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Comparing the Effects of Hydrogen Addition on Performance and Exhaust Emission in a Spark Ignition Fueled with Gasoline and CNG

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Abstract. With the concern of the foreseen reduction in fossil fuel resources and stringent environmental constraints, the demand of improving internal combustion (IC) engine efficiency and emissions has become more and more pressing. Hydrogen has been proved to be a promising renewable energy that can be used on IC engines. In this paper an evaluation and assessment of numerical and experimental investigations on performance and exhaust emission with hydrogen added to a spark ignited gasoline engine fuelled with gasoline and natural gas are performed. The experimental results showed that thermal efficiency, combustion performance, NOx emissions improved with the increase of hydrogen addition level. The HC and CO emissions first decrease with the increasing hydrogen enrichment level, but when hydrogen energy fraction exceeds 12.44%, it begins to increase again at idle and stoichiometric conditions. Numerical results showed that there is an increase in engine efficiency only if Maximum Brake Torque (MBT) spark advance is used for each fuel. Moreover, an economic analysis has been carried out to determine the optimum percentage of hydrogen in such blends, showing percent increments by using these fuels about between 10 and 34%.

Introduction

Finding new alternative fuels in place of petroleum for automobiles is becoming a necessity more than ever. The new alternative fuel should be satisfactory for low pollution, high efficiency, high output, as well as moderate cost, weight and volume. Nevertheless, to be alternative qualities such as engine power-up, suppression of abnormal combustion in the engine and reduction of NOx emission must be achieved. Through investigations of many researchers, it has been found that high pressure hydrogen injection in combustion chamber of the engine can improve the efficiency, increase the power output, and significantly help to eliminate abnormal combustion phenomena, at the same time, reduce NOx emission [1–2].

The ways of applying hydrogen to automobiles could be mainly divided as fuel cell and hydrogen fuelled IC engines. Though the fuel cell gains many advantages, such as high power output and zero emissions while operating, the high cost and short lifetime have become the concern of its wide application. At the same time, there are still many problems in its manufacturing that block its movement [3,4]. The properties of hydrogen and methane along with gasoline are listed in Table 1. Hydrogen is more suitable to be used on SI engines rather than compression ignition engines due to its high ignition temperature [5–10]. The diffusion coefficient of hydrogen is ten times as large as that of gasoline, which benefits the homogeneity of the in cylinder charge. The cyclic variation of hydrogen fuelled engines is lower than that of gasoline-fuelled engines since hydrogen has a flame speed five times more than gasoline which permits a short combustion duration [11]. Also, the low ignition energy of hydrogen eases the engine starting process, though it sometimes causes unexpected combustion such as pre-ignition. The pure hydrogen fuelled engines sometimes produce a weak power output because of its low energy density on volume basis [12]. Also, alternative fuels are clean compared to conventional ones derived from petroleum in IC engines. Natural gas (NG) is considered to be a possible alternative fuel due to its higher octane number and properties. Natural gas is a mixture of different gases where methane is its main component (75- 98% of methane, 0.5- 13% of ethane and 0- 2.6% of propane [13]). Natural gas combustion produces less emission than that of conventional fuels because the chemical structure of NG is less complicated, together with the non-existence of fuel evaporation [14]. The high octane number of NG (between 120 and 130) allows the engine to operate at high compression ratios, because it gives a high anti-knocking potential [15]. However, NG has a slow burning velocity, compared to liquid fuels, which can be solved by mixing it with a fuel with a high burning velocity, such as hydrogen [16].

Table 1 Some properties for hydrogen and other fuels under stoichiometric conditions

Properties	Hydrogen	Methanol	Methane	Gasoline	Unit
Flammability limits	4–75	7–36	5–15	1.0–7.6	Vol. %
Minimum ignition energy.	0.02	–	0.29	0.24	mJ
Flame temperature	2045	–	1875	2200	℃
Auto ignition temperature	585	385	540	230–500	℃
Maximum velocity of flame	3.46	–	0.43	–	m/s
Diffusion coefficient	0.61	0.16	0.20	0.05	10^{-3} m^2/s

Hydrogen Gas Mixtures

Hydrogen can be used advantageously in internal combustion engines as an additive to a hydrocarbon fuel. Also it is most commonly mixed with high pressure natural gas for this purpose since both gases can be stored in the same tank (but they are commonly stored separately in different pressures). If hydrogen is blended with other fuels, it usually has to be stored separately and mixed in the gaseous state immediately before ignition. In general, it is impractical to use hydrogen in conjunction with other fuels that also re-quire bulky storage systems, such as propane.

Gaseous hydrogen cannot be stored in the same vessel as a liquid fuel. Hydrogen's low density will cause it to remain on top of the liquid and not mix. Furthermore, liquid fuels are stored at relatively low pressures so that very little hydrogen could be added to the vessel [17].

Hydrogen can be used in conjunction with compact liquid fuels such as gasoline, alcohol or diesel provided each are stored separately. In these applications, the fuel tanks can be formed to fit into unused spaces on the vehicle. Existing vehicles of this type tend to operate using one fuel or the other but not both at the same time. One advantage of this strategy is that the vehicle can continue to operate if hydrogen is unavailable. Hydrogen cannot be used directly in a diesel engine since hydrogen's auto ignition temperature is too high (this is also true of natural gas). Thus, diesel engines must be outfitted with spark plugs or use a small amount of diesel fuel to ignite the gas (known as pilot ignition).

Methodology

The methodology used to carry out this work has been numerical and experimental. At the first way, the effective area is estimated by using a quasi-dimensional, constant volume combustion bomb is used to determine the burning velocity of the mixtures of CNG and hydrogen for different initial conditions of temperature and pressure and in the way of experimental was started after the engine has warmed up and hydrogen energy fraction in the total fuel was gradually increased.

Adding hydrogen to gasoline fuel

In the Beijing University of Technology, an experimental study has carried out recently, effect of hydrogen addition on the idle performance of a spark ignited gasoline engine at stoichiometric condition [18]. The engine was in-line 4 stroke and a comparison ratio of 10:1 and engine manufacturer was Hyundai Company. The experimental results showed that thermal efficiency, engine performance, NOx emissions are improved with the increase of added hydrogen ratio. The HC and CO emissions first decline with the increasing hydrogen enrichment level, but when H_2 energy fraction exceeds 12.44%, it begins to increase again at idle and stoichiometric conditions.

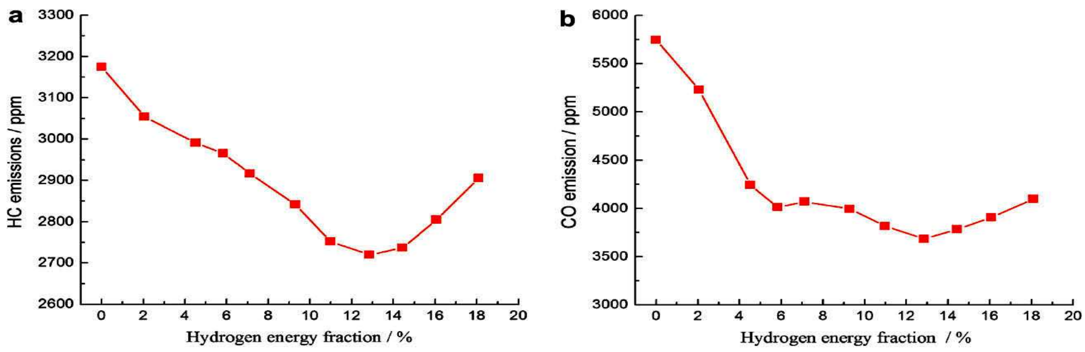

Fig 1 (a) Effect of hydrogen addition on HC emissions at idle and stoichiometric conditions. (b) Effect of hydrogen addition on CO emission at idle and stoichiometric conditions [18]

Also, the effect of hydrogen addition on combustion and emissions performance of a spark ignition gasoline engine at lean conditions was carried out by the researchers [19]. The engine was run at 1400 rpm, a manifold absolute pressure (MAP) of 61.5 kPa and various excess air ratios. Two hydrogen volume fractions were used in the total intake of 3% and 6% to check the effect of hydrogen addition fraction on performance of engine combustion. The test results showed that BTE was improved and kept roughly constant in a wide range of excess air ratio after hydrogen addition, the maximum brake thermal efficiency was increased from 26.37% of the original engine to 31.56% of the engine with a 6% hydrogen blending level. However, brake mean effective pressure (BMEP) was decreased by hydrogen addition at stoichiometric conditions, but when the engine was further leaned out BMEP increased with the increase of hydrogen addition fraction. The hydrocarbon and carbon dioxide emissions were reduced with hydrogen addition. When excess air ratio was approaching stoichiometric conditions, CO emission tended to increase with the addition of hydrogen. However, when the engine was gradually leaned out, CO emission from the hydrogen-enriched engine was lower than the original one. NOx emissions increased with the increase of hydrogen addition due to the raised cylinder temperature.

Mixture of hydrogen and natural gas

The use of hydrogen blended with natural gas is a viable alternative to pure fossil fuels because of the expected reduction of the total pollutant emissions and increase of efficiency.

Bagio Morrone and Andrea Unich [20] in university of Italy carried out Numerical investigation on the effects of natural gas and hydrogen blends on engine combustion and an economic analysis has been carried out to determine the over cost of hydrogen in such blends, showing percent increments by using these fuels about between 10 and 34%. Results showed that there is an increase in engine efficiency only if Maximum Brake Torque (MBT) spark advance is used for each fuel.

F. Tinaut, A. Melgar, B. Gime´nez, M. Reyes studied on prediction of performance and emissions of an engine fuelled with natural gas/hydrogen blends and results showed that the percentage of hydrogen in the NG increases the burning velocity of NG and decreases the optimal ignition timing to obtain the maximum indicated mean pressure of the engine running with these mixtures. The indicated efficiency rises as the percentage of hydrogen in the NG increases [21].

S. Orhan Akansu;, Zafer Dulger, Na1z Kahraman, T. Nejat Veziroglu [22] have shown that In general, HC, CO_2, and CO emissions decrease with increasing H_2, but NOx emissions generally increase. If a catalytic converter is used, NOx emission values can be decreased to extremely low levels and under certain conditions, efficiency values can be increased. In terms of BSFC, emissions and BTE (Brake Thermal Efficiency), a mixture of low hydrogen percentage is suitable for using.

Effects of blends on engine combustion

Theoretical investigations show that the percentage of hydrogen in the NG decrease the optimal ignition timing to obtain the maximum indicated mean pressure and CO emission are almost unappreciable in lean combustion conditions and with increasing the percentage of hydrogen NO emission due to higher burned temperature rises.

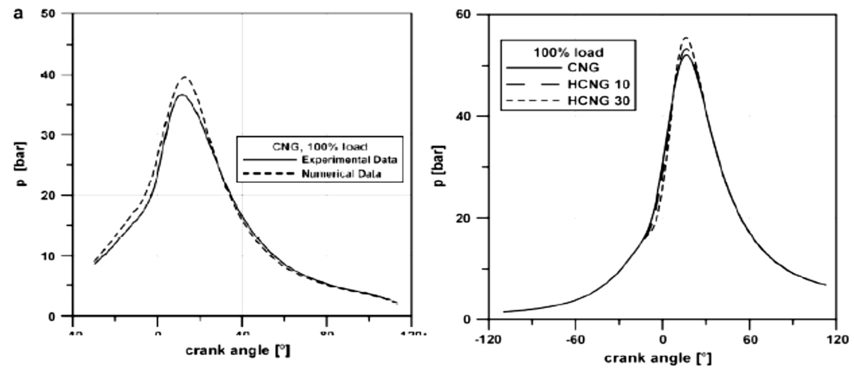

Fig.2 Cylinder pressure as function of the crank angle for CNG at 3000 rpm numerical and experimental results and HCNG 10 (10%) and 30 using MBT spark advance for load 100%.[20]

Also, the improvement of combustion speed is more evident at partial load, while that the load is 25%, the reduction of combustion duration is further of 50% and 100% load. However, due to the non- optimal ignition timing and due to the increase of mechanical losses caused by a higher peak pressure and consequently, the cylinder pressure is as a function of crank angle both for CNG and HCNG, HCNG10 fuel shows an advanced position of pressure peak with a value of 8% higher than CNG. Compared to CNG advance, where 25% load is considered, shows that the HCNG blends present a faster combustion than CNG fuel. Reduction of the combustion duration for HCNG10 and CNG30 is respectively 17% and 31% which implies a decrease of 7° and 14° in spark ignition advance, whereas it reduces to 3°and 7° at full load.

Conclusions

The pure gasoline-fuelled SI engine gains a higher energy flow rate and a lower thermal efficiency than the hydrogen- enriched SI engine at idle and stoichiometric conditions. In the numerical investigation for CNG and HCNG fuels, the results were negligible variation of the engine brake efficiency in spite of faster combustion rate, instead both HCNG10 and 30 have shown relevant increments of the engine efficiency at MBT spark advance.

Emissions of CO and HC first decrease with hydrogen addition, but when hydrogen energy fraction exceeds from a certain amount for each engine, it begins to increase again and The concentrations of NOx emissions are obviously reduced with the increasing hydrogen enrichment due to the decreased in-cylinder temperature and increased residual gas fraction at the experimental conditions at idle and stoichiometric conditions.

The percentage of hydrogen in the NG decreases the optimal ignition timing to obtain the maximum indicated mean pressure of the engine running with these mixtures and increases the burning velocity of NG, the indicated efficiency and NO emission rise with increasing percentage of hydrogen and CO emissions will be almost unappreciable if the tests are developed in lean combustion conditions.

References

[1] Yi HS, Lee SJ, Kim ES. Performance evaluation and emission characteristics of in-cylinder injection type hydrogen fuelled engine. Int J Hydrogen Energy 1996;7:617–24.

[2] Takashi K, et al. A study on the mechanism of backfire in external mixture formation hydrogen engines about backfire occurred by cause of the spark. SAE Transaction, 1997, 971704.

[3] Rankin DD. Lean combustion technology and control. Elsevier; 2008.

[4] Shudo T. Improving thermal efficiency by reducing cooling losses in hydrogen combustion engines. International Journal of Hydrogen Energy 2007;32(17):4285–93.

[5] Andrea TD, Henshaw PF, Ting DSK. The addition of hydrogen to a gasoline- fueled SI engine. International Journal of Hydrogen Energy 2004;29(14):1541–52.

[6] Das LM. Hydrogen–oxygen reaction mechanism and its implication to hydrogen engine combustion. International Journal of Hydrogen Energy 1996;21(8):703–15.

[7] Heywood JB. Internal combustion engine fundamentals. New York: McGraw-Hill; 1988.

[8] Kahraman E, Ozcanl SC, Ozerdem B. An experimental study on performance and emission characteristics of a hydrogen fueled spark ignition engine. International Journal of Hydrogen Energy 2007;32(12):2066–72.

[9] Padiyar S. Properties of hydrogen. In: Proceedings of summer school of hydrogen energy. Chennai, India: IIT Madras; 1985.

[10]Das LM. Hydrogen engine-research and development in IIT Delhi. International Journal of Hydrogen Energy 2002;27:953–65.

[11] Ma FH, Wang Y, Liu HQ, Li Y, Wang JJ, Ding SF. Effects of hydrogen addition on cycle-by-cycle variation in a lean burn natural gas spark-ignition engine. International Journal of Hydrogen Energy 2008;33(2):823–31.

[12] Ganesh RH, Subramanian V, Balasubramanian V, Mallikarjuna JM, Ramesh A, Sharma RP. Hydrogen fuelled spark ignition engine with electronically controlled manifold injection: an experimental study. Renewable Energy 2008; 33(6):1324–33.

[13] Naber JD, Siebers DL, Di Julio SS, Westbrook CK. Effects of natural gas composition on ignition delay under diesel conditions. Combustion and Flame 1994; 99:192-200.

[14] El-Sherif AS. Effects of natural gas composition on the nitrogen oxide, flame structure and burning velocity under laminar premixed flame conditions. Fuel 1998; 77:1539-47.

[15] Das LM, Gulati R. A comparative evaluation of the performance characteristics of a spark ignition engine. International Journal of Hydrogen Energy 2000;25:783-93.

[16] Akansu SO, Dulger Z, Kahraman N, Veziroglu TN. Internal combustion engines fuelled by natural gas -hydrogen mixtures. International Journal of Hydrogen Energy 2004;29: 1527-39.

[17] Hydrogen Fuel Cell Engines and Related Technologies, Hydrogen Use In Internal Combustion Engines, College of the desert: Rev 0, December 2001.

[18] Changwei Ji, Shuofeng Wang. effect of hydrogen addition on the idle performance of a spark ignited gasoline engine at stoichiometric condition. International Journal of Hydrogen Energy 2009:34: 3546-3556

[19] Changwei Ji, Shuofeng Wang. Effect of hydrogen addition on combustion and emissions performance of a spark ignition gasoline engine at lean conditions. International Journal of Hydrogen Energy 2010:34: 7823 – 7834

[20] Bagio Morrone, Andrea Unich. Numerical investigation on the effects of natural gas and hydrogen blends on engine combustion. International Journal of Hydrogen Energy 2009: 4626-4634

[21] Tinaut F, Melgar A, Gime´nez B, M. Reyes studied on Prediction of performance and emissions of an engine with natural gas/hydrogen blends. Journal of Hydrogen Energy 2010: 1-10

[22] Orhan Akansu S; Zafer Dulger, Nejat Veziroglu. Internal combustion engines fueled by natural gas-hydrogen mixtures. International Journal of Hydrogen Energy 2004:1527-39

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