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Analysis of Internal Combustion Engine Working on Hydrogen Fuel

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Abstract:

In History of internal combustion engine development, hydrogen has been considered at several phases as a substitute to hydrocarbon-based fuels. Starting from the seventeenth century, there have been several attempts to convert engines for hydrogen operation. Together with the progress in gas injection technology, it has become possible to control exactly the injection of hydrogen for safe operation. Since the fuel cell needs certain upgrade before it is widely used in vehicles, the traditional internal combustion engine is to play an important role in the transition. This study examines the performance characteristics and discharge of a hydrogen fueled traditional spark-ignition engine. Minute moderations are made for hydrogen feeding which do not change the basic characteristics of the original engine. Differentiation is made between the gasoline and hydrogen operation and engine design changes are discussed. Few remedies to overcome the backfire phenomena are attempted.

Keywords: Internal Combustion, Hydrogen Fuel, Combustion Engine

I. INTRODUCTION

Fossil fuels are the widely used energy demand today that is being depleted recently. Their combustion products are causing of global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution, which cause great danger for our environment. Engineers and scientists agree that the solution for all of the global problems is to replace the existing fossil fuel system with hydrogen energy system. Hydrogen is very efficient and clean fuel. Its combustion products no greenhouse gases, no ozone layer depleting chemicals, and no acid rain ingredients. Hydrogen, produced from renewable energy sources, result in a permanent energy system which would never have to be changed.

Fossil fuels possess very useful properties not shared by non-conventional energy sources that have made them popular during the last century. Unfortunately, fossil fuels are not renewable **Veziroglu TN. 1987[1]**. In addition, the pollutants emitted by fossil energy systems (e.g. CO, CO2, CnHm, SOx, NOx, radioactivity, heavy metals, ashes, etc.) are greater and more damaging than those that might be produced by a renewable based hydrogen energy system **Winter CJ. 1987[2]**. Since the oil crisis of 1973, considerable progress has been made in the search for alternative energy sources. A long term goal of energy research has been the seek for a method to produce hydrogen fuel economically by splitting water using sunlight as the primary energy source. Much fundamental research remains to be done **Serpone N, Lawless D, Terzian R. 1992[3]**.

Global use of fossil fuels for energy need is rapidly resulting in critical environmental problem. Energy, finance, health, animals and plant life. There is an urgent need to implement hydrogen technology. A universal conversion from fossil fuels to hydrogen rejects many problems. Production of hydrogen from non-polluting sources is the ideal way **Zweig RM. 1992[4]**.

The worldwide photo voltaic market has grown rapidly in recent years, a growth that continues in various areas, especially in grid-connected photo voltaic applications **Rever B. 2001 [5].** H2 is a carbon-free fuel which oxidizes and form water as a combustion product. The generated water becomes, together with renewable primary energy for splitting it, a source of clean and abundant energy in a carbon-free, natural cycle **Gretz J. 1992 [6]**. In the development of all new energy options, hydrogen necessarily will play an important role because of its ability to supplement any energy stream and apply to any load. Hydrogen will act as a solar energy storage medium and transform solar energy into a transportation fuel **Block DL, Veziroglu TN. 1994 [7]**.

Lowering of carbon dioxide emission to reduce risk of climate change requires a major restructuring the energy system. The use of hydrogen is a long term option to reduce carbon dioxide discharge. However, at present time, hydrogen is best on comparative to other energy carriers.

Hydrogen has long been identified as a fuel having some special and highly desirable properties, for application as a fuel in engine **King RO, Rand M. 1955 [8]**. It is the only fuel that can be fabricated entirely from the liberal renewable resource water, though through the disbursement of comparatively much energy. Its burning in oxygen creates uniquely only water but in air it also constructs some oxides of nitrogen. These features make hydrogen an outstanding fuel to potentially meet the ever growing strict environmental controls of exhaust discharge from combustion devices, including the diminution of greenhouse gas discharge. Hydrogen as a renewable fuel resource can be produced through the outlay of energy to replace increasingly the depleting sources of traditional fossil fuels. A short statement and discussion of the supportive properties of hydrogen as a fuel and the related restrictions that are increasing difficulties in its wide application as an engine fuel are essential and needed. Hydrogen is widely use as a fuel for quite a long **Erren RA, Campbell WH. 1933 [9]**. Additionally, wide quantities of hydrogen are used increasingly as a raw material in a wide range of applications in the chemical industry, particularly in the improving of traditional fuel resources **Cox KE, Williamson KD. 1977[10]**. The viability of hydrogen as a fuel in traditional 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 restrictions that hinder its widespread

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application as an engine fuel are predominantly linked to its production portability, transport, storage, and purity. These restrictions can be measured to be extra serious than those facing the current and future applications of other fuels, containing natural gas.

2. LITERATURE REVIEW

In the early years of the development of internal combustion engines hydrogen was not the "tropical" fuel that it is today. Water separated by electrolysis was a well-known laboratory sensation. **Otto, in the early 1870s**, considered various fuels for his internal combustion engine, including hydrogen. He rejected gasoline as being excessively dangerous. Later evolutions in combustion technology made gasoline safer.

Most prior engine experiments were designed for burning a various types of gases, including natural gas and propane. When H2 was used in these engines it would backfire. Since hydrogen ignite faster than other fuels, the fuel-air mixture would ignite in the intake manifold as the intake valve close. Injected water controls the backfiring. Hydrogen gave less power than gasoline with or without the water.

Throughout World War-I hydrogen and clean oxygen were considered for submarine to use since the squad could get safe to drink water from the exhaust. Hydrogen was also measured for use in driving airship engines. The gas used for resilience could also be recycled for fuel. Even if helium were used to deliver lift, hydrogen gas could be used to fund extra resilience if stored at low pressure in a light vessel.

Rudolf A. Erren first prepared practical the hydrogen-fueled engine in the 1920s and transformed over 1,000 engines. His plans involved trucks and buses. After World War-II the partners revealed a submarine transformed by Erren to hydrogen power. Even the ruins were hydrogen powered.

In **1924 Ricardo** directed the first organized engine performance experiments on hydrogen. He used a single cylinder engine and checks various compression ratios. At a compression ratio of 7:1, the engine attains a highest efficiency of 43%. At compression ratio of 9.9:1, **Burnstall** found an efficiency of 41.3% with an equivalency ratio range of 0.58-0.80.

After World War-II, King establishes the cause of pre-ignition to be hot spots in the combustion chamber from the high temperature ash, the rest from burned oil and dust. He traced backfire to high flame rate at high equivalency ratios.

M.R. Swain and R.R. Adt at the University of Miami technologically advanced modified injection techniques with a 1,600 cm3 Toyota engine through a compression ratio of 9:1. The Illinois Institute of Technology converted a 1972 Vega using a propane carburettor. Converting to propane fuel uses alike technology as hydrogen.

Roger Billings, in partnership with Brigham Young University, arrived a hydrogen-converted Volkswagen in the 1972 Urban Vehicle Competition. The automobile attain first place in the discharge groups over 60 other automobiles even though the peak release were more than for other hydrogen powered automobiles away. Nitrous oxides overdone stages attained by other experimenters using direct injection.

Robert Zweig transformed a small truck to hydrogen power in 1975. He solved the backfiring problem by using an extra opening valve to add hydrogen separately from air. It is a simple, elegant vehicle that uses compressed hydrogen. The American Hydrogen Association shows the Zweig hydrogen small trucks in public exhibits.

The Brookhaven National Laboratory converted a Wankel engine to hydrogen. It worked better with hydrogen than traditional engines because its combustion chamber improves the emission of hydrocarbon pollutants.

Mazda has changed one of their rotary engine cars to working on hydrogen. The single design of the rotary engine retains the hydrogen and air distinct till they are joined in the combustion chamber.

The Indian Institute of Technology verified spark ignition engines converted to hydrogen and has come to the follow conclusion: Hydrogen allows a extensive range of fuel-air mixture. A minute throttling is required. The fuel-air ratio and the quantity of fuel are varied instead. Change requires higher compression ratios like up to 11:1. Hydrogen is 30 to 50% extra efficient than gasoline. The Indian investigators also extended certain decisions concerning the use of hydrogen in addition to diesel fuel in diesel engines. They reduced the compression ratios from 16.5:1 to 14.5:1. Because of hydrogen has high rate of combustion only a small quantity must be used mixed with diesel fuel. A great ignition temperature is essential: 585 °C. The additional hydrogen is mixed to the fuel mix the lesser is the level of toxic discharge.

The Billings Energy Corporation in Independence, Missouri, transformed a U.S. postal Jeep to hydrogen hydride. On gasoline it got 3.9 km/liter. The hydrogen fuel consumption is 4.9 km/liter per gasoline energy equivalent. This was an improvement of 24%. A special gaseous carburetor was used.

High flame speed and low ignition energy required narrowing the spark gap. Problems of rusting and pitting on the sparkplug tip developed. Billings replaced the plugs with Champion stainless steel plugs to eliminate the problem. Rusted plug tips can cause pre-ignition through the valves (backfire).

Since the firing rate was faster, they had to change the ignition timing on the inline six-cylinder engine.

The researchers added a water injection system to lower the combustion temperature and nitrous oxide production. The ratio was 4:1, by weight, of water to hydrogen. Daily fuel consumption was 1.4 kg of hydrogen and 5.4 kg of water. Water was injected as a fine mist directly into the manifold of the engine. This reduced backfiring into the manifold and boosted power.

In experiments in 1980 with a diesel engine converted to run on 100% hydrogen, the **U.S. Bureau of Mines, in collaboration with EIMCO Mining Machinery**, found that the nitrous oxide discharge for hydrogen is one-tenth of the amount for the same vehicle on diesel. With hydrogen, the

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only other emission was water vapor. This is important for vehicles working in mines and other confined spaces.

They mounted a 63.4 kW (85 hp) engine on a 4,500 kg truck. The diesel engine required the addition of spark ignition. Compression alone would not ignite the hydrogen at the reduced compression ratio. They added a turbocharger to increase the density of the incoming fuel.

The fuel induction system provides two intake paths; one for hydrogen and one for air. The fuel and air are kept separate until entering the cylinder to prevent backfiring **Peavey M. A. 2003 [11].**

The Laboratory of Transport technology (University of Gent, Belgium) has specialized in alternative fuels for the past 10 years or so. Natural gas, LPG, hythane and hydrogen have been the subject of extended research. In a first stage, a Valmet 420D engines, a natural aspirated diesel engine with direct injection were converted to a spark ignited engine for the use of hydrogen. This engine was used mainly for the development of a multipoint timed injection system and the study of different types of electromagnetic gas injectors **Sierens R, Rosseel E. 1995 [12]**. The tests showed several Short comings of the then available gas injectors: leakage, unequal response time (opening delay) and low durability. In the mean time however, the research on gaseous injection systems (natural gas, LPG, etc.) has been increased enormously by the specialized companies and these problems are largely solved now.

A second engine, a GM-Crusader V8, was then converted for hydrogen use. The first tests were done with a gas carburetor, which allowed testing with hydrogen, natural gas and hydrogen-natural gas mixtures (hythane), **Sierens R, Rosseel E. 1998 [13]**. In order to obtain a better control of the combustion process, the engine was then equipped with a sequential timed multipoint injection system. Such an injection system, as applied to liquid fuels (gasoline, liquid LPG, etc.) has several advantages including the possibility to tune the air-fuel ratio of each cylinder to a well-defined value, increased power output and decreased cyclic variation of the combustion process in the cylinders. Timed injection also has an additional benefit for a hydrogen fueled engine, as it implies a better resistance to backfire (explosion of the air-fuel mixture in the inlet manifold). In nearly all cases, backfire-safe operation implies a limitation of the operation region of the air-fuel mixture on the ―rich‖ side, thus for high load conditions. This restriction is decreased by the use of a multi-point sequential injection system. Direct injection in the combustion chamber, cryogenic storage (liquid hydrogen tank) and pump is even better, but not technically available for mass production **Furuhama S. 1995 [14]**. All these advantages are well known **(Sorusbay C)[15].**

The disadvantage of low pressure sequential gas injection is the low density of the gas. For smaller engines running at high speeds (traction application), the injectors have to deliver a high volume of gas in a very short time. Other problems may arise with the durability of the injectors and possible leaks.

The German Aerospace Research Establishment used cryogenic hydrogen with hybrid mixture formation on a BMW 745i vehicle in a joint effort with BMW. The cryogenic characteristics of hydrogen like high range per tank filling and low amount of mass for storage favor its use together with the cooling effect that occurs during external mixing. Satisfactory achievements were made by hybrid mixture formation, a proper combination of both internal and external mixture formation, in means of power and torque characteristics under steady and intermittent working conditions **Peschka W. 1998 [16].**

3. ENGINE MODIFICATIONS

SI engines are simply elastic to gaseous fuels like propane, methane, and hydrogen. Little modifications for the initiation of the fuel in appropriate amount are applied. A fuel source system that can be conversant according to the engine's need is even handed good enough to make the engine work. In case of hydrogen there are certain extra issues regarding safety and backfire-safe operation throughout the working region. The storage of fuel is another ingredient that impacts the range of the vehicle working on hydrogen. Due to its low energy per volume content, the compressed gas storage cannot compete with liquid gasoline.

Related to gasoline, hydrogen's low energy per unit volume produces less energy in the cylinder. An engine successively on hydrogen produces less power than with gasoline. Supercharging may help remedy this by compressing the received fuel/air mixture before it enters the cylinder. This raises the volume of energy per volume of fuel. Additional weight and complexity is added to the engine by such changes. But the power gain and backfires truggling stuff (by cooling the cylinder with more air) recompenses for the revealed disadvantages.

Scheming of bunch nozzles for marine is essential to provide backfire free operation. Though very simple in assembly, it is important to supply the right quantity of water conferring to load, engine speed and temperature.

If cryogenic hydrogen is provided, material predilection for the injectors, fuel supply line, tank and metering strategies must be make therefore. Meanwhile much improvement has been made in the safe handling and storing of liquid hydrogen in space industry, the residual focus needs to be done on applying this know-how to small vehicle systems.

1. Pre-ignition and Backfire

Hydrogen burns quickly and has a little ignition temperature. This may cause the fuel to be burned by hot plugs in the cylinder before the intake valve closes. It may also cause backfire, pre-ignition, or knock. These problems are particularly more with high fuel-air mixtures. Unrestrained pre-ignition fight back the upward compression knocks of the piston, thus dropping power. Tonics for backfire contain: timed port injection, delayed injection to make sure the fuel detonates only next to the intake valve is closed; water injection, 1.75 of water to hydrogen by weight 11. A suitably designed scheduled manifold injection system can stunned the difficulties of backfiring in a hydrogen engine.

2. Fuel Mixing Observance the air and fuel distinct till combustion is a significant plan for controlling the difficulties rising from the fast-burning properties of hydrogen. The low flammability bounds and low energy vital for ignition of hydrogen basis pre-ignition and backfire when using hydrogen fuel. Ignition ensues when a fuel-air mixture burns in the burning chamber before the intake valve ends. Pre-ignition can cause backfire when ignited fuel-air mixture blasts back into the intake system. It is supreme existing at higher loads and at advanced fuel-air mixtures near open throttle.

Pre-ignition is not a necessary pioneer to backfiring and possibly not occurs in normal conditions at enough compression and equivalence ratios. Because of the low volumetric energy content of hydrogen, higher compression ratios or higher fuel delivery pressures are needed to avoid reduced power. Supercharging spark ignition engines compresses the fuel-air mixture before being initiated into the cylinder.

Direct fuel injection includes mixing the fuel with air inside the combustion chamber. The fuel and air are kept distinct until then. If the fuel and air are mixed before arriving the combustion chamber; the procedure is called external mixing. A carburettor usually accomplishes this.

3. Mixture Formation and Engine Operation

The dangerous physical properties of hydrogen at ambient and cryogenic situations are of useful impact on combustion as well as on mixture development. In contrast to traditional fuels, the hydrogen fraction in a stoichiometric mixture at ambient temperature is about 30% of the mixture volume. The volumetric heat value of the hydrogen-air mixture (2890 J/l) results in a corresponding power loss at the engine associated to traditional fuel (3900 J/l). The wide flammability range of H2-air mixtures allows very lean process with substantially reduced nitrogen oxides discharge much more simply than with traditional fuels. Also, hydrogen deals a significant reduction of air throttle and cylinder charge intake flow losses. In this point hydrogen differs significantly from other gaseous fuels such as natural gas or propane.

3.1. Mixture Formation with Hydrogen At Ambient Conditions

Considerable reduction of nitrogen oxides discharge is confirmed with lean mixture concepts without using catalysts at the exhaust. To attain satisfactory engine procedure several extra measures are essential to prevent uncontrolled pre-ignition and backfiring into the intake manifold. Supercharging is an additional measure to prize for the loss of power productivity, which is connected to the lean mixture thoughts. As a significance of low energy content in the exhaust gas due to bigger partial load efficiency and minor volumetric heat value, exhaust gas turbo-charging is less suitable with hydrogen operation than with old-fashioned fuel despite throttled air supply. Due to poorer exhaust gas temperature with hydrogen process (approximately 650 0C) under partial load, there is not adequate energy presented from the exhaust gas for blaming up and improving torque. This ―turbocharger hole‖ can be efficiently connected with an extra centrifugal compressor driven directly by the engine via a high speed transmission gear. Although the recognized turbocharger deficiency can be diminished over the fall in flow orifice of the turbine's case, this results in increased choking of the exhaust gas and in supplementary problems with unrestrained pre-ignition. The difficulties with the hot lasting gas could essentially be reduced through an increase of the compression ratio (to 10:1 and 11:1). This measure, however, is self-contradictory to supercharging.

3.2. Internal Fuel Mixing

With internal fuel mixing air and fuel are mixed inside the combustion chamber. This is usually done as follows: air is taken in which also cools any hot spots in the cylinder, air intake valve is closed, fuel is injected, fuel inlet valve is closed, the mixture is ignited. When hydrogen is inducted into the cylinder under pressure no air is displaced in the combustion chamber. This prevents the power loss from externally mixed fuel-air systems. Theoretically, 20% more power is possible with directly injected hydrogen fuel than with the same engine using externally mixed gasoline. All types of engines can be modified in this way: four stroke, two stroke, diesel, and rotary. With internal mixing, high pressure is needed, up to 100 atm. A fuel pump is needed to supply fuel to the cylinder under pressure. Hydrogen is injected immediately after the intake valve closes and before the combustion chamber pressure reaches maximum.

The induction of air separately, rather than with the fuel, allows the air flow rate of a low density hydrogen engine to be essentially that of a carburetted engine operated on a higher density fuel such as gasoline.

Since liquid hydrogen is 10 to 20 times denser than gaseous hydrogen, direct injection of liquid hydrogen allows smaller and lighter valves. The relatively high density of liquid hydrogen, compared to gaseous hydrogen, causes it to generate pressure when evaporating. Because of this, internal fuel mixing combined with liquid hydrogen has the potential to surpass external mixing for gasoline or hydrocarbons.

There are two types of internal mixture formation: early injection and late injection. With early injection, fuel is introduced at the start of the compression stroke and continues until 90 degrees before TDC. With late injection, fuel is introduced at 5 degrees before TDC. High pressure is needed to get enough fuel into the chamber in a short time. With liquid hydrogen fuel, the fuel pump can supply some of this pressure. Fuel expansion from evaporating liquid hydrogen supplies the rest of the 100 atm pressure needed. Fuel injection in general, and late injection in particular, makes fuel-air mixing difficult because of the short time involved. Uneven mixtures cause: increased nitrous oxide formation, erratic ignition, ignition delay, incomplete combustion, delayed combustion.

These problems can be overcome by increasing the turbulence in the combustion chamber. This is accomplished in one of two ways. Changing the combustion chamber geometry or modifying the fuel injector arrangements.

3.3. External Fuel Mixing

Without adequate cooling measures H2-air mixtures tend toward uncontrolled pre-ignition above an equivalence ratio φ of about 0.7, by direct contact with the hot residual gas as well as hot spots in the combustion chamber where catalytic outcome play a considerable role especially at low engine speed **(Stewart 1986). [17]**. Through appropriate cooling measures like, for example; modification of the cylinder head's cooling water routes for improved exhaust-side cooling of the combustion chamber, sodium- or lithium-filled outlet valves, as well as water injection into the combustion chamber via intake air, about 70% of the power of traditional fuel can be attained under steady operation with Otto-cycle engines. The torque is especially unsatisfactory at low engine speeds. Water injection, which can only realistically be used in test engines, can be replaced by equivalent exhaust gas recirculation due to its resulting suppression of uncontrolled pre-ignition. Although it has the advantage of improved mixture formation, it also results in an additional power and torque loss as a result of an increase in temperature and decrease in the oxygen fraction of the mixture.

When air and fuel are outside the combustion chamber the light hydrogen fuel displaces air mixture, thereby reducing power 20 to 30% compared to gasoline. Hydrogen fuel passes through a pressure regulator where it is reduced pressure for delivery to the fuel mixer.

Sequential single cylinder injection into the intake port with an open intake valve does not have any impact on the intake manifold concerning the mixture parameter because the hydrogen is added directly to the air flow at the cylinder intake thus avoiding mixture formation in the intake manifold to the greatest possible extent. Constant mixture composition, a vitally important prerequisite for good homogeneity of the cylinder charge, can be attain only when the air mass flow rate during the intake phase remains constant as well as the hydrogen injection mass flow rate. An intake air mass flow rate that varies periodically during the intake phase can result in local excessive fuel concentrations in the mixture that can lead to uncontrolled pre-ignition. For steady hydrogen operation with the external mixture formation, sequential single cylinder injection provides the best possible continuity of power and torque.

The use of electronic engine management improves variable power operation substantially. Considering that external mixture formation basically represents a simple procedure, in reality a very technically complicated concept has to be developed, although it is not clear whether substantial upgrade can be attain for two-valve engines.

4. Water Induction

Internal combustion engines leftover about two-thirds of the combustion energy as heat. Totalling of water to hydrocarbon fuels allows the heat of combustion to combine the oxygen in the water with unburned carbon in exhaust. This produces a mixture of hydrogen and carbon monoxide. The hydrogen then ignites, generating additional power.

The induction of water vapour into the cylinder reduces the burning temperature of nitrous oxide development. Water induction is an effective means of controlling nitrous oxide minus loss of power, efficiency, or exhaust temperature. The efficiency of water induction grows with rpm.

Some cylinders of the same engine may produce extra nitrous oxide than others. With direct injection the equivalency ratio can be diverse to each cylinder in reaction to different radiation characteristics. This is not thinkable with external socializing in carburettors where a constant mixture is distributed to all cylinders. The non-uniformity of nitrous oxide creation from cylinder to cylinder needs a similar non-uniformity in water induction to compensate for this. Straight induction mixes water vapour with hydrogen afore the introduction of air.

When the equivalency ratio exceeds 1.0 to 1.6 the probability of pre-ignition is importantly increased. This is because of the presence of hot residual gas or solid combustion residues such as oil ash. The cooling effect of water injection remedies this. As water induction reduces combustion temperature it also reduces the probability of pre-ignition and backfires. By reducing the reaction rate of hydrogen and air in the cylinder and growing the energy required for ignition, a larger range of mixture may be used. Dipping the time, as well as the temperature, of combustion critically decreases nitrous oxide discharge. This also assists to extend engine life.

Advanced engine rpm needs more water. The water flow rate must be attuned to escape water leaky past the piston rings. A standard gas tank, carburettor, and fuel pump may be modified for water supply.

4. EXPERIMENTAL SETUP

Experiments test banks including water and eddy current type dynamometers, exhaust emission analyzers, fuel metering devices and support apparatus. The dynamometer and supportive electrical apparatus were standardized a few days before the tests began. To avoid temperature and pressure differences as far as possible, experiments with gasoline were instantly followed by hydrogen experiments with the engine already warmed up to operational temperature.

Compressed hydrogen at 200 bar from 50 one steel flasks was released down to 3 bar in the first stage regulator. The fuel line is a copper tube linked to a hydrogen flow meter. The second stage regulator supplies the gaseous hydrogen to the mixer conferring to the inlet manifold pressure.

The engine is joined to the dynamometer with its gearbox. The 4th gear has a ratio of 1:1 so the rotating speed measured at the dynamometer is accurately the same as the engine speed. Also the engine itself; flywheel, starting motor, alternator, fuel pump, fuel tank, dashboard assembly and exhaust assembly are adjusted to the required parts and places.

At the exhaust outlet, there is a standard muffler and a final

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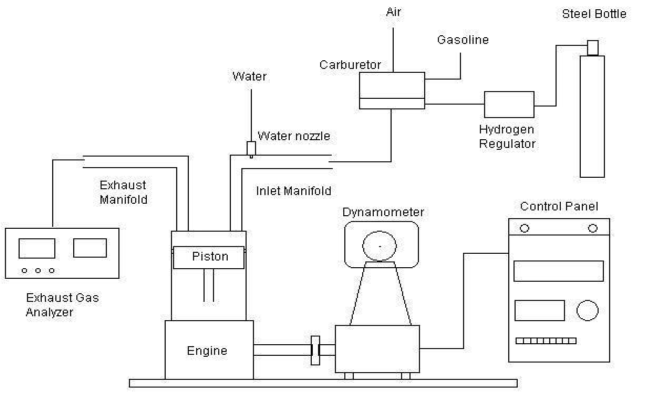

silencer muffler. Exhaust temperature was measured among the two muffler locations and emission values were obtained just after the last silencer.

Description of the Test Rig

Figure .1 illustrates the elementary setup of the test bench. The engine is joined with its original shaft to the dynamometer. The control panel of the dynamometer is located at a safe distance from the setup but is easily accessible. Ambient pressure and temperature as well as engine speed and torque values are simply read from the large size gauges. Load is diverse by two knobs that change the current in the stator of the eddy current dynamometer. Mainly three types of loading are possible, constant speed, variable speed and a combination of these.

Figure .1 Block Diagram of Test Setup

A 3-way switch is mounted on the dashboard assembly that allows instant switching from gasoline to hydrogen. This switch controls the solenoid valves on the gasoline line and hydrogen regulator. In this way, switching among fuels is possible without stopping the engine.

5. RESULTS AND DISCUSSION

For the purpose of detailed analysis, as many as possible working points were recorded. Much investigation has been done to stop backfire. Firstly the mixer was placed above the throttle valve, level with the air filter housing. In this procedure the engine's tendency to backfire was significantly high. For this reason it was located between the carburetor and inlet manifold. At idling and no load speeds, no backfire happened. When load was applied, a practical limit of about 20 Nm prohibited additional loading no matter how much water was given as a fine mist into the inlet manifold. At speed fewer than 2600 rpm serious backfire caused rapid loss of power and consequently the working range for hydrogen was set between 2600 rpm and 3700 rpm (the upper limit is due to the esteemed speed of the dynamometer).

Sample calculation for power, thermal effectiveness and mean effective pressure is as follows: For 2800 rpm,

For Gasoline T=22 Nm

P (kW) = 2π ω (rev/s) × T(Nm) × 10-3

P = 2 π × (2800 × 1 / 60) × 22 × 10-3

P = 6.45 kW

For Hydrogen T = 19 Nm

P (kW) = 2π ω (rev/s) × T(Nm) × 10-3

P = 2 π × (2800 × 1 / 60) × 19 × 10-3

P = 5.6 Kw

For Gasoline

$$\eta bth = \frac{Pb(kW)}{\dot{m}f(kg/s) \times QLHV(kj/kg)}$$

Where, Pb= 6.45 kW,

t = time for 100 ml of fuel, t = 74 s,

QLHV = 44000 kJ / kg •

$\dot{m}f$= 760 kg/m3× 10-6m3/ml × 100 ml / 74 s

$\dot{m}f$= 1.027 × 10-3kg / s

After calculation we get, ηbth= 14.3 %

For Hydrogen

$$\eta bth = \frac{Pb(kW)}{\dot{m}f(kg/s) \times QLHV(kj/kg)}$$

Where, Pb = 5.6 kW

QLHV = 120000 kJ / kg

$\dot{m}f$ = 0.084 kg/m3× 10-3 l/m3 ×139 l/min×1/60min/s

$\dot{m}f$= 1.946 × 10-4kg /s

After calculation we get, ηbth= 23.98 %

For Gasoline ,

$$mep(kPa) = \frac{Pb(kW) \times nr \times 10^3}{Vd(dm3) \times \omega(rev/s)}$$

Where. Pb = 6.45kW

Vd = 1.197 dm3

nr = 2 (4-strok engine)

ω = 46.7 rev /s

Aftr calculation, **mep = 230.8 kPa**

For Hydrogen

$$mep(kPa) = \frac{Pb(kW) \times nr \times 10^3}{Vd(dm3) \times \omega(rev/s)}$$

Where, Pb = 5.6

Vd = 1.197 dm3

nr = 2 (4-strok engine)

ω = 46.7 rev/s

On Calculation, **mep = 200.4 KPa**

6. CONCLUSION

Traditional 3 cylinder SI engine was modified to work on gaseous hydrogen. Compressed gas at 200 bar in steel bottles was familiarized to the engine by outside mixing. The first stage regulator drops the pressure to 3 bar to a copper gas supply line where a flow meter is mounted. The second stage controller delivers hydrogen to the mixing device mounted on the inlet manifold. Spray nozzles for water induction are placed nearly 4 cm away from the inlet valve. Ignition timing was set to 10° before TDC and fixed.

First tests were executed with the mixer mounted on topmost of the carburettor body. This is the usual configuration in propane mixing. Serious backfire was detected with this system. Another mixer was then put between the carburettor and inlet manifold. Backfire was prohibited in this selection. Under no-load condition, the engine worked flawless with a flat idling. When load is applied and engine speed is below 2600 rpm, serious backfire happened and initiated a sudden drop in engine power. Water mist from the spray nozzles critically enhances the backfire-safe operation.

Specific features of the use of hydrogen as an engine fuel were analyzed. Results of the tests demonstrated that there will be power loss for the low speed operation whereas high speed features could compete with gasoline presentation. The increase in thermal efficiency was obvious. It has been verified that hydrogen is a very bright contender as an engine fuel.

NOx discharge was about 10 times lower than with gasoline operation. CO and HC discharge were almost negligible as expected. Traces of these discharges were present because of the vaporizing and burning lubricating oil film on the cylinder walls.

Combustion properties of hydrogen favor fast burning circumstances such as in a high speed engine. Design changes that would allow the engine to higher speeds would have a helpful result. Suitable changes in the combustion chamber together with improved cooling of the valve mechanism would raise the probability of using hydrogen across a broader working range.

Successive injection of gaseous hydrogen in place of carburetion could seriously solve the backfire problem. Better performance could be attained. Even extra, liquid hydrogen either inside mixed or injected into the manifold could be a measure against backfire due to its surprising cooling effect (20 K temperature).

An electronic control unit that processes the speed, and differs the injection timing collected with ignition timing connected on a supercharged, intercooled, high compression ratio, short stroke and high speed engine looks to be the most suitable method to get the best from hydrogen's sole properties.

Hydrogen has the potential to attain problem-free procedure in IC engines. The upcoming advances depend on whether hydrogen can be learnt abundantly and economically.

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