CONVERSION OF DIESEL ENGINE INTO SPARK IGNITION ENGINE TO WORK WITH CNG AND LPG FUELS FOR MEETING NEW EMISSION NORMS

by

Syed KALEEMUDDIN [a] ***and Gaddale Amba Prasad RAO*** [b*]

[a] Greaves Cotton Ltd., Aurangabad, India
[b] Department of Mechanical Engineering, National Institute of Technology, Warangal, India

Original scientific paper
UDC: 662.612.12/.16:662.767/.769
DOI: 10.2298/TSCI1004913K

Fluctuating fuel prices and associated pollution problems of largely exploited petroleum liquid fuel has stimulated the research on abundantly available gaseous fuels to keep the mobility industry intact. In the present work an air cooled diesel engine was modified suitably into a spark ignition engine incorporating electronic ignition and variable speed dependant spark timing to accommodate both LPG and CNG as fuels. Engine was optimized for stoichiometric operation on engine dynamometer. Materials of a few intricate engine components were replaced to suit LPG and CNG application. Ignition timing was mapped to work with gaseous fuels for different speeds. Compensation was done for recovering volumetric efficiency when operated with CNG by introducing more volume of air through resonator. Ignition timing was observed to be the pertinent parameter in achieving good performance with gaseous fuels under consideration. Performance and emission tests were carried out on engine dynamometer and chassis dynamometer. Under wide open throttle and at rated speed condition, it was observed that the peak pressure with LPG was lying between diesel fuel and CNG fuel operation due to slow burning nature of gaseous fuels. As compression ratio was maintained same for LPG and CNG fuel operation, low CO emissions were observed with LPG where as HC + NO_x emissions were lower with CNG fuel operation. Chassis dynamometer based emission tests yielded lower CO_2 levels with CNG operation.

Key words: *dual-fuel operation, liquid petroleum gas, compressed natural gas, ignition timing, performance, emissions*

Introduction

Direct injection diesel engines are being favored in small and heavy duty applications owing to their high fuel conversion efficiency. Petroleum derived fuel run engines also brought along with enormous problems namely fuel crisis and pollution. Fuel crisis is leading to depletion in its resources. Extensive research has given a way for a number of alternate fuels to mitigate fuel crisis and associated automotive pollution. Use of gaseous fuels in the engines reduces reactive hydrocarbons and also do not pose the problems of atomization [1]. In the recent years

* Corresponding author; e-mail: ambaprasadrao@gmail.com

share of gaseous fuels such as liquid petroleum gas (LPG) and compressed natural gas (CNG) has increased [2]. However, as domestic sector is dominated by the use of LPG for meeting cooking and other allied applications, attention is being diverted by the researchers for the effective utilization of, "deep gas"– natural gas. Both of these fuels enjoy higher octane rating facilitating its use in spark ignited engines to work with higher compression ratios.

Combustion chemistry is simple for methane (CH_4 – a major constituent of natural gas) compared to conventional liquid fuels [3]. Liquefied petroleum gas and natural gas fueled engines could be operated lean with an equivalence ratio as low as 0.7 resulting lower in-cylinder temperatures that reduce NO_x emission levels. The engine-test results showed that alternative fuels exhibit longer ignition delay, with slow burning rates [4].

Aslam *et al.* [5] presented test results obtained from running a 1.5 L, 4-cylinder Proton Magma retrofitted spark ignition car engine with dynamometer and inferred that CNG operation showed low brake mean effective pressure (BMEP), low brake specific fuel consumption (BSFC), higher efficiency and lower emissions of CO, CO_2, and HC, but more NO_x compared to gasoline fuel operation.

Bysveen [6] reported experimental evaluation of engine characteristics for emissions and performance using mixtures of natural gas and hydrogen (HCNG) in order to improve the performance of engine with CNG. He observed superior performance of the engines with increase in amount of hydrogen. Lee *et al.* [7] experimentally studied performance and emission characteristics of an SI engine operated with di-methyl ether (DME) blended with LPG fuel when the engine was run under variable speed operation of 1800 and 3600 rpm.

They observed lower engine power output and deterioration in BSFC. They attributed the effects to the lower energy value of DME; however, they opined that LPG fuel was expected to have greater potential for expanding the DME market. Saleh [8] investigated the effect of variation in LPG composition on emissions and performance characteristics in a dual-fuel engine run on diesel fuel and five gaseous fuels of LPG with different composition. He concluded that the exhaust emissions and fuel conversion efficiency of the dual-fuel engine would be affected when different LPG composition was used and concluded that higher butane content led to lower NO_x levels while higher propane content reduces CO levels. Bayrakar *et al*. [9] investigated the performance and exhaust emissions of an automotive engine for the different blends of gasoline and LPG. Nadar *et al.* [10] carried out experimental studies on a single cylinder diesel engine by modifying it to work in dual-fuel mode and employed LPG to improve the performance of engine with methyl ester of mahua oil. They added pilot quantities of methyl esters of mahua oil. They observed exhaust emissions such as smoke, unburnt HC and CO were lower.

Nwafor [11] in his studies observed that the ignition delay was reduced through adopting advanced injection timing but tended to incur a slight increase in fuel consumption. The CO and CO_2 emissions were reduced through the use of advanced injection timing.

It was observed from the literature that most of the work on LPG and CNG fuels was carried out either adopting pilot-fuel injection concept for diesel engines or employing retro-fittings for SI engines [12]. In the present work, a dedicated diesel engine was modified into a SI engine to accommodate both LPG and CNG gaseous fuels in the same engine effectively. Present research work deals with the experimental investigations carried out to employ LPG and CNG in the same engine with suitable modifications on the base diesel engine and to finally comply with the new emission norms.

Experimental programme

Design modifications

Diesel engine specifications, complying with BS-II emission norms, adopted for conversion into spark ignition engine, are illustrated in tab. 1. Modifications in cylinder head, piston assembly, flywheel and replacing fuel injection system with electronic ignition system were carried out to obtain spark ignition version. Valve timing of existing diesel was found suitable for spark ignition engine and was unaltered.

Table 1. Specifications of base diesel engine

Parameter	Specification
Engine type	Direct injection, naturally aspirated, air cooled
Bore × stroke,	86 68 mm
Number of cylinders	1
Displacement	395 cm^3
Compression ratio	18:1
Fuel pump	PFE 1Q
Injector nozzle type	P type DSLA

Spark plug thread tapping was made at 20° inclination in the cylinder head, was in place of diesel injector, so as to arrange spark plug centrally with required protrusion in order to produce short flame travel which reflect in rapid and relatively complete combustion. To make engine more compact flywheel was machined to 6.25 kg from existing 14 kg. Piston top clearance was increased from 0.75-7.4 mm to achieve an optimum compression ratio of 9:1 from 18:1. Pan cake combustion chamber piston was adopted to avoid hot spot combustion [13]. Mechanical controlled variable depression carburetor with piston type throttle was selected. Carburetor piston was anodized in order to take care of wear and abrasion during engine running with gaseous fuels. Fuel injection system and governing mechanism of the base diesel engine were replaced with electronic multi mapped DC igniter with pulsar pickup [14, 15]. High tension coil of high energy capacity was used in order to take care of sluggish combustion of gaseous fuels. Twin electrode resistive spark plug was adopted on engine. Provision was also made to record spark plug temperature during engine and vehicle at different speeds. Cylinder head, valve and valve seat inserts upgraded with silicon-copper high alloy material to retain hardness at elevated temperature, valve material was made with mono-metal with bi-metal valve with satellite coating on valve head in order to avoid premature wear due to dryness of CNG fuel. Cobalt base alloy was used in valve seat inserts which remain intact even at elevated temperatures [14]. Typical fuel properties employed in experimentation are given in tab. 2.

Table 2. Fuel properties

Property	Gasoline	Diesel	LPG	CNG
Chemical formula	C_8H_{16}	$C_{12}H_{26}$	C_3H_8	CH_4
State	Liquid	Liquid	Gas	Gas
Lower heating value [$kJkg^{-1}$]	43500	42600	46500	42020
Octane rating	87~93	–	100~103	120~130
Auto ignition temperature	225 °C	220 °C	470 °C	450 °C
Stoichiometric ratio	14.7	15	15.6	17.6
Density at 15 °C, [kgm^3]	750	832	2.26	0.79

Experimentation

The engine was mounted on fully automated engine test-bed and coupled to eddy current dynamometer to monitor and control engine operating parameters: engine speed, load, lubricating oil temperature, fuel flow, and air flow rates. The dynamometer was equipped with the load cell for engine torque measurement. Magnetic sensor was provided for speed measurement. All the signals were fed to indicators on the control panel via the controller. Thermocouples were located at strategic points on the engine with their indication shown on electronic temperature indicators. The engine exhaust system was connected to a silencer. Air flow measurement was done through precision turbine flow meter. The exhaust gas analysis system consists of a group of analyzers for measuring soot (smoke), NO_x, CO, and total HC. Analyzers for NO_x and HC were fitted with thermostatically controlled heated lines. For measuring in-cylinder pressure, a Kistler miniature water cooled piezoelectric transducer was used and flush mounted to the cylinder head and connected to a Kistler charge amplifier. Also a Kistler piezoelectric transducer was connected on the high pressure pipe linking injector to injection pump to provide fuel

Table 3. Details of instrumentation

Instrument name	Range	Accuracy	Measurement technique	Percentage uncertainties
Eddy current dynamometer AG 20	60 Nm	0.25 Nm	Opposing eddy current	0.25
Load indicator	0-100 kgs	0.1kg	Strain gauge type load cell	0.2
Fuel consumption measurement	0-50 cm^3	0.1 cm^3	Volumetric type	0.1
Air flow meter	100 kg/h	0,01 kg/h	Turbine flow principle	–
Speed measuring unit	0-10,000 rpm	10 rpm	Magnetic pick up type	0.1
Temperature indicator	0-900 °C	0.1 °C	k- type (Cr-Al) thermocouple	0.15
Pressure pick up indicator	0-110 bar	0.10 bar	Piezoelectric transducer (Kistler)	0.10
Crank angle encoder		1°	Magnetic pick up type	0.20
Exhaust gas analyzers				
Carbon monoxide	0-10,000 ppm	20 ppm	Non-dispersive infra red sensor principle (NDIR)	0.20
Oxides of nitrogen	0-10,000 ppm	10 ppm	Chemiluminescence principle, electro chemical sensor	0.20
Total hydrocarbons	0-10,000 ppm	20 ppm	Flame ionization detector (FID)	0.20
Particulate matter	±10 mg	0.001 mg	Chromatograph principle	0.20
Smoke meter	0-100 HSU	0.1 HSU	Opacimeter	0.10

pressure signal. The top dead center (TDC) pick up signal was recoded from TDC magnetic pickup marker used for time reference. The details of equipment and data acquisition system are shown in tab. 3. Figure 1 shows the schematic layout of experimental set-up.

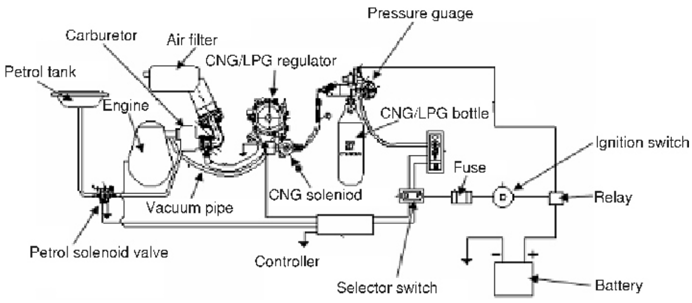


Figure 1. Schematic lay-out of engine with dual-fuel system

Results and discussion

With the above mentioned set-up variable speed performance tests were conducted on the engine with different fuels in the range of 1600-3600 rpm by coupling the engine to engine dynamometer. Ignition timing was mapped for each engine speed and load for better engine performance and fuel economy. To compensate for dual-fuel application, dual ignition timing curve was mapped to achieve better power, torque and over all performance, and also to meet the engineering target for mass emission test on chassis dynamometer. Variable ignition timing of 15° bTDC at low idling engine speed to 25° bTDC at rated engine speed was optimized for gasoline mode and 29° bTDC at rated speed was optimized for LPG and CNG mode as shown in fig. 2. Since the auto ignition temperature of CNG is on the higher side, its ignition timing was given utmost importance. With the different ignition timings torque and power trends were obtained as shown in figs. 3 and 4. It can be observed that both parameters are higher for 29° bTDC ignition advance timings at rated speed. Thus maximum brake torque (MBT) timings were obtained. Selection of re-

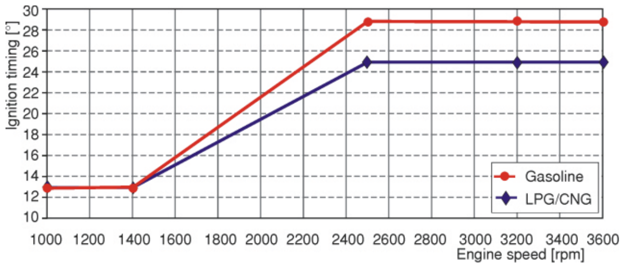


Figure 2. Variation of ignition timing with speed – MBT timing

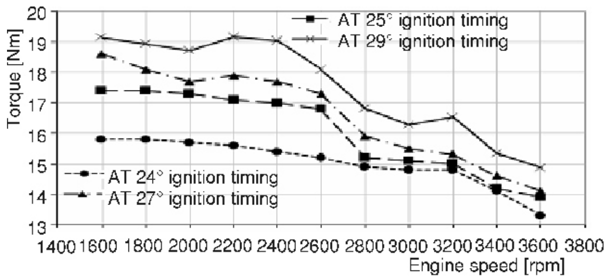


Figure 3. Variation of brake torque with speed for different ignition timings

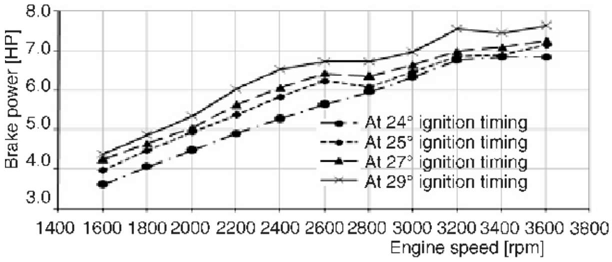


Figure 4. Variation of brake power speed for different ignition timings

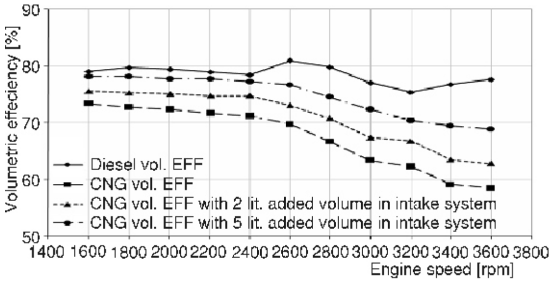


Figure 5. Variation of volumetric efficiency with speed

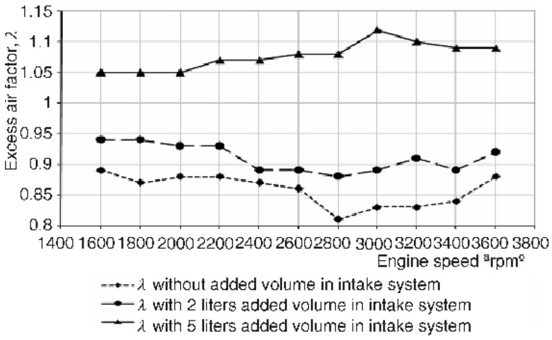


Figure 6. Variation of lambda with speed at different intake volume flows

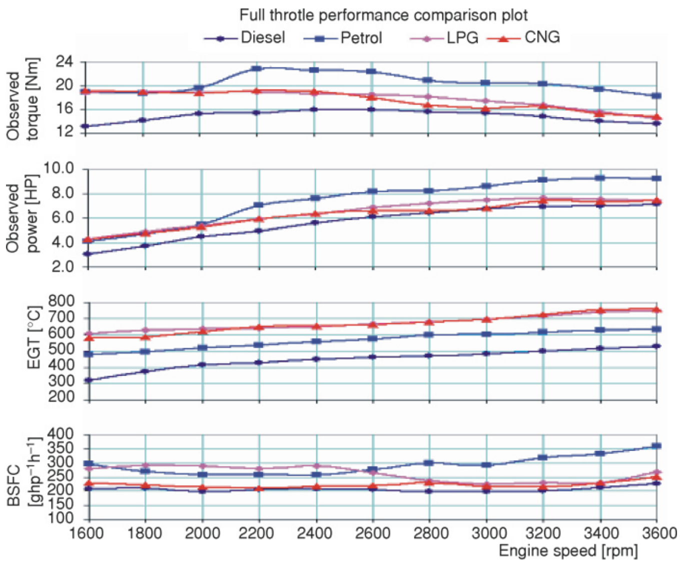


Figure 7. Variation of volumetric efficiency with speed

spective curve was sensed through change over switch from gas kit. Incidentally the exhaust gas recirkulation (EGT) and BSFC values were for the MBT timings.

Since natural gas has 1/3 of the volumetric energy density of gasoline and diesel and the CNG gas being lighter than air, earlier researchers have confirmed loss of volumetric efficiency [1, 4]. To compensate for the loss in volumetric efficiency with CNG operation, a pulsation resonator was adopted [12]. Figure 5 shows the trends of volumetric efficiency with different volume flows in intake system. The excess air factor (λ) was maintained between 1.05-1.1 through full load performance for obtaining near stoichiometric operation [16]. Resonator optimum volume of 5 liter could achieve nearly equivalent volumetric efficiency as that of diesel-fuel operation.

Experimental study was done on LPG and CNG system on engine. It was observed that the excess air factor, λ, setting plays an important role on engine performance. With increase in intake volume λ was merging towards unity to run engine on stoichiometric air fuel ratio. Trends of λ with different intake volume are show in fig. 6.

The variation of practical and observed parameters with speed is plotted in fig. 7 when engine was run under wide-open-throttle position. It can be seen that the torque values with petrol, LPG, and CNG fuels are on the higher side compared to pure diesel-fuel run operation.

The gaseous fuels exhibit lower specific density and to meet full-load condition (*i. e.*, wide-open-throttle condition), requires more fuel (rich mixtures). The operation of engine with rich mixtures results in development of more power. The reason for higher power could be due to higher calorific values of gasoline (CNG and LPG). Since the calorific value of diesel fuel is the lowest (among the chosen fuels) and hence developed lower power. In fig. 7, in addition to the torque values, the other engine performance parameters such as power, BSFC, and EGT values obtained are also compared. It can be observed that higher BSFC values are exhibited by gasoline, LPG and CNG fuel operation.

As the diesel-fuel engine was operated under leaner condition, it developed lower BSFC values. Moreover, since the LPG, CNG, and petrol-operated engines worked with rich mixtures, there could be possibility of incomplete combustion that resulted in higher exhaust gas temperatures, where as the temperatures are lower with diesel-fuel operation.

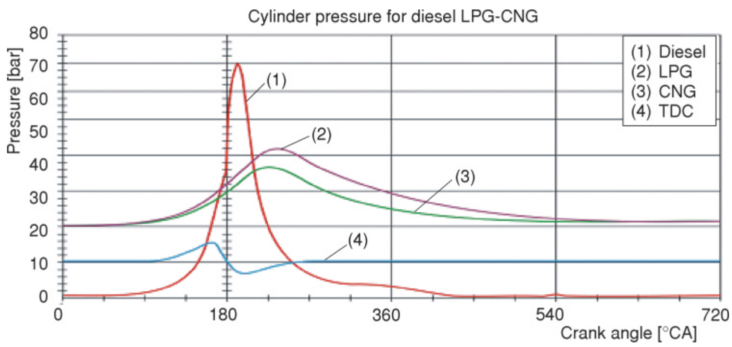


Figure 8. Combustion pressures at rated speed

The peak pressures were far lower with CNG operation and LPG being in between CNG and diesel fuel, as shown in fig. 8 . This can be attributed to the fact to the higher auto ignition temperature of CNG. Maximum combustion pressure in CNG was recorded at 17 crank degrees after TDC. It can also be seen that occurrence of peak pressure are delayed due to slow burning of gaseous fuels under consideration. Apart from engine dynamometer tests, the fuel flow was optimized on chassis dynamometer. Position of power screw was optimized in such a way that λ remains in a tolerance band close to unity at full throttle as well as part throttle condition.

Mass emission was recorded on chassis dynamometer as per legislative procedure laid by under Bharat stage – II (BS-II) emission norms. It is observed that substantial reduction in over all emissions. CO_2 emission with CNG was much lower as compared to diesel CO_2 emission as shown in fig. 9. This is due to lower carbon proportion as compared to diesel fuel. Also, the higher hydrogen-to-carbon ratio of natural gas compared to conventional diesel led to reduction of CO_2 emission compared to diesel-fuel run engines. Thus the operation of engine with CNG could be considered as eco-friendly operation.

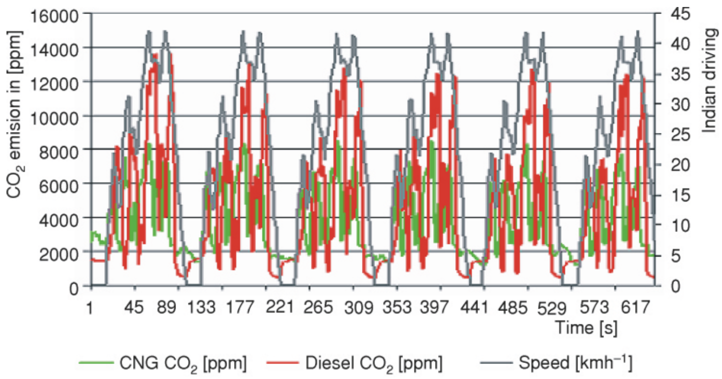
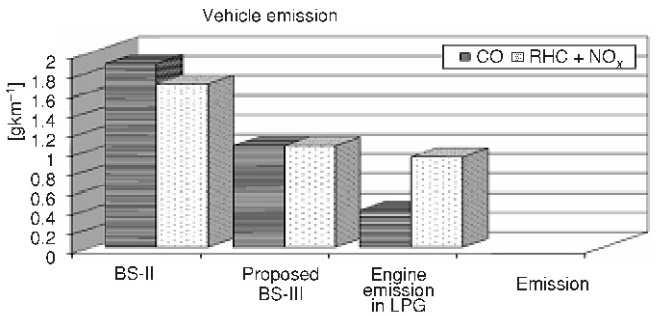


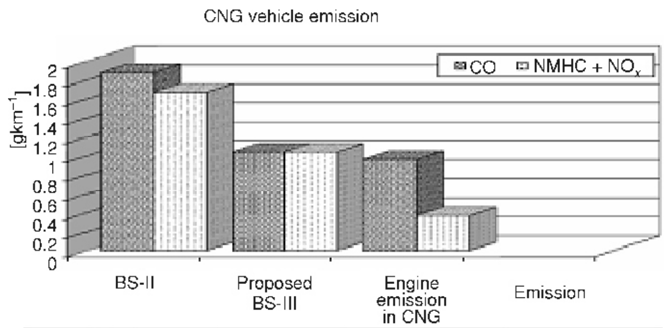
Figure 9. Comparison of CO_2 emission with diesel and CNG fuels (color image see on our web site)



Emission parameters	BS-II norms	Proposed BS-III norms	Engine emission in LPG
CO [gkm^{-1}]	1.88	1.04	0.380
RHC + NO$_x$ [gkm^{-1}]	1.67	1.04	0.926

Figure 10. Emissions with LPG as fuel in dual-fuel operation

In figs. 10 and 11, the emissions measured on chassis dynamometer are plotted. It can be observed that low CO emissions were observed with LPG where as HC + NO$_x$ emissions were lower with CNG fuel operation.



Emission parameters	BS-II norms	Proposed BS-III norms	Engine emission in CNG
CO [gkm^{-1}]	1.88	1.04	0.960
NMHC + NO$_x$ [gkm^{-1}]	1.67	1.04	0.368

Figure 11. Emissions with CNG as fuel in dual-fuel operation

Conclusions

Base diesel engine was converted into spark-ignition mode to employ gaseous fuels (LPG and CNG). Based on the experimental investigations the following conclusions are arrived at.

- Existing diesel engine was successfully converted into spark ignited engine with dual-multi mapped ignition timing.
- Advanced ignition timing is necessary for the use of LPG and CNG in the same engine.
- To realize more benefit from CNG operation, engine needs higher compression ratio.
- CO_2 emission is lower with CNG operation and thus can be a eco-friendly operation.

Modified engine could pass successfully proposed BS-III emission norms.
Wear resistant high grade material was needed for intake and exhaust valve and valve guide for dry gaseous fuel application to improve life of engine.
Low CO emissions are observed with LPG where as HC + NO_x emissions are lower with CNG fuel operation.

Acknowledgments

The authors would like to thank the management and the colleagues of R&D section of Greaves Cotton Limited, Aurangabad, India for providing overwhelming support for carrying out this work.

Acronyms

BS – Bharat stage
BSFC – brake specific fuel consumption
bTDC – before top dead center
CA – crank angle
CNG – compressed natural gas
EGR – exhaust gas recirculation
EGT – exhaust gas temperature
HSU – Hartridge smoke unit
IDC – indian driving cycle
LPG – liquid petroleum gas
MBT – maximum brake torque
NMHC – non-methane hydrocarbon
PM – particulate matter
RHC – reaction hydrocarbon
TDC – top dead center

References

[1] Heywood, J. B., Internal Combustion Engine Fundamentals, McGraw-Hill, New York, USA, 1988
[2] Bechtold, R. L., Alternative Fuels Guidebook (Properties, Storage, Dispensing, Vehicle Facility Modifications), SAE ISBN: 0-7680-0052-1, 2001
[3] Turns, S. R., Introduction to Combustion, McGraw-Hill International Edition, New York, USA, 2005
[4] Ahmad, N., Gajendra Babu, M. K., Ramesh, A., Experimental Investigation of Different Parameters Affecting the Performance of CNG-Diesel Dual-Fuel Engine, Transactions of Society of Automotive Engineers, SAE paper 2005-01-3767, 2005
[5] Aslam , M. U., *et al*., An Experimental Investigation of CNG as an Alternative Fuel for a Retrofitted Gasoline Vehicle, *Fuel, 85* (2006), 5-6, pp. 717-724
[6] Bysveen, M., Engine Characteristics of Emissions and Performance Using Mixtures of Natural Gas and Hydrogen, *Energy, 32* (2007), 4, pp. 482-489
[7] Lee, S., Oh, S., Choi, Y., Performance and Emission Characteristics of an SI Engine Operated with DME Blended LPG Fuel, *Fuel, 88* (2009), 6, pp. 1009-1015
[8] Saleh, H. E., Effect of Variation in LPG Composition on Emissions and Performance in a Dual- Fuel Diesel Engine, *Fuel, 87* (2008), 13-14, pp. 3031-3039
[9] Bayraktar, H., Durgun, O., Investigating the Effects of LPG on Spark Ignition Engine Combustion and Performance, *Energy Conversion and Management, 46* (2005), 13-14, pp. 2317-2333
[10] Nadar, K. N., Reddy, R. P., Combustion and Emission Characteristics of a Dual Fuel Engine Operated with Mahua Oil and Liquefied Petroleum Gas, *Thermal Science, 12* (2008), 1, pp. 115-123
[11] Nwafor, O. M. I., Effect of Advanced Injection Timing on Emission Characteristics of Diesel Engine Running on Natural Gas, *Renewable Energy, 32* (2007), 14, pp. 2361-2368
[12] Carlucci, A. P., *et al.*, Experimental Investigation and Combustion Analysis of a Direct Injection Dual-Fuel Diesel-Natural Gas Engine, *Energy, 33* (2008), 2, pp. 256-263
[13] Bosch, R., Gasoline Engine Management, 3rd ed., Bentley Publishers, Cambridge, Mass., USA, 2006
[14] Chun, K. J., *et al*., Study of Engine Valve and Seat Insert Wearing Depending on Speed Change, SAE paper 2004-01-1655, 2004

[15] Blair, G. P., Exhaust Tuning on a Four Stroke Engine, Experimental and Simulation. Small Engine Technology Conference, Transactions of Society of Automotive Engineers, SAE paper 2001-01-1797/4218
[16] Cho, H. M., He, B.-Q., Spark Ignition Natural Gas Engines, A Review, *Energy Conversion and Management, 48* (2007), 2, pp. 608-618

Paper submitted: April 23, 2009
Paper revised: August 5, 2009
Paper accepted: July 5, 2010