EFFECT PRESSURE ON THE FLAMMABILITY LIMITS OF ACETYLENE

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ABSTRACT

Flammability limits were one of the main factors that commonly considered in fuel properties for applications in gases industry. The objective of this study were to determine affect of atmospheric pressure on flammability limits of acetylene and also to determine flammability limits range of acetylene when manipulated pressure (below 1 atm). This study was very important due to pressure was one of the parameter that affect flammability limits. These experiments were performed in 20 L closed explosion vessel. Materials used in this study were pure acetylene, air and 10 J igniter. The igniters were ignited mixtures by spark permanent wire at center of the vessel. Explosion pressure data and graph were analyzed to determine the flammability limit ranges of acetylene. Major finding in this study was upper flammability limit was increased with increased of pressure without significant changes in lower flammability limits. Significance from this study was it can determine the suitable condition and flammable range to handle acetylene. Thus, the risk of incident in industry can possibly be reduced. As a conclusion, it was proven that the pressure was one of the parameter that will give effect to flammability limits of fuel.

ABSTRAK

Had kemudahbakaran adalah salah satu faktor utama yang di ambil kira dalam sifat-sifat bahan api untuk kegunaan dan aplikasi dalam industri gas. Objektif kajian ini dijalankan adalah untuk menentukan kesan tekanan atmosfera pada had kemudahbakaran acetylene dan juga untuk menentukan julat had kemudahbakaran acetyelene apabila dimanipulasikan pada tekanan (dibawah 1 atm). Kajian ini adalah sangat penting kerana tekanan adalah salah satu parameter yang amat memberi kesan kepada had terbakar. Eksperimen ini telah dijalankan di dalam 20 L bekas letupan yang tertutup. Bahan-bahan yang digunakan di dalam kajian ini adalah seperti alat penyala,acetylene, udara/oksigen dan 10J alat penyala. Alat penyala akan menyalakan campuran gas oleh dawai bunga api yang terletak di tengah-tengah bekas letupan. Data dan graf tekanan letupan akan dianalisis untuk menentukan julat had kemudahbakaran-acetylene. Kepentingan utama dalam kajian ini adalah had kemudahbakaran tinggi akan meningkat dengan peningkatan tekanan tanpa perubahan ketara dalam had terbakar rendah. Kepentingan daripada kajian ini ialah ia boleh menentukan keadaan yang sesuai dan had kemudahbakaran untuk operasi acetylene. Oleh itu, risiko kejadian yang tidak di ingini dalam industri berkemungkinan boleh dikurangkan. Kesimpulan dari eksperimen ini ialah, ia terbukti bahawa tekanan adalah salah satu parameter yang memberi kesan kepada had terbakar bahan api.

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LIST OF SYMBOLS

C_2H_2	Acetylene
LEL_i	Lower Explosive Limit of i-th Component
Pm	Corrected Explosion Overpressure
P	Pressure
t_1	Duration Of Combustion
UEL_i	Upper Explosive Limit of i-th Component
y_i	Mole (Volume) Fraction of i-th Component
$<$	Lower

LIST OF ABBREVIATIONS

BLEVE	Boiling Liquid Expanding Vapor Explosion
FLACS	Flame Acceleration Simulation
LFL	Lower Flammability Limits
UFL	Upper Flammability Limits
VS	Versus

CHAPTER 1

INTRODUCTION

1.0 INTRODUCTION

Combustion is a rapid oxidation of fuel accompanied by release of heat and light with formation of combustion product (Mohamad Noor, 2011). That is very dangerous if combustion of fuel in confined burner system is not controlled well. The explosion may occur and causing rapid increase in the pressure. However, combustion of fuel only occurs in the flammable range or flammability limit. Thus, it is very important to know the properties of fuel for safety handling, storage and operation.

Acetylene is well known in the industrial of gases due to its properties. It is one of the unsaturated hydrocarbon compounds with molecular formula C_2H_2. It is normally in compressed gases form at standard pressure and room temperature. However, for safety aspects it is stored as liquid form by dissolving with acetone solvent. Acetylene is one of the very highly flammable compounds under certain pressure. Moreover, it can spontaneously combustible in air at pressure exceed 2 bar (Boc Gases, 1995).

There are a lot uses of acetylene especially in an industrial gases. It commonly uses as chemical intermediate in closed system. Apart from that, it also use for other process such as a hydrocarbon compound for fuel, carburization of steel and others. Approximately 80 % of the annual acetylene production is used for chemical syntheses and the remaining 20 % is principally used for oxyacetylene cutting, heat treating, and welding (Air Product And Chemical, 1994).

There are two common process of production acetylene in industry. Firstly, is chemical reaction of calcium carbide with water resulting in acetylene (C_2H_2). Secondly, reaction between lime sludge and hydrocarbon molecules (crude oil) by cracking process as done in the petro-chemical industry. Acetylene has no harmful effect in critical exposure, only a simple anesthetic effect will be occurred (American Chemistry Council Acetylene Panel, 2003).

Acetylene normally known as highly flammable gases, which mean it spontaneously can ignite in air under certain condition. Acetylene has flammability limits in range around of 2.3-82 % volume in air. Flammability limits is one of the very important physical properties for a fuel compounds. Flammability limit also can be known as explosion limits (De Smedt et al., 1999).

Explosive limits means volume of concentration in air that an explosion can occur in present of sufficient an ignition source and air. There are two types of flammability limits that are upper flammable limit (UFL) and lower flammability limit (LFL). The parameter that may influence the flammability limits that are the apparatus containing the gas, the physical condition of the gas mixture and the operator (G. De Smedt., 1999).

However, flammable ranges more affected by parameter such as temperature, pressure and inert gases. Flammable gases very depended on that parameter which significant change of the parameter will change the flammable ranges of the material. (Kasmani, 2011). Thus, few studies have done to see the effect of parameter that may influence changes in flammable ranges. However, for this experiment, parameter of pressure was studied to determine the effect towards flammable ranges.

1.1 PROBLEM STATEMENT

Nowadays, people are more concern towards the safety aspects of material rather than the advantages. Thus, it is very important to understand their behavior and dangerous properties. Different material will give different physical and chemical properties. In addition, the flammable limit/explosive limit also different for each material. Knowing flammable limit is very important for safe handling of the material. A fire or an explosion might occur spontaneously if the condition exceeds their limit. There are a lot of condition that will affect the flammable limit such as temperature, pressure concentration of fuel and others (Harry, 2003).

Acetylene is one of the important chemical compounds in the gases industry. However, the problem encountered when handling with acetylene is it highly flammable. It is ignitable at 14.7 psia (101 kpa) when in a mixture of 13 percent or less by volume with air (Oregon Fire Code, 2007). Possibility incident to occur when handling this compound is very high. Flammability limits normally dependence on the parameter such as inert, pressure and temperature. UFL increases significantly as the initial pressure are increased (Po-Jiun et al., 2004). As a result, it can widen the flammable range of acetylene.

This shows that, at high pressure the range for combustion or explosion to occur is high too. Handling acetylene under controlled can lead to boiling liquid expanding vapor explosion (BLEVE) incident. Incident due to the explosion will give very big impact towards the environment and society. Incidents in plants can often be traced to an insufficient knowledge of the hazardous properties of combustible or flammable substances (Po-Jiun et al., 2004).

1.2 OBJECTIVES OF STUDY

This study was generally focusing on the flammability limits of acetylene since acetylene was one of the flammable gases that mostly use in industry gases field. There were two objectives of this study:

i. To determine effect of atmospheric pressure on flammability limits ranges of acetylene.

ii. To determine flammability limits range of acetylene when manipulated pressure (below 1 atm) to UFL and LFL.

1.3 SCOPE OF STUDY

This study was done using spherical equipment 20 L closed vessel, with a constant volume by using a conventional spark ignition system at a temperature 20 ºC. Generally, this study was done to determine the effect of pressure on flammability limits of acetylene. Thus, to achieve these objectives there were a few scopes that can be identified.

i. Study the effect pressure at vacuum pressure condition which at 0.97 bar and 1 bar.
ii. Determine the ranges of flammability limits (upper limit and lower limit) from the plotted graph of pressure maximum for each concentration of acetylene

1.4 RATIONALE AND SIGNIFICANCE OF STUDY

The rationale from these studies was to ensure the safety in handling of acetylene which related to the pressure. Significance by knowing the effect of pressure, it can determine the suitable condition and flammability limits for the operating of acetylene. As we known, pressure was one of the major factors that may give effect to the flammability limits. Thus, for highly flammable material there was very important to know their dangerous properties. Flammability limits was very important in the explosion field. As a result, by knowing the flammability limits range the risk of incident in industry can possibly be reduced.

CHAPTER 2

LITERATURE REVIEW

2.1 FIRE

Fire is a rapid oxidation reaction releasing smoke, heat, and light (Kasmani 2011.). For fire to successfully occur, the three main components must completely exist that is fuel, ignition source and air.

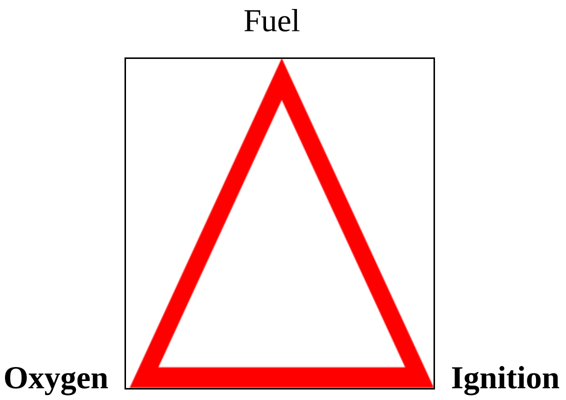

Figure 2.1: Concept of explosion-explosion triangle

Source: dag bjerketvedt, 1992

Based on Figure 2.1, air is the oxidizer which will react with the fuel to convert into combustion product that is carbon dioxide and water. While, fuel mainly consists of solid, liquid or gases form. The ignition source is a spark, lightning, static electricity and others. However, basic requirements for successful combustion to occur are correct amount of fuel and air, molecular mix of fuel and air and others.

Without one of this component, the fire or combustion may not successfully occur. Combustion will continue until the combustion material is removed or consumed, the oxidizing agent concentration is lowered below that essential and the combustible material is cooled below its ignition temperature.

2.2 FLAMMABILITY LIMITS

Table 2.1: Upper and Lower Flammability Limit

Fuel Gas	(LFL/LEL) (%)	(UEL/UFL) (%)
Acetaldehyde	4	60
Acetone	2.6	12.8
Acetylene	2.5	81
Ammonia	15	28
Arsine	5.1	78
Benzene	1.35	6.65
n-Butane	1.86	8.41
iso-Butane	1.80	8.44
iso-Butene	1.8	9.0
Butylene	1.98	9.65

Note : The limits indicated are for component and air at $20^{o}C$ and atmospheric pressure.

Table 2.1 show the upper and lower flammability limit of some material. Each material has a different value of flammable ranges. From the Table 2.1, acetylene has the wide ranges from the others material that is from 2.5 vol % until 81 vol %. This means that, acetylene is very flammable gases at standard condition. The ranges for combustion to occur are very wide within the flammable ranges. Thus, acetylene must be handling properly to prevent any explosion and incident occur.

Flammability limits is very important in the explosion field. Therefore, it is one of the important properties of fuel that is needed to consider when handling in the industry. It has been found experimentally that there are lower (lean) and upper (rich) values of the flammable gas concentration beyond which a flame will not propagate (Michael, 1965). Upper limits are mainly considered in the hydrocarbon storage vessel while lower limit is more concern in explosive safety. The flammability limits may depend on specific heats of gas, chemical nature of gas, ignition temperature and others. The wide flammable range of hydrogen tells us that it is easy to get a flammable cloud of hydrogen in air.

Definition of flammability limits is mixtures of flammable gases and air will burn only when they are mixed in certain concentration. It is dividing in two that is lower flammability limit (LFL) and upper flammability limit (LFL). LFL means the fuel concentration becomes too lean (sufficient in oxygen). Whereas,UFL the fuel concentration is too rich (deficient in oxygen). LFL is the smallest quantity of combustible when mixed with an air (or other oxidant) which will support a self propagating flame. UFL is the highest quantity of combustible when mixed with air (or other oxidant) which will support a self propagating flame (Md Kasmani 2011).

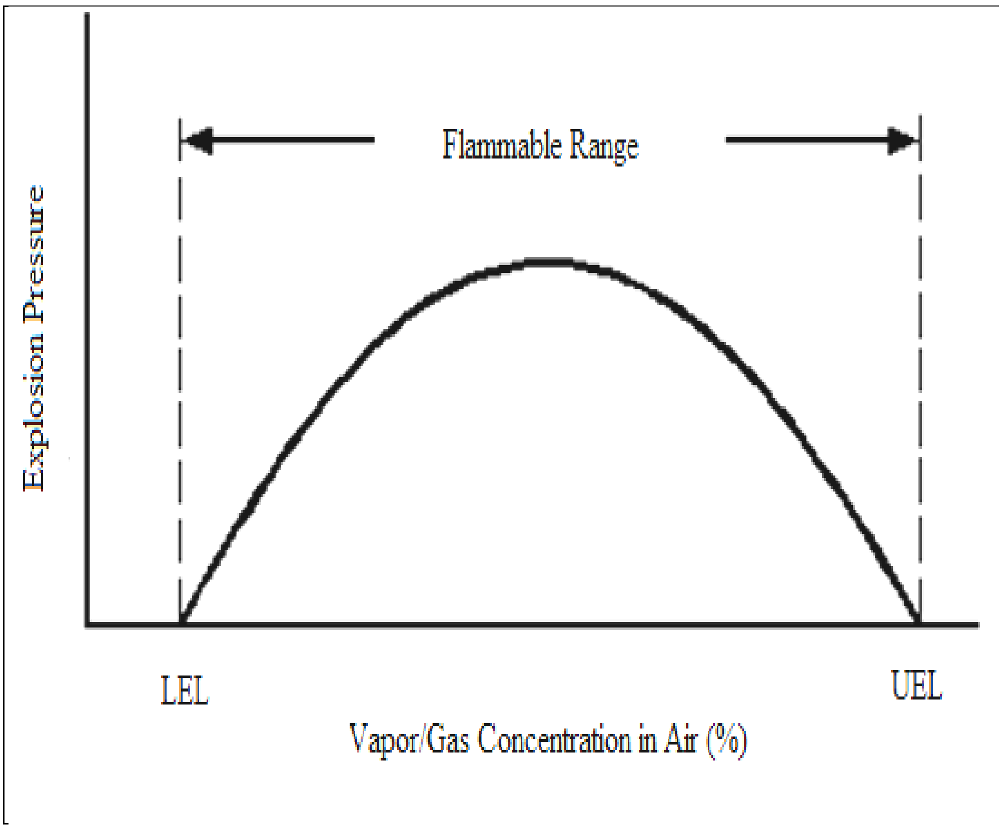

Figure 2.3 : Schematic represent flammability limits

Source:Dag Bjerketvedt, 1992

Figure 2.3 shows that, below the LFL the mixtures will not ignite and above the upper flammability limit the mixtures also will not ignite. Therefore, fuel will burn in a certain limits in exits of ignition sources or in increasing in temperature. The flammability limits are influence mostly by temperature, inert and pressure and are calculated experimentally. Flammable ranges will be widening in increasing of temperature. Changes in initial pressure for hydrocarbon will not change LFL significantly, but the UFL will increase (Marc, 2010)

Flammability limits will be influence by the temperature. The high temperature will widen the flammable range significantly (Takahashi, 2011). However, when the temperature is lower and the pressure is reducing enough, the mixture will be highly flammable. Figure 2.2 shows the relation between the temperature and the flammability limits ranges. By knowing the flammability limits ranges, the air supply also can be determining either in excess or lean air. Therefore, by knowing all these properties the successful combustion can be achieved and at same time can prevent the explosion from occur.

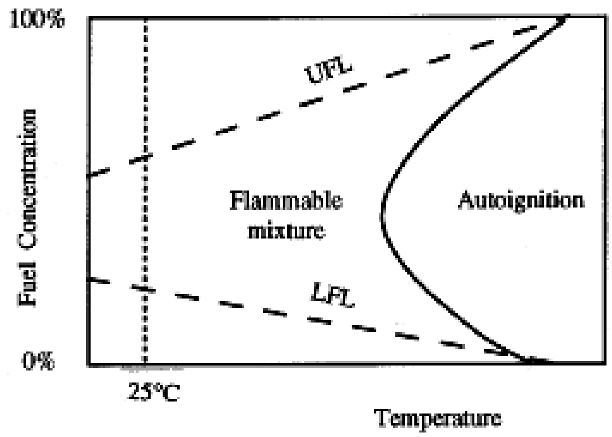

Figure 2.2: The effect of temperature on LFL and UFL.

Source: Wingerden, 1998

2.3 VACUUM PRESSURE

Vacuum pressure is a space that essentially empty and a gaseous pressure is below atmospheric pressure (Taftan, 1998). Vacuum pressure is a pressure between 0.0 until 14.7 psia (0.0 – 1.0 bar). The lower gas pressure means higher quality vacuum. Moreover, most of the equipment in the laboratory was setting at 1 bar absolutely and the operating pressure cannot be manipulated more than 1 bar. Therefore, in this experiment the manipulated pressure is at 0.97 bar and 1 bar.

Most of the gases industry processes operate within the confined space or equipment such as closed vessel, pipe, burner system and others. These confined spaces have higher possibility for explosion or combustion to occur. These due to confined equipment have little or no relief of pressure for explosion pressure. In this case, the relief process is often too slow to relieve the pressure fast enough, and the vessel may behave like a fully closed vessel with regard to pressure build-up (Bakke, 1998).

The pressure build-up will mainly depend on type and concentration of fuel, the initial pressure, and the filling ratio in the vessel, the burning rate, the venting and the oxidizer (Wingerden, 1998). In a confined space such as pipe, the pressure generated during explosion is having the possibility to propagate away from combustion front as shown in figure 2.4.

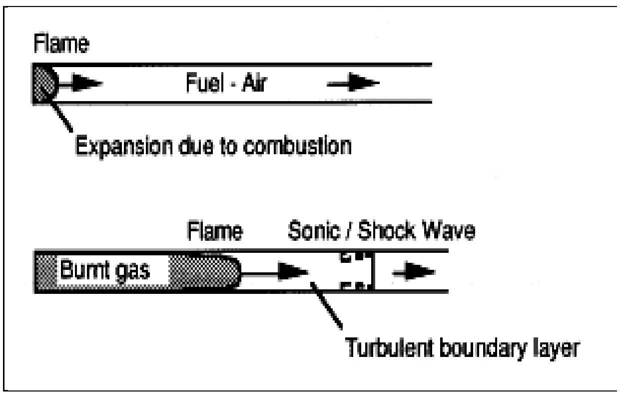

Figure 2.4: Flame acceleration in a pipe, channel or tunnel.

Source: Wingerden, 1998

2.4 FLAMMABILITY LIMITS DEPENDENCE ON PRESSURE

Flammability limits mostly is affected by initial pressure. Actually, normal variations in atmospheric pressure do not have any appreciable effect on flammability limits. A decrease in pressure below atmospheric usually narrows the flammable range and when the pressure is reduced low enough, a flame or an explosion can no longer propagated throughout the mixture (Riegel et al.,2007). Whereas, increase the pressure will widen the flammable range especially UFL.

By increasing the initial pressure, the energy content, i.e. heat of combustion, per unit volume will increase. Initial pressure has little effect on the LEL except at very low pressure (<50 mmHg absolute) where flames do not propagate, while UEL increases significantly as the initial pressure is increased, broadening the flammability range From Figure 2.5, there are nearly linear relation between the explosion pressure and the initial pressure. Increasing in the initial pressure will increase the explosion pressure of the fuel (Bjerketvedt, 1998).

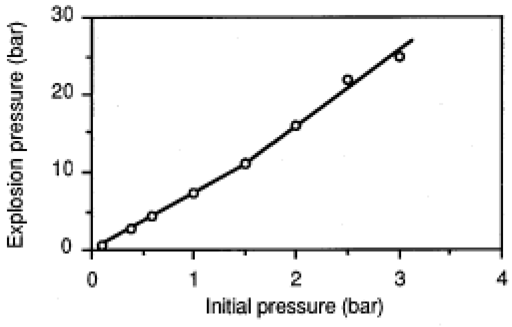

Figure 2.5: Explosion pressure versus initial pressure for Stoichiometric propane-air in a 7 L vessel

Source: Bjerketvedt, 1998

There are some an empirical expression for calculating the flammability limits for vapors as a function of pressure and also Le Chatelier equation (1981) and (Crowl and Louvar, 1990). These equations can predict the flammability limit and is nearly too real flammability limits. Moreover, by these equations (1)-(3) the error of experimental result and the theoretical can be calculated. The equations (1) - (3) are shown below:

$$UEL_P = UEL + 20.6(\log P + 1) \quad (1)$$

$$LEL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y_i}{LEL_i}} \quad (2)$$

$$UEL_{mix} = \frac{1}{\sum_{i=1}^{n} \frac{y_i}{UEL_i}} \quad (3)$$

Where

P = Pressure (MPa)

UFL = Upper Flammability Limits (vol %)

y_i = Mole (or Volume) fraction of i-th component

LEL_i = Lower Explosion Limit of i-th component

UEL_i = Upper Explosion Limit of i-th component

2.5 EXPLOSION PRESSURE

Explosive limits are same to the flammability limits when the combustion of the fuel is not controlled within the confines of the burner system. Explosion requires the simultaneous presence of a flammable mixture of gas and oxygen (air) and a source of ignition in a confined space (Flammable Gas Safety Code, 1996.). Eplosion can cause rapid increase in pressure and lead to rupturing of the property due to increase in internal pressure. The explosion pressure is depend on how fast flame propagate and how pressure can expand away.

There are two types' modes of flame propagation that is deflagration and detonation. A deflagration propagates at subsonic speed relative to the unburned gas, typical flame speeds (i.e. relative to a stationary observer) are from the order of 1 to 1000 m/s while detonation is a supersonic (relative to the speed of sound in the unburned gas ahead of the wave) combustion wave (Bjerketvedt et al., 1998).

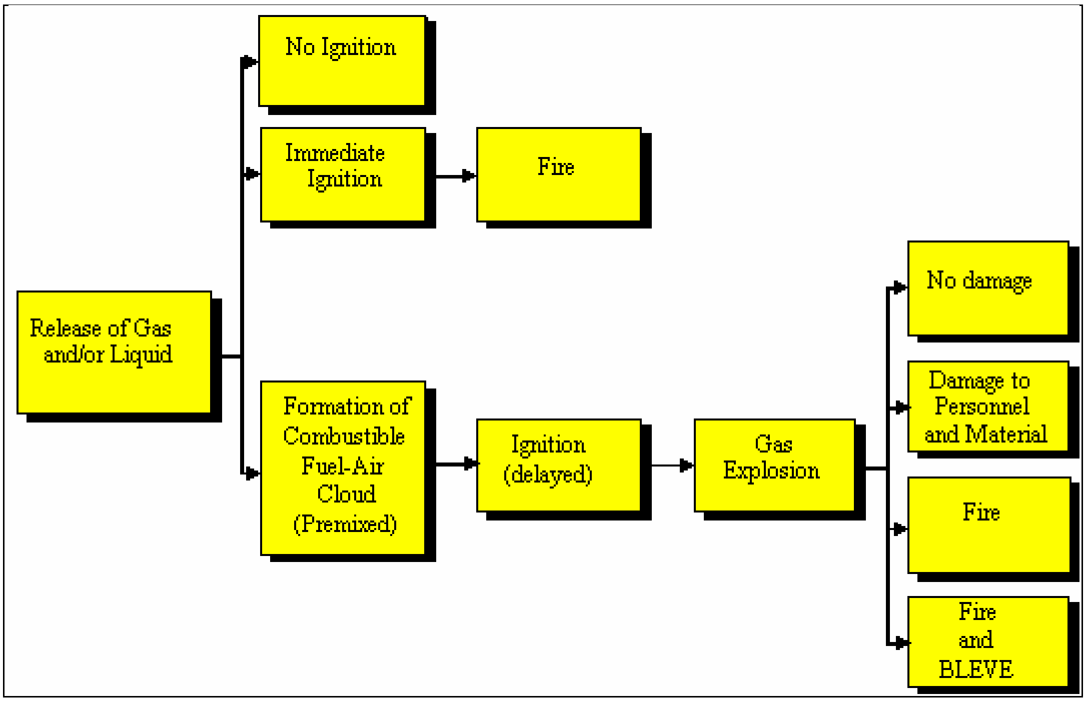

Figure 2.6: Events both before and after gas explosion process

Source: (Ishak, 2008)

Figure 2.6 are the events before and after gas explosion process. In case of leaking, the gas or liquid will be released to atmosphere. This can form hazardous explosion atmosphere and if the concentration is not within the flammable ranges or no ignition source, there are no explosion or fire. However, if the ignition source is available, fire can occur. The danger situation will occur if combustible fuel and air cloud formed and ignite. This lead to gas explosion which can give impact to damage of property, material, formation of fire and BLEVE event (Ishak, 2008).

In a confined situation, such as a closed vessel, a high flame velocity is not a requirement for generation of pressure. In a closed vessel there is no or very little relief (i.e. venting) of the explosion pressure and therefore even a slow combustion process will generate pressure (Bakke et al., 1998). Therefore, it is very dangerous if the combustion within the confined vessel is not controlled properly. Gas explosion is depending on the type of fuel and oxidizer, temperature, pressure, present inert gas and oxidant (Ishak, 2008).

CHAPTER 3

METHODOLOGY

3.1 EXPERIMENTAL APPARATUS

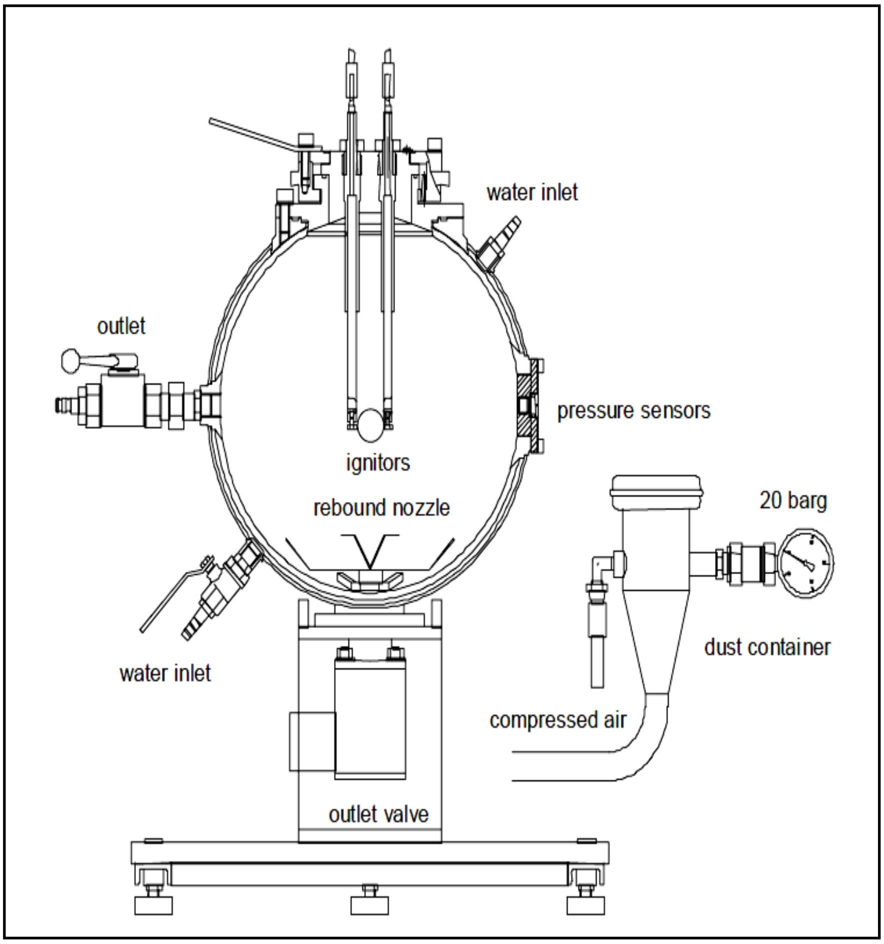

Figure 3.1: Schematic diagrams of 20-L-Explosion Vessel

Source: Siwek 2006