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RESEARCH ARTICLE

PERFORMANCE ANALYSIS OF IC ENGINE USING HYDROGEN FUEL

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ABSTRACT

Hydrogen is a pure and renewable energy source, which also has many excellent combustion properties for improving combustion and emission performance of Internal Combustion (IC) engine. Hydrogen has a high flammability, So that there is always risk of potential explosion. For avoid this hydrogen can store in three different ways: High pressure, Liquid storage, and metal oxide storage. In case of SI engine exhaust exergy is inversely proportional to the hydrogen addition. As hydrogen addition increases brake thermal efficiency was increases and emission of carbon dioxide (CO2) was reduced. However when engine lean out, carbon monoxide (CO) emission from hydrogen enriched engine was reduced. Oxides of nitrogen (NOx) emission increase with the increase of hydrogen addition due to the raised cylinder temperature. In case of CI engine (diesel engine), both NOx and soot emissions are taken under control with 15% and 40% energy content rates in the gas fuel compare to diesel only. Moreover gas fuel mixture reach a high value (75% energy content) as peak cylinder gas pressure decreases. With the addition of 75% hydrogen, diesel combustion characteristics of the engine converted into gasoline combustion. Thus it has been shown that hydrogen is good choice as an alternative engine fuel.

INTRODUCTION

Fossil fuels like coal, natural gas and petroleum depleted due to increasing energy demand. Also, combustion product of these fossil fuel such as carbon monoxide (CO), carbon dioxide (CO2), oxides of sulphur (SOx), oxides of nitrogen (NOx), hydrocarbon (HC) and ashes have been causing many environmental problem and danger for the world. Avoiding all of these problem it is necessary to replace these fossil fuel by clean and renewable energy source (Baris acikgoz, 2015; Yasin Karagoz *et al*., 2015). Hydrogen is a renewable, carbon free and light gaseous alternative fuel. Hydrogen fulfills certain criteria such as availability, high specific energy content, minimum pollution, easy and safe storage. Apart from this hydrogen has some disadvantages such as high NOx emission and small power output (Baris acikgoz, 2015). Hydrogen is a carbon free alternative fuel that generate only water after combustion. So that it is economical to use in internal combustion (IC) engine. Hydrogen can be produced from fossil fuel or biogas conversion, electrolysis, or direct thermochemical solar conversion. Hydrogen is extremely clean and environmental friendly fuel. Hydrogen can be used as secondary energy source such as electrical energy. Hydrogen used in Otto engine, when hydrogen is transmitted continuously from intake manifold causes problem like nearly 30% power reduction, pre-ignition, flare-back and backfiring problem. Apart from these it has high thermal efficiency and low specific CO2 emission as advantages. Due to high auto ignition temperature of hydrogen (approximately 858°K), it is more suitable to adopt hydrogen on SI engines rather than compression ignition (CI) engine (Baris acikgoz, 2015). To use hydrogen as a fuel in CI engine, an energy source is needed to provide ignition. Ikegami *et al*. used a glow plug injector, whereas Antunes *et al*. heated intake air to provide ignition.

Hydrogen remains an attractive fuel to petroleum and a number of investigators claim that adding hydrogen to the air intake manifold of a diesel engine will reduce criteria emission and diesel fuel consumption. Bose and Maji (2009) operated a 4-stroke, water cooled diesel engine, and a 0.15 kg/h hydrogen flow rate introduced into intake manifold. The test result compare with each other, and an important rise in thermal efficiency and a drop in CO, CO2, THC, and smoke emission were obtained with the addition of hydrogen. NOx emission drop due to the EGR system. Up to now, only hydrogen and methane fuel have been used with diesel fuel compression ignition engine. Due to storing problem of hydrogen, it is not possible to implement in vehicle. Although an improvement in combustion and emission characteristics have been observed after use of hydrogen fuel.

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Background

In 1806, Francois Issac de Rivaz designed the first internal combustion engine, which ran on hydrogen and oxygen mixture, known as De Rivaz engine. Paul Dieges patented in 1970 a modification to internal combustion engine which allowed a gasoline powered engine to run on hydrogen. From 1970, Tokyo City University has been developing hydrogen internal combustion engine. Recently they develop hydrogen fueled bus and truck. Mazda has developed Wankel engine that burns hydrogen. The advantages of using internal combustion engine such as wankel and piston engine is that the cost of retooling for production is decreases. Between 2005 - 2007, BMW tested a luxury car named 'The BMW Hydrogen 7' powered by a hydrogen ICE, which achieved 301km/h in tests. Alset GmbH developed a hybrid hydrogen system that allows vehicle to use petrol and hydrogen fuel individually or at a same time eith an internal combustion engine. This technology was used with Aston Martin Rapide S during the 24 Hours Nurburgring race. The Rapide S was the first vehicle to finish the race with hydrogen technology.

Experiment: Test on CI Engine

Test engine at 1500rpm for full brake load condition. For different gas energy level hydrogen and methane - 0%, 15%, 40%, 75% of total fuel. At the fixed value of brake torque (75.7Nm) and engine speed (1500rpm) check first of all pure diesel fuel until reached steady state operating condition, then different energy level were tested.

Brake Thermal Efficiency

As hydrogen is highly flammable, It burn completely causes increase in cylinder pressure (Yasin Karagoz, 2015). Due to piston position, brake thermal efficiency decreases. It is 24.7%, 22.5%, 21.7%, and 21.4% with 0%, 15%, 40%, 75%, hydrogen addition respectively. As shown in Fig. 1. Heat flux of hydrogen is higher than that of other conventional fuels. The thermal loss increases with the addition of hydrogen. The result of this study are consistent with the result of Varde and Frame and Zhou *et al.* in terms of brake thermal efficiency.

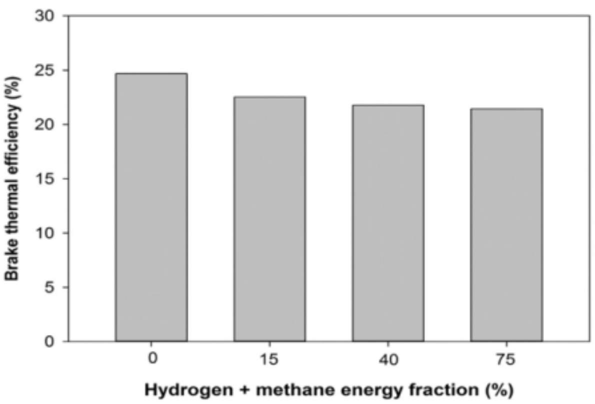

Fig. 1 Effect of hydrogen addition on brake thermal efficiency [Yasin Karagoz, 2015]

Carbon Monoxide

CO generated by partial oxidation of carbon atom. As diffusion coefficient of H2 is very high, it increases homogeneity of combustible mixture, therefore CO emission decreases. But due to disadvantages of methane (Low flame speed) CO emission increases. As shown in Fig. 2 the carbon monoxide increases from 0.21% vol. to 0.61% vol. with the addition of 15% hydrogen to 0.69% vol. with the addition of 40% hydrogen and so on (Yasin Karagoz, 2015).

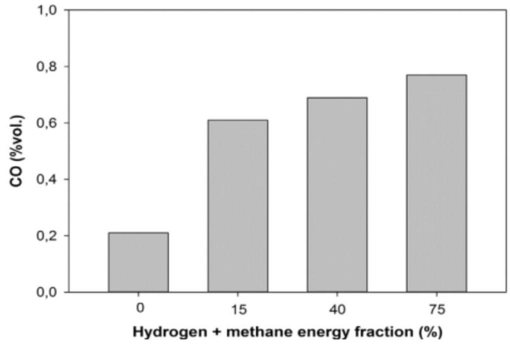

Fig. 2 Effect of hydrogen on CO emission at constant speed [Yasin Karagoz, 2015]

Oxides of Nitrogen

NOx formation is a function of temperature, reaction time and oxygen. As shown in Fig. 3 up to 15% of H2, due to no diesel pulverization, there is decrease in temperature; Causes reduction in NOx formation. But further addition H2, cylinder temperature increases rapidly. This increases NOx formation (Liew, 2010).

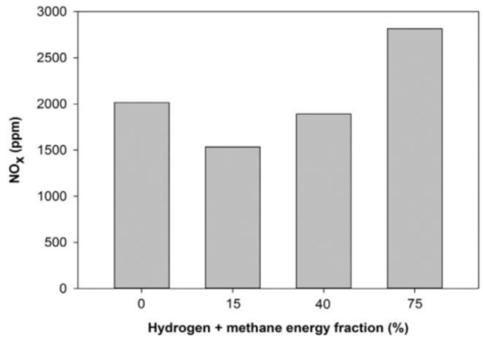

Fig. 3 Effect of hydrogen on NOx emission at constant speed [Yasin Karagoz, 2015]

Experiment: Test on Si Engine

For four stroke diesel engine test carried out with CH/H2 at different properties (90/10), (70/30), and (20/80). All test were performed under steady state conditions, at full load condition engine speed was changed between 1500 to 3100rpm with interval of 200rpm. Exergy analysis was calculated by the assumed exhaust temperature data; 663˚C for 10% CH4, 808˚C for 20% H2-80% CH4, 715˚C for 30% H2-70% CH4 and 683˚C for 10% H2-90% CH4 (Baris acikgoz, 2015).

Energy Power

Hydrogen has a less specific volume than CH4. Due to this H2 has low power output than CH4. Speed reduction increases mechanical losses. Therefore, at high speed overall power of system is increases with addition of H2. As shown in Fig. 4.

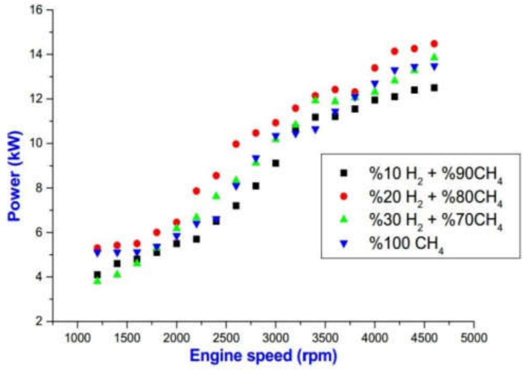

Fig. 4 Change in brake power with the hydrogen blends [Baris acikgoz, 2015]

Torque

As shown in Fig. 5. At a speed about 2100rpm hydrogen operate engine reaches the torque value for CH4 operated engine and exceed at greater speed. Since hydrogen has fast burning char, it is obvious to better result at high speed operation condition.

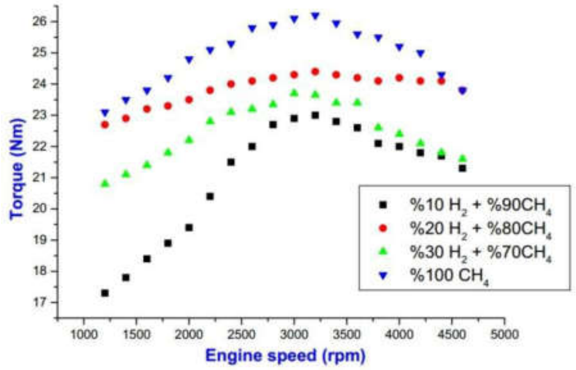

Fig. 5 Change in the torque with the hydrogen blends [Baris acikgoz, 2015]

Brake Specific Fuel Consumption (BSFC)

The BSFC is defined as the ratio of mass fuel consumption to the brake power. From Fig. 6 as the excess air ratio, BSFC decreased and brake thermal efficiency increased with the increased of hydrogen fraction in fuel. When excess air ratio was under 1.4, hydrogen addition was not suitable to improve efficiency. Hydrogen addition lower the unburned HC emission which meant improve combustion efficiency (Yasin Karagoz *et al*., 2015).

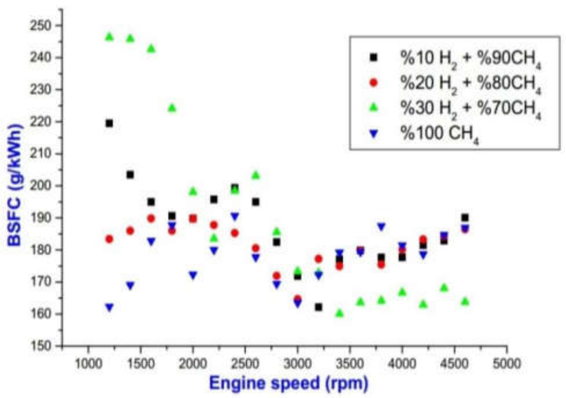

Fig. 6 Change in BSFC with the hydrogen blends [Baris acikgoz, 2015]

Advantage

- Hydrogen is a renewable energy source, which acts as an alternative fuel for fossil fuel.
- Hydrogen lower the unburned HC emission, i.e. improve combustion efficiency.
- High specific energy content.
- Environment friendly.

Limitations

- NOx emission increases as hydrogen increases.
- Storage of Hydrogen is a quiet difficult and hence proves costly storage process.
- Hydrogen is highly flammable gas.

Conclusion

From the study of performance of hydrogen fuel used in IC engine following conclusion have been made:

CI Engine

- With addition of 15%, 40% and 75% hydrogen fuel, the break thermal efficiency dropped to 8.7%, 11.7%, and 13.1% respectively.
- Carbon monoxide's (CO) increase was 190.4%, 228.5% and 266.6% at 15%, 40% and 75% addition of hydrogen.
- With addition of 15% and 40% hydrogen fuel, NOx decreased by 23.9% and 6.2% respectively.
- Soot emission decreased to 0.301 FSN, 0.171 FSN, and 0.082 FSN by addition of 15%,40% and 75% hydrogen respectively.

SI Engine

- There is increase in power output and engine efficiency.
- With addition of hydrogen BSFC decreases and break thermal efficiency increases.
- Thermal efficiency increased between 5.4% and 10.9% with H2.
- With addition of 5%, 8%, 10% and 15% hydrogen, engine speed decreased by 25%, 28.6%, 23.2%, and 32.1% and CO emission decreased by 3.4%, 3.2%, 3.1% and 2.9% respectively.
- With H2 addition energy flow rate reduced between 5.1% and 9.1%.
- 15% hydrogen addition gives max increased in indicated thermal efficiency.

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