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Performance, Emission and Combustion of LPG Diesel Dual Fuel Engine using Glow Plug

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Abstract

A single cylinder vertical air-cooled diesel engine was modified to use LPG in dual fuel mode to study the performance, emission, and combustion characteristics. The primary fuel, liquefied petroleum gas (LPG), was mixed with air, compressed, and ignited by a small pilot spray of diesel. Dual fuel engine showed a reduction in oxides of Nitrogen and smoke in the entire load range. However, it suffers from the problem of poor brake thermal efficiency and high hydrocarbon and carbon monoxide emissions, particularly at lower loads due to poor ignition. In order to improve the performance at lower loads, a glow plug was introduced inside the combustion chamber. The brake thermal efficiency improved by 3% in the glow plug assisted dual fuel mode, especially at low load, and also reduced the hydrocarbon, carbon monoxide, and smoke emissions by 69%, 50% & 9% respectively. The presence of glow plug had no effect on oxides of Nitrogen.

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Keywords: Liquefied Petroleum Gas; Glow Plug; Performance; Emission; Combustion

1. Introduction

LPG vehicles are being rapidly developed as economical and low-pollution cars [1-2] .The potential benefits of using LPG in diesel engines are both economical and environmental [3]. In the dual fuel gas engines, the gaseous fuel is inducted along with the air, and this mixture of air and gas is compressed like in conventional diesel engines. A small amount of diesel, usually called the pilot, is sprayed near the end of the compression stroke to initiate the combustion of the inducted gas air mixture [4-5]. With reduced energy consumption, the dual fuel engine shows a significant reduction in smoke density, oxides of nitrogen emission, and improved brake thermal efficiency [6]. The combustion of this pilot diesel leads to flame propagation and combustion of the gaseous fuel. The engine can be run in the dual fuel mode without any major modification, but is usually associated with poor brake thermal efficiency and high HC & CO emissions at low loads [7].

The increase in pilot diesel improves the brake thermal efficiency at low loads. At higher loads, it reduces efficiency due to rapid combustion [8-9]. Low efficiency and poor emissions at light loads can be improved significantly by advancing injection timing of the pilot fuel [10-11]. Any measures that lower the effective lean flammability limit of charge and promote flame propagation will improve part load performance [12]. The gas concentration is low at lower loads, thus ignition delay period of pilot fuel increases, and some of the homogeneously dispersed gaseous fuel remains unburned which results in poor performance. A concentrated ignition source is needed for combustion of the inducted fuel at low loads [13]. Poor combustion of the gaseous fuel at low loads results in higher emission of carbon monoxide and unburned hydrocarbons.

The hot surface assisted ignition concept is commonly applied to overcome the low temperature-starting problem in diesel engine. Introducing low cetane fuel such as alcohol and natural gas requires an extended application of the hot surface as continuous ignition assistance. The function of the hot surface is to provide favourable local ignition condition, followed by combustion propagating through the fuel air mixture to establish a stable diffusion flame [14-16].

The objective of the present work is to improve part load efficiency, which is the main drawback in dual fuel operation. In the present experimental work, the effect of introducing glow plug inside combustion chamber, which was not attempted earlier in the dual fuel operation, was studied. Pilot fuel quantity of 8.5 mg/cycle was introduced. It preheats the gas air mixture; and reduces the delay period of the pilot diesel. This results in improvement in the performance and in reduced emissions at low loads.

2. Experimental Setup and Experimentation

A single cylinder, 3.7 kW, four strokes, direct injection, and air-cooled diesel engine coupled to an electrical

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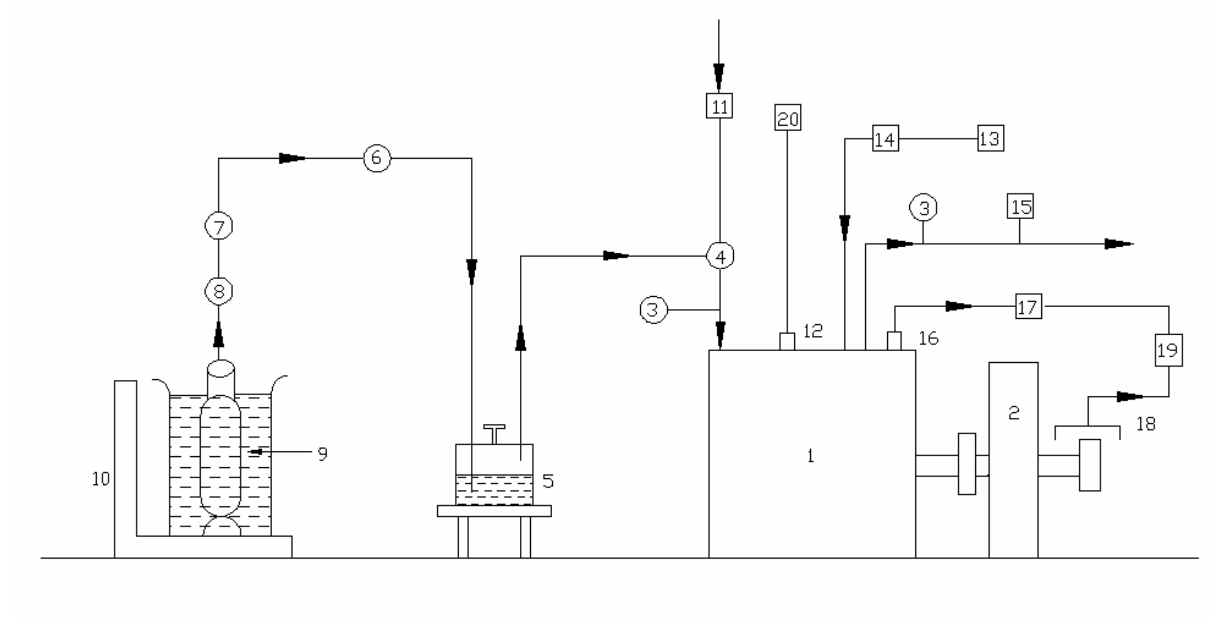

Figure 1. Schematic of the experimental set up.
* 1 Engine, 2 Dynamometer, 3 Temperature measurement, 4 Gas –air mixture, 5 Flame trap, 6 Gas flow meter, 7 Pressure regulator, 8 Control valve, 9 LPG cylinder, 10 Weighing machine, 11 Air flow surge tank, 12 Glow plug, 13 Diesel tank, 14 Diesel flow measurement, 15 Exhaust gas analyser, 16 Pressure pick up, 17 Charge amplifier, 18 Shaft position encoder, 19 CRO, 20 Battery

dynamometer were used for the experiments.The specifications of the DI diesel engine are shown in Table 1.

Table 1. Specifications of the test engine.

General detail	Single cylinder, four stroke, compression ignition, constant speed, vertical, air cooled, direct injection
Bore	80mm
Stroke	110mm
Compression ratio	16.5:1
Rated output	3.7kW at 1500 rpm
Rated speed	1500 rpm
Injection pressure	200 bar

The engine was modified to work in the dual fuel mode by connecting LPG line to the intake manifold with a flame trap, non-return valve, needle valve, and mixing unit [17]. A digital type platform weighing machine having an accuracy of 2 mg was used to measure the LPG fuel flow by weight difference method with an uncertainty of 1.8 %. A Kistler make piezo electric transducer with a sensitivity of 14.2 pC/bar was installed with a Kistler charge amplifier for monitoring the cylinder pressure. This was recorded in a personal computer. Using analog to digital converter, the average pressure was obtained from 100 consecutive cycles. Carbon monoxide and unburned hydrocarbons emissions were measured using a NDIR gas analyser with an uncertainty of 5%. Smoke emissions were measured by means of a Bosch smoke meter with an uncertainty of 6%. NOx emissions from the engine were measured using a Crypton make analyser with an uncertainty of 6%. Chromel – alumel (K – type) thermocouple was used to measure the exhaust gas temperature with an uncertainty of 0.5 º C. The brake thermal efficiency was calculated by considering the calorific value and mass flow rate of both fuels.

$$\textit{Brake thermal efficiency} = \textit{brake power} / ((m_f \times CV)_{LPG} + (m_f \times CV)_{Diesel}) \quad (1)$$

The schematic of the experimental setup is shown in Fig 1.

The experimental procedure consists of the following steps:

- Initially, engine was tested using the base fuel diesel at all loads to determine the engine operating characteristics and pollutant emissions. The engine speed was maintained constant through out the entire engine operation at 1500 RPM.
- The same procedure was repeated in dual fuel mode with 8.5 mg/cycle pilot diesel, with and without glow plug .The glow plug was powered by12V battery, and it was maintained at a maximum temperature of 850º C throughout the engine operation. The pilot diesel quantity was maintained constantly for the entire load range by varying the flow rate of LPG for each load condition. The mass fraction of LPG in the blend (Z) is shown in Table 2.

$$Z = (\dot{m}_{LPG} / (\dot{m}_{Diesel} + \dot{m}_{LPG})) \times 100\ \% \quad (2)$$

Table 2. Mass fraction of LPG in the blend .

Load in %	0	20	40	60	80	100
DF with GP (Z)	13.4	18.9	38.1	49.1	57.0	63.4
DF without GP (Z)	23.1	34.7	45.2	49.6	55.9	62.3

During the engine test conditions, the cylinder pressure, exhaust gas temperature, fuel consumption, exhaust smoke, and exhaust gas emissions were recorded at all the loads.

3. Results and Discussion

The results obtained in the dual fuel operation with and without the assistance of glow plug are compared to diesel; and are presented.

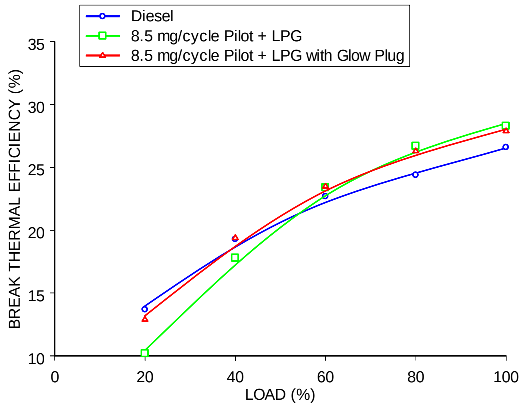

Figure 2 .Variation of Brake Thermal Efficiency with Load.

3.1. Brake Thermal Efficiency

The variation of brake thermal efficiency against load is shown in Figure 2. The glow plug assisted dual fuel mode of operation improves the efficiency by 2% up to 80% load, but there is no significant variation at full load operation. Brake thermal efficiency ranges from 12.9 % to 27.9 % with glow plug operation whereas in the case of dual fuel mode of operation without glow plug, it varies from 10.2 % to 28.3 %. This may due to the reduction in delay period of pilot diesel and an increase in the mixture temperature around the glow plug. The brake thermal efficiency for diesel varies from 13.7 % to 26.6 %.

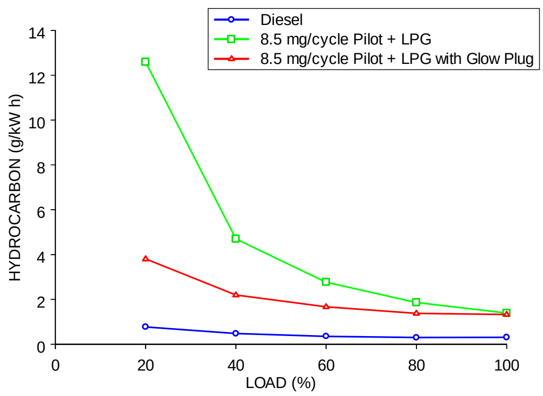

Figure 3. Variation of Hydrocarbon with Load.

3.2. HC and CO Emissions

Figure 3 shows the variation of hydrocarbon emission against load. The hydrocarbon emission is reduced throughout the engine operation in glow plug assisted dual fuel mode in comparison to dual fuel mode of operation. It ranges from 3.81 g/kW h to 1.33 g/kW h whereas in the case of dual fuel mode of operation without glow plug, it ranges from12.6 g/kW h to 1.4 g/kW h, and for diesel from 0.78 g/kW h to 0.31 g/kW h.

Reduction in delay period of pilot diesel, increase in pre flame reaction near the injector due to glow plug temperature, and high temperature of gas air mixture around the glow plug are the reasons for lower emissions in the case of glow plug assisted dual fuel operation.

The variation of CO emissions against load is shown in Figure 4. The CO emission is reduced throughout the engine operation in the glow plug assisted dual fuel mode in comparison to dual fuel mode of operation. It ranges from 0.49 g/kW h to 0.13 g/kW h whereas in the case of dual fuel mode of operation without glow plug, it ranges from 0.99 g/kW h to 0.14 g/kW h. The reason for lower emission is the increased mixture temperature by the glow plug temperature, which creates local turbulence and increase in flame velocity. The CO emission for diesel varies from 0.24 g/kW h to 0.11 g/kW h.

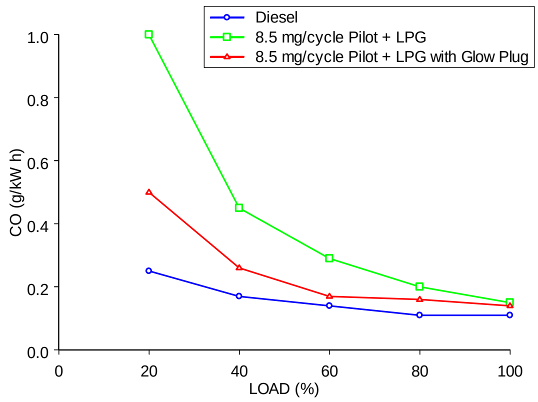

Figure 4 .Variation of CO with Load.

3.3. NOx Emission

The variation of NOx emission with load is shown in Figure 5. It increases marginally in the case of glow plug assisted dual fuel mode in comparison to dual fuel mode of operation. It ranges from 3.7 g/kW h to 3.1 g/kW h, whereas in the case of dual fuel mode of operation without glow plug, it varies from 3.28 g/kW h to 2.82 g/kWh, and for diesel from 7.77 g/kW h to 6.28 g/kW h. The primary fuel forms a homogeneous mixture, and it leads to complete combustion and rise in the peak pressure resulting in high temperature inside the engine during combustion, and it increases the possibility of NOx formation.

3.4. Smoke

The variation of smoke emissions against load is shown in Figure 6. A marginal reduction in smoke emission throughout the engine operation can be noticed in the glow plug assisted dual fuel mode in comparison to dual fuel mode of operation without glow plug. It ranges from 0.2 to 0.92 BSU whereas in the case of dual fuel mode of operation without glow plug, it ranges from 0.2 to 1.2 BSU. The reduction of smoke may be due do lower carbon/hydrogen ratio of LPG. The smoke emission for diesel varies from 0.2 to 0.92 BSU

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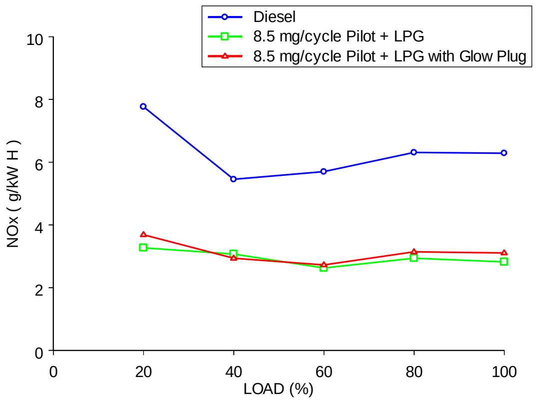

Figure 5. Variation of NOx with Load .

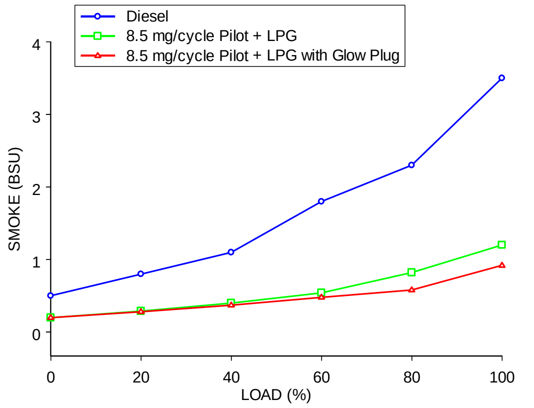

Figure 6. Variation of Smoke with Load.

3.5. Exhaust Gas Temperature

Figure 7 shows the variation of exhaust gas temperature against load. A marginal increase in exhaust gas temperature is noticed throughout engine operation in the glow plug assisted dual fuel mode due to high combustion temperature. It ranges from 215°C to 535°C, whereas in the case of duel fuel operation without glow plug it varies from 201°C to 531°C. The diesel mode of operation shows a variation from 224°C to 571°C.

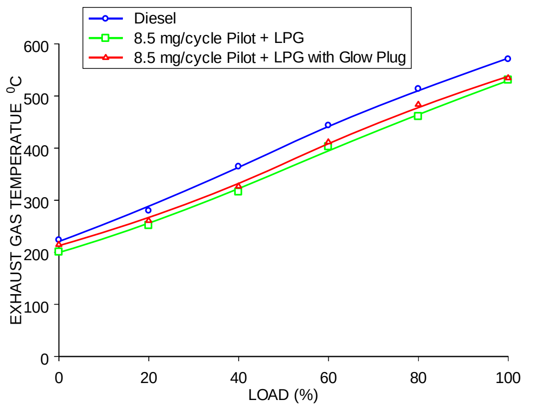

Figure 7 .Variation of Exhaust gas temperature with Load .

3.6. Combustion Parameters

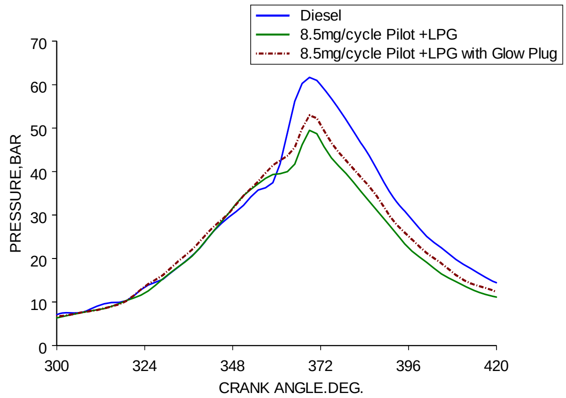

Figure 8. Variation of Pressure with Crank angle at 20 % Load.

3.6.1. Pressure Crank Angle Diagram

Figure 8 shows the cylinder pressure with crank angle for diesel, dual fuel mode, and glow plug assisted dual fuel mode at 20% of full load. The peak pressure in dual fuel mode without glow plug is 50 bars, and in glow plug assisted dual fuel mode it is 53 bars whereas in the case of diesel it is 61 bars. At low loads, pilot diesel initiates the combustion followed by LPG combustion due to high self-ignition temperature of LPG. It leads to a retardation in the peak pressure by 3˚ CA .The glow plug temperature reduces the delay period resulting in an increase in peak pressure.

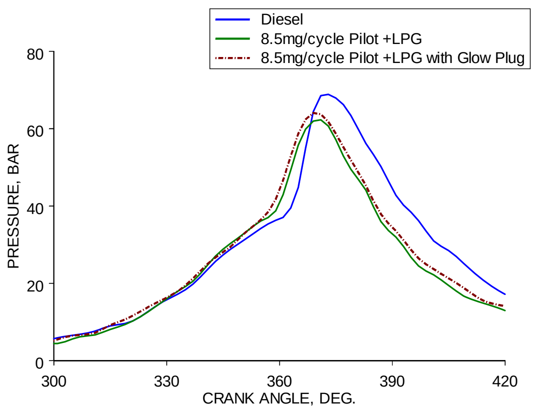

Figure 9. Variation of Pressure with Crank angle at Full Load

Figure 9 shows the cylinder pressure with crank angle at full load. The cylinder pressure obtained in dual fuel mode is less than the base diesel. The peak pressure obtained in the dual fuel mode of operation without glow plug is 62 bars, and in glow plug assisted dual fuel mode it is 64 bars whereas in diesel it is 68.7 bars. The peak pressure in the dual fuel mode is advanced by 2˚CA when compared to diesel. It is due to pre combustion of LPG followed by diesel combustion.

3.6.2. Heat Release Rate

The rate of heat release curves are drawn using pressure and crank angle value in the existing software. Figure10 shows the rate of heat release for glow plug assisted dual fuel mode, dual fuel mode, and diesel mode at 20% of full load. The combustion starts at the same crank angle of about 5° CA BTDC for both glow plug assisted dual fuel operation and diesel. But the combustion starts 5° CA after the glow plug assisted dual fuel operation in dual fuel operation without glow plug. The peak heat release rate of glow plug assisted dual fuel mode is 41 J /° CA, dual fuel mode is 34.9 J / ° CA, and for diesel mode it is 52 J / ° CA. Figure 11 shows the rate of heat release at full load. The peak heat release rate of glow plug assisted dual fuel mode is 59.7 J / ° CA, dual fuel mode is 48.4 J / ° CA, and for diesel mode it is 82.7 J / ° CA. The combustion in glow plug assisted dual fuel operation starts 2° CA before diesel. The combustion may be initiated by the glow plug before the pilot injection of diesel in the glow plug assisted dual fuel operation.

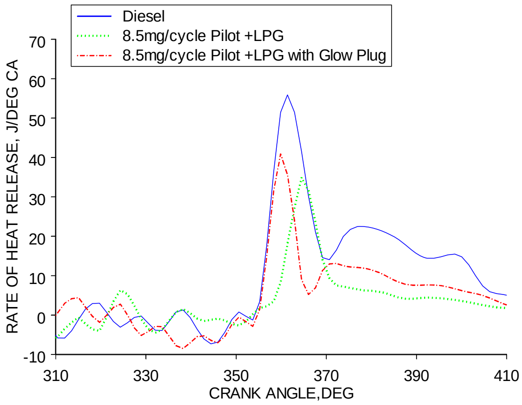

Figure 10. Variation of Heat Release Rate with Crank angle at 20 % Load.

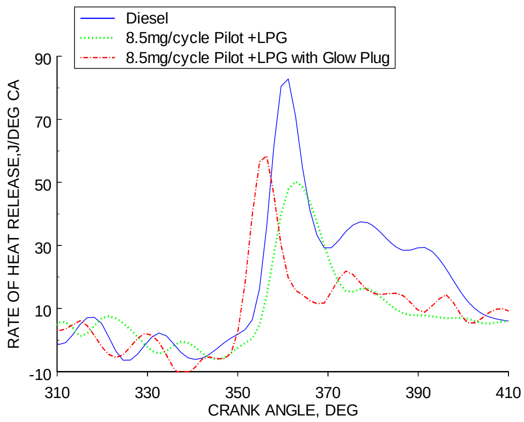

Figure 11. Variation of Heat Release Rate with Crank angle at Full Load.

4. Conclusions

The following conclusions are drawn based on the experimental investigation

- The glow plug assisted dual fuel mode shows an improvement of 3% in brake thermal efficiency at low loads compared to dual fuel mode of operation, with no appreciable change at high loads.
- HC and CO emissions are reduced by 69% and 50% in the glow plug assisted dual fuel mode of operation compared to dual fuel mode of operation without glow plug, but marginally higher than in diesel.
- The emission of smoke is reduced by 9% in the glow plug assisted dual fuel mode of operation compared to dual fuel mode of operation. Compared to diesel, it reduces by 69%.
- The glow plug assisted dual fuel operation improves the combustion. It shows higher peak heat release rate, compared to dual fuel operation without glow plug.
- The peak pressures are higher in glow plug assisted dual fuel operation in the entire load range when compared to dual fuel operation without glow plug.

In general glow plug assistance improves the part load performance in dual fuel engine with a significant reduction in emissions.

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