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E-mail: bjsir07@gmail.com

Effect of LPG Content on the Performance and Emissions of A Diesel-LPG Dual-Fuel Engine

G. A. Rao[a], A. V. S. Raju[b], C. V. M. Rao[c] and K. G. Rajulu[d]

[a]Dr.Paul Raj Engineering College, Bhadrachalam, Dist.Khammam, India, [b]JNT University, Kukatpally,Pin 507111, Hyderabad-500085, India [c]University College of Engineering, Kothagudem, Dist.Khammam, [d]JNT University, Anantapur. India.

Abstract

In the present work, LPG, a by-product of petroleum refining process is used to replace conventional diesel fuel, partially, for improved combustion efficiency and clean burning. A conventional diesel engine was operated on the dual-fuel mode, using LPG as the primary fuel and diesel as the pilot fuel. A four-stroke, single-cylinder diesel engine, most widely used in agricultural sector, has been considered for the purpose of experimentation. The engine was operated at a constant speed of 1500 rpm at a low engine load of 20% and a high engine load of 80%. Under both these operating conditions, combustion, performance and emission characteristics of the engine have been evaluated and compared with that of baseline diesel fuel operation. At 20 % engine load the brake thermal efficiency of the engine has found to decrease with an increase in the LPG content. On the other hand at 80% engine load, it has increased with an increase in the LPG content. Same trend has been observed with regard to the mechanical efficiency. The volumetric efficiency has decreased with an increase in the LPG content at both the loads. The engine operation is more economical on dual-fuel operation at 80% engine load, whereas at 20% engine load, diesel fuel operation is found to be better. With regard to emissions, smoke density and emissions of NOx were found to reduce with an increase in LPG content at both the loads; however, emissions of HC and CO have shown the reverse trend.

Key words: Dual-Fuel, LPG, Diesel, Combustion, Performance, Emissions Load.

Introduction

The purpose of internal combustion engines is the production of mechanical power from the chemical energy contained in the fuel. In internal combustion engines, as distinct from external combustion engines, this energy is released by burning the fuel inside the engine cylinder. The fuel-air mixture before combustion and the burned products after combustion are the actual working fluids. The work transfers which provide the desired power output occur directly between these working fluids and the mechanical components of the engine. Because of their simplicity, ruggedness and high power-to-weight ratio, the internal combustion engines have found wide applications in transportation and power generation.

In spite of many unconventional sources of energy developed, petroleum based fuels remain the primary source of energy in the field of power and propulsion all over the world. The demand for the petroleum products in India is increasing at an alarming rate. For instance the demand for the petroleum products was about 3.5 Million Metric Tons (MMT) in 1950-51, and in 1997-98 it has risen to about 84.3 MMT, in 2004-05 it has reached an alarming value of 111 MMT. At this rate it is believed that the demand may reach a staggering 234 MMT by 2019-20. The approximate petroleum reservoirs in the world are 700 MMT. The domestic production of crude oil is about 33 MMT and the diesel consumption is 40 MMT, the petroleum oils worth Rs.102500 crores were imported (Hey Wood, 2007).

Conventional fuels for internal combustion engines are getting dwindled at an alarming rate, primarily due to exponential rise in the population of automobile users world-wide. These fuels are likely to prevail for another 50-75 years unless newer reservoirs are explored. Further, these fuels, upon their combustion release toxic gases into the atmosphere, causing severe environmental pollution and degradation of the quality of air of the atmosphere.

* Corresponding author: E-mail: amarendar_g@rediffmail.com

Dual-fuel operation is found to be one of the attractive ways of conserving precious conventional fuels, diesel and petrol. In this mode of operation, two fuels would be used, normally a gaseous fuel and a liquid fuel.

Ghazi A.Karim (1980), has underlined the importance of understanding the combustion processes in dual-fuel engines with regard to enhanced engine performance and reduced air pollution. In this article the importance of various gaseous fuels with regard to their availability, performance, cost aspects and pollution aspects is discussed. Dong Jian (2001) *et al,* have developed have developed a new type of duel supply system, which could able to economically convert conventional diesel engines into dual-fuel engines like LPG/Diesel engines and CNG/Diesel engines. These are capable of using either single diesel fuel or dual-fuel including both diesel and LPG and diesel and CNG. These diesel-LPG engines have been applied to the diesel buses in the public transportation of Guangzhou city, one of the biggest cities in China. Compared with the diesel baseline engine, it was found that there were significant reduction in soot emission and an improvement in the fuel consumption with the diesel-LPG engine. Also the strategy on LPG content is discussed in order to meet the demands for soot emission, fuel economy, transient performance and the output power at the same time. Poonia (1999) *et al,* have investigated experimentally the factors that affect the performance of a LPG-Diesel dual-fuel engine. In this work, the effects of intake charge temperature, pilot fuel quality, exhaust gas recirculation and throttling of the intake on the performance of a LPG-diesel dual fuel engine have been studied. It is found that at low outputs an increase in intake temperature and pilot quality is advantageous as HC levels are reduced. Sahir Salman *et al* (2004) have investigated the reduction in exhaust gas emissions from a diesel engine under dual-fuel operation. For this purpose, a single-cylinder, direct injection diesel engine was modified to operate with dual-fuel operation (30% LPG and 70% diesel fuel by weight). During the experiments, the engine speed was kept constant (1650 rpm) and the load was changed. It was observed that the NOx and smoke emissions were reduced with the dual fuel operation. Further, it is found that the fuel property is one of the most important parameters, which effects the exhaust emissions. Srinivasa Rao (2005) *et al,* have made experimental investigations on single-cylinder vertical water cooled compression ignition engine run on the dual-fuel mode with diesel as the pilot fuel and LPG as the main fuel. The engine is run under different operating conditions and in each case the optimum combination of the inducted to inject fuel energy proportions are determined for the best efficiency. Amarendar Rao (2008) *et al,* have performed experimental investigation of a single-cylinder, 4-stroke diesel engine operating on the dual-fuel mode using LPG as the main fuel and diesel as the pilot fuel. The experiments have been carried out at a constant speed of 1500 rpm under varying load conditions. The results are compared with those of pure diesel operation. They have indicated that the by dual-fuel operation precious diesel could be conserved even up to 80%, however in their work it could be done only up to 45% due to severe engine vibrations.

Experimental set-up

The experimental setup consists of a single-cylinder, four-stroke diesel engine connected to an eddy-current dynamometer for loading of the engine. It was provided with necessary instruments for combustion pressure and crank angle measurements. The signals were interfaced to a computer through an engine indicator to obtain pressure-crank angle and pressure-volume diagrams. Provision was also made for interfacing air flow, fuel flow, temperatures and load measurement.

The brake power of the engine was measured by coupling the engine to an eddy-current dynamometer. It consists of a stator, on which number of electromagnets was fitted, and a rotor disc, and coupled to the output shaft of the engine. When the rotor rotated eddy-currents are produced in the stator due to magnetic flux set up the passage of the field current in the electromagnets. These eddy-currents oppose the rotor motion, thus loading the engine. These eddy-currents dissipate lot of heat, thus proper cooling is required for the dynamometer. A moment arm measures the torque; the load on the engine was controlled by regulating the current to the electromagnets.

The engine set up has stand-alone panel box, consisting of an air box, a fuel tank, a manometer, a fuel measuring unit, transmitters for air and fuel flow measurements, a process indicator and an engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement.

An NDIR AVL exhaust gas analyzer was used to measure the emissions of CO, HC and NOx. A smoke meter was employed to record the smoke intensity of the exhaust gases.

The schematic layout of the experimental set up is shown in figure 1. The specifications of the engine are depicted in Table I. In this work, LPG has been used as the primary fuel and diesel as the pilot fuel. The role of the pilot fuel is to initiate the combustion, while that of the primary fuel is to generate mechanical power.

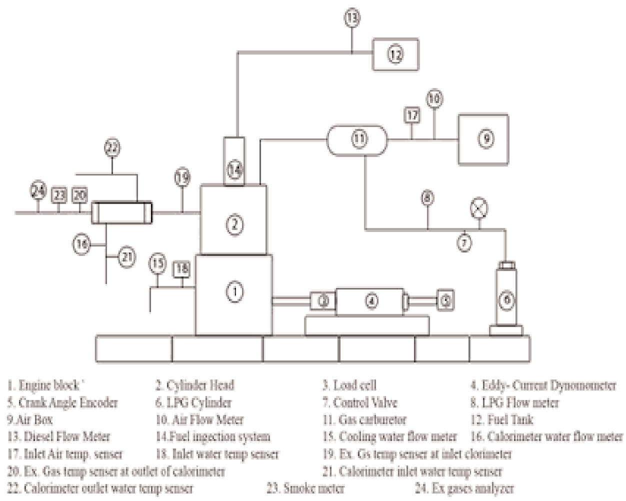

Fig.1: Layout of the Experimental Set-Up

Table I: Specification of the Engine set up

Engine	Make Kirloskar, Model TV1, Type1Cylinder, 4-Stroke, Water Cooled Diesel Engine
Rated Power	5.2 KW at 1500 rpm
Bore x Stroke	87.5 mm x 110 mm
Displacement Volume	661 cc
Compression Ratio	17.5
Dynamometer	Eddy-Current Type, Water Cooled with Loading Unit

Results and Discussions

A conventional diesel engine could be successfully converted to run on LPG-diesel dual-fuel operation. The influence of addition of LPG on the engine performance and emissions has been evaluated. Initially, baseline tests have been performed using diesel as the fuel. The tests have been conducted at a constant speed of 1500 rpm at two distinct loads of 20% and 80% of full load. Then, the tests have been performed on the engine at the same speed under the same operating conditions on dual-fuel mode. The content of LPG was gradually increased and diesel supply was reduced without affecting the engine power. At 20% engine load, 50% of diesel consumption could be replaced by LPG, but at 80% load, it could be done only up to 20%. This was due to engine operating difficulties, like undue vibrations of the engine parts, and excessive heating.

The effect of LPG content by energy on brake thermal efficiency of the engine at low (20%) and high engine loads is depicted in figure 2. From this figure it is evident that at low engine load, brake thermal efficiency has decreased with an increase in the LPG content. With zero LPG content (diesel fuel operation) it was found to be 14.4% and with 50% LPG (dual-fuel operation), it was reduced to 9.7%, a decrease of 32.6%. At 80% engine load, the brake thermal efficiency has increased with an increase in the LPG content.

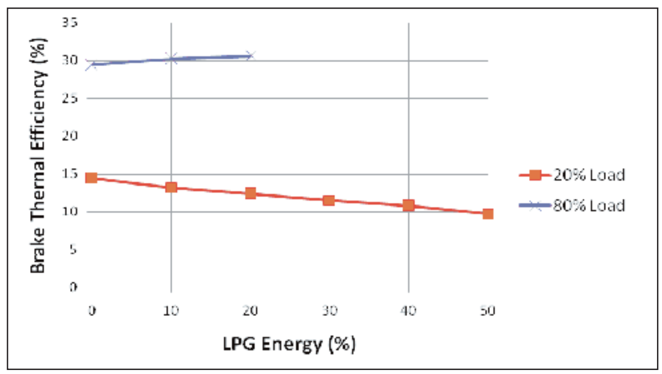

Fig. 2: Variation of Brake Thermal Efficiency with LGP Energy at 20% and 80% Loads

Figure 3 represents the effect of LPG content on the mechanical efficiency of the engine at low and high loads of the engine. At 20% engine load, mechanical efficiency of the engine has reduced with an increase in LPG content. It has

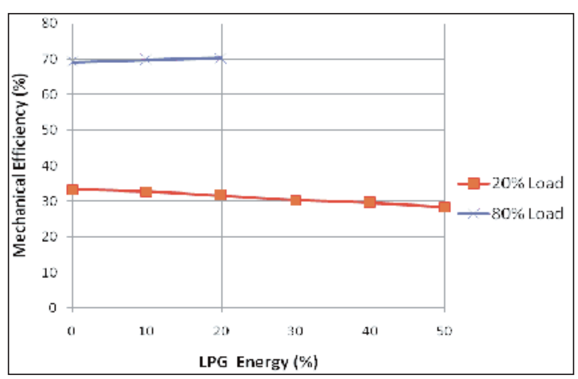

Fig. 3: Variation of Mechanical Efficiency with LGP Energy at 20% and 80% Loads

reduced from 33.3% with zero LPG to 28.3% with 50% LPG content, a drop of 15.01%. This could be due to incomplete combustion and inferior combustion environment. At 80% engine load it has increased with an increase in LPG content. On diesel fuel operation it was 69.2% and on dual-fuel operation it has increased to 70.3%.

The volumetric efficiency of the engine has reduced with an increase in LPG content at both the loads, as shown in figure 4. At 20% engine load, it was 77.8% on diesel fuel operation and reduced to 73.8% with dual-fuel operation. This is depicted in figure 4. Figure 5 represents the effect of LPG

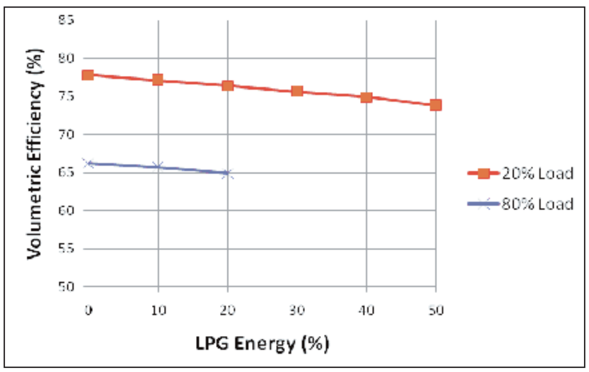

Fig. 4: Variation of Volumetric Efficiency with LPG Energy at 20% and 80% Loads

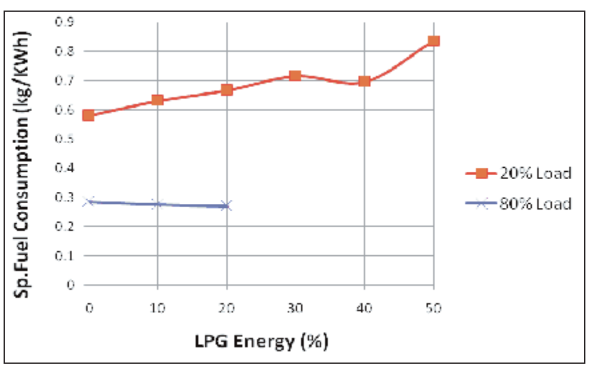

Fig. 5: Variation of Brake Specific Fuel Consumption with LPG Energy at 20% and 80% Loads

content on the brake specific fuel consumption of the engine. It is evident that, as the LPG content is increased, it has increased at 20% load, making the engine operation more costly. However, at 80% load, bsfc has decreased with an increase in the LPG content.

With regards to emissions, smoke density has remained almost constant at 20% engine load, but reduced significantly at 80% engine load. This could be due to better combustion of air-LPG mixture under high load conditions. This trend is represented in figure 6. On the other hand both HC, CO and NOx emissions have increased with an addition of LPG content under all operating conditions, as shown in figures 7, 8 and 9.

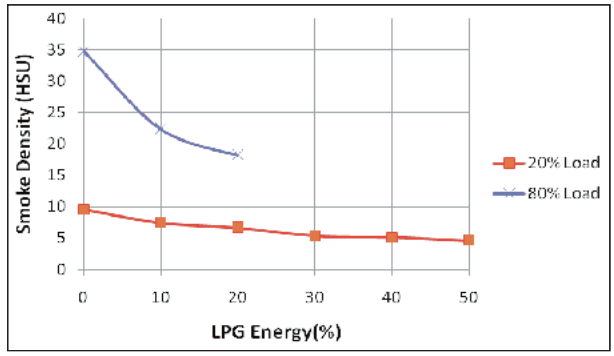

Fig. 6: Variation of Smoke Density with LPG Energy at 20% and 80% Loads

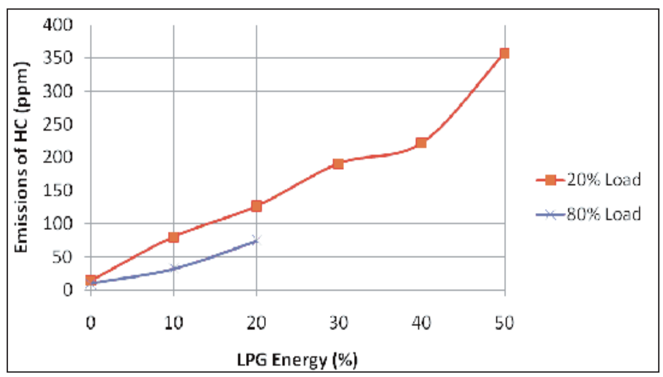

Fig. 7: Variation of Emissions of Hydrocarbons with LPG Energy at 20% and 80% Loads

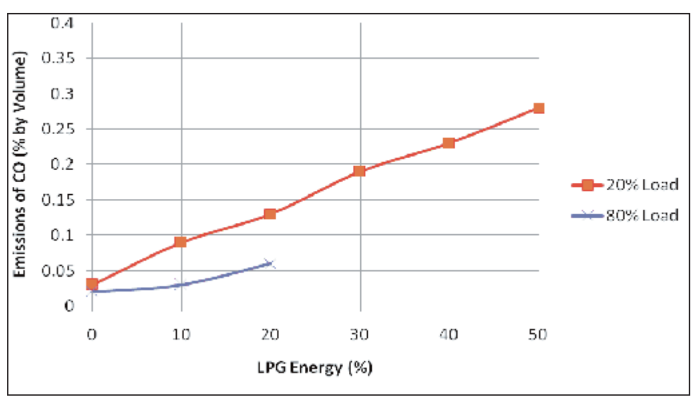

Fig. 8: Variation of Emissions of CO with LPG Energy at 20% and 80% Loads

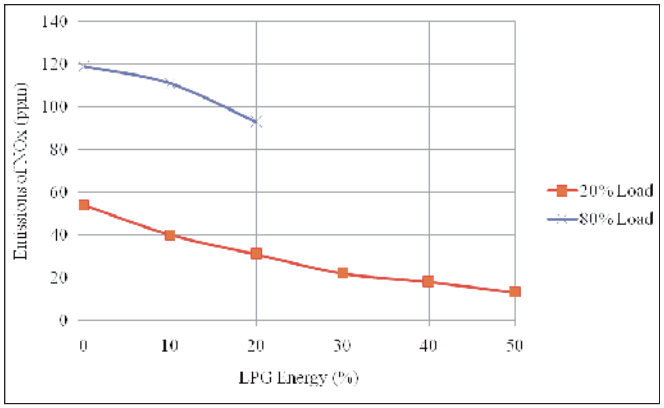

Fig. 9: Variation of Emissions of NOx with LPG Energy at 20% and 80% Loads

Conclusion

A conventional diesel engine could be successfully converted to LPG-diesel dual-fuel operation with minimum alterations. At 20% engine load, diesel could be replaced by LPG up to 50% without any operational difficulties; however, at 80% engine load it could be done only up to 20%, due to operational difficulties.

In the present work, a conventional diesel engine is operated on dual-fuel mode and its performance is evaluated in terms of the fuel consumption, power output and the emissions. From this study, the following conclusions are drawn:

1. At lower engine loads, the engine performance on dual-fuel mode is inferior compared to that of the conventional diesel fuel mode.
2. At higher engine loads, the dual-fuel mode of operation is found to be superior compared to that of the diesel fuel mode of operation.
3. With an increase in LPG energy, the brake thermal efficiency is found to reduce at lower loads, and it is found to increase at higher loads.
4. At 20% load, the brake thermal efficiency of the engine is 14.4% on diesel fuel mode of operation and it is reduced to 12.4% on the dual-fuel mode of operation with 50% LPG energy, a drop of 13.8%.At 80% engine load the corresponding values are 29.4% and 30.6%, an increase of 3.9%.
5. The volumetric efficiency of the engine has been found to decrease with an increase in the LPG flow rate at all the loads. This is due to the fact that a part of the cylinder space is occupied by the LPG, providing reduced space available for the incoming air.
6. The brake specific fuel consumption of the engine has increased with an increase in the LPG flow rate at lower loads, making the engine operation uneconomical; however, at higher engine loads the trend is reverse.
7. The smoke density has reduced with an increase in LPG energy at all the loads. At lower engine loads the decrease is marginal, but at higher engine loads the decrease is found to be significant.
8. At 20% load, it is found to be 9.5 HSU with diesel fuel operation and 6.6 HSU with dual-fuel operation with 50% LPG energy, a drop of 30.5%, on the other hand at 80% engine load the corresponding values are 34.8 HSU and 18.2 HSU with a drop of 47.7%.
9. Emissions of HC have increased with an increase in LPG content under all operating conditions. At 20% engine load, HC emissions are 14 ppm with diesel fuel operation and 126 ppm with dual-fuel operation with 50% LPG energy, an increase of 800%. At 80% engine load the corresponding values are observed to be 10 and 74, a rise of 640%.
10. Emissions of NOx have been found to decrease with an increase in the LPG content at both the loads.

At higher engine loads, conventional diesel engines can be switched over to dual-fuel operation, in order to have an overall improvement in the performance of the engine. The scheme developed can be extended for CNG-diesel dual-fuel operation.

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