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Full Length Research Paper

Effect of hydrogen and gasoline fuel blend on the performance of SI engine

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This paper presents the effects of introducing hydrogen with gasoline on the engine performance like power, torque and efficiency of spark ignition (SI) engine. Hydrogen is found to be one of the important energy substitutes of the future era. Hydrogen as a renewable energy source provides the potential for a sustainable development, particularly in the automotive and energy storing sector. Hydrogen driven vehicles reduce both local as well as global emissions. By changing the amount of hydrogen percentage with gasoline, the data has been recorded and analyzed to achieve the economical blend percentage of hydrogen and gasoline to obtain the best performance of the SI engine.

Key words: Hydrogen gasoline blend, engine performance, ignition timing, efficiency.

INTRODUCTION

Hydrogen is the fuel of the future. It is an energy carrier that can be used in internal combustion (IC) engines producing no greenhouse gas emissions virtually when combusted with oxygen. The only emission is water vapor. It is a carbon-free energy carrier, and likely to play an important role in a world with severe constraints on greenhouse gas emissions.

Hydrogen has extremely wide ignition limits. This allows a spark ignition engine to operate on hydrogen with very little throttling. Stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture. This gives great advantage in IC engines, leading to higher engine speeds and greater thermal efficiency (Ganeshan, 2007). The potential of using hydrogen for small horsepower SI engines was evaluated and compared with compressed natural gas (CNG).

Another study dealt on certain drawbacks of hydrogen fuelled SI engines, such as high NOx emission and small power output to determine the performance, emission and combustion characteristics of hydrogen fuelled SI engines. The design features and the current operational limitations associated with the hydrogen fuelled SI engines were reviewed (Karim, 2000). The onset of knock in hydrogen fuelled SI engine applications was investigated (Li and Karim, 2004).

Several problems of the injectors (leakage, unequal response time-opening delay and poor durability) as available then, have mostly been solved nowadays due to the worldwide increased research on gaseous injection systems (natural gas, LPG, etc). To run a hydrogen engine, the mixture formation of air and hydrogen need not to be controlled precisely (Das, 1990).

Consequently, simple systems such as an external mixture system with a gas carburetor can be used for the fuel supply. This system is firstly implemented on the tested engine. However, combustion process can be controlled completely only with an injection system and an electronic control unit (electronic management system), as used for all new gasoline engines. Hence, the carburetor is discarded to be replaced by a gas injection system in the inlet manifold, allowing multi-point

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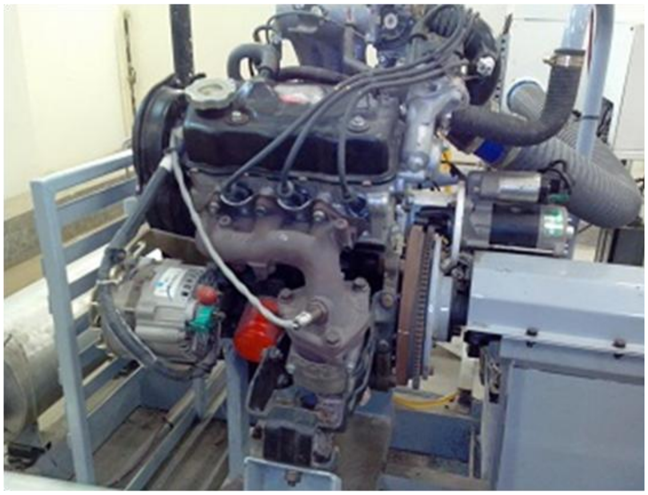

Figure 1. Experimental setup.

Table 1. Specifications of the test engine.

Items	Engine (gasoline)
Mark	231H
Engine type	Four stroke, Three cylinder
Bore (mm)	66.5
Stroke (mm)	72
Compression ratio	9.2/1
Fuel system	Petrol (MPFI)
cooling	Water cooled
Engine working temperature (°C)	120

sequential injection of the gaseous hydrogen fuel in each inlet channel just before the inlet valve. For gaseous fuels, an additional and important advantage is better resistance to backfire (explosion of the air/fuel mixture in the inlet manifold) (Sorusbay and Veziroglu, 1988; Kondo et al.,1996; Lee et al., 1995; Guo et al., 1999).

The danger of backfire is eliminated with a sequential timed multipoint injection of hydrogen and the corresponding electronic management system. As a result, the power output of the engine is increased. The optimization of the engine parameters was studied. The ignition timing has a strong influence on efficiency of the engine; it should be regulated adequately as a function of the mixture richness (Verhelst and Sierens, 2001). Moderate engine performance is obtained in hydrogen combustion with a special injector that is equipped with a leak structure and a glow plug (Ikegami et al., 1982). The smoke emission reduces from 4.8 BSN to 0.3 BSN with simultaneous reduction of NO_X when using the hydrogen in dual fuel mode.

Braking thermal efficiency increases from around 23.59 to 29% with optimized injection starting and duration. The emission such as CO, CO_2 and HC is reduced drastically. The NO_X emission decreases from 6.14 g/kW-h to 3.14 g/kW-h at full load. The reduction is due to efficient combustion resulting from the hydrogen combustion (Sarvanan et al., 2007).

The limit of flammability of hydrogen varies from an equivalence ratio of 0.1 to 7.1; hence the engine can be operated with a wide range of air fuel ratio (Yi et al., 2000). Hydrogen fuelled engine efficiency is superior to gasoline engine, especially at small partial loads operating conditions, due to a better combustion process and load qualitative adjustment method. The level of pollutant emissions decreases at the hydrogen fuelling. The exhaust gases do not contain CO_2 or lots of polluting substances provided by classic engines such as CO, HC, particles and lead compounds (Negurescu et al., 2012). Tyagi and Ranjan (2013) minimize exhaust pollutant by heating catalytic converter.

The objective of this work is to investigate the effect of the gasoline-hydrogen blended fuel on engine power and torque, to quantify engine performance and to find the best hydrogen and gasoline fuel blend ratio for SI engines.

EXPERIMENTAL SETUP

The experimental setup, shown in Figure 1, consists of test engine, dynamometer (D.C. dynamometer) and various measuring equipments. A three cylinder four stroke SI engine is used as the test engine. The specification of the test engine is given below in Table 1 and the properties of the gasoline and hydrogen are illustrated in Table 2. Due to its properties, hydrogen has proven to be an excellent fuel for internal combustion engines and signifies a reliable option to the fossil fuels replacement, providing also the benefit of maintaining the main principles of the existing engines design.

A multiport fuel injection system is implemented to take advantage of its controlling possibilities. The fuel is supplied from steel cylinders with compressed hydrogen at 210 bars. After a pressure reducing valve that expands hydrogen to a pressure of about 3.5 bar, the hydrogen is admitted to a common rail system. From the common rail, three tubes deliver the hydrogen to the three individual injectors. The injectors were developed to deliver hydrogen to the combustion chamber. Each cylinder has a short inlet pipe, and the injector is located at 10 cm from the cylinder head under an angle of 40°. Figure 2 gives a view of the installation of the injectors. The following parameters were measured and calculated to drive the engine performance data:

(1) Engine rpm
(2) Ignition timing
(3) Brake mean effective pressure (BMEP)
(4) Effective efficiency
(5) Torque
(6) Hydrogen and gasoline blend ratio
(7) Power

In Figure 3, flammability ranges of comparative fuels were given at atmospheric temperature. It is found through the previous literature that hydrogen has the maximum and wide range of flammability among all types of comparative fuels used, at atmospheric temperature. In Table 3, the heating values of different fuels were

Table 2. Property of fuels used (Neguresçu et al., 2012).

Property			Gasoline	Hydrogen
Molecular mass, [kg/kmol]			114	2.016
Theoretical air-fuel ratio, [kg/kg comb]			14.5	34.32
Density, at 0°C and 760 mmHg, [kg/m3]			0.735-0.760	0.0899
Flammability limits in air, at 20℃ and 760 mm Hg		**% vol.**	1.48-2.3	4.1-75.6
		λ	1.1-0.709	10.12-0.136
Flame velocity in air (λ=1), at 20℃ and 760 mm Hg [m/s]			0.12	2.37
Octane Number			90-98	>130
Min. ignition energy in air [mJ]			0.2-0.3	0.018
Autoignition temperature, [K]			753-823	848-853
Lower heating value (gas at 0°C and 760 mmHg)	Stoichiometric fuel-air mixture[kJ/m^3]		3661	3178
	[kJ/kg]		42 690	119 600

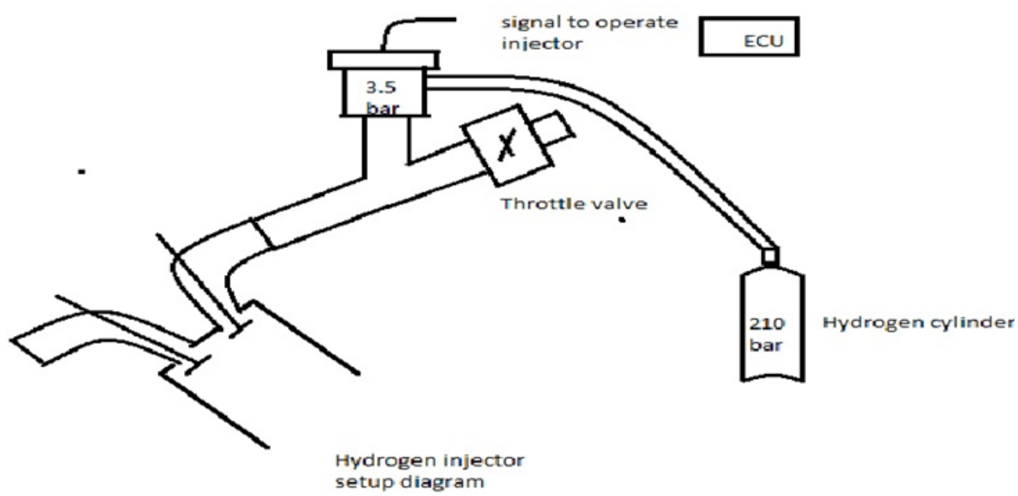

Figure 2. Schematic diagram of hydrogen injection (with specification).

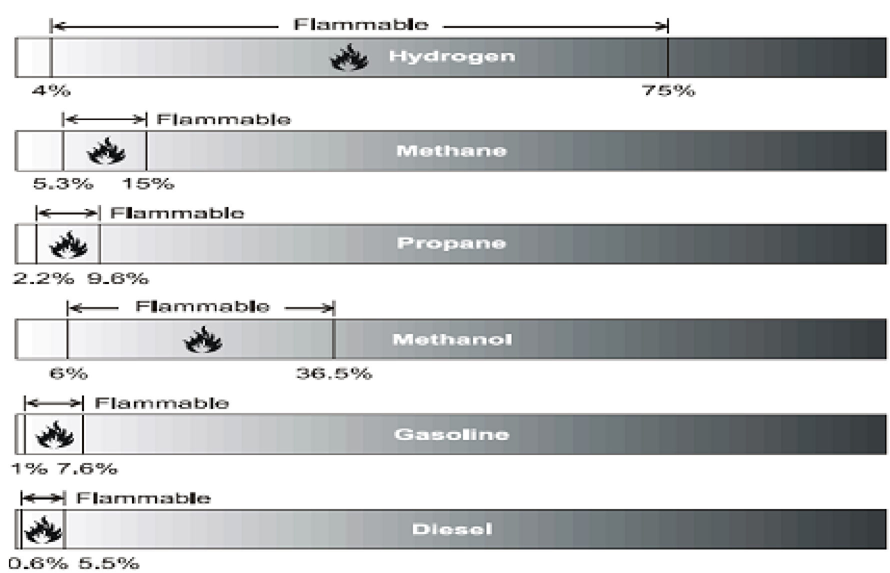

Figure 3. Flammability Ranges of Comparative Fuels at Atmospheric Temperature (Source: Lenz, 2001).

Table 3. Heating values of comparative fuels.

Fuel	Higher heating value (at 25 °C and 1 atm/kJ/g)	Lower heating value (at 25°C and 1 atm/kJ/g)
Hydrogen	141.86	119.93
Methane	55.53	50.02
Propane	50.36	45.60
Gasoline	47.50	44.50
Diesel	44.80	42.50
Methanol	19.96	18.05

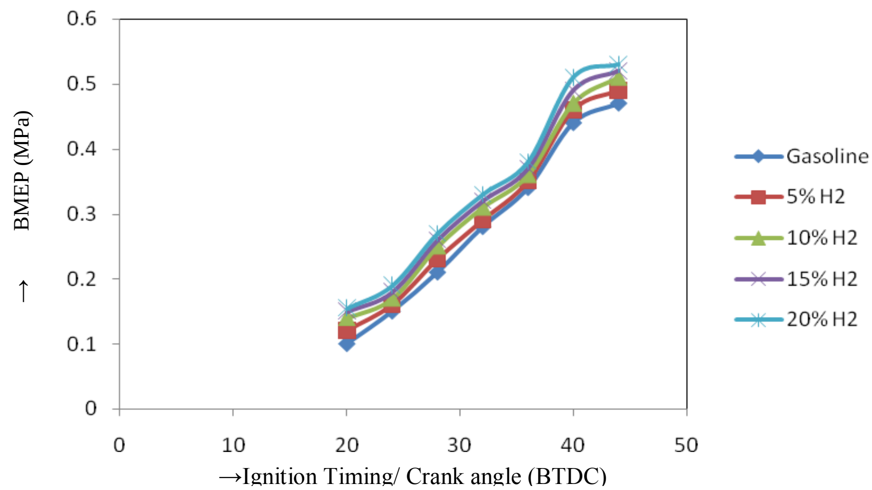

Figure 4. (BMEP vs IT).

illustrated and by calculating the difference between higher and lower heating values, hydrogen showed the maximum heating value range.

The main problem with the hydrogen fueled engine is backfiring. Hence, seven ignition timing were selected by keeping backfire in mind. To avoid backfire, the engine is run with a lean mixture. Seven ignition timings were selected from the range between 44'CA BTDC and 20'CA BTDC under fixed engine speed (1500 r/min), fixed fuel injection timing (180'CA BTDC), fixed fuel injection duration (15 m, corresponding to 115'CA) and fixed throttle opening (70% WOT). Thus, the influence of ignition timings on gasoline-hydrogen blend can be clarified by varying the ignition timing while keeping other parameters unchangeable.

Cold rated spark plugs were used to avoid spark plug electrode temperatures exceeding the auto-ignition limit and causing backfire. The benefit of cold rated spark plugs use is that, there were hardly any spark plug deposits to burn off. The cold rated spark plug has advantage over spark plug with platinum electrodes so as to eliminate hydrogen oxidation. The gap between spark plug was kept at 0.25mm.

RESULT AND DISCUSSION

The efficiency of a hydrogen fueled engine is very dependent on optimally adjusted ignition timing as a function of the richness of the mixture varying with the load condition. In Figure 4, a graph has been plotted which figurate the effect of the ignition timing of gasoline and it blending with hydrogen on brake mean effective pressure (bmep). It is found that with the increase in the amount of hydrogen blend with gasoline, brake mean effective pressure also increases. Hydrogen rapid combustion allows very little heat loss to the surrounding and hence, high, instantaneous local temperatures are produced and ultimately the brakes mean effective pressure.

In Figure 5, graph has been plotted which deals with the effect of the ignition timing of gasoline and its blending with hydrogen on effective thermal efficiency ($\eta_{effective}$). The effective thermal efficiency of engine increases with the increase in hydrogen injection. Even stoichiometric hydrogen air mixture burns seven times as fast as the corresponding gasoline air mixture. This gives great advantage in IC engines, leading to higher engine speeds and greater thermal efficiency.

In Figure 6, the main objective of the optimization was to obtain maximum engine torque over the whole of the speed range (1500-3300 rpm). This optimization was done with a fixed air to fuel ratio λ of 2 to avoid backfire and torque (Nm) for the speed range(1500-3300) with λ=2 and the ignition timing (IT) set to 20° crank angle BTDC. With this, the required results were obtained

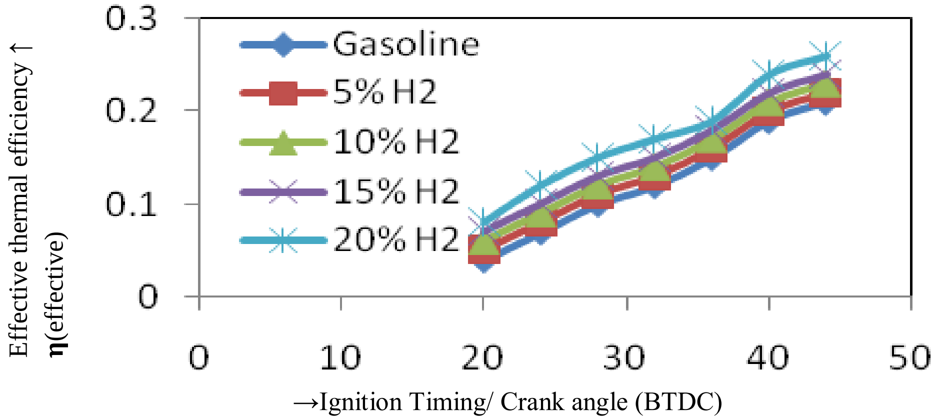

Figure 5. ($\eta_{effective}$ vs IT).

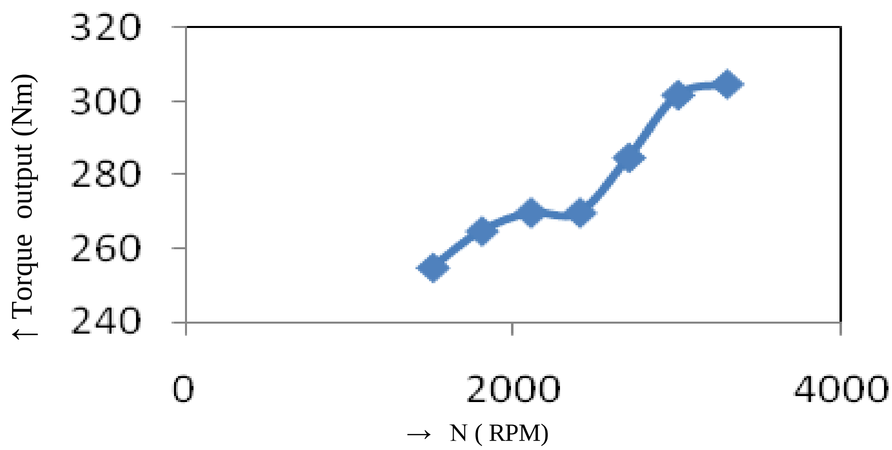

Figure 6. (Torque output vs engine rpm).

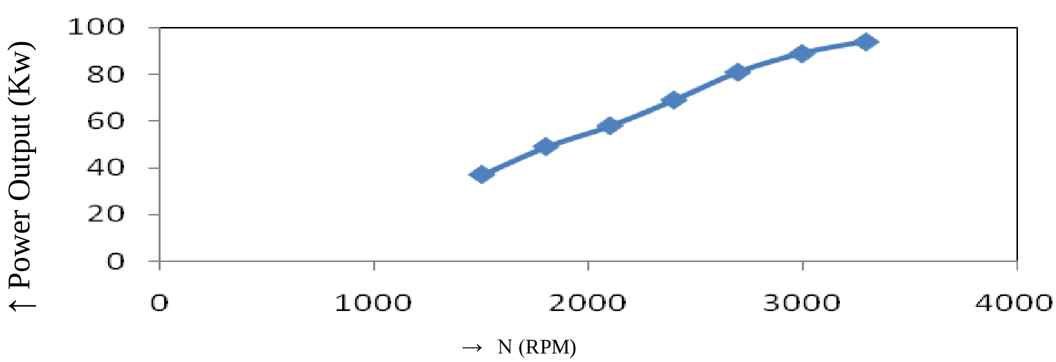

Figure 7. (Power output (kW) vs engine rpm).

without backfire. In Figure 7, graph has been plotted for different values of power output (kW) vs. engine speed (rpm). Due to rapid combustion of hydrogen, a very little heat was lost to the environment and it burned many times faster than gasoline air mixture. Hence, higher engine speeds and thermal efficiency is obtained. With the increase in the engine speed, the amount of power output also increased at a relative air to fuel ratio λ of 2 to avoid backfire. Power output (kW) for the speed range (1500-3300) with relative air fuel ratio of λ=2 and the ignition timing (IT) set to 20° crank angle BTDC. The power output was found to be increasing due to high calorific content of hydrogen.

Conclusion

Combustion characteristics of a hydrogen fueled SI engine with gasoline-hydrogen blends under seven different ignition timings, 70% wide open throttle(WOT) and lean mixture condition were investigated, and the important results were drawn. The power output of the engine is increased without danger of backfire, with a timed multiport fuel injection system of hydrogen and the corresponding electronic management system. The optimization of the engine parameters were discussed in terms of power output, brake mean effective pressure, torque output and effective thermal efficiency.

The injection of hydrogen at the beginning of the compression stroke has shown smooth engine running at stoichiometric air fuel ratio without abnormal burning. The advantage of lean mixtures to operate at low load conditions without a throttle valve is found to be valid. For specific ignition timing, the brake mean effective pressure and the effective thermal efficiency increased while the combustion durations decreased with the increase of hydrogen fraction in gasoline hydrogen blend.

There is a significant influence of Ignition timing on engine performance and combustion. With the decrease in time intervals from the ending of fuel injection to the ignition start, brake mean effective pressure and effective thermal efficiency increased.

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