INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2015) 1–9

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

# Effects of MBT spark timing on performance emission and combustion characteristics of S.I engine using hydrogen-CNG blends

P.T. Nitnaware [a,*], J.G. Suryawanshi [b]

[a] D Y Patil College of Engineering, Akurdi, Pune 411044, M.S, India

[b] Visvesvaraya National Institute of Technology, Nagpur 444010, M.S, India

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form
9 November 2015
Accepted 15 November 2015
Available online xxx

Keywords:
CNG
HCNG
MBT
NOx
CPmax
MFB

ABSTRACT

This paper shows the effects of 0%, 5%, 10% and 15% blends of hydrogen by energy with Compressed Natural Gas (CNG) on multi-cylinder bi-fuel spark ignition engine using sequential port fuel injection system. At WOT (Wide Open Throttle) position MBT (Maximum Brake Torque) spark timing shown improvement in performance parameters with reduction in NOx emission. MBT spark timing increased with increase in speed and decreased with increase in hydrogen addition for all fuel blends. Hydrocarbon (HC) and carbon monoxide (CO) emissions rose up with decrease in equivalence ratio and reduced with increase in HCNG blends. Hydrogen addition had shown rise in peak pressure, increase in heat release rate and decrease in combustion duration. The optimum MBT spark timing observed for 5% hydrogen blend at 2500 rpm is 25°CABTDC for compromise with oxides of nitrogen (NOx) and performance output.



## Introduction

Much interest has been centred on CNG due to its potential for low particulate matter and hydrocarbon emissions. Lean burn is widely accepted as an effective approach to simultaneously improve spark ignition engine thermal efficiency and decrease exhaust emissions. But although lean burn has a lot of advantages it is also associated with several difficulties such as slow flame speed and increased cycle by cycle variation [1]. Hydrogen addition is thought to be an ideal approach to tackle these problems. Hydrogen addition extends lean operation limit, increases combustion speed, increase combustion temperature and reduces combustion duration in CNG engine. An increase in the combustion temperature increases NOx emission as compared to pure natural gas (CNG) at the same excess air ratio [4,5]. Table 1 shows the properties of Gasoline, CNG and Hydrogen.

Abbreviations: BMEP, brake mean effective pressure; BSEC, brake specific energy consumption; BTE, brake thermal efficiency; CO, carbon monoxide; $COV_{IMEP}$, coefficient of variation of indicated mean effective pressure; $COV_{Pmax}$, coefficient of variation of maximum cylinder pressure; CNG, compressed natural gas; HCNG, hydrogen CNG blends; $H_2$, hydrogen; HC, hydrocarbon; IMEP, indicated mean effective pressure; MFB, mass fraction burn; NOx, nitrogen oxides; ST, spark timing; WOT, wide open throttle.

* Corresponding author. Tel.: +91 9822870841 (mobile).
E-mail address: ptnitnaware1972@gmail.com (P.T. Nitnaware).

http://dx.doi.org/10.1016/j.ijhydene.2015.11.074

Table 1 – Properties of fuels.

| Sr. No | Property | Units | Hydrogen | Methane | Gasoline |
|---|---|---|---|---|---|
| 1. | Auto-ignition temp. | K | 858 | 813 | 501–744 |
| 2. | Stoichiometric composition in air | % volume | 29.53 | 9.48 | 1.65 |
| 3. | Combustion energy per kg of stoichio. mixture | mJ | 3.37 | 2.56 | 2.79 |
| 4. | Density (gas) at 1 atmp. and 300 K | $kg/m^3$ | 0.082 | 0.717 | 5.11 |
| 5. | Density (liquid) | kg/lit | 0.071 | 0.42 | 0.73 |
| 6. | Diffusion coefficient into air at NTP | $cm^2/s$ | 0.61 | 0.189 | 0.05 |
| 7. | Equivalence ratio ignition lower limit in NTP air | | 0.10 | 0.53 | 0.70 |
| 8. | Energy of stoichiometric mixture | $MJ/m^3$ | 3.6 | 3.5 | 3.9 |
| 9. | Flame temp. in air at $\lambda = 1$ (adiabatic) | K | 2318 | 2190 | 2470 |
| 10. | Higher heating value | MJ/kg | 141.7 | 52.68 | 48.29 |
| 11. | Higher heating value | $MJ/m^3$ | 12.10 | 37.71 | 233.29 |
| 12. | Kinematic viscosity at 300 K | $mm^2/s$ | 110 | 17.2 | 1.18 |
| 13. | Laminar burning velocity at NTP | m/s | 1.9 | 0.38 | 0.37–0.43 |
| 14. | Lower heating value | MJ/kg | 120 | 46.72 | 44.79 |
| 15. | Lower heating value | $MJ/m^3$ | 10.22 | 33.95 | 216.38 |
| 16. | Minimum energy for ignition in air | mJ | 0.02 | 0.28 | 0.25 |
| 17. | Molar carbon to hydrogen ratio | | 0 | 0.25 | 0.44 |
| 18. | Normal boiling point | K | 20.3 | 111.6 | 310–478 |
| 19. | Quenching gap at NTP | mm | 0.64 | 2.03 | 2 |
| 20. | Octane number | | 130+ | 125 | 87 |
| 21. | Stoichiometric fuel/air mass ratio | – | 0.029 | 0.058 | 0.0664 |
| 22. | Thermal conductivity at 300 K | mW/m K | 182.0 | 34.0 | 11.2 |
| 23. | Thermal energy radiated from flame to surrounding | % | 17–25 | 23–33 | 30–42 |
| 24. | Volumetric LHV at NTP | $kJ/m^3$ | 10046 | 32573 | 195800 |
| 25. | Volumetric fraction of fuel in air Ø = 1 at NTP | | 0.290 | 0.095 | 0.018 |
| 26. | Specific mixture energy | $kJ/m^3$ | | 3200 | 3670 |
| 27. | $CO_2$ formation | gm $CO_2$/kWh | Nil | 200 | 265 |
| 28. | Tank volume (equal to gasoline) | litre | | 200 | 50 |
| 29. | Flammability limits | % volume | 4–75 | 5.3–15.0 | 1.2–6.0 |

All above values are taken from literature survey.

## Literature review

Detailed literature review is carried out to know the effects of fuel injection system, spark timing and fuel injection pressure on performance, emission and combustion characteristics on SI engine with hydrogen and CNG blends. Different researchers carried out experimentation on single cylinder and multi-cylinder engine (gasoline SI engine, dedicated CNG engine and modified diesel engine). It is observed that port fuel injection system reduces combustion losses and increases wall heat losses for HCNG blends compared to CNG [6]. Hydrogen enrichment significantly extends lean operation limit, improves engine combustion ability and decreases burn duration. NOx emission increases with increase in hydrogen addition if the spark timing is not optimized [7]. Equal spark timing increases cylinder wall heat losses with hydrogen addition due to smaller quenching distance and higher combustion temperature. With 15% hydrogen addition and 3° CA retard, there is a large reduction in NOx emission at excess air ratio 1.45 [8]. Hydrogen addition reduces CO & $CO_2$ emission due to decrease in C/H ratio. HC emission increases at lean condition due to lower mixture combustion quality. Hydrogen addition contributes more to speeding up flame development phase than to speeding up the flame propagation speed at lower values of $\lambda$. At low load level increase in engine speed is beneficial to extend lean operation limit but this is not true at high load level. Advancing spark timing is generally good to improve engine lean burn capability [9]. Hydrogen can be used both in spark ignition as well as compression ignition engines without any major modifications in the existing system. Appropriately designed timed manifold injection system can reduce undesirable combustion characteristics. Hydrogen supplementation for automotive application as duel fuel mode is better option than pure hydrogen [10]. MBT spark timing increases brake thermal efficiency and mean gas temperature. The rapid combustion duration decreases and heat release rate increases with increase in hydrogen fraction at low engine speeds. 15–20% hydrogen addition by volume is observed as optimum blend because NOx emission increases with further increase in hydrogen addition [11]. In Port injection system with increase in hydrogen addition, the MBT spark timing decreases and gets closer to the top dead centre. CO, HC and NOx emissions descends with increase in spark advance angle and ascend with increase in load. 1° CA combustion duration shortened per 10% hydrogen addition [12]. Throttle body injection system reduced $COV_{Pmax}$ and $COV_{IMEP}$ with increase in hydrogen addition at lean condition. The flame development duration as well as CCV reduces simultaneously with hydrogen addition, all of which improves combustion stability. MBT spark timing had shown no obvious rise in NOx emission after hydrogen addition. HC emission in HCNG fuelling is lower than CNG fuelling. Hydrogen addition is an effective and applicable approach to keep down CCV in lean burn spark ignition engine [13]. Sequential injection system with 7.9 bar injection pressure reduced backfire for 18% hydrogen addition at idling condition. Retarding ignition timing reduces $COV_{IMEP}$

Please cite this article in press as: Nitnaware PT, Suryawanshi JG, Effects of MBT spark timing on performance emission and combustion characteristics of S.I engine using hydrogen-CNG blends, International Journal of Hydrogen Energy (2015), http://dx.doi.org/10.1016/j.ijhydene.2015.11.074