane (30%) and butane (70%), depending on the season—in winter more propane, in summer more butane. Commercial LPG marketed in this country (30% propane and 70% butane) exerts a vapor pressure of approximately 700 kPa (100 psig).Propylene and butylenes are usually also present in small concentration. A powerful odorant, ethanethiol, is added so that leaks can be detected easily.

Explosions in LPG-air gaseous mixtures in confined spaces are a well-recognized hazard, due to the high pressure and high rate of pressure rise reached quickly after ignition by a local energy source. Such processes may damage a vessel without a proper venting or explosion-suppressing device. The cause is the fast delivery of the combustion heat that cannot be compensated by the slow heat dissipation through conduction, convection or radiation, before contact of the flame front with the walls.

Knowledge of the fundamental explosion parameters of gas-air mixtures, like maximum explosion pressure, maximum rate of explosion pressure rise, lower and upper explosion limits plays a significant role in formulating safe working conditions for various industrial installations.

The knowledge of the appropriate values of the main explosion parameters is necessary, because various explosion research centers have published data, which often differ significantly from each other, for instance. Results of experiments depend on many different parameters of the investigated process, such as energy and type of ignition source, size and shape of explosion chamber, initial temperature and pressure of the flammable mixture. Distributions of the obtained results of the measured explosion parameters also depend upon conditions of carrying out the research. For this reason, the details of the apparatus parameters and research procedures used in the investigations should be taken into consideration.

2.2 Typical Characteristics of Commercial LPG

LPG is odorless but a stench agent is added to assist in its detection in case of leakage. The odorant used in LPG is ethyl mercaptan, which possesses a distinctive and unpleasant odor. Ethyl mercaptan is selected because it is non-corrosive, has low sulphur content and possesses a boiling point very near that of LPG.

LPG is colorless whether in liquid or vapor form. The white cloud, which appears around a LPG leakage point, is not the product itself but chilled water vapor condensed from the surrounding air by the evaporating liquid or cooled vapors.

At ambient temperatures, LPG is highly volatile and flammable. Its vapor forms flammable and explosive mixtures with air. The vapor is heavier than air and can travel along the ground, into drains and conduits to a possible distant ignition source and can flash back explosively.

LPG consists almost entirely of carbon and hydrogen with negligible amounts of sulphur and other impurities. For practical purposes, therefore, stoichiometric air requirements and waste gas volumes can be determined by assuming complete combustion of the carbon and hydrogen contents.

LPG is a high performance fuel, but will only ignite if mixed with a quantity of air in roughly a gas:air ratio of between 1:50 and 1:10 (lower than the limits for mains gas). This low limit of flammability means that even small leaks could have serious results.

LPG is chemically reactive and will cause natural rubber and some plastics to deteriorate. Only equipment and fittings specifically designed for LPG should be used. **Table 2.1** shows the physical and chemical properties of LPG from the Shell Company. The safety data sheet for LPG is shows in the **appendix B1**.

Table 2.1: Physical and chemical properties of LPG (Shell Company)

LPG	**Properties**
Form	Gas. May be liquefied by pressurization
Color	Colorless
Odor	Very faint petroleum odor 22,000 to 36,000 mg/m^3
Specific gravity	0.5 @ 20ºC
Vapor density	1.55 (air = 1)
Vapor Pressure at ambient	500 kPa
Boiling point	-40°C to 80 °C (-40 to 176°F)
Freezing point	-190°C (-310°F) (propane)
Coefficient of water/oil	2.36 [log P]

Flash point	-104°C (-156°F)
Auto ignition	450°C (842°F)
Lower flammable limit	1.8% -1.9%
Upper flammable limit	9.5%
Hydrocarbon Composition (by Volume)	
Commercial Propane (C_3H_8)	30%
Commercial Butane (C_4H_{10})	70%
Total Sulphur (stenched)	< 75 mg/kg
Free Water (Visual Inspection)	none
Relative density (compared to dry air)	1.85
Copper Corrosion Strip	1
Calorific Value, gross	49.5 MJ/kg 21,300 Btu/lb
Calorific Value, nett	45.7 MJ/kg 19,600 Btu/lb

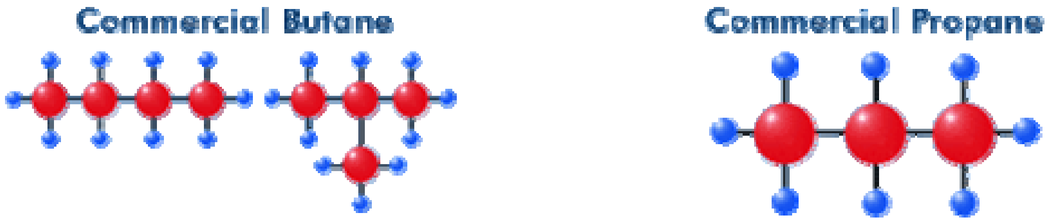


Figure 2.1: Structure of commercial butane and commercial propane

Figure 2.1 shows the structure of commercial butane and commercial propane in tree dimension. The chemical composition of propane is C_3H_8 and butane, C_4H_{10}. Because the make-up of each gas contains traces of other gases, there may be small variances in the exact composition. The terms commercial propane and commercial butane are often used to describe LPG of acceptable quality for most applications.

The characteristics of propane and butane are different. it can be describe easily by its chemical properties. **Table 2.2** shows the physical and chemical properties propane. **Table 2.3** shows the physical and chemical properties butane.

Table 2.2: Physical and chemical properties propane

Appearances	Colorless liquefied gas
Odor	Odorless, odorant added to provide a distinctive smell
Boiling Point	-42°C
Flash Point	-104 °C
Flammability Limits	2% to 11% in air
Auto flammability	460-580 °C
Vapor Pressure	7.5 bar at 15 °C
Specific Gravity of Liquid	0.512 at 15 °C (Water = 1.0)
Specific Gravity of Vapor	1.5 at 15 °C (Air = 1.0)
Solubility in Water	Insoluble

Table 2.3: Physical and chemical properties butane

Appearances	Colorless liquefied gas
Odor	Odorless, odorant added to provide a distinctive smell
Boiling Point	-2°C
Flash Point	-60 °C
Flammability Limits	2% to 9% in air
Auto flammability	410-550 °C
Vapor Pressure	2 bar at 15 °C
Specific Gravity of Liquid	0.575 at 15 °C (Water = 1.0)
Specific Gravity of Vapor	2.0 at 15 °C (Air = 1.0)
Solubility in Water	Insoluble

2.3 Explosion

An explosion is defined as an event in which energy is released over a sufficiently small period of time and in a sufficiently small volume to generate a pressure wave of finite amplitude traveling away from the source. This energy may have been originally stored in the system as chemical, nuclear, electrical, or pressure energy. However, the release is not considered to be explosive unless it rapid and concentrated enough to produce a pressure wave that can be heard [2].

Gas explosions can occur inside process equipment or pipes, in buildings or off-shore modules, in open process areas or in unconfined areas. When we are talking about a gas explosion as an event, it is a more general term. It is then common to include the events both before and after the gas explosion process, see the diagram below.

Figure 2.2 shows what can happen if combustible gas or evaporating liquid is accidentally released into the atmosphere. If the gas cloud, formed from the release, is not within the flammability limits or if the ignition source is lacking, the gas cloud may be diluted and disappear. Ignition may occur immediately, or may be delayed by up to tens of minutes, all depending on the circumstances. In case of an immediate ignition (before mixing with air or oxidizer has occurred) a fire will occur.

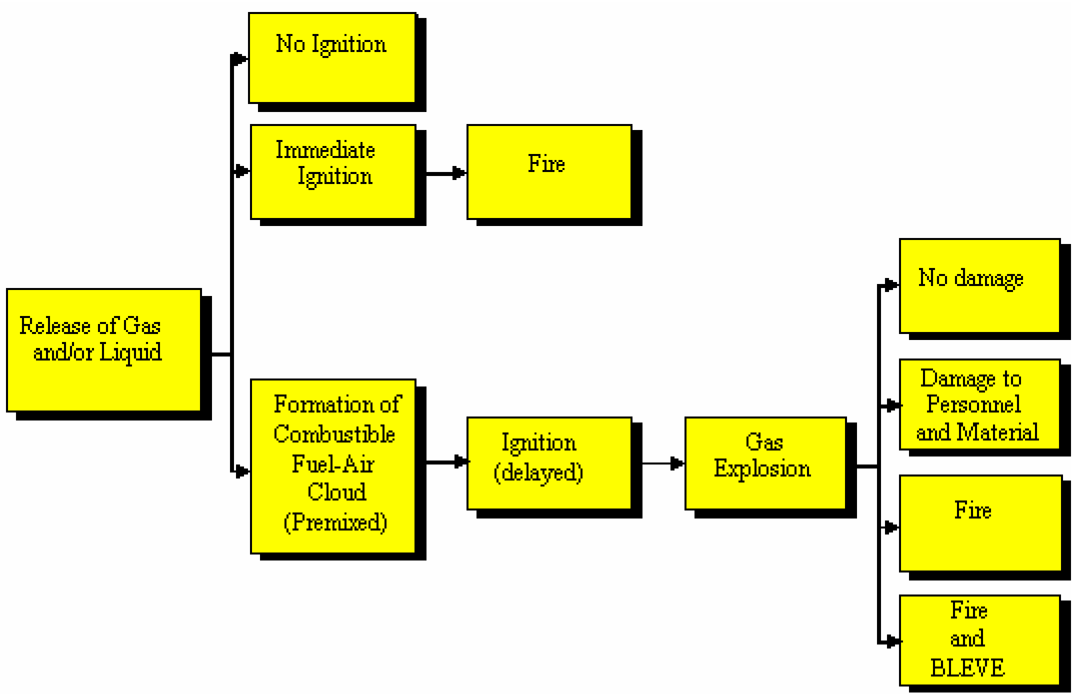


Figure 2.2: An event tree showing typical consequences of accidental releases of combustible gas or evaporating liquid into the atmosphere [3]

The most dangerous situation will occur if a large combustible premixed fuel-air cloud is formed and ignites. The time from release start to ignition can be from a few seconds up to tens of minutes. The amount of fuel can be from a few kilograms up to several tons.

The pressure generated by the combustion wave will depend on how fast the flame propagates and how the pressure can expand away from the gas cloud (governed by confinement). The consequences of gas explosions range from no damage to total destruction. The pressure build-up due to the gas explosion can damage personnel and material or it can lead to accidents such as fires and bleve's. Fires are very common events after gas explosions. When a cloud is ignited the flame can propagate in two different modes through the flammable parts of the cloud. These modes are deflagration and detonation

The deflagration mode of flame propagation is the most common. A deflagration propagates at subsonic speed relative to the unburned gas, typical flame speeds (relative to a stationary observer) are from the order of 1 to 1000 m/s. The explosion pressure may reach values of several barg, depending on the flame speed.

A detonation wave is a supersonic (relative to the speed of sound in the unburned gas ahead of the wave) combustion wave. The shock wave and the combustion wave are in this case coupled. In a fuel-air cloud a detonation wave will propagate at a velocity of 1500-2000 m/s and the peak pressure is typically 15 to 20 bar.

An explosion results from ignition of a combustible material (dust, gas or mist) when mixed with oxygen present in the air. When this takes place inside a process or storage enclosure, the rapid rise in pressure developed will exert destructive forces within a few milliseconds that will place both personnel and equipment at risk. Most materials handling, processing and storage equipment is not designed to resist the pressure of a deflagration. Only equipment designed to resist the maximum pressure (P_{max}) developed by the combustion process will survive, such design pressures typically exceed 75psig (5.2 bar), making design for containment of a deflagration prohibitively expensive in most cases.

The maximum rate of pressure rise during a closed vessel explosion, $(dP/dt)_{max}$, is defined as the highest value of pressure rise rate observed at a given fuel concentration, under specific initial temperature and pressure conditions [4]. Besides the explosion pressure, the maximum rate of pressure rise is one of the most important safety parameters for assessing the hazard of a process and design of vessels to withstand an explosion of vents used as relief devices of enclosures against damages produced by gaseous explosions [5-8].

Explosion behavior depends on a large number of parameters. Explosion behavior is difficult to characterize. Many approaches to the problem have been undertaken, including theoretical, semi empirical, and empirical studies. Despite these efforts, explosion behavior is still not completely understood. Practicing engineers, therefore, should use extrapolated results cautiously and provide a suitable margin of safety in all designs.

An explosion results from the rapid release of energy. The energy release must be sudden enough to cause a local accumulation of energy at the site of the explosion. This energy is then dissipated by a variety of mechanisms, including formation of a pressure wave, projectiles, thermal radiation, and acoustic energy. The damage from an explosion is caused by the dissipating energy.

If the explosion occurs in a gas, the energy causes the gas to expand rapidly, forcing back the surrounding gas and initiating a pressure wave that moves rapidly outward from the blast source. The pressure wave contains energy, which results in damage to the surroundings. For chemical plants much of the damage from explosions is due to this pressure wave. Thus, in order to understand explosion impacts, we must understand the dynamics of the pressure wave.

2.3.1 Deflagrations

A deflagration is defined as a combustion wave propagating at subsonic velocity relative to the unburned gas immediately ahead of the flame, which is. the burning velocity, U, is smaller than the speed of sound, C, in the unburned gas. The velocity of the unburned gas ahead of the flame is produced by the expansion of the combustion products. [3]

Deflagration is a rapid chemical reaction in which the output of heat is enough to enable the reaction to proceed and be accelerated without input of heat from another source. The effect of a true deflagration under confinement is an explosion. Confinement of the reaction increases pressure, rate of reaction and temperature, and may cause transition into a detonation.

In an accidental gas explosion the deflagration is the common mode of flame propagation. In this mode the flame speed, ranges from order of 1m/s up to 500 - 1000 m/s corresponding to explosion pressures between a few mbar and several bar. For strong deflagrations, shock waves may propagate ahead of the deflagration.

2.3.2 Detonations

A detonation is defined as a combustion wave propagating at supersonic velocity relative to the unburned gas immediately ahead of the flame, that is the detonation velocity, D, is larger than the speed of sound, C, in the unburned gas.

Detonation is a violent chemical reaction within a chemical compound or mechanical mixture evolving heat and pressure. Detonation is a reaction which proceeds through the reacted material toward the un-reacted material at a supersonic velocity. The result of the chemical reaction is exertion of extremely high pressure on the surrounding medium forming a propagating shock wave that originally is of supersonic velocity. A detonation, when the material is located on or near the surface of the ground, is characterized normally by a crater.

In simple terms, a detonation wave can be described as a shock wave immediately followed by a flame (ZND theory). The shock compression heats the gas and triggers the combustion. However, an actual detonation wave is a three dimensional shock wave followed by the reaction zone. **Figure 2.3** shows a detonation wave can be described as a shock wave immediately followed by a flame.

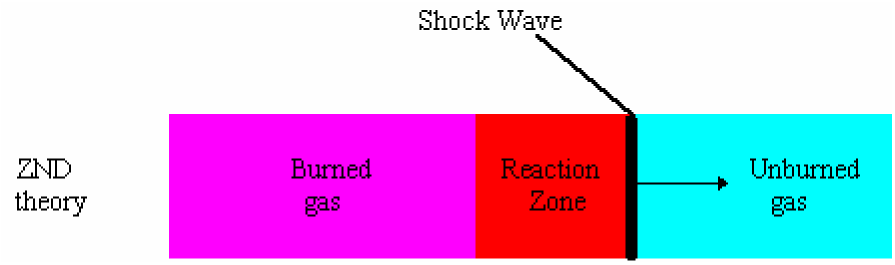


Figure 2.3: A detonation wave can be described as a shock wave immediately followed by a flame (ZND theory) [3]

For fuel air mixtures at ambient pressure the detonation velocity can be up to 2000 m/s and the maximum pressures produced are close to 20 bar. A detonation can either:

- Be initiated directly by detonating a high explosive charge, or
- Be produced when a deflagration accelerates due to obstacles and confinement and transits into a detonation

2.4 Confined Gas Explosions

Confined gas explosions are explosions within tanks, process equipment, pipes, in culverts, sewage systems, closed rooms and in underground installations. Confined explosions are also called internal explosions. The two most common confined explosion scenarios involve explosive vapors and explosive dusts. Empirical studies have shown that the nature of the explosion is a function of several experimentally determined characteristics. These characteristics depend on the explosive material used and include flammability or explosive limits, the rate of pressure rise after the flammable mixture is ignited, and the maximum pressure after ignition. **Figure 2.4** shows how the confined explosion occurs within a tank.

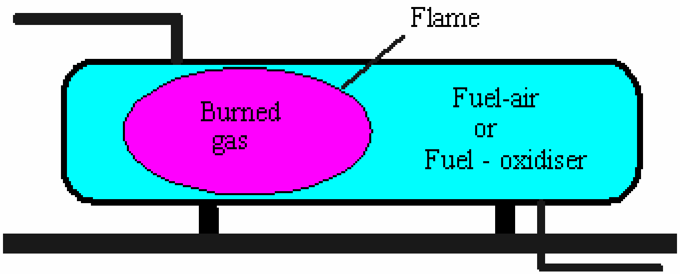


Figure 2.4: Confined explosion within a tank [3]

2.5 Bleves

Acronym for Boiling Liquid Expanding Vapor Explosion (BLEVE). The BLEVE is an explosion due to flashing of liquids when a vessel with a high vapor pressure substance fails. The failure of the vessel is often caused by an external fire as shown in **Figure 2.5**

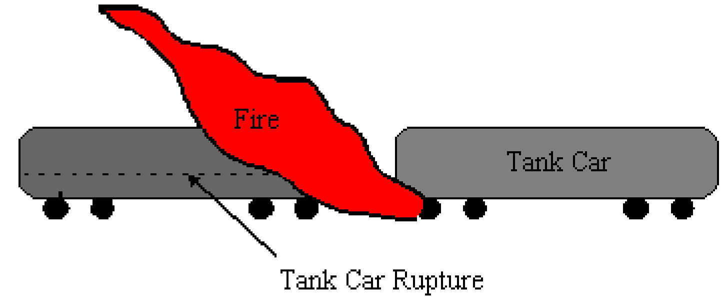


Figure 2.5: A situation that can lead to a bleve [3]

If the substance released is a fuel, the bleve can result in very large fire balls. Rocketing vessels are also hazards related to bleves. **Figures 2.5** and **Figure 2.6** show a bleve and a fire ball in a tank car accident, but bleves can also happen in process areas or in offshore modules.

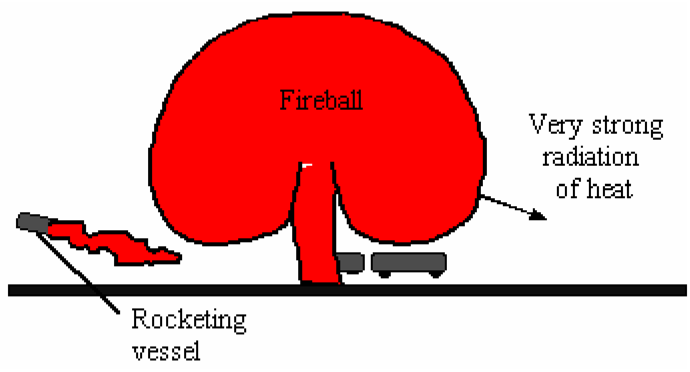


Figure 2.6: Fire balls and rocketing vessels are often the main hazards of a bleve [3]

2.6 Effects of Explosions

An explosion is a gas dynamic phenomenon there are a variety of effects of the spherically expanding heat and pressure wave. These effects assist the investigator in understanding the dynamics of the explosion and the sequence of events that took place during the explosion. The effect of explosion is shows in **Figure 2.7**

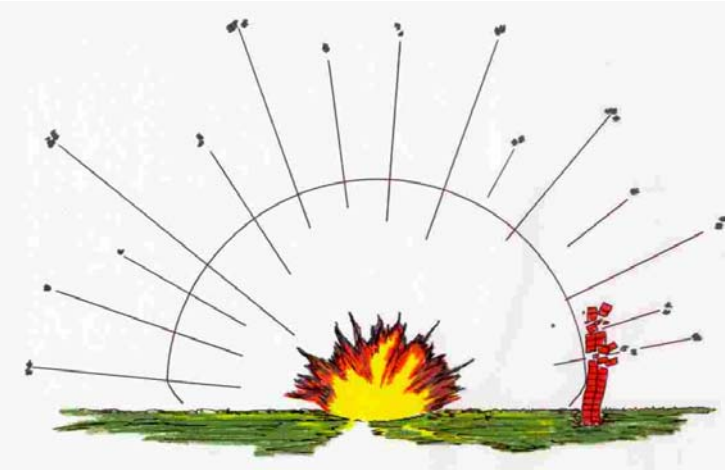


Figure 2.7: Illustration of explosion effect [3]

2.6.1 Blast Pressure Front Effect

The initiation of chemical explosives and fuel gases result in the generation of quantities of gases. These gases expand at a high speed and move outward equally in all directions until an obstruction is encountered. [3]

2.6.1.1 Positive Pressure Phase

The positive pressure phase is when the blast pressure front is moving away from the point of origin. The positive pressure phase is stronger than the negative and is responsible for most of the damage. **Figure 2.8** shows the effect of explosion to the surroundings.

Figure 2.8: Illustration of explosion effect to the surroundings [3]

2.6.1.1.1 Spherical shape of the Pressure Wave

Under ideal conditions the shape of the blast front from an explosion is spherical in nature, moving outward from the origin equally in all directions. However, obstructions or vents will change the configuration of the blast front. The different spherical shape of the pressure wave in one room is show in **Figure 2.9**. It starts from small and become bigger in one room.

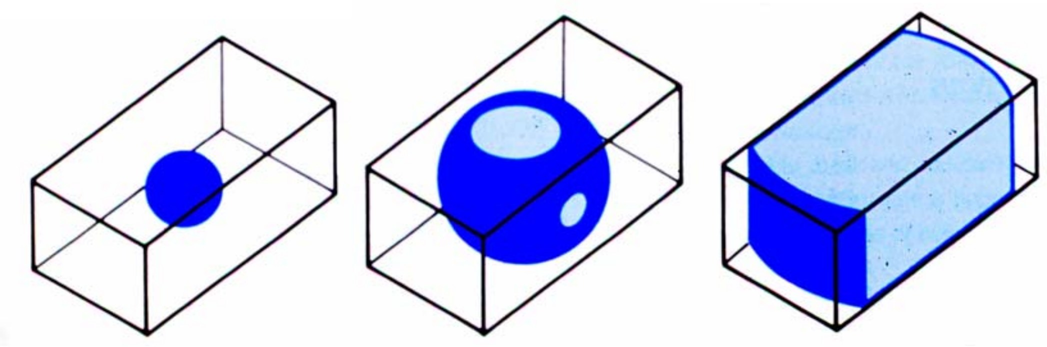


Figure 2.9: Illustration of spherical shape of the pressure wave [3]

2.6.1.1.2 Rate of Pressure Rise vs. Maximum Pressure

The damage caused as a result of the blast pressure front of an explosion is a result of two items. The maximum pressure and the rate of pressure rise. If the rate of pressure rise is rapid, then the containing vessel will not have sufficient time to resist the forces.

2.6.1.2 Negative Pressure Phase

As a result of the movement outward from the origin of the positive pressure phase, a low pressure area is created. This low pressure area allows the movement back towards the origin of the surrounding air. The negative pressure phase causes additional or secondary damage, and it is common to find the debris moving towards the point of origin or in opposite directions from the positive pressure phase. **Figure 2.10** shows the negative pressure phase effect to the surroundings.

Figure 2.10: Illustration of negative pressure phase [3]

2.6.2 Fragmentation (Shrapnel) Effect

Containers, structures, or vessels that contain or restrict the movement of the positive pressure fronts may rupture and produce pieces of debris that may travel long distances and cause considerable damage or injury. The distance that they may travel depends on a variety of factors, including the types of fuels involved, the strength of the container, type of initiation, and venting that may be present. [3]

- Fragmentation : Debris from the container, for example the structure.
- Shrapnel : Debris that was placed in the area of a device, in order to inflict harm to those in the area.

2.6.3 Thermal (Incendiary) Effect

Combustion explosions release quantities of energy that may heat light solid combustibles or gases present to their ignition temperature. Often diffuse fuels (vapors or gases) or high surface to mass solids such as flexible urethane foam cushions or vehicle interiors are more likely to be ignited as a result of the thermal effects of an explosion. Dense solid fuels are not as likely to be ignited due to the duration of the heating that takes place. [3]

2.6.4 Secondary Blast Pressure or Ancillary Effects

2.6.4.1 Reflection

Reflection is caused when the blast pressure front contacts an object and as a result the front moves in a different direction. This "reflection" often causes damage in other directions or locations.

Refraction is often caused by different temperature layers. Blast focusing can be caused as a result of reflection and refraction. The key is that the damage can be amplified as a result of the movement of the blast pressure front in one direction. Often in cities this damage can be increased as a result of the configuration of the street and surrounding structures. [3]

2.6.4.2 Seismic

As the blast pressure wave expands, and damaged portions of buildings collapse, significant localized seismic waves may be transmitted throughout the ground. Velocity of the wave and the affect of the wave will vary depending on soil conditions. [3]

2.7 Explosion Apparatus for Vapors

The apparatus used to determine the explosive nature of vapors is shown in **Figure 2.16**. The test procedure includes (1) evacuating the vessel, (2) adjusting the temperature, (3) metering in the gases to obtain the proper mixture, (4) igniting the gas by a spark, and (5) measuring the pressure as a function of time. After ignition the pressure wave moves outward within the vessel until it collides with the wall; the reaction is terminated at the wall. The pressure within the vessel is measured by a transducer located on the external wall. A typical pressure versus time plot is shown in **Figure 2.11**.

Experiments of this type usually result in a deflagration with a few atmospheres of pressure rise. The rate of pressure rise is indicative of the flame front propagation rate and thus of the magnitude of the explosion. The pressure rate or slope is computed at the inflection point of the pressure curve. The experiment is repeated at different concentrations.

The pressure rate and maximum pressure for each run are plotted versus concentration, as shown in **Figure 2.12**. The maximum pressure and maximum rate of pressure rise are determined. Typically, the maximum pressure and pressure rates occur somewhere within the range of flammability (but not necessarily at the same concentration). By using this relatively simple set of experiments, the explosive characteristics can be completely established; in this example the flammability limits are between 2% and 8%, the maximum pressure is 7.4 bar, and the maximum rate of pressure rise is 360 bar/s.

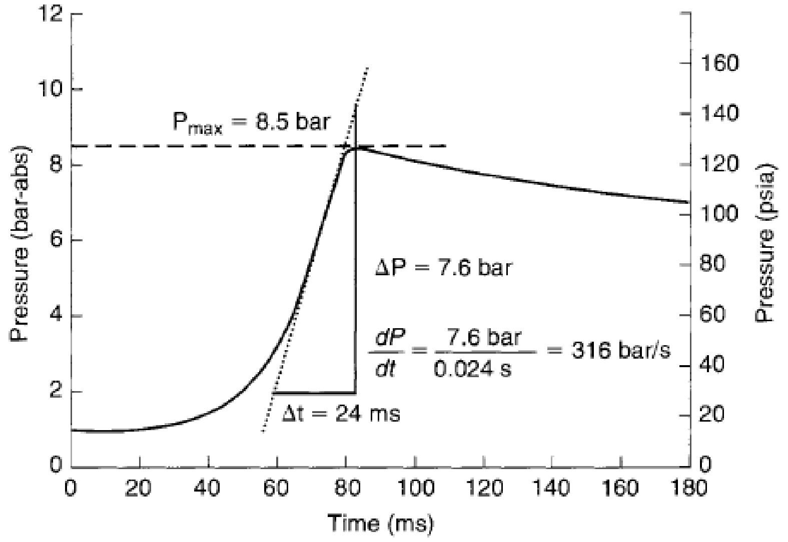


Figure 2.11: Typical pressure versus time data obtained from gas explosion apparatus [10].

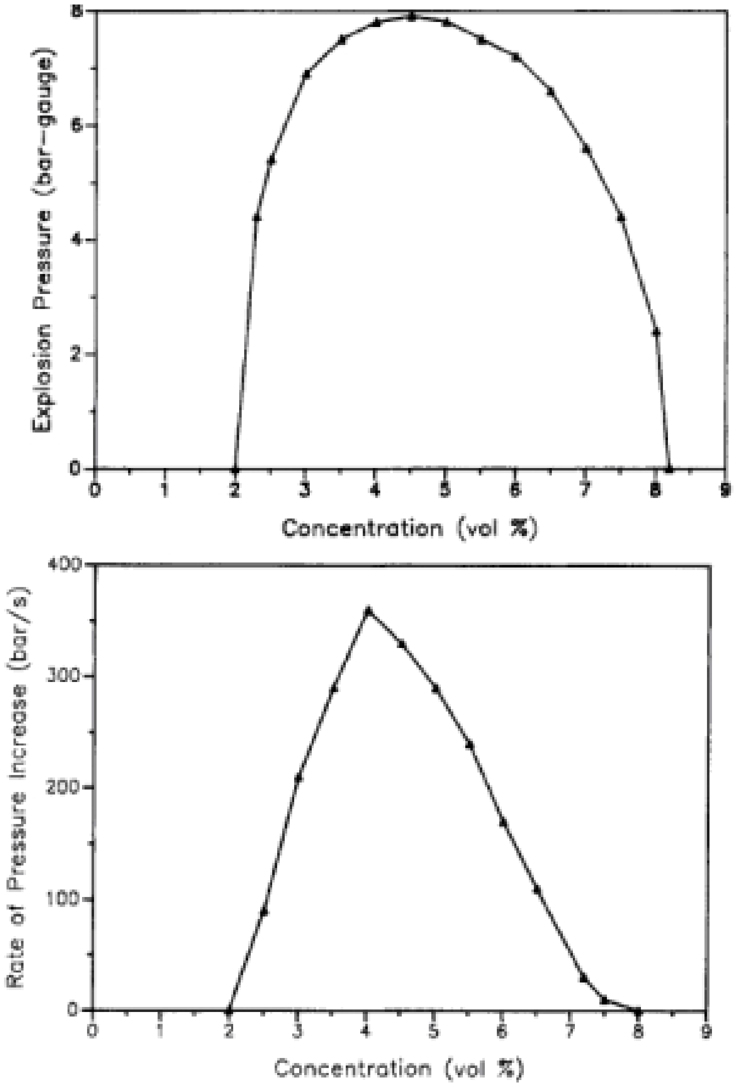


Figure 2.12: Pressure rate and maximum explosion pressure as a function of vapor concentration.[10]

2.8 Deflagration Index or K_G

$$\boxed{\left[\left(\frac{dP}{dt}\right)_{\max} V^{1/3}\right]_{\text{in vessel}} = \left[\left(\frac{dP}{dt}\right)_{\max} V^{1/3}\right]_{\text{experimental}} .}$$

The subscript "in vessel" is for the reactor or building. [10] The subscript "experimental" applies to data determined in the laboratory using either the vapor or dust explosion apparatus. Equation above allows the experimental results from the dust and vapor explosion apparatus to be applied to determining the explosive behavior of materials in buildings and process vessels. The constants K_G is not physical properties of the material because they are dependent on the follows:

- The composition of the mixture
- The mixing within the vessel
- The shape of the reaction vessel
- The energy of the ignition source

It is therefore necessary to run the experiments as close as possible to the actual conditions under consideration.

Experimental studies indicate that the maximum explosion pressure is usually not affected by changes in volume, and the maximum pressure and the maximum pressure rate are linearly dependent on the initial pressure.

Assessing the effect of potential confined fuel–air explosions involves the examination of several essential parameters. These include the limits of combustion, maximum pressure and the deflagration index or K_G. Accurate measurement of these parameters can be influenced by numerous experimental conditions. This paper describes the sensitivity of one of these parameters (K_G) to several experimental influences. The deflagration index, K_G, is important since it is the main design parameter for explosion protection systems. These studies used a highly automated 20 liter combustion sphere, with a 10 mm fuse wire igniter. The results for LPG combustion show that the deflagration index, K_G, is very sensitive to:

- The gas composition; a 1% change in nitrogen composition changed the index value by 12 bar-m/s along the stoichiometric line. The studies also identified some problems with mixing gases to the desired composition.
- The moisture content of the gas, which can change the index by 13 bar.m/s.

For some combustion gas compositions, it was difficult to describe a K_G value due to significant fluctuations in the pressure vs. time data. Finally, an extensive study of fuse wire igniter dynamics identified a means to provide a consistent energy delivery to the igniter. All of these problems contribute significantly to specifying a standard procedure for determining the deflagration index.

Usually a hybrid of technical measures is required to manage the deflagration process safety risk. The technology employed in deflagration management can be divided into passive and active. Typically passive technology functions by mechanical means, automatically, without external energy requirements. Explosion vents (also known as explosion panels) are a passive protection technology. Active systems require one or more sources of energy to function. Explosion suppression systems are an active protection technology. Spark detection and extinguishing systems are an active prevention technology designed to detect and eliminate sources of ignition that could lead to fire or explosion.

2.9 The Maximum Rates of Explosion Pressure Rise

The maximum rates of explosion pressure rise are used for calculating the severity factor (or “deflagration index”) K_G, of gas explosions in enclosures and can vary considerably with the flammable gas. The influence of vessel volume on the maximum rate of explosion pressure rise for a given flammable gas is characterized by the cubic law:

$$\boxed{(dP/dt)_{max}\, V^{1/3} = K_G = \text{constant}}$$

Where, V = vessel volume (m^3)

K_G = Deflagration index (bar-m/s)

$(dP/dt)_{max}$ = maximum pressure rise (bar/s)

The cubic law may be applied only to systems that are similar with respect to vessel shape, degree of turbulence, ignition source, and concentration of gas-air mixture. **Table 2.4** shows the K_G values of some flammable gases obtained by using spark gap ignition with ignition energy of 10 J. **Table 2.5** shows the maximum pressures and deflagration indexes for a number of gases and vapors.

Table 2.4: Average K_G Value of Gases, Ignited at Zero Turbulence [9]

Flammable Gas	**K_G (bar-m/s)**
Methane	55
Propane	75
Hydrogen	550

Table 2.5: Maximum pressures and deflagration indexes for a number of gases and vapors [10]

Chemical	Maximum pressure P_{max} (bar g)	Deflagration index K_G (bar.m/s)
Acetylene	10.6	109
Ammonia	5.4	10
Butane	8.0	92
Carbon disulfide	6.4	105
Diethyl ether	8.1	115
Ethane	7.8	106
Ethyl alcohol	7.0	78
Ethyl benzene	6.6	94
Ethylene	-	-
Hydrogen	6.9	659
Hydrogen sulfide	7.4	45
Isobutene	-	-
Methane	7.05	64
Methyl alcohol	-	-
Methylene chloride	5.0	5
Pentane	7.65	104

Propane	7.9	96
Toluene	-	-

2.10 Blast Damage Resulting from Overpressure

The explosion of a dust or gas (either as a deflagration or a detonation) results in a reaction front moving outward from the ignition source preceded by a shock wave or pressure front. After the combustible material is consumed, the reaction front terminates, but the pressure wave continues its outward movement. A blast wave is composed of the pressure wave and subsequent wind. It is the blast wave that causes most of the damage.

Figure 2.13 shows the variation in pressure with time for a typical shock wave at a fixed location some distance from the explosion site. The explosion occurs at time t_o. There exists a small but finite time *t,* before the shock front travels from its explosive origin to the affected location. This time, *t,,* is called the arrival time. At *t,* the shock front has arrived and a peak overpressure is observed, immediately followed by a strong transient wind. The pressure quickly decreases to ambient pressure at time *t,,* but the wind continues in the same direction for a short time. The time period *t,* to *t,* is called the shock duration. The shock duration is the period of greatest destruction to free-standing structures, so its value is important for estimating damage. The decreasing pressure continues to drop below ambient pressure to a maximum underpressure at time *t,*.

For most of the underpressure period from *t,* to *t4* the blast wind reverses direction and flows toward the explosive origin. There is some damage associated with the underpressure period, but because the maximum underpressure is only a few psi for typical explosions, the damage is much less than that of the overpressure period. The underpressure for large explosions and nuclear explosions, however, can be quite large, resulting in considerable damage. After attaining the maximum underpressure *t*,, the pressure will approach ambient pressure at *t4*. At this time the blast wind and the direct destruction have terminated.

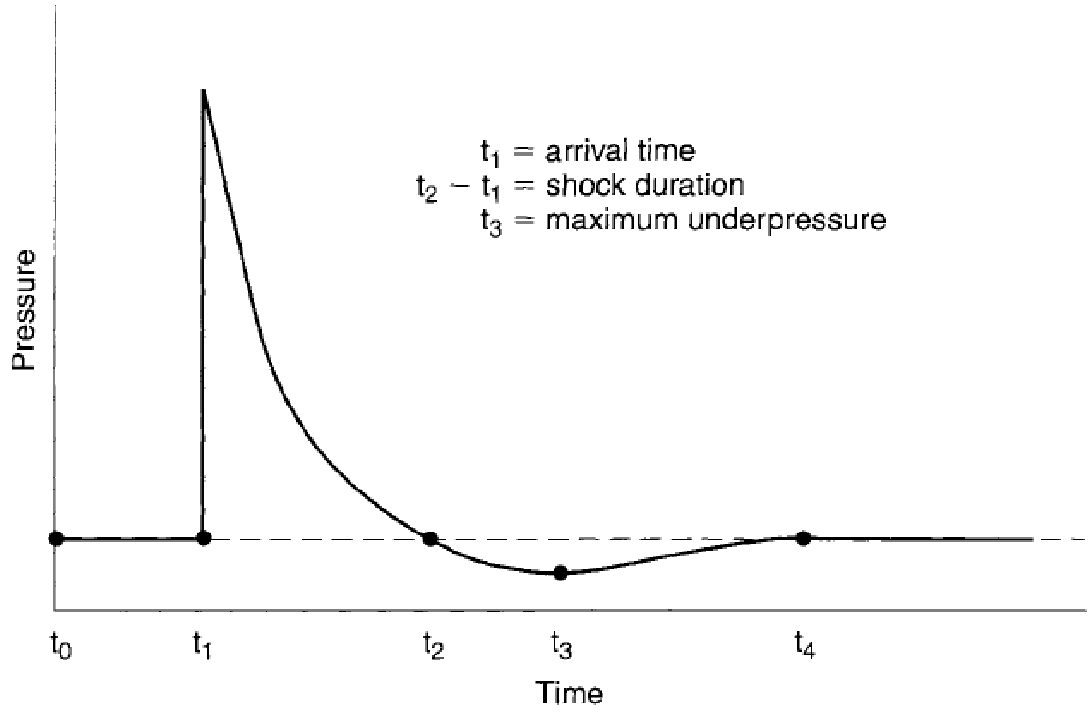


Figure 2.13: Blast wave pressure at a fixed location [10]

An important consideration is how the pressure is measured as the blast wave passes. If the pressure transducer is at right angles to the blast wave, the overpressure measured is called the side-on overpressure (sometimes called the free-field overpressure). At a fixed location, shown in **Figure 2.13**, the side-on overpressure increases abruptly to its maximum value (peak side - on overpressure) and then drops off as the blast wave passes. If the pressure transducer is placed facing toward the oncoming shock wave, then the measured pressure is the reflected overpressure. The reflected overpressure includes the side-on overpressure and the stagnation pressure. The stagnation pressure is due to deceleration of the moving gas as it impacts the pressure transducer. The reflected pressure for low side-on overpressures is about twice the side-on overpressure and can reach as high as 8 or more times the side-on overpressure for strong shocks.

The reflected overpressure is a maximum when the blast wave arrives normal to the wall or object of concern and decreases as the angle changes from normal.

Many references report overpressure data without clearly stating how the overpressure is measured. In general, overpressure implies the side-on overpressure and frequently the peak side-on overpressure.

Blast damage is based on the determination of the peak side-on overpressure resulting from the pressure wave impacting on a structure. In general, the damage is also a function of the rate of pressure increase and the duration of the blast wave. Good estimates of blast damage, however, are obtained using just the peak side-on overpressure.

2.11 Parameter

There are several parameters that affect the maximum explosion pressure and rate of explosion pressure rise. Parameters like concentration, initial pressure, explosion limit, maximum explosion pressure and maximum rate of explosion pressure are the main evaluation because it will give a big effect to the explosion graph.

2.11.1 Concentration

Explosion pressure and rate of explosion pressure are easily changed with the different concentration. Each percent of concentration change will make the effect of explosion graph.

2.11.2 Flammability Limit

A premixed fuel-air mixture will only burn as long as the fuel concentration is between the upper and lower flammability limits, that is. UFL and LFL. Vapor-air mixtures will ignite and burn only over a well-specified range of compositions. The mixture will not burn when the composition is lower than the lower flammable limit (LFL). It is too lean for combustion and also not combustible when the composition is too rich, that is when it is above the upper flammable limit (UFL). A mixture is flammable only when the composition is between the LFL and the UFL. Commonly used units are volume percent fuel (percentage of fuel plus air).

The flammability limits are experimentally determined data. The flammability limits in air depend on initial temperature and pressure. Standard test conditions are 25°C and 1 atm.

Explosion limits is the same meaning as flammable limits, that is. UEL = UFL and LEL = LFL. Flammability limits for vapors are determined experimentally in a specially designed closed vessel apparatus. Vapor-air mixtures of known concentration are added and then ignited. The maximum explosion pressure is measured. This test is repeated with different concentrations to establish the range of flammability for the specific gas. **Figure 2.14** shows the flammable range for fuel-air mixtures at 1 atm. and 25°C.

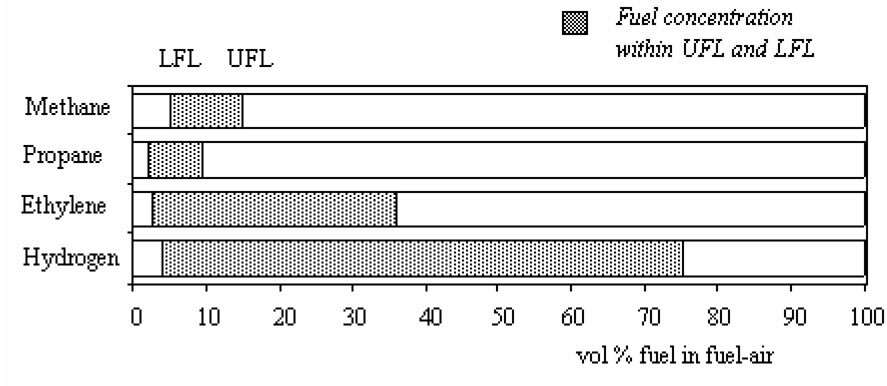


Figure 2.14: Flammable range for fuel-air mixtures at 1 atm and 25°C [10]

The wide flammable range of hydrogen tells us that it is easy to get a flammable cloud of hydrogen in air. For propane and methane, the flammable range is much narrower, an ignition source may *sit and wait* until the cloud can be ignited and explode. If the UFL has been passed, one has to go through the flammable concentration in the dilution process. It is good practice to operate safely below the LFL.

As shown in **Figure 2.15**, the flammable range will widen when the initial temperature is increasing. Changes in initial pressure will for hydrocarbons in air not change the LFL significantly, but the UFL will increase.

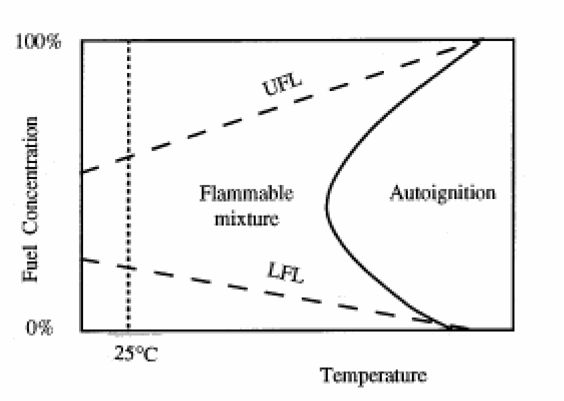


Figure 2.15: The effect of temperature on LFL and UFL. [10]

2.11.2.1 Lower Explosion Limit (LEL)

By definition, the lower explosion limit, LEL, of a gas/vapor is the highest concentration at which a gas/vapor explosion is not detected in three successive tests [10].

In other definition, lower explosion limit is the lower end of the explosion range of a flammable solvent, which represents the range of air/vapor mixtures that can ignite. The explosion range is delineated by the upper and lower explosion limit. Outside this range of air/vapor mixtures, the mixture will not explode.

For investigations under quiescent conditions, ignition energy (IE) is 10 J and ignition delay time (tv) is 0 sec. The mixture of the LPG and air directly takes place in the 20-L Apparatus. Accordingly, the required LPG-air mixture can be produced readily with the partial pressure procedure.

In practice, the 20-L-Apparatus has to be cleaned thoroughly before each test. Then the test series starts with an initial gas sample concentration of 1 or 1.5 vol.%, followed by a stepwise decrease or increase of 0.25 vol.%. After the initial tests, these series are continued with a systematic increase of the gas concentration until ignition of the LPG -air mixture is observed. The test is then repeated with a gas concentration of 0.25 vol.% lower, and the concentration is reduced in further tests until no ignition of the LPG - air mixture is observed in at least three successive tests. [10]

2.11.2.2 Upper Explosion Limit (UEL)

Upper explosion limit is the highest concentration (percentage) of a gas or vapor in air capable of producing a flash of fire in presence of an ignition source (arch, flame, heat). Concentrations higher than UEL are 'too rich' to burn. The procedure for determining the UEL is similar to the procedure for determining the LEL.

2.12 Research Stand with 20L Explosion Chamber

The current study was aimed at determining the fundamental explosion parameters of LPG-air mixtures at normal and elevated temperature. Parameters such as: maximum explosion pressure, maximum rate of explosion pressure rise, lean explosion limit (LEL), upper explosion limit (UEL) and optimal explosion concentration were found.

Experiments were carried out in a 20L volume explosion chamber. The general view of the research stand is shown in **Figure 2.16** and a scheme of the apparatus is presented in **Figure 2.20**. The stand consists of explosion chamber and systems of: ignition, data acquisition, pressure and temperature measuring and equipment for preparing the required mixtures. The cylindrical steel explosion chamber is the main element of the stand.

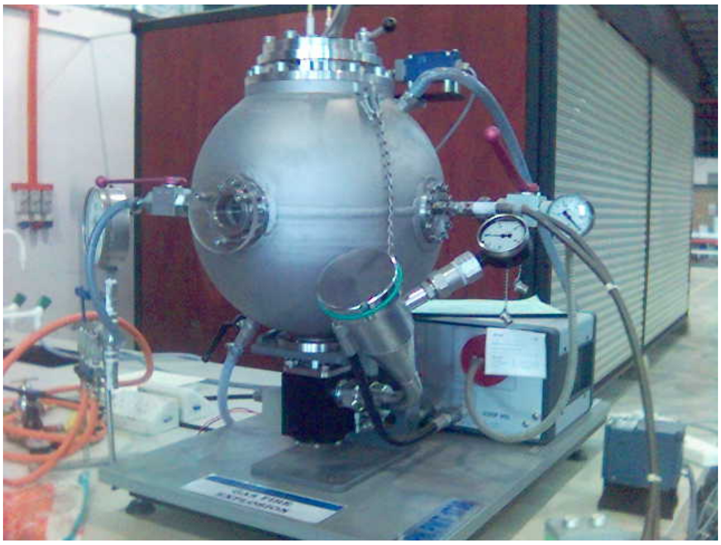


Figure 2.16: General view of 40 dm^3 explosion chamber.

The initial temperature of the mixture inside the chamber can be increased by means of three electrically powered flat bands located on the external surface of the chamber. The ignition system was prepared. The electrodes were positioned in the center of the vessel. A high voltage transformer and a short circuit current were used to produce the ignition spark. The spark discharge time was adjusted to 0.2 second. If a spark discharge time of 0.2 second did not result in ignition of the tested mixture, the experiment was repeated with a spark discharge time of 0.5 second.

The pressure inside the explosion chamber was measured by means of piezo-electric transducer manufactured by Kistler. The thermocouple was used for measuring the temperature of the test mixture inside the test vessel. The data acquisition system was based on the ESSAM-3000 computer card. It enables continuous registration of obtained measurement results. For preparing combustible mixture of the required composition in the bottle outside the test vessel, the stand shown in **Fig. 2.16** was constructed. The stand enabled the mixture to be prepared by using the partial pressure method. The stand is equipped with a steel bottle, a vacuum pump and a set of precise manometers of high reading accuracy.

Figure 2.17: General view of the stand for precise preparing of the test mixtures.

The experimental procedure was as follows: pumping out the test chamber to a pressure <5 mbar and filling it in with the specific LPG - air mixture, then preheating the test vessel containing the test mixture to the required temperature, igniting the quiescent test mixture and recording an explosion overpressure inside the chamber. The test mixture is considered as an explosive one, if the measured explosion overpressure is equal to or greater than the overpressure formed by the ignition source itself, plus (5+0.1)% of the initial pressure. [11]

2.13 Sphere Vessel

The test chamber is a hollow sphere made of stainless steel, with a volume of 20 liters. A water jacket serves to dissipate the heat of explosions or to maintain thermostatically controlled test temperatures.

For testing, the gas is dispersed into the sphere from a pressurized storage chamber via the outlet valve and a nozzle. The outlet valve is pneumatically opened and closed by means of an auxiliary piston. The valves for the compressed air are activated electrically.

The ignition source is located in the center of the sphere. On the measuring flange two "Kistler" piezoelectric pressure sensors are installed. The second flange can be used for additional measuring elements or for the installation of a sight glass. **Figure 2.18** shows the 20L of gas fire explosion.

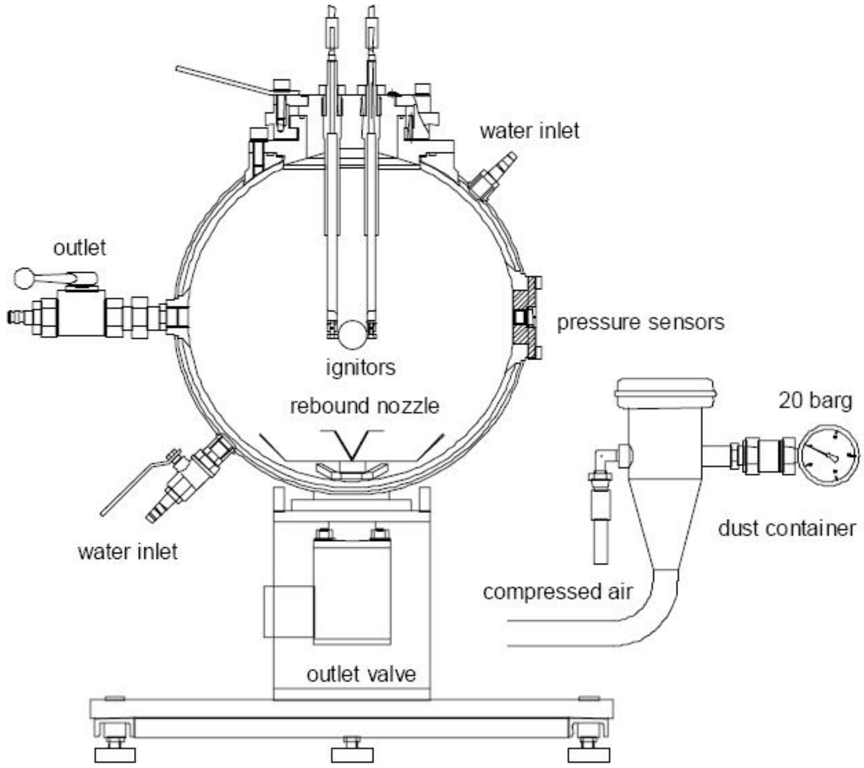


Figure 2.18: 20 L Sphere Vessel [11]

2.14 Control Unit

The control unit KSEP 310 is installed as an auxiliary unit behind the sphere on the same base plate. Make sure the wire connection is right. **Figure 2.19** shows the front side and back side view of control unit. Safety switch must be on when the experiment in progress.

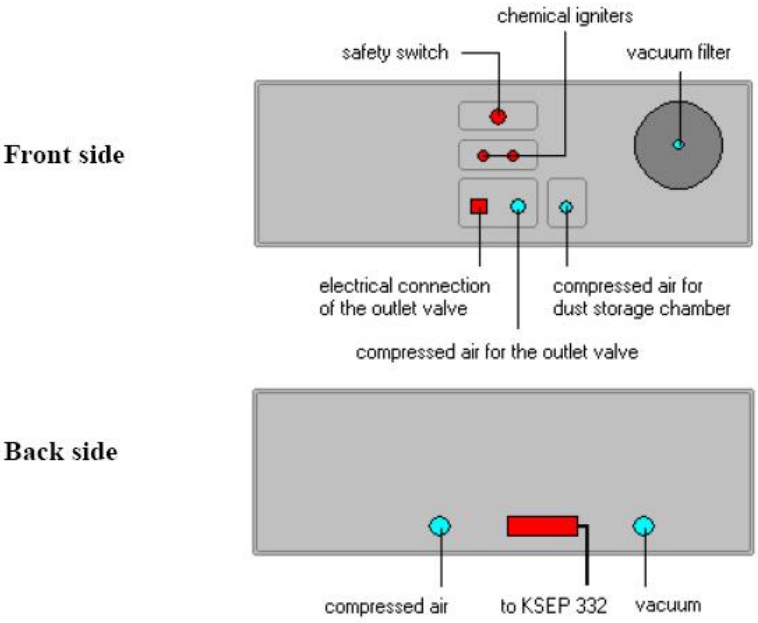


Figure 2.19: Front side and back side view of control unit [11]

2.14.1 Compressed Air

Compressed air is used to power the outlet valve and is also connected to the inlet valve of the dust storage chamber. The pressure in the storage chamber corresponds directly to that of the external compressed air system.(Standard = 20 bar, overpressure = 21 bar absolute).

The 20 bar compressed air connection must have an adequate cross section. It must be possible to pressurize the storage chamber (V = 0.6 l) within 5 seconds.

For the 20L apparatus only normal compressor compressed air may be used (in cylinders). The synthetic compressed air explosion indices which are clearly different were obtained. [11]

2.14.2 Vacuum

Prior to dispersing the dust, the sphere is evacuated to such a degree, that the remaining pressure, together with the air contained in the storage chamber, result in the desired starting pressure for the explosion test. For that purpose, the ball-valve on the vacuum connection of the sphere is opened and the sphere is evacuated via the vacuum filter until the vacuum meter shows the desired vacuum. The vacuum filter can easily be removed for cleaning.

2.15 Measurement and Control System

The KSEP 332 unit uses piezoelectric pressure sensor’s to measure the pressure as a function of time and controls the valves as well as the ignition system of the 20-l-apparatus. The measured values to be processed by a personal computer are digitized at high resolution. The use of two completely independent measuring channels gives good security against erroneous measurements and allows for self checking. **Figure 2.20** shows the scheme of research stand with 20 L explosion chamber

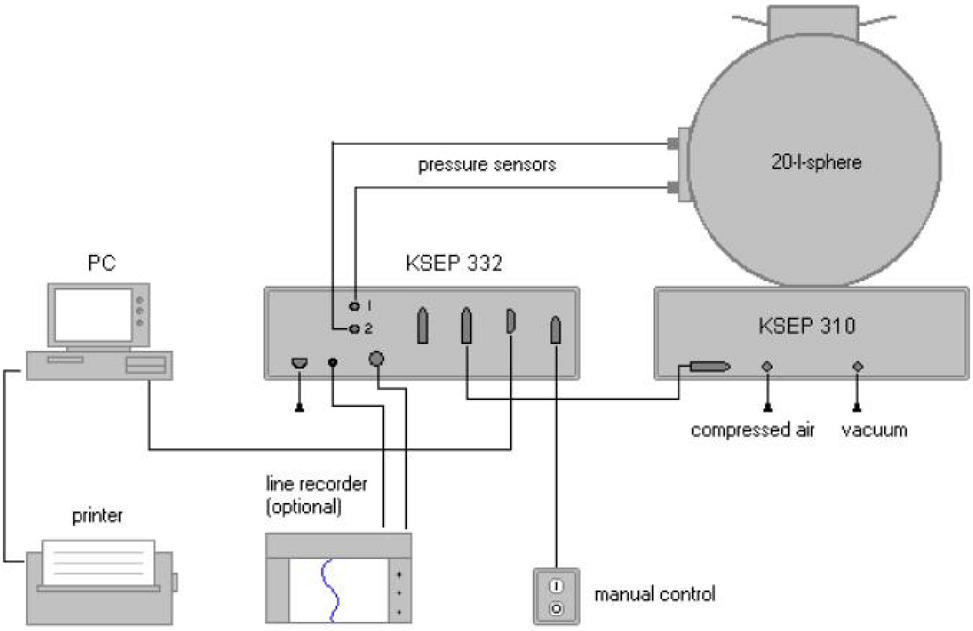


Figure 2.20: Scheme of research stand with 20 L explosion chamber [11]

The transducer output is digitized at high resolution and stored in the KSEP 332 memory (0.2ms / 10,000 measurements per channel). The Personal Computer only receives part of it (500 measurements / channel). For test purposes only, the complete record of the KSEP 332 can be shown with a normal Y/t-line recorder.

2.15.1 Pressure Sensors

The pressure sensor's (manufactured by Kistler) are based on the piezoelectric principle: a quartz crystal is deformed by pressure. By this deformation, an electrical charge proportional to the differential pressure is generated on the surface. Measuring unit: "Coulomb" **C** (10E-12 C = 1pC) [11]

The piezoelectric system allows only the measurement of pressure differences. Thus, no indication of the absolute pressure within the 20-l-sphere is possible. Furthermore, the unavoidable insulation resistance in the connecting cables and plugs and stray currents of the following amplifier will cause a slow drift of the charge signal. This means that the electrical signal will change even when the sensor is exposed to static pressure. However, for the short duration of an explosion recording, this drift can be neglected. It is recommended to flush the connectors with a cleaning spray (Kistler no. 1001) before plugging them together.

The membrane of the pressure sensor has to be protected against the flame front of the explosion by a layer of silicone rubber (e.g. Kistler no. 1043) of approx. 2 mm thickness. Too hard or too thick protective layers will have a "shunting" effect on the membrane and cause faulty measurements especially in the vacuum range. The protective silicone layer must be renewed periodically.

2.15.2 Sample Preparation

2.15.3 Water Cooling

A high test frequency will necessitate keeping the operating temperature at approx. 20°C by means of water cooling, i.e. the operating temperature should correspond to room temperature. Thermo-static control of the cooling water is not necessary, but care should be taken that there is always some flow of water and that the outlet temperature of the cooling medium not exceeds 25°C.

2.15.4 Fitting of Igniters

Two chemical igniters (**Z**) each having energy of 5kJ are connected to the electrode (**S**) as shown in **Figure 2.21**. The two igniters are firing horizontal and in opposite directions. Electrical the igniters are connected in parallel.

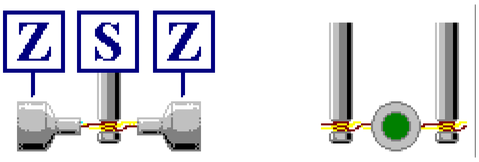


Figure 2.21: Fitting of igniters [11]

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will discuss about flow experiment using gas fire explosion step by step from sample preparation, test check and test until analysis the result. In this study, LPG will be used as the sample for experiment. Experiment will be running at the ambient temperature, 1 bar and elevated concentration. The pictures taken during the experiment are show in the **appendix C1**.

3.2 Framework of Study

These frameworks give a view of the research methodology applied to obtain the deflagration index for LPG using gas fire explosion. **Figure 3.1** shows the framework of study for all process to determine the deflagration index.

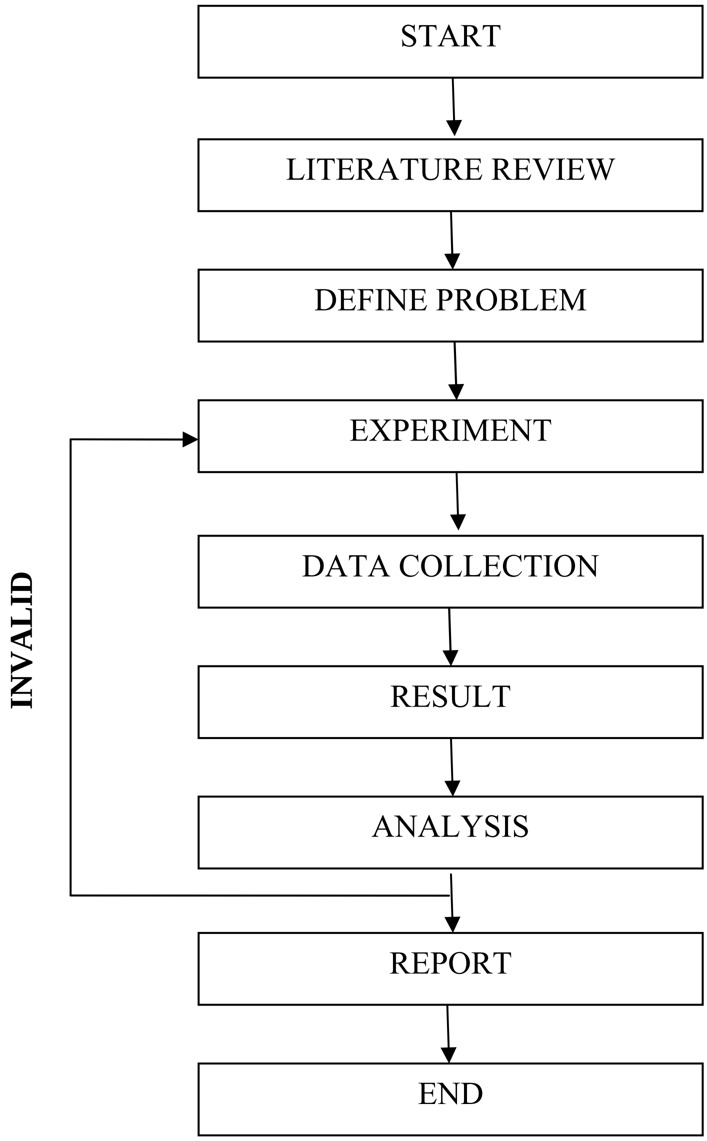
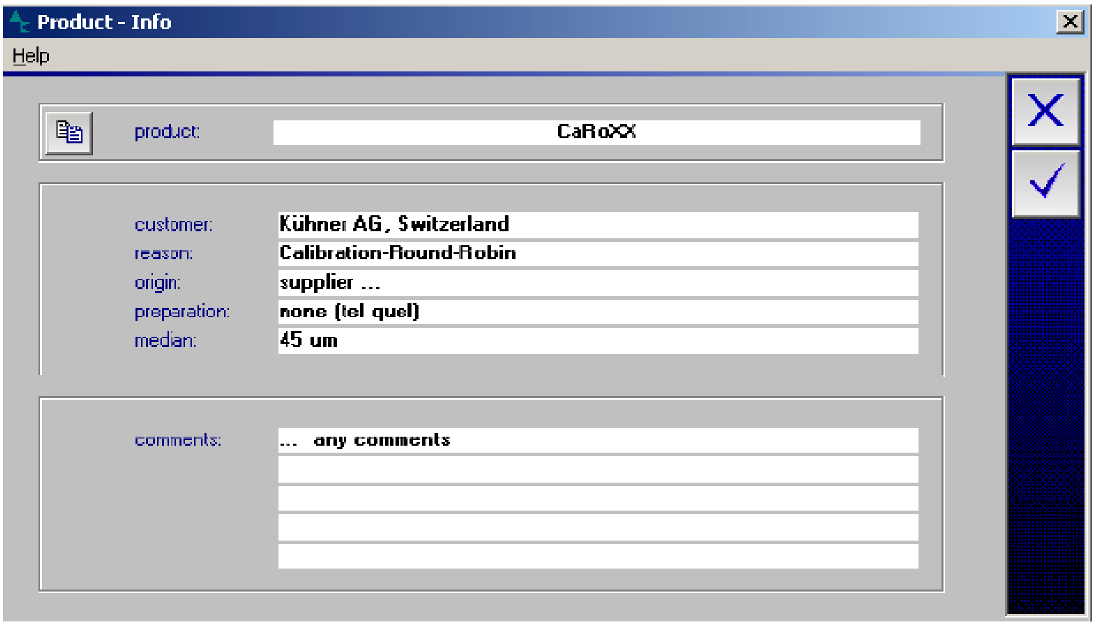


Figure 3.1: The framework of study

3.3 Test Check Manual

A test check is a test sequence without dust and without chemical igniters. Thereby, the correct function of the entire system is checked in a simple way. It is recommended that the check be repeated at the onset of each test series.

At the start of a test with a new dust, a new file is opened. The file name is automatically allocated by the program. A new window will open as the **Figure 3.2**. **Figure 3.2** show the product info for gas fire explosion.



product: CaRoXX

customer: Kühner AG, Switzerland
reason: Calibration-Round-Robin
origin: supplier ...
preparation: none (tel quel)
median: 45 um

comments: ... any comments

Figure 3.2: Product info for gas fire explosion

Working with the equipment is facilitated considerably by grouping the tests according to tasks or functions, because the pre-adjustment of the test-parameters and the graphic display differ from task to task. Open this window and select the function Test check. **Figure 3.3** shows the selection of test method. To make a test for LPG, it must select the Gas, Solvent function. Test check function is used just to make a pretest for gas fire explosion and it will be run without any gas. It is to ensure the gas fire explosion can work properly.

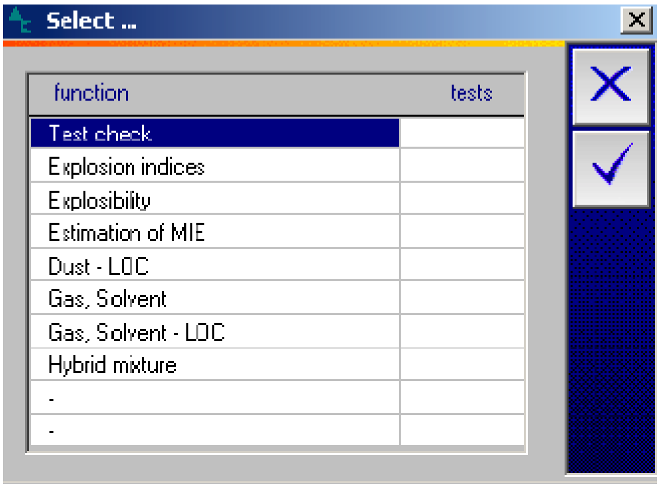
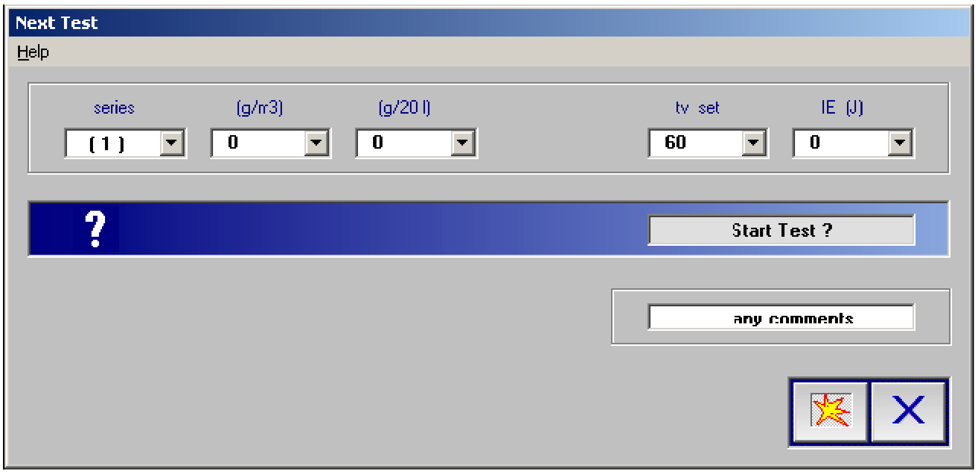


Figure 3.3: Selection of test method

Open the window “Next Test” by a click on this button or push the “enter”-key. Under the function “Test Check” all parameters are pre-set as follows: **Figure 3.4** shows the pre-set parameter before make the LPG test. All of values are set as the value in the **Figure 3.4** except the “tv set” value. It will be set to zero because it is depend on the temperature in the 20L sphere vessel during the experiment. For the test at ambient temperature, it must set to zero.



series	[g/m3]	[g/20 l]	tv set	IE [J]
(1)	0	0	60	0

Figure 3.4: Pre-set parameter before LPG test

3.4 Before Test

Connect the source of LPG from LPG tank to the entering place (L). Then make sure the water is flow in and out in the sphere jacket. This is important to control the temperature in the vessel so that it temperature is not too hot. Open the safety switch (S) and take out the cover by taking the bayonet-ring (B) out from the sphere. Clean the sphere using vacuum cleaner. Cleaning process is to ensure the inner part of vessel free from combustion left over before. **Figure 3.5** shows the 20L sphere vessel with labeled.

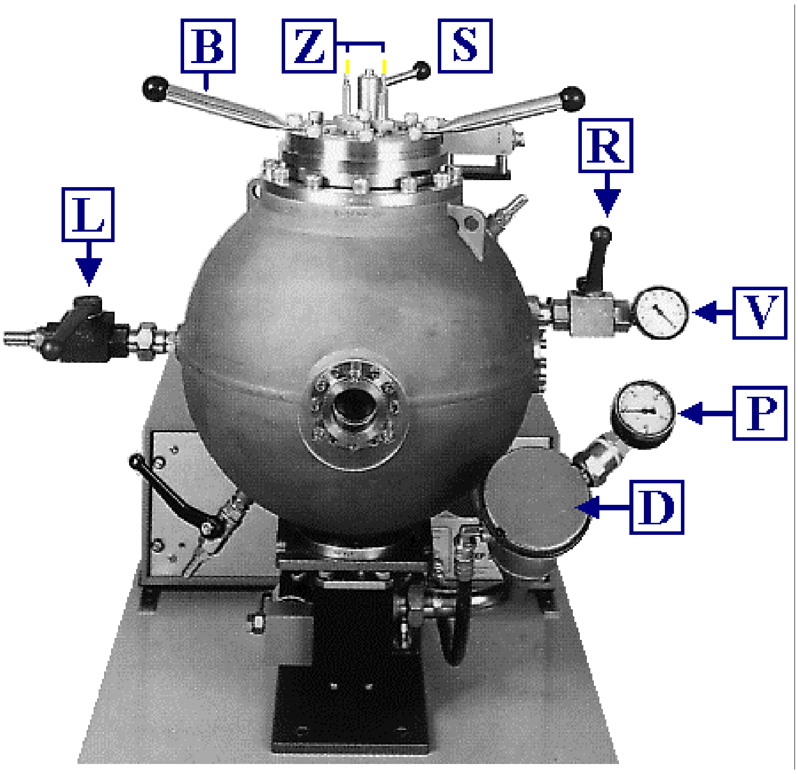


Figure 3.5: 20 L sphere vessel

3.5 Test Check

Connect the igniter to the two electrodes. Igniter wire must touch the electrode (figure 9). Put back the cover to the sphere and turn the bayonet-ring (B) in the final position. The safety switch (S) can be closed now. This is important to lock the cover because when explosion start, it will produce a huge pressure. Close the ball valve (L) - venting. Close the ball valve (R) - vacuum. Experiment can be running for test check.

During the test check, there are no gas feed to the vessel. The test check is pretest to ensure the equipment in functional condition.

3.6 Test

After finish clean the sphere (vacuum cleaner), Connect the igniter to the two electrodes. Igniter wire must touch the electrode. Put back the cover to the sphere and turn the bayonet-ring (B) in the final position. The safety switch (S) can be closed now. Open the ball valve (L) - venting. Open the ball valve (R) - vacuum. Vacuum the sphere to -0.7 bars. Close the ball valve (R) and switch off the vacuum pump.

For the first test, feed the sphere with lpg until -0.68 bar. Next test, feed lpg to -0.67, -0.66 and so on. Close the ball valve (L). Open the program KSEP6 in the computer. Refer figure 10. Run the test by press the button like a star. For the next test, repeat step 12 to step 20.

The volume of LPG to feed into the sphere is 1% to 10%. That mean each test will be running by 1% concentration of LPG mix with air. To measure the volume of LPG is exactly difficult but in this case, it should be measure by it pressure. The calculation of LPG volume that should feed into the sphere is by example below. This is how to calculate the 2% of LPG concentration.

Set 2% LPG volume concentration

$$2\%\ LPG = \frac{x}{1000\ mbar} \times 100\%$$

$$x = 20mbar$$

From the calculation above, it can be seen that 2% concentration of LPG is equal to 20mbar. That mean to feed 1% concentration of LPG, it must set the change of pressure to 10mbar.

3.7 After Test

Switch off pump, KSEP 322 and shutdown the computer. Clean the sphere by suck away remaining dust with a vacuum cleaner. Make sure the water flow in and out in the vessel jacket is close. Keep back the apparatus as before test.

3.8 Analysis

Analysis is made to ensure that the value from these tests is correct. In this case, it can be compare the range and value of explosion limit with the journal. When its value is same, then the test should be correct.

The value of rate of explosion pressure rise is different form the place, concentration and condition. LPG concentration is playing the important parameter to determine its value. A small change in the LPG concentration will make a conspicuous change to the rate of explosion pressure rise value.

CHAPTER 4

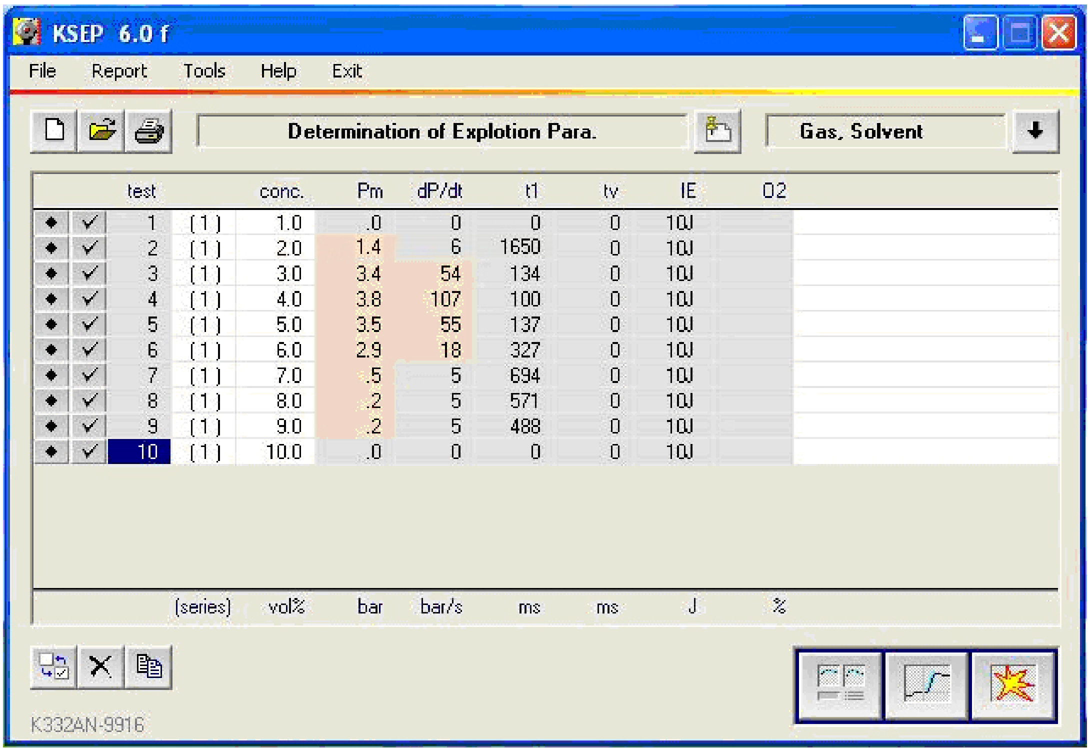
RESULT AND DISCUSSION

4.1 Introduction

From the result, it can be seen the whole experiment result in the table and the graph maximum explosion pressure P_{max} and rate of explosion pressure rise dp/dt. All of the graph and table result are analyzed by the computer. Each value of deflagration index will be calculated by using the value of rate of explosion pressure rise in the table. The higher value of deflagration index will be considered as very danger condition if an explosion occurs.

4.2 Table Result

All of the data during the experiment was recorded in the table. **Figure 4.1** shows the table result of experiment. The value of explosion pressure and rate of explosion pressure rise will be described one by one in the separated graph. Data during the experiment are show in the **appendix A1**.



		test		conc.	Pm	dP/dt	t1	tv	IE	O2
◆	✓	1	(1)	1.0	.0	0	0	0	10J	
◆	✓	2	(1)	2.0	1.4	6	1650	0	10J	
◆	✓	3	(1)	3.0	3.4	54	134	0	10J	
◆	✓	4	(1)	4.0	3.8	107	100	0	10J	
◆	✓	5	(1)	5.0	3.5	55	137	0	10J	
◆	✓	6	(1)	6.0	2.9	18	327	0	10J	
◆	✓	7	(1)	7.0	.5	5	694	0	10J	
◆	✓	8	(1)	8.0	.2	5	571	0	10J	
◆	✓	9	(1)	9.0	.2	5	488	0	10J	
◆	✓	10	(1)	10.0	.0	0	0	0	10J	
			(series)	vol%	bar	bar/s	ms	ms	J	%

Figure 4.1: Table result of experiment.

Results obtained from experiments at the different concentration are presented in figures below. The influences of concentration on the course of explosion pressure, as well as of rate of explosion pressure rise, as a function of LPG molar fraction in the mixture, are presented in figure below.

4.3 Discussion

Graph results are analysis by software. During the analysis, computer will process two data. Both of the data will show in the graph. The graph colored red is the first reading, and the second reading is blue color. Then the computer wills analysis both of the data to get the average value and it is colored green.

Pre-test with no fuel was made to ensure the gas fire explosion can work properly. For pre-test, the result will produce a graph with a very small rising effect because there is no fuel to produce some pressure during the explosion occurs. **Figure 4.2** shows the graph of explosion with no fuel.

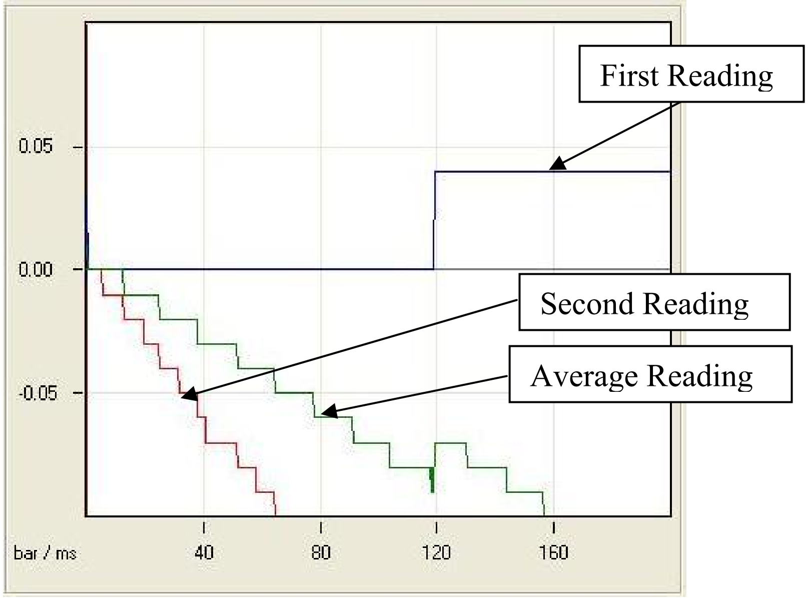


Figure 4.2: Graph of explosion with no fuel

There are no effects to the graph during the explosion. The explosion occurs are not enough pressure to make the graph curve above. It is just a pretest to determine whether the equipment is in functional condition or not. From this result, it shows that the equipment is in good condition and it can detect the pressure change in the vessel. Even though the explosion occurs in the vessel but there is no pressure exist in the vessel. All of the calculation for deflagration index was calculated and showed in the **appendix A2**.

Test was start with 2% concentration of LPG in 98% of air. There is a small graph curve above. At this concentration, it just made an explosion in the close vessel. According to the low flammability limit theory, LPG can ignite when 2.2% concentration of LPG mix with 97.8% of air. It can be call as lower explosion limit or lower flammability limit. The concentration 2% of LPG is enough to make the ignition or explosion. **Figure 4.3** shows the graph of the explosion at 2% of LPG in 98% of air.

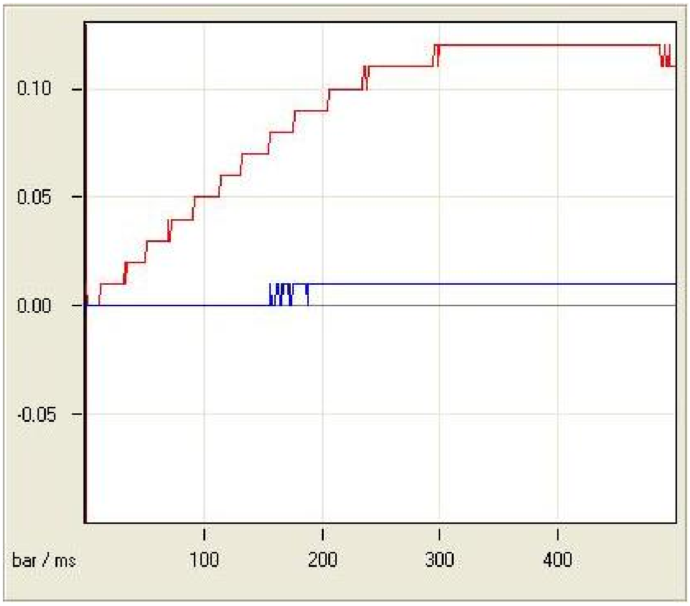


Figure 4.3: Graph of the explosion at 2% of LPG in 98% of air

It can be seen that the existing of pressure in the vessel when the explosion occur. By increase the concentration to 3% of LPG in 97% of air, the explosion pressure increase to 3.4 bar. **Figure 4.4** shows the graph of the explosion at 3% of LPG in 97% of air.

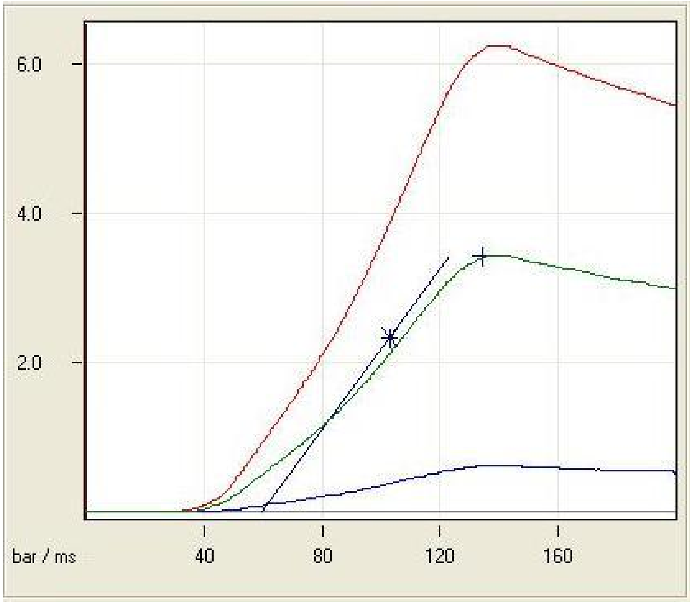


Figure 4.4: Graph of the explosion at 3% of LPG in 97% of air

It can be seen that the slope of the graph is high. The pressure in the vessel is rising very fast to 3.8 bar. The peak of the graph is the higher value of explosion pressure. **Figure 4.5** show the graph of the explosion at 4% of LPG in 96% of air.

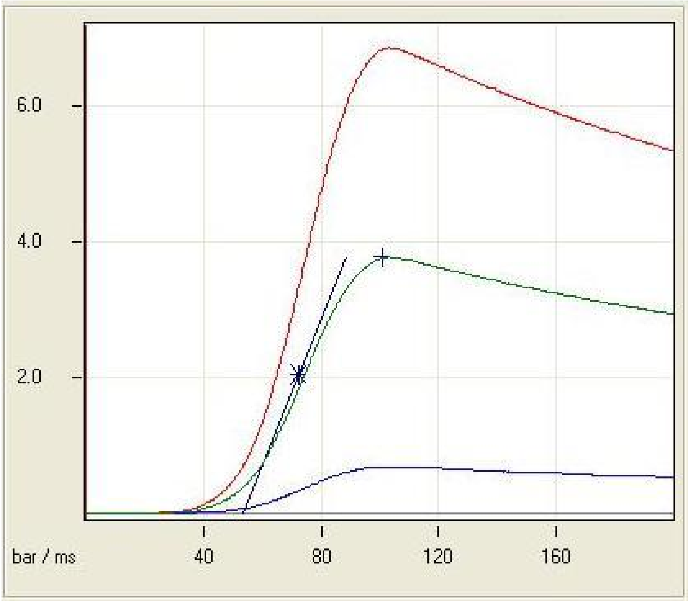


Figure 4.5: Graph of the explosion at 4% of LPG in 96% of air

LPG concentration at 4% is the maximum pressure produced during the explosion test. At this concentration, it can be determine the value of maximum explosion pressure and maximum rate of explosion pressure rise. Slope at this concentration is the highest. It produces a huge pressure during the explosion test. From this result, it can be determine the concentration of LPG that gives the dangerous condition.

LPG tank must be design by following the maximum value of explosion pressure. The tank must be able to accommodate the maximum explosion pressure. This is very important to ensure the customer can use LPG at the safety condition.

At 5% LPG concentration in the air mixture, the slope of graph was decrease. The pressure produced from explosion began to decrease. This shows that, at the 5% LPG concentration cannot produce a pressure more than 3.5 bar. The explosion pressure was decrease because the LPG cannot make a complete combustion at 5%

concentration of LPG in 95% of air. There are a few LPG molecule cannot take part in the combustion process. So when the explosion occurs, it cannot produce more pressure than 3.5 bar. 3.5 bar is the maximum explosion pressure can be produced from an explosion of 5% concentration of LPG in 95% of air. **Figure 4.6** shows the graph of the explosion at 5% of LPG in 95% of air.

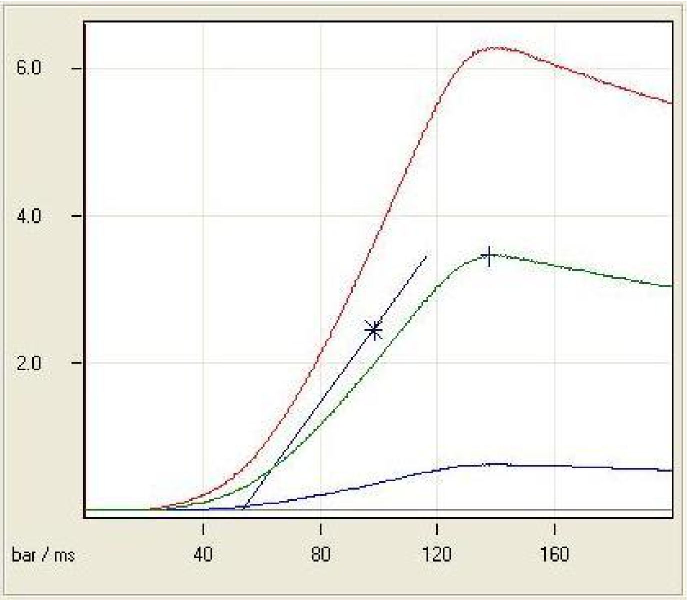


Figure 4.6: Graph of the explosion at 5% of LPG in 95% of air

Figure 4.7 shows the graph of the explosion at 6% of LPG in 94% of air. The explosion pressure is drop to 2.9 bar. There are more molecule of LPG cannot take part in combustion as explosion occurs. It can be seen that the explosion of LPG will achieve at the some concentration which it cannot release any pressure.

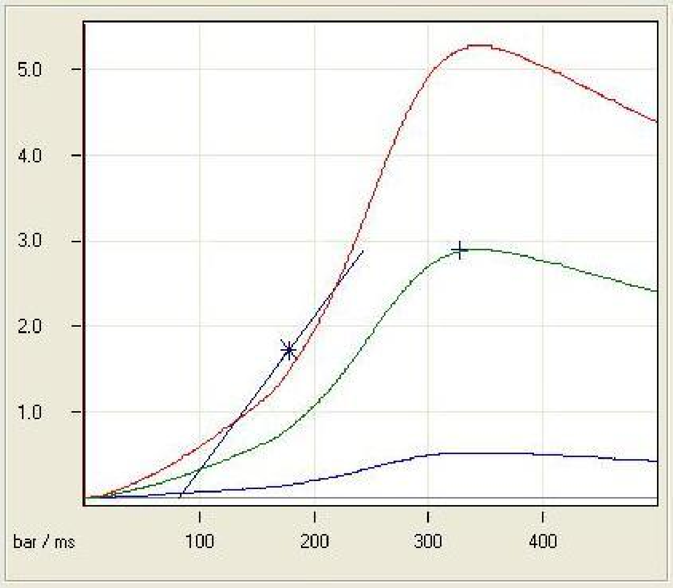


Figure 4.7: Graph of the explosion at 6% of LPG in 94% of air

At 7% concentration of LPG in 93% of air, an explosion just produces 0.5 bar. There are small part of LPG molecule can take part during the explosion occurs. These small parts of LPG just release pressure of 0.5 bar. **Figure 4.8** shows the graph of the explosion at 7% of LPG in 93% of air.

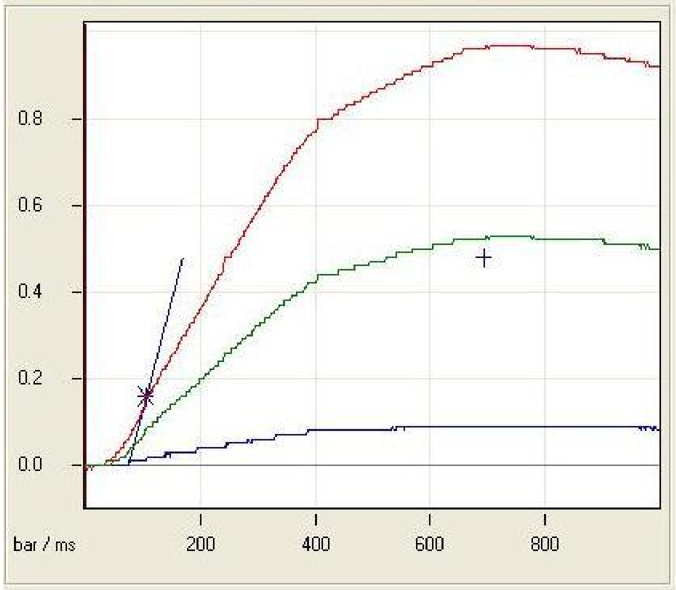


Figure 4.8: Graph of the explosion at 7% of LPG in 93% of air

At the 8% concentration of LPG in 92% of air, the value of maximum explosion pressure is 0.2 bar. There are no much pressure released during the explosion occurs. The amount of LPG not combust in the closed vessel during the explosion occurs is very little. So the explosion process cannot release more pressure than that. Figure 4.9 shows the graph of the explosion at 8% of LPG in 92% of air.

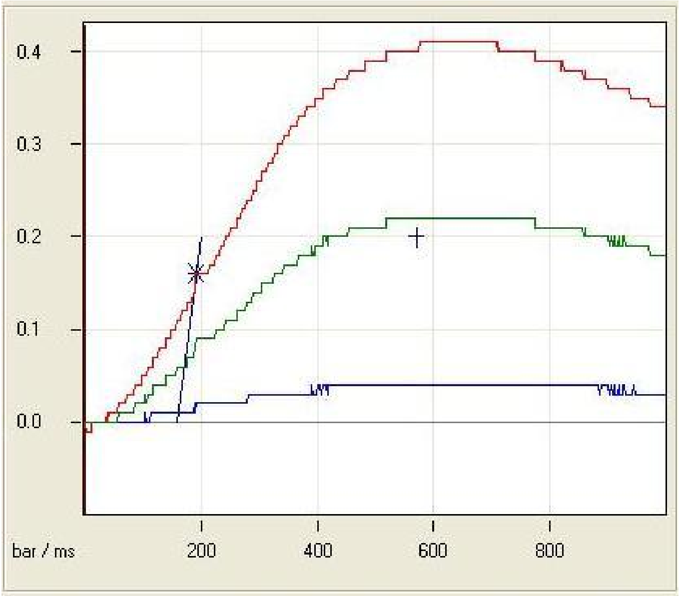


Figure 4.9: Graph of the explosion at 8% of LPG in 92% of air

It is still the same with 9% concentration of LPG in 91% of air. At this concentration, it produced the same maximum explosion pressure. The maximum explosion pressure was drop to 0.2 bar also. **Figure 4.10** shows the graph of the explosion at 9% of LPG in 91% of air.

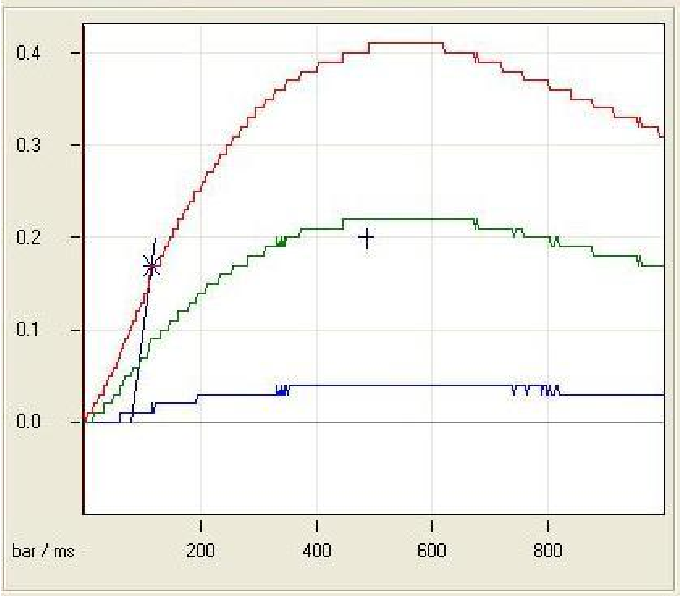


Figure 4.10: Graph of the explosion at 9% of LPG in 91% of air

The pressure becomes more decrease. The explosion still exists but it will produce the decreasing pressure. The pressure exists when explosion occurs until the concentration achieves at one point, upper explosion limit. **Figure 4.11** shows the graph of the explosion at 10% of LPG in 90% of air. It can be seen that the graph produced is not high anymore. This means that the pressure in the vessel becomes smaller. It is almost to have no pressure. After this, the pressure of the explosion cannot be produced anymore. That mean LPG is not combustibles after 10% concentration of LPG in 90% of air. Although there is a spark expose to LPG and air mixture, it cannot be igniting anymore. So, at this concentration, LPG achieves the final concentration to explode and it has been call as upper explosion limit.

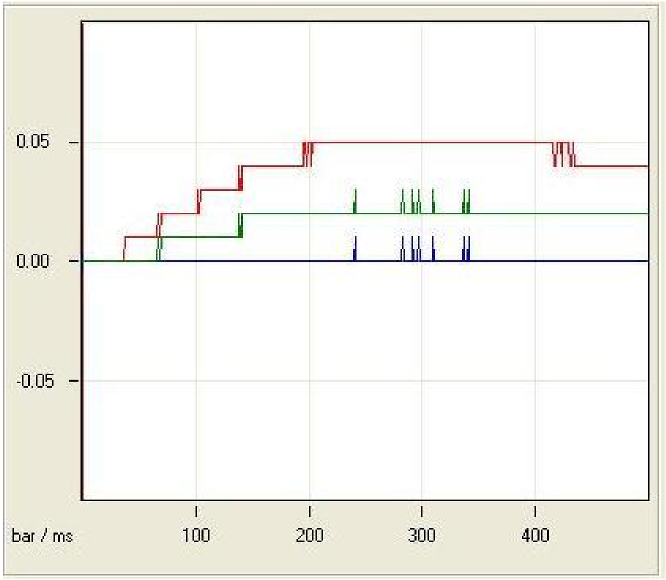


Figure 4.11: Graph of the explosion at 10% of LPG in 90% of air

From this graph, it can be determine the lower explosion limit and upper explosion limit of LPG and air mixture. The explosion of LPG and air mixture exactly occurs in this range. Lower explosion limit is the level of explosion just occurs. Explosion cannot occur below the explosion limit. Upper explosion limit is the level of explosion stop at that concentration. That mean the explosion of LPG and air mixture cannot occur after this concentration. **Figure 4.12** shows the explosion pressure as a function of the LPG concentration for different ambient of the LPG and air mixture.

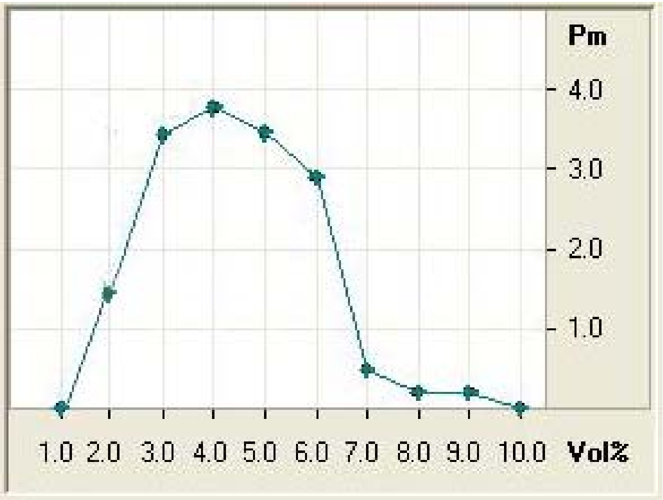


Figure 4.12: Explosion pressure as a function of the LPG concentration for different ambient of the LPG and air mixture.

It can be seen that the peak of explosion pressure in this range. This peak is maximum explosion pressure at 4% concentration of LPG in the air. At this concentration, LPG becomes more dangerous compare to other concentration. When the explosion occurs, it will produce a hugest pressure. **Figure 4.13** shows the rate of explosion pressure rise as a function of the LPG concentration for ambient temperature of the LPG-air mixture

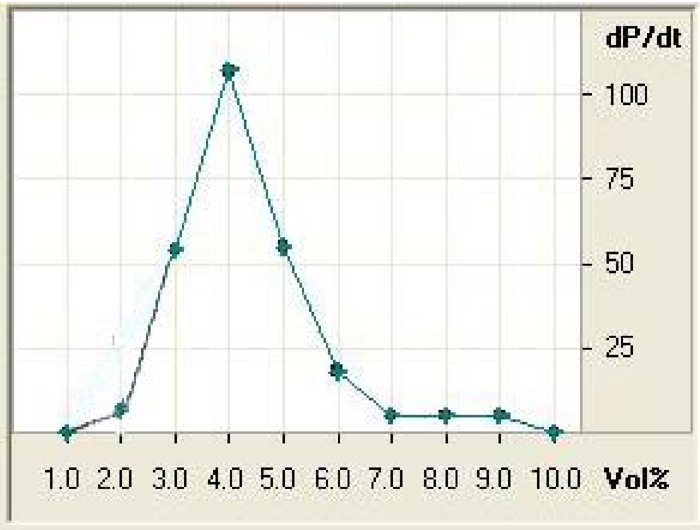


Figure 4.13: Rate of explosion pressure rise as a function of the LPG concentration for ambient temperature of the LPG-air mixture

The change of 1% of concentration will make the graph changed easily. That mean the concentration is the important element to influence the value of maximum explosion pressure.

If the graph is not proportional to the journal compared, there are a few factors that affect this case. The air used in this experiment is the ambient. The moisture content in the ambient mainly effected to the result because the deflagration index is very sensitive to the moisture content of the gas. The purified air should be use in this experiment to get the accurate result. The content of LPG in the tank is also the effect of the different graph from the journal compared. The content in the LPG tank is different because it has many compositions of propane and butane following to the place.

Table 4.1 show the value of deflagration index of LPG at certain concentration. It can be seen that the higher value of deflagration index is 29.04408. It is occur at 4% concentration of LPG in the air. From the beginning, the explosion starts at the concentration of 2% LPG in the air. The concentration of LPG is very poor in the air to make an explosion. So the value of explosion pressure is low and almost to zero. The value of deflagration index is also zero.

Table 4.1: K_G value of LPG at certain concentration.

% LPG in air	**V**	**P_m**	**$(dp/dt)_{max}$**	**K_G**
0	0.27144	0	0	0
2	0.27144	1.4	6	1.62864
3	0.27144	3.4	54	14.65776
4	0.27144	3.8	107	29.04408
5	0.27144	3.5	55	14.9292
6	0.27144	2.9	18	4.88592
7	0.27144	0.5	5	1.3572
8	0.27144	0.2	5	1.3572
9	0.27144	0.2	5	1.3572
10	0.27144	0	0	0

When the LPG concentration is 2% in the air, the value of explosion pressure becomes 1.4 bar. 2% concentration is enough to make the explosion pressure rise to 1.4 bar. The higher explosion occurs at 4% concentration of LPG in the air. LPG volume and air is balance to make the explosion occurs at the higher pressure. When the concentration is add to 5%, the explosion pressure is decrease again. This shows that the LPG concentration in the air is more than the needed. There are some molecule of LPG cannot be combust during the explosion occur. So the maximum explosion pressure just rise to 3.5 bar only.

The maximum explosion pressure after 4% concentration of LPG in the air is decrease. It is because of the balance between LPG volume and air volume. The optimum concentration of LPG in the air is 4%. If the concentrations of LPG are below than 4% or more than 4%, the maximum explosion pressure is not achieving the higher level.

The concentration below than 4% of LPG in the air is not enough to make the higher explosion pressure while the concentration more than 4% LPG in the air is exceed the optimum explosion pressure. That why the maximum explosion pressure below and above 4% concentration of LPG in the air is not achieving the maximum explosion pressure at 4% concentration of LPG in the air.

LPG needs a certain amount of air to make the complete combustion during explosion occur. When the air is not enough or more than enough, the explosion will not release the maximum explosion pressure more than an explosion occurs at 4% concentration of LPG in 96% of air. The optimum concentration will produce a maximum explosion pressure.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The change of concentration of the LPG-air mixture causes a significant maximum explosion pressure and maximum rate pressure rise. But it not means that the more concentration of LPG in air will increase the explosion pressure.

LPG just explodes at certain concentration only in the vessel. At some concentration, LPG becomes more hazards. In this experiment, the higher value of deflagration index is 29 at 4% concentration of LPG in the air. The designing of LPG tank storage should have value of deflagration index more than 29. It is to resist the over pressure from happen.

The increasing of concentration of the LPG-air mixture causes a significant increase of the explosion range which is the lower explosion limit decreases but the upper explosion limit increases. The change of lower as well as upper explosion limit versus concentration of the LPG-air mixture can be approximated by means of a linear function.

The increasing of the concentration of the LPG-air mixture at constant initial pressure decreases the maximum explosion pressure, and this pressure decrease is the highest for the stoichiometric mixture. Also maximum explosion pressure versus initial concentration of the LPG-air mixture can be approximated by means of a linear function.

The increase of the concentration of the LPG-air mixture at constant initial pressure does not influence significantly the rate of explosion pressure rise.

5.2 Recommendation

Since the deflagration index, K_G is very sensitive to the moisture content of the gas, it is recommended to use purified air in experiment. Purified is free from moisture. The ambient especially in Malaysia is rich with moisture. So, the effect of moisture will affect the result obtained.

Make the true calculation to estimate how much the percentage volume of LPG will be feed into the vessel. The mistake from this calculation will affect the result. Graph from the experiment is not smooth. The percentage of volume can be calculated by make the ratio of the pressure.

It is also recommended to add the elevated temperature as the scope of experiment. At elevated temperature, the range of explosion limit will change to be wider. The maximum explosion pressure and maximum rate pressure rise is also changed when the experiment ran at the different temperature.

The experiment should be running at the small interval of concentration. By doing this way, the graph produced from the experiment is smoother and more accurate. Determination of explosion limit is more accurate.

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APPENDIX A

A1: LPG Concentration Data

No.	**% LPG**	**P_{max}**	**$(dP/dt)_{max}$**
1	0	0	0
2	2	1.4	6
3	3	3.4	54
4	4	3.8	107
5	5	3.5	55
6	6	2.9	18
7	7	0.5	5
8	8	0.2	5
9	9	0.2	5
10	10	0	0

A2 Deflagration Index Calculations

$K_{max} = 0.27144 \times (dP/dt)_{max}$

$V^{1/3} = 0.02^{1/3}$

$= 0.27144$

K_G value of 0% of LPG in 100% of air

$K_{max} = 0.27144 \times 0$

$= 0$

K_G value of 2% of LPG in 98% of air

K_{max} = 0.27144 x 6

= 1.62864

K_G value of 3% of LPG in 97% of air

K_{max} = 0.27144 x 54

= 14.65776

K_G value of 4% of LPG in 96% of air

K_{max} = 0.27144 x 107

= 29.04408

K_G value of 5% of LPG in 95% of air

K_{max} = 0.27144 x 55

= 14.9292

K_G value of 6% of LPG in 94% of air

K_{max} = 0.27144 x 18

= 4.88592

K_G value of 7% of LPG in 93% of air

K_{max} = 0.27144 x 5

= 1.3572

K_G value of 8% of LPG in 92% of air

K_{max} = 0.27144 x 5

= 1.3572

K_G value of 9% of LPG in 91% of air

K_{max} = 0.27144 x 5

= 1.3572

K_G value of 10% of LPG in 90% of air

K_{max} = 0.27144 x 0

= 0

APPENDIX B

B1: Safety Data Sheet for LPG

Commercial Propane

Shell Malaysia ***Safety Data Sheet***

Issued: September 24, 1996

SDS No. DMC04022 **Liquid Petroleum Gas**

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND COMPANY

Product name:	Shell Gas
Product code:	16666
Product type:	Liquefied petroleum gas
Supplier:	Shell Malaysia Trading Sdn. Bhd/ Shell Timur Sdn. Bhd.
Address:	Bangunan Shell, Damansara Heights, 50490 Kuala Lumpur
Contact numbers:	
Telephone:	03-251-2118
Telex:	MA 31813
Fax:	03-251-2880
Emergency telephone number:	
Toll free	1 800 88 3899

2. COMPOSITION/INFORMATION ON INGREDIENTS

Synonyms: Liquefied Petroleum Gas, LPG

Preparation description: Complex mixture of hydrocarbons consisting predominantly of propane C3 and butane C4 hydrocarbons with low amount of others in the C1-C7 range. Low concentrations of sulphur, hydrogen sulphide and mercaptans may be present. It may also contain one or more of the following additives: odourants (usually ethyl mercaptan), anti-icing agents. 1,3-butadiene, classified as a Category 2 carcinogen, may be present at a concentration of less than 0.5 %(m/m).

Dangerous components/constituents:

Component name	CAS number	Content range	EC hazard	R phrases
Petroleum gases, liquefied	68476-85-7	>99 %(m/m)	F+	R12
1,3-butadiene	106-99-0	<0.5 %(m/m)	F+, Carc Cat 2	R12-45

Note: Dangerous Substances Directive, 67/548/EEC, Annex I numbers for the above substances are 649-202-00-6 and 601-013-00-X.

Contains the following substances for which exposure limits apply: liquefied petroleum gas, butane, 1,3-butadiene, hydrogen sulphide, ethyl mercaptan.

3. HAZARDS IDENTIFICATION

Human health hazards: Prolonged exposure to vapour concentrations may affect the central nervous system. May cause frost burns due to low boiling point.

Safety hazards: Extremely flammable liquefied gas. The vapour is heavier than air, spreads along the ground and distant ignition is possible.

Environmental hazards: No specific hazards under normal use conditions.

4. FIRST AID MEASURES

Symptoms and effects: Liquid may cause skin and eye burns. Prolonged exposure to vapour concentrations above the recommended occupational exposure standard may cause headache, dizziness, weakness, nausea, confusion, blurred vision, asphyxiation, cardiac irregularities, unconsciousness and even death.

Protection of first aiders: Take appropriate steps to avoid fire, explosion and inhalation hazards.

First Aid - Inhalation: Remove to fresh air. Keep warm and at rest. If the casualty is stuporous, some physical restraint may be necessary to prevent injury. If breathing but unconscious, place in the recovery position. If

	breathing has stopped, apply artificial respiration. If heartbeat absent give external cardiac compression.) Monitor breathing and pulse. OBTAIN MEDICAL ATTENTION IMMEDIATELY.
First Aid - Skin:	Drench affected parts with water. Remove contaminated clothing, rings, watches, etc., if possible, but do not attempt to do so if they are adhering to the skin. Do not attempt to reheat the affected parts rapidly - reheat slowly. Cover with a sterile dressing. Do not apply ointments or powders. Note that contaminated clothing may be a fire hazard. Contaminated clothing should be soaked with water before being removed. It must be laundered before reuse.
First Aid - Eye:	DO NOT DELAY. Flush eye with copious quantities of water. Cover eye with a sterile dressing. OBTAIN MEDICAL ATTENTION IMMEDIATELY.
First Aid - Ingestion:	In the unlikely event of ingestion, obtain medical attention immediately.
Advice to physicians:	Treat symptomatically.

5. FIRE FIGHTING MEASURES

Specific hazards:	Hazardous combustion products may include: carbon monoxide, oxides of nitrogen, oxides of sulphur, unburnt hydrocarbons. The vapour is heavier than air, spreads along the ground and distant ignition is possible. Sustained fire attack on vessels may result in a Boiling Liquid Expanding Vapour Explosion (BLEVE).
Extinguishing media:	Shut off supply. If not possible and no risk to surroundings, let the fire burn itself out. Large fires should only be fought by properly trained fire fighters. Dry powder, carbon dioxide may be used for small fires. Water fog should be used to assist the approach to the source of the fire. All containers subject to fire or to radiant heat should be cooled by spraying with water.
Unsuitable extinguishing media:	Water in a jet. Use of Halon extinguishers should be avoided for environmental reasons.
Other information:	Keep adjacent containers cool by spraying with water. All storage areas should be provided with adequate fire fighting facilities.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions:	Vapour can travel along the ground for considerable distances. Remove all possible sources of ignition in the surrounding area and evacuate all personnel. Shut off leaks, if possible without personal risk. Do not enter confined spaces. Ventilate contaminated area thoroughly. Do not breathe: vapour. Avoid contact with: skin, eyes and clothing. Take off immediately all contaminated clothing - but do not attempt to do so if clothing adhering to the skin. Contaminated clothing may be a fire hazard and therefore should be soaked with water before being removed.
Personal protection:	Wear: monogoggles, neoprene or nitrile rubber gloves, safety shoes or boots.
Environmental precautions:	No specific measures.
Clean-up methods - small spillage:	Allow to evaporate. Do not disperse liquid using water.
Clean-up methods - large spillage:	Attempt to disperse the vapour or to direct its flow to a safe location, for example by using water fog sprays. Otherwise treat as for small spillage.
Other information:	Test atmosphere for vapours to ensure safe working conditions before other personnel are allowed into the area. Local authorities should be advised if significant spillages cannot be contained. Observe all relevant local regulations.

7. HANDLING AND STORAGE

Handling:	This product is intended for use in closed systems only. Do not use in confined areas. When using do not eat, drink or smoke. Do not breathe: vapour. Take precautionary measures against static discharges. Use cylinders in the upright position only - unless specially designed for use in other orientations.
Storage:	Store only in purpose designed pressure vessels or cylinders. Store outdoors or in adequately ventilated storerooms. Locate tanks away from heat and other sources of ignition. Do not store in the vicinity of cylinders containing compressed oxygen. All storage areas should be provided with adequate fire fighting facilities. Keep out of reach of children.

Product transfer:	Electrostatic charges may be generated during pumping. Ensure electrical continuity by bonding all equipment. Avoid contact with equipment in view of the risk of cold burns. Do not use compressed air for filling, discharging or handling.
Tank cleaning:	Cleaning, inspection and maintenance of storage tanks is a specialist operation which requires the implementation of strict procedures and precautions. These include issuing of work permits, gas-freeing of tanks, using a manned harness and lifelines and wearing air-supplied breathing apparatus.Prior to entry and whilst cleaning is underway, the atmosphere within the tank must be monitored using an oxygen meter and/or explosimeter.
Recommended materials:	For containers use: mild steel. For seals and gaskets, use: compressed asbestos fibre, or other materials specifically approved for use with this product. Spirally wound metal gaskets are also suitable.
Unsuitable materials:	With respect to metals, aluminium should not be used if there is a risk of caustic contamination of the product. Certain forms of cast iron are unsuitable. With respect to non-metallic materials, natural rubbers must not be used. Nitrile rubbers and certain plastics may also be unsuitable, depending on the material specification and intended use.
Other information:	Ensure that all local regulations regarding handling and storage facilities are followed. Where large quantities of liquefied petroleum gas are stored, emergency and disaster plans must be developed in conjunction with local authorities.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering control measures:	Use only in well ventilated areas. Provide adequate ventilation in storage areas.
Occupational exposure standards:	ACGIH threshold limit values are given below. Lower exposure limits may apply locally.

Component name	**Limit type**	**Value**	**Unit**	**Other information**
Liquefied petroleum gas	TWA	1800	mg/m^3	
Butane	TWA	1900	mg/m^3	
1,3-butadiene	TWA	4.4	mg/m^3	
Hydrogen sulphide	TWA	14	mg/m^3	

Hydrogen sulphide	STEL	21	mg/m^3
Ethyl mercaptan	TWA	1.3	mg/m^3

Note: ACGIH - 'Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices', American Conference of Governmental Hygienists, Cincinnati, Ohio, 1996 edition.

Respiratory protection:	Not normally required.
Hand protection:	Wear neoprene or nitrile rubber gloves. Gloves must maintain flexibility down to the atmospheric boiling point of this product.
Eye protection:	If splashes are likely to occur, wear: monogoggles, face shield.
Body protection:	Safety shoes or boots - chemical resistant. If splashes are likely to occur, wear: overalls made of cotton or other natural fibres.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Liquefied gas
Colour:	Colourless
Odour:	Distinctive and unpleasant if stenched, odourless if unstenched
Boiling point:	circa - 20°C
Vapour pressure:	circa 5.8 bar/ga at 37.8°C
Density:	circa 560 kg/m^3 at 15°C
Vapour density (air=1):	circa 1.5 at 15°C
Flash point:	-104°C
Flammability limit - lower:	2.2 %(V/V)
Flammability limit - upper:	10 %(V/V)
Auto-ignition temperature:	> 450°C
Explosive properties:	In use, may form flammable/explosive vapour-air mixture
Oxidizing properties:	Not applicable
Solubility in water:	Data not available
n-octanol/water partition coefficient:	log $P_{ow} = 2.3$ (estimated value)
Evaporation rate:	Data not available

10. STABILITY/REACTIVITY

Stability:	Stable.
Conditions to avoid:	Heat, flames and sparks.
Materials to avoid:	Strong oxidizing agents.
Hazardous decomposition products:	None known.

11. TOXICOLOGICAL INFORMATION

Basis for assessment: Toxicological data have not been determined specifically for this product. Information given is based on data on the components and the toxicology of similar products.

Acute toxicity - oral: Data not available.

Acute toxicity - dermal: Data not available.

Acute toxicity - inhalation: LC_{50} >5 mg/l (Gas).

Eye irritation: Not irritating. Liquid causes cold burns.

Skin irritation: Not irritating. Liquid causes cold burns.

Respiratory irritation: Not irritating (Gas).

Skin sensitization: Not expected to be a skin sensitizer.

Carcinogenicity: This product has not been evaluated in long-term chronic exposure tests. May contain 1, 3-butadiene, classified as a Category 2 carcinogen at a concentration of less than 0.1% (m/m). Other components are not known to be associated with carcinogenic effects.

Mutagenicity: Not considered to be a mutagenic hazard (Gas).

Human effects: See Section 4 for information regarding acute effects to humans.

12. ECOLOGICAL INFORMATION

Basis for assessment: Ecotoxicological data have not been determined specifically for this product. Information given is based on data on the components and the toxicology of similar products.

Mobility: Evaporates extremely rapidly from water or soil surfaces. Disperses rapidly in air.

Persistence/degradability: Oxidizes rapidly by photochemical reactions in air.

Bioaccumulation: Does not bioaccumulate.

Ecotoxicity: Low acute toxicity to mammals.

Sewage treatment: Not applicable.

Other information: In view of the high rate of loss from solution, the product is unlikely to pose a significant hazard to aquatic life.

13. DISPOSAL CONSIDERATIONS

Precautions: See Section 8.

Product disposal:	Given the nature and uses of this product, the need for disposal seldom arises. If necessary, dispose by controlled combustion in purpose-designed equipment. If this is not possible, contact the supplier.
Container disposal:	Return part-used or empty cylinders to the supplier.
Local legislation:	Environmental Quality Act

14. TRANSPORT INFORMATION

UN Number:	1965
UN Class/Packing Group:	2.1, Packing Group not applicable
UN Proper Shipping Name:	Hydrocarbon Gas Mixture, Liquefied, n.o.s. (Propane Mixture)
UN Number (sea transport, IMO):	1965
IMO Class/Packing Group:	2.1, Packing Group not applicable
IMO Symbol:	Flammable Gas
IMO Marine Pollutant:	No
IMO Proper Shipping Name:	Hydrocarbon Gas Mixture, Liquefied, n.o.s. (Propane Mixture)
ADR/RID Class/Item:	2, 4° (b)
ADR/RID Symbol:	Flammable Gas Shunt With Care (RID only)
ADR/RID Kemler Number:	23-1965
ADR/RID Proper Shipping Name:	Mixture C (Trade name: propane mixture)
ADNR Class/Item:	
UN Number (air transport, ICAO):	1965
IATA/ICAO Class/Packing Group:	2.1, Packing Group not applicable
IATA/ICAO Symbol:	Flammable Gas
IATA/ICAO Proper Shipping Name:	Hydrocarbon Gas Mixtures, Liquefied, n.o.s. (Propane Mixture)
Local regulations:	
Other information:	UN Number 1965 is an AEGPL recommendation. Other numbers may be required to be used locally. Transport of this product on passenger aircraft is forbidden.

15. REGULATORY INFORMATION

EC Label name:	Contains propane
EC Classification:	Extremely Flammable
EC Symbols:	F+

EC Risk Phrases: R12 Extremely flammable

EC Safety Phrases: S2 Keep out of the reach of children.

S9 Keep container in a well-ventilated place.

S16 Keep away from sources of ignition - No Smoking.

EINECS (EC): All components listed

National legislation:

Other information: Mobile gas cylinders containing butane, propane or liquid petroleum gas are currently exempt from the labelling provisions of European Commission Directive 67/548/EEC.

16. OTHER INFORMATION

Uses and restrictions: Fuel for use in suitably designed domestic and industrial combustion equipment, domestic cooking appliances and motor vehicles. Also used as an aerosol propellant and a feedstock for the petrochemical industry. This product must not be used in applications other than the above without first seeking the advice of the supplier. Abuse involving repeated and prolonged exposures to high concentrations of vapour ('sniffing') may cause death by either asphyxiation or cardiac arrest. Abuse involving direct ingestion of the liquefied gas may cause death by freezing the larynx and causing the lungs to fill with fluid - an effect similar to drowning.

Technical contact point: OG BUSINESS

Technical contact number:

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Telex: MA 31813

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Section 2: List of dangerous components added.
Section 3 and 7: Editorial changes.
Sections 6 and 8: Revised personal protection.
Section 12: Estimated ecotoxicity data deleted.
Changes indicated by vertical bar to left of text.

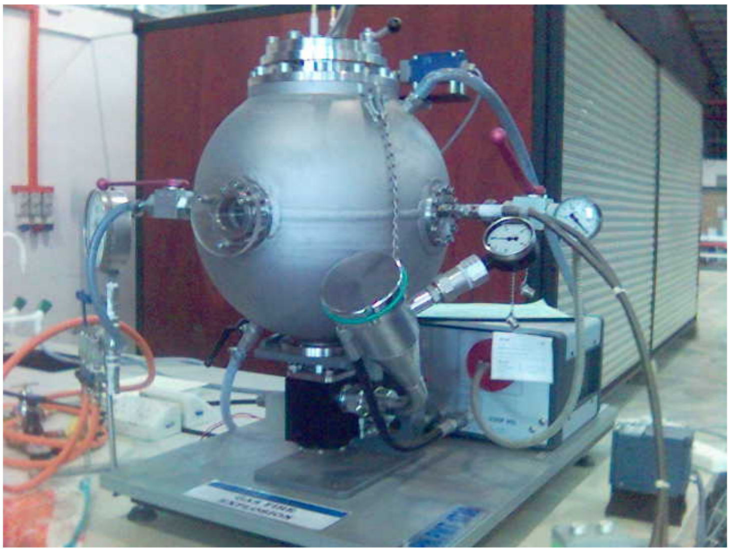
SDS distribution:	This document contains important information to ensure the safe storage, handling and use of this product. The information in this document should be brought to the attention of the person in your organisation responsible for advising on safety matters.
Other information:	(To be provided by the supplier)
References:	Useful references include the following: The Institute of Petroleum, London, 'Model Code of Safe Practice', Part 9, current edition. The Liquefied Petroleum Gas Association Codes of Practice, LPGA. CONCAWE, Brussels, 'Liquefied petroleum gas'. Product dossier No 92/102, 1992. UK Health and Safety Executive, 'The Storage of LPG at Fixed Installations', Health and Safety Series Booklet HS(G)34, current edition. UK Health and Safety Executive, 'The Keeping of LPG in cylinders and Similar Containers', Guidance Note CS4, current edition. National Fire Protection Association, 'Standard for the Storage and Handling of Liquefied Petroleum Gases', NFPA 58

This information is based on our current knowledge and is intended to describe the product for the purposes of health, safety and environmental requirements only. It should not be construed as guaranteeing any specific property of the product.

APPENDIX C

C1: Pictures

Set computer



Gas fire explosion

KSEP 332

Pressure gauge measurement

Igniter wire

The Ignitor of Gas Fire Explosion. The place where the fuse is attached