International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 9, Volume 2 (September 2015) www.ijirae.com

Effect of using hydrogen mixed gases as a fuel in internal Combustion engines – A Review

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Abstract* - The growing concern about depleting oil reserves, detrimental effects of greenhouse gas emissions and the need to reduce emissions from vehicles and power plants are some of the prime factors that increase the necessity for development of alternative energy options. The present paper reviews the effect of using hydrogen mixed gases as a fuel in internal combustion engines. In this review, the investigations done by the researchers were categorized into two forms. One was using hydrogen mixed gases as a fuel in SI engines and the other one was using hydrogen mixed gases as a fuel in diesel engines. In all the categories, the data of gasoline / diesel fuel operation was taken as a base line configuration to examine the effectiveness of the hydrogen mixed gases as fuels in internal combustion engines. The review showed that the hydrogen mixed gases can be readily used in internal combustion engines without much modification in the existing configuration of the engines.

***Keywords* - hydrogen, S.I engine, diesel engine, dual fuel, NO_X emission**

I. INTRODUCTION

In the beginning, all engine experiments were designed for burning a variety of gases, including natural gas, hydrogen, and propane. There had been many investigations on hydrogen enriched combustion in internal combustion engines. Rivaz [1] of Switzerland invented an internal combustion engine with electric ignition which used the mixture of hydrogen and oxygen as fuel. He designed a car for his engine. This was the first internal combustion powered automobile [2]. Later, he obtained French patent for his invention in 1807. Hydrogen can compensate some of the demand for hydrocarbon fuel by being combusted along with gasoline, diesel, or natural gas in an internal combustion engine. This type of combustion is called dual fuel combustion. It either uses very small amounts of hydrogen to modify combustion or uses a large amount of hydrogen as the principal source of energy in the combustion chamber.

II. HYDROGEN INDUCTION METHODS

A. Carburetion

Carburetion is the simplest technique for inducting the fuel - air mix into the cylinder. The air flows through a venturi nozzle where its velocity gets increased. This leads to a pressure drop in the throat of the venturi. Its magnitude depends on the air flow rate and this draws the fuel into the air stream [3]. Thus it controls the power output of the engine by varying the amount of fuel - air mix drawn into the cylinder. The technique of carburetion was used to operate hydrogen engines by several researchers [4-7]. The advantage of this technique is that it does not require a high pressure hydrogen supply. This technique also allows the fuel to mix uniformly with the air before being allowed into the cylinder, leading to a more efficient combustion. However, this technique reduces power by 15% [8].

B. Inlet manifold and port injection

As the name implies, inlet manifold and port injection methods use a constant amount of air induction through the inlet manifold per cycle and the fuel is injected into the air stream by a low pressure injector [8]. The power output of the engine can be controlled by the amount of fuel injected into the air stream, thus allowing the lean burn combustion. In inlet manifold or port injection method, the injection of the fuel can be scheduled to start sometime after the inlet valve is opened. This increases the cooling effect of pre-inducted air. This eventually eliminates the hot spots and the pre-ignition [9]. This also reduces the peak combustion temperature and leads to reduction in NO_X emission [10].

C. Direct Injection

The problem of back fire can be eliminated altogether if there is no combustible mixture present in the inlet manifold at any time during the combustion cycle [8]. This can be achieved with direct injection of the hydrogen gas into the cylinder. Most researchers adopt this technique of fuel induction to avoid such unwanted combustion phenomena [11-14]. In direct injection technique, only air is inducted during intake stroke. The high pressure gaseous hydrogen is injected into the cylinder at some time during the compression stroke and is ignited soon afterwards. The high pressure injection of hydrogen creates high turbulence in the fuel - air stream. This assists the mixing of the fuel with the air and forms more homogenous mixture of fuel and air.

III. RESULTS AND DISCUSSIONS

Park et al [15] experimentally investigated the effect of addition of hydrogen on the performance and emission characteristics of a naturally aspirated S.I engine which was fuelled with biogas.

They ran the engine at constant engine rotational speed of 1800 rpm under a 60 kW power output condition. They blended H_2 fractions ranging from 5 to 30% to the biogas. Their engine test results indicated that the addition of hydrogen improved in-cylinder combustion characteristics, extending lean operating limit as well as reducing THC emissions while elevating NO_X generation. Fig. 1 and 2 show the emission characteristics of engine. In terms of efficiency, however, they observed a competition between enhanced combustion stability and increased cooling energy loss with a rise in H_2 concentration.

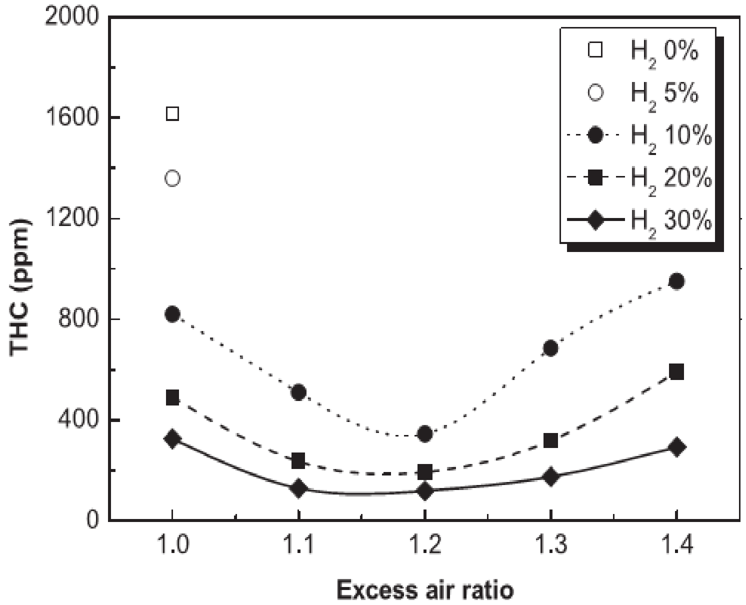

Fig. 1 THC emissions for various H_2-biogas blend fuels as a function of excess air ratio at MBT spark timing [15]

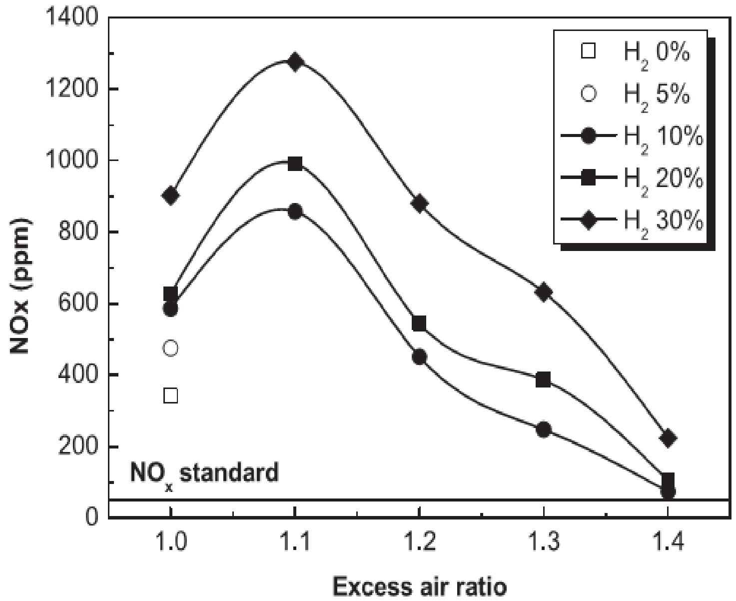

Fig. 2 NO_X emissions for various H_2-biogas blend fuels as a function of excess air ratio at MBT spark timing [15]

They got maximum engine efficiency at 5% to 10% of H_2 concentration. They reported that an increase of H_2 improved flame propagation speed and extended lean flammability limit while NO_X increased. As H_2% was increased, the burn duration got decreased due to the improvement in the propagation speed of the blended fuel combustion. In addition, they observed no knocking or back-fire phenomena during engine operations for all the fuel conditions. This meant that stable and efficient combustion could be achieved even in the lowest quality gas by H_2 addition while abnormal combustion was still suppressed.

Fang et al [16] investigated the driving performance and emission characteristics of a 125 cc motor cycle equipped with an on-board plasma reformer for producing Hydrogen Rich Gas (HRG). To produce HRG, they inducted butane with suitable air flow rate into the plasma reformer.

They ran the motorcycle under steady and transient conditions on a chassis dynamometer to assess the driving performance and exhaust emissions. Prior to run, they optimized the operation parameters of the plasma reformer in a series of tests and they concluded that the O_2/C ratio of 0.55 and a butane supply rate of 1.16 lpm was the optimum condition to produce HRG. They used gas chromatograph of Agilent 6850 GC for analysing the gas emission and a scanning electron microscope for observing carbon deposit arising from the reforming process. For analysing the driving tests, they used Japanese made Horiba 554JA emission analyser; US made CAI 600 NO_X analyser, a fuel flow meter, an oscilloscope and a temperature data recorder. From their results, it was interpreted that at O_2/C ratio of 0.55, the NO_X emission at a vehicle speed of 40 km/h got reduced from 600 ppm to 220 ppm. They attributed this to the diluting effect of HRG, as it contained CO_2 and N_2 also. They observed that when 2.95% HRG was added, the highest peak pressure was obtained. Further, in the addition of 4.11%, the pressure rise rate became slower and the peak pressure also became lower than other conditions. Fig. 3 displays the cylinder gas pressure of engine with different hydrogen-rich gas volume ratio. They concluded that the acceleration characteristics of the vehicle were similar under both fuelling systems.

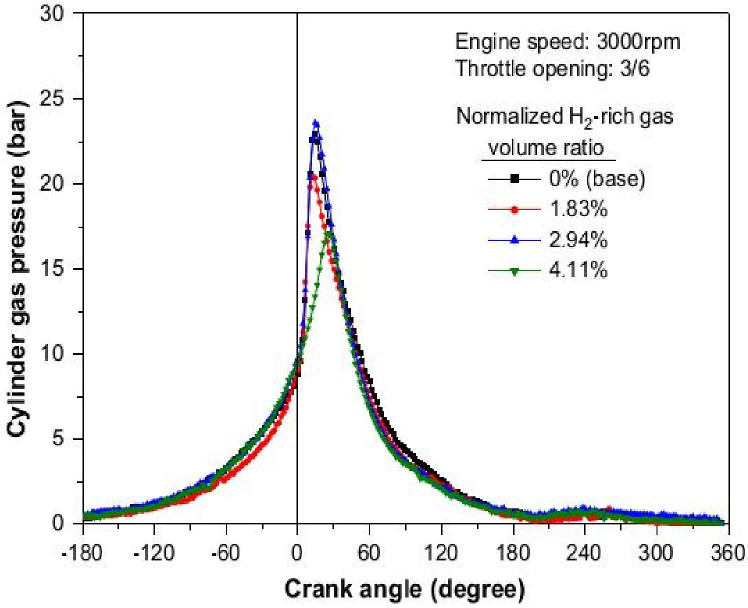

Fig. 3 Cylinder gas pressure of engine with different hydrogen-rich gas volume ratio [16]

Sahoo et al [17] carried out the experiments in a Kirloskar TV1 diesel engine to evaluate its characteristics when syngas mixture of hydrogen and carbon monoxide was inducted into the combustion of diesel.

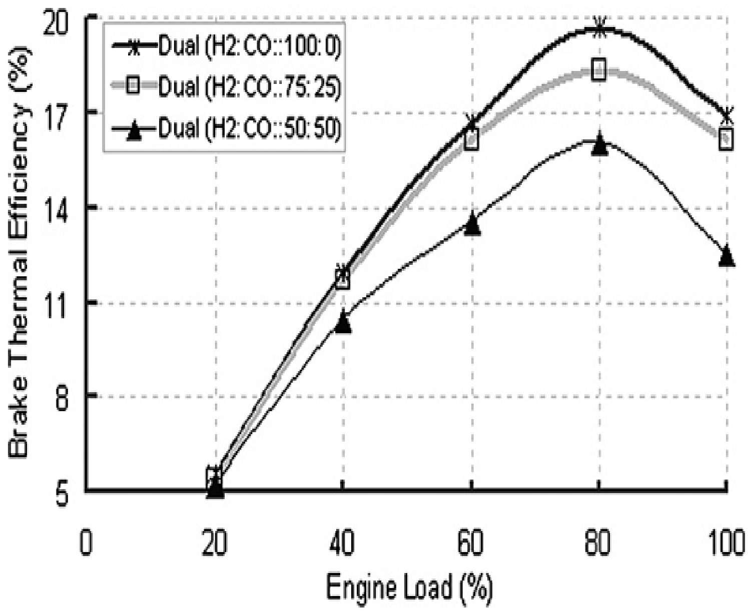

Fig. 4 Variation of brake thermal efficiency with load [17]

The engine used for their study was a single cylinder, water cooled, direct injection, four stroke, having a bore of 87.5 mm, stroke of 110 mm, compression ratio of 17.5:1, rated power of 5.2 kW at 1500 rpm. They analysed the flue gas compositions using a multi-component analyser based on infrared and chemical cell technique.

Their results showed that the 100% H_2 syngas mode resulted in a maximum in-cylinder pressure and combustion temperature which in-turn increased the NO_X emissions and the exhaust gas temperature compared to that of 75% and 50% H_2 syngas modes. They observed the NO_X emissions of 127 ppm, 175 ppm, and 220 ppm at peak power output for 50%, 75%, and 100% H_2 syngas modes respectively. They related this to the higher flame speed and higher energy content of the syngas at 100% H_2 syngas mode. Fig. 4 depicts the performance characteristics of the engine and Fig. 5 displays the variation of diesel substitution rate with load.

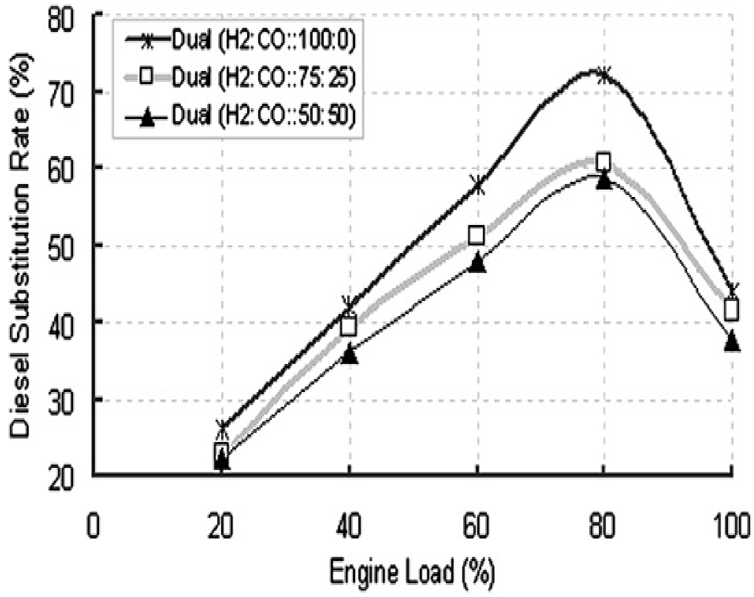

Fig. 5 Variation of diesel substitution rate with load [17]

Mohammadi et al [18] carried out an investigation on diesel engine used for power generation to see the effects of addition of LCG (Low Calorific Gases) and LCG with small portion of hydrogen and nitrogen on performance and emissions characteristics of the engine. These gases were originally produced in various chemical processes such as gasification of solid wastes or biomass. The test engine used by them was a four-stroke single cylinder naturally aspirated direct-injection diesel engine (Yanmar NFD-170) with a bore of 102 mm and a stroke of 105 mm, injection nozzle spray angle of 150° with four holes and with 0.29 mm hole diameter. They carried out the combustion analysis by measuring in-cylinder pressure at every 1^oCA using piezoelectric pressure transducer (Kistler 6052A). They used diesel having a density of 828 kg/m^3, lower heating value of 44200 kJ/kg, and cetane number of 55 for this tests.

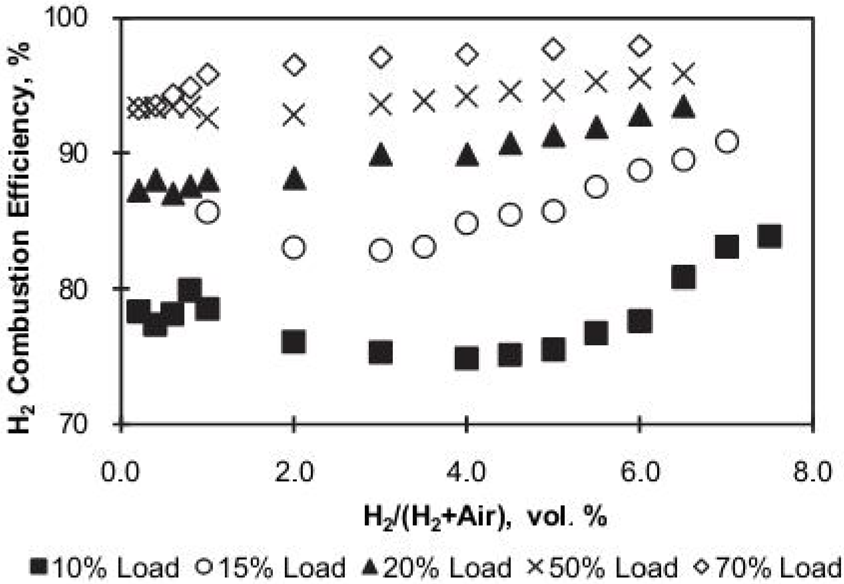

Fig. 6 Effect of H_2 addition and engine load on the combustion efficiency of H_2 [19]

Fig. 6 portraits the effect of hydrogen addition and engine load on the combustion efficiency of hydrogen. They conducted all experiments at thermally steady state of the engine with injection timing of 12° BTDC and engine speed of 1800 rpm. They introduced nitrogen from a high pressure vessel into the intake of the engine using a gas mixer installed at downstream of surge tank. And, they introduced hydrogen gas using an orifice nozzle with diameter of 6 mm.

They measured the flow rate of both gases preciously using thermal mass flow meters. In their experiment, they first adjusted the flow rate and composition of LCG and then the amount of diesel fuel injected to achieve considered output.

They fixed the engine load as constant at brake mean effective pressure of 0.6 MPa. Their results showed that at ratio of hydrogen (rH) = 0 and ratio of LCG (rLCG) = 25% when 25% of intake air was replaced with nitrogen, the efficiency of the engine was slightly lower than diesel fuel operation. However, when they introduced hydrogen with LCG, it lowered the consumption of diesel fuel. At rLCG=25% and rH=30%, the corresponding saving in consumption of diesel fuel was about 40%. At rH=0 when only nitrogen was added to the engine intake, it increased ignition delay with little effects on combustion process. However, at given rLCG, increasing the hydrogen concentration, promoted the premixed and diffusion combustions and it resulted in higher peak combustion pressure and temperature. Increasing rH increased the peak level and advancement in its timing.

IV. CONCLUSIONS

The present review of using hydrogen mixed gases as a fuel in internal combustion engines draws the following facts.

- Hydrogen mixed gases can be readily used as a fuel in an unmodified internal combustion engines.
- Usage of hydrogen mixed gases increase Brake thermal efficiency and reduce BSEC.
- NO_X emission gets increased because of instantaneous combustion.
- Smoke emission gets decreased in all load ranges of the engine.

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