THE EFFECT FLAMMABILITY LIMIT IN CONVENTIONAL COMBUSTION OF HYDROGEN ENRICHMENT IN NATURAL GAS

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I declare that this thesis entitled "The Effect Flammability Limit in Conventional Combustion of Hydrogen Enrichment in Natural Gas" is the result of my own research except as cited in references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature :………………………………

Name : Nur Syuhada binti Mohd Shokri

Date : 2 May 2009

Dedicated to my father, Mohd Shokri, my mother, Nurizam, my sisters, Atiqah, Wafeeqah, and my little brother, Syafiq for their unconditional love and support.

For my friends, thanks for your friendship and everything you taught me.

For everyone else, thank you for being a part of my life. I would not be where I am today without all of you. May God bless you all.

To future researchers, good luck!

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

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ABSTRACT

The use of hydrogenated fuels shows considerable promise for applications in gas turbines and internal combustion engines. The aims of this study are to determine the flammability limits of natural gas/ air and to investigate the effect on flammability limit of natural gas/ air enriched up to 60% hydrogen of fuel by volume at atmospheric pressure and ambient temperature. The experiments were performed in a 20 L closed explosion vessel. The mixtures were ignited by using spark permanent wire that placed at the centre of the vessel. The pressure-time variations during explosions of natural gas/air mixtures in explosion vessel were recorded. The explosion pressure data is used to determine the flammability limit which flame propagation is considered occurred if explosion pressure greater than 0.1 bar. In this study, the result shows the flammability limits is from 6 vol% to 15 vol% of natural gas and have revealed that the addition of hydrogen in natural gas extends the lower flammability limit initially 6 vol% to 2 vol% of methane.

ABSTRAK

Penggunaan bahan api campuran hidrogen boleh diaplikasikan pada gas turbin dan enjin pembakaran. Objektif penyelidikan ini adalah untuk menentukan had pembakaran campuran gas asli dan udara dan untuk menyiasat kesan penambahan hidrogen sebanyak 60% isipadu daripada jumlah bahan api terhadap campuran gas asli dan udara pada tekanan atmosfera dan suhu bilik. Eksperimen ini dilakukan di dalam 20 L bekas letupan yang tertutup. Campuran ini dicucuh dengan wayar percikan tetap yang terletak di tengah bekas letupan. Variasi tekanan-masa semasa letupan campuran gas asli dan udara direkodkan. Data tekanan letupan digunakan untuk menentukan had pembakaran dimana pergerakan nyalaan dianggap berlaku sekiranya tekanan letupan lebih daripada 0.1 bar. Dalam penyelidikan ini, keputusan menunjukkan had pembakaran adalah daripada 6% kepada 15% isipadu gas asli dan menunjukkan penambahan hidrogen dalam pembakaran gas asli dan udara melanjutkan had bawah pembakaran daripada 6% kepada 2% isipadu methane.

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LIST OF ABBREVIATIONS

NG	-	natural gas
CH_4	-	methane
H_2	-	hydrogen
NOx	-	nitrogen oxide
Vol%	-	volume percent
STP	-	standard temperature pressure
Pexp	-	explosion pressure
t1		ignition time

CHAPTER 1

INTRODUCTION

1.1 Introduction

Knowledge of the flammability limits of gaseous mixtures is important for the safe and economic operation of many industrial and domestic applications that produce or use flammable mixtures. Flammability limits indicates the region of fuel–air mixture ratios within which flame propagation can be possible while outside that flame cannot propagate. There are two distinct separate flammability limits for a mixture which are lean limit or lower flammability limit (LFL) and rich limit or upper flammability limit (UFL) (S.Y. Liao, 2005). In other words, combustion will take place and be self-sustaining only if fuel and air are mixed within the upper and lower flammability limits.

Increasing requirements to reduce emissions and increase fuel efficiency these days makes the utilization of leaner flammability limit of premixed combustion technology has strong interest in numerous practical applications for power generation such as gas turbine and internal combustion engine.

In internal combustion engine there is a situation when we used Natural Gas Vehicles such as taxis, where petrol is needed for starting up in firstly running then replaced with natural gas when the temperature is sufficient for starting the ignition. This is called 'Cold Start Phenomenon' which is occurs at the initial stage of combustion, either in conventional or catalytic combustion. The problem is whereby the failure in internal combustion engine increases the volumetric emission produced. This problem can be solved if the combustion be able to run at leaner condition.

Hydrogen enrichment is a possible option to extend the flammability limits because hydrogen has a wider flammable mixture range, lower ignition energy, faster flame propagation rate compare to natural gas. These characteristics help to improve the lean burn capability (Fanhua Ma and Yu Wang, 2008).

Moreover, there exists a renewed interest in hydrogen addition to natural gas as a possible means of reducing the emissions of carbon monoxide and carbon dioxide in lean combustion devices. For example, in the Netherlands, government considers adding hydrogen to the natural gas grid, which feeds all household burners (Schoor et al 2008).

The use of hydrogen addition into fuel shows considerable promise for application in combustion burner. The ability to effectively burn these fuels will provide a substantial cost advantage, while minimizing adverse effects on the environment.

1.2 Problem statement

With the growing crisis of energy resources and the strengthening of pollutant legislations, the use of natural gas as an alternative fuel has been promoted recently, natural gas is being regarded as one of the most promising alternative fuels for industrial and domestic applications such as gas turbine and internal combustion engine.

Engines fuelled with natural gas emit less carbon-monoxide and non methane hydrocarbons compared to a gasoline engine, but the nitrogen oxide emission may not be low enough to meet the increasingly more stringent emission requirements.

Moreover, in internal combustion engine there is a situation when we used Natural Gas Vehicles such as taxis, where petrol is needed for starting up in firstly running then replaced with natural gas when the temperature is sufficient for starting the ignition. This is called ‘Cold Start Phenomenon’ which is occurs at the initial stage of combustion, either in conventional or catalytic combustion. The problem is whereby the failure in internal combustion engine increases the volumetric emission produced. This problem can be solved if the combustion be able to run at leaner condition.

Thus, ultra lean limit combustion is needed in order to overcome these problem regarding the pollutant emission and ‘Cold Start Phenomenon’. This is because lean premixed combustion condition makes combustion is possible at the lower flame or ignition temperature that needed to minimize the nitrogen oxide emissions and helps to improve fuel efficiency due to improvements in combustion efficiency to start the engine without using petrol.

1.3 Objectives of study

The objectives of this study are:

1) To determine the flammability limit of premixed natural gas-air mixture in a combustion bomb at atmospheric pressure and ambient temperature.
2) To determine the effect of hydrogen enrichment on flammability limit of premixed natural gas-air mixture in a combustion bomb at atmospheric pressure and ambient temperature.

1.4 Scope of study

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

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

The lower flammability limit (LFL) and upper flammability limit (UFL) of natural gas-air mixture were determined at concentration from 3 vol% to 17 vol%.

The effect of hydrogen in natural gas-air mixture was investigated at hydrogen enrichment up 60 vol% hydrogen of fuel by at methane concentration from 3 vol% to 17 vol%.

1.5 Significant of study

In this study, the effect of hydrogen enrichment in conventional combustion of natural gas is investigated. Addition of hydrogen is said can extend the flammability limit of natural gas-air mixture.

It is significant to determine the leaner flammability limit of natural gas since the concerns about pollution of the environment and lack of fossil fuels have become increasingly greater these days.

Combustion at leaner flammability limit can reduce the volume of natural gas usage for the combustion and can reduce the nitrogen oxide (NOx) emissions of the combustion. It is well known that the most effective way for reducing NOx emissions is to perform combustion at low temperature. Since homogeneous mixing of the fuel and air at lean combustion provide a reduction of flame temperature so the NO_x emission would be minimized and 'Cold Start Phenomenon' can be solved where natural gas can be used for starting up the engine instead of petrol.

The characteristics of hydrogen which are higher flame speed, lower flammability limit and more reactive compare to natural gas shows considerable promise the usage of hydrogen addition into fuel for application in combustion burner such as internal combustion engine and gas turbine.

CHAPTER 2

LITERATURE REVIEW

2.1 Combustion characteristics of methane and hydrogen

Table 2.1 Combustion characteristics of methane and hydrogen

Parameter	Hydrogen	Methane
Flammability limits in air (%)	4.0-75.0	5.0-15.0
Ignition temperature in air (K)	855	925
Ignition energy @ STP (J/cc)	0.74	0.97
Stoichiometric flame temperature in air (K)	2580	2340
Flammability limits in pure oxygen (%)	4.6-93.9	5.4-59.2
Heat of combustion (kJ/g)	135.4	52.8
Liquid heat of combustion (MJ per liter)	9.59	22.29
Gas heat of combustion (MJ per liter)	12.09	37.70
Peak combustion pressure ratio Air	8.8	8.0
Lower oxygen combustion limit in O2-N2 mixture (%)	3.2	4.0

(M.A Green, 2005)

2.2 Flammability limit

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

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

There are two distinct separate flammability limits for a mixture which are lean limit or lower flammability limit (LFL) and rich limit or upper flammability limit (UFL).

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

In other words, combustion or explosion will take place and be self-sustaining only if fuel and air are mixed within the upper and lower flammability limits.

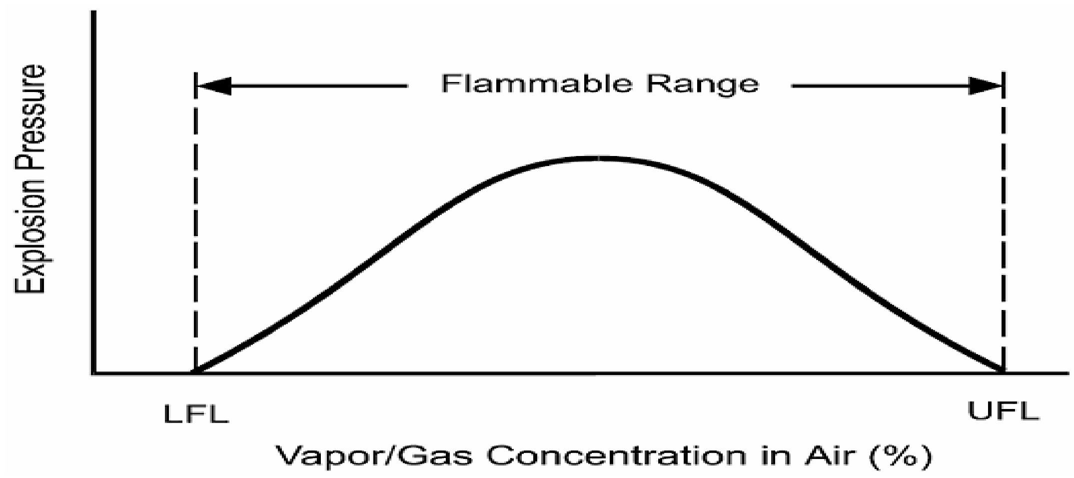

Figure 2.1 Schematic represents flammability limit

It is now acknowledged that flammability limits are physical–chemical parameters of flammable gases and vapors of flammable liquids, which are related to many factors including the heat losses from the flame by conduction, convection and radiation to the apparatus walls, instabilities in the flame front resulting from buoyant convection, selective diffusion and flame stretch, as well as radical loss or their generation on apparatus walls (S.Y. Liao, 2005).

2.2.1 Experimental methods

The standardized measurements of flammability limits are usually conducted in the flammability tubes or closed vessels.

There are several criteria to determine the flammability limits. A successful attempt can be determined by one or a combination of the following criteria:

1. Inspection of the visualization of the flame kernel produced by the spark, namely visual criterion
2. Measurements of pressure or temperature histories in the vessel and appropriate pressure or temperature rise criteria can be used to designate flammability rather than the purely visual observation of flame development

A successful ignition would induce a rapid pressure increase and temperature rise within a short time as well as produce a propagating flame front that could be readily observed.

Previous gas flammability limit data were obtained mainly in flammability tubes which in those test a gas mixture in a vertical tube was ignited and flame propagation was inspected by visual criterion. However, the wall quenching has a significant effect on the flammability measurement in flammability tube.

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

2.2.2 LeChatelier's rule

As to the lower flammability limit of multiple component fuel mixture in air, the LFL value of the mixture can also be estimated by following formula,
According to LeChatelier's rule**:**

$$LFL = \frac{100}{\sum(\frac{Ci}{LFLi})}$$

where,

LFL is the lower flammability of mixture by volume,

C*i* the concentration of component, *i* in the gas mixture on an air-free basis by volume,

LFL*i* is the lower flammability limit for component *i* by volume

The estimation of LeChatelier's rule for natural gas/air mixtures is 4.98 vol% (D.M Jiang et al 2005). Generally, good agreement has been found between the measurement and LeChatelier prediction.

2.3 Explosion pressure

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

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

i. The explosion pressure, P_{exp} is the highest pressure reached during the explosion in a closed volume at a given fuel concentration
ii. The maximum explosion pressure, P_{max} is the highest pressure reached during a series of explosions of mixtures with varying fuel concentration
iii. The explosion time, θ_{exp} is the time interval between ignition time and the moment when the explosion pressure attained

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

2.3.1 Regimes of pressure- time traces

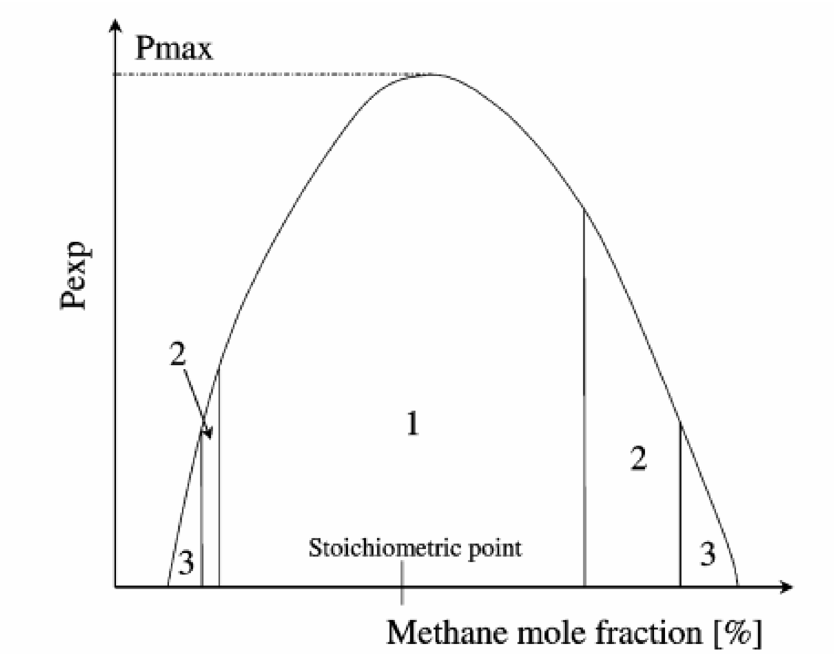

Figure 2.2 Schematic represents of three different combustion regimes.

Based on the pressure time traces three regimes of explosion development or combustion conversion can be identified. The regimes depend on the initial mixture composition, at given conditions as illustrated at Figure 2.1. In the first one, marked as 1, the pressure increases fast and smoothly to the maximum value, after ignition. This type of pressure development is seen for near stoichiometric mixtures. In the second regime, the pressure trace is distinctly S shaped (a shoulder). Such type of pressure development is a narrow fuel lean concentration range and in a wider concentration range with fuel rich mixtures. In the third regime the shoulder disappeared, and the increase is low and slow. (A.A.Pekalski, 2005).

2.4 20-L-Appartus

The experimental 20-L-Apparatus (or 20 Liter Spherical Explosion Vessel) was obtained from Adolf Kühner AG and is shown in Fig. 1. The test chamber is a stainless steel hollow sphere with a personal computer interface. The top of the cover contains holes for the lead wires to the ignition system. The opening provides for