Design of an Engine Using Hydrogen Fuel Derived From Biomass Gasification

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LIST OF ABBREVIATION

H_2	Hydrogen
CO_2	Carbon dioxide
CO	Carbon monoxide
N_2	Nitrogen
SI	Spark ignition
HCCI	Homogenous charge compression ignition
GHSV	Gas hourly space velocities
WHSV	Weight hourly space velocity
WGSR	Water gas shift reaction

LIST OF NOMENCLUTURE

Q	Heat losses (kW)
Qe	The heat lost through the exhaust gases (kW)
M_f	Fuel consumption (kg sn^{-1})
mf	Fuel flow rate (kg h^{-1})
CV	Lower calorific value of the fuel (kJ kg^{-1})
*M*e	Flow rate of exhaust gases (kg sn^{-1})
Ce	Specific heat of exhaust gases (kJ $kg^{-1}K^{-1}$)
*M*w	Flow rate of the cooling water (kg sn^{-1})
Cw	Specific heat of the cooling water (kJ $kg^{-1}K^{-1}$)
P_b	The brake power (kW)
T	*T*orque (Nm)
N	*C*rankshaft rotational speed (rev s^{-1})
η_{th}	Thermal efficiency
sfc	Specific fuel consumption (g $kW^{-1}h^{-1}$)
bsfc	Brake specific fuel consumption (kg $kW^{-1}h^{-1}$)
λ	Air ratio

Design of an Engine Using Hydrogen Fuel Derived From Biomass Gasification

Abstract

Hydrogen is seen as one the important energy vector of next century. Hydrogen as an energy carrier provides the potential for a sustainable development of new engines. A hydrogen fueled engines has a potential for substantially cleaner emissions than other internal combustion engines. The hydrogen fueled engine is being developed into a hydrogen fueled engine with manifold injection, direct injection in cylinder, or dual injection according to the fuel supply method. A four stroke spark ignition (SI) engine was used for conducting this system. Hydrogen used in this engine is obtained from biomass gasification. Biomass system gasification results in conversion of carbonaceous materials to permanent gases, char and tar. There are many ways of biomass thermochemical process such as pyrolisis and gasification using either with air or steam. Catalytic biomass system is used in order to get rich hydrogen. Development of hydrogen fueled engine will become an alternative choice for future application.

Rekabentuk Enjin Menggunakan Hidrogen Sebagai Bahan Bakar Yang Terhasil Daripada Pembakaran Biomass

Abstrak

Hidrogen telah dikenalpasti mampu menjadi salah satu sumber tenaga yang penting pada masa akan datang. Hidrogen bertindak sebagai pembawa tenaga yang berpontensi untuk dibangunkan sebagai bahan api bagi penggunaan enjin baru. Enjin yang menggunakan hidrogen sebagai bahan api menghasilkan hasil yang lebih bersih daripada enjin pembakaran dalaman yang biasa. Enjin hidrogen mula dibangunkan bersama dengan suntikan manifold, suntikan langsung di dalam silinder atau suntikan berkembar sebagai kaedah pembekalan bahan api. Enjin nyalaan percikan empat lejang digunakan dalam sistem ini. Hidrogen yang digunakan untuk enjin ini diambil daripada pembakaran biomass. Sistem pembakaran biomass ini berfungsi menukarkan bahan-bahan berkarbon kepada gas-gas, abu dan tar. Terdapat pelbagai cara untuk memproses biomass secara termokimia seperti pyrolisis dan pembakaran dengan menggunakan udara atau wap. Sistem biomass bermangkin digunakan untuk mendapatkan gas hidrogen dalam kuantiti yang banyak. Pembangunan enjin berasaskan hidrogen mampu menjadi pilihan alternatif untuk dijadikan sumber bahan bakar utama pada masa akan datang.

CHAPTER 1

Introduction

1.1 Background

The present energy situation has simulated active research interest in non-petroleum, renewable, and non-polluting fuels. The world reserves of primary energy and of raw materials are obviously limited. The enormous growth of the world population during the last decades, a strong increased in technical development and standard of living in the industrial nations have led to an intricate situation in the field of energy supply. Much of the present worlds energy demand may still be supplied by exhaustible fossil fuels (natural gas, oil, and coal), which are also the material basis for the chemical industry. It is well known that combustion of fossil fuel causes air pollution in cities acid rains which damages forests, and leads to the build up of carbon dioxide, changing the heat balance of the earth (Maher, 2004). Figure 1.1 shows general process of hydrogen energy system.

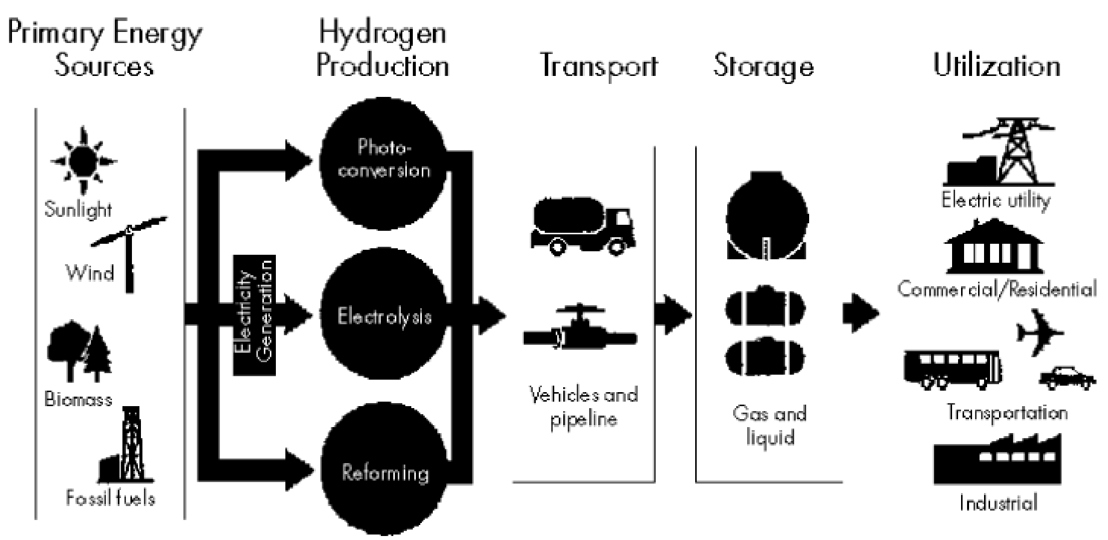

Fig.1.1 A hydrogen energy system. (Seth Dunn, 2002)

Everything, which can be done to save our environment, is important. Biomass as a source of renewable energy presents at least one advantage over fossil fuels. Biomass includes living things such as trees, grass and ocean plants, or the waste products of living things such as agricultural wastes and manure, and urban wastes such as garbage. Biomass energy systems are considered to be environmentally superior to traditional ones from the viewpoints of the CO_2 mitigation and the effective utilization of resources. However, the energy cost of these systems tends to be higher than that of conventional fossil-fuel systems. The amount of electricity that can be produced from biomass power systems can be increased by 50% or more by replacing less efficient conventional boiler systems with advanced biomass gasified/gas-turbine systems.

Hydrogen is not a primary fuel. It can be obtained from either fossil fuels such as natural gas, naphtha, and coal or non fossil energy resources and water by electrolysis, photolysis and thermolysis. As a renewable resource, it has an advantage of low environment impact compared to the fossil fuels. The price of hydrogen obtained by direct gasification of biomass is at least three times higher than hydrogen produced by steam reforming of natural gas (Ayhan, 2004). Hydrogen has been long believed to be one of the most promising alternative fuels for internal combustion and spark ignition engine in terms of emissions control and engine performance. Hydrogen gas is characterized by a rapid combustion speed, wide combustible limit and low minimum ignition energy (Y.Y et al., 2005).

The use of hydrogen as an automotive fuel appears to promise a significant improvement in the performance of a hydrogen fueled engine. The hydrogen fueled engine is being developed into a hydrogen fueled engine with manifold injection, direct injection in cylinder, or dual injection according to the fuel supply method. The present contribution focuses primarily on hydrogen applications in conventional spark ignition engine. There is also much information available and development work relating to hydrogen fueled compression ignition engines of the dual fuel type, homogenous charge compression ignition engines and where ignition is effected, either through surface or catalytic ignition. Values of cycle variation for hydrogen fueled engines with direct injection are higher than those of hydrogen fueled engines with manifold injection or those of gasoline engine, due to a decrease in the mixing period by direct injection in the process of compressing hydrogen gas.

1.2 Problem Statement

Most of today's engines are using gasoline as fuel. The usage of hydrogen to substitute gasoline as fuel needed large budget for producing the hydrogen itself and some renovation to the engine. Biomass system promised to produce hydrogen gas commercially and continuously. By this the shortage of hydrogen can be solved. The biomass system also controls the pollution and avoids the energy wasting. Development of hydrogen engine can be done by applying a few type of fuel such as hydrogen and gasoline mixture, hydrogen and air mixture and pure hydrogen. These hydrogen engines are able to overcome the shortage of fuel. These engines are capable to work in many systems as energy producer. The combination with biomass system promised the continuous supply of hydrogen.

1.3 Aim And Objective

There are four main purposes of this project which are to the study the application of hydrogen as fuel in an engine and to study the process of getting hydrogen from biomass. Others are to choose the type of engine to be used and lastly to study the performance and efficiency of hydrogen fueled engine.

1.4 Scope Of Project

The scope of this project is to study the application of hydrogen as fuel in an engine. The engine used is direct injection hydrogen fuel engine. The hydrogen needed will be obtain from biomass using catalytic gasification.

CHAPTER 2

Literature Review

2.1 Biomass System

The focus on the world's energy recourses was given an international attention at the beginning of the 1950s. It was at that time the industrial world, which practically is self-sufficient in energy, very rapidly became enormously dependent on imports for energy purposes. For the most part it was oil that was allowed to supplant virtually every other alternative. Within 20 years, for examples, the energy situation in Western Europe changed from virtual self-sufficiency to 60% dependency on imports. It was that time too that the energy requirements of the third world became palpably secure and inexpensive energy supplies being, the key to development.

Development needs, combined with rapid population growth, made it necessary to find substitutes for what was then and still remains the dominant source of energy in third world-wood burning. It is easy enough to understand heavy demand on oil. Oil was cheap, convenient and versatile. But the oil crisis of the 1970s demonstrated with brutal clarity the perils of close and one sided dependency on a few types of imported energy. Most countries too realized the effects of allowing energy consumption to rise almost without restraint on the basis of cheap energy. During the 1970s more and more attention came to focus on the environmental impact of energy use on the tremendous damage caused by acidification, with lakes, rivers and forests being populated and poisoned at accelerating rate (H.Egneus et al., 1984).

2.2 Hydrogen from Biomass

Thermochemical hydrogen production technologies use heat and chemical reactions to convert hydrocarbon feedstock to hydrogen. Steam methane reforming, partial oxidation of methane, and biomass gasification and pyrolysis can all be used to produce hydrogen.

The thermal processing techniques for plant material (biomass) and fossil fuels are similar, with a number of the downstream unit operations being essentially the same for both feedstocks. Using agricultural residues and wastes, or biomass specifically grown for energy uses, hydrogen can be produced via pyrolysis or gasification. Biomass pyrolysis produces a liquid product (bio-oil) that, like petroleum, contains a wide spectrum of components that can be separated into valuable chemicals and fuels. The pyrolysis reaction yields coke, methanol, and other gases.

Gasification is not a new technology; however, its use for the conversion of biomass into a viable fuel has been investigated for only the past 20 years. The first system to investigate on the pilot scale was a fluidized bed that incorporated dry ash-free (daf) corn stover as the feed. Corn stover was selected as the feed because, as of 1977, the annual production of ‘corn crop waste”. Biomass gasification develops for the production of medium and high energy gases has received worldwide technical acclaim. The system can utilize a diverse array of feedstock including whole biomass, fractionated biomass, peat, and municipal solid waste (Lee et al., 1996). With the addition of air the gasification reaction then results is a stream of 20% H_2, 20% CO, 10% CO_2, 5% CH_4, and 45% N_2. The processes to generate hydrogen from biomass are listed below:

2.2.1 The Redox Process

Hydrogen may be generated from biomass fuel gas using a method of cyclic reduction and oxidation (Redox) of iron oxides. Redox technology was initially developed during the late 19th and early 20th century for the production of hydrogen and nitrogen from coal. Hydrogen production efficiency depends significantly on the gasifier fuel gas composition and the thermochemical properties of the redox material. The redox technology development was eventually abandoned as other technologies such as pressure swing adsorption (PSA) and cryogenic separation began to dominate. In recent years there has been a renewed interest in developing the redox technology. The technology was based on cyclic reduction and oxidation of iron oxides. In the first stage the metal oxide material was reduced using fuel gas (Fig 2.1). The material was then re-oxidized in a second stage by either steam for hydrogen production or air for nitrogen production (R.Sime et al., 2003).

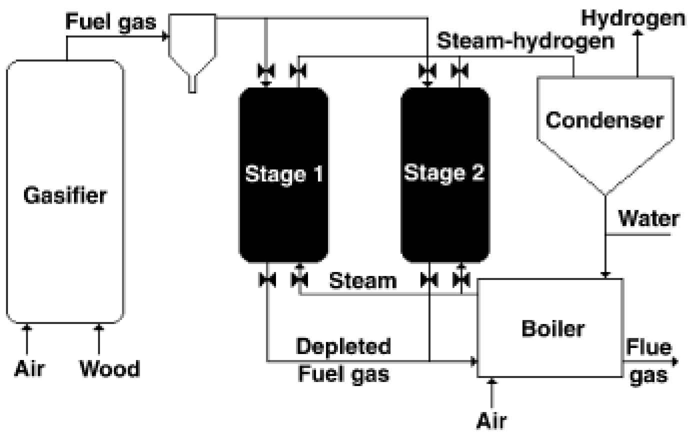

Fig.2.1 Basic REDOX process diagram (R.Sime et al., 2003).

2.2.2 Steam Gasification using a CO_2 Sorbent

In H_2 production from woody biomass by steam gasification using CaO as a CO_2 sorbent, the effect of reaction parameters such as the molar ratio of CaO to carbon in the woody biomass ([Ca]/[C]), reaction pressure, and reaction temperature was investigated on H_2 yield and conversion to gas. In the absence of CaO, the product gas contained CO_2. The H_2 yield and conversion to gas were largely dependent on the reaction pressure, and exhibited the maximum value at 0.6MPa. H_2 was obtained from woody biomass at a much lower pressure compared to other carbonaceous materials such as coal (>12 MPa) and heavy oil (>4.2 MPa) in steam gasification using a CO_2 sorbent. H_2 yield increases with increasing reaction temperature. Woody biomass is one of the most appropriate carbonaceous materials in H_2 production by steam gasification using CaO as a CO2 sorbent (Toshiaki et al., 2005)

2.2.3 Fixed Bed Gasifier

Fixed bed gasifier is the hydrogen production potential from sewage sludge by applying downdraft gasification technique. An experimental study was conducted using a pilot scale (5 kWe) throated downdraft gasifier. The flow rates of the wet product gas, the mass flow rate and volumetric percentage of hydrogen were determined and illustrated. The effects of temperatures of oxidation zone on the production of hydrogen were discussed, and the conversion ratios of dried sewage sludge to hydrogen and ash were also designated. It was concluded that substantial amount of hydrogen gas could be produced utilizing a renewable biomass source such as dried and undigested sewage sludge pellets by applying air blown downdraft gasification technique. The product gas obtained mainly consists of H_2, N_2, CO, CO_2 and CH_4 with a maximum average gross calorific value of 4 MJ/m^3. Around 10 –11% (V/V) of this product gas is hydrogen which could be utilized for fuel cells. Moreover, sewage sludge can be assumed as an alternative renewable energy source to the fossil fuels, and the environmental pollution originating from the disposal of sewage sludge can be partially reduced (Adnan et al., 2002).

2.2.4 Gasification in Supercritical Water Process

Converting biomass into hydrogen can be accomplished in supercritical water. Char and tars formation may be the most significant technological problem. However, catalysis should be the solution to obtain higher yields of hydrogen and to decrease the amounts of chars and tars. A conversion yield reaches 98% with a proportion of hydrogen higher than 50% in the gaseous phase, the next step to consider in a successful transfer to the industrial scale is to evaluate the energy cost of the process. The results showed that the energy efficiency from thermodynamic calculation reaches 60% when considering hydrogen, carbon monoxide and methane as valuable specie in the ideal case. Including energy recovery from the water at 280 bar and 740 C, the overall energy yield reaches 90%. These calculations are overestimated because no heat losses are taken into account. However, the process is energy recovery as the chemical reaction is endothermic and needs high temperature and a rather large ratio of water/biomass (Y.Calzavara et al., 2005).

2.2.5 Supercritical Water Extraction

The aqueous conversion of whole fruit shell to hydrogen rich gas under low temperature, but supercritical conditions was investigated. The yields of total extraction products from supercritical water extraction increase with increasing temperature for all runs. The yields of hydrogen (YHs) increase with increasing temperature and pressure for all runs and the increase of YHs with pressure are higher than those with temperature. Compared with other biomass thermochemical processes such as pyrolysis, gasification, air gasification or steam gasification, the supercritical water gasification can directly deal with the wet biomass without drying, and have high gasification efficiency at lower temperature (Ayhan, 2004).

2.2.6 Catalytic Gasification Of Biomass

Biomass steam gasification leads to a mixture containing water, hydrogen, carbon oxides and small amount of methane and higher hydrocarbon. Ni-Olivine catalyst used for increasing hydrogen production in fluidized bed gasification has been optimized. Performance of the system in methane dry reforming has been studied as a function of nickel content, precursor salt, and calcinations temperature. The optimized catalysts was prepared from nickel nitrate and contained more than 5wt% of nickel oxide on olivine after calcinations at 1100°C. Nickel oxide is strongly linked to olivine, in form of grafts and is still reducible under catalytic test. With a CH_4/CO_2 ratio of 1, methane conversion and hydrogen yield were 95% after 80h of test 800°C (C. Courson et al., 2002).

Catalytic biomass steam gasification runs were performed in a bench scale plant consisting essentially of a fluidized bed gasifier and a secondary catalytic fixed bed reactor. This secondary reactor employed alternatively two different steam reforming catalysts and calcined dolomite. The operating conditions in the gasifier (temperature, biomass/steam ratio and biomass feed rate) were kept constant for all the runs (77O°C, 1 and 764 kg of biomass per hour per m^3 of bed, respectively).

The influence of the operating conditions in the catalytic converter on the production of gases, especially H_2, was investigated over the temperature range of 660-83O°C, for Gas Hourly Space Velocities (GHSV) in the range 9000-27,700 h^{-1}. About 2 m^3 of dry gas (at ambient conditions) per kg of daf biomass were obtained by utilizing the fresh catalyst at the highest temperature level, with more than 60% by volume being hydrogen. The lowest tar residue was 0.45 g/kg of daf biomass, which increased slightly over the three hours gasification time. Substantial carbon deposition was observed, mainly on the catalyst layers contacting the inlet gas. On the basis of these results, a process configuration suitable for industrial applications is discussed (S. Rapagna et al., 1998).

2.3 Hydrogen

The scarcity of fossil fuels and the pollution problems associated with them have drawn researchers towards the search for alternative fuels. Alternative fuels considered at present are synthetic fuels from coal, methanol, ethanol, biodiesel and hydrogen. Hydrogen is a very attractive fuel in two important ways. It is the least polluting fuel that can be used in an internal combustion engine, and it is potentially available anywhere (F. Yuksel et al., 2003). Hydrogen has long been recognized as a fuel having some unique and highly desirable properties, for application as a fuel in engines. It is the only fuel that can be produced entirely from the plentiful renewable resource water, albeit through the expenditure of relatively much energy. Its combustion in oxygen produces uniquely only water but in air it also produces some oxides of nitrogen. Hydrogen as a renewable fuel resource can be produced through the expenditure of energy to replace increasingly the depleting sources of conventional fossil fuels. Accordingly, research into all aspects of hydrogen technology, especially in recent years has been truly massive and diversified.

Hydrogen gas has been in wide use as a fuel for quite a long time. Additionally, enormous quantities of hydrogen are used increasingly as a raw material in a wide range of applications in the chemical industry, particularly in the upgrading of conventional fuel resources. These features make hydrogen an excellent fuel to potentially meet the ever increasingly stringent environmental controls of exhaust emissions from combustion devices, including the reduction of green house gas emissions. The viability of hydrogen as a fuel in general and in engine applications in particular, is critically dependent on the effective, economic and satisfactory solution of a number of remaining key limiting problems. These limitations that hinder its widespread application as an engine fuel are primarily related to its production, storage, portability, transport and purity. These limitations can be considered to be far more serious than those facing the current and future applications of other fuels, including natural gas (Ghazi, 2003).

A number of advantages arise when using hydrogen in small controllable amounts with other fuels. Hydrogen may be used to extend the lean limit of conventional fuels in order to achieve higher efficiency and lower pollutant emissions. The basic properties of hydrogen and gasoline are shown in Table 2.1. Because of its wide flammability limits and high flame speeds, the hydrogen rich fuel lends itself readily to ultra lean combustion (and should allow the use of higher compression ratios). Combining the increase in heating value and recovery of waste energy from engine exhaust, lean operation provides a potentially high increase in thermal efficiency for hydrogen enriched fuels over that of the conventional fuels. However, hydrogen has an extremely low density, which causes reduction of the energy density of hydrogen–gasoline–air charge, and hence the power output. Since the primary end use of fossil fuels is gasoline, and the burning of gasoline is the main source of atmospheric pollution, the first area for application of hydrogen fuel should be internal combustion engines. A number of researchers have investigated the possibility of combining hydrogen with other fuels in dual fuel applications (F. Yuksel et al., 2003).

Property	**Hydrogen**	**Gasoline**
Molecule mass	2.016	107.0
Density (g cm^{-3}) (20 °C, 760 mm Hg)	83.764x10^{-6}	0.70–0.75
Liquid density (g cm^{-3})	0.708	0.70–0.75
Range of combustion in air in volume (%)	4–75	1.0–7.6
Stoichiometric content in volume (%)	29.63	1.76
Working mixture content–ratio		
of amount of air and fuel		
—ratio of air and fuel (in units of weight)	364.8–4.8	25–4.3
—ratio of air and fuel (in units of volume)	24–0.3	100–16.7
Theoretical content of the working mixture		
—ratio of air and fuel (in units of weight)	34.3	15.1
—ratio of air and fuel (in units of volume)	2.38	59.5
Minimum ignition energy in air (mJ)	0.02	0.24
Quenching gap in air (cm)	0.064	0.2
Self-ignition temperature (K)	858	501–744
Combustion speed in air at normal conditions (cm s^{-1})	265–325	37–43
Flame temperature in air (K)	2318	2470
Low heat of combustion in mass (kJ kg^{-1})	120 000	44 000
Net energy density (MJ m^{-1})	10.3	202

Table 2.1 Some properties of hydrogen and gasoline (F. Yuksel et al., 2003)

2.4 Hydrogen Engine

The use of hydrogen as an engine fuel has been attempted on very limited basis with varying degrees of success by numerous investigators over many decades and much information about their findings is available in the open literature. However, these reported performance data do not necessarily display consistent agreement between various investigators. There is also a tendency to focus on results obtained in specific engines and over narrowly changed operating conditions. Moreover, the increasingly greater emphasis being placed on the nature of emissions and efficiency considerations often renders much of the very early work fragmentary and mainly of historical value.

The concept of hydrogen enrichment was first proposed by Jamal, et.al. (1994) at Jet Propulsion Laboratory (JPL) to allow lean operation of the engine to produce low NOx emissions. Parks (1976) carried out experiments on a CFR engine at 1200 rpm and operating with a compression ratio of 8:1. The equivalence ratio was decreased from 0.9 in steps of 0.1, and values of the ratio of the hydrogen mass flow rate to that of the gasoline were selected as 0, 13, 23, 48 and 100% to study the effects of hydrogen enrichment of hydrocarbon and NOx emissions. For all fuel mass fraction values other than 100%, the minimum hydrocarbon level occurred at approximately 0.8 equivalence ratio and then increased until the lean limit for that equivalence ratio was reached. For all values of fuel mass fraction, NOx emissions peaked at approximately 0.85 equivalence ratio and fell sharply as equivalence ratio decreased towards the lean limit. Lucas, et.al. (1982) have reported their experience with an engine running on composite hydrogen gasoline. The engine was allowed to run with a constant hydrogen flow and hydrogen only at idling conditions. Gasoline was added as the load increased. The experiments produced extremely interesting results; there was an increase in part load efficiency due to reduced pumping losses and reduced heat losses to the coolant. Specific fuel consumption was also reduced to about 30%. As far as exhaust emission studies indicate, both CO and NOx emissions were reduced, even though an increase was observed in HC emissions. Mercedes-Benz has utilized gasoline–hydrogen duel fuel engines in some of its prototype vehicles (Povel et al., 1987). The engines for these vehicles were designed to utilize the positive combustibility characteristics of hydrogen while avoiding the pitfalls of pure hydrogen operation. For start-up and idle conditions, the engine was operated on a mixture of hydrogen and gasoline. The high excess air operation possible with hydrogen at low and part loads could be used to reduce the overall formation rate of NOx, increase the thermal efficiency of the engine, and reduce fuel consumption. At full load, pure gasoline operation was used to avoid the power loss associated with the lower per volume calorific value of hydrogen. Sher, et.al (1987) carried out work on a 2310 cm 3 4-cylinder engine with gasoline and hydrogen enriched gasoline. Significant reduction in the brake specific fuel consumption of the order of 10–20% was achieved with hydrogen enriched gasoline for hydrogen to fuel mass ratio of 2–6%. Above 6% of hydrogen enrichment, the decrease in the brake specific fuel consumption was marginal throughout the experimental range. Cycle-to-cycle variation was reduced when a small amount of hydrogen was introduced.

Hongwei has brought out some interesting results through his research on mixed fuel operation of hydrogen and gasoline in motor vehicles. The results of this investigation showed that as the hydrogen supply increased from 0 to 5%, the total horse power decreased by about 5%, and total indicated specific fuel consumption decreased by 11% as compared to the pure gasoline operations. These experiments on road testing of the vehicle showed a saving of 30–40% of gasoline when only 4% hydrogen was supplied into the engine (Petkov et al., 1987). Experiments with internal combustion engines very often involve a thermal balance on the engine. Energy is supplied to the engine as the chemical energy of the fuel and leaves as energy in the exhaust, cooling water, brake power and heat transfer. Heat losses must be decreased to improve the engine efficiency. Therefore, it is very important to know the fraction of the heat loss mechanisms. This is the aim of the thermal balance experiments. There are many reports about the effects of the hydrogen supplementation on the performance and emission characteristics. However, it is apparent that a little information is available on thermal balance of electronically controlled spark ignition engines operating on hydrogen supplementation. The objective of the study reported in this paper is to establish the thermal balance of such a conventional spark ignition engine.