HYDROGEN ENHANCED COMBUSTION ENGINE

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Abstract: **This project involves a detailed study on the "HYDROGEN ENHANCED COMBUSTION ENGINE ". Internal Combustion Engines are used widely in present generation. The internal combustion engine is an engine in which the combustion of a fuel occurs with an oxidizer in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine (ICE) the expansion of the high temperature and high pressure gases produced by combustion apply direct force to some component of the engine. Our Project has been undertaken at Hero Moto Corp in Boll arum which is a very reputed in service centre on behalf of Hero Organization which is specialized in improving the fuel efficiency & to reduce the NOX & CO emission This project consists of a small water tank, pump, microcontroller unit, engine set up and fuel injector. The microcontroller unit is used to setting the water injection period. The pump is used to suction the water in to deliver the fuel injector. The 12 volt fuel injector is used to inject the water in to the cylinder. This 12v fuel injector is controlled by the microcontroller unit. In Our Project we will inject the water by which the removal of the carbon deposits takes place in the combustion chamber by which the life span of the engine is improved. By these methods we would be improving the efficiency of an I.C Engine.**

Keywords: **Internal Combustion Engine.**

I. INTRODUCTION

Fossil fuels (i.e., petroleum, natural gas and coal), which meet most of the world's energy demand today, are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution, which are posing great danger for our environment, and eventually, for the total life on our planet. Many engineers and scientists agree that the solution to all of these global problems would be to replace the existing fossil fuel system with the clean hydrogen energy system. Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gases, no ozone layer depleting chemicals, and little or no acid rain ingredients and pollution. Hydrogen, produced from renewable energy (solar, wind, etc.) Sources would 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. In addition, the pollutants emitted by fossil energy systems are greater and more damaging than those that might be produced by a renewable based hydrogen energy system. 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. Global utilization of fossil fuels for energy needs is rapidly resulting in critical environmental problems throughout the world. Energy, economic and political crises, as well as the health of humans, animals and plant life, are all critical concerns. There is an urgent need of implementing the hydrogen technology.

In the early years of the development of internal combustion engines hydrogen was not the "exotic" fuel that it is today. Water splitting by electrolysis was a well known laboratory phenomenon. Otto, in the early 1870s, considered a variety of fuels for his internal combustion engine, including hydrogen. He rejected gasoline as being too dangerous. Later developments in combustion technology made gasoline safer. Most early engine experiments were designed for burning a variety of gases, including natural gas and propane. When hydrogen was used in these engines it would backfire. Since hydrogen burns faster than other fuels, the fuel-air mixture would ignite in the intake manifold before the intake valve could close. Injected water controlled the backfiring. Hydrogen gave less power than gasoline with or without the water.

II. IC ENGINE

The internal combustion engine is an engine in which the combustion of a fuel (normally a fossil fuel) occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit. In an internal combustion engine (ICE) the expansion of the high temperature and high pressure gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy.

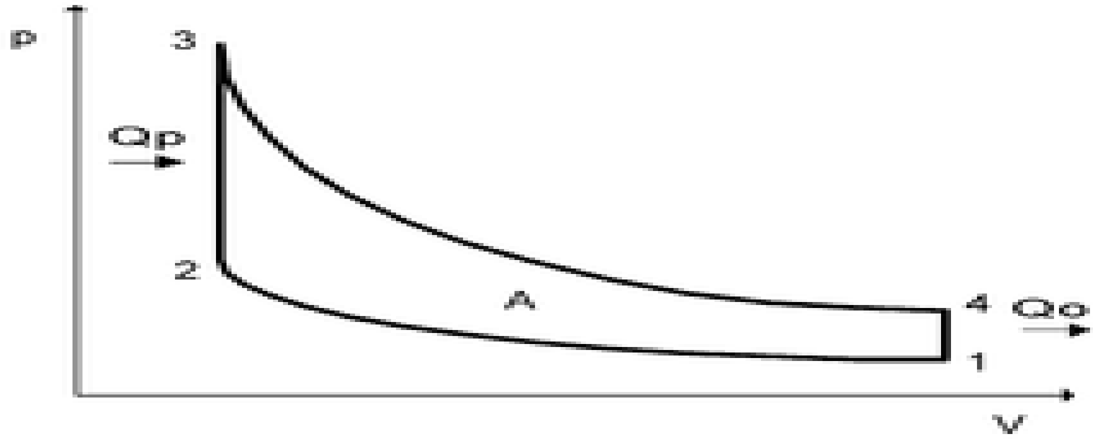
Internal Combustion Engine

The term internal combustion engine usually refers to an engine in which combustion is intermittent, such as the more familiar four-stroke and two-stroke piston engines. A second class of internal combustion engines use continuous combustion: gas turbines, jet engines and most rocket engines, each of which are internal combustion engines on the same principle as previously described.

The ICE is quite different from external combustion engines, such as steam or Stirling engines, in which the energy is delivered to a working fluid not consisting of, mixed with, or contaminated by combustion products. Working fluids can be air, hot water, pressurized water or even liquid sodium, heated in some kind of boiler. ICEs are usually powered by energy-dense fuels such as gasoline or diesel, liquids derived from fossil fuels. While there are many stationary applications, most ICEs are used in mobile applications and are the dominant power supply for cars, aircraft, and boats.

III. FOUR STROKE

Engines based on the four-stroke ("Otto cycle") have one power stroke for every four strokes (up-down-up-down) and employ spark plug ignition. Combustion occurs rapidly, and during combustion the volume varies little ("constant volume").They are used in cars, larger boats, some motorcycles, and many light aircraft. They are generally quieter, more efficient, and larger than their two-stroke counterparts.



PV Diagram of OTTO Cycle

1. Intake stroke: The first stroke of the internal combustion engine is also known as the suction stroke because the piston moves to the maximum volume position (downward direction in the cylinder) creating a drop in pressure. The inlet valve opens as a result of the cam lobe pressing down on the valve stem, and the vaporized fuel mixture is sucked into the combustion chamber. The inlet valve closes at the end of this stroke.
2. Compression stroke: In this stroke, both valves are closed and the piston starts its movement to the minimum volume position (upward direction in the cylinder) and compresses the fuel mixture. During the compression process, pressure, temperature and the density of the fuel mixture increases.
3. Power stroke: When the piston reaches a point just before top dead center, the spark plug ignites the fuel mixture. The point at which the fuel ignites varies by engine typically it is about 10 degrees before top dead center. This expansion of gases caused by ignition of the fuel produces the power that is transmitted to the crank shaft mechanism.
4. Exhaust stroke: In the end of the power stroke, the exhaust valve opens. During this stroke, the piston starts its movement in the maximum volume position. The open exhaust valve allows the exhaust gases to escape the cylinder. At the end of this stroke, the exhaust valve closes, the inlet valve opens, and the sequence repeats in the next cycle. Four-stroke engines require two revolutions.

IV.CARBURETOR

A carburetor is a device that blends air and fuel for an internal combustion engine. When carburetors are used in aircraft with piston engines, special designs and features are needed to prevent fuel starvation during inverted flight. Later engines used an early form of fuel injection known as a pressure carburetor.

Carburetors

Most production carbureted (as opposed to fuel-injected) engines have a single carburetor and a matching intake manifold that divides and transports the air fuel mixture to the intake valves, though some engines (like motorcycle engines) use multiple carburetors on split heads. Multiple carburetor engines were also common enhancements for modifying engines in the USA from the 1950s to mid-1960s, as well as during the following decade of high-performance muscle cars fueling different chambers of the engine's intake manifold.

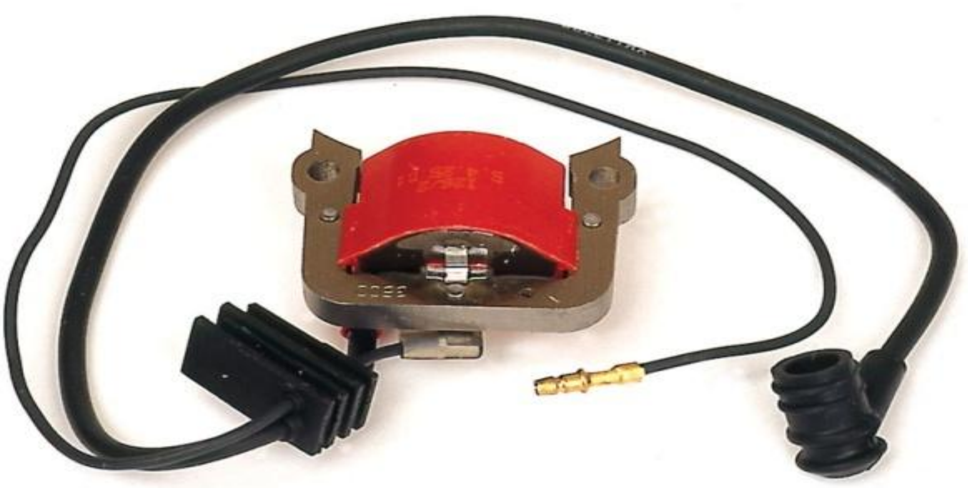
Older engines used updraft carburetors, where the air enters from below the carburetor and exits through the top. This had the advantage of never "flooding" the engine, as any liquid fuel droplets would fall out of the carburetor instead of into the intake manifold; it also lent itself to use of an oil bath air cleaner, where a pool of oil below a mesh element below the carburetor is sucked up into the mesh and the air is drawn through the oil-covered mesh; this was an effective system in a time when paper air filters did not exist.

V. PRINCIPLE

The carburetor works on Bernoulli's principle: the faster air moves, the lower its static pressure, and the higher its dynamic pressure. The throttle (accelerator) linkage does not directly control the flow of liquid fuel. Instead, it actuates carburetor mechanisms which meter the flow of air being pulled into the engine. The speed of this flow, and therefore its pressure, determines the amount of fuel drawn into the airstream.

VI. POWER COIL

An ignition coil (also called a spark coil) is an induction coil in an automobile's ignition system which transforms the battery's low voltage to the thousands of volts needed to create an electric spark in the spark plugs to ignite the fuel. Some coils have an internal resistor while others rely on a resistor wire or an external resistor to limit the current flowing into the coil from the car's 12 volt supply. The wire that goes from the ignition coil to the distributor and the high voltage wires that go from the distributor to each of the spark plugs are called spark plug wires or high tension leads.



Power Coil

Originally, every ignition coil system required mechanical contact breaker points, and a capacitor. More recent electronic ignition systems use a power transistor to provide pulses to the ignition coil. A modern passenger automobile may use one ignition coil for each engine cylinder (or pair of cylinders), eliminating fault-prone spark plug cables and a distributor to route the high voltage pulses. Ignition systems are not required for diesel engines which rely on compression to ignite the fuel/air mixture.

VII. AIR FILTER

A particulate air filter is a device composed of fibrous materials which removes solid particulates such as dust, pollen, mold, and bacteria from the air. A chemical air filter consists of an absorbent or catalyst for the removal of airborne molecular contaminants such as volatile organic compounds oro zone. Air filters are used in applications where air quality is important, notably in building ventilation systems and in engines.

In 2003 Ford Motor Company introduced the Visteon Long Life Filtration System to the Ford Focus.[2] This system has foam filter placed in the bumper of the car and is stated to have a 150,000 mile (240,000 km) service interval. According to a technical paper published by Society of Automotive Engineers, this design offers higher and more stable filtration efficiency than conventional air filters.

VIII. EXHAUST SYSTEM

An exhaust system is usually piping used to guide reaction exhaust gases away from a controlled combustion inside an engine or stove. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes. Depending on the overall system design, the exhaust gas may flow through one or more of:

- Cylinder head and exhaust manifold
- A turbocharger to increase engine power.
- A catalytic converter to reduce air pollution.

A muffler (North America) / silencer (Europe), to reduce noise

IX. HYDROGEN

There are a number of unique features associated with hydrogen that make it remarkably well suited in principle, to engine applications. Some of these most notable features are the following:

Hydrogen, over wide temperature and pressure ranges, has very high flame propagation rates within the engine cylinder in comparison to other fuels. These rates remain sufficiently high even for very lean mixtures that are well away from the stoichiometric mixture region. The associated energy release is also so fast that the combustion duration, tends to be short and contributes towards producing high-power output efficiencies and high rates of pressure rise following spark ignition. The lean operational limit mixture in a spark ignition engine when fuelled with hydrogen is very much lower than those for other common fuels. This permits stable lean mixture operation and control in hydrogen fueled engines.

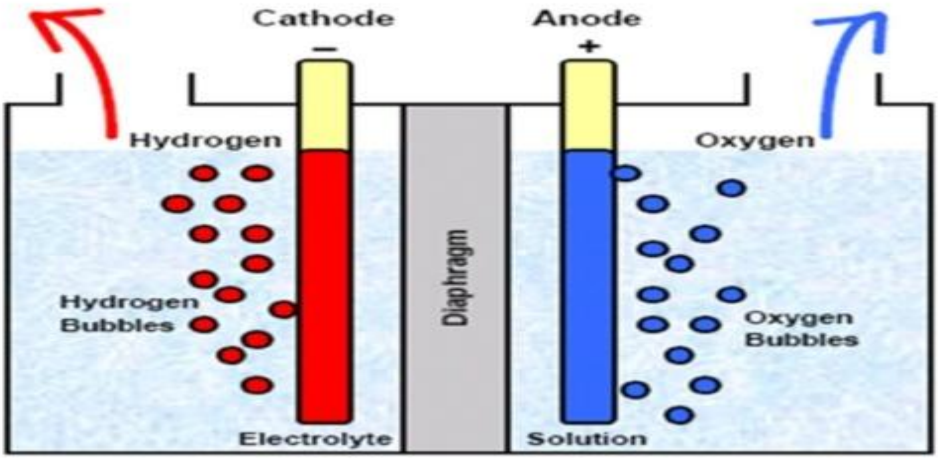
The operation on lean mixtures, in combination with the fast combustion energy release rates around top dead center associated with the very rapid burning of hydrogen–air mixtures results in high-output efficiency values. Of course, such lean mixture operation leads simultaneously to a lower power output for any engine size. One of the most important features of hydrogen engine operation is that it is associated with less undesirable exhaust emissions than for operation on other fuels. As far as the contribution of the hydrogen fuel to emissions, there are no un burnt hydrocarbons, carbon monoxide, carbon dioxide, and oxides of sulfur, smoke or particulates. The contribution of the lubricating oil to such emissions in well-maintained engines tends to be rather negligible. Only oxides of nitrogen and water vapor are the main products of combustion emitted. Also, with lean operation the level of no_x tends to be significantly smaller than those encountered with operation on other fuels.

The fast burning characteristics of hydrogen permit much more satisfactory high-speed engine operation. This would allow an increase in power output with a reduced penalty for lean mixture operation. Also, the extremely low boiling temperature of hydrogen leads to fewer problems encountered with cold weather operation. Varying the spark timing in hydrogen engine operation represents an unusually effective means for improving engine performance and avoidance of the incidence of knock. Also, the heat transfer characteristics of hydrogen combustion in engines are significantly different from those in engines operating on other fuels. The radioactive component of heat transfer tends to be small yet the convective component can be higher especially for lean mixture operation. The sensitivity of the oxidation reactions of hydrogen to catalytic action with proper control can be made to serve positively towards enhancing engine performance.

X. ELECTROLYSIS

Currently, the majority of hydrogen (~95%) is produced from fossil fuels by steam reforming or partial oxidation of methane and coal gasification with only a small quantity by other routes such as biomass gasification or electrolysis of water. There are three main types of cells, solid oxide electrolysis cells (SOEC's), polymer electrolyte membrane cells (PEM) and alkaline electrolysis cells (AEC's). SOEC's operate at high temperatures, typically around 800°C. At these high temperatures a significant amount of the energy required can be provided as thermal energy (heat), and as such is termed High temperature electrolysis. The heat energy can be provided from a number of different sources, including waste industrial heat, nuclear power stations or concentrated solar thermal plants.

This has the potential to reduce the overall cost of the hydrogen produced by reducing the amount of electrical energy required for electrolysis. PEM electrolysis cells typically operate below 100°C and are becoming increasingly available commercially. These cells have the advantage of being comparatively simple and can be designed to accept widely varying voltage inputs which make them ideal for use with renewable sources of energy such as solar PV. AEC's optimally operate at high concentrations electrolyte (KOH or potassium carbonate) and at high temperatures, often near 200 °C.



Standard Electrolysis

We have prepared the hydrogen kit to produce hydrogen gas and we have successfully produced the hydrogen gas with help of electrolysis of water. During electrolysis, electrical energy is used to cause a non-spontaneous chemical reaction to occur. Electrolysis is often used to obtain elements that are too chemically reactive to be found free in nature. In this experiment electrolysis will be used to separate water into hydrogen gas and oxygen gas. During this experiment you will perform certain tests for the products of each of the half-reactions involved in the process. Reduction will occur at the cathode. At this electrode hydrogen gas and hydroxide ions are formed. The electrons required for this reduction will come from the power source.

$$4H2O + 4\ e \rightarrow 2\ H2 + 4\ OH$$

Oxidation will occur at the anode, producing oxygen gas and hydrogen ions. The electrons that are produced will return to the power source

$$2H2O \rightarrow O2 + 4\ H + 4\ e$$

Adding the two half-reactions together gives us a net reaction of

$$6\ H2O \rightarrow 2\ H2 + O2 + 4H + 4OH$$

Hydrogen production via water electrolysis promises to be of great future importance and process having long been known. However, there are disadvantages when using this process. Two-thirds of the operation costs of the electrolyzers are electricity cost. The challenge, addressed by various researchers in the last few years, is the cost reduction by increasing efficiency of process through plant design and operating parameters (temperature, input power supply, distance between electrodes).

The aim of this work was the attempt to optimize the distance between electrodes with electrolytic hydrogen production from brine solution, through the variation in voltage. It was noticed that higher efficiency of electrolysis was found with lesser distance between the electrodes.

XI. CONSTRUCTION

The box is made up of empty battery box. The box is divided into six segments. To these partitions we have made the holes for the circulation of water through the complete box. Above these partitions there is one plywood of the size lesser than box which can be easily rested on partitions. We have made the holes to the plywood in three alternate rows to insert the carbon rods which is working as a positive electrode. There are 24 carbon rods in each row. For the negative electrodes we have used stainless steel spoons. These are also arranged in three rows alternatively. These spoons are connected to each other with the help of copper conductors. We have connected all carbon rods and spoons in series. Holes are made on plywood to come out the hydrogen gas from electrolysis process. There is some gap between cover of box and plywood in order to keep some space for collection of hydrogen. Cover of box is having one outlet from which supply of hydrogen is given to the engine. Box is made completely air tight so that there should not be any leakage of hydrogen. We have used pvc solvent for making the box making completely air tight. The two wires are taken out for connection to the battery. We are using 12 volt battery for supply of electricity.

XII. WORKING

Our kit is completely working on the electrolysis process. First of all we have poured the water inside the box sufficiently. For the better electrolysis process we have added some amount of salt which will increase the conductivity of water. Two wires coming out from the box are connected to the battery for giving supply. When circuit becomes complete the electrolysis process begins. The h+ ions are attracted towards negative electrode (spoons) and oh- ions are attracted towards the positive electrodes (carbon rods). H+ ions collect one electron from negative electrode and hydrogen gas is librated around spoons. By the time passes hydrogen gas is gets collected in the space in between cover of box and plywood. Hydrogen gas is taken out from this free space through the pipe which is connected to the cover of the box. This gas is used as a additive for engine.

XIII. CHANGE IN POWER OUTPUT AFTER INJECTION OF HYDROGEN

Hydrogen engine depends on the air/fuel ratio and fuel injection method used. As mentioned, the stoichiometric air/fuel ratio for hydrogen is 34:1. At this air/fuel ratio, hydrogen will displace 29% of the combustion chamber leaving only 71% for the air. As a result, the energy content of this mixture will be less than it would be if the fuel were gasoline (since gasoline is a liquid, it only occupies a very small volume of the combustion chamber, and thus allows more air to enter). Since both the carbureted and port injection methods mix the fuel and air prior to it entering the combustion chamber, these systems limit the maximum theoretical power obtain-able to approximately 85% of that of gasoline engines.

For direct injection systems, which mix the fuel with the air after the intake valve has closed (and thus the combustion chamber has 100% air), the maximum output of the engine can be approximately 15% higher than that for gasoline engines. Therefore, depending on how the fuel is metered, the maxi-mum output for a hydrogen engine can be either 15% higher or 15% less than that of gasoline if a stoichiometric air/fuel ratio is used. However, at a stoichiometric air/fuel ratio, the combustion temperature is very high and as a result it will form a large amount of nitrogen oxides (nox), which is a criteria pollutant. Since one of the reasons for using hydrogen is low exhaust emissions, hydrogen engines ar not normally designed to run at a stoichiometric air/fuel ratio. Typically hydrogen engines are designed to use about twice as much air as theoretically required for complete combustion. At this air/fuel ratio, the formation of Nox is reduced to near zero. To make up for the power loss, hydrogen engines are usually larger than gasoline engines, and/or are equipped with turbochargers or supercharger .The volumetric efficiency needs to be maximized so as to enhance the power output. Variable valve timing needs to be incorporated and optimized to effect higher volumetric efficiency and better control of exhaust gas recirculation.

XIV. ENGINE MODIFICATION

SI engines are easily adaptable to gaseous fuels like propane, methane, and hydrogen. Slight modifications for the introduction of the fuel in appropriate amount are applied. A fuel supply system that can be tuned according to the engine’s need is just good enough to make the engine work. In case of hydrogen there are certain additional issues concerning safety and backfire-safe operation throughout the whole operating region. The storage of the fuel is another aspect that affects the range of the vehicle operating on hydrogen. Due to its low energy per volume content, the compressed gas storage cannot compete with liquid gasoline.

Compared to gasoline, hydrogen’s low energy per unit volume produces less energy in the cylinder. An engine running on hydrogen produces less power than with gasoline. Supercharging may help remedy this by compressing the incoming fuel/air mixture before it enters the cylinder. This increases the amount of energy per volume of fuel. Additional weight and complexity is added to the engine by such modifications. But the power gain and backfire resisting property (by cooling the cylinder with more air) compensates for the mentioned drawbacks.

Addition of spray nozzles for water is essential to provide backfire free operation. Although very simple in structure, it is important to supply the right amount of water according to load, engine speed and temperature.

If cryogenic hydrogen is to be supplied, material selection for the injectors, fuel supply line, tank and metering devices must be made accordingly. Since much progress has been made in the safe handling and storage of liquid hydrogen in space industry, the remaining focus needs to be done on applying this know-how to small vehicle systems.

XV. PRE-IGNITION AND BACKFIRE

Hydrogen burns quickly and has a low ignition temperature. This may cause the fuel to be ignited by hot spots 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. Uncontrolled pre-ignition resists the upward compression stroke of the piston, thereby reducing power. Remedies for backfire include: timed port injection, delayed injection to make sure the fuel detonates only after the intake valve is closed; water injection, 1.75water to hydrogen, by weight (Peavey 2003). An appropriately designed timed manifold injection system can overcome the problems of backfiring in a hydrogen engine.

XVI. FUEL MIXING

Keeping the air and fuel separate until combustion is an important strategy for controlling the difficulties arising from the fast-burning properties of hydrogen. The low flammability limits and low energy required for ignition of hydrogen cause pre-ignition and backfire when using hydrogen fuel. Ignition occurs when a fuel-air mixture ignites in the combustion chamber before the intake valve closes. Pre-ignition can cause backfire when ignited fuel-air mixture explodes back into the intake system. It is most present at higher loads and at higher fuel-air mixtures near open throttle.

Pre-ignition is not a necessary precursor to backfiring and probably not occurs under normal circumstances at moderate 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 inducted into the cylinder.

Direct fuel injection involves mixing the fuel with air inside the combustion chamber. The fuel and air are kept separate until then. If the fuel and air are mixed before entering the combustion chamber; the arrangement is called external mixing.

XVII. WATER INDUCTION

Internal combustion engines waste about two-thirds of the combustion energy as heat. Adding water to hydrocarbon fuels allows the heat of combustion to combine the oxygen in the water with unburned carbon in the exhaust. This produces a combination of hydrogen and carbon monoxide. The hydrogen then burns, creating additional power. The induction of water vapor into the cylinder reduces the combustion temperature of nitrous oxide formation. Water induction is an effective means of controlling nitrous oxide without loss of power, efficiency, or exhaust temperature. The effectiveness of water induction increases with rpm.

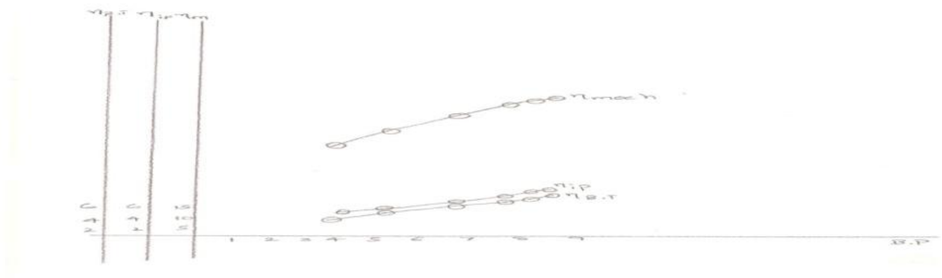
Some cylinders of the same engine may produce more nitrous oxide than others. With direct injection the equivalency ratio can be varied to each cylinder in response to individual emission characteristics. This is not possible with external mixing in carburetors where a uniform mixture is delivered to all cylinders. The non-uniformity of nitrous oxide formation from cylinder to cylinder requires a similar non-uniformity in water induction to compensate for this. Direct induction mixes water vapor with hydrogen before the introduction of air.

When the equivalency ratio exceeds 1.0 to 1.6 the possibility of pre-ignition is greatly 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 increasing the energy needed for ignition, a larger range of mixtures may be used. Reducing the time, as well as the temperature, of combustion greatly reduces nitrous oxide emissions. This also serves to prolong engine life. Higher engine rpm requires more water. The water flow rate must be adjusted to avoid water leaking past the piston rings. A standard gas tank, carburetor, and fuel pump may be adapted for water supply.

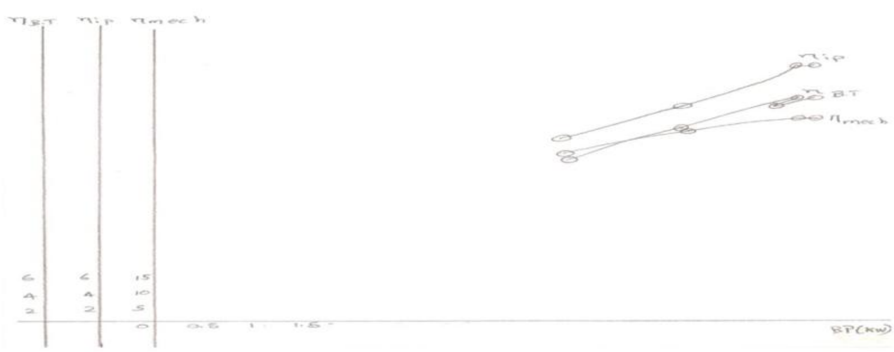
XVIII. RESULT

For the purpose of detailed analysis, as many as possible operating points were recorded. Much experimentation has been done to avoid backfire. Firstly the mixer was placed above the throttle valve, level with the air filter housing. In this arrangement the engine's tendency to backfire was considerably high. For this reason it was placed between the carburetor body and air filter. At idling and no load speeds, no backfire occurred. When load was applied, a practical limit of about 20 Nm prevented further loading no matter how much water was given as a fine mist into the inlet manifold. At speeds below 2600 rpm serious backfire caused sudden loss of power and therefore the operating range for hydrogen was set between 2600 rpm and 5500 rpm.

The variation of brake torque, which is read directly from the dynamometer, with engine speed can be clearly seen in Figure. At a speed of about 3100 rpm hydrogen achieves the torque values for gasoline and exceeds them at greater speeds. Since hydrogen has fast burning characteristics, it is expected to show better results at high speed operation. Figure shows the brake power for both fuels. At low speeds hydrogen suffers power but competes well within the second operating speed range (3000 rpm – 4000 rpm).



Efficiency vs Brake Power (Without H2 Kit)



Efficiency vs Brake Power (With H2 Kit)

Due to its low energy content per unit volume, an externally mixed hydrogen engine has less power than a conventional gasoline fueled engine. This drawback can be overcome by supercharging. In this way more air can be charged in the cylinder and more fuel as well. It also helps to cool down the cylinder avoiding pre-ignition. Hydrogen has a wide flammability range (4-75 %). Certain non-homogeneity in the fuel air mixture has no considerable effect on its combustion. The mixture burns completely and thermal efficiency tends to be higher. With external mixture formation non-homogeneity is lower than internal mixture formation. This is also the reason for the high backfire tendency when external mixing is applied.

There is fuel air mixture ready to burn flowing into the cylinder through the manifold. At any time this mixture can be ignited by a hot spot within the cylinder. Comparison of brake thermal efficiency of gasoline and hydrogen operation is made in Figure. Obviously hydrogen has a higher brake thermal efficiency. It is known for gasoline engines that they show their effective efficiency at greater part loads whereas hydrogen can operate even at low part loads with better efficiency. Plot of another performance parameter. Again at speeds below 3000 rpm the gasoline engine is more effective. Hydrogen operation shows a slightly better effectiveness at speeds above 3200 rpm.

Temperature analysis of the exhaust gas can be made in Figure. As soon as the hydrogen engine gets into the high speed range, the exhaust temperature starts to increase significantly. The cooling effect of water that is added with hydrogen is observed. But fast burning that occurs at increased speed during hydrogen operation results in temperature rise. Although more air than required for complete combustion is present in the cylinder (fuel lean operation), the engine is not capable of burning the total amount of fuel. Carbon monoxide emissions are due to incomplete combustion of fossil fuels. It is expected that the hydrogen engine has zero carbon monoxide emissions since hydrogen is a carbon-free fuel. As the results in Figure. Show, some amount of carbon monoxide is still present even with hydrogen. This is due to the burning of the lubricating oil film inside the cylinder. As speed increases, these emissions tend to diminish. A similar presentation of results for carbon dioxide emissions is contained in Figure. For hydrogen there is practically no emission, only very slight values again due to combustion of the lubricating oil film.

During combustion the temperature inside the cylinder is extremely high. As the piston expands, this heat evaporates a certain amount of the oil. Observing Figure, the contribution of the evaporated and incompletely burned oil to the overall emission can be guessed. Gasoline is a long-chain hydrocarbon and when not completely burned, breaks up into short chain hydrocarbons. Hydrogen is a gaseous fuel and does not dissolve the oil film on the cylinder walls. This is another advantage of it against conventional fuels. Better lubricating characteristics and longer engine life is obtained. At low speed the gasoline engine is choked and therefore more un burnt hydrocarbons are present in the exhaust gases. The only hydrocarbon emission from the hydrogen engine is due to the above mentioned oil film evaporation.

Since the tests were performed at part load, fuel lean operation was needed. Especially to cool down the cylinder and operate the engine safely without backfire, in hydrogen operating case, mixture was leaned by following the oxygen content in the exhaust gas. The oxygen levels in the exhaust gas. During hydrogen operation, the engine was kept on extremely lean side.

XIX. CONCLUSION

A conventional 4 cylinder SI engine was adapted to operate on gaseous hydrogen. Compressed gas at 200 bar in steel bottles was introduced to the engine by external mixing. The first stage regulator drops the pressure to 3 bar to a copper gas supply line where a flow meter is installed. The second stage regulator supplies hydrogen to the mixing apparatus installed on the inlet manifold. Spray nozzles for water induction are placed approximately 4 cm away from the inlet valves. Ignition timing was set to 10° before TDC and fixed.

First tests were performed with the mixer installed on top of the carburetor body. This is the usual configuration in propane mixing. Serious backfire was observed with this installation. Another mixer was then put between the carburetor body and inlet manifold. Backfire was prevented in this option. Under no-load condition, the engine operated flawless with a smooth idling. When load is applied and engine speed is below 2600 rpm, serious backfire occurred and caused a sudden drop in engine power. Water mist from the spray nozzles greatly 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 characteristics could compete with gasoline performance. The increase in thermal efficiency was obvious. It has been proved that hydrogen is a very bright candidate as an engine fuel.

No_x emissions were about 10 times lower than with gasoline operation. CO and HC emissions were almost negligible as expected. Traces of these emissions were present because of the evaporating and burning lubricating oil film on the cylinder walls. Combustion properties of hydrogen favor fast burning conditions such as in a high speed engine. Design changes that would allow the engine to greater speeds would have a beneficial effect. Appropriate changes in the combustion chamber together with better cooling of the valve mechanism, would increase the possibility of using hydrogen across a wider operating range.

Sequential injection of gaseous hydrogen instead of carburetion could greatly solve the backfire problem. Better performance could be obtained. Even further, liquid hydrogen either internally mixed or injected into the manifold could be a measure against backfire due to its extraordinary cooling effect (20 K temperature). An electronic control unit that measures the speed, and varies the injection timing together with ignition timing installed on a supercharged, intercooled, high compression ratio, short stroke and high speed engine seems to be the most appropriate way to get the best from hydrogen's unique properties. Hydrogen has the potential to achieve problem-free operation in IC engines. The future advances depend on whether hydrogen can be obtained abundantly and economically.

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