The Effect of Hydrogen Fuel on the Performance and on the Oil of Internal Combustion Engine

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To his parents, brothers and sisters; the author is deeply grateful for their love, encouragement, and for their help through his study in other ways too numerous to mention.

To the Commercial and Industrial Company (Ford), the author is deeply grateful for its help and encouragement.

DEDICATION

To my parents.

To my brothers.

To my sisters.

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Nomenclature

h	airflow manometer reading	mm
$\dot{m}_a$	mass flow rate of air	kg/s
$\dot{m}_f$	mass flow rate of fuel	kg/s
p	pressure	Pa, (mb)
$\bar{p}_i$	indicated mean effective pressure	N/m^2 (Pa)
sfc	specific fuel consumption	kg/kWh
sg_f	specific gravity of fuel	
t	time for engine to consume given quantity of fuel	s
A	cylinder cross-sectional area	m^2
L	engine stroke	m
V_S	swept volume ($= A \times L$)	m^3
N	engine speed	rev/min
τ	torque	Nm
T	absolute temperature	K
T_f	friction torque	Nm
V_a	volume flow of air	m^3/s
V_f	volume flow of fuel	m^3/s
μ	coefficient of viscosity	kg/ms
ρ_a	density of air	kg/m^3
ρ_f	density of fuel	kg/m^3
ρ_w	density of water	kg/m^3
η_b	brake thermal efficiency	

η_m	mechanical efficiency	
η_v	volumetric efficiency	
BTDC	before top dead centre	
ATDC	after top dead centre	
BBDC	before bottom dead centre	
ABDC	after bottom dead centre	
TDC	top dead centre	
BDC	bottom dead centre	
Re	Reynold’s number	
rpm	Revolution per minute	
LHV	Lower heating value	MJ/kg

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Abstract

In this work a comparison in the performance of an engine when it is powered by hydrogen fuel and gasoline fuel was carried out. Also, the effect of hydrogen fuel on the engine oil was investigated.

Mass flow rates of the fuel and air as well as the torque of the engine were measured. Then thermal and volumetric efficiencies, brake power and specific fuel consumption were calculated. Hence the performance of the engine was obtained.

It was found that the brake power and the volumetric efficiency of the engine drop down when the engine is powered by hydrogen, while the specific fuel consumption is drastically improved by about 30% when hydrogen is used as a fuel. Thermal efficiency was also slightly increased compared with that for gasoline.

Equally important is that the engine oil is not affected when the engine is powered by hydrogen fuel for the test duration.

Finally, it was found that there is no hydrocarbon compounds (HC), carbon monoxide (CO) emissions. Nitrogen oxides (NO_x) emission reduced when the engine powered by hydrogen fuel.

1. INTRODUCTION

1-1 General:

Fossil fuels, which meet most of the world energy demand today, are being depleted rapidly. Also, combustion products are causing global problems, such as greenhouse effect, ozone layer depletion, acid rain and pollution, which are posing great danger for our environment and eventually, for the total life on our plant.

Air pollution from road vehicles and power stations is not only major contributor to climate change, but has also been implicated in diseases from asthma to lung cancer. Indeed, the World Health Organization estimates show about that three million deaths per year globally are directly attributable to localized air pollution.

Many engineers and scientists agree that the solution to all of these global problems is to be replace the existing fossil fuel systems with the hydrogen fuel system.

Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gasses, no ozone layer depleting chemicals and little or no acid rain ingredients and pollution. Hydrogen may be produced by utilizing renewable energy sources, e.g. solar that may be converted into the electrical power, which is necessary for electrolysis of water.

1-2 Objectives of the present work:

In this work internal combustion engine will be powered by hydrogen fuel. Experimental investigation is carried out to determine the performance of the engine by measuring mass flow rate of fuel and air as well as the torque of the engine. From these parameters the thermal and volumetric efficiencies, brake power and specific fuel consumption can be estimated and hence the performance of the engine.

Then comparing the performance of the engine using hydrogen fuel with the performance of the engine using gasoline fuel. Finally the effect of the hydrogen fuel on the engine oil will be investigated by the analysis of different oil samples that will be withdrawn from the engine at specified time intervals.

1-3 Layout of the thesis:

This thesis is divided into seven chapters; the first chapter is the introduction. Literature review is presented in chapter two. Hydrogen basics and general information about hydrogen are presented in chapter three. Experimental setup and procedure are presented in chapter four. Theory of combustion is presented in chapter five. The obtained results are shown in chapter six. Also, the discussion of these result presented in this chapter. Finally, chapter seven presents conclusions and recommendations.

2. LITERATURE SURVEY

2-1 Literature Survey:

A lot of research has been published on the performance of hydrogen fuel on the internal combustion engines either as a pure hydrogen or mixed with other fuel.

Ricardo (1923) used hydrogen as fuel in internal combustion engines during the late 1800's and he was able to achieve high thermal efficiencies. However, serious problems resulted from using this fuel in the spark-ignited engine, for example one of the most important problem is poor engine operation that was thought to be caused by detonation of the hydrogen-air mixture.

Erren (1933) refreshed the work on hydrogen as a fuel where he used it to power large dirigibles. Further, he solved the carbureator and backfiring problems by direct injection of hydrogen into the combustion chamber.

Billings *et al.* (1966) have modified and tested a hydrogen-powered engine. The modification included the installation of a gaseous-type carburetor modified to accommodate hydrogen, accompanied by a water injection system to cool the combustion flame and to quench the hot spots within the cylinder which can cause backflashing. Furthermore, the modification to overcome the backflashing problem included the installation of stainless steel spark plugs and the decreasing of the spark gap. Finally, they found that the modified hydrogen fired engine is more efficient than the corresponding gasoline-fired one.

Liu *et al.* (1994) studied the effects of the admission of hydrogen on the knocking characteristics and operation of a duel-fuel engine. These effects were examined through modeling, in the chemical reaction of the pre-ignition and subsequent combustion processes. It was noted that the knocking characteristics of hydrogen tend to be markedly different from those encountered with other gaseous fuels.

Nakamura *et al.* (1995) developed and investigated a 250 W class portable fuel cell system with a hydrogen supplier utilizing a hydrogen-absorbing alloy to meet demand for clean and silent power source. The operating performance of the fuel cell unit was examined and the hydrogen supplier using this alloy was characterized. The hydrogen supplier and the fuel cell unit showed a successful operating performance.

Das (1996) discussed various possible storage techniques for hydrogen use in the automobile sector. He concluded that while considering hydrogen for automotive applications one important factor must be carefully viewed; namely, the fuel metering system should be capable for supplying the desired quantity of fuel to the engine at appropriate point in the engine cycle to ensure engine operation.

Karim *et al.* (1997) made a review of the effects of the presence of some hydrogen with methane on the main combustion characteristics of the fuel for engine application. It was shown experimentally that the performance of a single cylinder spark ignition engine fuelled with methane can be improved significantly through mixing some hydrogen with methane.

Vandenborre *et al.* (1998) an existing urban diesel bus has been used to demonstrate a proof of the concept with regard to the conversion of such a bus towards the non-polluting fuel hydrogen. The performance of the modified bus was measured using a test cycle of 13.6 km length with 28 start/stops at varying intervals. Results on the road were measured. Exhaust gas measurements were carried out during different test drives during cycle, (concentrations of CO_2, CO, HC and H_2) are below the resolution of measuring devices and the readings were “Zero”.

Yasuo *et al.* (2000) used a hybrid electric vehicle with internal combustion engine fired with hydrogen. The effect of compression ratio, surface/ volume ratio of combustion chamber and the boost pressure on thermal efficiency and exhaust emissions were investigated. Finally, they found that a decrease in the surface/ volume ratio may result in a maximum increase in the indicated thermal efficiency by 44%. Nitrogen oxides (NO_x) emission was found to be less than 10 ppm.

3. HYDROGEN BASIC AND GENERAL INFORMATION

3-1 Hydrogen Basic:

Hydrogen, the simplest element, is composed of one proton and one electron. It makes up more than 90% of the composition of the universe. More than 30% of the mass of the sun is atomic hydrogen. It is the third most abundant element in the earth's surface and is found mostly in water. Under ordinary (earthly) conditions, hydrogen is colorless, odorless, tasteless, and nonpoisonous gas composed of diatomic molecules (H_2).

3-2 Advantages and Opportunities:

Hydrogen is often considered as complementary energy carrier for the future. It has some unique properties, which make it an ideal energy carrier or fuel:

- Hydrogen has two distinguishing properties which separate it in each case by an order of magnitude from hydrocarbon fuels: low ignition energy, which makes it susceptible to ignition by a smaller heat sources, and higher flame speed, which contributes to rapid growth of small flame nuclei and decreases the time available for quenching.
- Hydrogen can be produced from a variety of renewable sources, e.g., solar and biomass and has many uses in our economy. Thus, the dependence on petroleum products will be decreased. Because of

versatility of production methods and end use, wide-spread hydrogen energy use will create significant benefits to the agricultural, manufacturing, transportation, and service sectors.

- Hydrogen can be combined with gasoline, ethanol, methanol, or natural gas; adding a 5% hydrogen to the gasoline/air mixture in an internal combustion engine could reduce nitrogen oxide emissions by 30-40%. An engine converted to burn pure hydrogen produces only water and minor amounts of nitrogen oxides in the exhaust.
- Hydrogen, can be converted to other forms of energy in five different ways; in addition to flame combustion, it can be converted directly to steam, converted to heat through catalytic combustion, act as a heat source and/or heat sink through chemical reactions, and converted directly to electricity through electro-chemical processes (fuel cell). In other words hydrogen is the most versatile fuel.

3-3 Production of Hydrogen:

There are many methods to produce hydrogen. The choice of production method will vary depending on the quantity and desired purity of hydrogen. The most popular production methods are discussed briefly:

3-3-1 Electrolysis:

Electrical energy is used to split water into hydrogen and oxygen as gas:

$$2H_2O + \text{electricity} \rightarrow 2H_2 + O_2$$

Renewable energy sources of electricity, such as solar, wind, and hydropower, which employed to generate green electricity that can be used in this process.

3-3-2 Natural Gas Steam Reforming:

The first step of this process is to expose natural gas to high-temperature steam to produce hydrogen, carbon monoxide, and carbon dioxide. The second step is to convert the carbon dioxide with steam to produce additional hydrogen and carbon monoxide. Most hydrogen is produced by this process..

3-3-3 Photoelectrolysis:

In a one-step process, sunlight is absorbed in a semiconductor, splitting water into hydrogen and oxygen.

3-3-4 Biomass Gasification and Pyrolysis:

The production of hydrogen can result from high-temperature gasifying and low-temperature pyrolysis of biomass (feedstocks, include wood, and forest and agricultural residues).

3-4 Hydrogen Storage:

The main problem with using hydrogen to power a vehicle its storage. Because the containers have to withstand very high pressure and have to be crash resistant. This section outlined two techniques for hydrogen storage:

3-4-1 Electrochemical Electricity Generation (Fuel Cells):

Hydrogen can be combined with oxygen without combustion in an electrochemical reaction (reverse of electrolysis) and produce electricity Direct Current (DC). The device where such a reaction takes place is called the electrochemical fuel cell or just fuel cell.

The fuel cell have two semi-porous electrodes separated by a liquid electrolyte, effectively creating a capacitor. The interior sides of the electrodes are coated in a platinum catalyst to aid the reaction. When the hydrogen and oxygen seep through the porous electrode, they come into contact with the catalyst and the electrolyte, and they each ionize. The hydrogen ion is then attracted to the oxygen ion and they combine to form water. The electricity created runs through the circuit.

$$2H_2 + O_2 \xrightarrow{\text{platinum catalyst}} 4H^+ + 2O^{-2} \xrightarrow[\text{out}]{\text{electricity}} 2H_2O$$

Fuel cells on their own are very small and do not produce much electricity so; they are usually arranged in a formation known as a stack. Because fuel cells have no moving parts this makes them very efficient and so, perfectly adopted for vehicle use. The estimated cost, on commercial scale for a fuel cell engine is about that of an internal combustion engine, but the long term costs should be far less due to the lack of moving parts.

3-4-2 Hydrogen Storage in Metal Hydrid:

Hydrogen can form metal hydrides with some metals and alloys. During the formation of the metal hydride hydrogen molecules are split and hydrogen atoms are inserted in spaces inside the lattice of suitable metals and/or alloys.

In such a way an effective storage is created comparable to the density of liquid hydrogen. However, when the mass of the metal or alloy is taken into account then the metal hydride gravimetric storage density is comparable to storage of pressurized hydrogen.

During the storage process (charging or absorption) heat is released which must be removed in order to achieve the continuity of the reaction.

During the hydrogen release process (discharging or desorption) heat must be supplied to the storage tank.

An advantage of storing hydrogen in hydriding substances is the safety aspect. For example, serious damage to a hydride tank, such as the one which could be caused by a collision, would not pose fire hazard since hydrogen would remain in the metal structure.

4. EXPERIMENTAL SET UP AND PROCEDURE

This chapter describes the apparatus used to perform the experiments and the procedure that was followed throughout the experiments.

4-1 Experimental Equipment:

In the present work the following equipments were used:

4-1-1 TD43 Internal Combustion Engine:

The TD43 test rig is built a round a farryman A30 main water-cooled single cylinder and four stroke engine. The compression ratio may be varied between 5:1 & 18:1.

The engine is directly coupled to an electrical dynamometer. This also used to start the engine and to turn the engine for friction power tests. Both the engine and the dynamometer are mounted on a rigid steel bedplate, which is free standing on four vibration isolation feet.

Two panels stand behind the engine and dynanometer. One panel contains the electrical controls, for controlling the dynamometer in its motor and generation modes as well as the switches for loading the dynamometer. The other panel houses the instruments for measuring engine performance.

Fuel tank for petrol and diesel are mounted above the panel, together with the cooling water tank. Behind the panel is a viscous flow measuring the air consumption of the engine, and the radiator/ fan unit used to cool the engine.

4-1-2 Gas Regulator:

The regulator is made up of aluminum. It is located between the engine and the hydrogen cylinder put on the cylinder side. The regulator is triggered by the suction pressure and hence it keeps the fuel supply lines open under negative pressure only, which exists under no leak conditions and when the engine is running. Further, the regulator will eliminate the occurrence of backfire; this is because of the selected quenching diameter technique installed at the inlet and at the outlet ports. Also the regulator will ensure smooth flow of hydrogen from the cylinder to the carburetor and eliminate the pulsating flow whatever is the pressure inside the cylinder and it permits a fixed amount of hydrogen to flow, this lead to cut in the fuel consumption.

A schematic diagram of the regulator is shown in figure.4-1. Initially the needle, which is of conical geometry, is set such that pressure caused by the stiffness of the spring balances both the inlet and outlet pressures of hydrogen: this is the idling conditions. When more fuel is required by the engine, the suction pressure down at the outlet port decreases, as a result the pressure inside the regulator decreases leading to inward motion of the diaphragm, hence the connecting arm pushes the needle backward to allow more fuel to flow into the engine. The reverse occurs when less fuel is required by the engine, as a result the suction pressure increases leading to an increase in pressure inside regulator and hence the connecting rod push the needle forward leading to decrease in the flow of fuel into the engine.

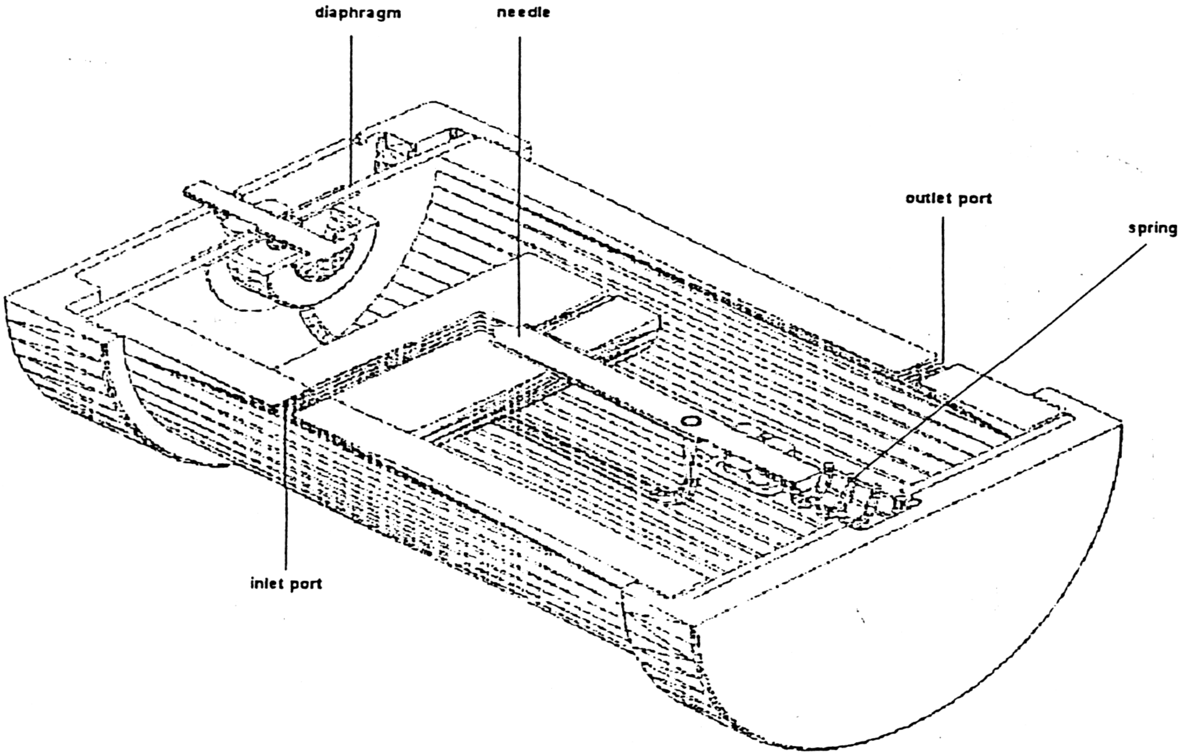
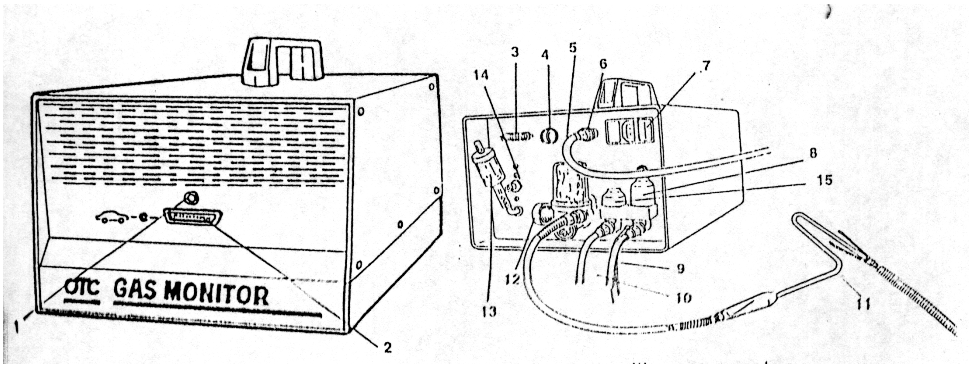


Figure. 4-1. Gas Regulator

4-1-3 Gas Monitor:

Gas monitor (analyzer) was used to analyze the exhaust gases from the engine. Fig.4-2 shows the main parts of this device.



1. ON/OFF light.
2. Auxiliary connector.
3. DB25S connection.
4. Power line for printer.
5. 12 volt fuse.
6. Battery jack.
7. 110 volt AC inlet power switch.
8. Oxygen sensor.
9. Drain hose.
10. Waste gas hose.
11. Exhaust Sampling hose and probe.
12. Input sample filter.
13. Air filter.
14. Calibration gas fitting.

Figure.4-2. Gas monitor and its parts

5. THEORY

5-1 Criteria of Performance:

Efficiency of an engine is measured by the ratio of the rate of fuel energy in and the mechanical power out. The available energy in the fuel is defined by the lower heating value (LHV), fuel measurement, while not required for closed loop control, is very useful to determine the operating efficiency of the engine. The energy flowing into the engine can be calculated and the brake power (mechanical energy out) can be measured. The result can be expressed either as thermal conversion efficiency or specific fuel consumption (sfc) or volumetric efficiency.

5-3-1 Brake Power:

The power actually available at the engine shaft is called the brake power, since it is usually obtained from measurements of the engine torque when driving against a brake and it is given by the following formula:

$$\text{Brake Power} = \frac{2\pi NT}{60}(\text{watt})$$

Where: N = engine speed (rpm), τ = torque (Nm).

5-3-2 Mechanical Efficiency and Friction Power:

The difference between the indicated and brake powers is the lost in mechanical friction.

Friction power = indicated power – brake power

Friction power can be calculated directly by recording the torque required to turn the engine with dynamometer acting as a motor, which represented by the following formula:

$$\text{Friction Power} = \frac{2\pi N\tau_f}{60}(\text{watt})$$

Where τ_f = friction torque reading from the meter.

- Mechanical efficiency is defined as:

$$\xi_m = \frac{\text{brake power}}{\text{indicated power}}$$

5-3-3 Specific Fuel Consumption:

Specified consumption is defined as the fuel flow rate per unit power output. It is a measures of how efficiently an engine is using the fuel supplied to produce work and represented by the following formula:

$$\begin{aligned} \text{sfc} &= \frac{\text{consumption of fuel (mass/unit time)}}{\text{brake power}} \\ &= \frac{\dot{m}_f}{\text{brake power}} \end{aligned}$$

Where: $\dot{m}_f$ is mass flow rate per unit time.

$$\dot{m}_f = \frac{16\times10^{-3} * \text{sgf}}{t}\text{kg/sec.}$$

The specific gravity of gasoline is typically 0.741.

5-3-4 Brake Thermal Efficiency:

The brake thermal efficiency is a measure of the overall efficiency of the engine, which is defined as:

$$\xi_{bth} = \frac{\text{brake power}}{\text{energy supplied}}$$

$$\xi_{bth} = \frac{\text{brake power}}{\dot{m}_f \times \text{lower heating value of fuel}}$$

Which is inversely proportional to the specific fuel consumption.

5-3-5 Volumetric Efficiency:

The power output of an engine depends on the amount of charge that can be induced into the cylinder. In practice the engine does not induce a complete cylinder full of air on each stroke, and it is convenient to define a volumetric efficiency as:

$$\xi_v = \frac{\text{mass of air consumed per unit time}}{\text{mass of flow of air to fill swept volume at the atmospheric conditions}}$$

For TD43 which has a swept volume of 582 cm^3. The mass flow of air required to fill this volume in unit time is:

$$\rho_a \times 582 \times 10^{-6} \times \frac{n}{2 \times 60}$$

$$= 4.85 \times 10^{-6} \rho_a N$$

The volumetric efficiency is therefore given by:

$$\xi_v = \frac{\dot{m}_a}{4.85 \times 10^{-6} \times \rho_a N}$$

Where $\dot{m}_a$ is in kg/sec. In practice, since the value of m, is very small, it is usual to redefine $\dot{m}_a$ in terms of kg/hr.

Therefore, $\xi_v = \dfrac{\text{mass of air/hr}}{0.0175\rho_a N}$

6. RESULTS AND DISCUSSIONS

6-1 Results and Discussions:

The recorded experimental data were used to compare the performance of both hydrogen and gasoline fired engines.

Figures.6-1 through 6-4 show the variation of brake power with engine speed for different ignition timing. It is noted that the brake power produced by gasoline fired engine is of higher value than that produced with hydrogen. This because: the torque produced when hydrogen used is less than the torque produced by gasoline and this is due to two reasons. First, hydrogen is characterized with low energy density compared with gasoline, the energy density of gasoline is 2600 times that of hydrogen, which means that for a certain volume of a fuel enters the cylinder, hydrogen has less energy than gasoline and as a result the output torque is small, consequently the output power will be also small. Second, this may be due to the fact that volumetric efficiency of hydrogen powered engine is less than that of gasoline powered engine. So, the amount of fuel-air mixture is less in the case of hydrogen powered engine which produces less torque and power.

The optimum spark timing, is achieved such that the complete composition of fuel, is achieved when the piston has just reached to Top Dead Center (TDC). Results indicate that the maximum brake power was obtained at 0 BTDC when engine is fired by hydrogen fuel, while it was obtained at 10 BTDC for the gasoline fired engine. This is may be attributed to:

- Flame speed for hydrogen is much larger than that for gasoline, so hydrogen needs less time to burn out.
- Hydrogen is a gas and ready to burn, but gasoline needs more time to evaporate and mix homogenously with air.

Figures.6-5 through 6-8 show the variation of brake thermal efficiency with engine speed for different values of ignition timing. It may be noticed that hydrogen produced better thermal efficiency, and this may be due to the nature of combustion, specially flame speed.

The flame speed of hydrogen fuel is higher than that of gasoline which causes an improvement in the combustion efficiency and as a result enhance engine performance.

Another cause of the good thermal efficiency may be due to what is called quenching effect (quenching diameter). From theory, quenching diameter for hydrogen is less than that for gasoline, which will enable the hydrogen flame to travel through a narrow diameter which lead to less fuel consumption under similar operating conditions and as a result improve the thermal efficiency.

Figures.6-9 through 6-12 represent the variation of volumetric efficiency with engine speed for different values of ignition timing. It is noticed that the volumetric efficiency of gasoline is greater than that of hydrogen, and this may be due to the gaseous nature for the hydrogen fuel which is very sensitive to temperature changes. From the exhaust heat the engine may cause a rise in the hydrogen temperature, which cause a reduction in the hydrogen flow rate and as a result a drop in volumetric efficiency. In the case of gasoline, heat from exhaust to the input gasoline will cause vaporization of the gasoline and improve its combustion product.

Figures.6-13 through 6-16 show variation of specific fuel consumption with engine speed for different values of ignition timing. From these figures it may be noticed that specific fuel consumption of hydrogen is lower than that of gasoline. For gasoline the fuel consumption is minimum at a speed of 1250 rpm, which corresponds to the cruise speed.

As shown in figures the specific fuel consumption of a hydrogen fired engine is almost independent of speed, for speed test range in this work, while it increases at certain speed for gasoline fired engine.

It may be noticed that the optimum specific fuel consumption was achieved at 0 BTDC ignition starting. This behavior is in fully agreement with the theory.

It was found that gasoline fired engine suffers from knocking especially at low ignition timing at high speed, but in the case of hydrogen fired engine there was no knocking in the engine this is because:

1- Flame speed reaction of hydrogen is larger than that for gasoline, which means that the flame will reach the end of mixture, i.e. charge, before itself ignite.
2- Self ignition temperature, are (585°C) and about (228-417°C) for hydrogen and gasoline respectively. So in case of hydrogen the end mixture needs more time to self ignite.

Figures.6-17 through 6-20 show the exhaust gases emissions variation with engine speed, when engine powered by gasoline. For hydrogen powered engine there is no emissions except small amount of nitrogen oxides gas.

Tables 6-1 through 6-3 represent the amount of metals in the engine oil before and after the engine operation. It may be noticed that the concentration of aluminum and chrome is zero when the engine powered either by hydrogen or gasoline. But iron concentration was about the same for hydrogen and gasoline fuels, i.e. 47 and 53.5 respectively.

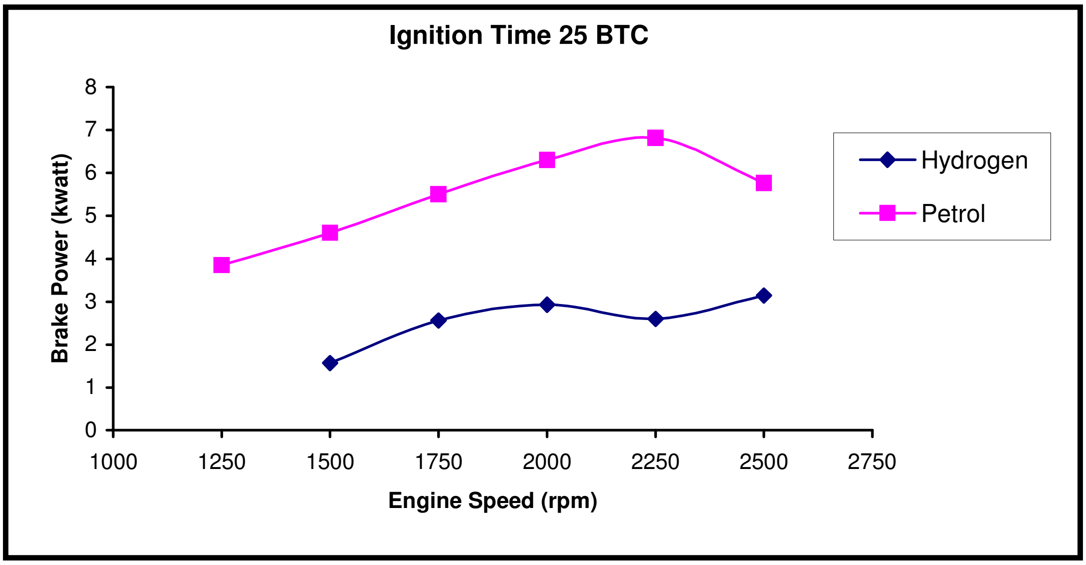


Fig.6-1. Variation of brake power with engine speed for hydrogen and gasoline fuel at ignition timing 25 BTC

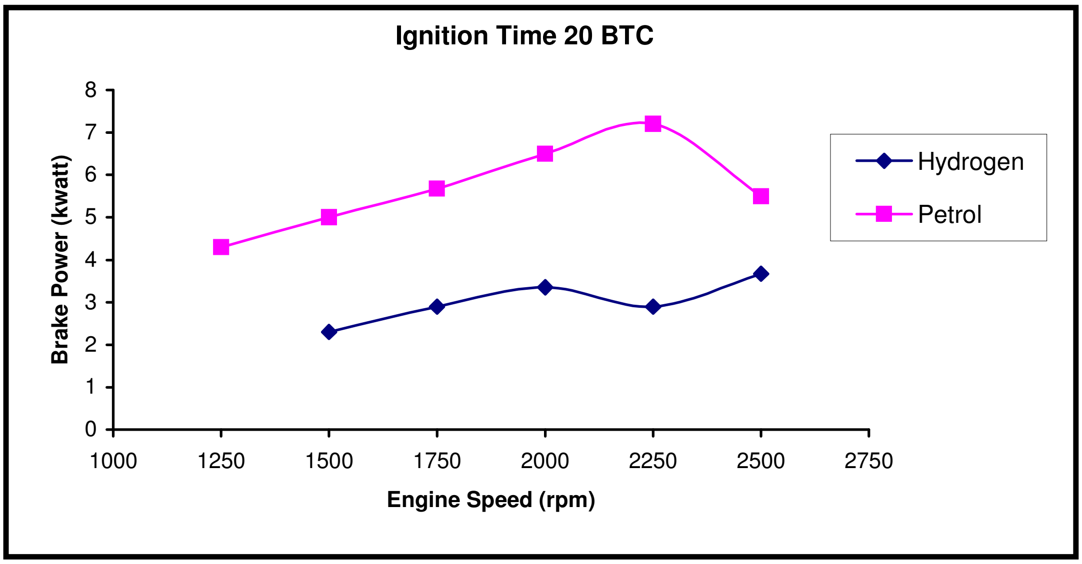


Fig.6-2. Variation of brake power with engine speed for hydrogen and gasoline fuel at ignition timing 20 BTC

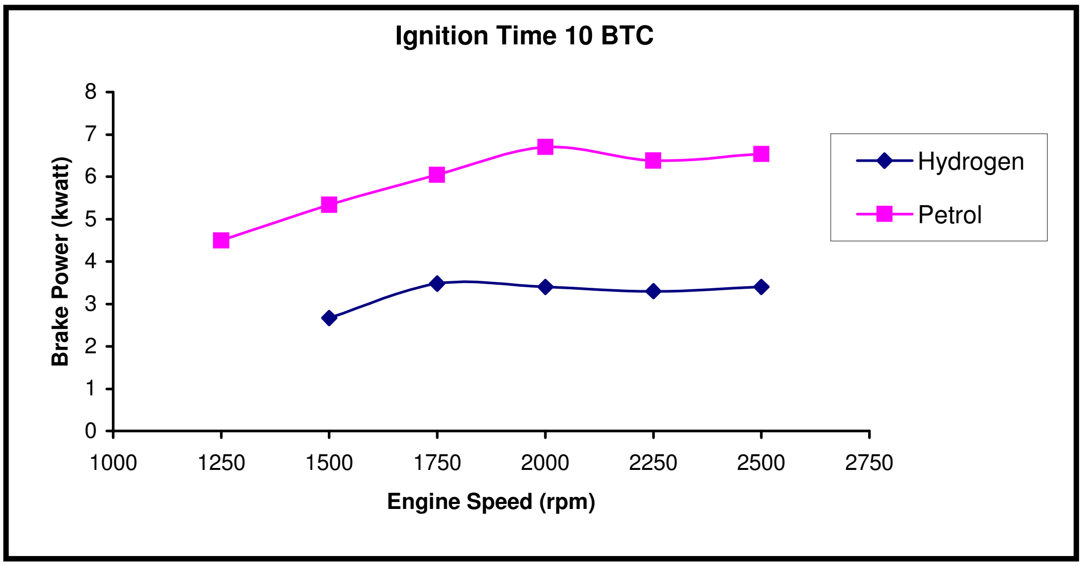


Fig.6-3. Variation of brake power with engine speed for hydrogen and gasoline fuel at ignition timing 10 BTC

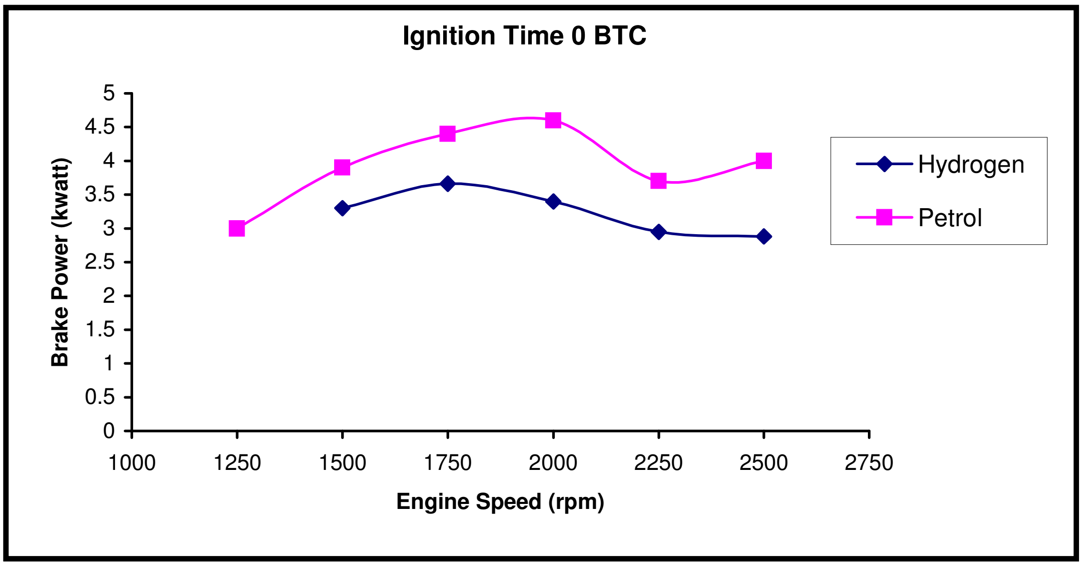


Fig.6-4. Variation of brake power with engine speed for hydrogen and gasoline fuel at ignition timing 0 BTC

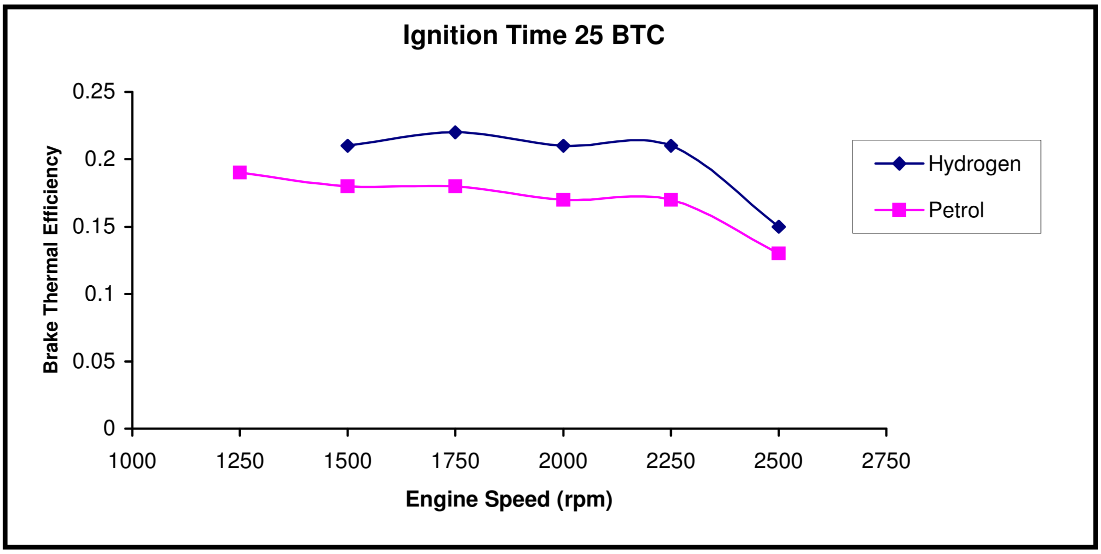


Fig.6-5. Variation of brake thermal efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 25 BTC

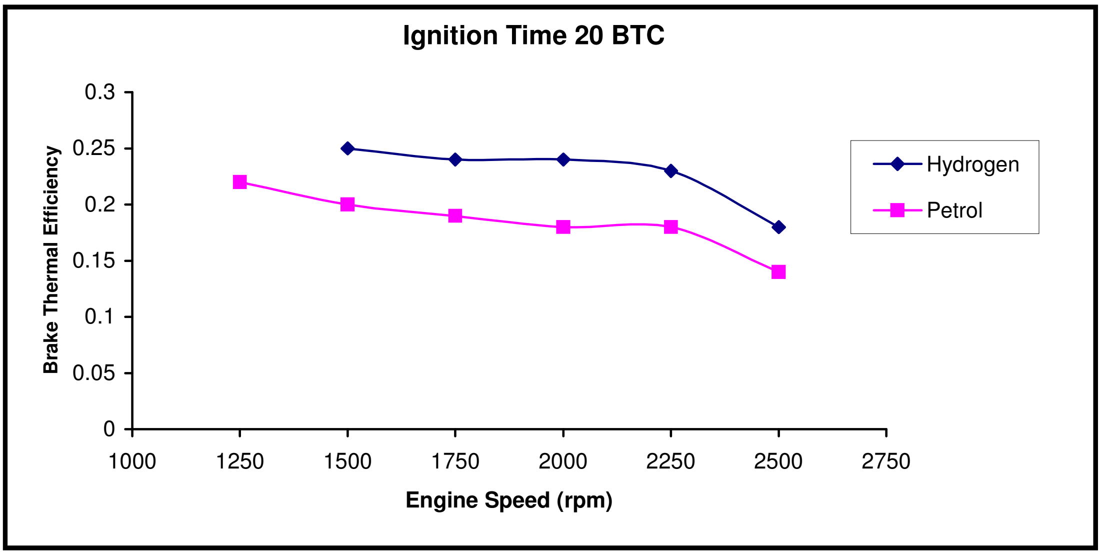


Fig.6-6. Variation of brake thermal efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 20 BTC

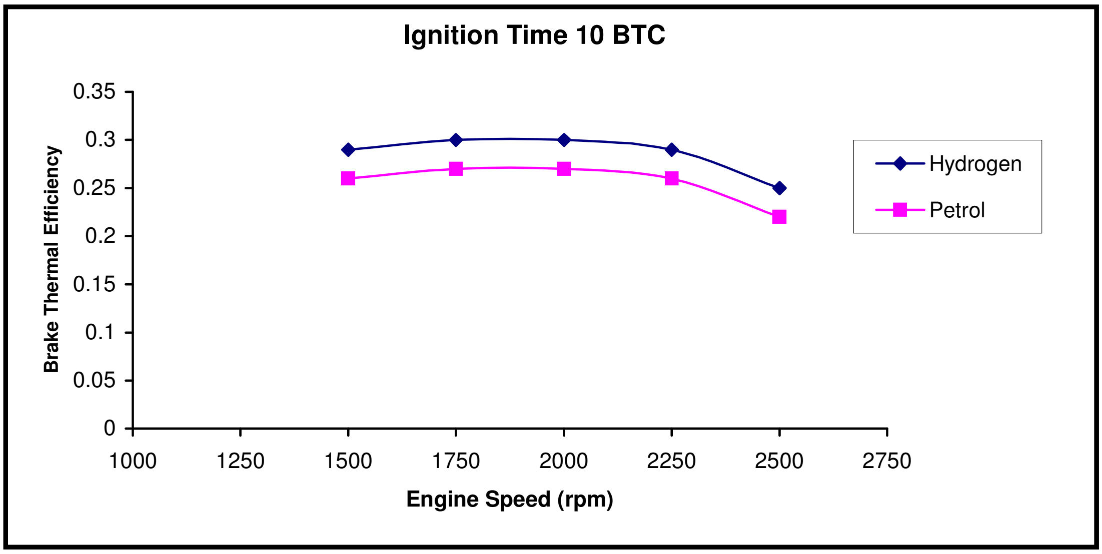


Fig.6-7. Variation of brake thermal efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 10 BTC

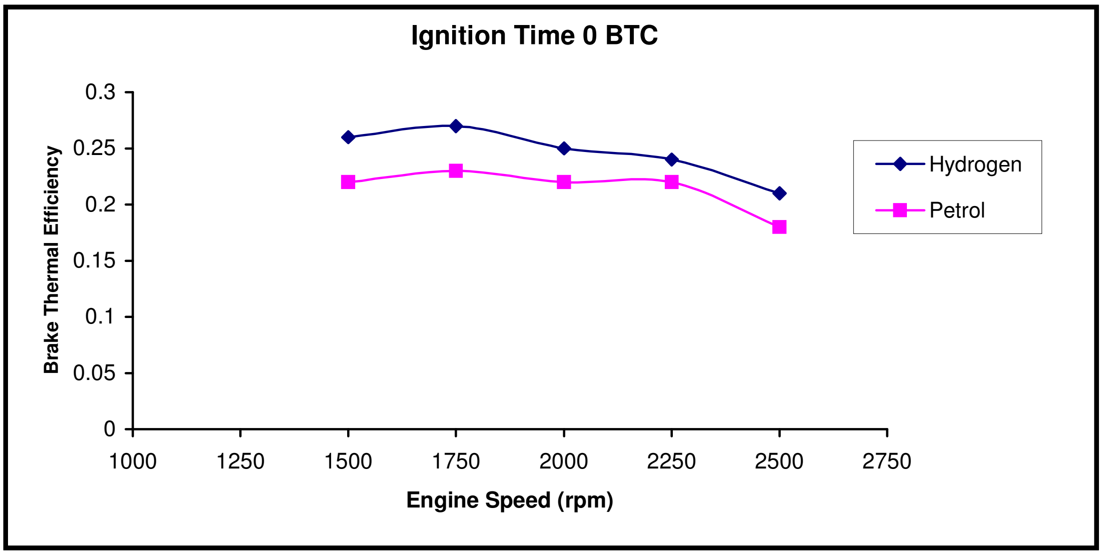


Fig.6-8. Variation of brake thermal efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 0 BTC

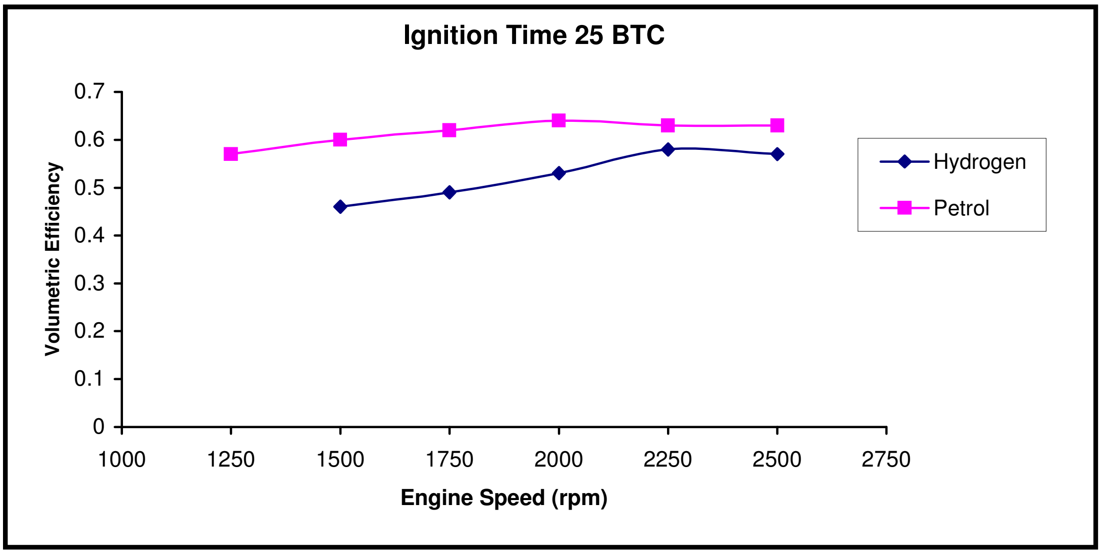


Fig.6-9. Variation of volumetric efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 25 BTC

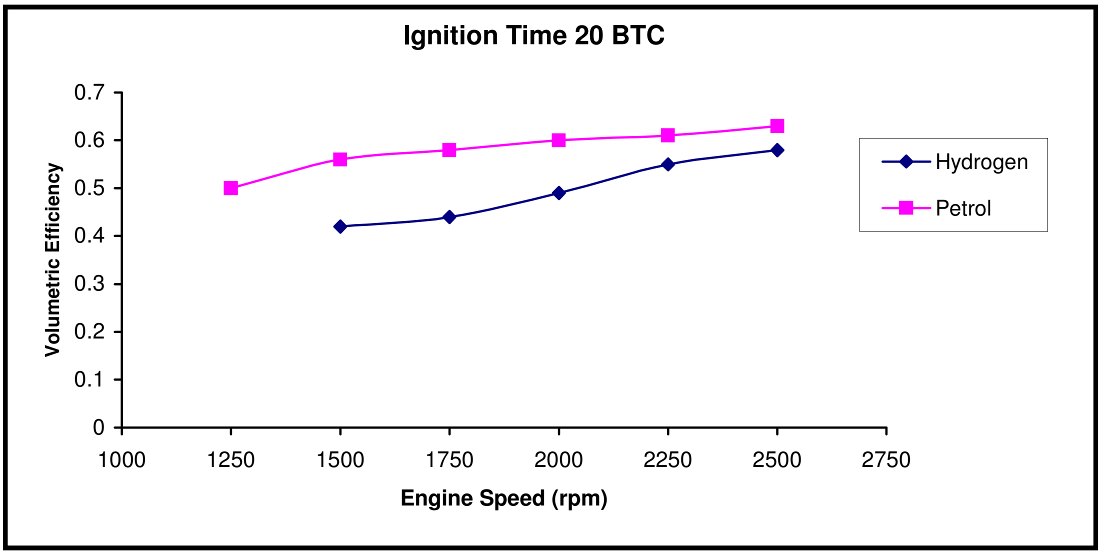


Fig.6-10. Variation of volumetric efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 20 BTC

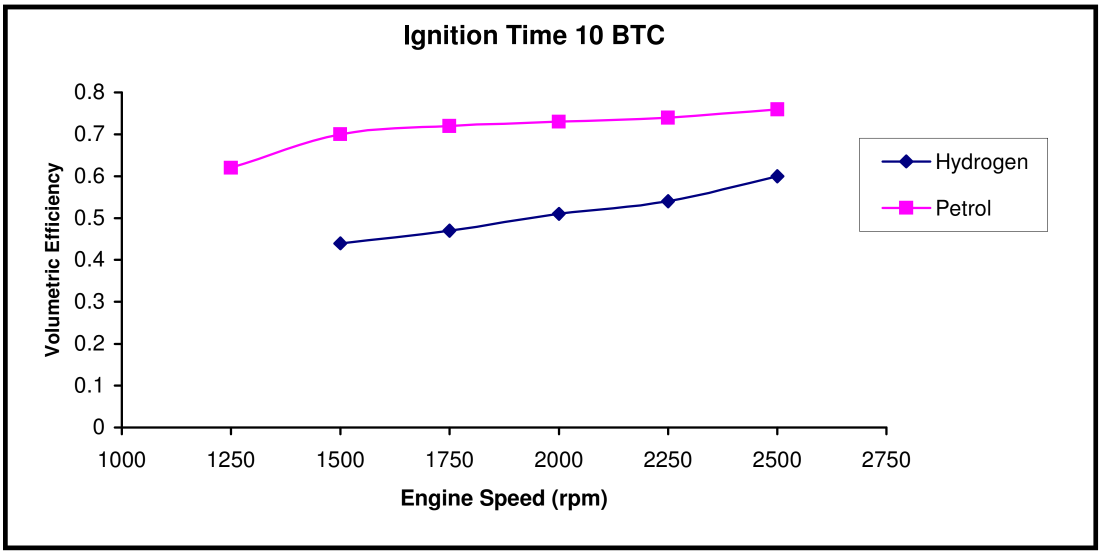


Fig.6-11. Variation of volumetric efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 10 BTC

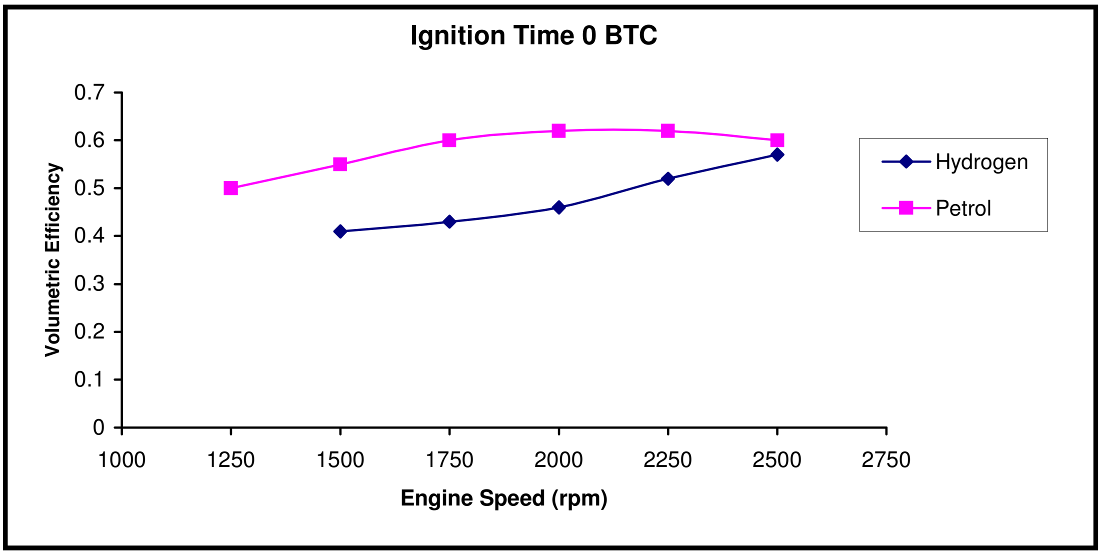


Fig.6-12. Variation of volumetric efficiency with engine speed for hydrogen and gasoline fuel at ignition timing 0 BTC

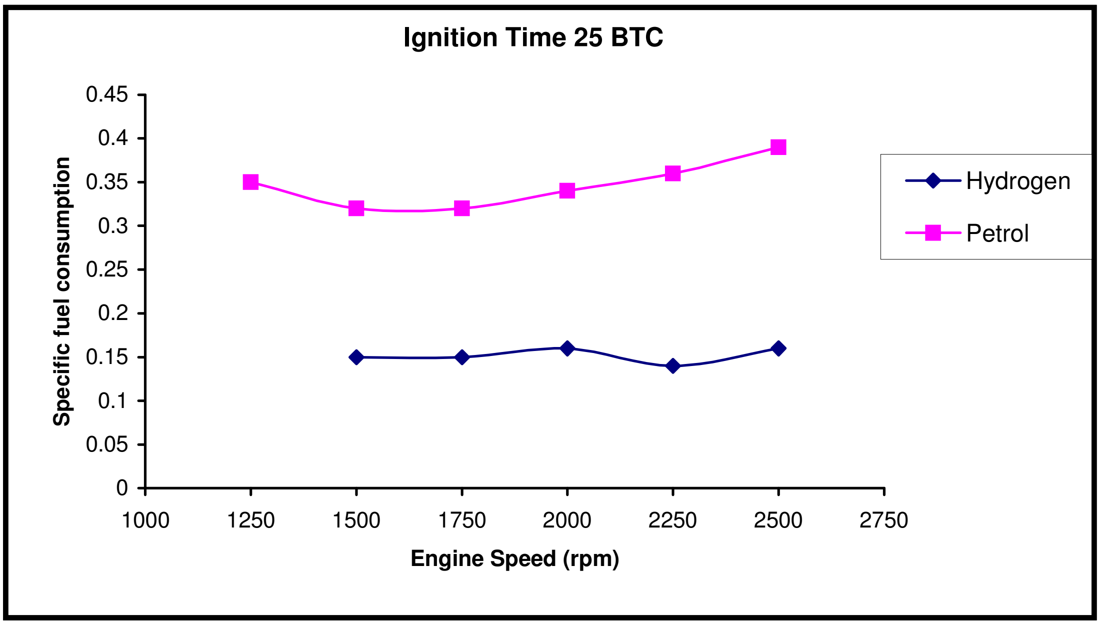


Fig.6-13. Variation of specific fuel consumption with engine speed for hydrogen and gasoline fuel at ignition timing 25 BTC

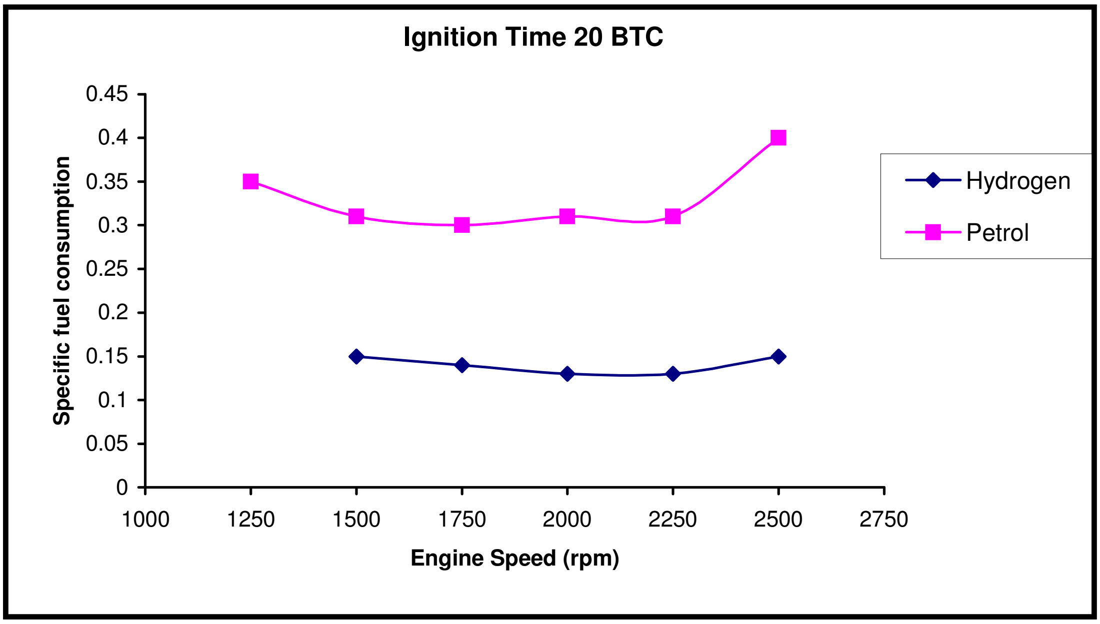


Fig.6-14. Variation of specific fuel consumption with engine speed for hydrogen and gasoline fuel at ignition timing 20 BTC

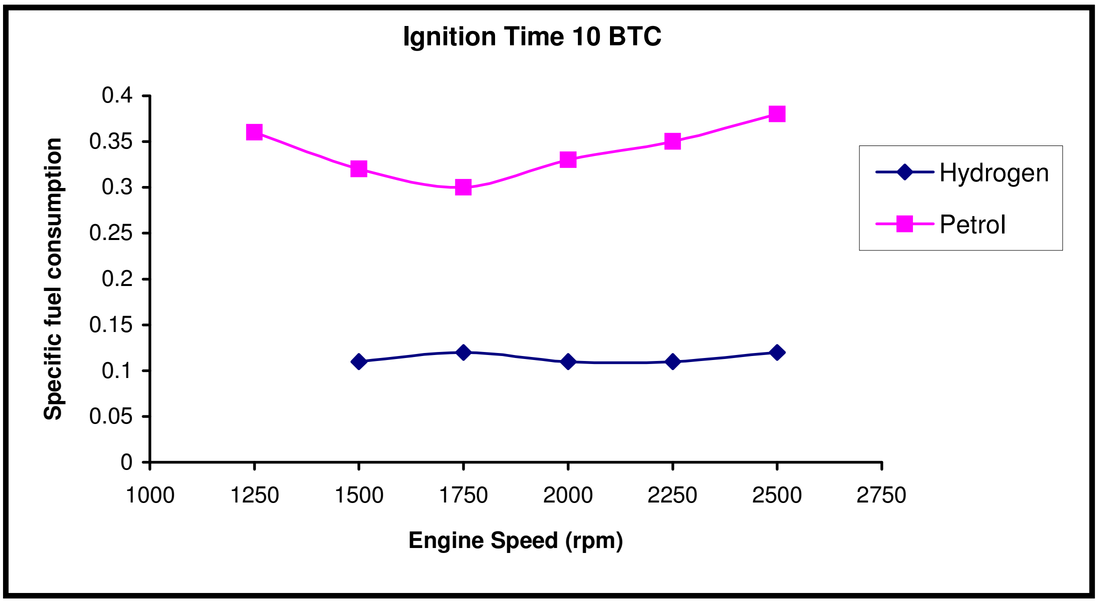


Fig.6-15. Variation of specific fuel consumption with engine speed for hydrogen and gasoline fuel at ignition timing 10 BTC

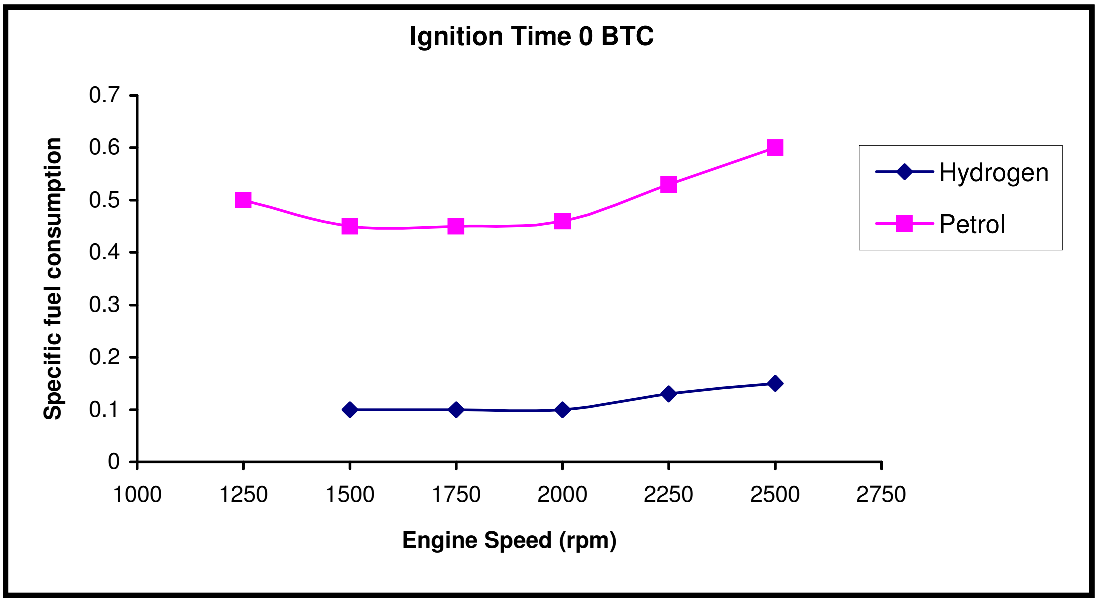


Fig.6-16. Variation of specific fuel consumption with engine speed for hydrogen and gasoline fuel at ignition timing 0 BTC

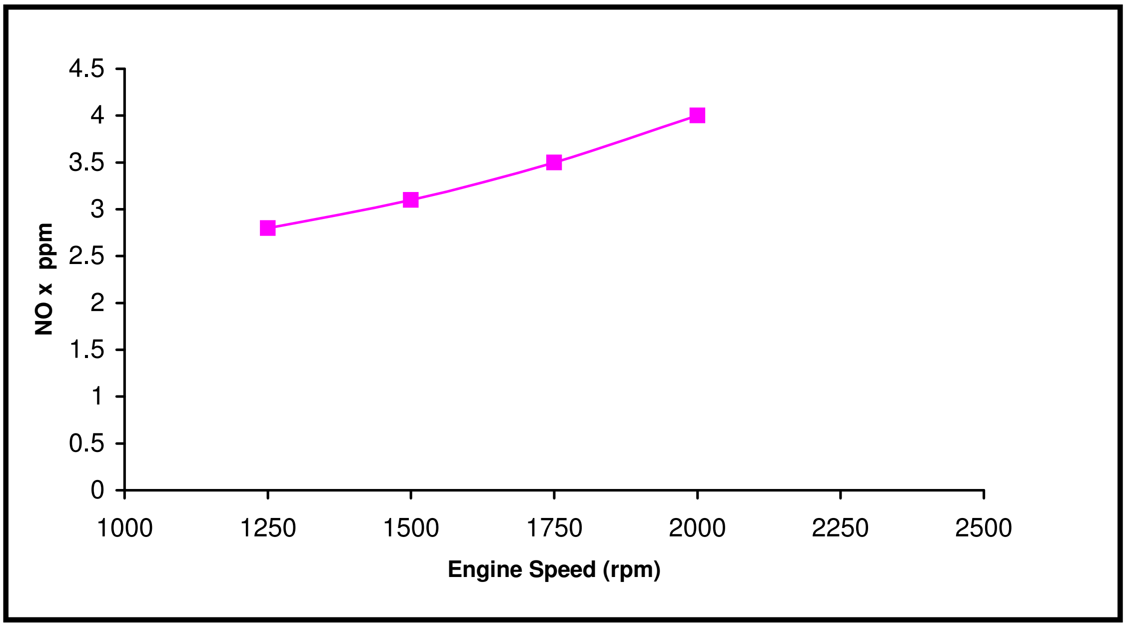


Fig.6-17. Variation of NO_X emission with engine speed for gasoline power engine at ignition timing 10 BTC

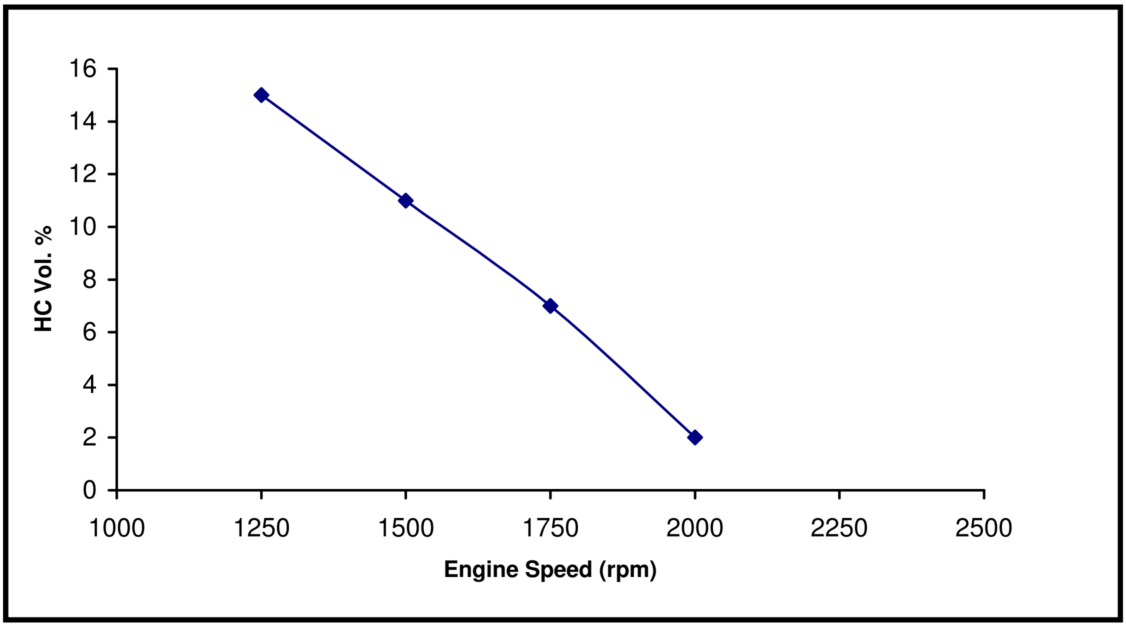


Fig.6-18. Variation of HC emission with engine speed for gasoline power engine at ignition timing 10 BTC

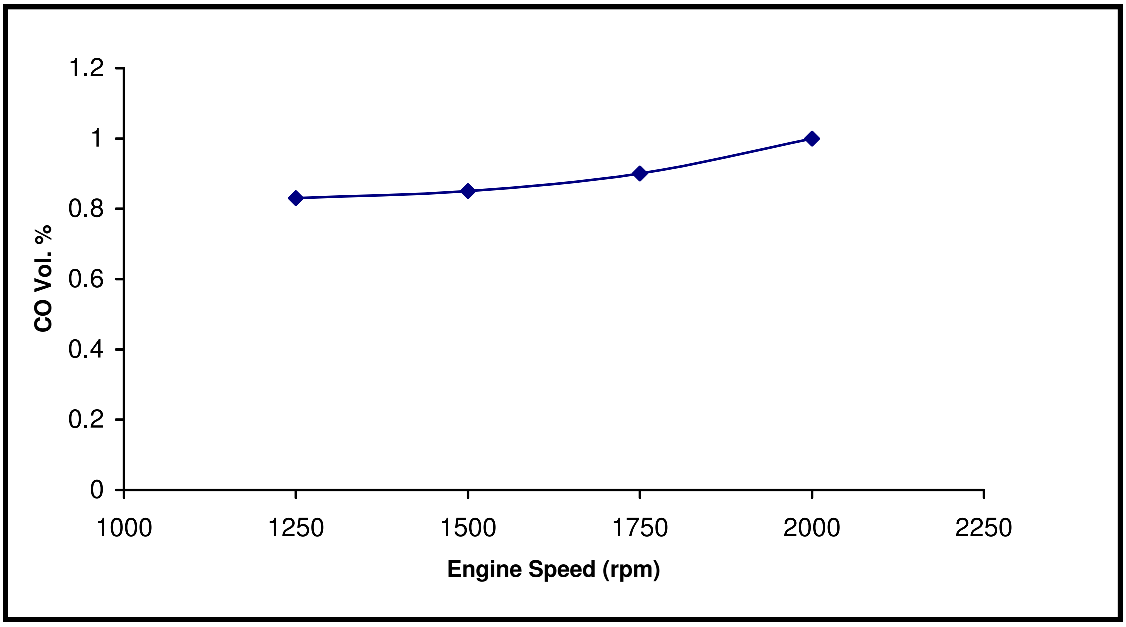


Fig.6-19. Variation of CO emission with engine speed for gasoline power engine at ignition timing 10 BTC

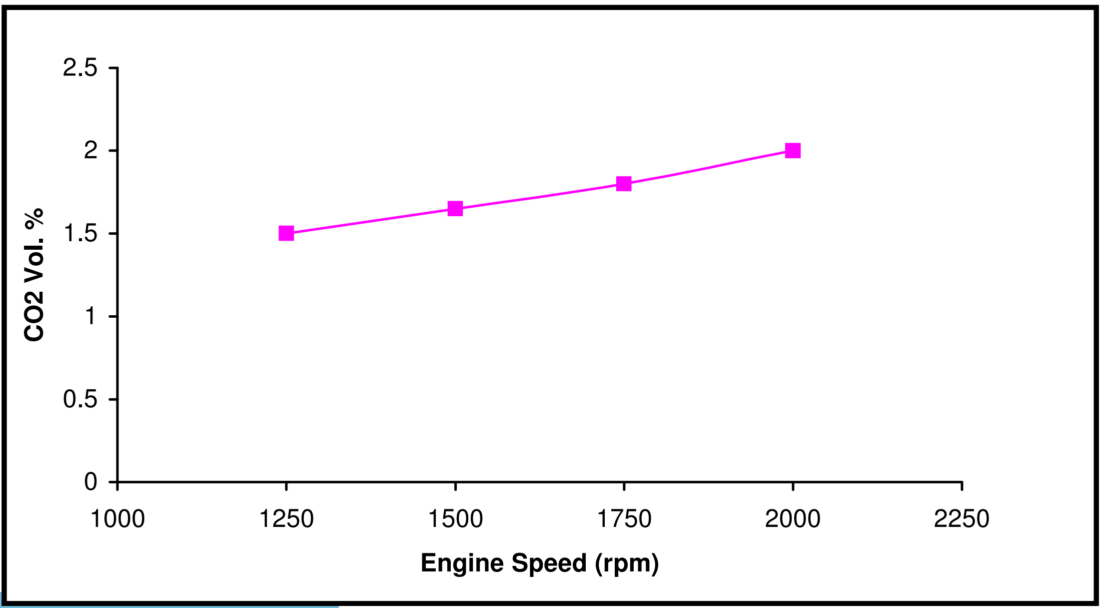


Fig.6-20. Variation of CO_2 emission with engine speed for gasoline power engine at ignition timing 10 BTC

Engine oil analysis:

Table. 6-1. Engine oil analysis before introduced into the engine

Metal	Concentration
Aluminum	None
Iron	0.5 ppm
Chrome	None

Table. 6-2. Engine oil analysis after the engine powered by Gasoline Fuel

Metal	Concentration
Aluminum	None
Iron	53.5 ppm
Chrome	None

Table. 6-3. Engine oil analysis after the engine powered by Hydrogen Fuel

Metal	Concentration
Aluminum	None
Iron	47 ppm
Chrome	None

7. CONCLUSIONS AND RECOMMENDATIONS

7-1 Conclusions:

The following points may be concluded:

1. The brake power generated when the engine is fired by hydrogen is less than that generated when gasoline is used, however they are of the same trend.

2. Brake thermal efficiency achieved when the engine fired by hydrogen is slightly higher than that achieved when gasoline is used and they are of the same trend.

3. The volumetric efficiency of a hydrogen fired engine is less than of a gasoline fired engine. It is increased with the speed.

4. It was noticed that the hydrogen fired engine turn off at speed of 1250 rpm since the power produced by the engine is less than the friction power.

5. Specific fuel consumption of a hydrogen fired engine is less than that of a gasoline fired engine and it is approximately one-third of that for gasoline.

5. When engine fired with hydrogen, the specific fuel consumption is independent of speed within operation conditions and limitations in this study.

6. Engine oil is not affected when the engine fired with hydrogen for the test duration in this work.

7. Nitrogen oxides (NO_X) emissions for hydrogen fired engines is typically smaller than those from gasoline fired engine.

7-2 Recommendations

In spite of achieving the objectives of this study, there are few points, which are worth future considerations:

1. The Effect of hydrogen fuel on oil is not clear and this may be due to the duration of the test, so it is recommended to carry out experiments with relatively longer duration.

2. Since, hydrogen is sensitive to temperature which effects the performance of the engine, especially, volumetric efficiency it is recommend to try to eliminate this effect in future work.

3. It is recommended to investigate a large range of speed (above 2500 rpm).

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Appendix (A)

Experimental Measured Data and Results

Table. A-1. Measured data for gasoline fired engine at ignition timing 25 BTDC

Engine speed (rpm)	Torque (Nm)	Time for 16 ml (second)	Manometer (mm H_2O)
2500	22	19	35.5
2250	29	19	32
2000	30	22	30
1750	30	24	26.5
1500	29.5	27	20

Table. A-2. Measured data for gasoline fired engine at ignition timing 20 BTDC

Engine speed (rpm)	Torque (Nm)	Time for 16 ml (second)	Manometer (mm H_2O)
2500	21	19.5	35.5
2250	30.5	19.00	33.0
2000	31	21	30
1750	31	24.5	24
1500	32	27	20.5

Table. A-3. Measured data for gasoline fired engine at ignition timing 10 BTDC

Engine speed (rpm)	Torque (Nm)	Time for 16 ml (second)	Manometer (mm H_2O)
2500	15	19.5	36.5
28	28	19	33.5
2000	29	21	29.5
1750	31.5	24	22
1500	31.5	27	19

Table. A-4. Measured data for gasoline fired engine at ignition timing 0 BTDC

Engine speed (rpm)	Torque (Nm)	Time for 16 ml (second)	Manometer (mm H_2O)
2500	3	20.5	34.5
2250	14	19	32.5
2000	22	21	29
1750	24	24	24.5
1500	25	27	18

Table. A-5. Measured data for hydrogen fired engine at ignition timing 25 BTDC

Engine speed (rpm)	**Torque (Nm)**	**Manometer H_2O (mm)**	$\dot{M}_f$ **(kg/hr)**
2500	12	33	0.47
2250	11	31	0.37
2000	14	24.5	0.47
1750	14	20	0.37
1500	10	16	0.34

Table. A-6. Measured data for gasoline fired engine at ignition timing 20 BTDC

Engine speed (rpm)	**Torque (Nm)**	**Manometer H_2O (mm)**	$\dot{M}_f$ **(kg/hr)**
2500	14	33.5	0.42
2250	12.5	29	0.37
2000	16	23.5	0.42
1750	16	15	0.42
1500	14.5	14.5	0.33

Table. A-7. Measured data for hydrogen fired engine at ignition timing 10 BTDC

Engine speed (rpm)	**Torque (Nm)**	**Manometer H_2O (mm)**	$\dot{M}_f$ **(kg/hr)**
2500	13	35	0.40
2250	14	28.5	0.37
2000	19	21.5	0.42
1750	19	19	0.37
1500	17	15.5	0.37

Table. A-8. Measured data for gasoline fired engine at ignition timing 0 BTDC

Engine speed (rpm)	**Torque (Nm)**	**Manometer H_2O (mm)**	$\dot{M}_f$ **(kg/hr)**
2500	11	34	0.47
2250	12.5	27.0	0.39
2000	19	19	0.42
1750	20	17	0.36
1500	21	14.5	0.34

(I) Results for petrol engine:

Table. A-9. Results data for gasoline fired engine at ignition timing 25 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	5.76	22	61	0.39
2250	6.82	26	61	0.33
2000	6.28	27	64	0.33
1750	5.50	27	65	0.32
1500	4.63	25	57	0.34
1250	3.85	24	67	0.33

Table. A-10. Results data for gasoline fired engine at ignition timing 20 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	5.50	21	61	0.40
2250	7.18	27	63	0.31
2000	6.50	27	64	0.31
1750	5.68	28	59	0.30
1500	5.00	27	59	0.31
1250	4.30	26	68	0.30

Table. A-11. Results data for gasoline fired engine at ignition timing 10 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	6.56	22	76	0.38
2250	6.38	25	74	0.35
2000	6.70	28	73	0.3
1750	6.05	32	73	0.27
1500	5.34	31	63	0.28
1250	4.51	32	69	0.27

Table. A-12. Results data for gasoline fired engine at ignition timing 0 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	0.79	3	60	0.98
2250	3.36	13	62	0.68
2000	4.60	19	62	0.44
1750	4.40	21	60	0.40
1500	3.90	21	52	0.40
1250	3.00	21	61	0.40

(II) Results for hydrogen engine:

Table. A-13. Results data for hydrogen fired engine at ignition timing 25 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	3.14	20	57	0.15
2250	2.60	21	59	0.14
2000	2.93	18	53	0.16
1750	2.56	21	49	0.15
1500	1.57	14	46	0.22

Table. A-14. Results data for hydrogen fired engine at ignition timing 10 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	3.67	26	58	0.11
2250	2.90	24	55	0.13
2000	3.35	24	49	0.13
1750	2.93	21	38	0.14
1500	2.30	21	42	0.15

Table. A-15. Results data for hydrogen fired engine at ignition timing 10 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	3.40	25	60	0.12
2250	3.30	27	54	0.11
2000	3.40	28	46	0.11
1750	3.48	28	47	0.11
1500	2.67	22	44	0.14

Table. A-16. Results data for hydrogen fired engine at ignition timing 0 BTDC

Engine speed (rpm)	Brake power (kW)	Brake thermal efficiency (%)	Volumetric efficiency (%)	s.f.c (kg/kW.hr)
2500	2.88	18	58	0.17
2250	2.95	22	52	0.13
2000	3.40	28	46	0.11
1750	3.66	30	41	0.10
1500	3.30	29	42	0.10

Table. A-17. Selected properties of hydrogen

Molecular weight		2.016
Density	kg/m^3	0.0838
Higher heating value	MJ/kg MJ/m^3	141.90 11.89
Lower heating value	MJ/kg MJ/m^3	119.90 10.05
Boiling temperature	K	20.3
Density as liquid	kg/m^3	70.8
Critical point Temperature Pressure Density	 K bar kg/m^3	 32.94 12.84 31.40
Self-ignition temperature	K	858
Ignition limits in air	(vol.%)	4.75
Stoichiometric mixture in air	(vol.%)	29.53
Flame temperature in air	K	2318
Diffusion coefficient	cm^2/s	0.61
Specific heat (c_p)	$kJ/kg\,K$	14.89

تأثير وقود الهيدروجين على أداء وزيت محرك احتراق داخلي

إعداد
سامر صالح نهار حجازي

المشرف
الأستاذ الدكتور محمد أحمد حمدان

ملخص

يهدف هذا البحث إلى إجراء مقارنة في أداء محرك احتراق داخلي باستخدام وقود الهيدروجين والبنزين، وكذلك دراسة تأثير وقود الهيدروجين على زيت المحرّك.

تمّ قياس معدل تدفق الوقود والهواء والعزم الناتج من المحرك، ومن ثم تمّ دراسة أداء المحرك من خلال حساب كل من الكفاءة الحجمية الحرارية والقدرة الكبحية ومعدل استهلاك الوقود النوعي.

وُجد أن استخدام وقود الهيدروجين يؤدي إلى انخفاض في القدرة الكبحية والكفاءة الحجمية الحرارية، وتحسن ملحوظ في استهلاك الوقود النوعي، وتحسن طفيف في الكفاءة الحرارية، في حين أنه لم يلاحظ أي تأثير على زيت المحرك.

لوحظ عدم انبعاث مركبات هيدروكربونية أو أكاسيد الكربون، وقد لوحظ انخفاض بمعدل انبعاث أكاسيد النيتروجين عند استخدام وقود الهيدروجين.