A STUDY OF NITROGEN DILUTION EFFECT ON THE FLAMMABILITY LIMITS OF METHANE

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A STUDY OF NITROGEN DILUTION EFFECT ON THE FLAMMABILITY LIMITS OF METHANE

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A thesis submitted to the Faculty of Chemical and Natural Resources Engineering in partial fulfillment of the requirement for the Degree of Bachelor of Engineering

in

Chemical Engineering

Faculty of Chemical and Natural Resources Engineering
University Malaysia Pahang

APRIL 2010

I declare that this thesis entitled 'A Study of Nitrogen Dilution Effect on the Flammability Limits of Methane' is the result of my own research except as cited in references. The thesis has not been accepted for any degree and it is not concurrently submitted in candidature of any degree.

Signature : ……………………………………………………

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“

Allah! There is no God but Him;
The living, the Self-subsisting, the Eternal.
No slumber can seize Him, nor sleep.
All things in heaven and earth are His.
Who could intercede in His presence without His permission?
He knows what appears in front of and behind His creatures.
Nor can they encompass any knowledge of Him except what he will.
His throne extends over the heavens and the earth,
and He feels no fatigue in guarding and preserving them,
for He is the Highest and Most Exalted.

”

(Surah Al-Baqarah: 255)

To my family members,
my friends – reality or virtual,
my fellow colleagues,
and all faculty members

And for those who keep whispering…
“You can do it!!!”

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Your contributions and sacrifices are so great in magnitude that only God can return your kindness.

ABSTRACT

Explosive/Flammability limits data are essential for a quantitative risk assessment of explosion hazard associated with the use of combustible gas. The present work is to obtain the fundamental explosive data for prevention of the hazards in the practical applications. Experiments have been conducted in a constant volume combustion bomb, and the fuel considered here is natural gas (NG). In this study, the nitrogen (N_2) dilution effects on the flammability limits for pure hydrocarbons are explored. The effects of nitrogen on NG–air flammability limits have been investigated. By adding diluents nitrogen (N_2) into NG–air mixture, the dilution effects on the flammability limits have been explored as well, and the results are plotted as functions of diluents ratio. From the results, it can be conclude that the range of flammability limits of methane is from 5 vol % until 18 vol %. The effect of nitrogen dilution on the upper flammability limit of methane observed with the reduction from 10 vol % to 30 vol % by increasing the vol % of nitrogen.

ABSTRAK

Batas bahan mudah meletup / terbakar data sangat penting untuk penilaian risiko bahaya letupan kuantitatif berkaitan dengan penggunaan gas yang mudah terbakar. Karya ini adalah untuk mendapatkan data mendasar letupan untuk pencegahan bahaya dalam aplikasi praktikal. Percubaan telah dilakukan di bom pembakaran kelantangan konstan, dan bahan api yang dipertimbangkan di sini adalah gas alam (NG). Dalam kajian ini, nitrogen (N_2) kesan dilusi pada batas hidrokarbon murni mudah terbakar untuk dieksplorasi. Pengaruh nitrogen terhadap batas mudah terbakar NG-udara telah diteliti. Dengan menambah nitrogen (N_2) ke dalam campuran NG-udara, kesan penambahan pada batas mudah terbakar telah dieksplorasi juga, dan keputusan data diplot sebagai fungsi dari nisbah pencair. Dari keputusan experimen, dapat disimpulkan bahawa batas pembakaran metana adalah dari 5 % sampai 18 vol % . Pengaruh dilusi nitrogen pada batas atas metana mudah terbakar diamati dengan penurunan dari 10 % hingga 30 vol % dengan meningkatkan vol % nitrogen.

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NG	Natural gas
CH_4	Methane
N_2	Nitrogen
CO_2	Carbon Dioxide
Vol%	Volume percent
STP	Standard temperature pressure
Pexp	Explosion pressure
t1	Ignition time
dP/dt	Rate of pressure rise
(dP/dt)max	Max. rate of pressure rise
Kmax	Product specific constant
LFL	Lower Flammability Limit
UFL	Upper Flammability Limits
Pm [bar]	Pressure maximum

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Knowledge of the flammability limits of gaseous mixtures is important for the safe and economic operation of many industrial and domestic applications that produce or use flammable mixtures. Flammability limits indicates the region of fuel–air mixture ratios within which flame propagation can be possible while outside that flame cannot propagate. There are two distinct separate flammability limits for a mixture which are lean limit or lower flammability limits (LFL) and rich limit or upper flammability limit (UFL) (S.Y. Liao, 2005). In other words, combustion will take place and be self-sustaining only if fuel and air are mixed within the upper and lower flammability limits. Flammability limits have been discussed extensively in the combustion literature. There are several criteria to determine the flammability limits. A successful attempt can be determined by one or a combination of the following criteria: (1) inspection of the visualization of the flame kernel produced by the spark, namely visual criterion, and (2) measurements of pressure or temperature histories in the vessel and appropriate pressure or temperature rise criteria can be used to designate flammability rather than the purely visual observation of flame development.

Basically, a successful ignition would induce a rapid pressure increase and temperature rise within a short time, as well as produce a propagating flame front that could be readily observed. Previous gas flammability limits data were obtained mainly in flammability tubes, in those tests, a gas mixture in a vertical tube was ignited and flame propagation was inspected by a visual criterion. The wall quenching has a significant effect on the flammability measurement in flammability tube. The larger size of combustion charmer can minimize wall effects and can allow for the potential use of stronger igniters to ensure the absence of ignition limitations, so most of the flammability measurements are conducted in closed chambers recently. And more attentions are being given to the effects of environmental parameters, such as the vessel size, initial temperature and pressure on the fundamental characteristics. Moreover, the theoretical studies are carried out for providing analytical predictions about the flammability limits. With the growing crisis of energy resources and the strengthening of pollutant legislations, the use of natural gas (NG) as an alternative fuel has been promoted recently; natural gas is being regarded as one of the most promising alternative fuels for industrial and domestic applications. The chemical composition of natural gas varies from field to field, but the main chemical component of natural gas is believed to be methane. There is a large volume of flammability limits data available for fuels, such as methane, ethane, propane, butane, etc. But to the best of our knowledge, no work has been reported so far on the flammability limits of NG–air mixture.

Therefore, the present work is promoted purposely. The experiments are made systematically to determine the flammability limits of NG–air mixture in a constant volume combustion bomb, using conventional spark ignition system. The explosion pressure traces are recorded and an appropriate pressure rise criterion is used to define the flammability limits.

1.1.1 Explosion Protection

Explosion protection is used to protect all sorts of buildings and civil engineering infrastructure against internal and external explosions or deflagrations. It was widely believed until recently that a building subject to an explosive attack had a chance to remain standing only if it possessed some extraordinary resistive capacity. This belief rested on the assumption that the specific impulse or the time integral of pressure, which is a dominant characteristic of the blast load, is fully beyond our control. Avoidance will make it impossible for an explosion or deflagration to occur, for instance by means of consistent displacement of the O_2 necessary for an explosion or deflagration to take place, by means of padding gas (CO_2 or N_2), or, by means of keeping the concentration of flammable content of an atmosphere consistently below or above the explosive limit, or, by means of consistent elimination of ignition sources. Constructional explosion protection aims at pre-defined, limited or zero damage that results from applied protective techniques in combination with reinforcement of the equipment or structures that must be expected to become subject to internal explosion pressure and flying debris or external violent impact.

1.1.2 Explosion Suppression

Explosion suppression provided a method for extinguishing a growing fireball and relies on early detection of an incipient explosion. This is most commonly achieved by ‘set-point’ pressure detection.

Explosion suppression is often used it is not possible to protect by containment or explosion relief venting and particular where the pressure and flame of the explosion cannot be vented to a safe location. Explosion suppression is particularly important is cases where loss of process containment could cause the emission of toxic dust or other substances harmful to the people or surroundings.

1.2 Background of Study

This project is mainly focuses on the suppression system as the main alternative to prevent or mitigate explosion from occur especially in industrial. According to National Fire Protection Association (NFPA), the grouping that might be considered ‘industrial’ are basic industry, utilities, manufacturing and many of the storage properties, NFPA statistics for the 1990 (Karter, 1991) indicate that there were 22,000 fires and explosion in the combined categories of basic industry, utilities and manufacturing. An additional 39,500 fires and explosion in the storage properties are also recorded. (Zalosh, 2002)

Early detection and protection system are very important to be considering in every industry in order to prevent fires and explosion from occur. In this project, the Nitrogen gas as the suppression agent will apply to the explosion to test and determine the effect to the explosion limit. As the fuel source, natural gas (NG) will be use due to its properties and potential in the occurrence of explosion.

1.3 Problem Statement

Nowadays many an explosion protection system especially in the process industries as a explosion prevention especially in industries. But there are some disadvantage of some method is the potential of the suppression agent to mitigate the explosion limit especially when dealing with hydrogen and methane, in addition some suppression agent is expensive. There are many methods to prevent fire and explosion such as isolating, venting and suppression. Venting is system release pressure indoor or closed system, especially when dealing with LPG, natural gas and hydrogen where they are high velocity combustion speed and greatest flammable, so its need early method is suppression by using inert gas such as helium, carbon dioxide, nitrogen or argon, in this research, nitrogen is used as a suppression agent, where nitrogen gas is cheaper and easy to get.

1.4 Objectives of Study

The objectives of this study are:

i. To determine the flammability limit of natural gas dilute nitrogen gas mixture in a combustion bomb at atmospheric pressure and ambient temperature.

ii. To determine the effect of nitrogen suppressing on flammability limit of premixed natural gas-air mixture in a combustion bomb at atmospheric pressure and ambient temperature.

1.5 Scope of Study

This study is conducted to determine the flammability limits of premixed fuel-air-nitrogen mixture in a constant volume spherical vessel with a volume of 20 L by using conventional spark ignition system which is located at the centre of the vessel.

In this study methane with 96 % purity is used to replace the natural gas. Methane can be used to indicate the properties of natural gas since the major component in natural gas is methane.

The lower flammability limit (LFL) and upper flammability limit (UFL) of natural gas-air mixture were determined at concentration from 3 vol % to 18 vol %. The effect of nitrogen in natural gas-air mixture was investigated at nitrogen enrichment up 30 vol % nitrogen of fuel by at methane concentration from 3 vol % to 18 vol %.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Knowledge of the flammability limits of gaseous mixtures is important for the safe and economic operation of many industrial and domestic applications that produce or use flammable mixtures.

Flammable limits apply generally to vapors and are defined as the concentration range in which a flammable substance can produce a fire or explosion when an ignition source (such as a spark or open flame) is present. The concentration is generally expressed as percent fuel by volume. When the combustion of the fuel is not controlled within the confines of a burner system, the limits of flammability can be called the explosive limits. There are two distinct separate flammability limits for a mixture which are lean limit or lower flammability limit (LFL) and rich limit or upper flammability limit (UFL):

i. Above the upper flammable limit (UFL) the mixture of substance and air is too rich in fuel (deficient in oxygen) to burn. This is sometimes called the upper explosive limit (UEL).

ii. Below the lower flammable limit (LFL) the mixture of substance and air lacks sufficient fuel (substance) to burn. This is sometimes called the lower explosive limit (LEL).

In other words, combustion or explosion will take place and be self-sustaining only if fuel and air are mixed within the upper and lower flammability limits. Usually the LFL and UFL of a combustible material are expressed in volume percentage (vol %) in the literature; however, as the hydrocarbon gas could be taken as an ideal gas at atmospheric pressure, LFL and UFL could be also explained as the molar fraction, which is the expression adopted in this study. To avoid misleading the meaning in formulation, three terminologies are defined here:

i. Fuel mixture the mixture composed of hydrocarbon and air (no inert gas)

ii. Blended gas the mixture composed of hydrocarbon and inert carbon dioxide (no air)

iii. Total mixture-the mixture composed of the blended gas and air.

Many manufacturing processes involve flammable chemicals, and an accident involving a fire or an explosion can occur in storage or process equipment if a flammable chemical exists inside it or if a loss of containment of flammable chemicals occurs. Because the gas mixture of a flammable substance could be ignited only if he concentration of the flammable substance lied within a given range known as the flammability limits, the flammability limits are one of the important features in the development of safe practices for handling a flammable vapour or gas. For this reason, they constitute a crucial issue in research on processing and storing flammable chemicals safely. In the literature, different methods have been proposed to predict the flammability limits of a flammable chemical, especially the lower flammability limit (LFL) of a pure flammable chemical. Industry works with mixtures under many situations, for example, in a reactor or in a distillation column.

The Le Chatelier equation is widely adopted to estimate the flammability limits of a mixture composed of flammable gases. However, complex mixtures composed of flammable gases and non-flammable gases are also formed in process industries, for example, the inerting procedure. Inerting is the process of adding an inert gas to a combustible mixture to reduce the concentration of oxygen below the limiting oxygen concentration (LOC) for the purpose of lowering the likelihood of explosion. In process industries, the inert gas is usually nitrogen or carbon dioxide, although sometimes steam may be used. As the inert gas does not take part in the reaction mechanism, the method of “calculated adiabatic flame temperatures” is usually applied to estimate the flammability limits of a mixture of fuel and inert gas in the literature Vidal et al .

According to LeChatelier’s rule:

$$\mathrm{LFL} = \frac{100}{\sum(C_i/\mathrm{LFL}_i)} \tag{2.1}$$

Where LFL is the lower flammability limit of mixture (vol. %), C*i* the concentration of component i in the gas mixture on an air-free basis (vol. %), and LFL*i* is the lower flammability limit for component *i* (vol %).

Inert gas could be obtained. However, prediction models based on adiabatic flame temperature theories typically produce satisfactory results in forecasting LFL, but this is not the case in predicting the upper flammability limit (UFL). Because the procedure of diluting a combustible gas with inert gas could be also taken as a mixing process of flammable gas and inert gas, Kondo et al. have attempted to modify the Le Chatelier equation so that it could be extended to the case of a mixture of flammable gases and inert gases. The following assumptions were included in their work:

i. At LFL, the heat of combustion per mole of a mixture composed of fuel gas and inert gas is equal to the heat of combustion per mole of pure fuel gas times the molar fraction of the fuel gas in the mixture (i.e., adding inert gas to fuel gas does not change the reaction mechanism at LFL). The heat release is the same for all limit mixtures at LFL.

ii. The fuel gas would react completely when combustion takes place at LFL

iii. At UFL, the ratio of the number of moles of oxygen required to burn one mole of the mixture of fuel gas and inert gas to the number of moles of oxygen required to burn one mole of pure fuel gas equals the molar fraction of the fuel gas in the mixture (i.e., adding the inert gas to the fuel gas does not change the reaction mechanism at UFL)

iv. Oxygen would react completely when combustion takes place at UFL.

The addition of inert gases influences the LFL and UFL of a fuel-air mixture. Figure 2.1(a) reveals the effect of added inerts on the flammability of methane and air. The left side is the same as the methane side of Figure 2.1 (a) but the right side of Figure 2.1 (a) shows the effect of, for example, added nitrogen on the LFL and UFL and how a flammability envelope is generated. The far right portion of the envelope is termed the nose. At this LFL and UFL values are published for a significant number of fuels for ambient conditions [i.e. 20 °C (68 °F) and 760 mm Hg (14.7 psia)] because room conditions are the easiest conditions to create for flammability testing.

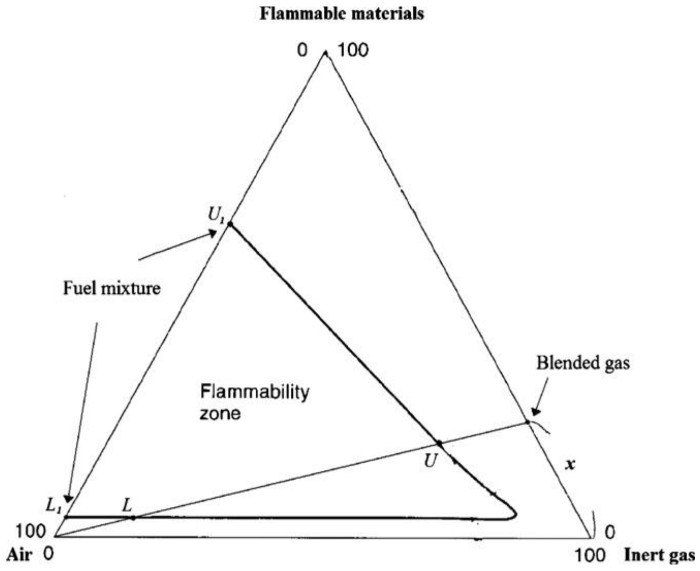


Figure 2.1 (a): Illustration of the terminologies and notations.

As Figure 2.1(b) shows, the change in UFL is usually more obvious than that in LFL when the inert gas is added, It could be found in Figure 2.1 (b) that when the concentration of inert gas is low, the LFL of the methane/inert gas mixture will increase as the concentration of the inert gas increases if the inert gas is carbon dioxide or steam; the LFL of methane/inert gas mixture seems to be irrelative of the concentration of inert gas if the inert gas is nitrogen; and the LFL of methane/inert gas mixture will decrease as the concentration of inert gas increases if the inert gas is helium.

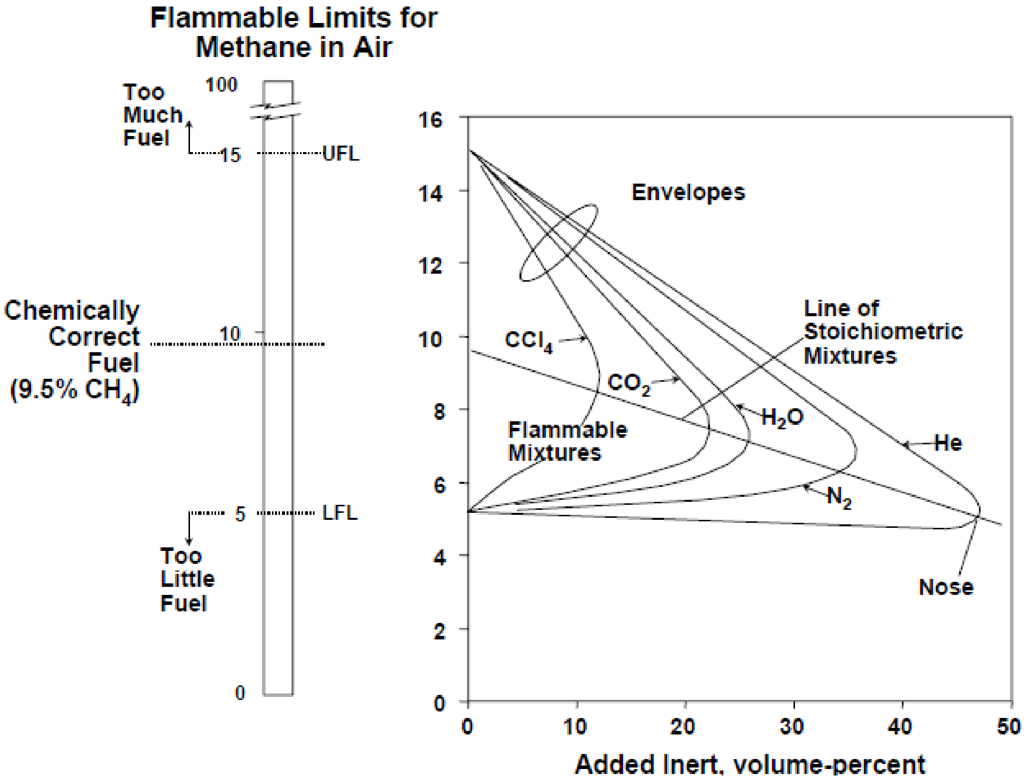


Figure 2.1 (b): Flammability curves of methane for different inert gases.

2.2 Experimental Methods

The standardized measurements of flammability limits are usually conducted in the flammability tubes or closed vessels. There are several criteria to determine the flammability limits. A successful attempt can be determined by one or a combination of the following criteria:

i. Inspection of the visualization of the flame kernel produced by the spark, namely visual criterion

ii. Measurements of pressure or temperature histories in the vessel and appropriate pressure or temperature rise criteria can be used to designate flammability rather than the purely also observation of flame development

A successful ignition would induce a rapid pressure increase and temperature rise within a short time as well as produce a propagating flame front that could be readily observed. Previous gas flammability limit data were obtained mainly in flammability tubes which in those test a gas mixture in a vertical tube was ignited and flame propagation was inspected by visual criterion. However, the wall quenching has a significant effect on the flammability measurement in flammability tube.

Recently, the flammability measurements are conducted in closed chambers. This is because the larger size of combustion chamber can minimize wall effects and can allow potential use of stronger igniters to ensure the absence of ignition limitations (D.M Jiang et al 2005).

2.3 Explosion

An explosion is a rapid increase in volume and release of energy in an extreme manner, usually with the generation of high temperatures and the release of gases. An explosion creates a shock wave. If the shock wave is a supersonic detonation, then the source of the blast is called a "high explosive". Subsonic shock waves are created by low explosives through the slower burning process known as deflagration.

High explosives are explosive materials that detonate, meaning that the explosive shock front passes though the material at a supersonic speed. High explosives detonate with explosive velocity rates ranging from 3,000 to 9,000 meters per second. They are normally employed in mining, demolition, and military applications. They can be divided into two explosives classes differentiated by sensitivity: Primary explosive and secondary explosive. The term high explosive is in contrast to the term low explosive, which explodes (deflagrates) at a slower rate.

Low explosives are compounds where the rate of decomposition proceeds through the material at less than the speed of sound. The decomposition is propagated by a flame front (deflagration) which travels much more slowly through the explosive material than a shock wave of a high explosive. Under normal conditions, low explosives undergo deflagration at rates that vary from a few centimetres per second to approximately 400 meters per second. It is possible for them to deflagrate very quickly, producing an effect similar to a detonation. This can happen under higher pressure or temperature, which usually occurs when ignited in a confined space. A low explosive is usually a mixture of a combustible substance and an oxidant that decomposes rapidly (deflagration), however they burn slower than a high explosive which has an extremely fast burn rate. Low explosives are normally employed as propellants. Included in this group are gun powders and light pyrotechnics, such as flares and fireworks.

2.3.1 Explosive and Explosive Limit

The Flammable Range (Explosive Range) is the range of a concentration of a gas or vapor that will burn (or explode) if an ignition source is introduced. Below the explosive or flammable range the mixture is too lean to burn and above the upper explosive or flammable limit the mixture is too rich to burn. The limits are commonly called the "Lower Explosive or Flammable Limit" (LEL/LFL) and the "Upper Explosive or Flammable Limit" (UEL/UFL).

The lower and upper explosion concentration limits for some common gases are indicated in the Table 2.3.1 below. Some of the gases are commonly used as fuel in combustion processes. The flammability limit of gaseous is show in Table 2.3.1 below:

Table 2.3.1: The flammability limit of some gaseous.

Fuel Gas	"Lower Explosive or Flammable Limit" (LEL/LFL) (%)	"Upper Explosive or Flammable Limit" (UEL/UFL) (%)
Acetaldehyde	4	60
Acetone	2.6	12.8
Acetylene	2.5	81
Ammonia	15	28
Benzene	1.35	6.65
n-Butane	1.86	8.41
iso-Butane	1.80	8.44
Butylene	1.98	9.65
Ethane	3	12.4
Ethylene	2.75	28.6
Ethyl Alcohol	3.3	19
Gasoline	1.4	7.6
Kerosene	0.7	5
Methane	5	15
Methyl Alcohol	6.7	36
n-Heptane	1.0	6.0
n-Hexane	1.25	7.0
n-Pentene	1.4	7.8

2.3.2 Explosion Pressure

Knowledge of pressure-time variation during explosions of fuel-air mixtures in enclosures is a very important component of safety recommendations for a wide range of human activities, connected to production, transportation or use of fuels.

The characteristic parameters of a closed vessel explosion are the explosion pressure, the explosion time and the maximum rate of pressure rise. The explosion pressure and explosion time were recently defined in the European standard on maximum explosion pressure determination:

i. The explosion pressure, Pexp is the highest pressure reached during the explosion in a closed volume at a given fuel concentration

ii. The maximum explosion pressure, Pmax is the highest pressure reached during a series of explosions of mixtures with varying fuel concentration

iii. The explosion time, exp is the time interval between ignition time and the moment when the explosion pressure attained

Explosion pressures and explosion times are important for calculating laminar burning velocities from closed vessel experiments, vent area design, and characterizing transmission of explosions between interconnected vessels (D. Razus et al 2006).

Based on the pressure time traces three regimes of explosion development or combustion conversion can be identified. The regimes depend on the initial mixture composition, at given conditions as illustrated at Figure 2.3.2.below. In the first one, marked as 1, the pressure increases fast and smoothly to the maximum value, after ignition. This type of pressure development is seen for near stoichiometric mixtures. In the second regime, the pressure trace is distinctly S shaped (a shoulder). Such type of pressure development is a narrow fuel lean concentration range and in a wider concentration range with fuel rich mixtures. In the third regime the shoulder disappeared, and the increase is low and slow. (A.A.Pekalski, 2005).

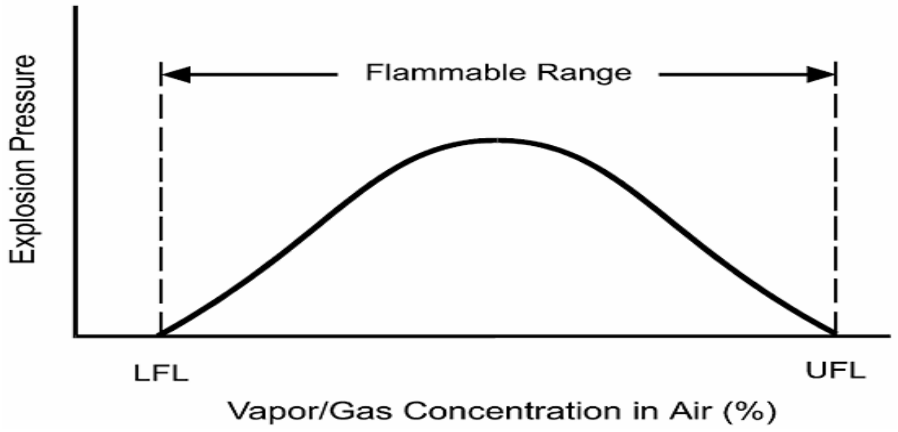


Figure 2.3.2: Schematic represents flammability limit

2.3.3 Detonation

Detonation involves an exothermic front accelerating through a medium that eventually drives a shock front propagating directly in front of it. They are observed in both conventional solid and liquid explosives, as well as in reactive gases. The velocity of detonations in solid and liquid explosives is much higher than that in gaseous ones, which allows far clearer resolution of the wave system in the latter.

Gaseous detonations normally occur in confined systems but are occasionally observed in large vapour clouds. Again, they are often associated with a gaseous mixture of fuel and oxidant of a composition, somewhat below conventional flammability limits. There is an extraordinary variety of fuels that may be present as gases, as droplet fogs and as dust suspensions. Other materials, such as acetylene, ozone and hydrogen peroxide are detonable in the absence of oxygen; fuller lists are given by both Stull and Bretherick. Oxidants include halogens, ozone, hydrogen peroxide and oxides of nitrogen and chlorine.

In terms of external damage, it is important to distinguish between detonations and deflagrations where the exothermic wave is subsonic and maximum pressures are at most a quarter of those generated by the former. Processes involved in the transition between deflagration and detonation are covered thoroughly by Nettleton.

The simplest theory to predict the behaviour of detonations in gases is known as Chapman-Jouguet (CJ) theory, developed around the turn of the 20th century. This theory, described by a relatively simple set of algebraic equations, models the detonation as a propagating shock wave accompanied by exothermic heat release. Such a theory confines the chemistry and diffusive transport processes to an infinitely thin zone.

A more complex theory was advanced during World War II independently by Zel'dovich, von Neumann, and W. Doering. This theory, now known as ZND theory, admits finite-rate chemical reactions and thus describes a detonation as an infinitely thin shock wave followed by a zone of exothermic chemical reaction. With a reference frame of a stationary shock, the following flow is subsonic, so that an acoustic reaction zone follows immediately behind the lead front, the Chapman-Jouguet condition. Both theories describe one-dimensional and steady wave fronts. However, in the 1960s, experiments revealed that gas-phase detonations were most often characterized by unsteady, three-dimensional structures, which can only in an averaged sense be predicted by one-dimensional steady theories. Indeed, such waves are quenched as their structure is destroyed.

Experimental studies have revealed some of the conditions needed for the propagation of such fronts. In confinement, the range of composition of mixes of fuel and oxidant and self-decomposing substances with inerts are slightly below the flammability limits and for spherically expanding fronts well below them. The influence of increasing the concentration of diluents on expanding individual detonation cells has been elegantly demonstrated. Similarly their size grows as the initial pressure falls. Since cell widths must be matched with minimum dimension of containment, any wave overdriven by the initiator will be quenched. Mathematical modelling has steadily advanced to predicting the complex flow fields behind shocks inducing reactions. To date none has adequately described how structure is formed and sustained behind unconfined waves.

2.4 Explosion Suppression

Explosion suppression is the technique of detecting and arresting combustion in confined space while the combustion is in its incipient stage, thereby preventing the development of pressure that could result in structural damage.

It is the same as early detection of flash fire and rapid discharge of extinguishing agent into flame that result in the extract of heat to extinguish flame and limit explosion pressure typically applied to dust collectors, hoppers, mixer, dryer, cyclone, filters, bucket elevators and aspiration ducts.

Explosion suppression is often used where it is not possible to protect by containment or explosion relief venting and in particular where the pressure and flame of the explosion can’t be vented to a safe location. Explosion suppression is particularly important is cases where loss of process containment could cause the emission of toxic dust or other substances harmful to people or the surroundings.

2.4.1 Common Suppression

2.4.1.1 Inert Fire Extinguishing

Inert Fire Extinguishing is typically Inert Gas blends or a single Inert Gas on its own. Typical Inert products are Nitrogen and Argon. These are natural occurring gases, which are removed from the air we breathe. The principle of suppression is by increasing the nitrogen or Argon content of the protected space, which reduces by volume the oxygen to a safe level to sustain human life and at the same time reduce the protected environment to levels that do not allow combustion. Typical oxygen levels following a discharge are 12 %-15 %.

2.4.1.2 Inert Gas Suppression Systems

Inert is a pure gas which is found naturally in the air and returns to the atmosphere following a discharge. It is a chemically inert gas which is safe for use on electrical risks and delicate materials. It is safe for use in most risks as it does not tarnish surfaces, cause damage to equipment or contribute to atmospheric pollution once it has been discharged. Inert systems provide a total flood solution in accordance with international design requirements

2.4.1.3 Argonite

Argonite is a leading environmentally-friendly replacement for Halon 1301. An equal blend of nitrogen and argon, it produces no secondary combustion products and is particularly suiTable for fighting fires in confined spaces. Because its molecular weight is close to that of air, it lingers longer when discharged to extinguish a fire. This reduces the need for hermetic sealing of a protected room Ã± a process that can be very expensive and needs to be repeated every time structural changes are made. Aragonite is not prone to fogging, is non-toxic, non-corrosive, leaves no residue and is electrically non-conductive. This has led to it being successfully specified in applications where there is a need to avoid secondary damage by the fire fighting agent. Popular applications include computer and control rooms, tape and archive stores, electrical cabinets and switchgear compartments and around telecommunications equipment.

2.4.1.4 Carbon Dioxide Suppression Systems

Carbon Dioxide (C02) gas has a high ratio of expansion which facilitates rapid discharge and allows for three dimensional penetration of the entire hazard area quickly. Carbon Dioxide extinguishes a fire by reducing the oxygen content of the protected area below the point where it can support combustion. Carbon Dioxide Fire extinguishing systems typically store the agent in one of two different ways: in high pressure cylinders, or in low pressure CO_2 tanks. Due to the extreme density of the Carbon Dioxide, it quickly and effectively permeates the protected hazard area and suppresses the fire. Rapid expansion of the 4-6 inches of Carbon Dioxide snow to gas reduces the ambient temperature in the protected hazard area which aids in the extinguishing process and retards re-ignition.

2.4.1.5 Foam Systems

Fire fighting foam systems suppress fire by separating the fuel from the air (oxygen). Depending on the type of foam system, this is done in several ways. Foam blankets the fuel surface smothering the fire, cooling the fuel with the water content of the foam, and also the foam blanket suppresses the release of flammable vapors that can mix with the air.

2.4.1.6 Dry Chemical Suppression Systems

The best candidates for dry chemical fire suppression systems are industrial applications. The agents most commonly employed are ABC or BC type powder. They are extremely effective fire fighting agents that suppresses fire by coating the surface of the combusting material. The coating separates the fuel from the oxygen supply, and prevents flashback. Typical hazards protected include, Dip tanks, Flammable liquid storage areas, Mechanical rooms

2.5 Previous Work

Several experimental results of study flammability limit of methane/air mixture at atmospheric pressure and ambient temperature were reported in literature flammability limit data (vol %) for methane-air flames as Table 2.5 below:

Table 2.5: Previous works to determine flammability limit for methane-air

Test condition	LFL (vol %)	UFL (vol %)	Reference
15-L chamber	5.0	15.6	(D.M Jiang, 2005 using pressure rise criterion of 7 %
8-L chamber	5.0	-	(Hertzberg and Cashdollar, 1983) using pressure rise criterion of 7 %
20-L chamber	4.9	15.9	(Cashdollar, 2000) using pressure rise criterion of 7 %
Flammability test	4.9	15.0	(Kushta,1985) using visual criterion

2.6 20-L-Appartus

The experimental 20-L-Apparatus (or 20 Litre Spherical Explosion Vessel) was obtained from Adolf Kühner AG and is shown in Figure. 2.6. The test chamber is a stainless steel hollow sphere with a personal computer interface. The top of the cover contains holes for the lead wires to the ignition system. The opening provides for ignition by a condenser discharging with an auxiliary spark gap (Siwek, 1996) which is controlled by the KSEP 310 unit of the 20-L-Apparatus. The KSEP 332 unit uses piezoelectric pressure sensors to measure the pressure as function of time (ASTM, 1991; Operating Instructions for the 20-L-Apparatus, 1996). A comprehensive software package KSEP 6.0 is available, which allows safe operation of the test equipment and an optimum evaluation of the explosion test results.

In the past, the international standards have described the 1 m3vessel as the standard test apparatus (Chem. Systems Inc., 1995). In recent years, increased use has been made of the more convenient and less expensive 20-L-Apparatus as the standard equipment. The explosion behaviour of combustible materials (combustible dusts, flammable gases, or solvent vapors) must be investigated in accordance with internationally recognized test procedures. For the determination of combustible gases or vapors, the test is generally accomplished in a quiescent state (ignition delay time, t = 0 sec) (Operating Instructions for the 20-L-Apparatus, 1996).

In the 20-L-Apparatus, important explosion characteristics of gases and vapors, such as flammability limits, maximum explosion overpressure (Pmax), gas or vapor deflagration index (Kg), and minimum oxygen concentration (MOC), can be determined with adherence to standardized test procedures.

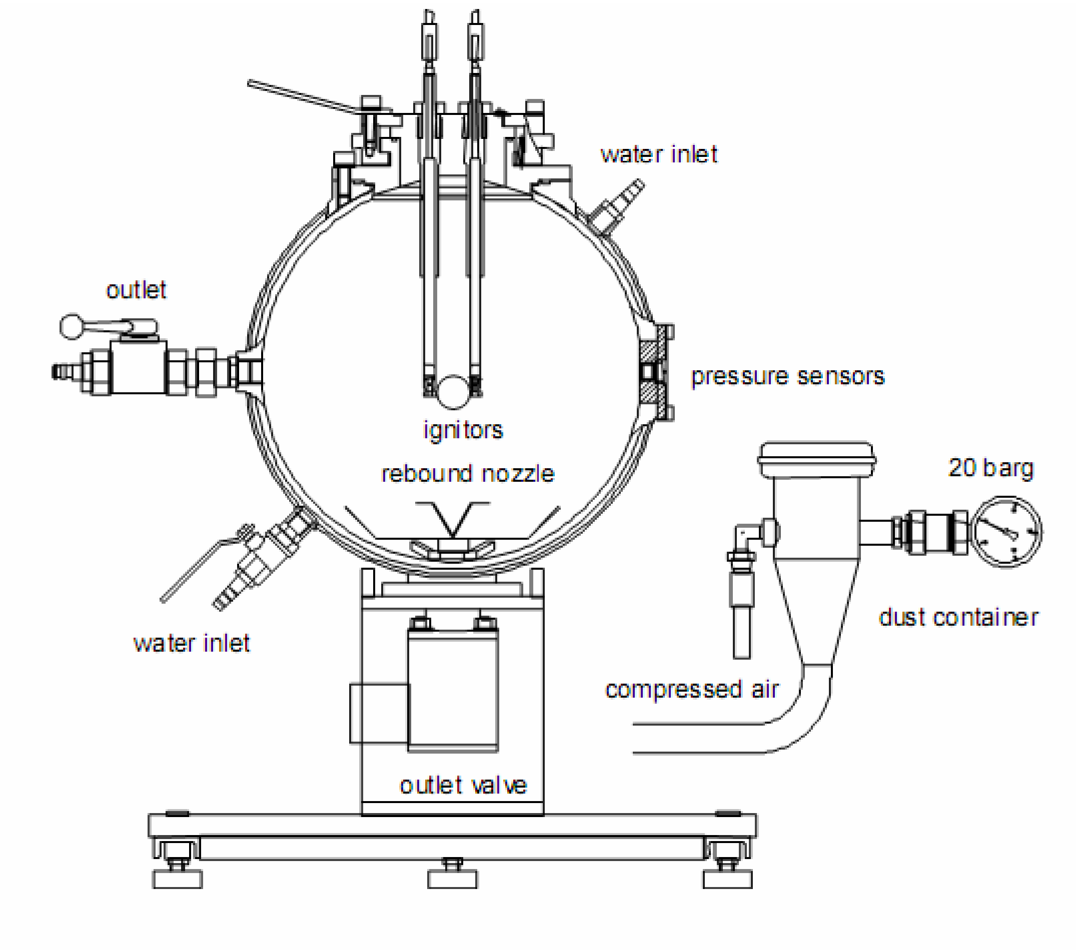


Figure 2.6: Schematic diagrams of 20-L-Apparatus

CHAPTER 3

RESEARCH AND METHODOLOGY

3.1 Material Selection

In order to determine the effect of suppression agent toward the natural gas explosion limits several important material used. In this research, just two materials used where it is methane (CH_4) gas and nitrogen gas (N_2).

3.1.1 Methane Gas

Methane is the major component of natural gas, about 87 % by volume. At room temperature and standard pressure, methane is a colourless, odourless gas when in small amounts; the smell characteristic of natural gas as used in homes is an artificial safety measure caused by the addition of an odorant, often methanethiol or ethanethiol. Methane has a boiling point of −161 °C at a pressure of one atmosphere. As a gas it is flammable only over a narrow range of concentrations (5–15 %) in air. Liquid methane does not burn unless subjected to high pressure (normally 4–5 atmospheres).

In the combustion of methane, several steps are involved: Methane is believed to form formaldehyde (HCHO or H_2CO). The formaldehyde gives a formyl radical (HCO), which then forms carbon monoxide (CO). The process is called oxidative pyrolysis:

$$CH_4 + O_2 \rightarrow CO + H_2 + H_2O$$

Following oxidative pyrolysis, the H_2 oxidizes, forming H_2O, releasing heat. This occurs very quickly, usually in significantly less than a millisecond.

$$2\ H_2 + O_2 \rightarrow 2\ H_2O$$

Finally, the CO oxidizes, forming CO_2 and releasing more heat. This process is generally slower than the other chemical steps, and typically requires a few to several milliseconds to occur.

$$2\ CO + O_2 \rightarrow 2\ CO_2$$

The result of the above is the following total equation:

$$CH_4\ (g) + 2\ O_2\ (g) \rightarrow CO_2\ (g) + 2\ H_2O\ (l) \quad \rightarrow 8\ 91\ \text{kJ/mol}$$

Where bracketed "g" stands for gaseous form and bracketed "l" stands for liquid form.

3.1.2 Nitrogen

Nitrogen is a non-metal, with an electro negativity of 3.04. It has five electrons in its outer shell and is therefore trivalent in most compounds. The triple bond in molecular nitrogen (N_2) is the strongest in nature. The resulting difficulty of converting N_2 into other compounds, and the ease (and associated high energy release) of converting nitrogen compounds into elemental N_2, have dominated the role of nitrogen in both nature and human economic activities.

At atmospheric pressure molecular nitrogen condenses (liquefies) at 77 K (−195.8 °C) and freezes at 63 K (−210.0 °C) into the beta hexagonal close-packed crystal allotropic form. Below 35.4 K (−237.6 °C) nitrogen assumes the alpha cubic crystal allotropic form. Liquid nitrogen, a fluid resembling water in appearance, but with 80.8 % of the density (the density of liquid nitrogen at its boiling point is 0.808 g/mL), is a common cryogen.

UnsTable allotropes of nitrogen consisting of more than two nitrogen atoms have been produced in the laboratory, like N_3 and N_4. Under extremely high pressures (1.1 million atm) and high temperatures (2000 K), as produced using a diamond anvil cell, nitrogen polymerizes into the single-bonded cubic gauche crystal structure. This structure is similar to that of diamond, and both have extremely strong covalent bonds. N_4 is nicknamed "nitrogen diamond."

3.2 Experimental Apparatus

3.2.1 20-L-Apparatus

The top of the cover contains holes for the lead wires to the ignition system. The opening provides for ignition which controlled by the KSEP 320 units of 20-L-Apparatus. The KSEP 332 unit uses piezoelectric pressure sensor's to measure the pressure as a function of time. A comprehensive software package KSEP 6.0 is used to allow safe operation of the test equipment and an optimum evaluation of the explosion test results. The Figure 3.2.1 below show the schematic diagram of experimental set up:

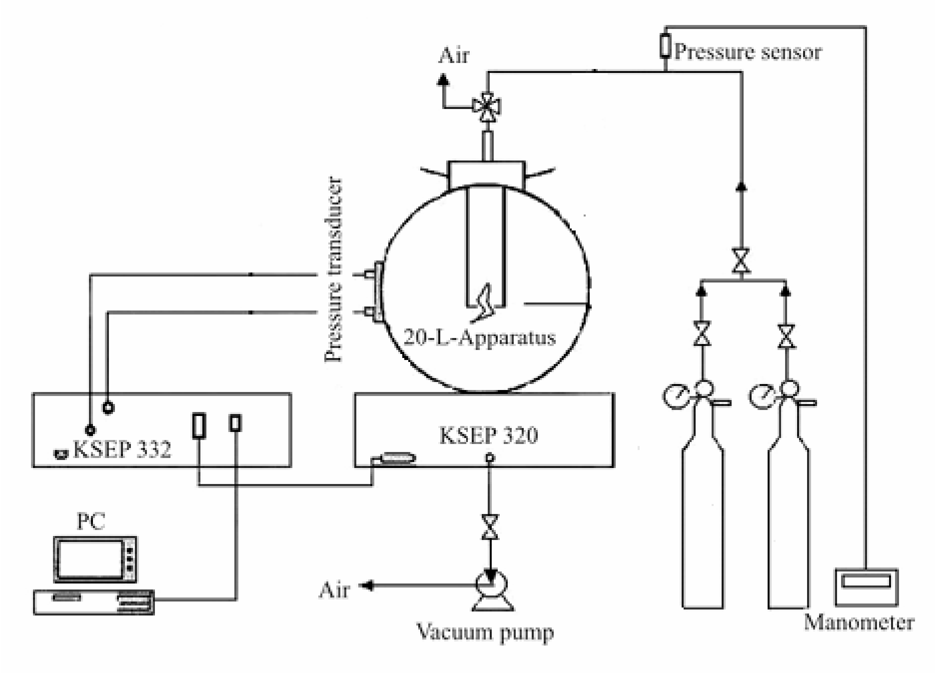


Figure 3.2.1: Schematic diagram of experimental set up

3.2.2 Measurement and Control System Ksep 332

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-lapparatus. 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.

For the determination of combustible gases or vapors, the test accomplished in a quiescent state which the ignition delay time, tv = 0s. (Operating Instructions for the 20-L-Apparatus, 1996)

3.3 Experimental Conditions

The flammability limit of methane/air mixtures and methane/air mixtures with hydrogen enrichment up 60 vol % hydrogen of fuel were investigated at methane concentration from 3 vol % to 17 vol %. In this study, methane with 99.5 % purity which indicates the natural gas and hydrogen with 99.9 % purity are used.

3.3.1 Pressure and Temperature

The initial pressure in the 20-L-sphere is regulated to 1 bar absolute. A water jacket to dissipate the heat of explosions or to maintain thermostatically controlled test temperatures. It is necessary to keep the operating temperature at approximately 20 °C by means of water cooling, whereby the operating temperature would correspond to room temperature. Therefore, there is always some flow of water and so that the outlet temperature of the cooling medium never exceeds 25 °C.

3.3.2 Ignition

Ignition is achieved by permanent spark which placed in the centre of the vessel. Since experiment was conducted under quiescent conditions, ignition energy (IE) is 10 J and the ignition delay is 0s. The igniters release 10 J independently of pressure or temperature. The pressure evolution after ignition is measured with a Kistler 701 A piezoelectric pressure transducer connected to a Charge amplifier (Kistler 5041 B).

Table 3.3.2: Test condition of experiment

Pressure	1 bar absolute
Temperature	Ambient temperature
Mixture state	Quiescent state
Ignition energy	10 J
Ignition delay time	0s

3.4 Research Parameter

In this research, two parameters will be considered in order to determine the effect of suppression agent toward natural gas explosion limit. The parameter involved are Maximum pressure (Pmax) and the percent of Methane volume %.

Maximum pressure (Pmax) in this research is referring to the maximum pressure that could be generated by the explosion in the vessel through the ignition of methane. Maximum pressure (Pmax) of the explosion will be observed during the explosion tests. The more effective the suppression agent (N_2) the lower maximum pressure, the maximum pressure (Pmax) of the explosion is lowers. The % by volume of methane and nitrogen gas use in this research is according to Table 3.2 (a), 3.3 (b), 3.4 (c) and 3.5 (d) below:

Table 3.4 (a): The concentration (vol %) of methane and air

No.	Methane concentration (vol %)	Air concentration (vol %)
1	4	96
2	5	95
3	6	94
4	7	93
5	8	92
6	9	91
7	10	90
8	11	89
9	12	88
10	13	87
11	14	86
12	15	85
13	16	84
14	17	83
15	18	82
16	20	81

Table 3.4 (b): The concentration (vol %) of methane and air for 10 % nitrogen dilution

No.	Methane concentration (vol %)	Nitrogen Concentration (vol %)	Air concentration (vol %)
1	4	10	86
2	5	10	85
3	6	10	84
4	7	10	83
5	8	10	82
6	9	10	81
7	10	10	80
8	11	10	79
9	12	10	78
10	13	10	77
11	14	10	76
12	15	10	75

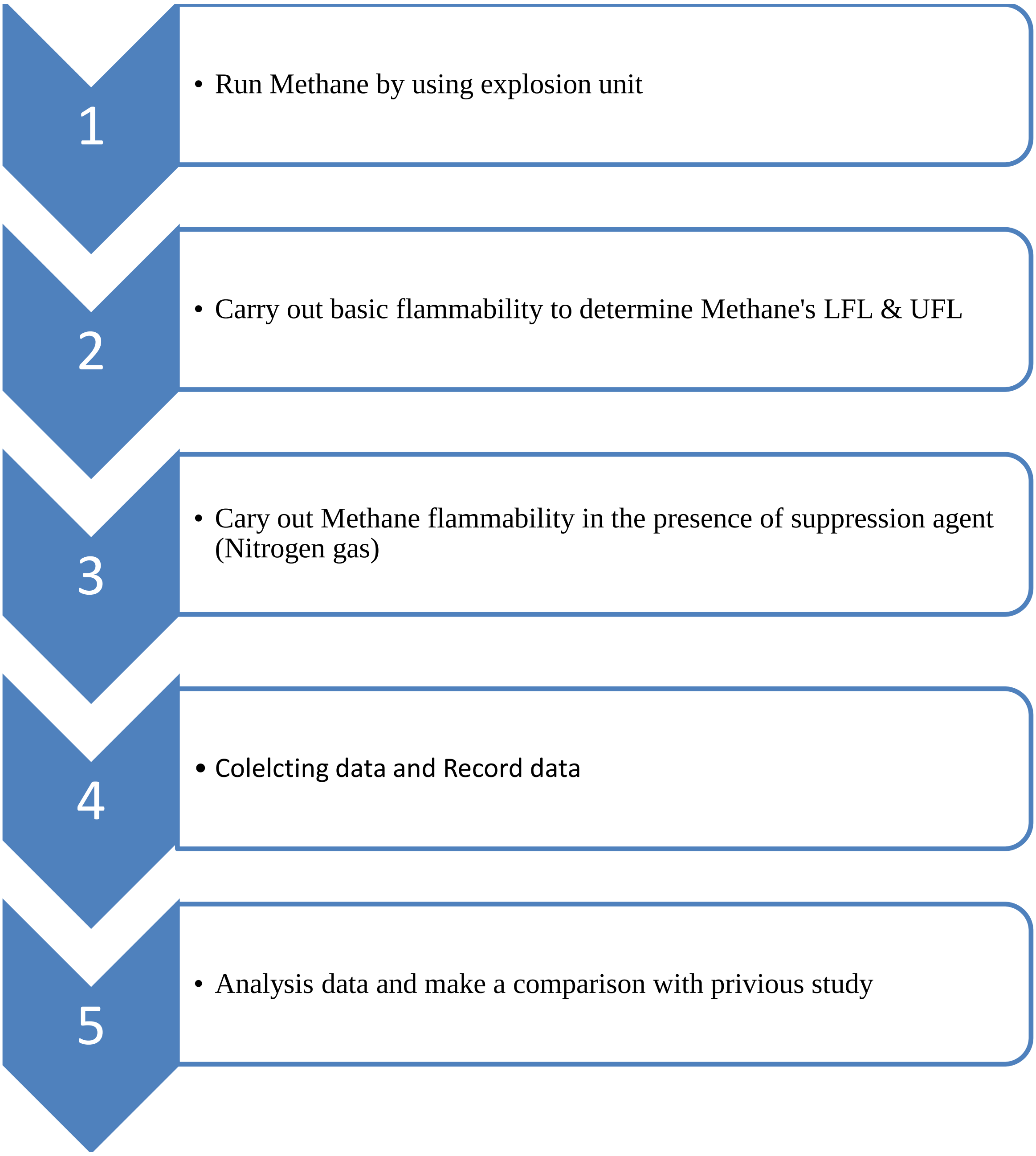
Table 3.4 (c): The concentration (vol %) of methane and air for 20 % nitrogen dilution

No.	Methane concentration (vol %)	Nitrogen Concentration (vol %)	Air concentration (vol %)
1	4	20	76
2	5	20	75
3	6	20	74
4	8	20	72
5	10	20	70
6	12	20	68

Table 3.5 (d): The concentration (vol %) of methane and air for 30 % nitrogen dilution

No.	Methane concentration (vol %)	Nitrogen Concentration (vol %)	Air concentration (vol %)
1	4	20	76
2	5	20	75
3	6	20	74
4	7	20	72
5	8	20	70

3.5 Experiment Stages



1. Run Methane by using explosion unit
2. Carry out basic flammability to determine Methane's LFL & UFL
3. Cary out Methane flammability in the presence of suppression agent (Nitrogen gas)
4. Colelcting data and Record data
5. Analysis data and make a comparison with privious study

Figure 3.5: Experiment stage of experiment

3. 5.1 Run the Methane Explosion by Using Explosion Unit

Figure 3.5.1 show the explosion unit used in the experiment. In this first stage, basic explosion of the methane (CH_4) will be carried out in order to set up the gas fire explosion to a standard condition. Set up the equipment, vacuum, and cleaning.

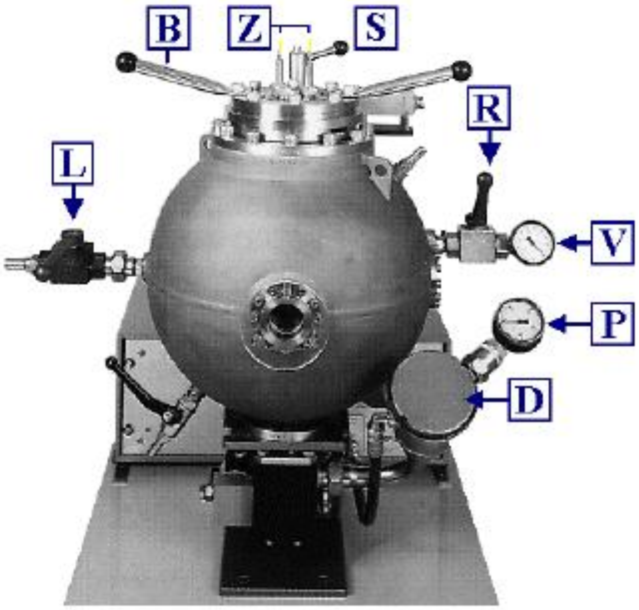


Figure 3.5.1: Gas Fire Explosion Unit

3.5.2 Determine the Methane Lower Flammability Limit (LFL) and Upper Explosion Limit (UFL)

In this stage, the maximum pressure (Pmax) of the methane will be determined as the standard references through the experiment and at the same time, lower explosive limit (LEL) and upper explosive limit (UEL) of the explosion can be recorded. The result can be compared to next experiment by mixed the methane gas with different percent of nitrogen gases where it is 10 %, 20 % and 30 % by volume.

3.5.3 Cary out Methane Flammability in The Presence of Suppression Agent (Nitrogen Gas)

The objective in this stage is to determine the maximum pressure (Pmax) and lower and upper of explosion limit of the methane mixed with nitrogen at different volume of nitrogen. The initial nitrogen percent used in this experiment is 10 % volume of nitrogen by volume (10 % v/v). The data can be determined after the experiment. The next experiment, run the experiment by using 20 % and 30 % nitrogen volume. The result will be used to compare.

3.5.4 Collecting Data and Record Data

After completing the experiment, the collected data will be analyzed by tabulating and plotting into graph.

3.5.5 Analysis Data and Make A Comparison

After tabulating and plotting data into graph, the collected data will be compared with the standard reference.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Since the spherical explosion vessel does not allow visual observation of the flame, the explosion vessel uses an indirect measurement of the flame propagation which is the pressure explosion. This is because successful ignition would induce a rapid pressure increase and temperature rise within a short time as well as produce a propagating flame front that could be readily observed (S. Y Liao,2005).Thus, pressure explosion criterion is used to define the flammability limit. In this experimental study flame propagation is said to have occurred if ignition followed by pressure explosion is 0.1 bar or greater than 0.1 bar. The result is shown in Table below.

4.2 Result and Discussions

4.2.1 Methane and Air

Table 4.2.1 below shows the result on the quiescent methane-air mixtures at ambient pressure and temperature. From the results, it can be seen that the pressure explosion obtained greater than 0.1 bar at concentration of methane 5 vol % until 18 vol % which means the flammability limits of methane/air mixtures is from 5 vol % to 18 vol % of methane. The highest pressure explosion from the measurements is 5.5 bars which obtained at methane concentration 10 vol %. Rate of pressure rise are also highest at 9 % volume concentration and taken time 116 ms. For this near stoichiometric mixture, the flame speed is fastest and rapid, and it takes lowest time for the flame to propagate from its point of ignition to the chamber wall compare to other methane/air mixtures. For this test, it shows that the entire mixture is almost completely consumed. Generally, the small pressure explosion is assumed to be associated with a limited upward propagation of the flame and is typically observed for mixtures on the edge of flammability. The high pressure explosion indicates that the mixture is almost completely consumed and that the flame has propagated both upwards and downwards (L. Vandebroek et al 2005).This is because upward propagation is easier than other propagation directions because combustion products are hotter and less dense than the reactants from which they are generated (Cashdollar et al 2000).

Explosion Indices:

Max. Explosion pressure:	Pmax	=	**5.5** bar
Max. Rate of pressure rise:	(dP/dt)max	=	**154** bar / s
Product specific constant:	Kmax	=	**25** m·bar / s

Table 4.2.1: Result for Methane + Air

Series Test	**Conc. Vol %**	**Pm[Bar]**	**dP/dt [bar/s]**	**t [ms]**
1	3	0	0	0
2	4	0	0	0
3	5	0	0	0
4	6	2.9	16	352
5	7	4.7	88	129
7	8	5.1	118	114
8	9	5.5	154	116
9	10	5.2	114	101
10	11	4.9	62	180
11	12	4.6	37	244
12	13	2.4	5	935
13	14	1.5	5	954
14	15	1.6	5	908
15	16	1.2	5	816
16	17	0.8	5	977
17	18	0	0	0

4.2.2 Methane and 10 % Nitrogen

The Table 4.2.2 below shows the result on the quiescent methane and 10 % nitrogen mixtures at ambient pressure and temperature. From the results, it can be seen that the pressure explosion obtained greater than 0.1 bar at concentration of methane 5 vol % until 15 vol % which means the flammability limits of methane/air/10 % nitrogen mixtures is from 6 vol % to 13 vol % of methane. The upper explosive limit (UEL) and the maximum pressure explosive is lower than methane-air mixture that because the amount of air is decreases with increase the nitrogen volume. Rate of pressure rise (dP/dt) the highest at 7 % volume where it takes lowest time. From the result time taken for the highest pressure is 132 ms.

Explosion Indices:
Max. Explosion pressure: Pmax = **2.7** bar
Max. Rate of pressure rise: (dP/dt)max = **36** bar / s
Product specific constant: Kmax = **10** m·bar / s

Table 4.2.2: Result for methane + air + 10 % nitrogen by volume

Series Test	**Conc. Vol %**	**Pm[Bar]**	**dP/dt [bar/s]**	**t [ms]**
1	3	0	0	0
2	4	0 .0	0	0
3	5	0 .0	0	0
4	6	1.6	6	491
5	7	2.2	33	310
6	8	2.6	34	135
7	9	2.7	36	132
9	10	2.4	20	196
10	11	1.6	8	552
11	12	0 .6	4	860
12	13	0 .1	3	373
14	15	0	0	0

4.2.3 Methane and 20 % Nitrogen

Table 4.2.3 below shows the result of tests on the quiescent methane-10 % Nitrogen mixtures at ambient pressure and temperature. From the results, it can be seen that the pressure explosion obtained greater than 0.1 bar at concentration of methane 6 vol % until 12 vol % which means the flammability limits of methane/air/20 % nitrogen mixtures is from 5 vol % to 12 vol % of methane. Rate of pressure rise (dP/dt) is highest at 6 % volume where it takes lowest time. From the result time taken for the highest pressure is 320 ms.

Explosion Indices:

Max. Explosion pressure:	Pmax	=	**1.7** bar
Max. Rate of pressure rise:	(dP/dt)max	=	**7** bar / s
Product specific constant:	Kmax	=	**2** m·bar / s

Table 4.2.3: Result for methane + Air + 20 % Nitrogen

Series Test	**Conc. Vol %**	**Pm[Bar]**	**dP/dt [bar/s]**	**t [ms]**
1	5	0 .0	0	0
2	6	1.7	7	320
3	8	1.6	5	443
4	10	0 .1	3	496
5	12	0 .0	0	0

4.2.4 Methane and 30 % Nitrogen

Table 4.2.4 below shows the result of tests on the quiescent methane-10 % Nitrogen mixtures at ambient pressure and temperature. From the results, it can be seen that the pressure explosion obtained greater than 0.1 bar at concentration of methane 6 vol % until 8 vol % which means the flammability limit of methane/air/30 % nitrogen mixtures is from 5 vol % to 9 vol % of methane. The upper explosive limit is very close with lower flammability limit, and the maximum explosive pressure is lower than 1 which it is 0.9 bars. Rate of pressure rise (dP/dt) is highest at 7 % volume where it takes lowest time. From the result time taken for highest pressure is 819 ms. Showing that the explosive of methane is too slow.

Explosion Indices:

Max. Explosion pressure:	Pmax	=	**0.9** bar
Max. Rate of pressure rise:	(dP/dt)max	=	**9** bar / s
Product specific constant:	Kmax	=	**1** m·bar / s

Table 4.2.4: Result of methane + air + 30 % nitrogen

Series Test	**Conc. vol %**	**Pm[Bar]**	**dP/dt [bar/s]**	**t [ms]**
1	5	0 .0	0	0
2	6	0 .4	6	819
3	7	0 .9	9	335
5	8	0.1	1	1238
6	9	0 .0	0	0

4.2.5 Graph Pm [bar] vs Vol %

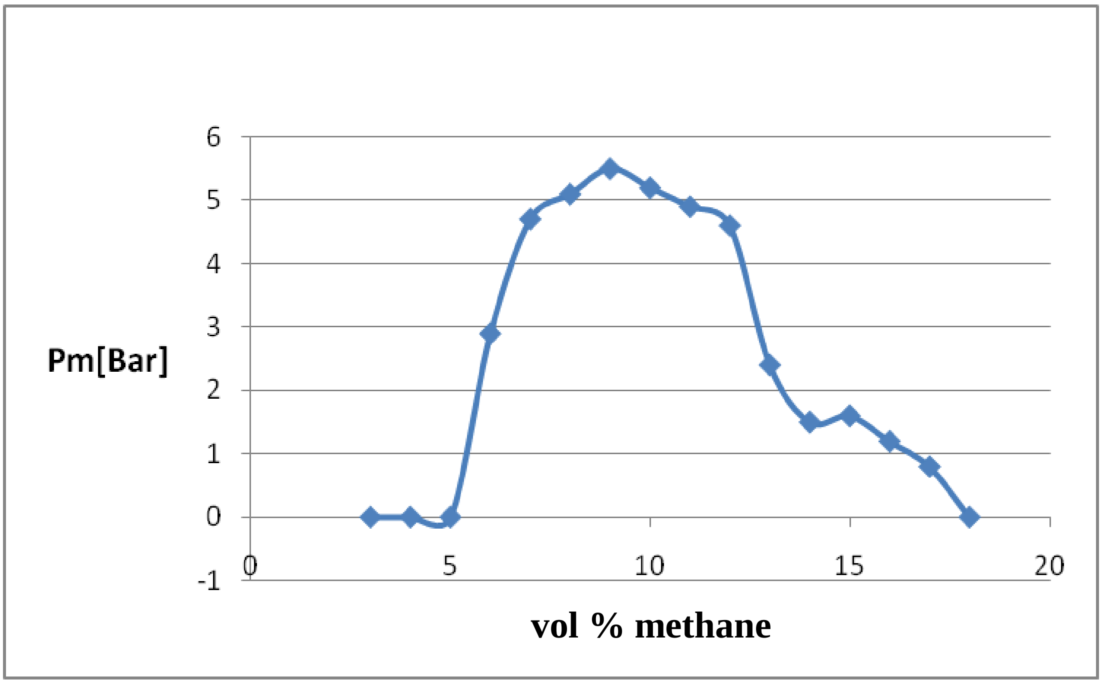


Figure 4.2.5 (a): Pm [Bar] vs vol % of methane

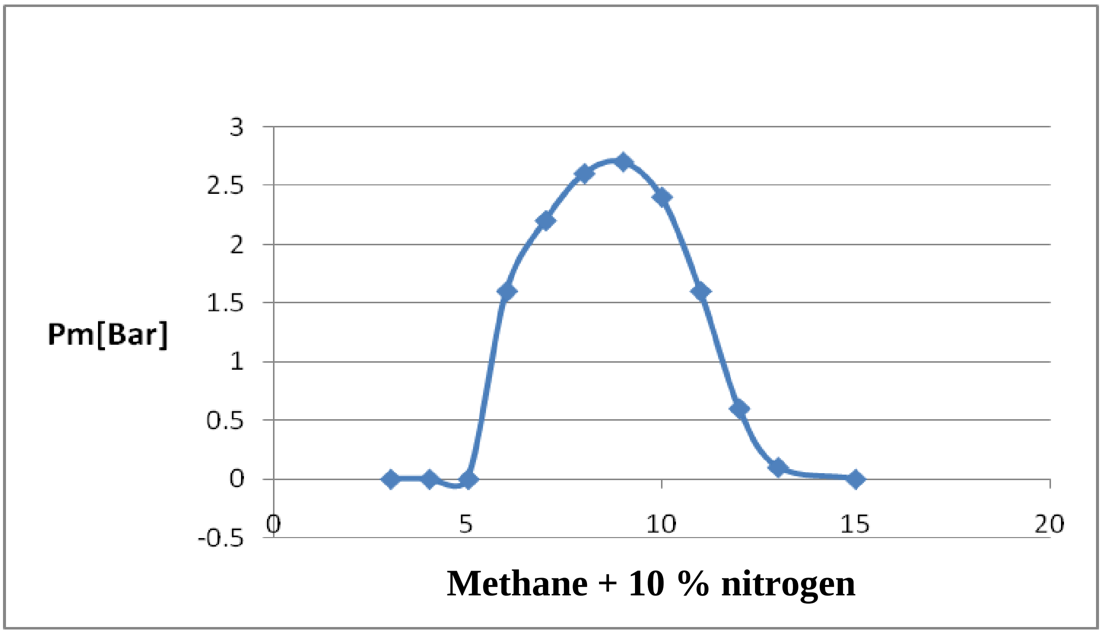


Figure 4.2.5 (b): Pm [bar] vs vol % methane + 10 % nitrogen dilution

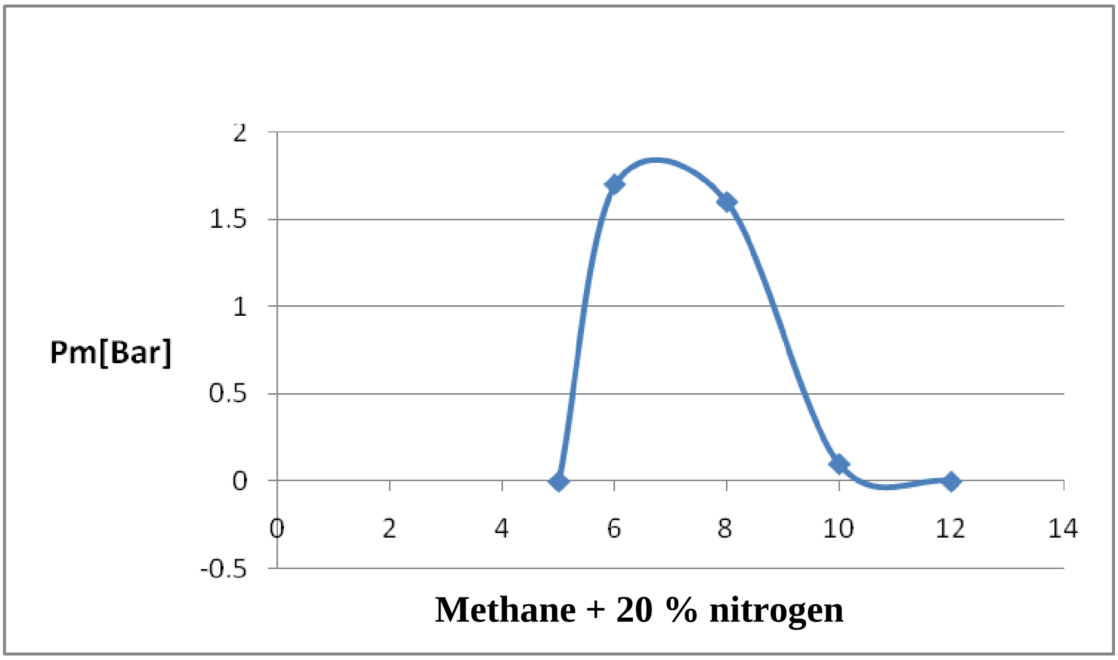


Figure 4.2.5 (c): Pm [bar] vs vol % methane + 20 % nitrogen dilution

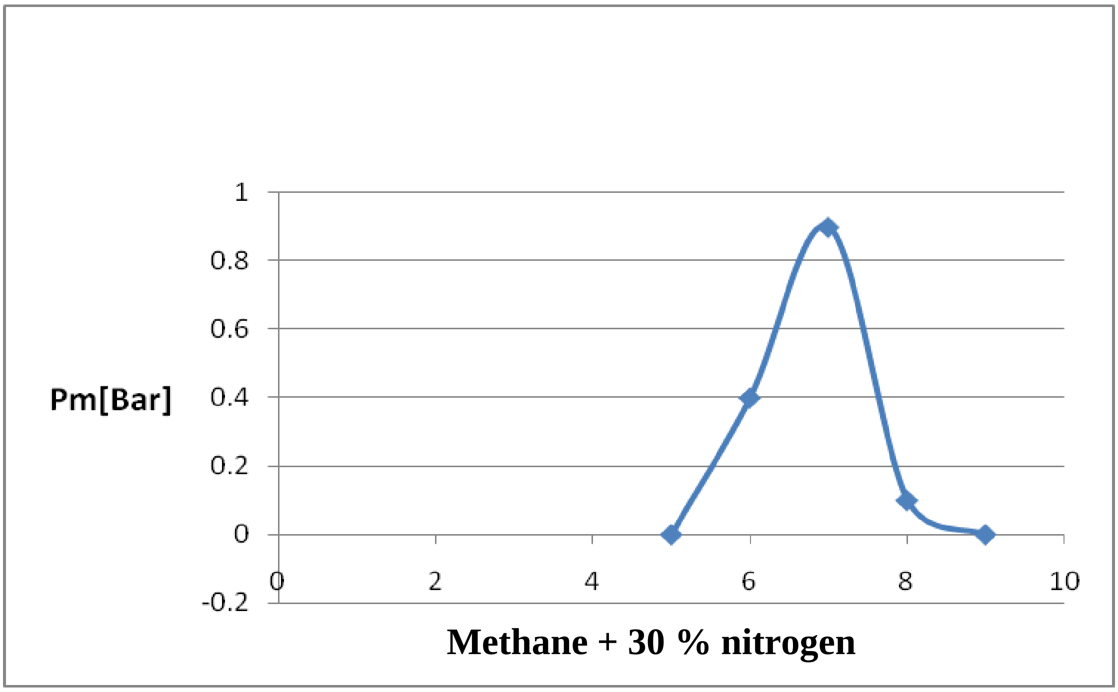


Figure 4.2.5 (d): Pm [bar] vs vol % methane + 30 % nitrogen dilution

4.2.6 Graph dP/dt[bar/s] vs Vol %

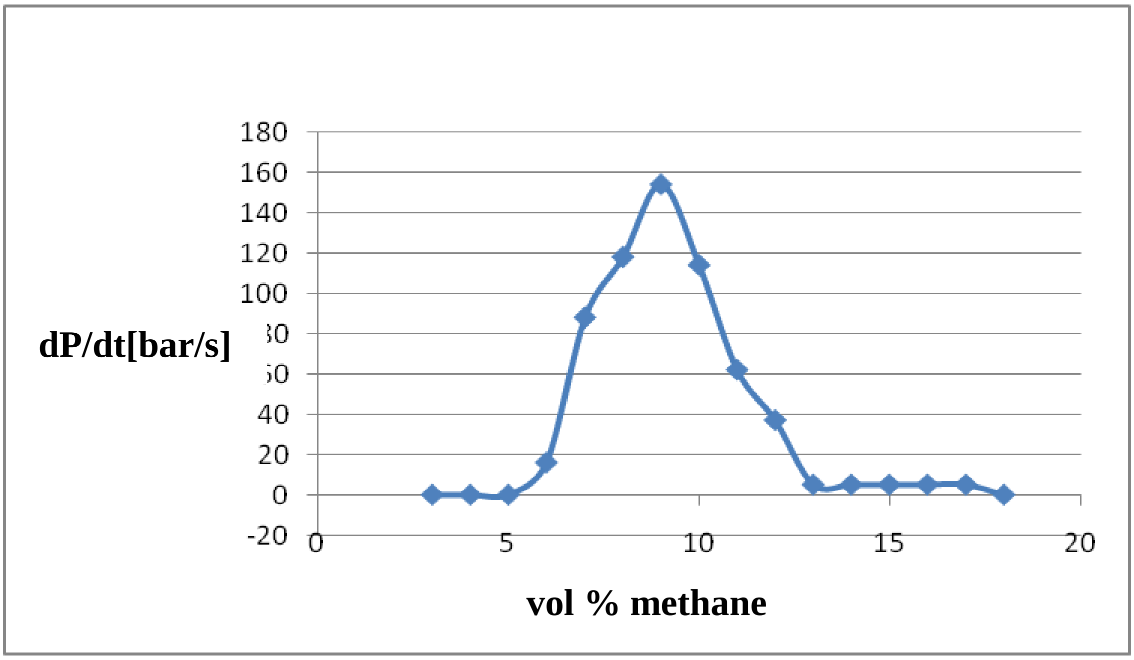


Figure 4.2.6 (a): dP/dt [bar/s] vs vol % methane + air

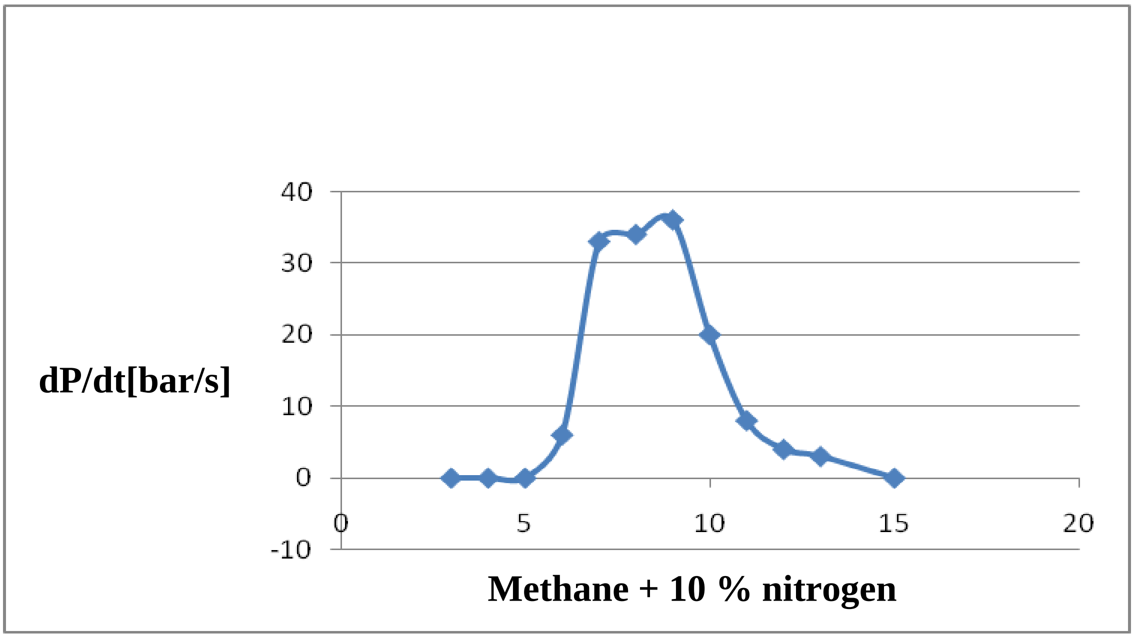
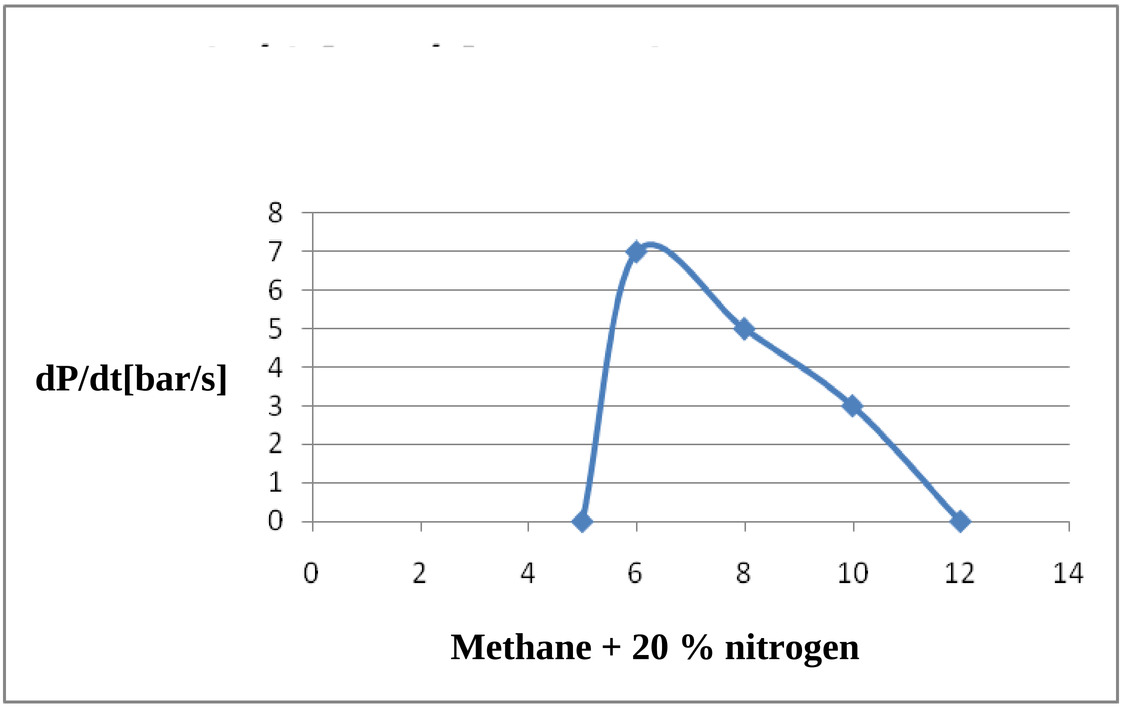
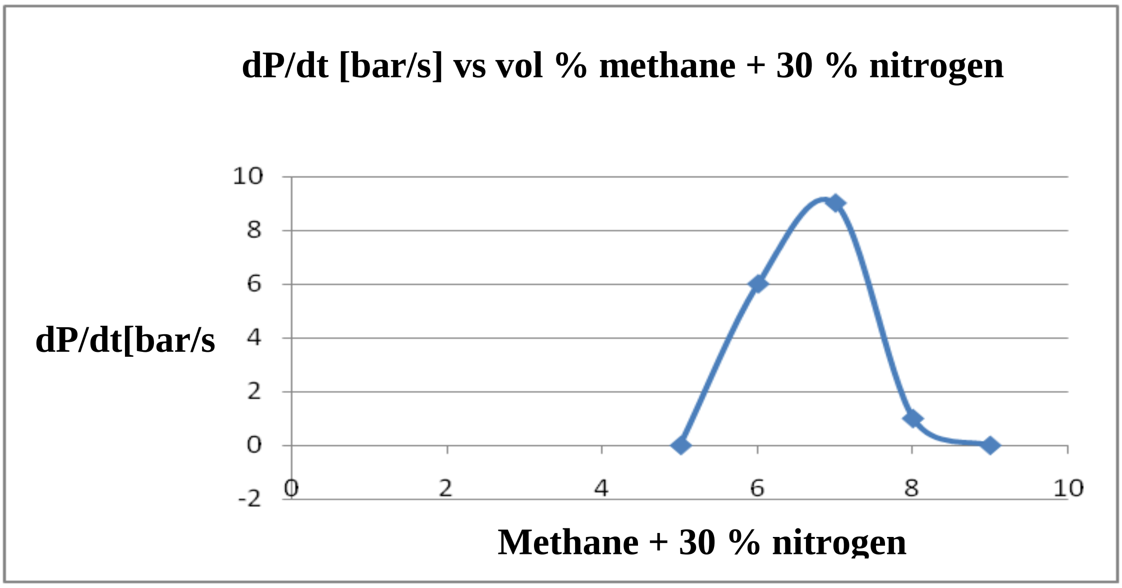


Figure 4.2.6 (b): dP/dt [bar/s] vs vol % methane + 10 % nitrogen dilution.



Graph 4.2.6 (c): dP/dt [bar/s] vs vol % methane + 20 % nitrogen dilution.



Graph 4.2.6 (d): dP/dt [bar/s] vs vol % methane + 30 % nitrogen dilution.

The Figure 4.2.6 (e) below showed the flammability limit of methane versus nitrogen volume %. In this Figure, at 0 % nitrogen added, the flammability limit of methane is 5 and 18 lower and upper limit respectively. After nitrogen added, the upper flammability limit of methane is decrease with increase the volume % of nitrogen from 10 % to 30 %.

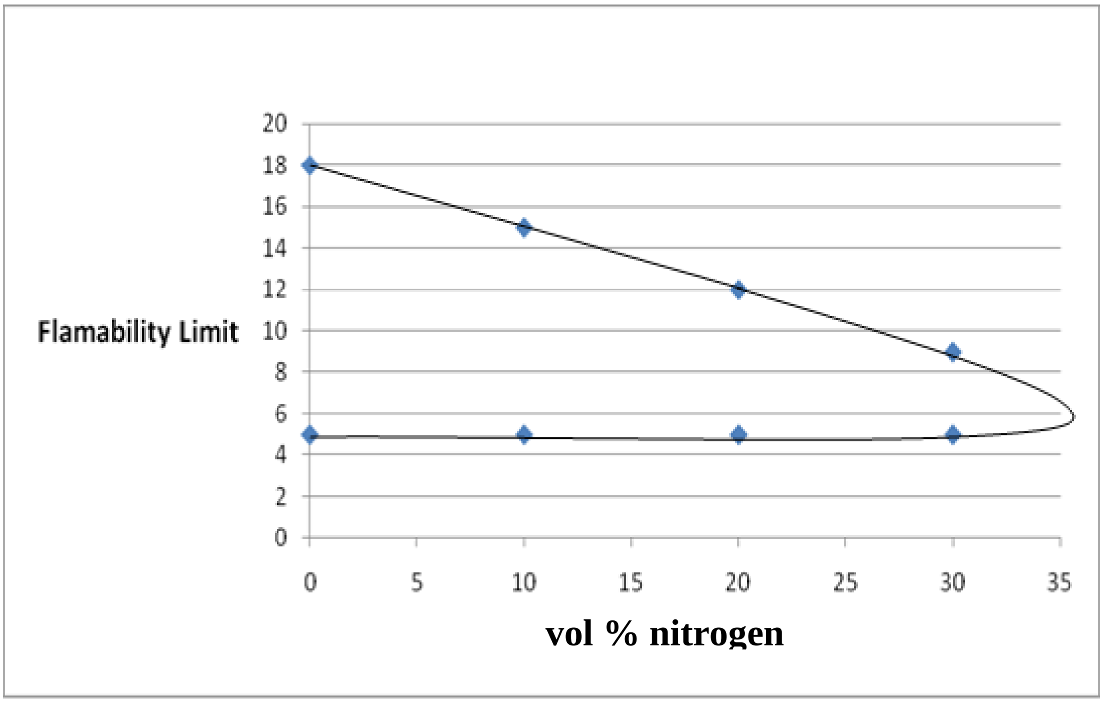


Figure 4.2.6 (e): Flammability limit methane vs. vol % nitrogen.

4.3 Comparison Data with Previous Studies

The Figure 4.3 above shown the result plotted by previous study. The result show the flammability limit of methane added nitrogen gas by different volume %. The data show the lower flammability limit of methane-Air is 5 % volume % and upper flammability limit is 15 methane volume %.

This data is different with in this experiment where the lower flammability limit of methane is 6 % methane volume % and upper flammability limit is 18 % methane volume %. What is the same data in this study with previous study is, the upper flammability is decrease with increase the added nitrogen gas.

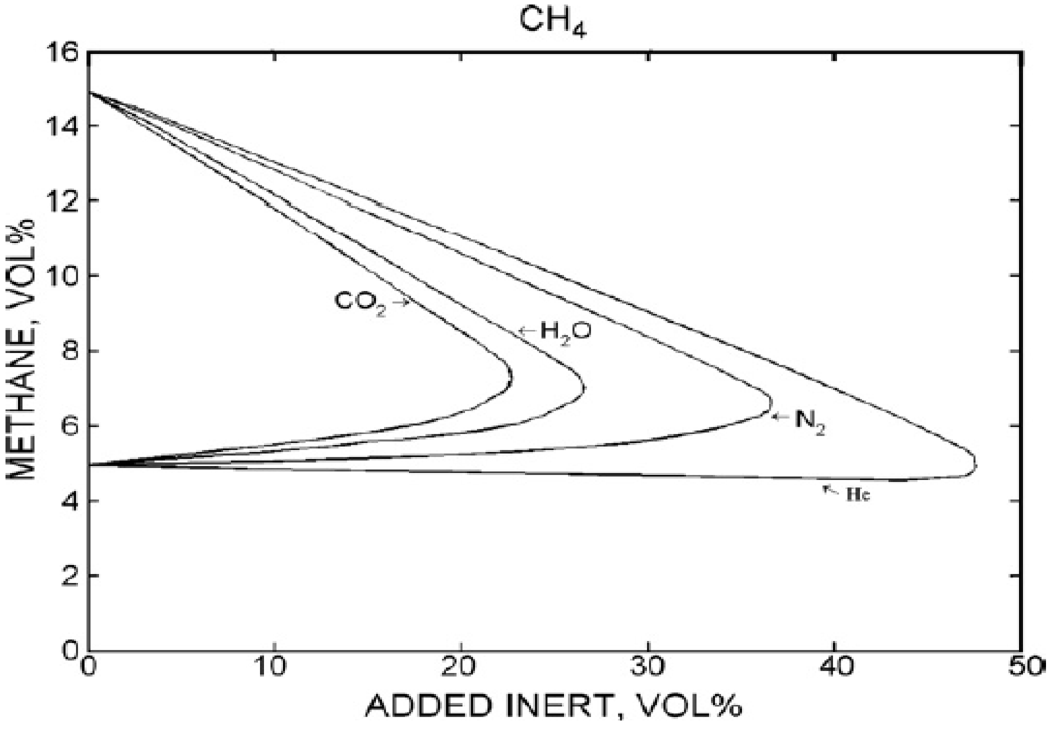


Figure 4.3: Flammability curves of methane for different inert gases. (C.-C. Chen et al.)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study is carried out to determine the flammability data of methane-/air mixture and to investigate the effect of nitrogen suppression on flammability limits of methane/air mixture at ambient conditions. Experimental investigations are conducted by systematically measuring the pressure histories in a 20 L explosion vessel with permanent spark placed in the centre of the vessel which released ignition energy of 10J.

From this study, it is found out that the flammability limits of quiescent methane/air mixture is from 6 % to 18 % of methane by volume. The flammability limit of methane/air/10 % nitrogen mixtures is from 6 vol % to 13 vol % of methane. The flammability limit is decrease after the nitrogen added. The flammability limit of methane/air/20 % nitrogen mixtures is from 6 vol % to 12 vol % of methane and the flammability limit of methane/air/30 % nitrogen mixtures is from 6 vol % to 8 vol %. In this result it can concluded that the upper flammability and maximum pressure explosion decrease with increase the volume percent of nitrogen gas.

5.2 Recommendations

Here are some recommendations to improve the efficiency of the study in order to increase the accuracy of the findings:

i. Use pressure gauge manometer with smaller range; so that the various composition of the fuel/air mixture can be obtain for the experiments since partial pressure method is used to determine composition of the fuel/air mixture

ii. Allow fuel/air mixture to become homogeneous or well mixed after the mixture take place in the explosion vessel before the mixture is ignited

iii. Study the flammability limits of methane/air mixture at elevated pressure and temperature

iv. Compare experimental result of explosion vessel method (pressure rise criterion) should be compared with the experimental result of glass tube method (visual observation)

v. Compare the flammability limits of methane or hydrogen with other suppression agent such as carbon dioxide CO_2, ammonium sulphate and etc

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APPENDIXES

APPENDIX A 1

DATA FROM COMPUTER

Fkksa ump

Sample:	**Methane + Air 5/3/2010**
Customer:	Tengku Fazli
Reason:	PSM2 Final Project.
Data to sample origin:	BKG KC07069
Preparation of sample:	Hafriz
Median value:	Methane + Air

Apparatus:	20-l-sphere
Ignition source:	chemical igniters
Dust-dispersion system:	rebound nozzle

Explosion Indices

Max. explosion pressure:	Pmax	=	**4.7** bar
Max. rate of pressure rise:	(dP/dt)max	=	**154** bar / s
Product specific constant:	Kmax	=	**25** m·bar / s

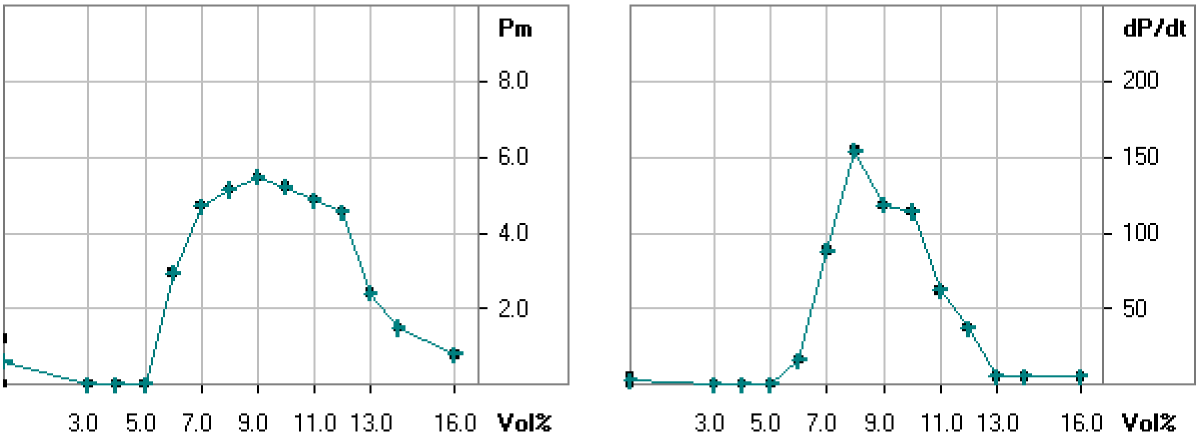


Figure 17: graph pm vs vol % and dP/dt vs vol % of methane + air

Methane + Air

(series) Test	Conc. [vol%]	Pm [bar]	dP/dt [bar/s]	t1 [ms]	tv eff [ms]
(1) 1	3.0	.0	0	0	0
(2) 2	4.0	.0	0	0	0
(3) 3	5.0	.0	0	0	0
(4) 4	6.0	**2.9**	**16**	**352**	0
(5) 5	7.0	**4.7**	**88**	**129**	0
(6) 7	8.0	**5.1**	**118**	**114**	0
(7) 8	9.0	**5.5**	**154**	**101**	0
(8) 9	10.0	**5.2**	**114**	**116**	0
(9) 10	11.0	**4.9**	**62**	180	0
(10)11	12.0	4.6	37	244	0
(11)12	13.0	2.4	5	935	0
(12)13	14.0	1.5	5	954	0
(13)14	15.0	1.6	5	908	0
(14)15	16.0	1.2	5	816	0
(15)16	17.0	.8	5	977	0
(16)17	18.0	.0	0	0	0

APPENDIX A 2

Fkksa ump

Sample: **Methane + 10% Nitrogen**

Customer: tengku fadzli
Reason: psm 2
Data to sample origin: kc07069
Preparation of sample: hafiz
Median value: methane + Nitrogen

Apparatus: 20-l-sphere
Ignition source: chemical igniters
Dust-dispersion system: rebound nozzle

Explosion Indices

Max. explosion pressure: Pmax = **2.7** bar
Max. rate of pressure rise: (dP/dt)max = **36** bar / s
Product specific constant: Kmax = **10** m·bar / s

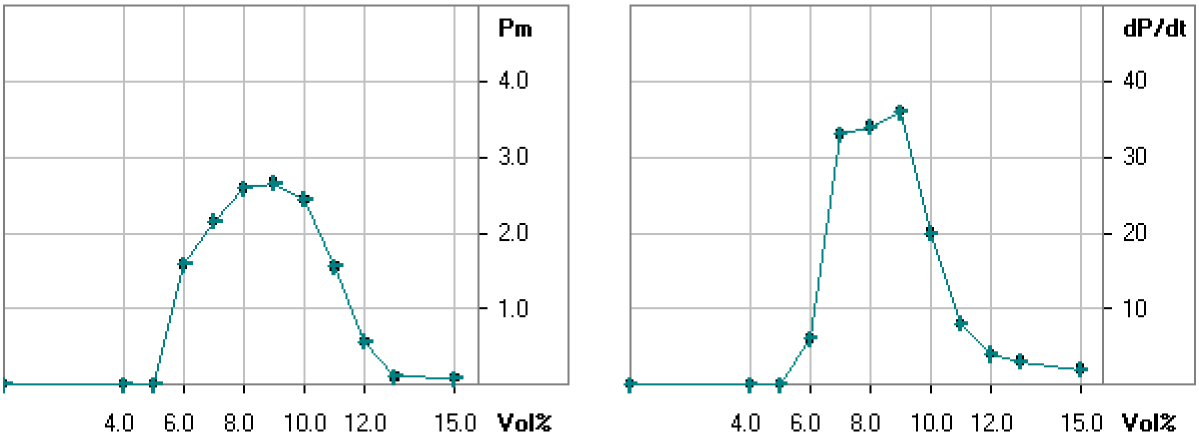


Figure 18: graph pm vs vol % and dP/dt vs vol % of methane + air + 10 % nitrogen

Methane + 10 % Nitrogen

(series) Test	Conc. [vol%]	Pm [bar]	dP/dt [bar/s]	t1 [ms]	tv eff [ms]
1	4.0	.0	0	0	0
2	5.0	.0	0	0	0
3	5.0	.0	0	0	0
4	6.0	1.6	6	491	0
5	7.0	2.2	33	310	0
6	8.0	2.6	34	135	0
7	9.0	2.7	36	132	0
9	10.0	2.4	20	196	0
10	11.0	1.6	8	552	0
11	12.0	.6	4	860	0
12	13.0	.1	3	373	0
14	15.0	.0	0	0	0

APPENDIX A 3

Fkksa ump

Sample: **Methane + 20 % Nitrogen**

Customer: tengku fadzli
Reason: PSM 2
Data to sample origin:
Preparation of sample: En.Haffiz
Median value:

Apparatus: 20-l-sphere
Ignition source: chemical igniters
Dust-dispersion system: rebound nozzle

Explosion Indices

Max. explosion pressure: Pmax = **1.7** bar
Max. rate of pressure rise: (dP/dt)max = **7** bar / s
Product specific constant: Kmax = **2** m·bar / s

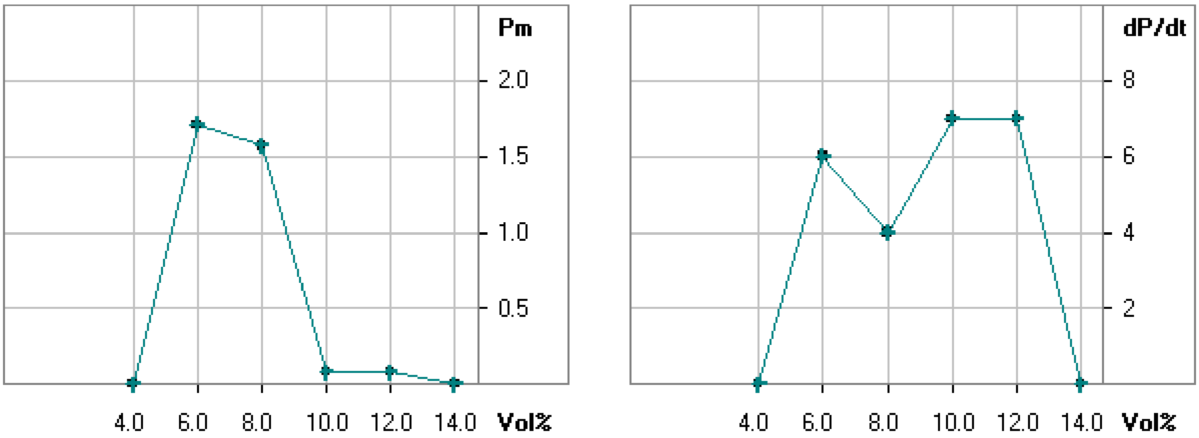


Figure 19: graph pm vs vol % and dP/dt vs vol % of methane + air + 20 % nitrogen

Methane + 20 % Nitrogen

(series) Test	Conc. [vol%]	Pm [bar]	dP/dt [bar/s]	t1 [ms]	tv eff [ms]
1	5.0	.0	0	0	0
2	6.0	1.7	7	320	0
3	8.0	1.6	5	443	0
4	10.0	.1	**3**	496	0
5	12.0	.0	**0**	0	0

APPENDIX A 4

Fkksa ump

Sample: **Methane + 30 % Nitrogen**

Customer: tengku fadzli
Reason: psm 2
Data to sample origin: kc07069
Preparation of sample: en.hafiz
Median value:

Apparatus: 20-l-sphere
Ignition source: chemical igniters
Dust-dispersion system: rebound nozzle

Explosion Indices

Max. explosion pressure: Pmax = **.9** bar
Max. rate of pressure rise: (dP/dt)max = **9** bar / s
Product specific constant: Kmax = **1** m·bar / s

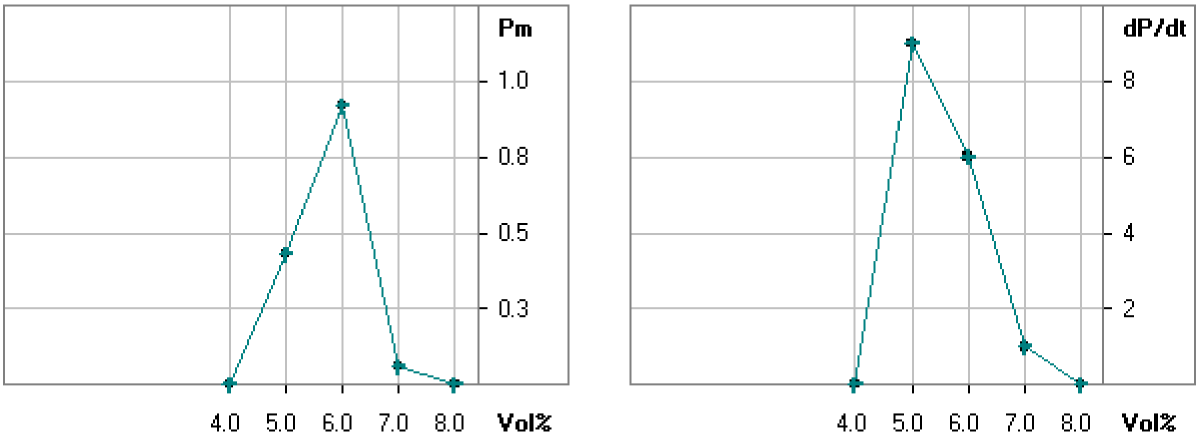


Figure 20: graph pm vs vol % and dP/dt vs vol % of methane + air + 20 % nitrogen

Methane + 30 % Nitrogen

(series) Test	Conc. [vol%]	Pm [bar]	dP/dt [bar/s]	t1 [ms]	tv eff [ms]
1	4.0	.0	0	0	0
2	5.0	.4	**6**	819	0
3	6.0	.9	9	335	0
4	7.0	**.1**	**1**	1238	0
5	8.0	.0	0	0	0

Data error notice: At concentration 5 vol%, the explosive is impossible occur because in this experiment, the lower explosive limit of methane is at 6 vol% concentration.

APPENDIX B

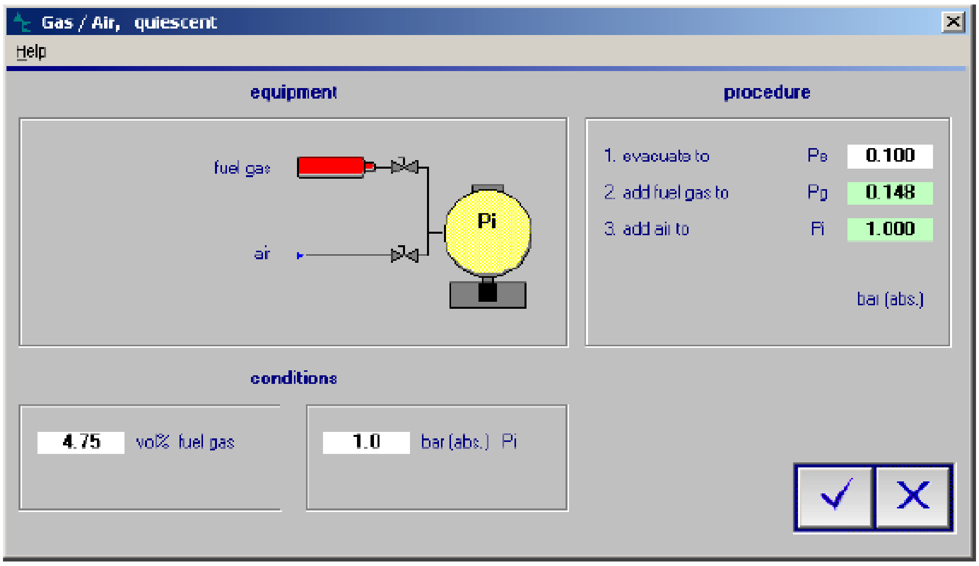
MANUAL OF 20-l-APPARATUS

1.1 GENERAL RULES FOR GAS AND SOLVENT VAPORS (QUIESCENT)

i. It is customary to determine the explosion indices for gas and solvent vapors, if possible, at room temperature and normal pressure, using as an ignition source a permanent spark with an ignition energy of approx. E = 10 J.

ii. The explosion characteristics can be determined either in a quiescent state or under turbulent condition for the gas (vapor)/air mixtures. In the following the condition for the gas/air mixtures will be quiescent and therefore the dust dispersion device has to be removed and the connection sealed.

iii. The required gas-air mixtures can be produced easily with the partial - pressure - procedure. Prior to the tests it is recommended to check the composition of these gas/air mixtures using suiTable instruments.



1. evacuate to Pe 0.100
2. add fuel gas to Pg 0.148
3. add air to Pi 1.000

bar (abs.)

4.75 vol% fuel gas

1.0 bar (abs.) Pi

Figure 21: Experiment set up to check gas/air mixtures

iv. For investigations under quiescent conditions input **tv = 0**. The admixture of the fuels takes place directly in the 20-l-sphere and not through the storage container. Therefore no expansion pressure of the storage container can be measured (Pd = 0 bar). The ignition signal occurs immediately after starting the test. The evaluation of Pd and td will be suppressed.

1.2 GAS LOWER EXPLOSION LIMIT (LEL) AND GAS UPPER EXPLOSION LIMIT (UEL)

1.2.1 Test Conditions

Function = Gas, Solvent
Ignition source = Permanent Spark
Ignition energy IE = 10 J
Ignition delay time tv = 0 ms
Dispersion pressure Pz = 0 bar (1 bar absolute, no pre-evacuation)

1.2 2 Test Method

The 20-l-sphere has to be cleaned thoroughly before each test. A test series is initiated, starting with gas concentrations of an integral multiple of 0.25 vol% for example 2 or 3 vol%. The series is continued with a systematic increase of the gas concentration until ignition of the gas/air mixture is observed. Repeat the test with a gas concentration 0.25 vol% lower, and continue to reduce the concentration in further tests until a concentration is reached at which no ignition of the gas/air mixture is observed in three successive tests. For the determination of the UEL the LEL-procedure can be used accordingly. To obtain accurate values for the LEL and UEL, **3** negative tests for each concentration must be observe

1.2.3 Test Evaluation (IE = 10 J)

Pex [bar]	Pm [bar]	Decision:
< **0.1**	< **0.1**	**no ignition**
0.1	**0.1**	ignition

The lower explosion limit LEL as well as the upper explosion limit UEL are reported as those concentrations at which a gas explosion is just not possible in **3** successive tests. If only one test series is carried out (1 negative test), the value for LEL or UEL has to be reported as approximately ... vol %.

1.3 Pressure Course: Definitions

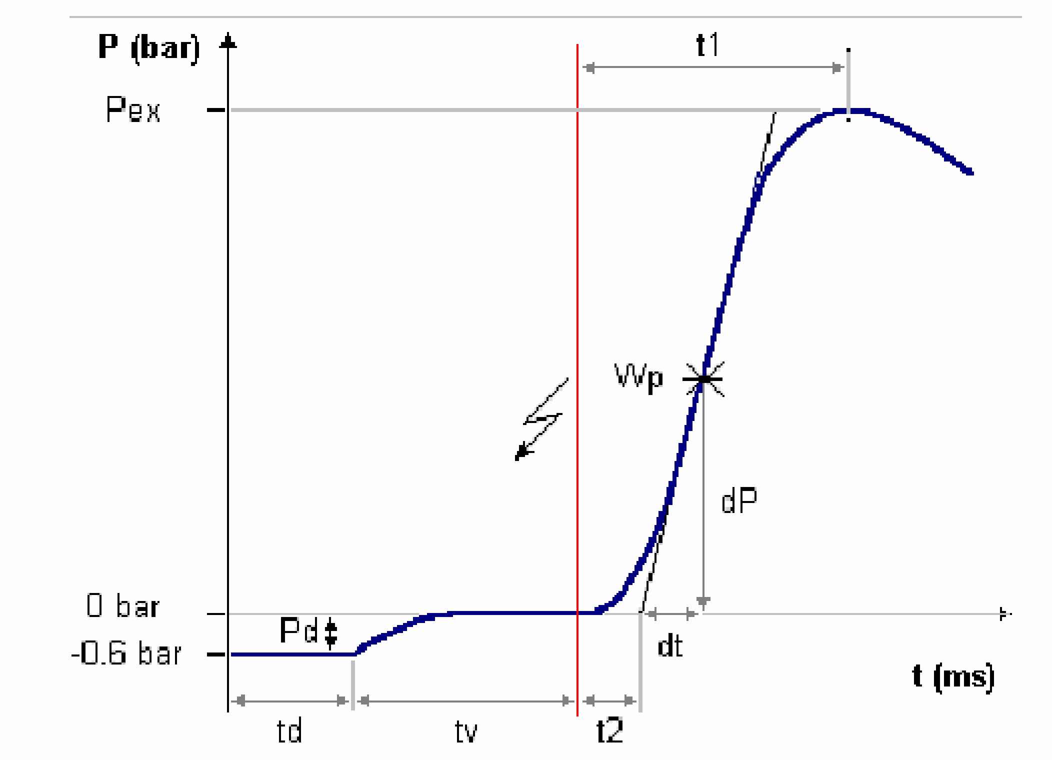


Figure 22: Pressure course: definitions curve

Pex	Explosion overpressure: the difference between the pressure at ignition time (normal pressure) and the pressure at the culmination point is the maximum explosion overpressure Pex measured in the 20-l-apparatus at nominal fuel concentration
Pm	Corrected explosion overpressure: Due to cooling and pressure effects caused by chemical igniters in the 20-l-apparatus, the measured explosion overpressure the Pex has to be corrected.
Pmax	Maximum explosion overpressure: Maximum value of Pm determined by tests over a wide range of fuel concentrations.
(dP/dt)m	Rate of pressure rise with time at nominal fuel concentration. It is defined as the maximum slope of a tangent through the point of inflexion (Wp) in the rising portion of the pressure vs. time curve.

(dP/dt)max	Maximum rate of pressure with time: Maximum value of (dP/dt)m determined by tests over a wide range of fuel concentrations.
Kmax	Product specific constant = 0.27144 x (dP/dt)max.
t1	Duration of combustion: time difference between the activation of the ignition and the culmination point.
t2	Induction time: time difference between the activation of the ignition

APPENDIX C1

TECHNICAL DATA OF 20-L-SPHERE

Material of construction No	1.4435
Wall thickness of inner jacket	min. 4 mm
Wall thickness of outer jacket	min. 2 mm
Volume of sphere	20 l
Volume of water jacket	1.5 l
Design pressure of sphere	30 bar
Design pressure of jacket	10 bar
Test pressure of sphere	39 bar
Test pressure of jacket	14.3 bar
Design temperature	60 °C
Bayonet ring aperture	mm diameter
Cleaning aperture	140 mm diameter
Sight glass	30 mm diameter
Measuring flange	3 tapped bores M14 x 1.25
Venting connection	hose ID. 12 mm
Vacuum connection	Serto, 1/4" G
Water connections	hose ID. 10 mm
Overall dimensions (w,h,d)	650 x 875 x 820 mm
Weight	75 kg