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A Review on Use of LPG in IC Engines as an Alternate Fuel

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ABSTRACT: Oil, gas, power, even water has very limited availability and with each passing day, they are moving towards being extinct. The steady increase in energy consumption along with environmental pollution has promoted various research activities in alternative and renewable energy. The liquefied petroleum gas (LPG) is the most attractive alternative fuel to conventional fuel for both CI and SI engines. The physicochemical properties of LPG make it promising fuel for IC engine. The LPG can be used as a direct substitute or in combination with standard fuel with minor modifications in the existing engine. Further, the emissions from LPG are much lesser than that of gasoline and diesel fuel. These articles reviews are about the research work done by the past researchers on CI and SI engines fuelled with LPG to improve the performance, emission and combustion characteristics of LPG fuelled engine under various operating conditions.

KEYWORDS: LPG, Dual Fuel, CI Engine, SI Engine, Performance Characteristics, Emission, Noise, Vibrations.

I. INTRODUCTION

In recent times the consumption of petroleum products has increased immensely due to the increased use of the automobile, rapid rate of industrial and technological revolutions throughout the world. Petrol and diesel are commonly used fuels in an automobile. Petrol and diesel are derived from crude oil, the cost of petrol & diesel is continually increasing. Moreover, the limited reserves are moving towards being extinct, thus a continuous increase in demand for conventional fuel, the fuel scarcity will become very grave. A further, automotive emission has become one of the most important concerns all over the world because of its impact on the environment. The environmental concerns and the diversification of energy sources arises the need for alternative fuel for automotive application [6]. The alternative fuel can be classified as synthetic fuels, alcohols and gaseous fuels. Among the various alternative fuels, the gaseous fuels are more promising because of their inherent characteristics like high octane number, lower exhaust emissions, higher calorific value and economically viable [2].

II. INTRODUCTION TO LPG

Among the various clean gaseous fuel available such as LPG, CNG, DME (Dimethyl-ether), Ethanol, LPG is one of the promising alternative fuel. LPG is produced as a by-product in numerous petroleum refining processes and its quality is relatively close to the engine fuel requirements. LPG fuel mainly consists of propane and butane, it may also include different hydrocarbons like propene, isobutane and n-butane in various proportions as shown in Table 1 [2, 4]. LPG is a useful alternative fuel because of its unique properties. LPG also be used under the high compression ratio because it has a higher octane value. In general, LPG can be liquefied at a low-pressure range of 0.7–0.8 MPa at atmospheric temperature. LPG has a lower density and stoichiometric fuel-air ratio than petrol & diesel, and thus, it could reduce the specific fuel consumption. If an LPG fuelled engine operates at the same stoichiometric ratio that of petrol & diesel fuelled engine, higher effective power could be expected due to the higher calorific value of LPG [2]. Combustion of LPG results in lower emissions of regulated pollutants and greenhouse gases. Also, the LPG has a higher ignition temperature than gasoline, which delays the auto-ignition of the fuel and hence prevents knocking [8].



S. No.	Components	% mol.	% wt.
1	n-butane	52.77	59.47
2	Propane	45.93	39.26
3	Isobutane	0.77	0.87
4	Ethane	0.34	0.20
5	Isobutene	0.19	0.21

III. PREVIOUS RESEARCH DONE ON IC ENGINE

Carlos Alberto Romero, Ricardo Acosta and Juan Fernando Lopez Lopez [1] focused on performance parameters related to engine power such as power output, emissions, efficiency, and noise levels when fuelled with LPG. Seven generators were tested, ranging from 100 to 1300 kW, coupled to a resistive load bank and instrumented for low-speed data and emissions. Out of seven two dual-fuel generator sets were tested, which were fitted with aftermarket conversion units and are running on LPG and Diesel, without any observable derating. The conclusion drawn from the study is that LPG is a viable alternative fuel for the Diesel engines. However, if dual fuel mode is not calibrated properly it leads to increased CO emissions. It was demonstrated that diesel engines can operate in a bi-fuel mode with LPG at replacement rates around 40%. However, if dual fuel mode is not calibrated properly it leads to increased CO emissions.

Bayraktar Hakan and Durgun Orhan [2] developed the governing equations of the mathematical model for cylinder pressure and temperature. These equations were first-order differential equations. Computer code was developed to perform numerical calculations over a wide range of engine speeds and air-fuel equivalence ratios. The simulation was performed in the quasi-dimensional SI engine to predict the cycle, performance and exhaust emissions of an automotive engine for gasoline and LPG. The comparative study of simulation results showed that LPG fuelled SI engines shows significant improvement in exhaust emission characteristics. The researcher also suggested to improve the engine cooling performance and structural elements should be produced from that material which has better resistance to high pressure and temperature.

Masi Massimo [3] carried out a comparative study on brake performance of four-stroke five-cylinder inline SI engine fuelled with LPG and petrol. The engine was converted to dual fuel mode of operation by standard third-generation kit. It was a sequential multi-point port fuel electronic injection system which delivers the gaseous LPG into the intake manifolds before the petrol injectors. The engine was coupled to a Borghi-Saveri mod.FE-260S eddy current electromagnetic dynamometer. The result indicated that at the same testing condition the brake power of the engine was more in petrol mode, the performance of LPG operation was degraded because of insufficient supply of LPG into the combustion chamber.

Mamidi Thirumal and Dr. Suryawnsi J.G. [4] carried out a test on a single-cylinder four-stroke spark ignition engine at full throttle position and at different load conditions. The compression ratios in gasoline and LPG mode were 4.67:1 and 5.49:1 respectively. In the LPG mode, the brake thermal efficiency of the SI engine increases as the compression ratio was increased. The burning rate of fuel was increased, resulting in a decrease in combustion duration in LPG mode. However, the CO and HC emissions were increased during increased compression ratio but these were lower than that of gasoline.

Patil Nivrutti Pundlik et al. [5] carried out a comparative study on frictional power losses, brake power and other performance parameters of SI engine fuelled by petrol and LPG under various engine operating conditions. The schematic of the modified SI engine for LPG operation is shown below in Figure 1. The study concluded that by using LPG in SI engine the power output and volumetric efficiency were decreased but increased the brake thermal efficiency. Further, the brake thermal efficiency and indicated thermal efficiency was found to be higher for different speed because of lean burning nature of the LPG.

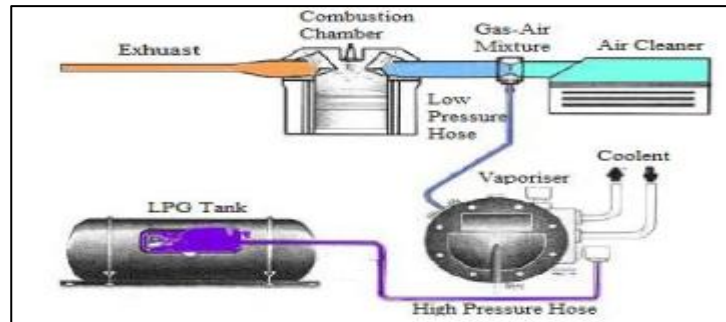


Fig. 1: Schematic of Modified SI Engine for LPG Operation

Mistry S. Chetan S. and Gandhi H. Anish [6] modified naturally aspirated, multi-cylinder, vertical, liquid-cooled petrol engine (Marutimake) to work on dual fuel mode with LPG and petrol as fuels. Morse test was carried out on engine under variable load condition and variable speed condition. From the result of the Morse test, it was found that the friction power was less in the case of petrol as compared to LPG. While the brake thermal efficiency and indicated thermal efficiency were found to be higher for petrol as compared to LPG. Furthermore, it was also observed that the spark timing needed to be advanced in order to compensate for low flame velocity in case of LPG.

Luft Slawomir and Michalczewski Andrzej [7] presented a study on the combustion process and the probability of knocking in dual fuel CI engine for LPG as main fuel while diesel as pilot fuel only to initiate combustion. The test was performed at a compression ratio of 16:1. The schematic of the LPG Fuelled CI engine is shown below in Figure 1. The study revealed that the volume of ignition diesel oil dose and injection timing strongly influences overall efficiency, maximum engine torque and emissions and value of combustion process parameters. The optimal regulation of dual fuel engine was found at 20° before top dead centre (BTDC). At optimal parameters, the combustion process in dual fuel mode gives the lower maximum pressure and the average rate of pressure rise without any misfiring and knocking in comparison with standard fuel.

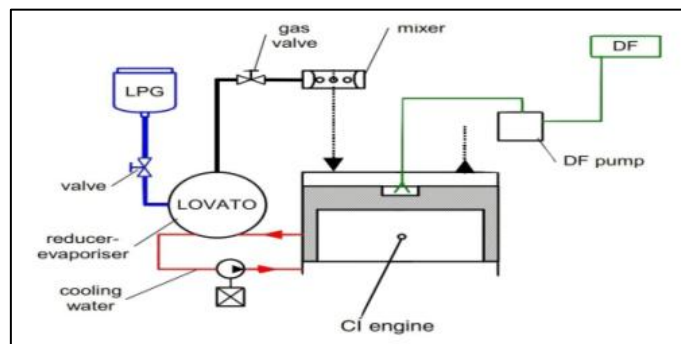


Fig.1. Schematic of the LPG Fuelled CI Engine [7].

Bisen B. Hitesh and Suple Y.R. [8] carried out an emission study on modified, dual fuel (LPG and petrol) Bajaj Saffier, single cylinder four-stroke SI engine coupled to a rope brake dynamometer. Supply of the petrol in the combustion chamber was done using a carburettor and the direct injection of LPG was done through an injector. The test was conducted at engine speeds of 300, 400, 500 and 600 rpm respectively. The measurement of CO, CO₂, NO_x, O₂ and HC emissions was done using advanced five gas analyser. At the same operating condition, the CO, CO₂, O₂ and HC emissions were less in LPG as compared to that of petrol. While NO_x emission were increased significantly in the case of LPG than petrol.

Dr. Ehsan Md. et al. [9] carried out research work on KUBOTA generator-engine single cylinder, 200 CC, four-stroke, air-cooled SI engine directly coupled with a generator rated at 1.5 kW, 220 V, 50 Hz electricity. The minor modifications were made to the engine to use LPG as fuel. The load on the engine was applied in the form of resistive load. The results showed that at the same loading condition the fuel consumption was higher in case of petrol than LPG. At zero load condition petrol flow was 0.52 kg/h and in full load was about 1 kg/h. While in case of LPG for 0 to 400 Watt the fuel consumption was 0.55 kg/h to 0.62 kg/h. At maximum load condition, the LPG fuel consumption was found out to be 0.78 kg/h.

Kale B. Tushar et al. [10] shows work on installing the LPG kit on the two-wheeler (Scooty Pep +) and running it with LPG. The LPG kit of 2 kg of volume, multivalve with five ports such as filler inlet port, an outlet port, and three operating ports for regularization of the feeling of gas and to pass the gas to the inlet suction of vaporizer was installed. The study suggested that two-wheelers can be successfully run on LPG with the installation of safety devices.

Kumaraswamy A. and Prasad Durga B. [11] ran the diesel engine on dual fuel mode operation LPG and diesel in CI engine. In order to run the engine on dual fuel mode, the LPG carburettor is incorporated on the air intake side of the engine. The fuel injection system is also altered so that it injects only pilot fuel. The contactless speed sensor along with the microcontroller unit is positioned under the flywheel of the engine. When the engine reaches the speed of 1000 rpm, the microcontroller will switch on the relay, which is connected with the solenoid valve of the LPG line. The solenoid valve opens which causes the flow of LPG gas into the air intake of the diesel engine. The result of the test showed that the brake power of the engine was found to be about 15% more on the dual-fuel operation, while the brake specific fuel consumption was found to be about 30% lower than diesel fuel mode of operation.

Rosha Pali et al. [12] evaluated the effect of EGR on performance and emission characteristics of diesel + LPG dual-fuel engine at six different load conditions (0%, 20%, 40%, 60%, 80% and 100%) at constant speed. The engine used in the experimentation was a single cylinder, air cooled with a rated power output of 3.7 kW DI diesel engine. The engine was modified for dual fuel supply. The hot EGR system was installed between the exhaust and intake pipe. The experimental test deduced that at full load the fuel consumption decreased by 8.75% and brake specific fuel consumption and brake thermal efficiency improved by 29% and 28.9% respectively in diesel + LPG + EGR. Further the NO_x , CO_2 emissions as compared to conventional diesel fuel alone.

Ceviz M.A. and Yüksel F. [13] compared the cyclic variability and emission characteristics of LPG and petrol fuelled SI engine at lean operating conditions. The experiment was carried out at four air-fuel mixtures 1.001, 1.090, 1.195 and 1.299 for gasoline and at five mixture values of 1.000, 1.092, 1.212, 1.293 and 1.410 for LPG. The study concluded that the increase in the relative air-fuel ratio increases the coefficient of variations in indicated mean effective pressure. However, the higher flame speed of LPG and good mixing of LPG with air causes a decrease in cyclic variations, and higher H/C ratio of LPG decreases the engine emissions. The LPG is a more suitable fuel for lean burn combustion engine compared to gasoline.

Changming Gong, et al. [14] carried out an experimental investigation on cold start firing and emissions characteristics of SI methanol engines using cycle-by-cycle control strategies. Test deduced that sufficient addition of LPG can ensure a reliable cold start firing. Also increased LPG addition fraction significantly decreased HC and unburned methanol tailpipe emissions.

Pundkar H. Albela et al. [15] experimented on performance and emissions characteristics of LPG fuelled engines. The study revealed that in SI engines, the lean burn operation resulted in improved fuel consumption for both full and half load cases. Further in lean burn operation with LPG, the increased flame speed and the decreased overall combustion duration in comparison to petrol was observed. Moreover, if LPG fuelled SI engines are operated at the same conditions with those of petrol fuelled SI engines, significant improvements in exhaust emissions in both stoichiometric and lean burn conditions were observed.

Bariş Erkuş, et al. [16] experimented on a spark-ignition (SI) engine fuelled with LPG by varying the ignition timing with excess air coefficients of 1.0 and 1.3. Experiments were conducted at wide open throttle at an engine speed of 4300 rpm. To test lean operation performance of an engine when fuelled with LPG at full load, performance parameters like Brake power, brake-specific fuel consumption (BSFC), brake thermal efficiency and exhaust emissions were studied during this experiment. The experiment deduced that advancing the ignition timing improved the performance of the LPG-fuelled SI engine for excess air coefficients above 0.8. The very best brake power and therefore the lowest brake specific fuel consumption were obtained with modified ignition timing at with excess air coefficient of 1.0. Moreover, advancing the ignition timings caused an increase in HC and NO_x emissions, while CO emission was negligible.

K. Ravi, E. Porpatham [17] carried out investigation over influence of piston squish area in LPG fuelled lean burn SI engine. Diesel engine was modified to operate as an SI engine with a compression ratio of 10:1 at 1500 rpm. The piston squish area was varied by 25%, 30%, 35% and 40% of total piston area. The test was carried out at wide open throttle. It was observed that the squish area beyond 30% leads to instability towards lean equivalence limit. The investigation suggested that 30% piston is the most suitable for LPG fuelled lean burn SI engine. Also, HC emissions were less in case of 30% squish area piston compared to 25%, 35% and 40% squish area pistons, while a significant increase in NO emissions compared to 35% and 40% squish area pistons.

Khanh Nguyen Duc, Vinh Nguyen Duy[18] carried out a simulation and experimental study on bi-fuel petrol-LPG for currently used fuel-injected motorcycle. In this research, simulation processes were conducted using a dedicated software analysis tool to optimize the operation process of the fuel system to maintain its stability and efficiency based on the characteristics of each type of fuels. Meanwhile, the original fuel supply system of the test motorcycle was modified for the experiment by developing the second Electronic Control Unit (ECU) to control LPG quantity supplied for the one. The study showed that the test motorcycle operates well on either gasoline or LPG on the new design. Besides, the specific fuel consumption and exhaust emissions of the test motorcycle were reduced significantly when running on LPG. The study suggests that the old generation of fuel-injected motorcycles can be run flexibly on bi-fuel in order to reduce fuel consumption and exhaust emissions.

Paul Jinson and Rajeswari B. [19] demonstrated the knocking characteristics of direct injection CI engine, fuelled with diesel and LPG in dual fuel mode. The naturally aspirated, single cylinder fourstroke water cooled diesel engine with a rated power of 5.2 kW was used for the test. The diesel was used as pilot fuel and the LPG as a main fuel. The LPG was inducted into the combustion chamber at a pressure slightly higher than atmospheric pressure using a bypass valve. The test indicated that the combustion process retarded at the beginning, afterwards become faster and finished earlier than combustion of pure diesel fuel. At higher loads and higher mass flow rate of LPG, the knocking was severe. The main factors that influence the knock were pilot fuel quantity, load, speed, gas flow rate and time interval of the secondary ignition

Rimkus Alfredas et al. [20] carried out the experimental analysis and numerical simulation using the AVL BOOST program on the CI engine operating on dual fuel mode (LPG and Diesel). The experimental test was carried out at 2000 rpm and the brake torque load of 60 N-m at five different blends of LPG and diesel. The supply of LPG into the engine cylinder was done with air through the intake manifold. The experimental test and numerical simulation showed that the mixture of diesel & 60% LPG the brake specific fuel consumption was less. The maximum engine efficiency was achieved at mixture of diesel & 40% LPG. The advancement in diesel injection increases the concentration of CO₂ and NO_x but decreases the concentration of CO, HC in the exhausts and smoke.

Chung SungSik et al. [21] implemented the DI technology for injection of LPG into the combustion chamber of the SI engine. The LPG injection and combustion processes were digitally recorded with a CCD camera. The Schlieren photography system makes use of the change in flow density gradients to take the LPG injection images. Outcomes of the experiment showed that high level of injection pressure leads to high levels of spray velocity, thus reducing the ignition probability. The desirable ignition probability was found when ambient pressure was 0.14-0.22 MPa and the mixture can be ignited at appropriate spark timing when injection pressure is within 0.7-0.9 MPa.

Barai Santosh Santram et al. [22] carried out experimental investigations of performance and emissions of single cylinder four-stroke SI engine at the wide open throttle and different load conditions for various compression ratios (4.67:1, 5.49:1). To measure several engine performance parameters engine was coupled to a ropeway dynamometer. A 5-gas analyzer with non-dispersive infrared (NDIR) was inserted into the engine exhaust tailpipe to measure the exhaust emissions. The test result showed that LPG has a closer performance to petrol. However, the brake specific energy consumption shows an improvement with LPG. The concentration levels of CO, CO₂ and unburnt HC recorded are found to be lower than the petrol fuelled engine.

IV. CONCLUSION

This paper gives a review of the research work carried out by various researchers on the use of LPG as an alternative fuel in both CI and SI engines. The dual-fuel mode operation found to be the most effective and prominent way. The performance, emission and combustion characteristics of the LPG fuelled engines have been reviewed from the various experimental research works. The studies suggested that by optimizing the engine operating parameters and design factors such as engine speed, loading condition, compression ratio, injection timing, pilot fuel supply, inlet manifold condition and ignition timing the performance, emission and combustion characteristics can be improved.

The following conclusions were drawn based on the present work on an LPG as alternative fuel:-

1. The application of LPG in the CI and SI engine is cost-effective while retaining the instant interchangeability of the system back to conventional fuel.
2. The use of LPG in the resulted in better mixing and combustion, lower fuel consumption and improved emission characteristics.

3. The brake specific fuel consumption is lowered in LPG fuelled engine in comparison to conventional fuel at same loading conditions.
4. The higher calorific value of LPG results in the increased rate of fuel burning resulting in a decrease in combustion duration, hence decreasing the brake specific fuel consumption.
5. The use of LPG permits the higher compression ratio below the level of knocking, improving the overall efficiency of the engine.
6. The cylinder pressure and temperature for LPG fuelled engines are higher than that of conventional fuelled engines.

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