THE EFFECT OF VACUUM PRESSURE ON THE FLAMMABILITY LIMITS OF NATURAL GAS (NG)

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ABSTRACT

The purpose of this study is to determine the effect of vacuum pressure on the flammability limits Natural Gas in a closed vessel explosions at various initial pressures within 0.98 and 0.96 bar and at ambient initial temperature. Times and pressure of the explosions were recorded. Experimental investigations are conducted by systematically measuring the pressure histories in a constant volume 20-L- apparatus. In this experimental study, we analyzed and do the comparison with 3 various pressure, which is 1 bar, 0.98 bar and 0.96 bar. Experimental result shown that at 10 volume percent of concentration natural gas ,pressure maximum for 0.98 bar natural gas – air mixture is 5.1 bar and for 0.96 bar natural gas- air mixture is 4.7 bar. While compare with 1 bar natural gas – air mixture, pressure maximum is 5.8 bar. Flammability limits for 0.98 and 0.96 bar is still 5 to 15 percent of concentration. As a conclusion, by reducing the pressure of Natural Gas- air mixture will not effected the flammability limits range but it will be decreased the pressure maximum (Pmax) of explosion

ABSTRAK

Tujuan dari kajian ini adalah untuk mengetahui pengaruh tekanan vakum di had mudah terbakar gas asli dalam letupan kawasan ditutup pada pelbagai tekanan awal lingkugan 0.98 dan 0.96 bar dan pada suhu awal ambien. Masa dan tekanan dari letupan itu direkodkan. Ujikaji dilakukan dengan sistematik mengukur tekanan dalam alat isipadu tetap 20 L-. Dalam kajian ini , kami menganalisis dan melakukan perbandingan dengan 3 tekanan yang berlainan , iaitu 1 bar , 0.98 bar dan 0.98 bar. Hasil percubaan menunjukkan bahawa pada 10 peratus kelantangan konsentrasi gas asli, tekanan maximum untuk gas asli bersama udara pada 0,98 Bar - adalah 5,1 bar dan untuk 0,96 bar adalah 4,7 bar. Sementara dibandingkan dengan 1 bar gas asli bersama udara, tekanan maksimum adalah 5.8 bar. Had mudah terbakar pada 0,98 dan 0,96 bar masih 5 hingga 15 peratus daripada konsentrasi. Sebagai kesimpulan, dengan mengurangkan tekanan campuran udara gas asli tidak akan berpengaruhi terhadap had mudah terbakar tetapi akan menurunkan tekanan maksimum (Pmax) letupan.

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LIST OF ABBREVIATIONS

CH_4	methane
IE	ignition energy
LEL	lower explosion limit
NG	natural gas
P_d	pressure difference
P_{ex}	gretest explosion overpressure at any desired fuel concentration, measured in the 20-l-Sphere
P_{max}	maximum value of the explosion index Pm at optimum fuel concentration, measured in the 20-l- Sphere according to the ISO -Standard
P_i	initial pressure
t_{1SS}	combustion time
t_2	induction time
t_v	ignition delay time
UEL	upper explosion limit
vol %	volume percent

CHAPTER 1

INTRODUCTION

1.1 Overview of Research

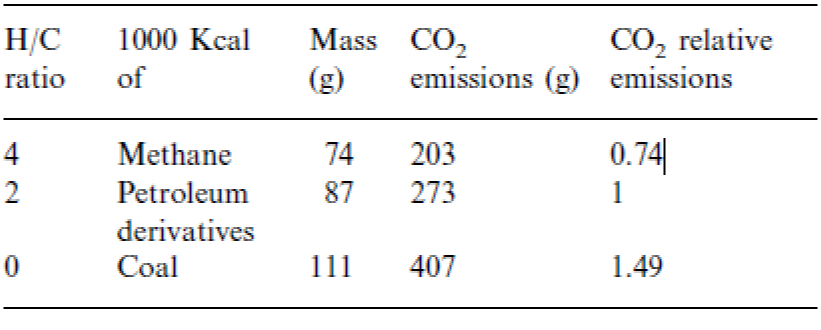
Natural gas is a highly flammable hydrocarbon gas consisting chiefly of methane (CH_4). Although methane is always the chief component, it may also include other gases such as oxygen, hydrogen, nitrogen, ethane, ethylene, propane, and even some helium. Natural gas is easily combustible and form explosive mixture.

It is formed by the decomposition of prehistoric vegetable and animal matter, and trapped in porous rock formations beneath the surface of the earth. Natural gas is lighter than air, and this fact enhances its safety. Unlike other fuels such as diesel, petrol or LPG, which are heavier than air, should a natural gas leak occur, the gas will readily dissipate into the atmosphere. This eliminates the risk of the fuel accumulating or pooling at ground level and causing a greater risk or hazard. Natural gas is colourless and odourless when it is extracted from the earth, and an odorant is added for safety, before it is piped to consumers, as a ready means of leak detection. An average person can easily detect the smell of gas at a concentration as low as 1 % by volume in air. That concentration is about 5 times lower than the level that will support combustion.

A well-known fact about natural gas (which is more than 90% methane in composition) is that it exhibits the highest H/C ratio of all the fossil fuels. This implies both lower CO_2 emissions and a lower material intensity (lower mass per unit of energy). From an energy point of view, in fossil fuels only carbon (C) and hydrogen (H) contribute significantly to the energy content, while other elements (oxygen, sulfur, nitrogen) play a minor role(Stefano Di Pascoli et al.,2000). If combustion is performed under the best of conditions (correct quantity of oxygen), hydrogen leads to water vapor (H_2O), while carbon gives carbon dioxide (CO_2). Since water emissions have a lower environmental impact than CO_2, a high H/C ratio is preferred.

Even in a mass per unit energy perspective hydrogen is preferable, since its mass per unit energy is about one-third that of carbon. This is because hydrogen's atomic mass is only 1/12 of that of carbon, although its energy content is about 14 Bearing in mind that NG typically has a carbon content of 75 % by weight, while oil and petroleum derivatives have a carbon content of 86 %, it can be seen that the material intensity of NG is 74 versus 87 mg/Kcal for gasoline and diesel fuel in Table below.

Table 1.1 Energy contents, mass, and CO_2 emissions(Stefano Di Pascoli et al.,2000)



H/C ratio	1000 Kcal of	Mass (g)	CO_2 emissions (g)	CO_2 relative emissions
4	Methane	74	203	0.74
2	Petroleum derivatives	87	273	1
0	Coal	111	407	1.49

Natural gas, like most fuels, is safe when it is used properly. But accidents can happen. That is why it is important for knowledge of pressure time variation during explosions of natural gas–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 resultant fire and explosion of natural gas–air mixtures can injure and or kill people, damage property and cause poisonous materials to be released into the atmospheric (Erdem A. Ural 2004). Natural gas will not explode in the presence of a flame until it reaches a very specific concentration in the air - below a certain level it is deemed too lean to burn and above a certain level it may be too rich to burn. Within a flammable range, the gas will ignite and may cause an explosion. (Neil Muchatutaa, and Steven Sale, 2007)

There are two composition limits of flammability for air and gaseous fuel under specific conditions.

1. Lower Flammability Limit ("LFL")
2. Upper Flammability Limit ("UFL")

The LFL is the concentration of natural gas in the air below which the propagation of a flame will not occur on contact with an ignition source. The natural gas LFL is 5 %. This means that, in most cases, the smell of gas would be detected well before combustion conditions are met. The UFL is the concentration of natural gas in the air above which the propagation of a flame will not occur on contact with an ignition source(Bjerketvedt et al 1997) . The natural gas UFL is 15 %.Natural gas has no known toxic or chronic physiological effects (that is, it is not poisonous). Exposure to a moderate concentration may result in a headache or similar symptoms due to oxygen deprivation but it is likely that the smell would be detected well in advance of concentrations being high enough for this to occur.(Liao and Cheng, 2004)

1.2 Problem Statement

Air and natural gas in the proper proportions will ignite, liberating heat, which is adsorbed primarily by the product combustion. Knowledge of pressure explosions of natural gas–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 natural gas because of the pressure can influences the flammability limits, for example at low pressure, say 0.064 bar, natural gas –air mixtures are not combustible but at high pressures, the upper limit rises rapidly. When the temperature rise of the gas causes an increase in pressure and under confinement, can result in an explosion. Unwanted combustion of or explosion of fugitive natural gas mixed with air is a prime safety manner.

1.3 Objective

The main objective of this research is to analyze the effect of pressure on natural gas explosion hazards in closed vessel and to study flammability limits of natural gas air mixture.

1.4 Scope of Research

In order to achieve the above objective, the following scopes of research have been identified:

I. Determine flammability limits of premixed natural gas air mixture by using a fire explosion experiment 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.

II. Pressure various 0f 0.98 and 0.96 bar

III. Volume % of NG between 5- 15 %

1.5 Rational and Significant

We have all heard about accidental gas explosions and the destruction they can cause. Fortunately most of us will not experience accidental explosions. However, preventing them from happening requires a good understanding of what a gas explosion is and what can be done to reduce the frequency and consequences of such events and it is importance to ensure the safety in industrial and domestic applications that produce or use flammable mixtures.

In this study, we can summaries that the advantages of understanding the effect of pressure on the flammability limits of natural gas is

a) Can protect the equipment or plant , for example pipeline system for transportation form explosion

b) Detect the incipient fire before a deflagration ignition occurs so that an explosion can be prevented from developing.

c) Lessen the loss of property and prevent casualties

CHAPTER 2

LITERATURE REVIEW

2.1 Pressure

Pressure is a type of stress which is exerted uniformly in all directions; its measure is the force exerted per unit area. In fluid dynamics we often use the terms of

i. static pressure,
ii. dynamic pressure and
iii. stagnation pressure.

Static pressure is what we normally call the pressure. The strict definition of static pressure is:

(a) the pressure that would exist at a point in a medium if no sound waves
were present

(b) the normal component of stress, the force per unit area, exerted across a surface moving with the fluid, especially across a surface which lies in the direction of the flow (McGraw-Hill) .

Dynamic pressure is the pressure increase that a moving fluid would have if it was brought to rest by isentropic flow against a pressure gradient (Bakke, Hjertager, 1985). The dynamic pressure can also be expressed by the flow velocity, u and density, p.

$$p_{\mathrm{Dyn}} = \frac{\rho \cdot u^2}{2} \qquad \text{Equation 2.1}$$

Stagnation pressure is the pressure that a moving fluid would have if it was brought to rest by isentropic flow against a pressure gradient (McGraw-Hill) .The stagnation pressure is the sum of the static and the dynamic pressures.

$$p_{\mathrm{Stag}} = p_{\mathrm{Stat}} + p_{\mathrm{Dyn}} \qquad \text{Equation 2.2}$$

2.2 Fire and Explosion

Gas explosion is a process where combustion of a premixed gas cloud, i.e. fuel-air or fuel oxidiser is causing rapid increase of pressure. Gas explosions can occur inside process equipment or pipes, in buildings or offshore modules, in open process areas or in unconfined areas. It is then common to include the events both before and after the gas explosion process.

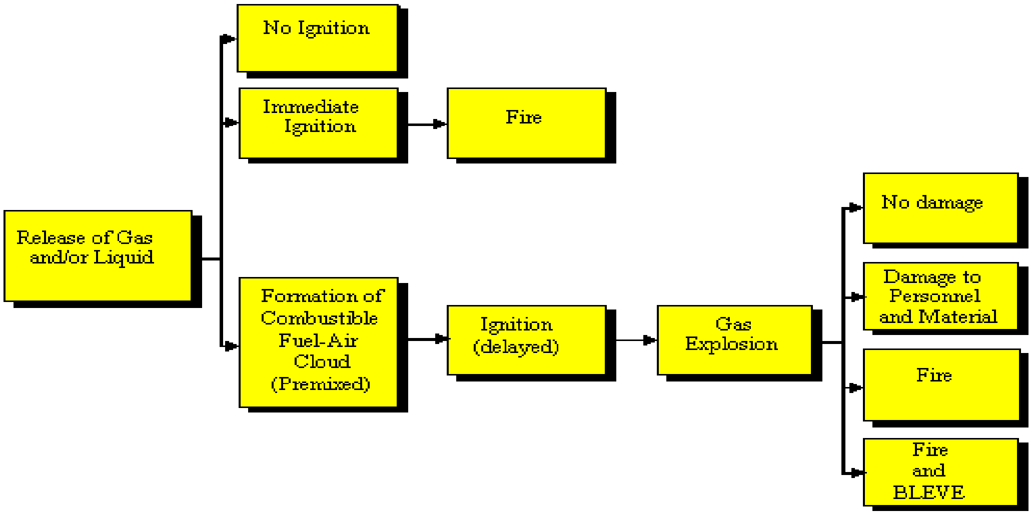


Figure 2.1 Events both before and after gas explosion process

Figure 2.1 shows what can happen if combustible gas or evaporating liquid is released accidentally 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 (i.e. before mixing with air or oxidiser has occurred) a fire will occur. 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 ranges from a few seconds to tens of minutes. The amount of fuel ranges from a few kilograms 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 caused by the gas explosion can damage personnel and material or it can lead to accidents such as fires and boiling liquid expanding vapor explosion (BLEVE) (domino effects) (Piccinini 2009). 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:

(i) deflagration
(ii) detonation

A deflagration is the combustion event where the flame propagation is slower than a speed of sound. Deflagration is a combustion that propagates through a gas or along the surface of an explosive at a rapid rate driven by the transfer of heat. A detonation is the combustion event where the flame propagation is faster than a speed of sound. Caused by the compression and heating of the gases following the passage of an intense pressure wave called a shock wave. The constant velocity is the order of 1800 m/s. In Standard Explosion Protection system deals on deflagration events as the propagation of a detonation is too quick for the respond time to the system (Bjerketvedt, 1997).

2.3 Flammability Limits

The flammability properties of natural gas are in considerable concern to workers who handle these flammable gas since understanding these properties helps make it possible to recognize and predict hazardous situation and to take proper steps to eliminate them (Wilbur,1966). Flammability limits, give the proportion of combustible gases in a mixture, between which limits this mixture is flammable. Gas mixtures consisting of combustible, oxidizing, and inert gases are only flammable under certain conditions (Yang Lizhong, 2001)

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).

a. Lower flammability Limit (LFL): The explosive limit of a gas or a vapor is the limiting concentration(in air) that is needed for the gas to ignite and explode. The lowest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source(arch, flame, heat). At concentration in air below the LFL there is not fuel to continue an explosion. Concentrations lower than LFL are "too lean" to burn. eg: Methane gas has a LFL of 4.4 % (at 138 °C) by volume, meaning 4.4 % of the total volume of the air consists of methane. At 20 °C the LFL is 5.1 % by volume.

b. Upper flammability Limit (UFL): Highest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source (arch, flame, heat). Concentration higher than UFL are "too rich" to burn. Also called upper explosive limit (UFL)

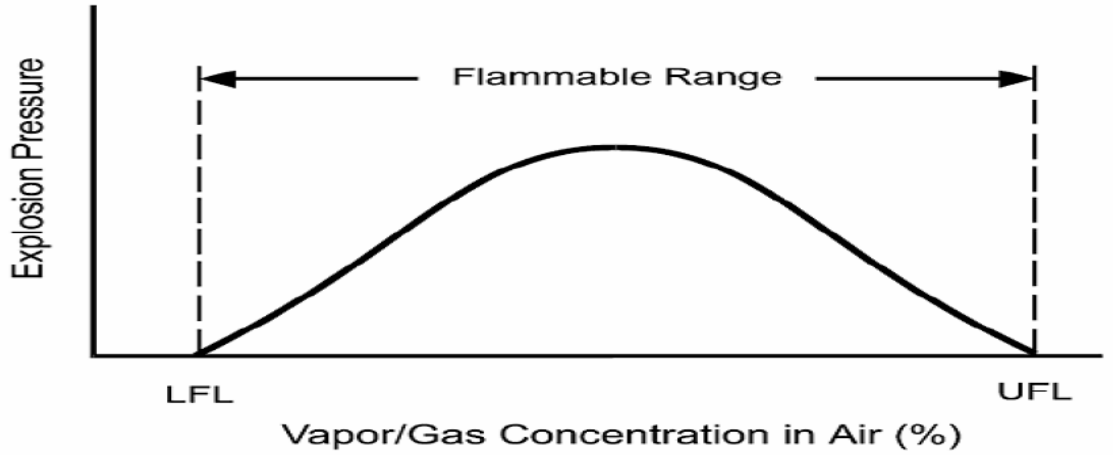


Figure 2.2 Schematic represents flammability limits

2.4 Ignition

To ignite a gas cloud requires an ignition source with sufficient strength the minimum ignition energy depends on fuel concentration and type fuel where the ignition energy is strong ,the gas cloud will be ignited when the edge of the cloud reached the ignition source. If the ignition source is weak, however the source may fail to ignite the cloud in the early phase of the dispersion process or ignite only a small part of cloud (Melvin Gersteina , William Stin 1973) .

2.5 Confined gas explosions

Confined gas explosions are explosions within process equipment, tanks, pipes, in culverts, closed rooms sewage system and in underground installations. For this kind of explosion is that the combustion process does not nee to be fast in order to cause serious pressure build up. Confined explosions are also called internal explosions (D.Bjerketvedt et al 1997).

2.6 Partly confined gas explosions

Occur when a fuel is accidentally released inside a building which is partly open. Typical cases are compressor rooms and offshore modules. The building will confine the explosion and the explosion pressure can only be relieved through the explosion vent areas, for example open areas in the walls or light relief walls that open quickly at low overpressure (Bjerketvedt et al 1997).

2.7 Unconfined gas explosions

The term unconfined was used to describe explosions in open areas such as process plants. Large scale tests have demonstrated that a truly unconfined, unobstructed gas cloud ignited by a weak ignition source will only produce small overpressures while burning (flash fire).. In a process plant there are local areas which are partly confined and obstructed. In case of a deflagration it is these areas that are causing high explosion pressures. However if an unconfined cloud detonates the explosion pressure will be very high, in the order of 20 bar and in principle independent of confinement and obstructions. (Bjerketvedt et al 1997).

CHAPTER 3

METHODOLOGY

3.1 Experimental Apparatus

The explosion severity parameters Pmax, maximum pressure, and (dP/dt)max, maximum rate of pressure rise, have been determined in a 20 L Sphere shown in Fig. 3.1 (Kühner AG). The test chamber is a hollow sphere made of stainless steel. A cooling water jacket dissipates the heat of the explosion. During a test, the dust is dispersed into the sphere from a pressurized storage chamber via the outlet valve and a disperser.

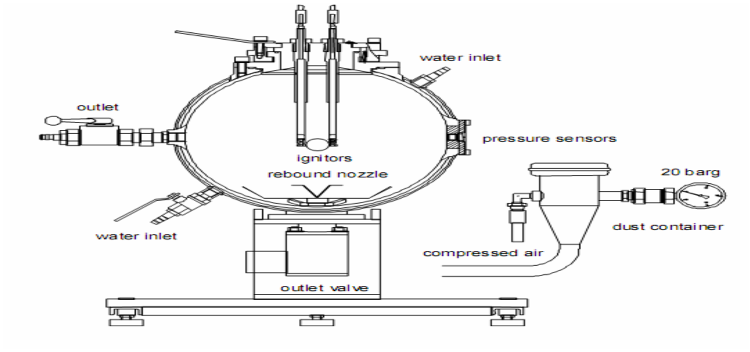


Figure 3.1 The 20 L Sphere (from Kühner manual)

The ignition source is located in the center of the sphere. On the measuring flange two " Kistler" piezoelectric pressure sensor's are installed. The second flange can be used for additional measuring elements or for installation of a sight glass

Tests have been performed with two pyrotechnic ignitors of 10 J each as ignition source. The ignition delay, i.e. the time between the onset of explosion and the activation of the ignition of the natural gas/air mixture, has been set for testing. The explosion pressure is recorded as a function of time using piezoelectric pressure sensors (Figure 3.2). The pressure is then varied over a 1-0.8 bars range. This apparatus also allows the determination of minimum explosive concentration, below which explosion is not possible.

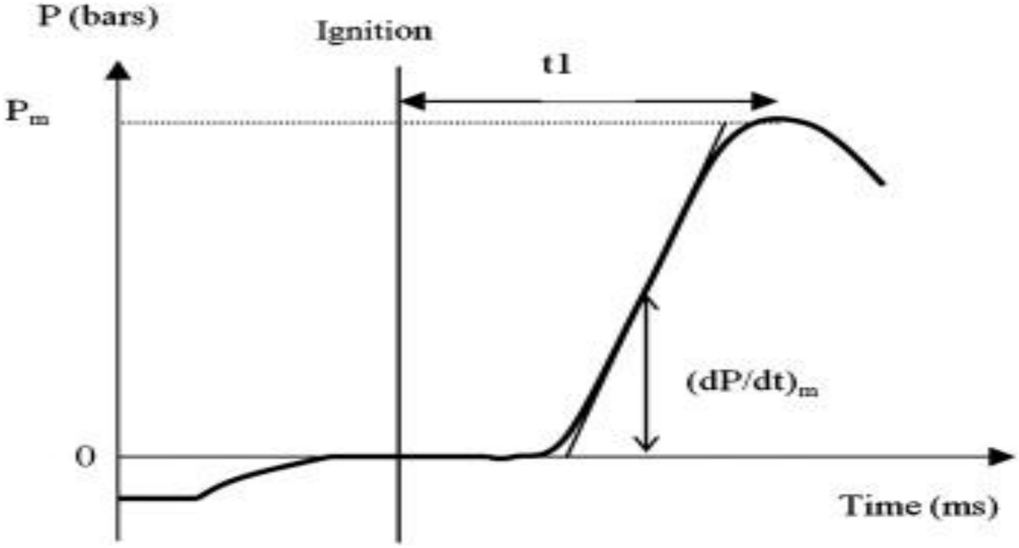


Figure 3.2 Schematic representation of the pressure evolution during the pressure explosion.

For cleaning the sphere can be open on top by turning the bayonet ring. The diameter of the " hand hole" is 94 mm. A large opening of 140 mm can be obtained by unscrewing the top flange. A safety switch controls the correct closing position of the bayonet ring.

3.1.2 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-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.

3.2 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.