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Full Length Article

Effect of compression ratio and hydrogen addition on part throttle performance of a LPG fuelled lean burn spark ignition engine

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HIGHLIGHTS

- Brake power, brake thermal efficiency increases with raise in compression ratio.
- Increase in compression ratio and hydrogen addition extends the lean misfire limit.
- Emissions of HC, NO and CO_2 increases with increase in compression ratio.
- Hydrogen addition enhances combustion rate and brake thermal efficiency.
- Hydrogen addition result in reduction in HC, CO and CO_2 emissions.

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ABSTRACT

A single cylinder CI engine was modified to operate as a LPG fuelled lean burn SI engine. The engine was tested at 1500 rpm and 20% throttle opening at compression ratios 9:1, 10:1, 10.5:1 and 11:1 by varying equivalence ratios. The influence of compression ratio and 15% hydrogen substitution on energy basis at the optimal compression ratio of 10.5:1 on performance, emission and combustion behavior were studied and compared. The brake thermal efficiency and brake power output increases with rise in compression ratio, and above a critical value of 10.5:1 the improvement was small when compared to the increase in emissions. The advantage of brake thermal efficiency from higher compression ratio is narrow under low load conditions. The ever increasing load due to the auxiliaries which are likely to grow more require better low load performance and emissions. Wide flammable limits of hydrogen enable ultra-lean combustion and its anti-knock enhancement makes it advantageous compared to increasing the compression ratio at part throttle condition. Hydrogen addition enhanced the combustion rate and heat release rate, reduced cyclic variations, and extended the lean limit of operation. There was perceptible improvement in brake thermal efficiency, brake power and considerable reductions in hydrocarbon, carbon monoxide and carbon dioxide levels. Due to retarded ignition timing the NOx emission increase was not significant.

1. Introduction

The ever increasing demand of petroleum products diminishes the reserves at rapid phase. We need to preserve the resources for the future generation and substitute it with other possible alternate fuels. It is also our conscientiousness to preserve nature with less pollution. Gaseous fuels generally result in lower emissions, economical and are available in abundant. The properties of various gaseous fuels and gasoline are given in Table 1.

Liquefied Petroleum Gas (LPG), hydrogen and Compressed Natural Gas (CNG) are encouraging alternatives for Internal Combustion (IC) engines because of their high hydrogen to carbon ratio, wide ignition limits, high flame speeds and high knock resistance. Combustion of very lean mixtures of these fuels leads to lower emissions and increase in thermal efficiency. Hydrogen, producer gas and biogas are obtained from renewable sources. LPG, a byproduct of the petroleum refining mainly consists of propane and butane is also produced from natural gas and shale gas. It is generally stored in cylinders as liquid at pressures in the range of 10–15 bar which eliminate the requirement of a fuel feed pump. Higher compression ratios can be used in engines due to the higher auto-ignition temperature and octane rating of LPG.

The lean combustion technology is slowly replacing conventional stoichiometry combustion for reducing carbon print and pollutants in automobiles. The energy conversion efficiency of an

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Table 1
Properties of Gasoline, LPG, CNG and Hydrogen.

Properties/fuels	Gasoline	LPG	CNG	Hydrogen
Chemical structure, Composition (% vol)	C_4 to C_{12} C_7H_{17}	C_3H_8-40% C_4H_{10} -60%	CH_4-85% C_2H_6 and C_3H_8-9% N_2 and CO_2-6%	H_2
Physical state	Liquid	Liquid/Gas	Compressed gas	Compressed gas
Density at 15 °C, kg/m^3	737	0.557 / 2.21	0.78	0.08
Octane number	86–94	103–105	120	130
Lower heating value (MJ/kg)	43.44	45.7	47.14	120
High Heating Value (MJ/kg)	46.53	49.53	52.20	
Stoichiometric air/fuel ratio	14.7	15.5	17.3	34.2
Flammability limits (vol. % in air)				
Leaner	1.4	1.9	5	4
Richer	7.6	9.7	15	75
Auto-ignition temperature °C	371	488–502	540	585
Flame speed (cm/s)	37.5	38.25	34	275
Stoichiometric A/F (kg of air/kg of fuel)	14.7	15.5	17.3	34.2

Source: IS 4576, IS 14861, Gas India.

engine becomes greater and the exhaust emissions go lower when the fuel air mixture is made lean, but the design of lean burn engine is certainly more difficult and its performance is very sensitive to operating conditions. Special techniques have to be used when lean mixtures are employed in order to avoid cycle by cycle variations and erratic combustion. Superior combustion characteristics of hydrogen when added with LPG in small quantities improve performance, reduce emissions and extend lean limit. This research work intends to study the influence of compression ratio and addition of hydrogen on the performance and emission aspects of LPG fuelled lean burn Spark Ignition (SI) engine at part throttle condition. Part throttle operation requires power for driving auxiliaries like electrical generator, water pump, cooling fan, air compressor, air conditioner, heater, servo motors, oil pump, power brakes and power steering pump, which account to 10% of the total fuel consumption and is likely to grow in the future.

Sita Rama Raju et al. [1] reported extension of lean limit and improved thermal efficiency. Increase in Hydrocarbon (HC) emission and oxides of nitrogen (NOx) with increase in compression ratio was observed with LPG and CNG fuels. Zheng et al. [2] investigated the compression ratios (8:1, 10:1, 12:1 and 14:1) effects on performance and emissions with CNG and concluded that compression ratio has a significant influence on the combustion duration at lean combustion. In another study, Poompipatpong et al. [3] compared 9:1, 9.5:1, 10 and 10.5:1 compression ratios for CNG as fuel. At 9.5:1 compression ratio, lower fuel consumption was reported. Total Hydrocarbon (THC) and NOx emissions increased with increase in compression ratio, but NOx emission declined at 10.5:1 compression ratio. Porpatham et al. [4] observed the performance of a single cylinder SI engine fuelled with biogas run at compression ratios of 9.3:1, 11:1, 13:1 and 15:1 under different throttle conditions. The observations inferred that higher compression ratio lead to higher thermal efficiency. Pradeep et al. [5] conducted experiments on a direct injection LPG fuelled two stroke SI engine. The results showed reduction in HC emission and increase thermal efficiency. Sayin et al. [6] focused on the effect of compression ratio on a SI engine fuelled with *iso*-butanol (10%, 30% and 50%) along with gasoline. The results indicate that at all compression ratios, increased performance and decreased emissions were seen with the increased ratio of *iso*-butanol. Fleming et al. [7] investigated the influence of compression ratio on a single cylinder SI engine with natural gas and gasoline as fuel at minimum advance for maximum brake torque (MBT) timing and at compression ratios ranging from 8.4:1 to 18.5:1. It was reported that at a compression ratio of 8.4:1, spark timing for natural gas was 2 to 6 crank angle degrees advanced than the gasoline engine and the indicated thermal efficiency was higher than petrol at an equivalence ratio lower than 0.8.

Rakopoulos et.al [8] developed an advanced simulation model with accurate flame front formulation for availability analysis and suggested supplying increasingly leaner mixtures as loads rise in order to keep the emitted NOx low. Quather [9] tested the response of engine variables on the lean limit at equivalence ratios ranging between 1.1 and leanest possible limit using propane and *iso*-octane as fuels. He found that with compression ratio of 10:1, the lean limit equivalence ratio was extended from 0.82 to 0.69. Ladommatos et al. [10] conducted experiments with natural gas/carbon dioxide mixtures on a high compression ratio (15:1) fast burn spark combustion system. It was observed that a lean burn, high compression, open chamber, turbulent combustion system would enable gas engines to operate efficiently with low specific emission. Ma et al. [11] experimented on six cylinder natural gas engine under different compression ratios (10:1, 11:1 and 12:1) at 1200 rpm, excess air ratio of 1.6 and manifold pressure of 50 kPa. Higher compression ratio resulted in higher torque as well as lower fuel consumption, accelerated heat release rates and lowered Coefficient of Variations (COV) of Indicated Mean Effective Pressure (IMEP). Rakopoulos et.al [12] used higher order statistical parameters like stochastic analysis for averages, standard deviations, probability density functions, autocorrelation, power spectra, and cross-correlation coefficients that can reveal cause and effect relationships for cyclic variability.

Lim et al. [13] studied the outcomes of compression ratio on general characteristics in a SI engine operated with Hydrogen enriched Compressed Natural Gas (HCNG) 30 and reported that at 11.5:1 compression ratio, the thermal efficiency increased and NOx emission decreased. Hora et.al [14] performed experiments at three compression ratios (10:1, 11:1 and 12:1) under identical conditions on two different HCNG compositions. 30HCNG showed relatively lower brake specific fuel consumption compared to 20HCNG. Combustion parameters including heat release rates and peak pressure improved at higher compression ratios for both HCNG mixtures. However, 30HCNG performed slightly better than 20HCNG. Selim et al. [15] studied the effects of compression ratios from 9.6:1, 12.5:1 and 15:1 on an altered Compression Ignition (CI) engine. The observations indicate that the higher torque and lower fuel utilization were achieved at 12.5:1 compression ratio. De Boer PCT et al. [16] observed the results of a range of compression ratios between 9:1 and 12:1 and inferred that hydrogen operation at higher compression ratios are liable to adverse knocking.