Effect of Compression Ratio and Spark Timing on Performance and Emission of Dedicated 4-Stroke S.I Engine Fuelled With LPG : A Technical Review

Ashish M. Ambaliya
P.G. Student, Mechanical Dept.
L.D.College of Engineering, Ahmedabad, India.

N. M. Chudasama
P.G. Student, Mechanical Dept.
L.D.College of Engineering, Ahmedabad, India.

Prof. M. A. Shaikh
Assi. Professor in Automobile Dept.
L.D.College of Engineering, Ahmedabad, India.

Abstract

The research on Alternative fuels have become very important for both SI and CI engine due to depletion of petroleum products and the rate at which earth atmosphere get polluted and also need to reduce dependency on petroleum and even socioeconomic aspect. A review is given of the contemporary research on LPG fuelled engine. We first describe LPG engine fundamentals by examining the properties of LPG fuel, suitability of LPG as an alternative fuel. Due to higher octane number of LPG, it can be run at higher compression ratio than petrol engine. The HC and CO found to be less for LPG as compared to conventional fuel for SI engine. The present study is a review of LPG as an alternative fuel for SI engine and its effect on performance and emissions. The factor like compression ratio and ignition timing that affect on efficiency and emission was considered for study. We show that performance will improved and lower the emission by varying Compression Ratio & Spark Timing. Finally we select to optimizing C.R and Spark Timing for enhancement of performance of dedicated engine fuelled with LPG.

Keyword—Compression Ratio, Spark timing, Liquefied Petroleum Gas (LPG), Performance Characteristics and Emission.

1. Introduction

Air pollution is fast becoming a serious urban as well as global problem with the increasing population and its subsequent demands. Finding an alternative to conventional fuels would help to reduced it. Vehicles running on cleaner fuels produce fewer harmful emissions, and can offer some savings on fuel costs, compared with petrol or diesel. In addition to cleaner, low sulphur versions of the conventional vehicle fuels petrol and diesel, the main alternatives are currently road fuel gases LPG, CNG, bio-fuels, hydrogen fuels, methanol; fuel cells, and electric vehicles [1]. Among clean fuels such as LPG, CNG, LNG, DME (dimethyl-ether), LPG is one of the best candidates for an alternative fuel because it can be liquefied in a low pressure range of 0.7–0.8 MPa at atmospheric temperature, and it has a sufficient supply infrastructure. LPG fuel also has a higher heating value (46500 KJ/Kg.) compared with other fuels [2].

LPG is typically a mixture of several gases in varying proportions. Major constituent gases are propane (C_3H_8) and butane (C_4H_{10}), with minor quantities of propene (C_3H_6), various butanes (C_4H_8), iso-butane, and small amounts of ethane (C_2H_6). Table-1 shows the typical composition of LPG. Physically it's a gas at room temperature but can be compresses into a liquid at reasonable temperatures under pressure (approx. 800 Kpa or 120 psi) [17]. LPG is colourless, tasteless, and odourless. But it is also very volatile, heavier than air and flammable. The composition of commercial LPG is quite variable. Being a gas at normal temperature and pressure LPG mixes readily with air in any proportion [3]. Since the major components of LPG are propane and butane. The LPG engine can operate under a high compression ratio due to its high octane number (112) compare to gasoline (88-100). Thus, it has a greater thermal efficiency than a gasoline engine owing to its higher octane number. Furthermore, LPG has a good potential for the lean burn condition because of its wide inflammable range [2].

Table-1 Typical Composition of LPG [17, 19]

Propane	85% min. by liquid volume
Propylene	5% max. by liquid volume
Butane and heavier HC	2.5% max. by liquid volume
Sulphur	120 ppm max. by weight

The potential benefits of using LPG in diesel engines are on economical and environmental side The LPG is an alternative for diesel engine with real future opportunities due to the following aspects: the NOx emission level is lower; the PM emission is indistinguishable; CO2 emission is maintained to the same level; the engine power is the same or can increases; the automotive autonomy increases; the HC and CO emissions level decreases; LPG protects the particles filter and environment because doesn't contains sulphur.

Table-2 All India Auto LPG Dispensing Stations [20].

Sr. No.	State	No. of Station
1	Andhra Pradesh	106
2	Assam	04
3	Chandigarh	05
4	Chhattisgarh	08
5	Dadra & Nagar Haveli	01
6	Delhi	20
7	Goa	04
8	Gujarat	124
9	Haryana	02
10	Jammu & Kashmir	02
11	Jharkhand	04
12	Karnataka	150
13	Kerala	107
14	Madhya Pradesh	34
15	Maharashtra	173
16	Odisha	03
17	Pondicherry	04
18	Punjab	14
19	Rajasthan	50
20	Tamil Nadu	130
21	Uttar Pradesh	39
22	Uttarakhand	09
23	West Bengal	39

The infrastructure for LPG distribution already exists worldwide. In order to reduce the pollutants emissions level and to increase thermal efficiency which is directly related with CO2 emission level is advantageous to use LPG in diesel engine [4].

Today Auto LPG is available in more than 500 cities with a network of close to1100 stations as shown in Table-2. [20] Which makes it the most widely available alternative fuel. This has encouraged an increasing number of vehicle owners to convert to Auto LPG, an economical & environment friendly fuel – paving way for India to become one of the leading Auto LPG markets of the world in the next few years. Low costs of infrastructure and conversion, easy availability, versatility of use and of course, an impeccable safety record makes Auto LPG a viable, unadulterable, environment friendly alternative auto fuel in India. [20]

2. LPG as an Alternative Fuel for IC Engine

The gaseous nature of the fuel-air mixture in an LPG vehicle's combustion chambers eliminates the cold-start problems associated with liquid fuels. LPG defuses in air fuel mixing at lower inlet temperature than is possible with either gasoline or diesel. This leads to easier starting, more reliable idling, smoother acceleration and more complete and efficient burning with less unburned hydrocarbons present in the exhaust. In contrast to gasoline engines, which produce high emission levels while running cold, LPG engine emissions remain similar whether the engine is cold or hot. Also, because LPG enters in engine combustion chambers as a vapour, it does not strip oil from cylinder walls or dilute the oil when the engine is cold. This helps to have a longer service life and reduced maintenance costs of engine. Also helping in this regard is the fuel's high hydrogen-to-carbon ratio (C3H8), which enables propane-powered vehicles to have less carbon build-up than gasoline and diesel powered vehicles. LPG delivers roughly the same power, acceleration, and cruising speed characteristics as gasoline.

Its high octane rating means engine's power output and fuel efficiency can be increased beyond what would be possible with a gasoline engine without causing destructive knocking. Such fine-tuning can help compensate for the fuel's lower energy density. The higher ignition temperature of gas compared with petroleum based fuel leads to reduced auto ignition delays, less hazardous than any other petroleum based fuel and expected to produce less CO, NOx emissions and may cause less ozone formation than gasoline and diesel engines [1].

Table-3 LPG Properties Compared to Gasoline and Diesel Fuel [5-8, 18].

Fuel Property	LPG	Gasoline	Diesel
Formula	C_3H_8/C_4H_{10}	C4 to C12	C8 to C25
Density (kg/L,15ºC)	0.50	0.69-0.79	0.81-0.89
Specif gravity (15ºC)	0.5	0.69-0.79	0.81-0.89
Freezing point, ºC	-187	-40	-40 to -1
Boiling point, ºC	-42	27-225	188-343
Vapor pressure, kPa (38ºC)	1303	48-103	<1
Specific heat, kJ/kg-K	2.48	2.0	1.8
Viscosity, Ns/m (20ºC)	0.102	0.37-0.44	2.6-4.1
Latent Heat of Vaporization, kJ/kg	426	349	233
Lower Heating Value, kJ/kg	46500	43500	42600
Flash point, ºC	-104	-43	74
Autoignition Temperature, ºC	457	257	316
Stoichiometric Air-Fuel Ratio, Weight	15.7	14.7	15
Upper Flammability limit in air (% vol.)	74.5 (P)	7.6	-
Lower Flammability limit in air (% vol.)	4.1 (P)	1.3	-
Octane number Research Motor	112 97	88-100 80-90	- -
Cetane number	-	-	40-55

3. LPG Engine Fundamentals

LPG can be produced from natural gas and crude oil. Although this fuel mainly consists of propane and butane, it may also include different hydrocarbons such as propene, iso-butane and n-butane in various proportions. High auto ignition temperature of LPG (457ºC) means, LPG is more suitable as a fuel for spark ignition (SI) engine. It is also suitable for C.I engine with some modification due to its high compression ratio.

3.1 Use of LPG in IC Engines

Petrol and diesel vehicle can be converted to operate on LPG with special kit fitment. Vehicles with catalytic convertors can also be fitted with LPG kit without any difficulty as LPG does not contain lead. Petrol engine can be run on LPG as a bi-fuel or dedicated LPG engine by modification. Diesel Engines can be converted on LPG, either by installing dual fuel kit or converting the existing CI engine into spark ignition engine. In the second type of diesel conversion existing diesel engine will become dedicated LPG engine.

3.1.1 Bi-Fuel Vehicles

A bi-fuel vehicle can run on LPG or petrol. With a flip of a switch mounted on a dashboard one can change from LPG to petrol mode and vice-versa. Many are designed to switch automatically to petrol when the LPG fuel tank reaches empty or when rpm of the engine reaches to ascertain value. It has problems with low power output and combustion instability under lean-burn condition. [9]

3.1.2 Dual-Fuel Vehicles

A vehicle that run either on diesel fuel only or diesel fuel and LPG simultaneously. In a dual-fuel vehicle the combustion of the diesel fuel serves to ignite the LPG. The mixture of LPG and air is drawn inside the engine cylinder by conventional manner and a jet of diesel is then sprayed inside the engine cylinder to initiate the ignition of the fuel. It needs Two Fuel Supply System and still has problem with high HC emissions.

3.1.3Dedicated Vehicles

A dedicated LPG vehicle runs on LPG only. Dedicated LPG vehicles can be petrol-fuelled or diesel fuelled vehicles that have been converted to run on LPG by adapting LPG kits on them with necessary modification. The converted engine typically operates on bi-fuel mode by modifying cylinder head, piston assembly, flywheel, compression ratio and fuel injection systems. The ignition timing as well as valve overlap is altered suitable for LPG operation. The spark timing is another key factor for optimization of the SI engine in LPG as the flame speed of LPG is lower than gasoline and diesel fuel, which affects the combustion efficiency and power performance. Most dedicated LPG vehicles in India, however, are produced by conversion of SI engines into after-market retrofit conversion kits. [9]

3.2 LPG Combustion and Emission

3.2.1 Combustion

An LPG fuelled SI engine has lower level of NOx emission than gasoline, NOx emission from stoichiometric operation are very high. In addition, high exhaust temperature at stoichiometry causes a durability problem and lower thermal efficiency for LPG fuelled SI engine. Therefore, lean burn strategy has been proposed to reduce NOx emission and improve thermal efficiency. However, lean burn strategy, especially for an LPG SI engine, has some drawbacks. It has been reported that burning rate of fuel lean mixture is significantly lower than that of stoichiometric mixture. This lead to increase in the overall combustion duration, which in turn leads to increase the heat transfer loss to the cylinder wall and a decrease in the overall system thermal efficiency in the long run. A number of design factors such as spark plug location, intake port configuration, cavity shape and combustion chamber shape influence the burning rate due to turbulent mixture motion. As ignition timing advanced, lean misfire limit decreased due to enhancement in engine combustion efficiency. As the inlet air temperature increase the lean misfire limit decreases. As the fuel-air equivalence ratio is leaned, the ignition timing need to be advanced to provide more time for reaction due to the excess presence of oxygen in the fuel-air mixture. [10]

3.2.2 Emission

LPG shares several emission advantages with natural gas. Like natural gas, LPG vehicle do not have any evaporative or running loss emission associated with the fuel. Unburned hydrocarbons from LPG are easier to oxidize in oxidation catalysts than methane, which result in low unburned hydrocarbon emissions. Being a gas, LPG mixes very well with the air before entering the engine, resulting in low carbon monoxide emissions, assuming that the fuel does not allow an overall rich mixture

A brief comparison of vehicular emission of auto LPG with Petrol and Diesel is as follows:

Table-4 LPG Emission as Compare to Petrol and Diesel. [10]

Compared to Petrol	Compared to Diesel
Up to 15% less CO_2	10% less CO_2 emissions of hydrocarbon
Up to 50% less particulates	90% less particulates
Up to 60% less CO	75% less carbon monoxide,
Up to 33% less NO	90% less oxides of Nitrogen
Virtually zero evaporative	85% less Hydrocarbons
Up to 80% less air toxic	87% less ozone forming potential

4. Effect of Compression Ration and Spark Timing on LPG Engine

Varying compression ratio and Spark timing that affect the performance and emission of engine is as under:

O.Badr et al [3]. They carried out parametric study on the lean operational limits of a Ricardo E6 engine using propane and liquefied petroleum gas (LPG) as fuels. The effects of speed, spark timing, compression ratio, intake temperature, intake pressure (supercharging), and relative humidity of intake air on the engine operational limits. They observed, decrease in the lean limit with the increase in the spark timing is attributed to the fact that the first misfire limit is basically a partial burn limit and thus, the increased spark advance allows more time for flame propagation and complete combustion. As the compression ratio was increased, the misfiring limit of LPG-air mixtures showed some decrease while those of propane-air mixtures changed only a little. Lean knocking limit, on the other hand, decreased sharply with the increase in compression ratio.

S.M.Lawankar et al [11]. In present work brake thermal efficiency of LPG fuelled engine is compared with that of gasoline at different compression ratio and ignition timing. The engine used in the study was a single cylinder, water cooled ,four-stroke, naturally aspirated diesel engine converted to operate as spark ignition mode with a maximum rated power output of 2 kW at 1500 rev/min. and provision was made to conduct the experiment at different compression ratio , different fuels (LPG and Gasoline) and at ignition timing. Conclusion of this study was, the maximum brake efficiency for LPG fuelled engine was found to be increased by 24.31% from 9 to 10 compression ratio, increased by 5.63% from 10 to 11and increased by 4.04% from 11 to 12 compression ratio at ignition timing 30º BTDC.

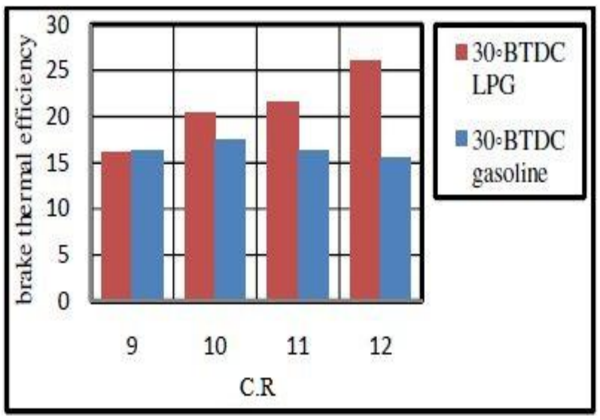

Figure-1 Comparison of Maximum Brake Thermal Efficiency [11].

Thirumal mamidi et al. [12] In this study, Experimental investigations have been carried out to performance and emissions of single cylinder four-stroke spark ignition engine at full throttling position of engine and different load conditions is used to different fuels (Gasoline and LPG) at various compression ratios (4.67:1,5.49:1). Conclusion arise from experimental study are, as compression ratio increases, brake thermal efficiency increases. LPG has a higher octane rating and hence the engine can run effectively at relatively high compression ratios without knock. The CO and HC emissions increase as the compression ratio, speed, and load increase. In the case of using LPG in SI engines, the burning rate of fuel is increased, and thus, the combustion duration is decreased. Therefore, the cylinder pressures and temperatures Predicted for LPG is higher compared to gasoline.

B.L.N.Oliveira et al [13]. They analyze the performance of a diesel engine converted into an Otto cycle engine and the tests were conducted on a Perkins diesel engine 1104C - 44TAG turbocharged, whose compression ratio was reduced to 9.33:1. Based on the analyzed data it is possible to reach the following conclusions:

(1) There is a consistent connection between the spark advance angle of the converted engine and its fuel consumption: the larger the angle, the smaller the consumption.

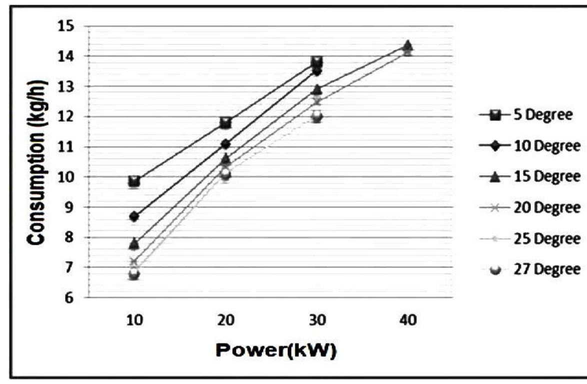

Figure-2 Effect of Spark Advance in Fuel Consumption [13].

(2) Increasing the spark advance contributes to enlarge the production of NOx and then to decrease the temperature of the exhaust gas. Therefore, the use of catalysts may be required in some cases.

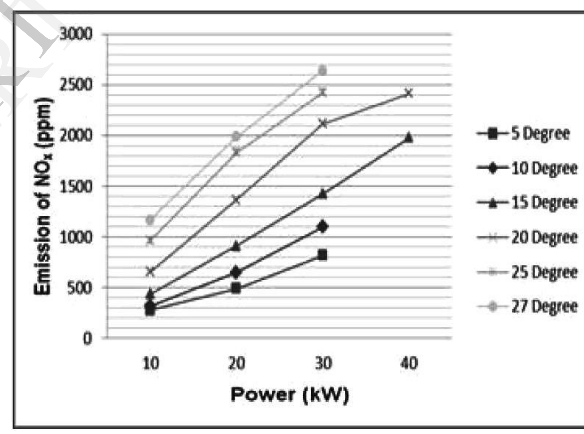

Figure-3 Effect of Spark Advance in NOx Emission[13].

(3) Adjusting the spark advance angle allows minimizing the fuel consumption

J.V.Hirani et al [14]. Study on experimental investigation had been conducted to perform the optimization studies on the dual fuel engine using LPG as primary fuel and HOME as pilot fuel on a DI Diesel Engine. : Effect of Injection Timing suggest that with the advancement from 19^0 BTDC to 27ºBTDC the brake thermal efficiency increased and smoke opacity, HC and CO emissions decreased. On the other hand NOx emission increased and is found to be maximum at 27ºBTDC. NOx can be controlled using EGR technique. Effect of Compression Ratio shows that with the increasing compression ratio from 15 to 17.5 the brake thermal efficiency increased for both 80% and 100% loads. The smoke opacity, HC and CO emissions decreased. On the other hand the NOx emissions increase. The optimum compression ratios are found to be 17.5.

LPG biodiesels fuelled dual fuel operation in both induction and injection modes resulted in poor performance compared to diesel operation. However, LPG injected dual fuel operation resulted in improved overall performance compared LPG inducted operation. It can be stated that port injection, as a methane supply method for dual fuel engines, is a very effective method to reduce unburned hydrocarbons and nitric oxides emissions. Shifting from homogeneous to port injection method, HC levels tend to decrease while NOx increase.

5. Conclusion

- The cost of LPG is less than that of gasoline and Diesel in market. Uses of LPG as fuel in engine give best performance and lower emission. So LPG is economical and environment Friendly, it will be best alternative fuel for IC engine and LPG is suitable alternative for SI engine.
- The maximum brake efficiency was found to be increased as compression ratio increased as compared to gasoline engine, while LPG was used in SI engine.
- With the different ignition timings torque and power trends were obtained and both parameters are higher for 29ºBTDT ignition advance timing. Also, as 35ºBTDC spark timing was advanced, both lean knocking and misfiring limits were reduce.
- Existing CI diesel engine (Agriculture, Small scale power plant, light duty vehicle.) can be converted to SI LPG engine by modification of Compression ratio and advancing the Spark timing.

All experimental investigation shows that modification of 4-stroke C.I Diesel engine to S.I LPG engine helps to improve performance and reduce emission level from the exhaust. So, optimizing of compression ratio and spark timing accommodate LPG as an alternative fuel gives better performance, lower emission level and improve power output.

Acknowledgment

The authors would like to thank H.O.D and teaching staff of mechanical and automobile engineering department for providing their valuable guidance and overwhelming support to carrying out this work.

6. References

[1] Albela H.Pundkar, S.M. Lawankar, Dr. Sameer Deshmukh, “Performance and Emissions of LPG Fuelled Internal Combustion Engine: A Review”, International Journal of Scientific & Engineering Research Volume 3, Issue 3, March -2012.

[2] Kihyung Leea, Jeaduk Ryub, “An experimental study of the flame propagation and combustion characteristics of LPG fuel”, Fuel 84, 1116–1127, 2005.

[3] O. Badr, N. Alsayed and M. Manaf, “A Parametric Study on The Lean Misfiring and Knocking Limits of Gas-Fuelled Spark Ignition Engines”, Applied Thermal Engineering Vol. 18, No. 7, pp. 579-594, 1998.

[4] Constantin Pana, Niculae Negurescu, Marcel Ginu Popa And Alexandru Cernat, “Experimental Aspects of The Use of LPG at Diesel Engine.”, U.P.B. Sci. Bull., Series D, Vol. 72, iss.1, 2010.

[5] Bechtold, R.L., “Alternative Fuels Guide Book”, SAE Inc., PA, U.S.A., 1997.

[6] T. Korakianitis, A.M. Namasivayam, R.J. Crookes, “Natural-gas fuelled spark-ignition (SI) and compression-ignition (CI) engine performance and emissions”, Progress in Energy and Combustion Science 37, 89-112, 2011.

[7] Mohamed Y.E. Selim, M.S.Radwan, H.E.Saleh, “Improving the performance of dual fuel engines running on natural gas/LPG by using pilot derived from jojoba seeds”, Renewable Energy 33, 1173-1185, 2008.

[8] Syed Kaleemuddin and Gaddale Amba Prasad Rao, “Conversion of Diesel Engine into Spark Ignition Engine to Work With CNG and LPG Fuels for Meeting new Emission Norms”, THERMAL SCIENCE: Vol. 14, No. 4, pp. 913-922., Year 2010.

[9] D.M.Dave, Assi.Prof. M.A.Shaikh, “Effect of Ignition Parameters for Enhancement of Performance and Emission of a Four Stroke Single Cylinder SI

Engine Fuelled with CNG: A Technical Review", international journal of Engineering Research & Technology, Vol. 2 Issue 4, April- 2013.

[10] "Alternative Fuels", Concept, Technology and Development. By S.S. Thipse, jaico publication house, Chapter-1, 7.

[11] S.M.Lawankar and L.P.Dhamande, "Comparative Study of Performance of LPG Fuelled Si Engine at Different Compression Ratio and Ignition Timing", International Journal of Mechanical Engineering and Technology (IJMET), Volume 3, Issue 3, pp. 337-343, September – December-2012.

[12] Thirumal mamidi and Dr. J.G. Suryawnshi, "Investigations on S.I. Engine Using Liquefied Petroleum Gas (LPG) As an Alternative Fuel", International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 1, pp. 362-367, Jan-Feb 2012.

[13] B. L. N. Oliveira, E. F. Jaguaribe, A. F.Bezerra, A. S. Rumão, and B. L. C. Queiroga, "A Diesel Engine Converted Into Otto Cycle Engine: The Influence of The Spark Advance on Its Performance And on NOx Emissions", CP. 58059-900, J. Pessoa, Paraíba, Brasil, 2013.

[14] J.V. Hirani and S.R. Kulkarni et.al "Effect of Injection Timing and Compression Ratio on the Performance of LPG-Home Biodiesel Dual Fuel Engine", International Journal of Emerging Technology and Advanced Engineering, Volume 3, Special Issue: ICERTSD 2013, Feb 2013.

[15] Sulaiman M. Y., Ayob M. R and Meran I, "Performance of Single Cylinder Spark Ignition Engine Fuelled by LPG", Malaysian Technical Universities Conference on Engineering & Technology 2012.

[16] Heywood, J.B., "Internal Combustion Engine Fundamentals" ,McGraw-Hill, Singapore, 1998.

[17] Dr. Md. Ehsan, S.M. Zahidur Rahman, K Mashrur Javed, M Mustofa Mahboob, "Performance of a LPG Run SI Engine for Small Scale Power Generation", 4th International Conference on Mechanical Engineering, Dhaka, Bangladesh/pp. III 97-102, December 26-28, 2001.

[18] S M Lawankar & L P Dhamade, "A Review on Performance and Emissions Characteristic of LPG Fuelled SI Engine.", International Journal of Mechanical Engineering (IJME) ISSN: 2319-2240, Vol.2, Issue 1 Feb, 2013.

[19] Dr. Md. Ehsan1, S.M. Zahidur Rahman, K Mashrur Javed, M Mustofa Mahboob, "Performance of a LPG Run SI Engine for Small Scale Power Generation", 4th International Conference on Mechanical Engineering, Dhaka, Bangladesh/pp. III 97-102, December 26-28, 2001.

[20] All India Auto LPG Dispensing Station (ALDS) Directory-2013, "http://www.iac.org.in/ALDS-complete.pdf"