FINAL YEAR PROJECT REPORT

Modeling the performance characteristics of hydrogen engine with fuel injection systems using GT-Power

MOHD ADZAHARI BIN ADNAN

PROF DR ROSLI BIN ABU BAKAR
MOHAMMED KAMEL BIN MOHAMED

PROGRAMME OF AUTOMOTIVE ENGINEERING
FACULTY OF MECHANICAL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature
Name of Supervisor: Prof Dr Rosli Bin Abu Bakar
Position: Faculty Mechanical Dean
Date:

Signature
Name of Co-Supervisor: Mohammed Kamel bin Mohamed
Position: Phd Student
Date:

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature
Name: Mohd Adzahari Bin Adnan
ID Number: MH06035
Date:

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ABSTRACT

This study was addressed the effect of speed on engine performance for 1-cylinder for port and direct injection fuel systems. GT- power utilized to develop the model for port injection and direct injection hydrogen fuel systems. This port injection was installed before the cylinder head for port injection and injection timing are 74.01 g/sec at 5 º before top dead center for direct injection hydrogen fueled system and inducted with low pressure about 1bar – 2bar for port injection while 80bar for direct injection.

Air-fuel ratio was varied from rich limit (AFR=22.88) to a lean limit (AFR=68.66) when the engine speed constant at 3000 rpm. The rotational engine speed was varied from 1000 to 6000 rpm when the air-fuel ratio constant at 34.33 at stoichiometric condition. The obtained results seen that the engine speed and air-fuel ratio are greatly influence on the Brake Mean Effective Pressure (BMEP), Brake Specific Fuel Consumption (BSFC). It also seen that the decreases of the BMEP with increase of the engine speed, however, increase the brake specific fuel consumption (BSFC). The optimum minimum value of BSFC occurred within a range AFR from 38.14(φ=0.9 to 42.91 (φ= 0.8) for selected range of speed. The higher volumetric efficiency emphasizes that the direct injection hydrogen fuel system is a strong method solution to solve the problem of the low volumetric efficiencies of hydrogen engine. Maximum brake torque for hydrogen engine occurs at lower speed compared with gasoline. The present contribute suggests that the direct injection hydrogen fuel supply system as a strong method for solving the power, torque and abnormal combustion problems.

ABSTRAK

Kita mempelajari tentang prestasi engine dengan menggunakan pencucuk minyak terus dan pencucuk minyak tidak terus pada satu enjin silinder. Kite boleh membuat model satu engine silinder dengan menggunakan isian GT-POWER. Pencucuk minyak tidak terus dipasangkan sebelem kepala silinder dan tekanannya pada 1-2 bar manakala pencucuk minyak terus dipasangkan pada kepala silinder pada tekanan 80 bar dan masa minyak dimasukkan ke kepala silinder adalah 74.01 g/s pada 5 º sebelum TDC. Kadar minyak udara adalah dari kandungan kaya minyak (AFR=22.88) kepada kekurangan minyak (AFR=68.66) pada kelajuan enjin 3000 rpm. Kelajuan enjin adalah dari kelajuan 1000 to 6000 rpm apabila kadar minyak udara pada kadar yang tetap pada 34.33 iaitu pada kandungan udara cukup-cukup untuk membakar minyak dalam silinder enjin. Daripada keputusan perisian GT-Power, kandungan minyak udara dalam enjin mempengaruhi tekanan berkesan brek (BMEP) dan anggaran minyak specific brek (BSFC). Dapat diperhatikan dari perisisan GT-Power mendapati tekanan berkesan brek (BMEP) apabila kelajuan enjin meningkat, walaubagaimanapun, anggaran minyak specific brek (BSFC) menurun. Nilai maksimum dan minimum anggaran minyak specific brek (BSFC) berlaku pada jarak kandungan minyak udara AFR dari (φ=0.9) ke 42.91 (φ= 0.8) pada kelajuan enjin 3000 rpm. Keberkesanan isipadu didapati dari pencucuk minyak terus adalah cara yang paling bagus untuk selesaikan masalah kekurangan keberkesanan isipadu dalam enjin hydrogen. Maksimum torque brek untuk enjin hydrogen berlaku pada kelajuan enjin yang rendah berbanding enjin gasoline. Pada pendapat saya, pencucuk minyak terus adalah cara untuk menyelesaikan masalah kuasa, torque dan ketidaknormalan pembakaran dalam enjin.

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BSFC	Brake Specific Fuel Consumption
BMEP	Brake Mean Effective Pressure
AFR	Air Fuel ratio
BP	Brake Power
DI	Direct Injection
PI	Port Injection

Chapter 1

Introduction

1.1 Project

Hydrogen is the chemical element with atomic number one. Hydrogen is in group one in chemical table reaction. Hydrogen is a colorless, odorless, tasteless, flammable and nontoxic gas at atmospheric temperatures and pressure. It is the most abundant element in the universe but is almost absent from the atmosphere as individual molecules in the upper atmosphere can gain high velocity during collision with heavier molecules, and becomes ejected from the atmosphere. Hydrogen does not exist naturally and so it must be extracted from other chemicals such as electrolysis of water, generation by partial oxidation of coal or hydrocarbon, recovery by product hydrogen from electrolytic cells used to produce chlorine and other products and dissociation of ammonia. Hydrogen has a big amount of energy for transportation and the substantially cleaner emission compare other internal combustion engine fueled. Hydrogen fueled has wide flammability limits and the high flame propagation speed, both allowing better efficiency. Besides, Flammability limits (volume % in air), auto ignition temperature in air (K) Flame velocity (m s−1)b, stoichiometric volume fraction %, Heat of combustion (MJ/kgair)b is higher compare other internal combustion engine fueled. On the other hand, we prefer fundamental of the hydrogen is vapor or gas in single cylinder engine with port injection hydrogen fueled compared liquid gaseous. In order to produce hydrogen liquid, we need a big power plant. The hydrogen gaseous needs to compress to produced liquid hydrogen but the energy will lost to 30-40% as a consequences. In addition, we need to modified the fueled tank storage and too expensive to using liquid hydrogen as a alternate fueled. This the disadvantages about the liquid hydrogen and that’s why we choose hydrogen gaseous as the alternate fuel. In addition, we choose port injection and direct injection. In this study the difference between two injection system at single cylinder engine using GT-Power.

1.2 Problem statement

Fossil fuels such as petroleum, natural gas and coal meet most of the world's energy demand, at present time. But combustion produce of these fossil fuels, such as carbon monoxide(CO), carbon dioxide (CO2), oxides of sulfur (SO*x*), oxides of nitrogen (NO*x*), hydrocarbon (HC), toxic metals which gave green house emission. In order to reduce the world pollution to zero the engineer found new alternative fuel called hydrogen to replace fossil fuel. The combustion of hydrogen in fuel engine is still under research and didn't practical in transportation because there still have some problem which has to solve to make dream come true. There some problem is still on research on how to solve the problem.

The problem is when hydrogen combust in engine the hydrogen was undergo abnormal combustion. One of the abnormal combustion is pre-ignition also called backfire. Pre-ignition is defined as combustion prior to spark discharge, and in general, results from surface ignition at engine hot spots, such as spark electrodes, valves or engine deposits. The minimum ignition energies of hydrogen–air mixtures will be much lower than propane–air and heptanes–air mixtures. The minimum ignition energy will lead the engine failure run because the heat was release in rapid pressure rise and higher heat rejection in cylinder.

On the other hand, knocking also known as abnormal combustion. When knocking occurs, there is a rapid release of the chemical energy in the remaining unburned mixture, causing high local pressures and generating propagating pressure waves in amplitude of several bars across the combustion chamber. The amplitude pressures in cylinder combustion chamber lead the engine failure.

Furthermore, the high combustion pressure is one of the problems. This occur when the hydrogen undergo pre-ignition and combustion knocking because the chemical release heat rate exceed the higher heat rejection that leads to higher in-cylinder surface temperatures and the engine will failure.

1.3 Objective

This hydrogen fuel injection port engine objectives are :-

i. Develop a model for H_2 ICE with direct and port injection fuel systems
ii. Compare between two delivery system direct and port injection
iii. Accessing the performance characteristics of each system

1.4 Scopes

The aim is analyzing the combustion in port injection hydrogen engine :

i. Developing a simulation model suitable for optimization and parameter studies.
ii. The model will be suitable for normal engine operation.
iii. The attention will be limited to the power cycle, i.e. the part of the engine cycle from intake valve closing time to exhaust valve opening time.

Chapter 2

Literature review

2.1 Introduction

This chapter discusses hydrogen abnormal combustion, hydrogen properties, hydrogen delivery system and some of related hydrogen fueled engine with port fuel injection. It also describes, summarize, evaluate and clarify the research that has been done for the benefit of this project. The aim of this research is to study the advantages and disadvantages of using hydrogen as alternate fueled replace gasoline using single cylinder gasoline engine besides verify the model experimentally.

2.2 Related work

Sixty years later, during his work with combustion engines in the 1860s and 1870s, N. A. Otto (the inventor of the Otto cycle) reportedly used a synthetic producer gas for fuel, which probably had a hydrogen content of over 50%. Otto also experimented with gasoline, but found it dangerous to work with, prompting him to return to using gaseous fuels. The development of the carburetor, however, initiated a new era in which gasoline could be used both practically and safely, and interest in other fuels subsided.

Hydrogen has since been used extensively in the space pro-gram since it has the best energy-to-weight ratio of any fuel. Liquid hydrogen is the fuel of choice for rocket engines, and has been utilized in the upper stages of launch vehicles on many space missions including the Apollo missions to the moon, Skylab, the Viking missions to Mars and the Voyager mission to Saturn. However the human awakens about the usage hydrogen as a alternate fueled is one of the invention internal combustion engine. Hydrogen was first suggested as an alternative fuel for internal combustion engines in the 1920s [1]. However, one problem with homogeneous charge hydrogen fuelled internal combustion engines is that they sometimes suffer from flash back phenomenon during the intake stroke, especially during high load operations Nowadays, many engineer has research and develop new technology in order to replace gasoline fueled to hydrogen fueled.

April 1994

Department of Mechanical Engineering, Seoul National University, Seoul describes the experimental results on a hydrogen fueled single cylinder engine to study the characteristics of a solenoid-driven intake port injection type hydrogen injection valve. The fuel-ail equivalence ratio was varied from the lean limit at which stable operation was guaranteed to the rich limit at which flash-back occurred and spark timing was also changed. As a consequence, a hydrogen intake port injection system can be easily installed on a spark ignition engine only with simple modification and the flow rate of hydrogen supplied can also be controlled conveniently. Furthermore, department of manufacturing engineering, City University of Hong Kong and department of energy engineering, zhejiang university, hangzhou has study about hydrogen supply system and combustion system to solve such problem abnormal combustion in hydrogen fueled engine. A fast response solenoid valve, which posses good switch characteristics and very fast response and its electronic control system are described. A high pressure hydrogen injector is designed to improved hydrogen jet penetration and mixture formation in the combustion chamber and to prevent backfire occurring in the hydrogen supply system pipe between the fast response valve and the combustion chamber. Besides they study about abnormal combustion such as backfire, pre-ignition high pressure and injection timing optimally.

1998

The characteristics of cryogenic hydrogen, such as high density and considerable cooling effect, favor the fuel injection, the mixing process and thus the combustion process. In addition to the preferred use of liquid hydrogen due to its range per tank filling and low amount of mass for storage in the vehicle, the cryogenic characteristics of hydrogen provide significant advantages. In addition to engine operation with external mixture formation, considerable success was achieved with internal mixture formation with injection of cryogenic high pressure hydrogen.

June, 2002

Center for Environmental Research and Technology, College of Engineering, University of California have been run experiment about NOx emission and performance data for a hydrogen fueled internal combustion engine at 1500 rpm using exhaust gas recirculation. This experiment including six experiments conducted on a 2-liter, 4-cylinder Ford ZETEC internal combustion engine developed to operate on hydrogen fuel. The experiments were conducted to ascertain the effect exhaust gas recirculation (EGR) and a standard 3-way catalytic converter had on NOx emissions and engine performance. All the experiments were conducted at a constant engine speed of 100 rpm and each experiment used a different fuel 8ow rate, ranging from 0.78 to 1:63 kg=h. These fuel 8ow rates correspond to a fuel equivalence ratio, _, ranging from0.35 to 1.02 when the engine is operated without using EGR (i.e. using excess air for dilution). The experiments initially started with the engine operating using excess air. As the experiments proceed, the excess air was replaced with exhaust gas until the engine was operating at a stoichiometric air/fuel ratio. The results of these experiments demonstrated that using EGR is an effective means to lowering NOx emissions to less than 1 ppm while also increasing engine output torque.

September, 2003

Department of Mechanical and Manufacturing Engineering, University of Calgary has discovery hydrogen abnormal combustion in engine application. They state that knock remains one of the prime limitations that need to be addressed so as to avoid its incidence and achieve superior performance. They research about hydrogen relating to the spark ignition hydrogen-fuelled engine, the e1ects of changes in key operating variables, such as compression ratio, intake temperature and spark timing on knock-limiting equivalence ratios are established both analytically as well as experimentally. The onset of knock, which is caused mainly by the auto-ignition of the unburned mixture in the “end gas region” of the charge which is at any moment yet to be burned, involves exceedingly rapid rates of combustion of the fuel–air mixture, increased heat transfer to the cylinder walls, excessively high cylinder pressure and temperature levels and increased emissions.

June, 2003

University of California, Riverside College of Engineering, Center for Environmental Research and Technology have been run experiment about NOx emission reduction in a hydrogen fueled internal combustion engine at 3000 rpm using exhaust gas recirculation. This experiment including five experiments conducted on a 2-l, 4-cylinder Ford ZETEC internal combustion engine (ICE) developed to operate on hydrogen fuel. The experiments were conducted to ascertain the effect exhaust gas recirculation (EGR) and a standard 3-way catalytic converter had on NOx emissions and engine performance. All the experiments were conducted at a constant engine speed of 3000 rpm and each experiment used a different fuel 7ow rate, ranging from 1.63 to 2:72 kg=h.
These fuel 7ow rates correspond to a fuel equivalence ratio, _, ranging from 0.35 to 0.75 when the engine is operated without using EGR (i.e. using excess air for dilution). The experiments initially started with the engine operating using excess air.
As the experiments proceed, the excess air was replaced with exhaust gas until the engine was operating at a stoichiometric air/fuel ratio. The results of these experiments

demonstrated that using EGR is an effective means to lowering NOx emissions to less than 1 ppm while also increasing engine output torque

March, 2005

Department of Thermal Engineering, School of Mechanical Engineering, National Technical University of Athens has done the surveys the publications available in the literature concerning the application of the second-law of thermodynamics to internal combustion engines. A detailed reference is made to the findings of various researchers in the field over the last 40 years concerning all types of internal combustion engines, i.e. spark ignition, compression ignition (direct or indirect injection), turbocharged or naturally aspirated, during steady-state and transient operation. All of the subsystems (compressor, after cooler, inlet manifold, cylinder, exhaust manifold, turbine), are also covered.

October, 2005

A new method ingeniously adopting fuzzy-neural network (FNN) system to calculate the optimizing control laws for the optimizing control model has been designed, and a series connection control system has been set up, which is composed of FNN controllers combined with an adaptive controller for ignition timing to realize open-loop or closed-loop control pattern with stepping regulation of ignition timing.

November, 2005

Sandia National Laboratories, Combustion Research Facility have been study about low volumetric efficiencies and frequent pre-ignition combustion events, the power densities of premixed or port-fuel-injected hydrogen engines are diminished relative to gasoline-fueled engines, develop of advanced hydrogen engines with improved power densities and The ability for hydrogen to burn cleanly and operate efficiently is owed to the unique combustion characteristics of hydrogen that allow ultra-lean combustion with dramatically reduced NO*x* production and efficient low-engine load operation. Besides they undergo the examination of hydrogen properties relevant to engine operation and control to observe the hydrogen fueled at low and high engine load.

August, 2006

Program of Energy Engineering, Izmir Institute of Technology and Department of Mechanical Engineering, Izmir Institute of Technology, Turkey have been done an experimental study on performance and emission characteristics of a hydrogen fuelled spark ignition engine and investigate experimentally about the performance and emission characteristics of a conventional four cylinder spark ignition (SI) engine operated on hydrogen and gasoline. The test results have been demonstrated that power loss occurs at low speed hydrogen operation whereas high speed characteristics compete well with gasoline operation. Fast burning characteristics of hydrogen have permitted high speed engine operation. Less heat loss has occurred for hydrogen than gasoline.
July, 2007

Michigan Technological University Houghton and Czestochowa University of Technology have been done research about the Comparisons of hydrogen and gasoline combustion knock in a spark ignition engine. Their further engine studies examining combustion knock characteristics were conducted with hydrogen and gasoline fuels in a port-injected, spark-ignited, single cylinder cooperative fuel research (CFR) engine and characterization of the signals at varying levels of combustion knock from cylinder pressure and a block mounted piezoelectric accelerometer were conducted including frequency, signal intensity, and statistical attributes. Further, through the comparisons with gasoline combustion knock, it was found that knock detection techniques used for gasoline engines, can be applied to a H2-ICE with appropriate modifications. This work provides insight for further development in real time knock detection. This would help in improving reliability of hydrogen engines while allowing the engine to be operated closer to combustion knock limits to increase engine performance and reducing possibility of engine damage due to knock.

July, 2007

Engine studies examining combustion knock characteristics were conducted with hydrogen and gasoline fuels in a port-injected, spark ignited, single cylinder cooperative fuel research (CFR) engine. Characterization of the signals at varying levels of combustion knock from cylinder pressure and a block mounted piezoelectric accelerometer were conducted including frequency, signal intensity, and statistical attributes. Further, through the comparisons with gasoline combustion knock, it was found that knock detection techniques used for gasoline engines, can be applied to a H2-ICE with appropriate modifications. This work provides insight for further development in real time knock detection.This studies improving reliability of hydrogen engines while allowing the engine to be operated closer to combustion knock limits to increase engine performance and reducing possibility of engine damage due to knock.

2009

Universiti Malaysia Pahang was investigate the effect of fuel air ratio (AFR) and engine speed on performance of the single cylinder fueled port injection using GT-Power and develop computational model for port injection engine. Throughout the study, air fuel ratio was varied from stoichiometric mixture to lean. The engine speed was varied from 2500 to 4500 rpm. The result show that air fuel ratio(AFR) and engine speed were greatly influence on the performance of hydrogen fueled engine especially Brake Mean Effective Pressure(BMEP), Thermal Efficiency and brake specific fuel consumption (BSFC).

2009

University Malaysia Pahang was study the influence air fuel ratio and injection timing on the engine performance of 4-cylinder direct injection hydrogen fueled engine. The 4-cylinder direct injection hydrogen engine model was develop utilizing the GT-Power commercial software. This model represent one dimensional gas dynamics to represent the flow and heat transfer in the components of engine model.

2.3 Hydrogen properties

Wide flammability range

Compared to other fuels, hydrogen is not so fussy with its density mixture. It can ignite anywhere from a Fuel-to-Air mixture of 4 to 74 percent.

Easily ignitabily.

Hydrogen ignites easier than gasoline. This provides for efficient and prompt ignition but the drawback is hot spots within the combustion chamber can cause premature ignition.

High expansion mass.

The expanding gases formed by spent hydrogen have a much higher velocity and mass compared to gasoline.

Easily dispersed.

The ability of hydrogen to blend with air is greater than gasoline, thus forming a more uniform mixture.

Low density.

Hydrogen occupies a very large volumetric area in its gaseous state. To facilitate the storage of hydrogen gas, it has to be stored in its liquid form within high pressure tanks.

Low boiling temperature.

Liquid hydrogen cannot be mixed with other liquid fuels. Its low boiling point (-252 C) will freeze other fuels. This means a separate storage tank is needed to store liquid hydrogen.

Small quenching distance

Consequently, hydrogen flames travel closer to the cylinder wall than other fuel before they extinguish. Thus, it is more difficult to quench a hydrogen flame than a gasoline flame. The smaller quenching distance can also increase the tendency for backfire since the flame from a hydrogen-air mixture more readily passes a nearly closed intake valve, than a hydrocarbon-air flame.

Low Ignition Energy

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition

High Auto ignition Temperature

The high auto ignition temperature of hydrogen allows larger compression ratios to be used in a hydrogen engine than in a hydrocarbon engine.

High Flame Speed

Hydrogen has high flame speed at stoichiometric ratios. Under these conditions, the hydrogen flame speed is nearly an order of magnitude higher (faster) than that of gasoline. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle.

High Diffusivity

Hydrogen has very high diffusivity. This ability to disperse in air is considerably greater than gasoline and is advantageous for two main reasons.

2.4 Hydrogen delivering system

After reviewing the literature and balancing the advantages and disadvantages of the four basic types of known hydrogen fueling systems (carburetor, throttle body-injection, intake port fuel injection (PFI) and direct in-cylinder injection (DI) it was decided to observe the difference between two delivery system port injection (PI) and direct in-cylinder injection using commercial software, GT-Power.

Port injection is the most suitable choice because there no need to modified the gasoline engine. The port injection was installed before the fuel inlet to the cylinder and the pressure for inject the hydrogen fueled has a low pressure compare when the hydrogen inject directly to the cylinder engine which much higher about 80 bar compare to port injection about 2-4 bar. However, port injection gave less power output and less volumetric efficiency compare to direct in-cylinder injection. Beside, the gasoline engine need to modified and its too costly.

Furthermore we choose the port injection fuel because it has a simple modification to control the the fuel-ail equivalence ratio was varied from the lean limit at which stable operation was guaranteed to the rich limit at which flash-back occurred and spark timing was also changed called solenoid valve. As a consequence, a hydrogen intake port injection system can be easily installed on a spark ignition engine only with simple modification and the flow rate of hydrogen supplied can also be controlled conveniently.

A fast response solenoid valve which good switch characteristic and very fast response and a high pressure injector is designed to improve hydrogen jet penetration and mixture formation in the combustion chamber and to prevent backfire in hydrogen supply between the fast response valve and the combustion chamber. Besides that, the chip microprocessor is developing to control the ignition and injection timing optimally.