Boost Pressure Effects on HCCI Combustion Performance

Dr. P. M. Diaz[1], N. Austin[2], Dr. K. Maniysundar[3] and M. Julie Emerald Jiju[4]

[1]Professor, Ponjesly College of Engineering, Tamilnadu, India
[2]Research Scholar, Sathyabama University, Tamilnadu, India
[3]Principal, Ponjesly College of Engineering, Tamilnadu, India
[4]Professor, CSI Institute of Technology, Tamilnadu, India
pauldiaz71@gmail.com

Abstract: This paper describes use of reformer gas (RG) to alter and control combustion in a CNG-fueled HCCI engine. Experimental work used a mixture of simulated RG (75% H_2 and 25% CO) to supplement base CNG fueling in a COMET engine upgraded to achieve high compression ratios. RG was used to improve the engine's operating performance and to control combustion onset in experiments. The building compressed air supply was used to supercharge a CNG fueled COMET engine operating in HCCI mode. This sufficiently raised the engine's indicated power that it could overcome internal friction for even leaner mixtures and thus produced a significantly wider operating range. Operation near the lean boundary could be extended to the point where misfiring and partial burning cycles were identified. As well as illustrating the potential for widened operating range through pressure boosting, this study also examined the direct effects of pressure on the HCCI combustion processes.
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1. Introduction

Homogeneous Charge Compression Ignition (HCCI) combustion engines have recently gained attention from automotive researchers because of the potential for high efficiency with low NO_x emissions [1, 2]. Unfortunately, they suffer from a narrow operating range because they lack a means to control combustion timing. Ignition is governed by the mixture temperature history during compression and the auto-ignition chemistry of the fuel/air/residual mixture. This makes the study of ignition mechanisms for such mixtures important because of the potential to lead to improved engine control techniques. There have been many attempts to control ignition timing using techniques such as changing the exhaust gas recirculation (EGR) ratio [3-5], adjusting initial operating conditions [6], varying engine compression ratio [7], and using different fuel blends [8-10]. EGR quantity control using variable valve timing (VVT) has been proven to control HCCI ignition [11]. However, the cost and complication of VVT which would enable such a technique makes it less attractive. A variable fuel blend is more attractive because it can be adjusted on a cycle-by-cycle basis by changing the fraction of each fuel injected [12-14]. Moreover, using a reformer gas produced from the base fuel as the blending agent [15], offers a substantial fuel change with less inconvenience than supplying and storing two fuels. Fuel reformers convert base fuels to low-molecular weight gases dominated by hydrogen (H_2) and carbon monoxide (CO). The reformer gas (RG) may also contain variable amounts of unreformed fuel as well as inerts like carbon dioxide and nitrogen.

In a comprehensive experimental and modeling study of HCCI combustion of natural gas, ethanol, and iso-octane by Christensen et al (1998) [1], a maximum IMEP of 14 bar was reported on natural gas with intake pressure boosted up to 2 bar gauge and intake temperature adjusted accordingly. In another experimental study by the same group (Christensen and Johansen (2000) [2]), a boost pressure of 1.5 bar was used to expand the operating region of an HCCI engine. The engine achieved 16 bar IMEP at high EGR rate and λ close to stoichiometric for natural gas HCCI combustion. Hyvonen et al (2003) [16] also presented results of the intake pressure variation (both boosting and throttling) of an HCCI engine. They found that maximum load and brake efficiency were higher with turbo charging than with mechanical supercharging. Using a turbocharger on HCCI engines leads to practical considerations as the exhaust temperature is lower than that of conventional engines and also exhaust back pressure affects internal EGR and consequently combustion timing. Those practical considerations of using a turbocharger or mechanical supercharger have been discussed in a paper by Olsson et al (2004) [17]. Recently in an experimental study by Yap and Megaritis (2005) [18], a high IMEP of 7.5 bar was achieved in an HCCI engine fueled with bio-ethanol with high intake pressure and without intake heating. It was mentioned that while λ can be used as a means to control combustion timing, variation of intake boost pressure can control load at any specified combustion phasing. Boost pressure increases air/fuel ratio and thus increases the thermal mass to be heated by the combustion heat release resulting in expanding operating region towards high load range.

The minimum ignition energy (MIE) is higher for methane than the heavier alkanes, which indicate that more energy has to be added before reactions are initiated. Hydrogen is the lightest of all gases, and it has very low minimum ignition energy. The H_2 molecule is however rather stable, because the H-H bond is quite strong. The bond enthalpy of H_2 is 436 kJ/mol while an average C-H bond is 412 kJ/mol. Nevertheless, when the H-H bonds are broken the two H radicals are very reactive which results in very fast reactions. The strong H-H bonds are the reason why hydrogen has an auto ignition temperature not much lower than methane and higher than heavier hydrocarbons. Hydrogen diffuses very rapidly into other gases and has a broad range of concentration where it is flammable in air. A small spark or a hot surface may ignite a hydrogen/air mixture much easier than a hydrocarbon/air mixture. It was found that RG blending with base CNG fuel in HCCI engine produces wider operating range towards lean burn boundary and increases measured combustion efficiency, particularly for leaner mixture.

2. Experimental Setup

All experiments were conducted on a modified COMET engine to operate in HCCI mode using CNG fuel. Table I summarizes the engine specifications for the current experiment. Figure 1 shows experimental setup. RG is a mixture of light gases dominated by hydrogen (H_2) and carbon monoxide (CO) and can be produced from CNG using low current and non-thermal plasma boosted fuel converters. Plasmatrons are electrical devices that take advantage of the finite conductivity of gases at very elevated temperatures.

At these temperatures, the gas is partially ionized and electrically conducting. Plasmatron fuel converters provide electrical discharges in flowing gases of CNG fuels and air (and/or other oxidants). The resulting generation of reactive species in the flowing CNG along with increased mixing accelerates reformation of CNG fuels into hydrogen rich CNG fuel.

3. Results and Discussion

The operating region for the natural gas HCCI engine with boosted intake is shown in Figure 2 which illustrates the HCCI operating window in terms of excess air ratio, λ, as well as in terms of engine torque or IMEP. For any given EGR fraction, the operating region is limited between a rapid combustion boundary with decreasing λ, (rich mixtures), and a slow combustion/misfire boundary with increasing λ, (lean mixtures). At the rich limit, the boundary is set by severe knock. At the lean boundary, the limit is imposed by stalling due to low IMEP (when IMEP produced is less than FMEP) or by excess variability, partial burning and misfiring, (which is more common with higher EGR rates. Under these partial burn conditions, the HC emissions increase dramatically. Figure 3 shows the relation of air and fuel mass flow rates to intake pressure for the case of natural gas. Boosting the intake pressure increases the mass and energy.

Table 1. Experimental apparatus and fuels

Engine Make	COMET
Engine Type	four stroke single cylinder, Research
Ratedpower output	3.5 kW at 1500 rpm
Bore Diameter	30 mm
Stroke Length	110 mm
Throttle	Fully open
Main fuel	CNG
Additive fuel	RG
Exhaust Valve Open	43° BBDC
Exhaust Valve Close	6° ATDC
Inlet Valve Open	8°ATDC
Inlet Valve Close	36° ABDC
Wall temperature(K)	460K

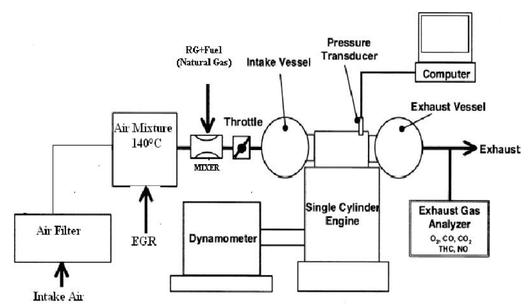

Figure 1. Schematic Diagram of Experimental Setup

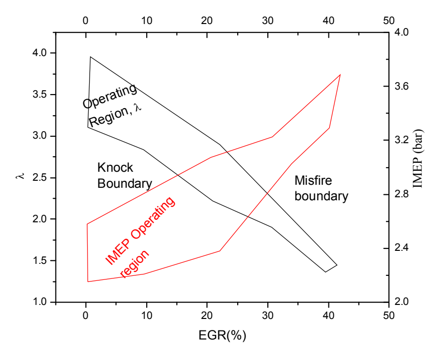

Figure 2. Operating region of CNG HCCI engine with boosted intake pressure and partial fuel reforming

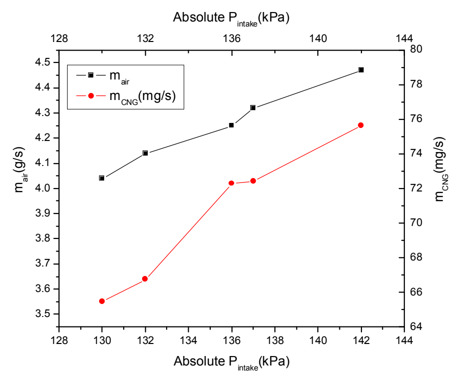

Figure 3. CNG flow rate adjustment with intake pressure to keep constant λ = 3.62

Boosting the intake pressure increases the mass and energy flows into the engine, leading to a proportionally higher IMEP/indicated power as shown in Figure 4.This figure also shows that the relative cyclic variation of IMEP decreased as the power increased. The operating points chosen are near to the high λ/idling boundary where the power output is low and even low pressure fluctuation leads to a high relative value for coefficient of variation. However, for these conditions it is also notable that the decrease in relative IMEP fluctuation was much greater than the corresponding increase in IMEP, indicating a true reduction in combustion variability as intake pressure is boosted. It is normally reported that HCCI combustion has extremely low cyclic variation of IMEP and other, more sensitive indicators of combustion variation may be used. For the natural gas-fueled HCCI engine shown, the variation of maximum cylinder pressure was between 1.5% and 4.5% while the variation of maximum cylinder pressure timing was between 0.23% to 0.27%,(of average ignition timing in °CA ATDC).

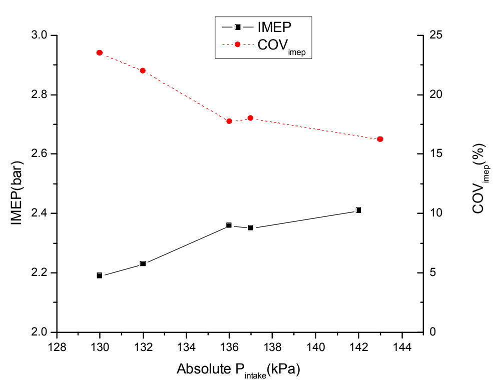

Figure 4. Intake Pressure effect on IMEP and COV_{imep} of HCCI engine

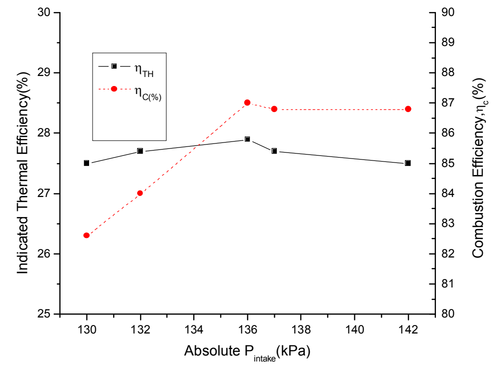

Figure 5. Intake Pressure effect on indicated thermal efficiency and combustion efficiency, CNG HCCI engine

Thermal efficiency for these operating cases was low and almost constant with intake pressure as indicated in Figure 5. Combustion phasing is important in any engine and it has a major role in determining thermal efficiency of the HCCI engine. For these low-power experimental cases, the timing was not optimum and thermal efficiency was in the 27% range. For a well-optimized HCCI engine, thermal efficiency on the order of 50% might be expected. The constant thermal efficiency reveals that combustion characteristics did not change considerably as intake pressure changed for a constant λ. The combustion efficiency, an indication of completeness of combustion, was generally low for these cases, falling in the 82 to 88% range. Higher combustion efficiency was associated with increasing intake pressure. It is postulated that higher energy flow to the engine led to higher gas temperatures and thus to more complete combustion.

4.Conclusion

To expand the operating region of a COMET engine operated in HCCI mode, the intake system was modified for pressure boosting using the building compressed air supply as a pressurized air source. This provided a simple research method for operating the high-internal-friction COMET engine at a sufficiently lean mixture that it could exhibit a true lean limit due to misfiring and partial burn cycles rather than the friction-limited, low IMEP boundary exhibited for naturally aspirated cases. The direct effects of increasing intake pressure on power and efficiency were also studied for natural gas HCCI operation. Keeping all influential parameters of compression ratio, intake mixture temperature, EGR rate, and λ constant, increasing the intake pressure produced proportionately higher indicated power. Indicated thermal efficiency did not consistently change with supercharging. It increased slightly with supercharging and then decreased. Also, both fuels showed a significant increase in combustion efficiency due to the higher energy flow to the engine and higher combustion temperature.

Corresponding Author:
Dr.P.M.Diaz
Department of Mechanical Engineering
Alampaarai,Vettunnimadam p.o,
Nagercoil, Tamilnadu, India-629003.
Cell No: 09443558554
Tel No: 914651-279160
E-mail: pauldiaz71@gmail.com

References

1. M. Christensen and B. Johansson, Homogeneous charge compression ignition with water injection, SAE Paper(1999) 1999-01-0182.
2. M. Christensen and B. Johansson, Supercharged homogeneous charge compression ignition (HCCI) with exhaust gas recirculation and pilot fuel, SAE Paper (2000) 2000-01-1835.
3. D. Law, Controlled Combustion in an IC-Engine with a Fully Variable Valve Train, SAE Paper (2000) 2000-01-0251.
4. D. Kawano, H. Suzuki, H. Ishii, Y. Goto, M. Odaka, Y. Murata, J. Kusaka and Y. Daisho, Ignition and Combustion Control of Diesel HCCI, SAE paper (2005) 2005-01-2132.
5. Chladny RR, Koch CR and Lynch AF, Modeling of Automotive Gas-Exchange Solenoid Valve Actuators IEEE Transactions on Magnetics. 41(2005)1155-1162.
6. S Zhong, Experimental Investigation into HCCI Combustion Using Gasoline and Diesel Blended Fuels, SAE Paper (2005) 2005-01-3733.
7. J. Olsson, P. Tunestal, B. Johansson, S. B Fiveland, R. Agama, M. Willi and D. N Assanis, Compression Ratio Influence on Maximum Load of an HCCI Engine, SAE Transactions 111(2002) 442-458.
8. V. Hosseini and M. D Checkel, Effect of Reformer Gas on HCCI Combustion- Part I: High Octane Fuels, SAE papers (2008) 2007-01-0208.
9. S. Peucheret, M. L Wyszynski, R. S Lehrle, S Golunski and H Xu, Use of catalytic reforming to aid natural gas HCCI combustion in engines: experimental and modeling results of open-loop fuel reforming. Int J Hydrogen Energy, 30(2005)1583-1594.
10. Y. Jamai and L. Wyszynski, On-Board Generation of Hydrogen-rich Gaseous Fuels – A review. Int J Hydrogen Energy, 19(1994)557-572.
11. A. Helmantel and I. Denbratt, HCCI Operation of a Passenger Car DI Diesel Engine with an Adjustable Valve Train. SAE paper (2006) 2006-01-0029.
12. D. Yap, S Megaritis, S. Peucheret and M. L.Wyszynski, Effect of Hydrogen Addition on Natural Gas HCCI Combustion, SAE paper (2004) 2004-01-1972.
13. V. Hosseini and M. D. Checkel, Reformer Gas Enrichment of Natural Gas HCCI Combustion Institute / Canadian Section, Spring Technical Meeting, Waterloo(2006)55-60.
14. V. Hosseini and M. D. Checkel, Alternate Modes Combustion Study: HCCI Fueled with Heptane and Spark Ignition Fueled with Reformer Gas. Proceedings of ICEF 05, ICEF(2005)1236-1240.
15. P. Kongsereeparp and M. D Checkel, Investigating the Effects of Reformed Fuel Blending in a Methane- or n-Heptane-HCCI Engine Using a Multi-Zone Model, SAE paper (2007) 2007-01-0205.
16. J. Hyvonen, G. Haraldsson, B. Johansson, Supercharging HCCI to extend the operating range in a multi-cylinder VCR-HCCI Engine, SAE Paper(2003) 2003-01-3214.
17. J. O. Olsson, P. Tunestal and B. Johansson, Boosting for high load HCCI. SAE Paper (2004) 2004-01-0940.
18. D. Yap and A.Megaritis, Applying Forced Induction to Bioethanol HCCI Operation with Residual Gas Trapping. Energy & Fuels, 19(2005)1812-1821.

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