CERTIFICATION OF APPROVAL

High Seismic Energy

by

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD TAOFIQ BIN SALEHUDIN

ABSTRACT

A seismic source generates controlled seismic energy that is used in both reflection and refraction seismic surveys. A seismic source can be simple, such as dynamite, or it can use more sophisticated technology, such as a specialized air gun. Seismic sources can provide single pulses or continuous pulses of energy that generates seismic waves, which travel through a medium such as water or layers of rocks. Some of the waves then reflect and refract to receivers, such as geophones or hydrophones. Dynamite has been used since 1950's in seismic survey. After mid 1960's a number of non-dynamite sources were in various stage of development. For example development of air gun in 1966 at Texas and its have been widely used in the industries nowadays. But, various researches also been done to overcome the disadvantage of dynamite such as its insolubility in water and its liquid form and high gravity render makes it's very unfavourable in submarine operation. The purpose of this report is to represent an introduction about the project and state the problem along with the objectives and methodology used to solve the problem. The first chapter makes brief introduction to the project. The report continues with the second chapter, which is literature review. Then it is followed by methodology. Conclusion part summarizes the report content. The objective of the present research is to develop chemical explosion that can be used as seismic source which are safe to use and environmental friendly. Understanding on chemical explosion is crucial so that all safety precaution can be taken during all the experiment. Two different types of fuel will be used which are acetylene gas and gunpowder.

ACKNOWLEDGEMENT

First and foremost, I would like to praise God the Almighty for His guidance. Although difficulties occurred, His guidance has given me the chance to still accomplish a challenging Final Year Project (FYP) successfully.

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Apart from that, I would like to thank, Dr. Mohannad El- Harbawi, for his help and guidance in safety evaluation within this project. Besides that, special thanks to post technicians, and my other friends for helping me with the experiments.

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ABBREVIATIONS AND NOMENCLATURES

VCE	Vapour Cloud Explosion
BLEVE	Boiling Liquid Expansion Vapour Explosion
LOC	Limiting Oxygen Concentration
UEL	Upper Explosion Limit
LEL	Lower Explosion Limit
CPQRA	Chemical Process Quantitative Risk Analysis

CHAPTER 1: INTRODUCTION

1.1 Background of Study

High seismic energy can be produce by explosion. Explosion can produce high impulse pressure which produces seismic waves. Several definitions for explosion. AIChE/CCPS (1994) defines an explosion as "a release of energy that causes blast." A blast is subsequently defined as "a transient change in the gas density, pressure, and velocity of the air surrounding an explosion point." Another definition from (Crowl and Louvar 1990) explosion is rapid expansion of gases resulting in a rapidly moving pressure on shock wave. An explosion can be thought of as rapid release of a high-pressure gas into the environment. This release must be rapid enough that the energy dissipated as a pressure or shock wave. Explosions can arise from strictly physical phenomena such as catastrophic rupture of a pressurize gas container or chemical reaction such as combustion of flammable gas in air. These latter reactions can occur within buildings or vessels or in the open in potentially congested areas (CPQRA Guideline 1989).

1.2 Problem Statement

Various parameters need to consider so that an explosion can be produce. In explosion, there are two type of reaction of explosion; detonation and deflagration. Detonation reaction front moves at a speed of sound. A shock front is found a short distance in front of the reaction front. The detonation produces a shock front, with an abrupt pressure rise, a maximum pressure, and total duration of typically less than 1 ms. (Daniel A. Crowl/ Joseph F. Louvar 2002). For deflagration reaction the energy from reaction is transferred to unreacted mixture by heat conduction and molecular diffusion (Daniel A. Crowl/ Joseph F. Louvar 2002) This process relatively slow, causing reaction front to propagate at a speed less than sonic velocity. In the deflagration mode the flame speed ranges from a few ms-1 up to 500-1000ms-1. The explosion pressure will range from a few mbar to several bar, depending on the flame speed. Another parameter needs to consider including types of casing, type of fuel, fuel concentration and ignition energy.

1.3 Objectives

The objectives of this project are to develop chemical explosion that can be used as seismic source which are safe to use and environmental friendly and to do experiments to evaluate seismic energy produce by the explosion by using geophones. Evaluation of the explosion will be cover on pressure produce by the explosion and impact on human by using safety analysis method.

1.4 Scope of Study

The scope of this project consists of research, experiments, analysis and improvement. The research is important to increase the understanding of the theory and concept of explosion and seismic energy. Experiments with selected fuel and explosion produce will be evaluated using geophones and data will be captured by the seismograph. Furthermore, analysis of the experiment results and improvement of the design are included in the scope of this project.

CHAPTER 2: LITERATURE REVIEW AND THEORY

2.1 Seismic Operation

The seismic survey is one form of geophysical survey that aims at measuring the earth's (geo-) properties by means of physical (-physics) principles such as magnetic, electric, gravitational, thermal, and elastic theories. It is based on the theory of elasticity and therefore tries to deduce elastic properties of materials by measuring their response to elastic disturbances called seismic (or elastic) waves [7].

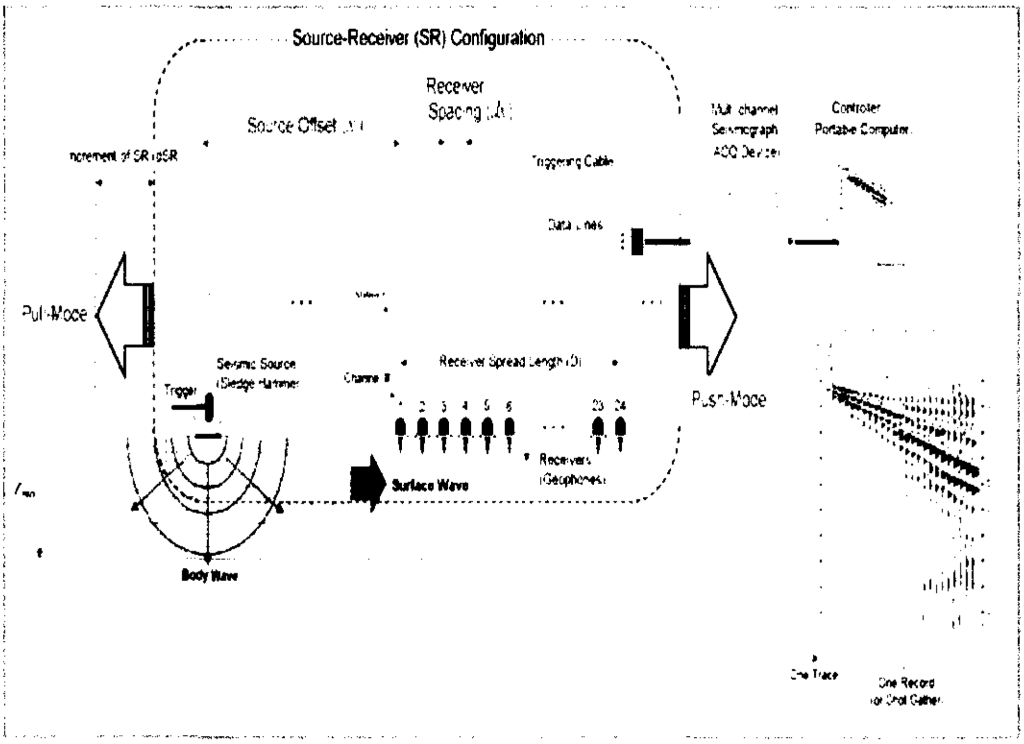


Figure 2.1: Schematic of overall field setup for a seismic survey

A seismic source-such as sledgehammer or an explosion -is used to generate seismic waves, sensed by receivers deployed along a preset geometry (called receiver array), and then recorded by a digital device called seismograph. Based on a typical propagation mechanism used in a seismic survey, seismic waves are grouped primarily into direct, reflected, refracted, and surface waves

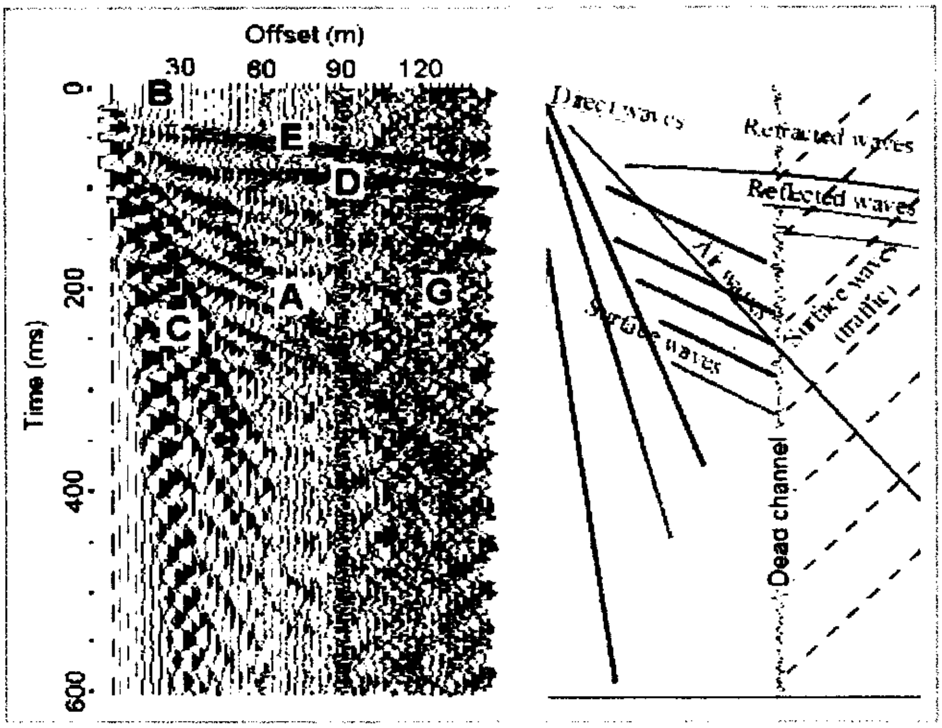


Figure 2.2: Example of seismograph

2.2 Seismic Waves

Seismic waves can be categorized into two major groups: body and surface waves (Fig. 2.9). Body waves propagate through the entire body, whereas surface waves travel along the surface of the medium. Seismic body waves include two different types according to the relative direction of disturbance with respect to direction of propagation: P- and S-waves (Fig. 2.10). Seismic surface waves also include several different types, the Rayleigh wave being one (Fig. 2.10). Velocities of P- and S-waves (Vp and Vs) are determined by several aspects of a material called elastic constants (or moduli). If a material's shear modulus vanishes as with fluid, then only P-waves, not S-wave, can exist and this special type of elastic wave is called acoustic waves. Velocities of surface waves are governed mainly by shear modulus of materials. Seismic waves used for the survey can be generated in two ways: actively or passively. They can be generated actively by using an impact source like a sledgehammer or passively by natural (for example, tidal motion and thunder) and cultural (for example, traffic) activities. A seismic survey of the former type is called the active method, whereas the latter is called the passive method. Most seismic surveys historically implemented have been the active type.

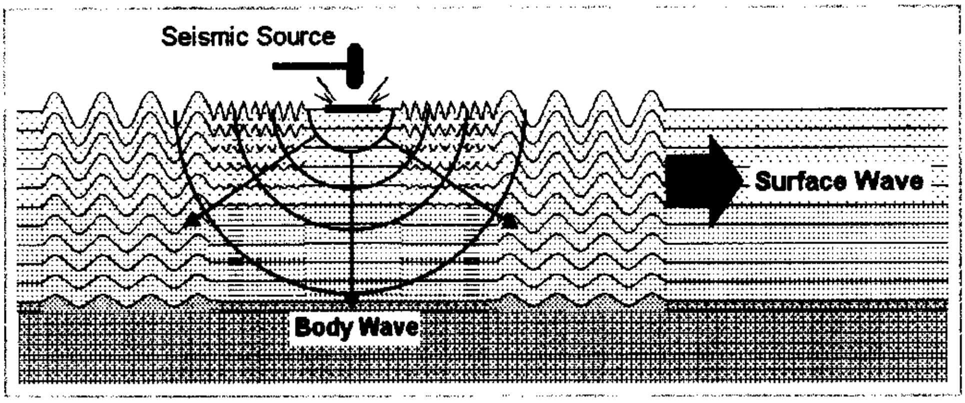


Figure 2.3: Two major group of seismic waves; body waves and surface waves.

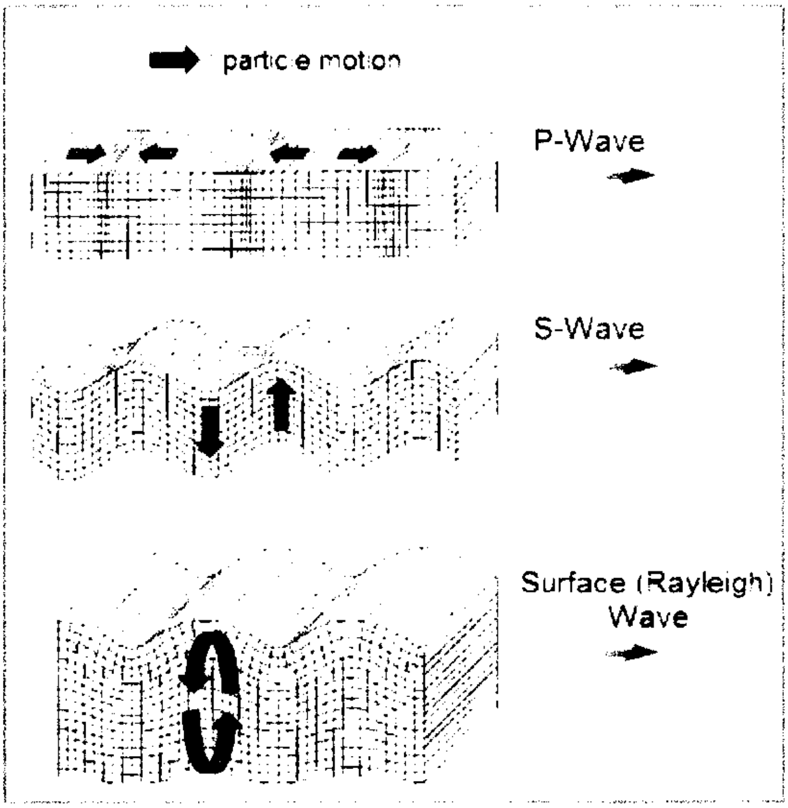


Figure 2.4: Two different types of body waves and one surface wave.

2.3 Type of Explosion

2.3.1 Dust Explosion

Dust explosion initiated by the rapid combustion of flammable particulates suspended in air. Any solid material that can burn in air will do so with a violence and speed that increases with the degree of sub-division of the material [1] Higher the degree of sub-division (in other words smaller the particle size) more rapid and explosive the burning, till a limiting stage is reached when particles too fine in size tend to lump together. If the ignited dust cloud is unconfined, it would only cause a flash fire. But if the ignited dust cloud is confined, even partially, the heat of combustion may result in rapid development of pressure, with flame propagation across the dust cloud and the evolution of large quantities of heat and reaction products. The furious pace of these events results in an explosion. Besides the particle size, the violence of such an explosion depends on the rate of energy release due to combustion relative to the degree of confinement and heat losses. In exceptional situations a destructive explosion can occur even in an unconfined dust cloud if the reactions caused by combustion are so fast that pressure builds up in the dust cloud faster than it can be dissipated at the edge of the cloud [2]. The oxygen required for combustion is mostly supplied by air. The condition necessary for a dust explosion is a simultaneous presence of dust cloud of appropriate concentration in air that will support combustion throughout the process and a suitable ignition source. In case of dusts made up of volatile substances, the explosion may occur in three steps which may follow each other in very quick succession—

i) Devolatization (where volatiles are let off by the particle or the particles are vaporized),
ii) Gas phase mixing of fuel (released by dusts) and oxidant (usually air)
iii) Gas phase combustion.

Basic equations for an explosion are;

$$\text{Fuel} + \text{oxygen} \rightarrow \text{oxide} + \text{heat} \qquad (2.1)$$

2.3.2 VCE (vapor cloud explosion) or Gas explosion

Gas explosion is a process where combustion of a premixed gas cloud, example; fuel-air or fuel-oxidizer, is causing a rapid increase of pressure. When explosion occurs in gas phase, the energy caused the gas to expand rapidly, forcing back the surrounding gas and initiating a pressure wave that moves rapidly outward from the blast source. [**Daniel A. Crowl/ Joseph F. Louvar 2002**].

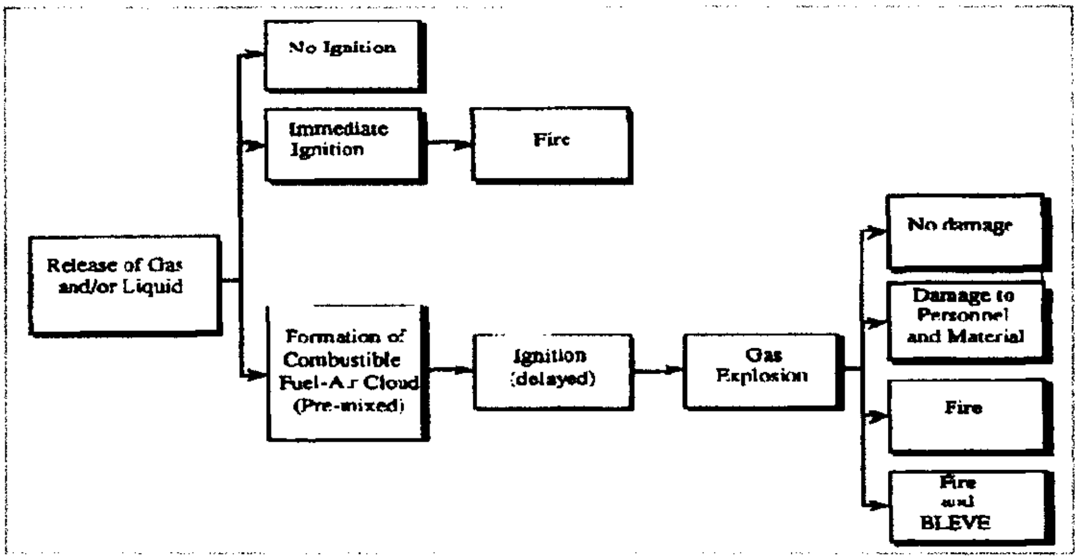


Figure 2.5: Tree diagram for an explosion to occur based on safety and hazard analysis. (Gas Explosion Handbook)

A vapor cloud explosion may be simply defined as an explosion occurring outdoors, producing a damaging overpressure (Factory Mutual Research Corporation, 1990). It begins with the release of a large quantity of flammable vaporizing liquid or gas from a storage tank, process or transport vessel, or pipeline. There are several features need to be present for a vapor cloud explosion with damaging overpressure to occur:

1) First, the released material must be flammable and at suitable conditions of pressure or temperature. Such materials include liquefied gases under pressure (e.g., propane, butane); ordinary flammable liquids, particularly at high temperatures and/ or pressures (e.g., cyclohexane, naphtha); and nonliquefied flammable gases (e.g., methane, ethylene, acetylene).

2) Second, a cloud of sufficient size must form prior to ignition (dispersion phase). Should ignition occur instantly, a large fire, jet flame, or fireball may occur, but significant blast-pressure damage is unlikely. Should the cloud be allowed to form over a period of time within a process area, then subsequently ignite, blast pressures that develop can result in extensive, widespread damage. Ignition delays of 1 to 5 minutes are considered the most probable for generating vapor cloud explosions, although major incidents with ignition delays as low as a few seconds and greater than 30 minutes are documented.

3) Third, a sufficient amount of the cloud must be within the flammable range of the material to cause extensive overpressure. A vapor cloud will generally have three regions: a rich region near the point of release, a lean region at the edge of the cloud, and a region in between that is within the flammable range. The portion of the vapor cloud in each region depends on many factors, including type and amount of the material released; pressure at time of release; size of release opening; degree of confinement of the cloud; and wind, humidity, and other environmental effects (Hanna and Drivas 1987).

4) Fourth, the blast effects produced by vapor cloud explosions can vary greatly and are determined by the speed of flame propagation. In most cases, the mode of flame propagation is deflagration. Under extraordinary conditions, a detonation might occur.

For vapor cloud explosion there is a minimum ratio of fuel vapor to air below which ignition will not occur. Alternately, there is also a maximum ratio of fuel vapor to air, at which ignition will not occur. These limits are termed the lower and upper explosive limits. For gasoline vapor, the explosive range is from 1.3 to 6.0% vapor to air, and for methane this range is 5 to 15%. Many parameters contribute to the potential damage from a vapor cloud explosion, including the mass and type of material released, the strength of ignition source, the nature of the release event (e.g., turbulent jet release), and turbulence induced in the cloud (e.g., from ambient obstructions).

2.3.3 BLEVE (Boiling Liquid Expansion Vapor Explosion)

The only explosion relates to liquid is BLEVE. This kind of explosion usually occurs in the process industries which happen in tanks explosion. The BLEVE is an explosion caused by the flashing of liquids when a vessel with a high vapour pressure substance fails. BLEVE occur in 3 sequences;

i) It takes place in superheated liquid
ii) Pressure increase within the vessel
iii) Vessel cannot withstand the pressure and burst

2.4 Detonation and Deflagration

The damage effect from explosion depends highly on whether the explosion results from a detonation or deflagration. The differences depend on whether the reaction front propagates above or below speed of sound. Sonic velocity is the speed at which information is transmitted through gas.

2.4.1 Deflagration

For deflagration the energy from reaction is transferred to unreacted mixture by heat conduction and molecular diffusion (Daniel A. Crowl/ Joseph F. Louvar 2002) This process relatively slow, causing reaction front to propagate at a speed less than sonic velocity. In the deflagrative mode the flame speed ranges from a few ms-$_{1}$ up to 500-1000ms-$_{1}$. The explosion pressure will range from a few mbar to several bar, depending on the flame speed.

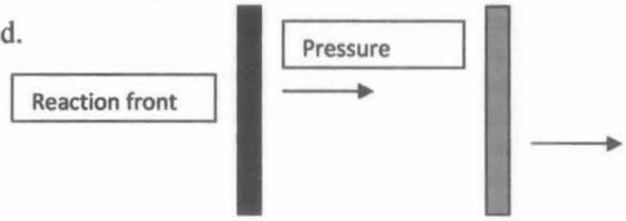


Figure 2.6: Movement of reaction and pressure in Deflagration

In a deflagration, the reaction front moves at a speed less than speed of sound, while the pressure front moves away from the reaction front at the speed of sound.

2.4.2 Detonation

For detonation, the reaction front moves at a speed of sound. A shock front is found a short distance in front of the reaction front. The detonation produces a shock front, with an abrupt pressure rise, a maximum pressure , and total duration of typically less than 1 ms. (Daniel A. Crowl/ Joseph F. Louvar 2002)

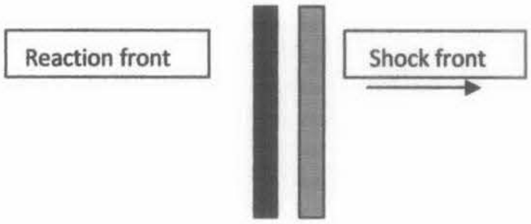


Figure 2.7: Movement of Reaction and Shock wave in Detonation

In a detonation, the reaction front moves at a speed greater than speed of sound, driving the shock front immediately are preceding it. Both moves at the same speed.

2.5 Flammability limit

This is crucial factor for an explosion to occur. Flammability limit define as vapor-air mixture will ignite and burn only over a well-specified range of composition. The mixture will not burn when the composition is lower than the lower flammability limit (LFL); the mixture is too lean for combustion. The mixture is also not combustible when the mixture is too rich; that is, when it is above the upper flammability limit (UFL). A mixture is flammable only when the composition is between the LFL and the UFL. Commonly used units are volume percent fuel (percentage of fuel plus air). Lower explosion limit (LEL) and upper explosion limit (UEL) are used interchangeably with LFL and UFL. For this experiment, which using acetylene gas as fuel, LFL/LEL is 2.5% vol fuel in air and UFL/UEL is 80% vol in air.

2.6 Limiting oxygen concentration.

The LFL is based on fuel in air. However, oxygen is the key ingredient and there is minimum oxygen concentration required to propagate a flame. This is an especially useful result, because explosion and fires can be prevented by reducing the oxygen concentration regardless of the fuel. Below the limiting oxygen concentration (LOC) the reaction cannot generate enough energy to heat the entire mixture of gases to the extent required for the self-propagation of the flame. (Daniel A. Crowl/ Joseph F. Louvar Chemical Process Safety 2001)

2.7 Flammability diagram

A general way to represent the flammability of a gas or vapor is by the triangle diagram shown in figure below. Concentration of fuel, oxygen, and inert material (in volume or mole %) are plotted on the three axes. Shaded area known as flammability region which determine each composition to be flammable or not.

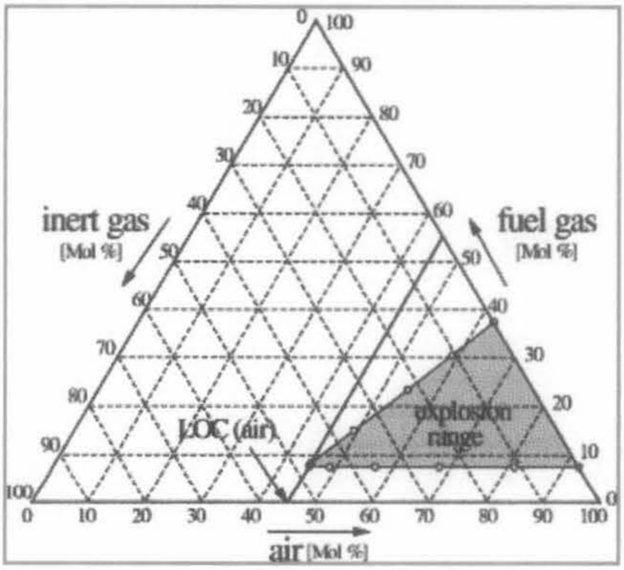


Figure 2.8: Example of flammability diagram of fuel gas

2.8 Explosion fuel

For an explosion to occur, 3 materials needed to be existed at one time; oxygen, ignition, and fuel. In this final year project, we are going to take 2 types of fuel into consideration which are acetylene gas and dust mixture (gun powder). Both of the fuel will give different impact on explosion pressure.

2.8.1 Acetylene gas

Acetylene has been chose to be gas fuel for the explosion. It is because acetylene gas has several advantages and meets the requirement for our explosion. The advantages are;

1) Acetylene gas very reactive; can explode without presence of oxygen in air (wikipedia)
2) Easy to captured and stored in the explosion casing
3) High energy of explosion (-1299 kJ/mol)
4) Have low ignition energy (0.02 mJ)

   Cheap and easy to purchase (RM 4 per kg of calcium carbide, current price year 2010)

Acetylene (IUPAC name: ethyne) is the chemical compound with the formula C_2H_2. It is a hydrocarbon and the simplest alkyne. This colorless gas is widely used as fuel and a chemical building block. It is unstable in pure form and thus is usually handled as a solution.

As an alkyne, acetylene is unsaturated because its two carbon atoms are bonded together in a triple bond. The carbon-carbon triple bond places all four atoms in the same straight line, with CCH bond angles of 180°.(Wikipedia 2009) Approximately 20 percent of acetylene is consumed for oxyacetylene gas welding and cutting due to the high temperature of the flame; combustion of acetylene with oxygen produces a flame of over 3600 K (3300 °C, 6000 °F), releasing 11.8 kJ/g. Acetylene is the third hottest natural chemical flame after cyanogen at 4798 K (4525 °C, 8180 °F) and dicyanoacetylene's 5260 K (4990 °C, 9010 °F).

Table 2.1: Chemical and physical properties of acetylene [3]

Molecular formula	C_2H_2
Molecular weight	26.04 g/mol
Critical point	Critical point temperature : 35.1 °C Critical point pressure : 61.91 bar
Triple point	Triple point temperature : -80.6 °C Triple point pressure : 1.282 bar
Heat capacities at constant pressure, Cp	(1.013 bar and 15.6 °C (60 °F) : 0.041 kJ/(mol.K)
Heat capacities at constant volume, Cv	(1.013 bar and 15.6 °C (60 °F) : 0.033 kJ/(mol.K)
Viscosity	0.0000954 Poise
Color	Colorless
Odor	Strong garlic odor
Density	1.097 kg/m^3
Melting point	−80.8 °C (189 K, subl)
Boiling point	−84 °C

Table 2.2 Flammability data for Acetylene [3];

Formula	C2H2
Energy of explosion (kJ/mol)	-1236.0
Energy of Combustion (kJ/mol)	-1299.6
Flammability limit (vol. % fuel in air)	Upper : 2.5 Lower : 80.0
Flash point temperature (C)	-17.8
Autoignition temperature (C)	305

2.8.2 Calcium Carbide

The simplest way to get an acetylene gas is by hydrolysis process of calcium carbide. Nowadays calcium carbide used as food ripening reagent. Calcium carbide also being used as car lamp in the 50`s. Hydrolysis of calcium carbide produce acetylene gas and by product of calcium hydroxide as precipitate. The chemical reaction of the process;

$CaC_2 + 2\ H_2O \rightarrow C_2H_2 + Ca\,(OH)_2$ (2.3)

Reaction of acetylene and oxygen will produce combustion. But, if the condition is right, we can have gas explosion. The chemical reaction of acetylene combustion is;

$C_2H_2 + 2.5\ O_2 \rightarrow 2CO_2 + H_20$ (2.4)

Where Hc, Heat of combustion = -1299 kJ/mol

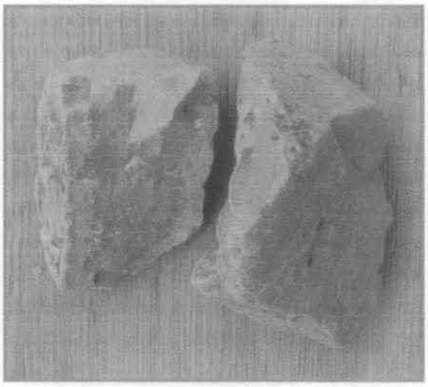


Figure 2.9: Example of calcium carbide

2.8.3 Gun Powder

Gun powder or Black powder was the sole propellant, explosive and pyrotechnic agent for 500 years, from 1300 to 1800, and is still in use for certain applications. It was invented as a pyrotechnic substance, then applied as a propellant in firearms, and finally used in engineering and mining. The composition of ordinary black powder is 65-75 KNO3, 15-20 C, 10-15 S, which is close to the "stoichiometric" ratio of 84:8:8 that give the ideal reaction:

10KNO3 + 8C + 3S → 2K2CO3 + 3K2SO4 + 6CO2 + 5N2

The heat released is 685 kcal/kg, and the volume expansion factor is 5100 (J. H. McLain, *Pyrotechnics* (Philadelphia: Franklin Institute Press, 1980).

The solid products make the characteristic white smoke. The actual reaction depends on the exact constitution of the powder, how it is prepared, and how it is detonated. The density of gunpowder is about 1.04 g/cc. Black powder is the safest of all explosives. It is insensitive to shock and friction or to electric spark. It must be initiated by heat or flame. Moisture renders black powder useless, and drying does not restore its properties. The nitrogen in KNO3 has a formal charge of +5, which is reduced to 0 in N2 (in such molecules the formal charge is taken as zero, its average value). The carbon is oxidized from 0 to +4 in CO2 and the carbonate, and the sulphur from 0 to +6. KNO3 is a stable and safe oxidizing agent, not capable of explosion on its own.

Black powder is a very stable explosive, insensitive to shock or friction, but sensitive to heat and flame. Like all explosives, it supplies its own oxygen and does not rely on the atmosphere. Note that it is much less efficient as a heat source than carbon and oxygen, which gives 2140 kcal/kg. Its utility lies in its ability to furnish its energy in a very short time, while the carbon will take a good while to burn. How the powder burns is affected by the grain size. The larger the grain, the slower the powder burns. Fine powder is used for blasting and small grain for firearms.

In seismic survey, they usually used dynamite or firing a bullet from inside of the ground. The purpose is all the same; to produce single pulse of energy to generate seismic waves. But, by using dynamite, several impact on the environment may not be favorable which dynamite can made a massive destructive on the ground. Gun firing also have its weaknesses for an example; bullet used maybe wasted because the bullet have no impact on seismic waves and the one which produce the seismic waves are the gun powder itself.

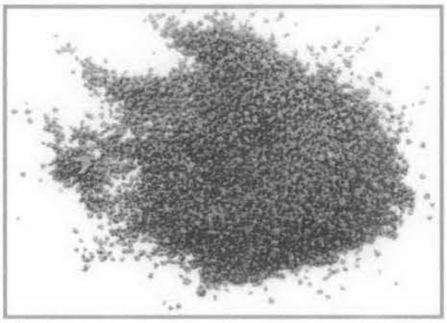


Figure 2.10: Example of Gunpowder

Figure 2.11: Picture before explosion of dynamite

Figure 2.12: Picture after the explosion of dynamite

Figure 2.13: Example of bullet used in gun firing

2.9 Ignition type

The minimum ignition energy is a measure of required energy for a localized ignition source, like a spark, to successfully ignite a fuel-oxidizers mixture. According to **(I. Glassman, Combustion, 3rd ed, Gas explosion handbook)** acetylene requires minimum ignition energy a low as 0.02mJ. Many hydrocarbons have minimum ignition energy of 0.2mJ. This is low compared to sources ignition. For example a static discharge of 22mJ is initiated by walking across a rug, and an ordinary spark plug has discharge energy of 25mJ.

2.9.1 Electric Matches

Electrical ignition systems use the ohmic heating caused by an electrical current passing through a conductor to initiate a pyrotechnic composition. They are typically designed to produce a short burst of hot gases and sparks for initiating other compositions further down the pyrotechnic chain.

Electric igniters, "fuse heads", "electric matches" or "e-matches", do not detonate. They contain only low-explosives and will not initiate a secondary high-explosive. However a similar device containing a primary high-explosive in a metal tube is called an electrical detonator and is used to initiate high-explosives.

Physically e-matches are two wires that come together at the pyrotechnic end of the device where a small blob of "pyrogen" composition is found. Within this blob of composition is usually a very fine "bridge wire", typically of nichrome alloy, that connects each of the lead wires. It functions purely as a heating element, its job is to reach the initiation temperature of the pyrogen and reliably initiate it. Some e-matches, so called "bridgeless" e-matches, have no bridge wire at all, the pyrogen is formulated to be conductive and forms its own bridge wire. Some e-matches come with a removable plastic shroud that protects the match head and can be used to direct the gases and sparks if required. [6]

No	Ingredient	Proportion	Formula
1	Potassium perchlorate	47.4%	KClO4
2	Calcium Silicide	23.6%	CaSi
3	Antimonous sulfide	23.6%	Sb2S3
4	Collodion(Solution)	5.4%	[C6H7O2(ONO2)8]n
Fuse head priming weight: 0.025g/pcs approximately			
Damp-proof paint: Nitrolacquer			

Table 2.3: Electric matches composition

Listed below is performance parameter of Electric matches.

- The resistance of bridge filament at 21: 1.3±0.1Ω 1.7±0.15Ω
- Connection in parallel or single rated ignition current: 0.50A 20ms
- Connection in series rated ignition current: 0.80A 5.0ms
- Firing point current: 0.40A
- The firing time while the current is 1A: 2ms
- Safety current: 0.25A 5s
- Test current: 0.50mA
- The size of protective cover of Powder head: Φ5.8mm
- Length: 16.7mm
- Perform at high temperature: 80 C
- Perform at low temperature: -60 C

There are several factors which make electric matches most favorable as ignition for the explosion;

1) Electric matches composition has been altered so that it will be safer to handle.
2) It have high autoignition temperature of 200C which mean it will not self-ignite when below 200 C.
3) Several tests also proved that it can operate at high humidity also in the water (damp-proof).

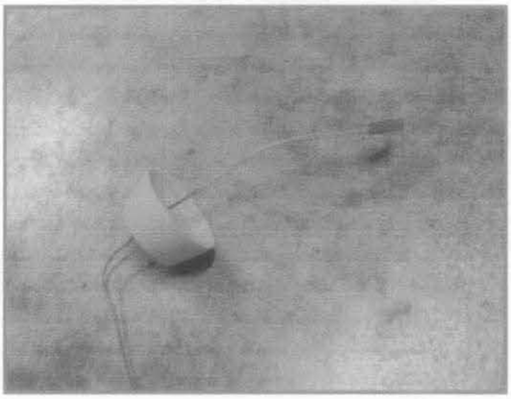


Figure 2.14: examples of electric matches

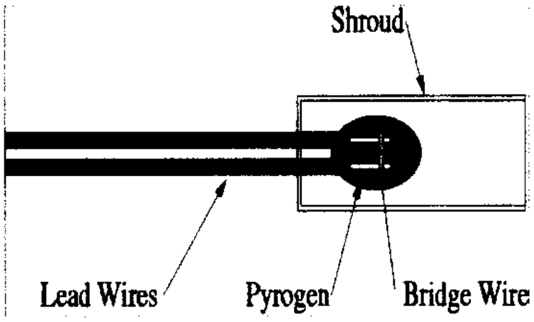


Figure 2.15: Electric Matches diagram

2.10 Shape of container

In the tube, the wedge-shaped and the cubical vessels, the respective modes of flame propagation will be planar, cylindrical and spherical. As shown in Fig. 4 a spherical mode of flame propagation requires higher flame velocity than a planar mode to generate the same explosion pressure. The pressure wave can expand more 'freely' in the spherical mode and the positive feedback mechanism is not as strong as in the planar mode. Van Wingerden et al. [5]. Experiments performed in a wedge-shaped vessel (sector) and a channel (respectively cylindrical and planar geometries) more shown in Fig.5 having the same length and similar obstacles showed that the terminal flame speeds were higher in the channel than in the sector.

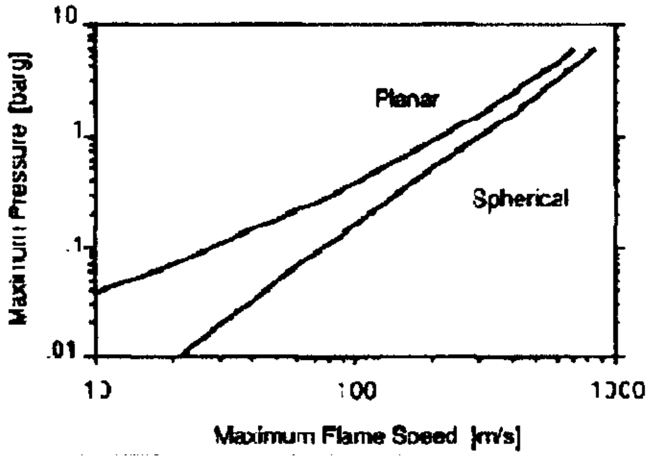


Figure 2.16: Maximum overpressure vs. flame velocity for planar and spherical flames (Gas Explosion Handbook)

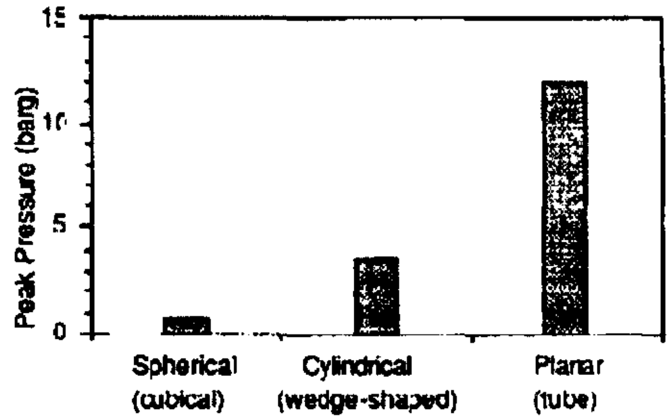


Figure 2.17: Peak explosion pressure for stoichiometric propane-air in cubical, wedge-shape and tube vessel. (Gas Explosion Handbook)

From the studies, we found that, planar (tube) shape give the highest explosion pressure. Thus the container is decided to have a planar (tube) shape.

2.11 Safety Analysis (Blast damage to people)

People can be injured by explosion from direct blast effects (including overpressure and thermal radiation) or indirect blast effects (mostly missile damage). Blast damage effects are estimated using probit analysis.

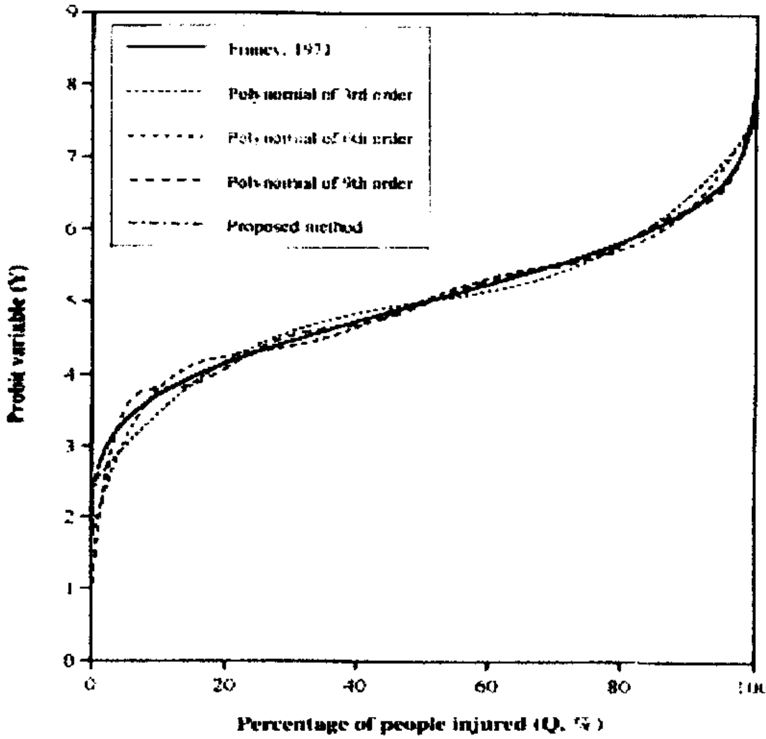


Figure 2.18: relation between percentage and probits [4]

For single exposures the probit (probability unit) method is particularly suited. Graph above in figure 10 represent relationship between probit variable and Y and probability P which given by equation

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y-5} \exp\left[-\frac{V^2}{2} \right] dV \qquad (2.5)$$

This relation is plotted in figure 10 and tabulated in table 1.

Table 2.4: Transformation from percentage to probit value [4]

%	0	1	2	3	4	5	6	7	8	9
(a) Relation between Probit variable and probability (percentage) (Finney, 1971)										
0	—	2.67	2.95	3.12	3.25	3.36	3.45	3.52	3.59	3.66
10	3,72	3,77	3.82	3,87	3.92	3,96	4,01	4.05	4,08	4,12
20	4.16	4.19	4.23	4,26	4.29	4,33	4,36	4.39	4,42	4,45
30	4,48	4,50	4,53	4,56	4,59	4,61	4,64	4,67	4,69	4,72
40	4,75	4,77	4.80	4,82	4.85	4,87	4,90	4,92	4,95	4,97
50	5,00	5,03	5.05	5,08	5.10	5,13	5,15	5.18	5,20	5,23
60	5,25	5,28	5,31	5,33	5,36	5,39	5,41	5,44	5,47	5,50
70	5,52	5,55	5.58	5,61	5.64	5,67	5,71	5.74	5,77	5,81
80	5,84	5,88	5,92	5,95	5,99	6,04	6,08	6.13	6,18	6,23
90	6,28	6,34	6,41	6,48	6,55	6,64	6,75	6,88	7,05	7,33
—	0,0	0.1	0.2	0,3	0.4	0.5	0,6	0.7	0,8	0,9
99	7,33	7,37	7.41	7,46	7.51	7,58	7,65	7.75	7,88	8,09

There are varieties of probit equation that have been developing for different types of exposures. In our explosion case, we will assess 4 different type of injury of damage which have been summarize in table 2.

Table 2.5: Selected probit Correlations from variety of exposures (Daniel A. Crowl/ Joseph F. Louvar Chemical Process Safety second edition)

Type of injury/damage	Causative variable	Probit Parameters	
		k_1	k_2
Death from lung hemorrhage	P	-77.1	6.91
Eardrum ruptures	P	-15.6	1.93
Glass breakage	P	-23.8	2.92
Structural Damage	P	-18.1	2.79

The causative factor represents the dose V. Probit variable Y is computed from

$$Y = k_1 + k_2 \ln V \qquad (2.6)$$

where Y – probit value

k_1 and k_2 – probit parameter

V – causative factor

2.11.1 Blast damage resulting from overpressure

Pressure that over the ambient pressure produce by the explosion called overpressure. In gas explosion, the energy causes the gas to expand rapidly, forcing back the surrounding gas and initiating a pressure wave that moves rapidly outward from the blast source. The pressure wave contains energy, which results in damage to the surrounding. Damage estimates based on overpressure are given in table 2.6.

Table 2.6: Damage estimates for common structures based on overpressure (Chemical Process Quantitative Risk Analysis 1989)

Pressure		
psig	**kPa**	**Damage**
0.02	0.14	Annoying noise (137 dB if of low frequency 10–15 Hz)
0.03	0.21	Occasional breaking of large glass windows already under strain
0.04	0.28	Loud noise (143 dB), sonic boom, glass failure
0.1	0.69	Breakage of small windows under strain
0.15	1.03	Typical pressure for glass breakage
0.3	2.07	"Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% window glass broken
0.4	2.76	Limited minor structural damage
0.5–1.0	3.4–6.9	Large and small windows usually shattered; occasional damage to window frames
0.7	4.8	Minor damage to house structures
1.0	6.9	Partial demolition of houses, made uninhabitable
1–2	6.9–13.8	Corrugated asbestos shattered; corrugated steel or aluminum panels, fastenings fail, followed by buckling; wood panels (standard housing) fastenings fail, panels blown in
1.3	9.0	Steel frame of clad building slightly distorted
2	13.8	Partial collapse of walls and roofs of houses
2–3	13.8–20.7	Concrete or cinder block walls, not reinforced, shattered
2.3	15.8	Lower limit of serious structural damage
2.5	17.2	50% destruction of brickwork of houses
3	20.7	Heavy machines (3000 lb) in industrial building suffered little damage; steel frame building distorted and pulled away from foundations
3–4	20.7–27.6	Frameless, self-framing steel panel building demolished; rupture of oil storage tanks
4	27.6	Cladding of light industrial buildings ruptured
5	34.5	Wooden utility poles snapped; tall hydraulic press (40,000 lb) in building slightly damaged
5–7	34.5–48.2	Nearly complete destruction of houses
7	48.2	Loaded train wagons overturned
7–8	48.2–55.1	Brick panels, 8–12 inches thick, not reinforced,fail by shearing or flexure
9	62.0	Loaded train boxcars completely demolished
10	68.9	Probable total destruction of buildings; heavy machine tools (7000 lb) moved and badly damaged; very heavy machine tools (12,000 lb) survive
300	2068	Limit of crater lip

To estimates the damage, we need to calculate the overpressure. Overpressure can be estimated using an equivalent mass of TNT, detonated m_{TNT}, and the distance from the ground zero point of explosion, detonated r, the empirical law is

$$Ze = \frac{r}{m_{TNT}^{1/3}} \qquad (2.7)$$

TNT equivalence is a simple method for equating a known energy of a combustible fuel to an equivalent mass of TNT. The equivalent energy of TNT is 1120 cal/g. There are 3 different pressure that are related each other. They are related by using equation,

$$Ps = \frac{Po}{Pa} \qquad (2.8)$$

Ps is the scaled pressure (unitless)

Po is the peak overpressure

Pa is the ambient pressure.

Ps, scaled overpressure can be calculated by using equation

$$\frac{Po}{Pa} = \frac{1616[1 + (Ze/4.5)^2]}{[1 + (Ze/0.048)^2]^{½} \times [1 + (Ze/0.32)^2]^{½} \times [1 + (Ze/1.35)^2]^{½}} \qquad (2.9)$$

The procedure for estimating the overpressure at any distance r resulting from the explosion of a mass of material is as follows;

1) Compute the energy of explosion using established thermodynamics procedures
2) Convert the energy to an equivalent amount of TNT
3) Use the scaling law and the correlation equation to estimate the overpressure
4) Use table 3 to estimates the damage.

CHAPTER 3: METHODOLOGY/ PROJECT WORK

3.1 Methodology

This project will be conducted according to this methodology to meet the objectives. The seismic energy experiment consists of seismic source, receiver (geophones) and data evaluation. Seismic source consist of explosion as energy source, ignition, fuel, and proper triggering system.

Firstly, the concept and theory of explosion, all the theories behind explosion, parameters need to be considered shall be gathered and understood. The second step is plan, research and purchase materials which need to be used for energy source, design the explosion container and ignition system. After the second step, the experiment will be done to prove the theory of explosion and test the ignition system. Preliminary evaluation based on safety analysis will be calculated to estimate blast damage on people and surrounding.

The next step is experiment the explosion as seismic energy source together with the seismic survey equipment which consist of receiver (geophones) and data recorder called seismograph. Next, the data recoded will be evaluated. The impact of explosion and energy efficiency can be evaluated. If there are any defects on the experiment result, retest will be done in order to get good data. Next, a basic comparison between dynamite and acetylene gas explosion as well as gun powder explosion will be done to see the advantage and disadvantage between these three energy sources.

Finally, the final report must be completed before the deadline. Figure 3.1 below shows the flow chart of methodology.

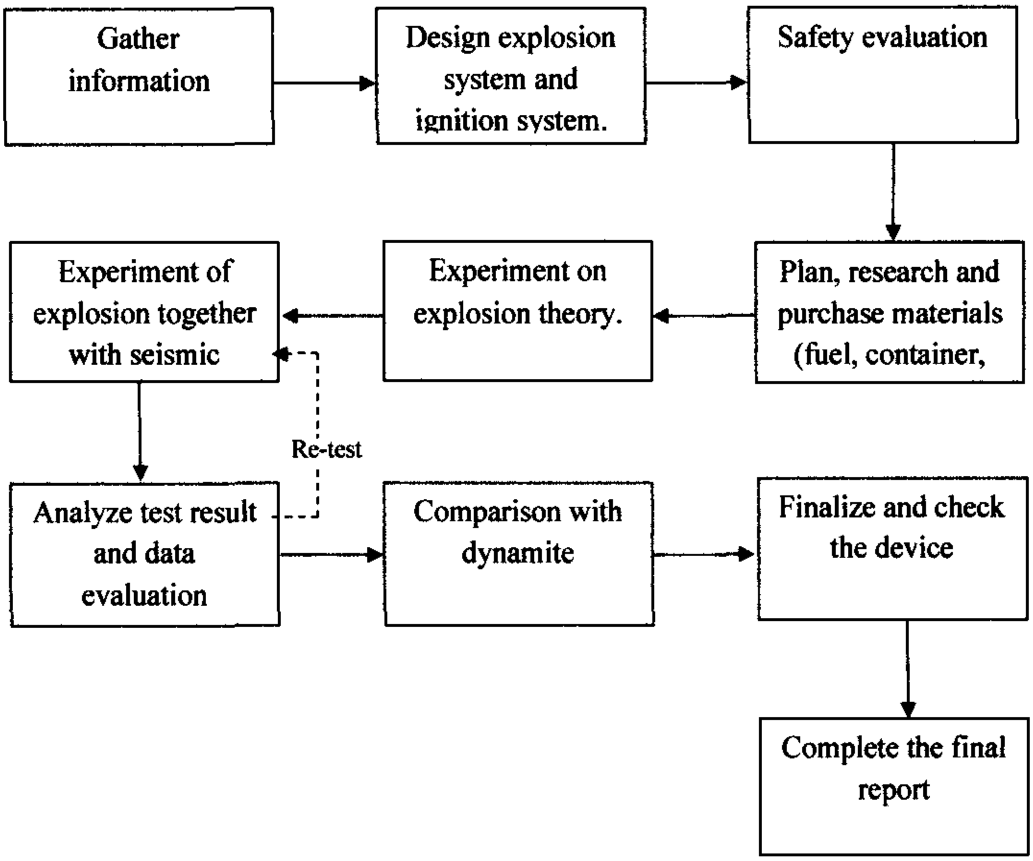


Figure 3.1: The flow chart of methodology

3.2 Tools/ Equipment

For this project, experiments have been planned to study the behaviour and condition of gas explosion. To study the explosion behaviour and condition needed, several trial an different condition has been perform. In this experiment, the same apparatus will be used which are 1500ml explosion container, 3m of electrical wire, single core electrical matches wire, single channel switch, calcium carbide and gun powder.

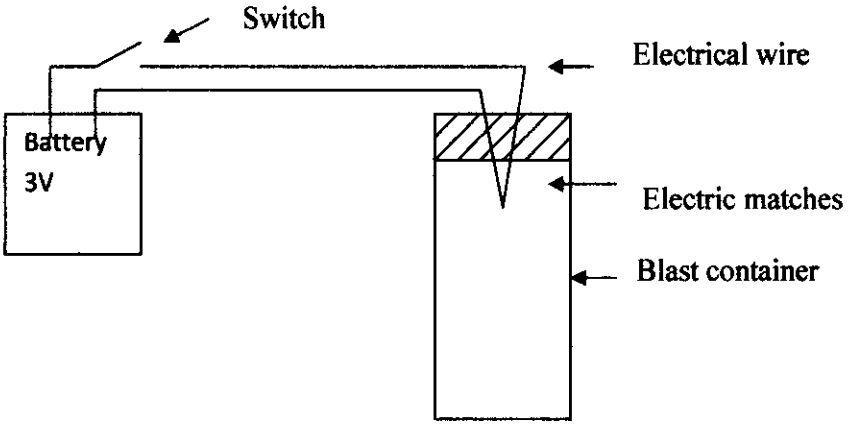


Figure 3.2: Diagram for the experiment

So far, the research on this project has been made. The same apparatus ha been used. The factor that has been manipulates including time delay for ignition and types of fuel. These will help to determine good estimation of time delay for acetylene gas filled up the container at a perfect volume so that it would fall into the flammability region. Types of fuel will give different impact on explosion. The explosion impact will be evaluated only based only on observation and damage towards surrounding, example; impact on container and ground. To measure explosion pressure, we needed more sophisticated apparatus which can measure pressure produce by an explosion with different composition of fuel. Unfortunately, the apparatus is not available UTP. Thus different approach is taken to consider the explosion impact which is by observation, theoretical calculation and seismic reading.

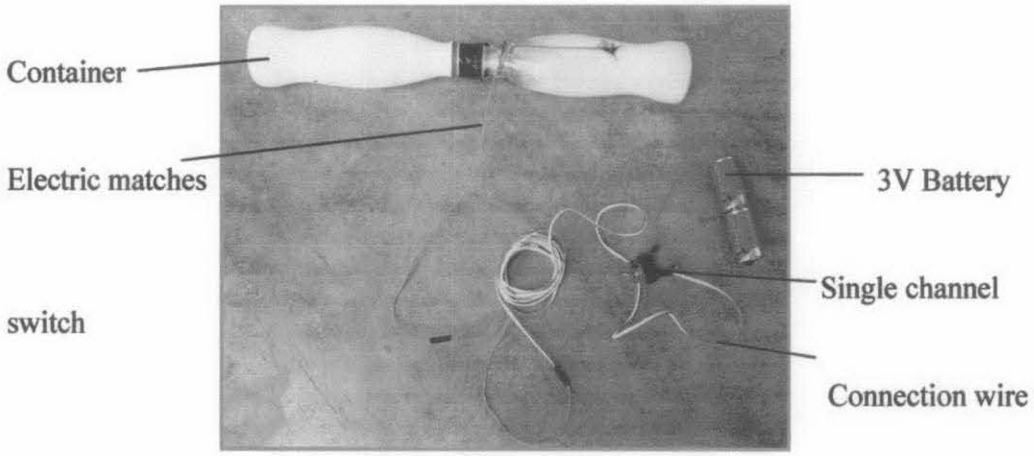


Figure 3.3: Arrangement of apparatus

3.3 Gunpowder preparation

There are three basic chemicals in gunpowder Potassium Nitrate, Charcoal powder, and Sulfur powder. Mixing all three chemicals would determine the effectiveness of the explosion. This is because charcoal has its own microscopic pores. To properly make gunpowder the particles of charcoal must be ground together with the potassium nitrate and sulfur, the process of grinding them smashes the potassium nitrate and sulfur into the pores of the charcoal creating a substance that will readily burn when ignited. These are apparatus needed for gunpowder preparation;

i. Ball mill
ii. Electronic scale
iii. Potassium nitrate, sulphur, charcoal powder
iv. Wire strainer

3.3.1 Gunpowder preparation procedure

Step 1; mixing the chemicals

Ratio of 75:15:10 of potassium nitrate: charcoal powder: sulphur, need to be followed. It is standard ratio for gunpowder compositions. Weight of empty cup is measured so that we can have accurate weight of each chemical. After that all chemicals will put into ball mill to have grinding process.

Step 2; Grinding

Two hours is the standard amount of time to let it grind for, however, to have higher quality of gun powder, longer time for grinding process is recommended.

Step 3: Sift out the powder

After two hours, the powder is separated from the ball mill using strainer.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Properties of acetylene

Review of studies has been made on acetylene explosion because of failure on several attempts of the explosion. Basically all the attempts fail because the container was filled with all the acetylene gas and the ignition not ignite the gas. After the review, we notice that we not consider the fundamental of explosion which are flammability limit or exclusivity limit and limiting oxygen concentration. The additional details on properties of acetylene gas are listed in table 5.1:

Properties of gas	
Upper flammability limit (UFL)	80 % vol fuel in air
Lower flammability limit (LFL)	2.5 % vol fuel in air
Perfect combustion with air	Air required 12.02 Nm^3 air/ Nm^3 gas
Perfect combustion with oxygen	Oxygen required 2.5 Nm^3 O_2/ Nm^3 gas
Limiting oxygen concentration (LOC)	3.75 % vol of O_2

Table 4.1: properties of acetylene gas (Daniel A. Crawl/ Louvar 2001)

We trap the air in 1.5 L bottle. Thus volume occupied for air is limited to 1.5 L. For an explosion to occur, we need between 2.5% to 80 % of fuel from 1.5 L volume which are equal to 0.0375L to 1.2 L of acetylene gas.

4.1.1 Limiting concentration of Oxygen (LOC)

Oxygen is the key ingredient for an explosion or fire to occur and there is a minimum oxygen concentration required to propagate a flame. Estimation of LOC for acetylene as per below;

The stoichiometry for the reaction is

$$C_2H_2 + 3/2\ O_2 \longrightarrow 2CO_2 + H_2O$$

LOC = (mole fuel/total mole) (mole O_2/mole fuel) = LFL (mole O_2/mole fuel)

= (2.5 mole fuel/total mole) (1.5 mole O_2/ mole fuel)

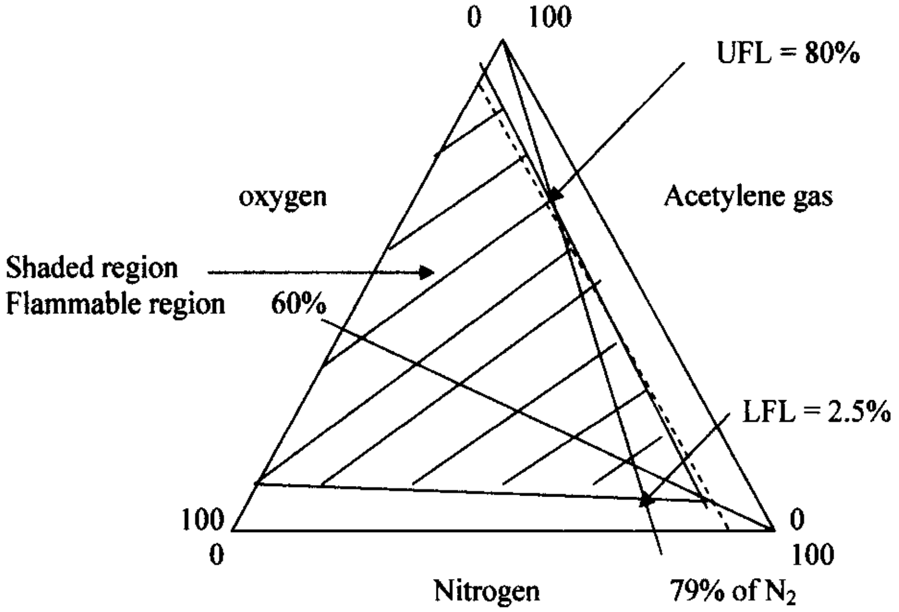
= 3.75 vol % O_2

If we used 1.5 L of container, minimum volume of oxygen needed is:

3.75 % of 1.5 L = 0.0563 L

4.2 Flammability region of acetylene

Based on additional data of flammability limits and LOC, flammability diagram can be draw.



From LOC calculation, we obtain z value = ratio of mole O2 and mole fuel

= 1.5

To find stochimetry line = 100 (1.5/ 1+1.5)

= 60%

4.3 Experiment setup for vapor cloud explosion

The purposes of these experiments are to test delay of ignition towards explosion. Figure 5.1 shows the experimental setup:

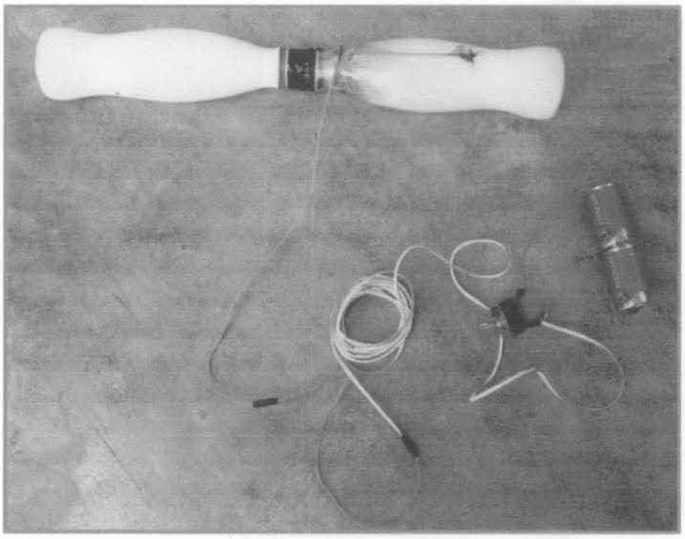


Figure 4.1: Actual equipment setup

Table 4.2: Result of different time delay towards ignition

Time delay to ignition, s	Explosion/ no explosion
2	Explosion
4	Explosion
6	Rapid burning of fire
8	No explosion

Table 4.2 shows the result for 4 different time delay. The experiment was done using acetylene gas as fuel for the explosion. Time for ignite delay from 2 second, 4 second, 6 second and 8 second from hydrolysis reaction of calcium carbide with water.

4.3.1 Time delay for ignition.

In this experiment, acetylene gas was release from hydrolysis of calcium carbide with water. The chemical reaction is:

$CaC_2 + 2\ H_2O \rightarrow C_2H_2 + Ca\ (OH)_2$

Water is taken as limiting reactant from the reaction. From the equation, 2 mol of water will produce 1 mol of acetylene gas. Assume that provided only tea spoon of water into the container. 1 tea spoon = 5g of water. Thus,

2 mol of H_2O $\longrightarrow$ 1 mol of acetylene

In 5g of H_2O = 0.278 mol

0.278 mol of H_2O $\longrightarrow$ 0.139 mol of acetylene gas

From ideal gas law, 1 mol of gas occupied 22.4 L of volume. Thus, 0.139 mol of acetylene will occupy 3.113L = 3113cm^3. Given density of acetylene gas = 1.097 x 10^{-3} g/m^3. Thus, mass of acetylene gas produce is 3.41g. Diffusivity of acetylene gas in air given 0.178 cm^2 s^{-1}(C.L Yaws, Handbook of Transport Property Data). At different delay time of ignition, the gas will occupy different area inside the container. Thus this will affect the gas fuel whether the fuel volume will fall into flammability region or not. From the result, its shows that ignition must be ignite between 2 – 4 second. If not, the gas will already fall into nonflammable region, and the explosion will not occur.

4.4 Safety Evaluation (blast damage to people)

The evaluation will be done based on 1.5L volumes of container. By doing this evaluation, we can see how much different on the overpressure produced by each container and damage to people. Assume that, 1.5L vessel rated at 1 barg/ 1atm contain (C2H2) and air at atmospheric pressure and 25 C. From flammability data of acetylene, stated that Energy of combustion = 310kcal/gm-mole

Chemical equation of the reaction given by:

$C_2H_2 + 2.5O_2 \rightarrow 2CO_2 + H_2O$

1 mole of air contains 3.76 mole of N2 and 1 mol of O2. Thus starting composition is

$C_2H_2 + 2.5O_2 + (2.5)(3.76) N_2 \rightarrow 2CO_2 + H_2O + 2.5(3.76)N_2$

Compound	moles	mole fraction
C_2H_2	1.0	0.078
O_2	2.5	0.194
N_2	9.4	0.728
Total	12.9	1.0

At 1.5L of blast container at 25 C contain

$$(0.0015\ m^{3)}(273K/298K)\frac{(1\ \text{gm-mole})}{(0.0224\ m^3)} = 0.061\ \text{gm-mole}$$

Amount of acetylene in this volume could combust

(0.078)(0.061 gm-mole) = 0.00476 gm-mole

Energy of combustion E_c = 0.00476 gm-mole (310 kcal/ gm-mole)

= 1.475 kcal

1 kg of TNT = 1120

How much TNT will produce energy = 1.475 kcal

Thus, m_{TNT} = 1.475/1120

= 0.00132 kg of TNT

Assume blast happen at radius of 5 m direct blast,

$$Ze = \frac{r}{m_{TNT}^{1/3}}$$

$$= \frac{5m}{(0.00088\ kg)^{1/3}} \qquad = 45.62\ m\ kg^{-1}$$

By using equation 2.9, substitute value of Ze = 45.62, we will get value of scaled overpressure, Ps = 0.0366

$\frac{Po}{Pa}$ = 0.0366 P ambient, Pa = 101.3 kPa

Thus, P overpressure = 3.71 kPa (gauge pressure)

Refer to table 3: Damage estimates for common structures based on overpressure (Chemical Process Quantitative Risk Analysis 1989), with P overpressure = 3.71 kPa, estimated damage is **large and small window usually shattered; occasional damage to window frames**.

4.4.1 Calculation of blast damage to people using probit analysis.

Case 1: Death from lung hemorrhage

Probit equation given by,

$Y = k1 + k2 \ln V$ which value of V given by P overpressure = 0.534 psig

$k1 = -77.1$, $k2 = 6.91$

Pressure in unit N/m^2 thus, $P = (0.534 \text{ psig}/ 14.7\text{psi/atm})(101325 \text{ N/m}^2)$

$= 3680.78 \text{ N/m}^2$

$Y = -77.1 + 6.91 \ln 3680.78$

$= -20.36$

From table 1, results show that there is no death from lung hemorrhage

Case 2: Eardrum ruptures

$k1 = -15.6$ $k2 = 1.93$

$Y = -15.6 + 1.93 \ln 3680.78$

$= 0.2469$

From table 1, results show that there is no eardrum ruptures

Case 3: Glass breakage

$k1 = -18.1$ $k2 = 2.79$

$Y = -18.1 + 2.79 \ln 3680.78$

$= 4.56$

Value of Y glass breakage = 4.56. From table 1, we get that 30.3 % probability of glass breakage to occur.

Case 4: Structural damage

$k1 = -23.8$ $k2 = 2.92$

$Y = -23.8 + 2.92 \ln 3039.75$

$= 0.175.$

From table 1, result show that there are no structural damage.

There are several weaknesses in vapor cloud explosion which not favorable in seismic test:

1) Blast effects produced by vapor cloud explosions were deflagration. Which, flames propagate at slow rate. Pressure produced by our experiment not good enough to give high seismic signal.
2) Sufficient amount of cloud need to be determine so that it could fall in the flammability region and explosion could occur.
3) Ignition delay so that a vapor cloud can form and mix with oxygen
4) High oxygen concentration also needed for good explosion. This will be a problem if we have a space constrain which vapor cloud need to be control in range as well as oxygen gas could be in the same container.

4.5 Result of gunpowder as second explosion fuel.

After ignition, we only have burning of gunpowder at slow rate. No explosions occur from the experiment. From the literature review, we can conclude that, there are several factors that lead to the slow rate combustion;

i. Wrong material was used in the making of gunpowder process. Activated charcoal was used in our case. Proposed in literature review was soft wood charcoal.
ii. Imperfect grinding process. This lead to grain size of dust which produce slow rate of burning. All the composition also not well mixture.
iii. There is moisture in the mixture. The gunpowder was stored in non air tight container.

CHAPTER 5: CONCLUSION

6.1 Conclusion

High seismic energy can be produce by provide single pulses or continuous pulses of energy that generates seismic waves, which travel through a medium such as water or layers of rocks. Dynamite and an explosion are examples of the seismic energy. The objectives of this project are to develop new explosion device which can be used as seismic energy source. It can produce high seismic energy and friendly users. Studies have been done to develop an explosion as seismic energy source which consist of acetylene gas as fuel of the explosion and gunpowder. This is because acetylene gas has met several requirements which can provide a good explosion impact. Gunpowder was chosen because it is the safest explosive material. It also provides good impulse for seismic wave's production.

Ignition Energy

For ignition system, an electric match has several factors which make it most suitable to be ignition for the explosion.

Flammability region

Calculation of limiting oxygen concentration has been done as well as flammability diagram sketch.

Properties of gas	
Upper flammability limit (UFL)	80 % vol fuel in air
Lower flammability limit (LFL)	2.5 % vol fuel in air
Perfect combustion with air	Air required 12.02 Nm^3 air/ Nm^3 gas
Perfect combustion with oxygen	Oxygen required 2.5 Nm^3 O_2/ Nm^3 gas
Limiting oxygen concentration (LOC)	3.75 % vol of O_2

Table 6.1: Properties of acetylene gas (Daniel A. Crawl/ Louvar 2001)

Ignition time delay

Experiment on ignition delay was executed to find the most suitable time delay for vapor cloud formation also for a suitable mix between fuel and air for an explosion to occur. Time taken for delay is 2s, 4s, 6s and 8s. Only 2s and 4s will produce explosion.

Safety evaluation (blast damage for people)

This evaluation was done for acetylene gas explosion which consist of 1.5L of fuel. From the result, the explosion produce $P_{overpressure}$ = 3.71kPa (gauge pressure) with estimated damage is large and small window usually shattered; occasional damage to window frames. From probit value, only 30.3 % probability of glass breakage to occur which shows small percentage of minor damage will occur.

Gunpowder explosion

From the experiment, only slow rate of combustion occur due to ignition. This is because several factor; wrong type of charcoal has been used, imperfect grinding of gunpowder, and grain size not suitable for explosion.

Recommendation

Problem faced in experiment of gunpowder was the preparation at the beginning of the process. To overcome this problem, several actions need to be taken;

1) Grind softwood charcoal or wood charcoal will be use.
2) Grinding process need to be long enough to ensure perfect mixing and grinding of the material.
3) Air tight container needed for storing purpose and keep the powder away from air moisture.

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