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RESEARCH ARTICLE OPEN ACCESS

Design of Hydrogen Internal Combustion Engine with Fuel Regeneration and Energy Recovery System

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ABSTRACT
To meet the demands of depleting fuel and prevent environmental pollution, an IC engine is designed where Hydrogen is chosen as fuel which undergoes combustion with oxygen and does not emit harmful by-products. It is a clean fuel since its final product is water. This innovative concept involves use of hydrogen as the fuel in IC engine without using a very expensive and bulky hold-up tank for storing liquid hydrogen. A water tank is used as the origin of the hydrogen. A pair of electrodes will be used inside the tank with more area exposing the surface for ionizing the water and generating the oxygen and hydrogen as fast as possible. The mixed gas with oxygen and hydrogen will be directed to the engine with a sealed pipe. The engine will work analogously to a normal gasoline engine with 4 strokes, intake, compress, combustion, and emission. The exception is that the emitted gas is vaporized H2O. The emitted vapor will not be released into the air. Instead, it will be collected and recycled to water tank after it is cooled down. The electricity to ionize the water is calculated as per unit volume of gases per unit time is required for combustion. The electrical energy is the ultimate source of the energy for powering up this system. The battery can be recharged with the power generated from different energy recovery systems including a thermoelectric ceramic covering around the engine, so as to improve the efficiency of the entire system and also by use of regenerative braking system. The advantage of this solution against the Electric Vehicle is no high voltage battery is required and for ionizing the water low voltage source is sufficient.
Keywords – Energy Recovery System, Fuel Regeneration, Hydrogen IC Engine.

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I. INTRODUCTION

Due to extreme air pollution and damage to wildlife and human life forms, there was a need to replace and reduce the use of gasoline and diesel-powered IC engines with a much better environmentally friendly and economically feasible alternate fuels. Recent advancements in the field of alternative have led to development of Nitrogen based compounds particularly Ammonia with certain additives to use it as an alternative fuel. Also advanced research is being carried out to use Hydrogen as an alternative fuel in IC engines due to its ability to undergo combustion and it does not produce and harmful toxic gases. Its combustion yields water, hence, it is categorized as a clean fuel.

The hydrogen internal combustion engine is simply a modified version of the traditional gasoline-powered internal combustion engine. This paper deals with the use of hydrogen as a fuel in internal combustion engines without using a bulky hydrogen storage tank for storing liquid hydrogen.

II. DEVELOPMENTS IN HYDROGEN IC ENGINE

2.1 History

Francois Isaac de Rivaz designed in 1806 the De Rivaz engine, the first internal combustion engine, which ran on a hydrogen/oxygen mixture. Étienne Lenoir produced the Hippomobile in 1863. Paul Dieges patented in 1970 a modification to internal combustion engines which allowed a gasoline-powered engine to run on hydrogen [1].

Mazda has developed Wankel engines that burn hydrogen. The advantage of using ICE (internal combustion engine) such as wankel and piston engines is that the cost of retooling for production is much lower [2]. Existing-technology ICE can still be used to solve those problems where fuel cells are not a viable solution yet, for example in cold-weather applications.

Between 2005-2007, BMW tested a luxury car named the BMW Hydrogen 7, powered by a hydrogen ICE, which achieved 301 km/h (187 mph) in tests. At least two of these concepts have been manufactured.

2.2 Hydrogen Fuel Enhancement

The Hydrogen fuel enhancement is the process of using a mixture of hydrogen and conventional hydrocarbon fuel in an internal combustion engine, typically in a car or truck, to improve fuel economy, power output, emissions, or a combination thereof. Methods include hydrogen produced through electrolysis, storing hydrogen on the vehicle as a second fuel, or reforming conventional fuel into hydrogen with a catalyst.

III. MODIFICATIONS REQUIRED IN EXISTING IC ENGINES

The differences between a hydrogen ICE and a traditional gasoline engine include hardened valves and valve seats, stronger connecting rods, non-platinum tipped spark plugs, a higher voltage ignition coil, fuel injectors designed for a gas instead of a liquid, larger crankshaft damper, stronger head gasket material, modified (for supercharger) intake manifold, positive pressure supercharger, and a high temperature engine oil [3]. All modifications would amount to about one point five times (1.5) the current cost of a gasoline engine. These hydrogen engines burn fuel in the same manner that gasoline engines do.

The power output of a direct injected hydrogen engine vehicle is 20% more than for a gasoline engine vehicle and 42% more than a hydrogen engine vehicle using a carburetor.

3. COMBUSTION PROPERTIES OF HYDROGEN

The Combustive properties of hydrogen are as follows:

3.1 Wide range of flammability

Hydrogen has a wide flammability range in comparison with all other fuels. As a result, hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. A significant advantage of this is that hydrogen can run on a lean mixture.

3.2 Low ignition energy

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline [4]. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition.

3.3 Small quenching distance

Hydrogen has a small quenching distance, smaller than gasoline. Consequently, hydrogen flames travel closer to the cylinder wall than other fuels before they extinguish [5]. Thus, it is more difficult to quench a hydrogen flame than a gasoline flame.

3.4 High auto ignition temperature

Hydrogen has a relatively high auto ignition temperature. This has important implications when a hydrogen-air mixture is compressed. In fact, the auto ignition temperature is an important factor in determining what compression ratio an engine can use, since the temperature rise during compression is related to the compression ratio [6]. The temperature rise is shown by the equation:

$$T2 = T1\ (V1/V2)\ \gamma\text{-}1 \qquad (1)$$

Where: V1/V2 = the compression ratio

T1 = absolute initial temperature

T2 = absolute final temperature

γ = ratio of specific heats

3.5 High flame speed at stoichiometric ratios

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is about one order of magnitude less than that required for gasoline [4]. This enables hydrogen engines to ignite lean mixtures and ensures prompt ignition.

3.6 High diffusivity

Hydrogen has very high diffusivity. This ability to disperse in air is considerably greater than gasoline and is advantageous for two main reasons. Firstly, it facilitates the formation of a uniform mixture of fuel and air [8]. Secondly, if a hydrogen leak develops, the hydrogen disperses rapidly. Thus, unsafe conditions can either be avoided or minimized.

3.7 Very low density

Hydrogen has very low density. This results in two problems when used in an internal combustion engine. Firstly, a very large volume is necessary to store enough hydrogen to give a vehicle an adequate driving range [9]. Secondly, the energy density of a hydrogen-air mixture, and hence the power output, is reduced.

4. ENERGY COMPARISON AND FUEL EFFICIENCY

The following diagram shows the Combustion chamber volumetric and energy comparison for Gasoline and Hydrogen Fueled Engines.

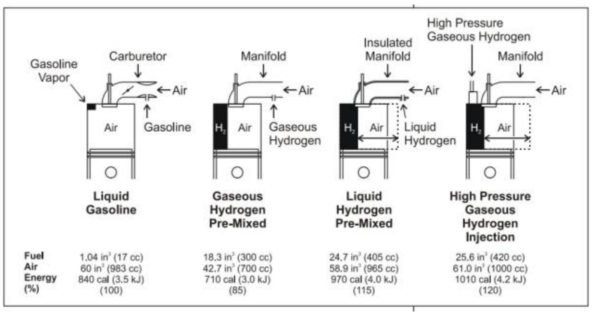

Fig -1: IC Engine

The liquid gasoline engine has a carburetor which sends a mixture of gasoline and air. The energy so produces for the above air fuel ratio is 840 cal.

Gaseous Hydrogen which is premixed with air undergoes combustion and results in production of energy equivalent to 710 cal [10].

Liquid Hydrogen premixed with air upon combustion releases 970 cal. And Gaseous Hydrogen Injection along with air produces 1010 cal.

From the above cases it was observed that Gaseous Hydrogen Injection setup produced the highest amount of energy which has a similar design to the existing Fuel injection systems used in gasoline IC engines. This setup of Hydrogen IC engine requires tough components which can bear the enormous force produced during combustion of Hydrogen.

The following table shows the Comparison of fuel economy expressed in MPG for hydrogen fuel cell vehicles available for leasing in California and rated by the U.S. Environmental Protection Agency as of August 2015 [11].

Vehicle	Model year	Combin edfuel economy (mpg)	City fuel economy (mpg)	Highway economy (mpg)	Range (Miles	Annual fuel cost (USD)
Toyota Mirai	2016	66 mpg	66 mpg	66 mpg	312	1250
Honda FCXClarity	2014	59 mpg	58 mpg	60 mpg	231	NA
Hyundai Tucson FuelCell	2013	50 mpg	49 mpg	51 mpg	265	1700

Table -1: Comparison of different vehicles and its fuel consumption.

The annual fuels costs of Hydrogen vehicle is around 1500 USD which is very much less when compared to annual gasoline fuel cost which is 9641 USD.

5. EMISSIONS FROM HYDROGEN ENGINE

The following diagram shows the Combustion chamber

The combustion of hydrogen with oxygen produces water as its only product:

$$2H2 + O2 = 2H2O \qquad (2)$$

The combustion of hydrogen with air however can also produce oxides of nitrogen (NOx):

$$H2 + O2 + N2 = H2O + N2 + NOx \qquad (3)$$

The oxides of nitrogen are created due to the high temperatures generated within the combustion chamber during combustion. This high temperature causes some of the nitrogen in X air to combine with the oxygen in the air. The amount of NOx formed depends on:

- The air/fuel ratio
- The engine compression ratio
- The engine speeds
- The ignition timing
- Whether thermal dilution is utilized

In addition to oxides of nitrogen, traces of carbon monoxide and carbon dioxide can be present in the exhaust gas, due to seeped oil burning in the combustion chamber.

6. PROPOSED DESIGN OF ENGINE

The following figure shows the proposed design with new modifications to the Hydrogen IC Engine for efficient operation and fuel recycling.

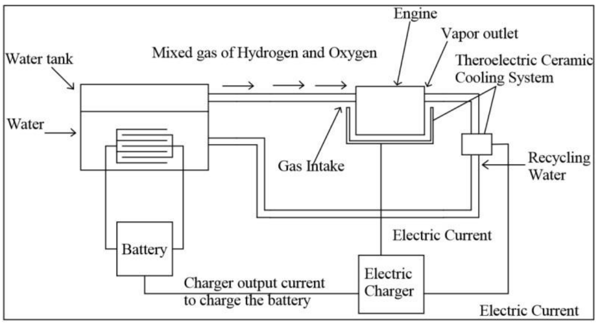

Fig - 2: Proposed IC Engine

The engine is a 4 Stroke SI engine which has high strength parts such has forged pistons, high quality crankshaft, connecting rods etc. these parts are tuned to bear the large amount of force produced due to combustion of a Hydrogen.

The water tank has processed water which is free of salt i.e. distilled water. There is a pair of electrodes (cathode and anode) placed in the water. It has large surface area and hence the more exposing surface provides proper ionization of water into hydrogen and oxygen. They are connected to battery which gives enough current for ionization to take place. This mixture of gas is then sent to IC engine via a control valve which varies its amount. This mixture once inside the IC engine it undergoes combustion due to ignition system. The main byproduct of this mixture is pure water. Since lot of heat is produced during combustion of hydrogen (33.9 kcal/g), the water is in vapor or steam form. If carried out in atmospheric air instead of pure oxygen (as is usually the case), hydrogen combustion may yield small amounts of nitrogen oxides, along with the water vapor. For this reason, air is not introduced in the combustion chamber.

The steam then passes through the Thermoelectric Ceramic Cooling System. Thermoelectric coolers operate according to the Peltier effect. The effect creates a temperature difference by transferring heat between two electrical junctions [12]. A voltage is applied across joined conductors to create an electric current. When the current flows through the junctions of the two conductors, heat is removed at one junction and cooling occurs. Heat is deposited at the other junction. It is used to condense the steam and it changes the state of water from gaseous to liquid. This condensed water is then recycled from the recycling pump and is then collected in the water tank. The electric charger is used to charge the battery which is used during ionization of water. This whole system is a closed system which requires the above components for its functioning. Exchange of energy takes place between various components and working fluid (water) and hence the efficiency of this system is further increased by insulating the heated portions of the pipe. This prevents heat loss due to conduction, convection, and radiation.

This system can be further optimized by connecting it to ECU and adding various sensors like Temperature sensors to measure temperature and Infrared sensors to sense the flow of working fluid. These sensors would prevent loss of heat flux and would enhance the efficiency of the system.

This system is arranged as shown along with the other components of the vehicle such as transmission; electronics etc. and allows recirculation of water hence the fuel circulation takes place. But water leaks out due to high pressure or minute cracks. This results in loss of heat potential and decreases efficiency.

Systems like KERS (Kinetic Energy recovery system) which charges the batteries and ensures that ionization process never stops. A thermoelectric cooling system also charges the battery and provides excess energy to power onboard electronic systems. Regenerative braking system can be used to utilize the braking power which is dissociated in the form of heat. It converts this energy to electricity which can be later used.

7. CONCEPT IMPLEMENTATION IN A VEHICLE

All these systems would be much more beneficial if the vehicle is a Hydrogen-electric Hybrid which would initially run-on hydrogen produced from water. And later can be switched from IC engine mode to Electric mode which would power the electric motors to propel the vehicle.

Different forms of energies would be extracted by different systems.

- KERS – Kinetic energy
- Regenerative braking system – Braking power
- Thermoelectric cooling system – Heat

These energies so collected would be converted to electric form and can be further used. Intelligent switching of propulsion source from IC Engine to Electric motor or vice versa would extend the mileage of the vehicle and the main advantage would be 100% Clean Energy which would not pollute the environment since the byproduct is pure water.

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REFERENCES

[1] Erol Kahramana, S. Cihangir Ozcanlib, Baris Ozerdemb(2007), An experimental study on performance and emission characteristics of a hydrogen fuelled spark ignition engine, International Journal of Hydrogen Energy, 32,pp. 2066 – 2072
[2] Das LM (2002), Hydrogen engine: research and development programs in Indian Institute of Technology, Delhi, International Journal of Hydrogen Energy, 27,9,953-965.
[3] Mazloomi, K., & Gomes, C. (2012). Hydrogen as an energy carrier: prospects and challenges. Renewable and Sustainable Energy Reviews, 16,5, pp..3024- 3033.
[4] SHAH, S. R. (2015). Extraction of electrical energy from heat produced during metal cutting operation on lathe by using thermocouples. Technology, 6(8), 78-95.
[5] Shah, S., Mullapudy, V., "Design of a Novel Foot Resting Mechanism Coupled with Vehicle Dynamics and Controls," FISITA 2016 World Automotive Congress, Busan, Korea, FISITA2016/F2016-VDCD-009
[6] Karim GA (2000), A comparative evaluation of the performance characteristics of a spark ignition engine using hydrogen and compressed natural gas as alternative fuels, International Journal of Hydrogen Energy, 25(8):783-93
[7] Singh, N., Sharma, A., Shah, S., and Gardampaali, B., "Mechatronics Based Accident Alarming System with Automatic Roadblock Prevention System," SAE Technical Paper 2017-01-1728, 2017, https://doi.org/10.4271/2017-01-1728.
[8] Shah, S. R. Design Of A Sand Casting Method Using Patterns Made Of Sublime Materials For Casting Intricate Shapes. J. Eng. Res. Appl, 8(12), 64-70.
[9] “Hydrogen Fuel Enhancement” Wikipedia. 16 September 2016 <https://en.wikipedia.org/wiki/Hydrogen_fuel_enhancement>.
[10] Shah, S., Kumar, D., Tiwari, N., “Design and Development Of An In-Wheel Suspension With Novel Automatic Camber Control Strategy For Improved Handling,” FISITA Web Congress 2020, F2020-VDC-081
[11] “Hydrogen Internal Combustion Engine Vehicle” Wikipedia. 16 September.2016 <https://en.wikipedia.org/wiki/Hydrogen_internal_combustion_engine_ vehicle>.
[12] Hydrogen use in Internal Combusiton Engines. https://www1.eere.energy.gov/hydrogenandfuelcells/tech_validation/pdf s/fcm03r0.pdf