Implications of Combustion Parameters on the Performance of a Hydrogen-Fuelled Research Engine

G.N. Kumar, G.P. Subash, L.M. Das

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 6: Stationary Applications / Transportation Applications
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-6
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-656-9

Implications of Combustion Parameters on the Performance of a Hydrogen-Fuelled Research Engine

G.N. Kumar, **G.P. Subash**, **L.M. Das**, Centre for Energy Studies, IIT, Delhi, New Delhi 110016, India

Abstract

This paper highlights part of the continuing R&D activities being carried out in the Engines and Unconventional Fuel Laboratory of Indian Institute of Technology for several years. Several engine configurations have been built up and widely tested to generate optimum performance and low-emission characteristics without any symptoms of undesirable combustion phenomena such as backfire and rapid rate of pressure rise. The results described in this paper centre round the experiments conducted on a research engine to study the effect of some critical operating parameters such as air-fuel ratio, ignition timing on the cylinder pressure and heat release rate using neat hydrogen gas. During these tests it was observed that an appropriately designed timed manifold Injection(TMI) system was extremely effective not only in getting rid of backfire, but also in ensuring ultralean operation resulting in drastic reduction in NOX emission level. An integrated control of several operating parameters showed that the if the engine was operated with fixed injection duration, peak pressure and rate of pressure rise showed an increasing trend with advanced spark timing. This could be due to the high burning velocity of hydrogen.

1 Introduction

The world today is caught between two major crises arising out of depletion of fossil fuels and rapid environmental degradation due to combustion of fossil fuels. The hydrogen fuel provides an ultimate solution to these twin problems. High flame speed, minimum ignition energy, wide range of flammability limits and high calorific value are some of the distinctive properties of hydrogen which make it suitable for use in internal combustion engines. Oxides of nitrogen, the only pollutant of concern, can be drastically reduced by lean operation even though it reduces power output. Exhaustive experiments have been conducted on a research engine to study the effect of some critical operating parameters such as air-fuel ratio, ignition timing on the cylinder pressure and heat release rate.

2 Hydrogen as an Alternative Engine Fuel

Research and development activities related to hydrogen engine are being pursued in the Engines and Unconventional Fuel Laboratory of Indian Institute of Technology, Delhi, for a period of close to three decades [1-2].Hydrogen has several typical properties which make it suitable for use in internal combustion engines. This paper discusses on those aspects of system development and optimization, which are critical to smooth engine operation without any combustion related problems. Low minimum ignition energy and wider flammability range of hydrogen facilitates ultra lean operation of engine resulting in higher thermal efficiency and lower NOx emissions.

The smaller quenching distance of hydrogen (0.064cm) can increase the tendency for backfire since the flame from a hydrogen-air mixture more readily gets past a nearly closed intake valve, than a hydrocarbon-air flame. The burning speed of hydrogen is 2.37–3.25 m/s and it is nearly an order of magnitude higher than that of methane or gasoline (at stoichiometric conditions)[3]. Thus hydrogen fires burn quickly and, as a result, trend to be relatively short-lived.

Hydrogen - Air combustion is associated with some well-known undesirable combustion phenomena such as flashback, pre-ignition, and knocking [4-6]. Studies by C.A. MacCarley *et. al* [7] have shown that the hydrogen injection techniques such as direct cylinder injection and port fuel injection greatly reduce the chances of backfire. The results of the present investigation are in close agreement with some of these results .In the present set of experiments, timed manifold injection has been observed to be the most appropriate fuel induction mechanism for neat hydrogen-operated SI engine systems [8]. It has been shown that the timed manifold injection increase thermal efficiency and reduces NOx emissions for a neat hydrogen-operated SI engine.

3 Experimental Test Rig

Tests were carried in a single cylinder 4 stroke water cooled spark ignition research engine. The experimental setup consists of three parts: The Engine, the Dynamometer and the Electronic Control Unit. Timed manifold fuel injection was developed to supply the fuel to the engine. The schematic layout of the experimental setup developed in IIT Delhi is shown in figure 1.

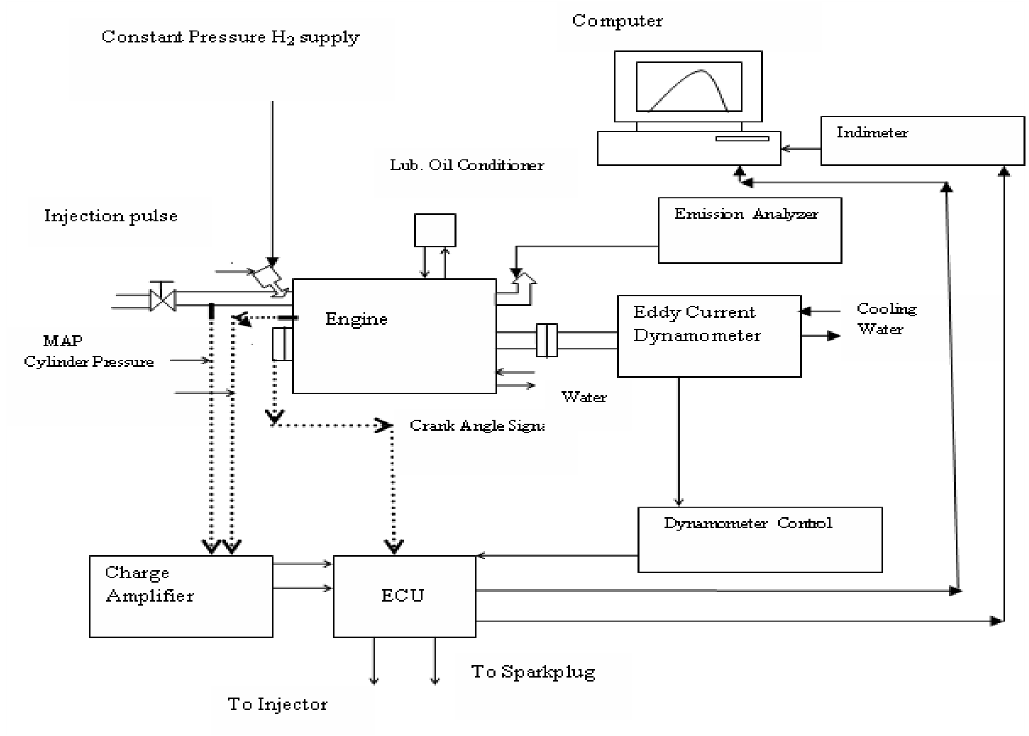

Figure 1: Schematic Diagram of Experimental Setup.

4 Results and Discussion

Comprehensive test were conducted on AVL research engine which was operated with WOT condition at different speeds for fixed equivalence ratio. The effect of speed on the torque is shown in figure 2 for baseline gasoline and hydrogen fuel. As it is clear from the graph the torque is relatively higher for gasoline operation in comparison to hydrogen fuel. This could be due to the fact that gasoline-air mixture was in stoichiometric condition whereas hydrogen – air mixture was leaner during the tests. Thus the energy content per unit volume is more in gasoline in comparison hydrogen fuel.

Figure 3 shows variation of thermal efficiency with engine speed at wide open throttle condition(WOT). The Break thermal Efficiency (BTE) is observed to be more for hydrogen operation due to high burning velocity in comparison to low burning velocity of gasoline-air mixture.

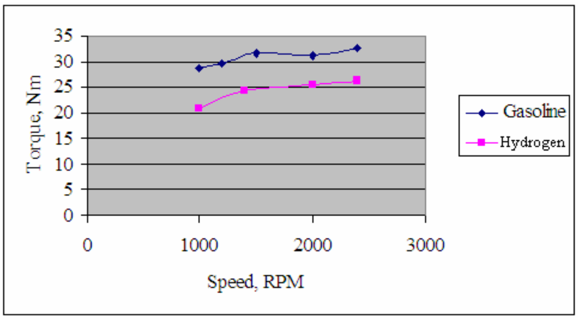

Figure 2: Engine Speed Vs Torque at WOT for gasoline and hydrogen fuels.

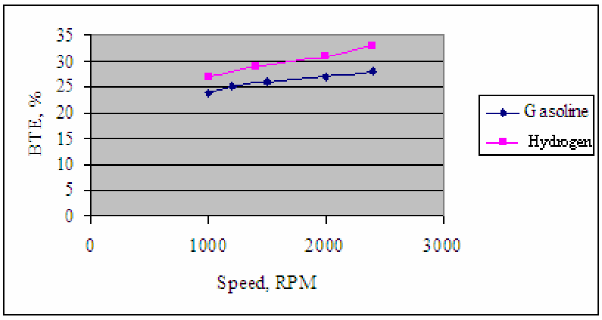

Figure 3: Engine Speed Vs BTE at WOT for gasoline and hydrogen fuels.

The engine was also operated at constant engine speed and fixed duration of injection. The increase in cylinder gas pressure and heat release rate was studied by varying the spark timing at this condition. From figure 4 and 5, it is observed that the cylinder gas pressure is less for the hydrogen operation than gasoline due to lower equivalence ratio and higher flame burning velocity. From the graph it is clear that for hydrogen the spark advancement is lesser compared to gasoline for smother engine operation without knocking. Knocking was observed when we increase spark timing beyond 26 deg of crank angle.

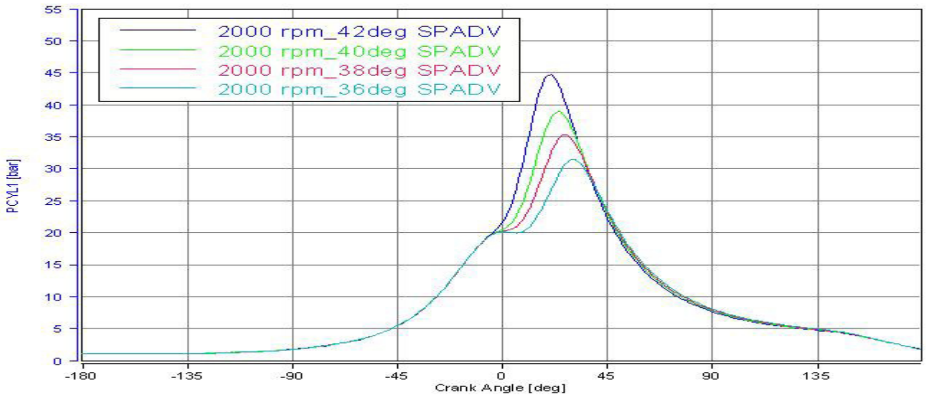

Figure 4: Variation of cylinder gas pressure with crank angle at different ignition timing for gasoline fuel.

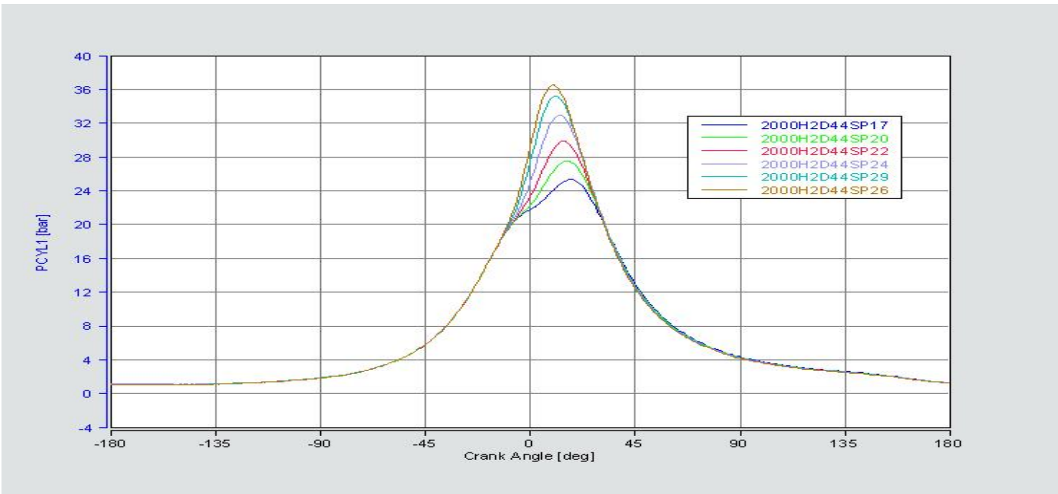

Figure 5: Engine cylinder pressure Vs crank angle at different ignition timing for hydrogen fuels.

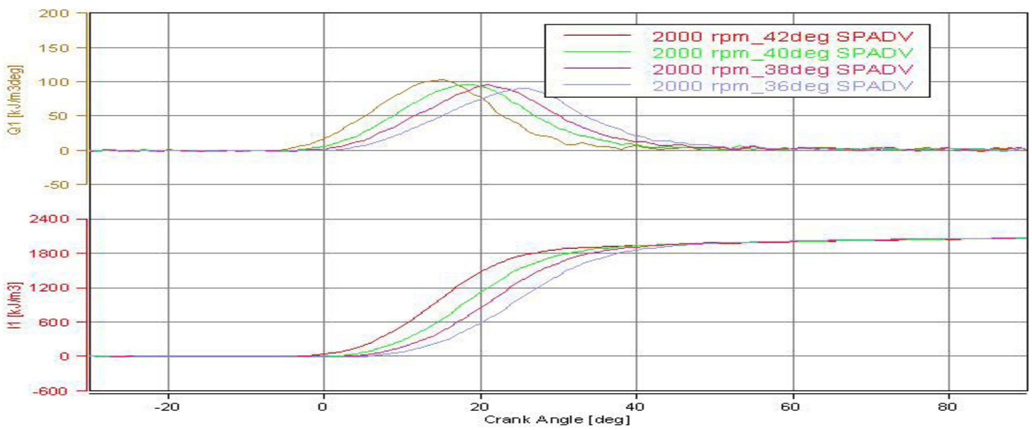

Figure 6: Effect of Spark advance on Heat Release Rate at 2000 RPM engine speed.

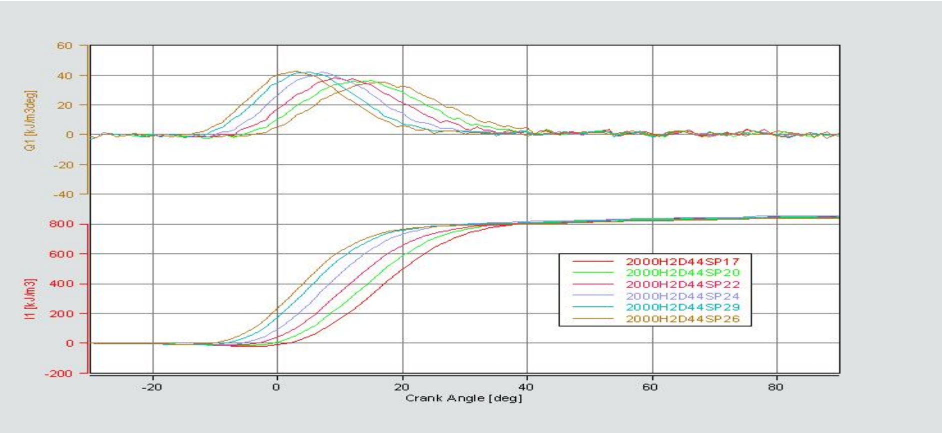

Figure 7: Effect of Spark advance on Heat Release Rate for hydrogen fuel.

From Figures 6 and 7 shows that the effect of spark timing on the heat release rate at 2000 rpm for gasoline and hydrogen fuels. Heat release will be less in hydrogen operated engine because of lean mixture is about 0.5 to 0.6 equivalence ratios in comparison to stoichiometric fuel air in the case of gasoline operation.

5 Concusions

Tests have clearly shown that hydrogen can be a used in the existing designs of internal combustion engines without any major modification in the existing engine. An appropriately designed timed manifold injection system can ensure neat hydrogen SI engine without any undesirable combustion phenomenon such as backfire. BTE will be more for hydrogen operation due to higher burning velocity and improved combustion in comparison to gasoline air mixture. Cylinder gas pressure is more for gasoline operation due to stoichiometric fuel air mixture burning.

References

[1] L. M. Das “Hydrogen engine: research and development (R&D) programmes in Indian Institute of Technology (IIT), Delhi” Int. J Hydrogen Energy, 2002; 27(9): 953-965.

[2] L. M. Das and R. Mathur “Exhaust gas recirculation for Nox control in a multicylinder hydrogen-supplemented S.I. engine” Int. J Hydrogen Energy, 1993; 18(12): 1013-1018.

[3] Module1: “Hydrogen properties” A report, College of Dessert, 2001.

[4] L.M.Das “Hydrogen Engines : A View of the past and a look into the future” Int. J. Hydrogen Energy,1990:15(6)425-443.

[5] J .T. Lee, Y.Y. Kim, C.W. Lee, “ An investigation of a cause of backfire and its control due to crevice volumes in a hydrogen fueled engine” 2000 Spring Technical Conference, ASME, ICE-Vol. 34-3.

[6] Sierens R, Rosseel E. “Backfire mechanism in a carbureted hydrogen fuelled compression iginition engine.” Proceedings of the 12th World Hydrogen Conference, Buenos Aires, Argentina, 1998 p 341-53.

[7] C.A. MacCarley and W.D. Van Vorst, “Electronic fuel injection techniques for hydrogen powered I.C.Engines” Int. J of Hydrogen Energy, Vo1980;5(2):179-203.

[8] L.M.Das, Rohit Gulati, & P.K.Gupta, Performance evaluation of a hydrogen-fuelled spark ignition engine using electronically controlled solenoid actuated injection system, Internal Journal of Hydrogen Energy 2000:25:569-579.