Comparative Study of Performance and Operating Condition of H_2ICE And SI Engine

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Abstract- *Hydrogen is a very efficient & clean fuel. It provides an emission free transportation fuel.H_2ICE is an engine which uses hydrogen gas to produce power. Hydrogen is expected to beone of the most important fuel in the near future to meet thestringent emission norms. Use of hydrogen as a fuel in theinternal combustion engine represents an alternative use toreplace the hydrocarbon fuels, which produce polluting gasessuch as carbon monoxide (CO), hydro carbon (HC) duringcombustion. This review is conducted to compare H_2ICE with conventional ICE. The main purpose of this comparison is to study design changes to be made in H_2ICE. Also, it is found that whether H_2ICE can perform on CI engine. The objective of this comparative study is to design H_2ICE, piston, connecting rod and crank.*

Keywords- Performance issues, Design changes in H2ICE, Emission issues, Material changes.

I. INTRODUCTION

Hydrogen is an energy carrier that can be used in internal combustion engines or fuel cells producing virtually no greenhouse gas emissions when combusted with oxygen. The only significant emission is water vapour. Hydrogen production and storage is currently undergoing extensive research. The potential for hydrogen-fuelled internal combustion engines (H_2ICEs) to operate as clean and efficient power plants for automobiles is now well-established. In particular, H_2ICEs with near-zero emissions and efficiencies in excess of conventional gasoline-fuelled IC engines have been demonstrated. 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. Ifwater is injected in the cylinder during combustion of hydrogen fuel, backfire problem can be controlled. [1]

During the last years, SI-engines have been further improved. Engine development has focused on the reduction of tailpipe emissions, better fuel economy and higher engine performance as well as reduction of system costs. Hydrogen in gaseous form has been inducted along with the intake air. The diluents helium and nitrogen, mixed in various proportions with hydrogen have been used to achieve higher proportions of hydrogen energy substitutions without knock. Apart from gaseous diluents, water injection in the intake manifold has also been tried with very encouraging results. In order to meet new requirements for emission reduction and fuel economy a variety of concepts are available for gasoline engines. In future, hydrogen would be helpful to use as alternative fuel in automotive.

Main elements that make hydrogen a promising fuel are:

- Due to the lower minimum ignition energy of hydrogen a more stable ignition can be obtained. [1]
- Laminar burning velocity of hydrogen is higher than that of gasoline. [1]
- The combustion duration of the hydrogen engine is shorter than gasoline, the constant volume combustion share increases and engine thermal efficiency increases. [2]
- The higher diffusion coefficient of hydrogen may enhance the mixing process, which also can increase the engine efficiency and help to produce less unburned hydrocarbons. [2]

II. HYDROGEN USE IN INTERNAL COMBUSTION ENGINE

A.HYDROGEN ENGINE

Hydrogen produces only water after combustion. It is a non-toxic, non-odorant gaseous matter and also can be burn completely Hydrogen has some peculiar features compared to hydrocarbons fuels, the most significant being the absence of carbon. The burning velocity is so high that very rapid combustion can be achieved. The limit of flammability of hydrogen varies from an equivalence ratio (φ) of 0.1 to 7.1 hence the engine can be operated with a wide range of air/fuel ratio [3]. The minimum energy required for ignition of hydrogen–air mixture is 0.02 mJ only. This enables hydrogen engine to run well on lean mixtures and ensures prompt ignition. The density of hydrogen is 0.0838 kg/m^3, which is lighter than air that it can disperse into the atmosphere easily. Hydrogen has the highest energy to weight ratio of all fuels. The flame speed of hydrogen is 270 cm/s that may cause a very high rate of cylinder pressure rise. The diffusivity of hydrogen is 0.63 cm^2/s. As the hydrogen self-ignition temperature is 858 K, compared to diesel of 453 K, it allows a larger compression ratio to be used for hydrogen in internal combustion engine. But it is not possible to achieve ignition of hydrogen by compression alone. Some sources of ignition have to be created inside the combustion chamber to ensure ignition [3].

B. SI ENGINE

Hydrogen can be used as a fuel directly in an internal combustion engine, almost similar to a spark-ignited (SI) gasoline engine. Most of the past research on H_2 as a fuel focused on its application in SI engines. Hydrogen is an excellent candidate for use in SI engines as a fuel having some unique and highly desirable properties, such as low ignition energy, and very fast flame propagation speed, wide operational range. The hydrogen fuel when mixed with air produces a combustible mixture which can be burned in a conventional spark ignition engine at an equivalence ratio below the leanFlammability limit of a gasoline/air mixture. The resulting ultra-lean combustion produces low flame temperatures and leads directly to lower heat transfer to the walls, higher engine efficiency and lower exhaust of NOx emission [5-6]. Therefore, the extensive research pure H2 as fuel has led to the development and successful marketing of hydrogen engine. For example, Ford developed P2000hydrogen engine, which was used to power Ford's E-450 Shuttle Bus. BMW developed a 6 litre, V-12 engine using liquid H2 as fuel. With an external mixture formation system, this engine has a power out about 170 kW and an engine torque of 340 Nm [3]

C. CI ENGINE

Hydrogen cannot be used as a sole fuel in a compression ignition (CI) engine, since the compression temperature is not enough to initiate the combustion due to its higher self-ignition temperature [3].Hence hydrogen cannot be used in CI engine without the assistance of a spark plug or glow plug. This makes hydrogen unsuitable for a diesel engine as a sole fuel. Because of this reason of the reported literature, activities on hydrogen fuelling of a diesel engine were based on dual-fuel mode. In a dual fuel engine the main fuel is inducted/carburetted or injected into the intake air while combustion is initiated by diesel fuel that acts as an ignition source. The pilot fuel quantity may be in the range of 10–30% while the rest of the energy is supplied by the main fuel. Hydrogen operated dual fuel engine has the characteristics to operate at leaner equivalence ratios at part loads, which results in NOx reduction, and increase in thermal efficiency thereby reducing the fuel consumption.

Water injection can also prevent knocking and pre-ignition during hydrogen combustion. Here water acts in a similar manner to diluents such as exhaust gas recirculation, cooling the charge and reducing the combustion rate. However, water injected into the intake manifold reduces volumetric efficiency

D. COMPARATIVE STUDY OF PROPERTIES OF HYDROGEN AND OTHER FUEL

Table No – 01 [8]

Properties	Hydrogen	Gasoline	Diesel
Formula	H_2	$C_nH_{1.87n}$ C4-C12	$C_nH_{1.8n}$ C8-C20
Auto Ignition Temperature	858	533-733	530
Min Ignition Energy (mJ)	0.02	0.24	-
Flammability Limits (vol. % in air)	4-75	1.4-7.6	0.7-5
Stoichiometric air fuel ratio on mass	34.3	14.6	14.5
Limits of Flammability(equivalence ratio)	0.1-7.1	0.7-3.8	-
Density at16°C and 1.01 bar(kg/m^3)	0.0838	721-785	833-881
Net heating value(MJ/kg)	119.93	43.9	42.5
Flame Velocity(cm/s)	265-325	37-43	30
Quenching gap in NTP air (cm)	0.064	0.2	-
Diffusivity in air (cm^2/s)	0.63	0.08	-
Octane number	130	92-98	-
Cetane number	-	13-17	44-55

III. EXPERIMENTAL SETUP

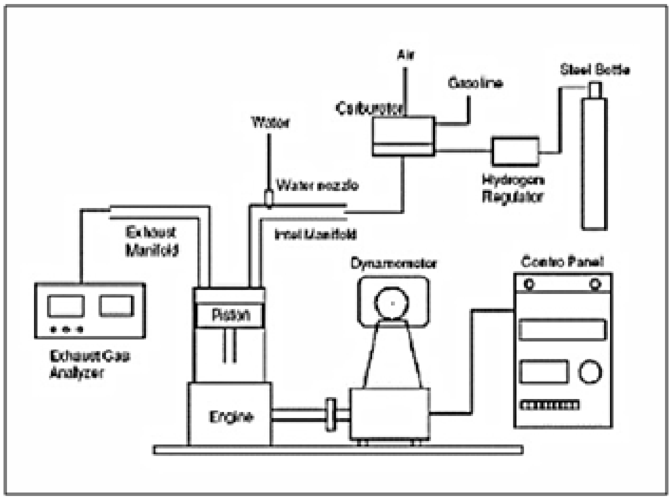

Fig No. 1: Experimental Set up [4]

Fig shows the setup for comparing performance of hydrogen and gasoline ICE. Engine used is four stroke SI engine Carburation Method is used to mix the gasoline and air during test for gasoline fuel. Then gasoline cut-offand test for hydrogen gas is taken. Hydrogen Regulator is used to regulate the flow of hydrogen in an engine. Eddy current Dynamometer is used to measure the brake power of an engine. Exhaust gas analyser is used to measure emission in an engine.

IV.RESULT

Comparison of Performance Characteristics

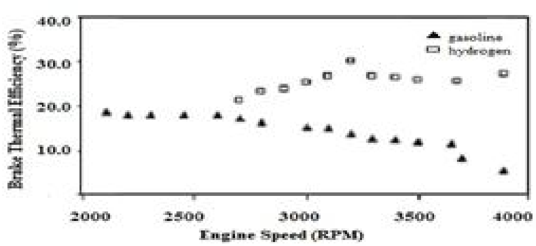

Fig. No.2: Performance Characteristics [4]

Hydrogen fuel has higher brake thermal efficiency and even can operate at lower engine loads with better efficiency. It can be noticed that brake thermal efficiency is improved to about 31 percentage with hydrogen fuelled engine compared to gasoline fuelled engine. Comparison of brake thermal efficiency of the fuels is shown in Fig.2 [4] here brake thermal efficiency of hydrogen is much better than the brake thermal efficiency of gasoline engine even at a low speed.

COMPARISON OF EMISSION CHARACTERISTICS

A. EMISSIONS OF NOx

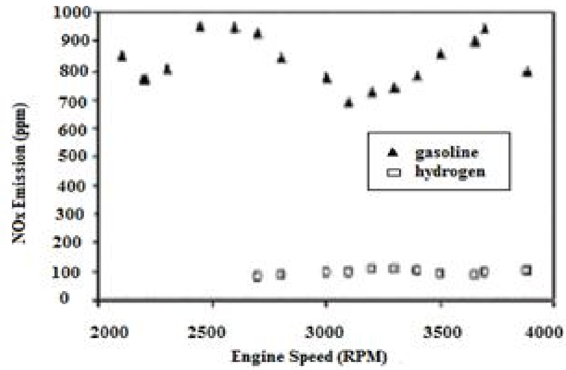

Fig.3: Emissions of NOx

Fig.3 [4] illustrates NO_x levels of both engines. Significant decrease in NO_x emission is observed with hydrogen operation. Almost 10 times decrease in NO_x can be noted, easily. The cooling effect of the water sprayed plays important role in this reduction. Also operating the engine with a lean mixture is kept NO_x levels low. The level of NO_x emission was almost negligible for a TMI-operated SI engine for an equivalence ratio below 0.6. As is well-known, the mechanism of NO_x formation is highly temperature-dependent. With lean operation in hydrogen engines, the lower temperature and slower chemical reactions weaken the kinetics and limit the formation of NO_x. [4]

Depending on the condition of the engine (burning of oil)and the operating strategy used (a rich versus lean air/fuel ratio), a hydrogen engine can produce from almost zero emissions (as low as a few ppm) to high NO_x and significant carbon monoxide emissions.

B. EMISSIONS OF CO

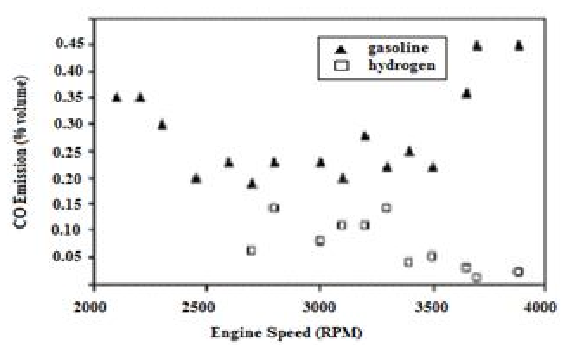

Fig.4: Emissions of CO [4]

V. DESIGN MODIFICATION IN H_2ICE.

Compared to gasoline, hydrogen's low energy per unit volume produces less energy in cylinder. An engine running on hydrogen produces less power than with gasoline. To achieve same power output for given gasoline engine, it should be compact or supercharging may help remedy this by compressing the fuel/air mixture before it enter the cylinder. Supercharging increase the amount of energy per volume of air. The flame speed of hydrogen is 270 cm/s which is very high than gasoline. Therefore, length to diameter ratio should be kept large in H_2ICE[5]

The most effective means of controlling pre-ignition and knock is to re-design the engine for hydrogen use, specifically the combustion chamber and the cooling system. A disk-shaped combustion chamber (with a flat piston and chamber ceiling) can be used to reduce turbulence within the chamber. The disk shape helps produce low radial and tangential velocity. Other Modifications are, use of higher voltage ignition coil, fuel injector designed for hydrogen gas, stronger head gasket material, modified intake valves, engine oil that will sustain high temperature.[5]

A. DIRECT INJECTION OF HYDROGEN

In direct injection system, Hydrogen fuel is injected at 200 bar after the intake has closed, the maximum output of an engine can be approximately 15% higher than that for gasoline engine.Therefore, depending on how the fuel is metered, the maximum 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 (NO_x). Hydrogen engines are not normally designed to run at a stoichiometric air/fuel ratio because of formation of NO_x. 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 NO_x 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. [5]

B. 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 vapour 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.

C. COOLING SYSTEM

The temperature at the inner surface is assumed constant at 250^0C to account for heat generated due to combustion inside the engine. Heat transfer rate increases after changing fin geometry and it is observed that heat transfer coefficient and turbulence are more in case of step shape fin model as compare to "S" shape fin model. Due to non-uniformness in the geometry of fins, turbulence of flowing air increases which results in more heat transfer rate. In H_2ICE, more heat is generated. Therefore, better cooling method is necessary to transfer heat from cylinder wall. [6]

D. POSTPONING IGNITION TIMING WITH WATER INJECTION OF INTAKE MANIFOLD

Postponing ignition timing is helpful to reducing the occurrence degree or inclination of pre-ignition, and water injection of intake manifold can be used to eliminate backfire. But if ignition were significantly postponed, power output and brake thermal efficiency would decrease, and water injection quantity would to bring power output to drop, and water injection would also cause engine's structure to change, moreover, the corrosion degree of cylinder would become worse and lubrication performance would further deteriorate with the increase of water injection quantity. So, using water injection to control backfire has many disadvantages. It is necessary to combine postponing ignition timing with water injection of intake manifold to give full play to their advantages, and avoid their disadvantages to the greatest extent. [7]

VI. MATERIAL CHANGES IN H_2ICE [9]

1. Piston should have enormous strength to withstand the high gas pressure and inertia forces .It should disperse the heat of combustion quickly to the cylinder wall, e.g. Aluminium Alloy.
2. Hardened valves and valve seats
3. Stronger connecting rod
4. Stronger head gasket material
5. High strength of crankshaft

VII.CONCLUSION

Hydrogen is used as an alternative fuel in an IC engine. It produces only water vapour at exhaust of an engine.To produce same power output for a given gasoline engine, it should be compact or supercharging may help remedy this by compressing the fuel/air mixture before it enter into the cylinder. Engine components can be modified or re-designed to use hydrogen as a fuel in ICE. Material of H_2ICE should be selected such that it should be lighter, high heat dissipation capacity and having low cost.

An appropriate direct injection system design specifically on the basis of hydrogen's combustion characteristics for a particular engine configuration ensures smooth engine operational characteristics without any undesirable combustion phenomena. Direct injection solves the problem of pre-ignition in the intake manifold; it does not necessarily prevent pre-ignition within the combustion chamber.

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