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Performance study for diesel engine: a single-cylinder using a new electronic control unit of (diesel+liquefied petroleum gas) mode

Diesel engines are important and effective in many services, but it is no friendly for environmentally. Since liquefied petroleum gas is prolific in Iraq at a lower price than other fuels and is clean and environmentally friendly, one of the important research topics is the use of liquefied petroleum gas in diesel engines because LPG has a high heat value, and the state of its gas makes mixing with air a burning issue simple and improved, reduces emissions and helps to harvest total energy. A new electronic control unit (ECU) is designed and used to inject liquefied petroleum gas via intake manifold as air enters the combustion chamber and a sensor is installed over a single-cylinder diesel engine, air-cooling. The test engine operation for fuel modes that were initially used is the D-100, after which the LPG-25, LPG-50 and LPG-100 fuel were used. The test under loads was 0%, 25%, 50%, 75% and 100% at different speeds of 1000, 1500 and 2000 rpm. At engine speeds, 1000, 1500, 2000 rpm compared to D-100 fuel, thermal efficiency was better in using LPG-50 fuel and improved by (4%, 3.6%, 4.9 %), and bsfc (9.81%, 9.4% and 9.68%) respectively, A decrease in emissions, NO_x, HC, CO and CO_2 was observed in all operating modes with liquefied petroleum gas and the best emission reduction situation is LPG -50.

Keywords: *Dual fuel, diesel engine, liquefied petroleum gas, emissions.*

1. Introduction

Among the engines of internal combustion, diesel engines are of great importance because they are of high energy and are considered to be long-suffering engines for energy production, whether it is thermal energy, electric or other energies that are commonly used in many other areas such as agriculture, industry, transportation, electricity generation, etc. But there are increasing fears of environmental damage and the scarcity of oil products. This made the researchers go to search for better, clean fuel that is friendly to the environment and contributes to improving engine performance and low fuel costs, especially in Iraq, which is blessed with oil wealth and contains liquefied petroleum gas available at a lower price than other fuels. One of the important research topics that have been updated is the use of liquefied petroleum gas (LPG) in diesel engines. The LPG has a high heat value, and its gaseous state makes mixing with air simple. It has perfect redound of combustion to increase the power output, and well as, good anti-knock due to high octane [1] [2] [3]. Gas fuel will not dilute lubrication oil on the engine. Lubrication oil replacement time may be longer [4]. Yet LPG's ignition time delay is longer because of the low cetane count, also the LPG helps to fully consume the fuel and thus reduces emission and helps to harvest the total energy found in the fuel [5]. The Increase in prices of diesel fuel compared to other oil derivatives used to operate internal combustion engines will be higher and because of the consequence of diesel fuel from the high price and the emissions it cause [6], as well as its impact on the life of the engine [7]. Rising energy prices will adversely affect economic growth and impede efforts to reduce poverty in developing countries such as Iraq, all these reasons led to research in alternative fuel that replaces diesel fuel; among these the fuel went of the selection of LPG can be used on diesel engines without much engine system modification. Dual-fuel engines, fuelled with a variety of gaseous fuel options, generate less exhaust emissions than conventional diesel engines without any significant increase in operating and capital costs. The LPG in diesel fuel can achieve good atomization of the spray and contributes to the process of mixing the fuel-air. Awareness about fossil fuels is increasing day by day due to high fuel cost, lack of fuel in the earth. This leads to the creation of alternative sources of fuel in IC engines. The extraction of many natural gas liquids (NGL) in a number of gas fields in Iraq has increased the country's capacity to produce LPG. The dual-fuel process is considered to be one of the influential methods of diesel and petrol conservation. The extraction of many natural gas liquids (NGL) in a number of gas fields in Iraq has increased the country's capacity to produce liquefied petroleum gas. In the spark ignition engines investigated by Chiriac et al [8] and

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Ehsan et al. [9], LPG was successfully used, but the dual-fuel operation in the diesel engine was relatively less investigated, (Jian, et al) [10]. A new type of dual supply system was developed that could transform traditional diesel engines to dual-engines (LPG/diesel engine and CNG/diesel engine) economically. They can use either single diesel fuel or dual-fuel, including diesel and LPG as well as diesel and CNG. These diesel-LPG engines were added to the diesel busses in the public transport system of Guangzhou City, one of the largest cities in China. Compared to the diesel baseline engine, it was found that soot emissions were significantly reduced and fuel consumption improved with the diesel-LPG engine. The LPG commodity strategy is also tackled to meet the demands for soot emissions, fuel efficiency, transient performance and output power simultaneously. Rao et al [11]. Experimental investigations have been carried out on a water-cooled single-cylinder compression ignition engine running at dual-fuel mode with diesel as pilot fuel and LPG as the main fuel. The engine work was under various conditions with the best efficiency and optimal combination of the proportions induced to inject fuel energy was calculated in each case. Salman et al. [12] investigated the reduction in the emission of exhaust gas from a dual-fuel diesel engine. Modified a single-cylinder, direct-injection diesel engine is to run with dual-fuel (70% diesel and 30% LPG by weight). The engine speed was maintained constant at 1650 rpm during the experiments and the load was changed. In several studies carried out by Qi et al. and Vijayabalan et al [13] [14], about 40 to 65 per cent diesel replacement by LPG was observed depending on the engine specification. The studies have shown that diesel-LPG dual operations can achieve the rated capacity of traditional diesel engines, above to a point of diesel replacement [13][14]. Saleh [1] has shown that both environmental and economic benefits of dual fuel service with LPG. Karim [15] stressed the need of understanding the essential mechanisms of dual-fuel combustion engines in terms of increased engine performance and reduced the pollution of air. One of the best ways to use LPG injection is the electronic control unit system, where many researchers have worked on this topic and have proven the success of this system in operating the engine with dual fuel [7][16].

From the reviewed of previous studies, it was found that the operation of the diesel engine in dual fuel mode is successful and improves the engine performance and emissions. In this study the operating mode LPG-25, LPG-50 and LPG-100 was used with diesel modes D-100, D-75, D-50 and D-0 by the electronic control unit that controls the amount of LPG fuel, and these modes were not used in previous studies; used diesel is primary fuel and LPG secondary. LPG is controlled by an electronic system designed to match the work of the diesel-LPG after making an adjustment to the engine and installing a magnetic sensor on the head of the engine. The engine was initially run on the base diesel mode and then it was run on proportions of LPG-25, LPG-50 and LPG-100 and under loads (0%, 25%, 50%,75% and 100%) at speeds ranging from (1000, 1500, 2000 rpm).

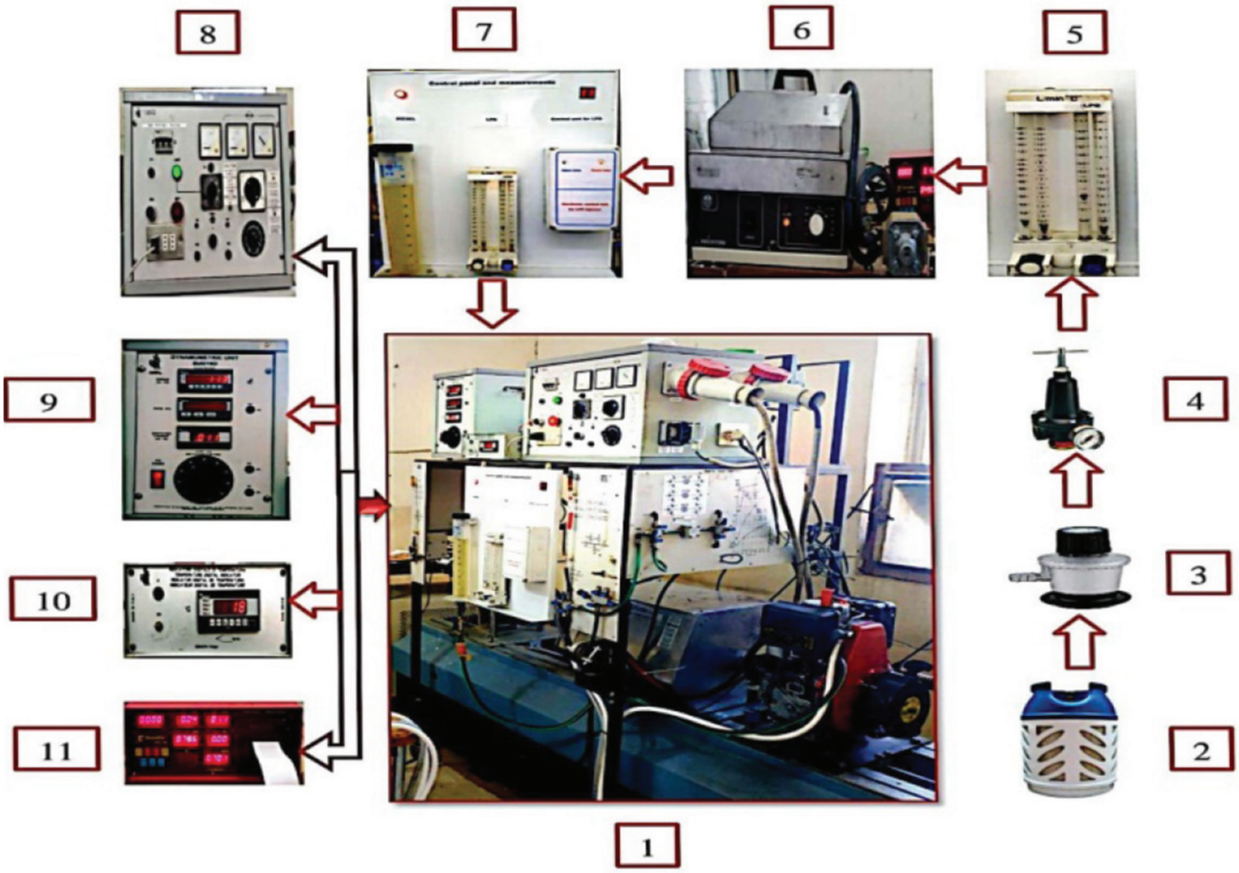
2. Experimental methodology

Didacta's T85D, the internal combustion engine test bed, was originally built for use in research laboratories to ensure full teaching performance in the field of internal combustion engines. The device shown in the Fig.1 manufactured by Lombardini LGA 226 company is used in the present work. A control panel equipped with the laboratory device (T85D) of Italian made controls these systems. The device is content for various operating parameters such as engine speed, operation and turns it off, load control and exhaust temperature measurement. Fig.2 shows the design and construction of an experimental apparatus engine modification to conduct the study. It consists of a unit of CI engine of LPG system. The engine is tested in two different operating modes. The engine is tested unmodified, only D-100 diesel fuel is used in the first process. In the second mode, the engine is tested by LPG but at rates (25%, 50% and 100%). Cylinder head of the engine is modified by a magnetic sensor mount that signals the electronic control unit of the LPG system that controls the amount and time of the intake manifold and mixes it with the air entering the combustion chamber of the engine at pressure 1 bar. The engine used in this experiment is single-cylinder direct injection 4-stroke; air-cooled diesel engine was used for our experiment. Brief specification is as shown in Table 1.

Table 1: Specification of the test engine

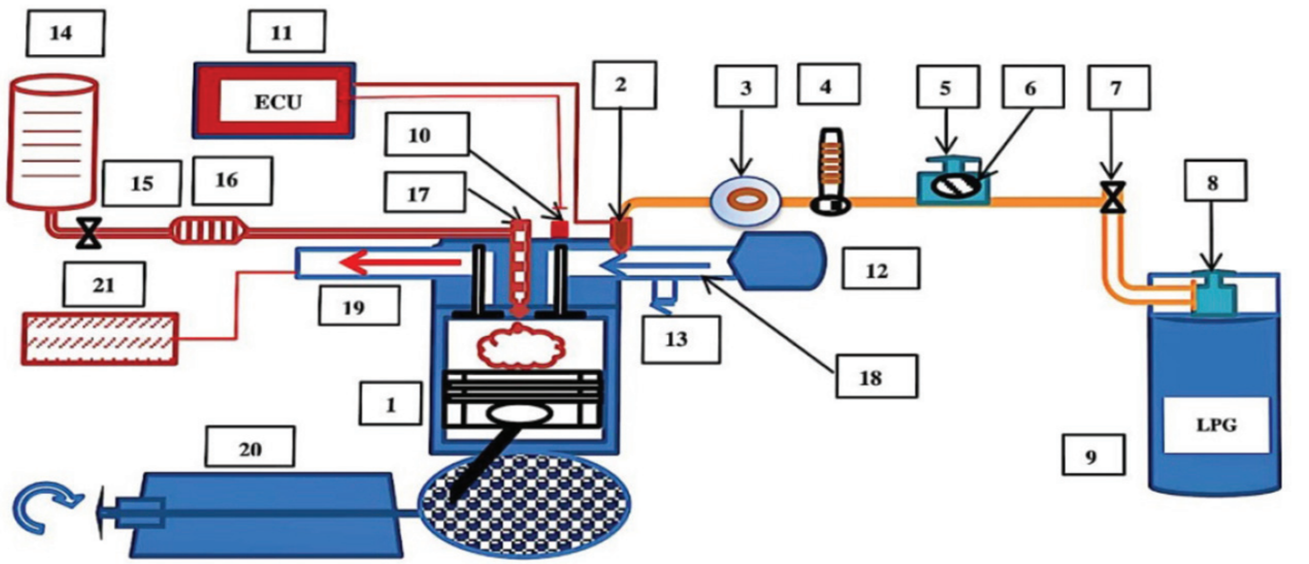
Brand	Measuring unit	Lombardini, Italy
Type		15LD315
Injector type		Direct injection
Engine type injection 4-stroke		Single cylinder direct
Cooling type		Air-cooled
Cylinders	N	1
Displacement	cm3	315
Bore	mm	78
Stroke	mm	60
Compression ratio		20.3:1
Maximum power		5.0kW/6.8 HP
Dryweigh	Kg	33
Maximum torque	NM	15@2400
Rated speed	RPM	3600
Dimension (L×W×H)	mm	295×374×445
Method of starting		Handcranking

These diesel and LPG fuels were used in the test as fuels in this experiment. The LPG content was consisted of gases of three mixtures of ethane (0.05 C_2H_6), propane (0.5 C_3H_8) and butane (0.45 C_4H_{10}). Test fuel properties are shown in Table 2.



1. Laboratory device T85D; 2. LPG cylinder; 3. Regulator 4. Pressure regulator and gage; 5. Flow meter for LPG; 6. Vaporizer; 7. Electronic control unit for LPG; 8. Control board; 9. Control of torque; 10. Indicate temperature; 11. Gas analysis.

Fig.1 Laboratory devices T85D and part of the experimental set up



1. Test engine, 2. LPG injector, 3. Vaporizer, 4. Flow meter for LPG. 5. Pressure regulator, 6. Pressure gage, 7.Valve for LPG, 8. Pressure valve, 9. LPG cylinder, 10. Magnetic senso, 11. Electronic control unit for LPG, 12. Air filter, 13. Air manometer, 14. Diesel flow meter, 15. Diesel valve, 16. Diesel filter, 17. Diesel injector, 18. Intake, 19. Exhaust, 20. Dynamometric unit, 21. Gas analysis unit

Fig.2 Block diagram of the experimental set up

Table 2: Shows the properties of commonly used fuels

	Properties	Diesel	LPG
1	Normal state	Liquid	Gaseous
2	Formula	$C_{9.12}H_{16.85}$	$C_{3.34}H_{8.68}$
3	Density (kg/m3) at 15°C	870	550
4	Boiling point, °C	160-320	-34
5	Flashpoint, °C	>52	-140
6	Auto ignition temperature, °C	242-257	525
7	Calorific value, KJ/kg	43500	49000

2.1 Diesel and LPG injection system

The amount of diesel fuel entering the combustion chamber is controlled by special nozzles that have been working according to the percentages (100%, 75%, 50% and 0%) diesel as shown in the Fig.3. These nozzles are used in each experiment according to the operation used in this study.

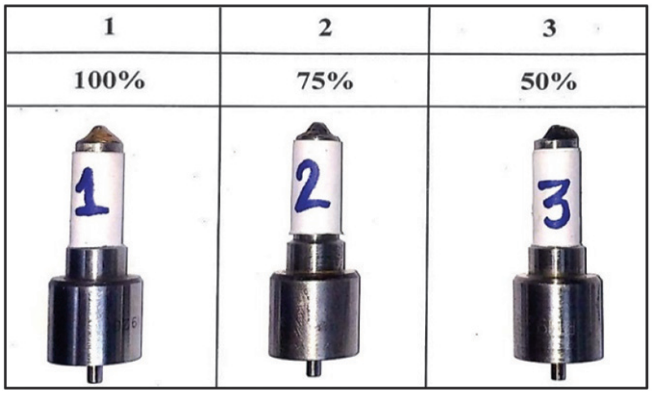


Fig.3 Types of diesel injectors used

The LPG injector used specifications are given below:

- Dimension: 30×55×50
- Working pressure: 1 ± 0.1 bar (LPG), 1.5
- Working temperature: –20° C and + 120°C
- Voltage: 12 V

2.2 Control unit for LPG

This electronic system controls the time and amount of LPG enters the engine via the injector and takes the signal through a magnetic sensor installed on the motor head as shown in the Fig.4 and connected to a 12-volt DC source.

3. Results and discussions

In the beginning of the experiment, the diesel engine was started in pure diesel fuel (D-100). The engine readings are recorded in the basic mode (pure diesel mode), and LPG was used in different proportions LPG-25, LPG-50 and LPG-100 under different loads (0%, 25%, 50%, 75% and 100%) and at engine speeds (1000, 1500 and 2000) rpm and the amount of liquefied petroleum gas is controlled by electronic control unit (ECU).

The fuel consumption information obtained during the test conditions, at the normal diesel mode D-100, LPG- 25, LPG-50 and LPG-100. The mass fraction of LPG (x) is calculated by formula (1) is a quotient of the mass flow rate of LPG divided by the total mass flow rate of the fuel (diesel and LPG):

$$x = \frac{m_{LPG}}{m_{LPG}+m_{Diesel}} \times 100\% \qquad \text{... (1)}$$

This formula was used to find out the consumption of LPG fuel. The term m_{Diesel} represents diesel fuel consumption as determined by a flow meter appropriate for used pure diesel fuel, while *mLPG* is the gaseous fuel consumption measured is the fuel flow meter.

The brake specific fuel consumption (bsfc) is a unit at kg/(kWh) by using Equation (2).

$$bsfc = \frac{\dot{m}f_{Diesel}+\dot{m}f_{LPG}}{bp} \qquad \text{... (2)}$$

The thermal efficiency was calculated by the equation (3) taking into account the lower heating and mass flow rate of both fuel (diesel and LPG)

$$\eta_{bth} = \frac{bp}{(\dot{m}f*LHV)_{Diesel}+(\dot{m}f*LHV)_{LPG}} \times 100\% \qquad \text{... (3)}$$

Through this experiment, the performance characteristics of the engine were studied in two modes, the basic diesel mode and the dual fuel mode, and the following was observed:

3.1 Brake thermal efficiency (η_{bth})

The effect of experimental fuels on the thermal efficiency

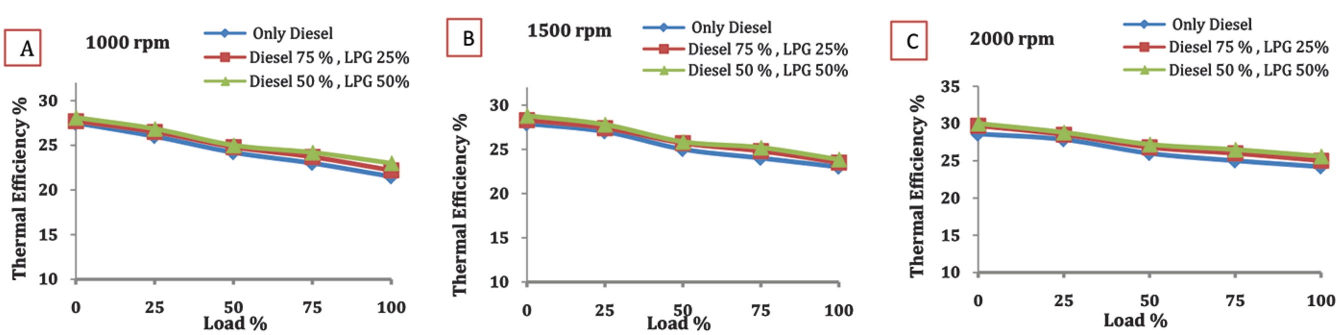


Fig.4 Variation of brake thermal efficiency depending on engine loads

depends on the engine speed and engine load as shown in Fig.4A, B and C. The following is noted. The thermal efficiency of the engine in dual-fuel has improved compared to diesel fuel. The Fig.4 (A, B, C) shows that the rate of thermal efficiency is better for it at dual fuel LPG-50 at the engine speed (1000, 1500 and 2000) rpm, as it has improved by (4%, 3.6%, and 4.9%) respectively compared to pure diesel mode situation at the same engine speed. Thermal efficiency results are at concordance with other studies [3][17][18][19].

3.2 Brake specific fuel consumption (bsfc)

The brake specific fuel consumption of experiment fuel is given as a function of engine loads in Fig.5A, B and C. The lowest bsfc was achieved with LPG-50 fuel at 100% engine load. When bsfc was compared to D-100, LPG-25 and LPG-50, it was shown that bsfc reduced behaviour by (9.81%, 9.4% and 9.68%) respectively (1000, 1500 and 2000) rpm compared to pure diesel mode D-100. Bsfc dropped because the LPG heat value was higher than pure diesel. The findings of other research were close [3][6][20][21].

3.3 Nitrogen oxide emissions (NOx)

The emission of NO_x from LPG of dual fuel engine is lower than that compared to the pure diesel. Fig.6 shows the variation of NO_x. High NO_x emissions were observed under higher loads due to the temperature that decreased during expansion and exhaust strokes. The largest amount of nitrogen oxides appear in the exhaust at the highest elevation of loads and with an increase in engine speeds where the results show the highest increase in pure diesel D-100.

Figs.6A and B and C show the differences in nitrogen oxides in different loads (0%, 25%, 50%, 75% and 100%) where it increases when the load increases in NO_x at LPG-25 and LPG-50. As explained below in detail:

1. The Fig.6A shows the difference in NO_x at 1000 rpm the nitrogen oxides were decreased by 3.8% and 3.19% at mode LPG-25 and LPG-50 respectively compared to the D-100.
2. The Fig.6B shows the difference in NO_x at 1500 rpm the nitrogen oxides were decreased by 7.57%, 18.18% at mode LPG- 25 and LPG-50 respectively compared to the D-100.
3. The Fig.6C shows the difference in NO_x at 2000 rpm the nitrogen oxides were decreased by 4.82%, 10.38% at mode LPG-25 and LPG-50 respectively compared to the D-100.

These findings are consistent with other studies [22][23][24].

3.4 Hydrocarbon emissions (HC)

The emission of unburned hydrocarbon (HC) comes from the combustion of part of the fuel injected into the engine. The HC emissions rely on many mechanisms such as oil layer adsorption and desorption of fuel, flame quenching, fuel leakage into crevices, and fuel deposition in engine deposits. HC emission values depend on speed engine and loads between (1000-2000) rpm and (0%-100%) respectively are given in Fig.7. HC emissions using different LPG ratios have

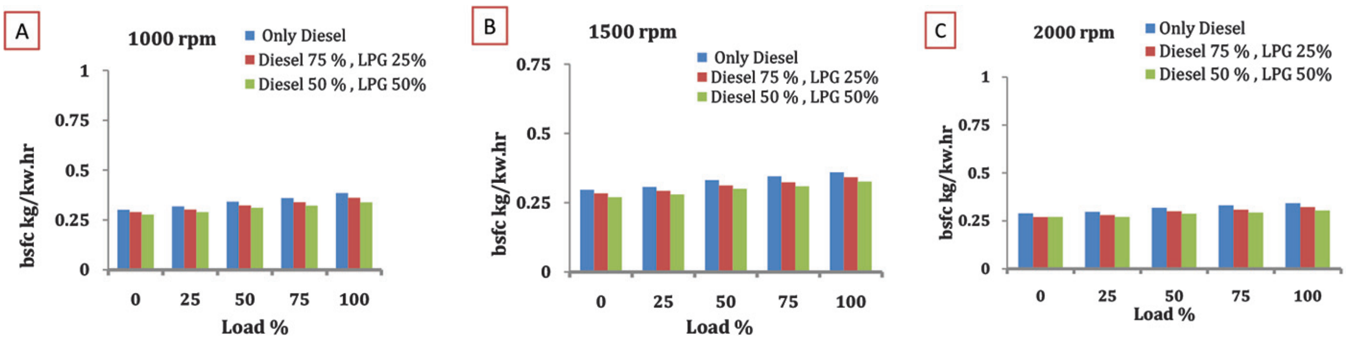


Fig.5 Variation of bsfc depending on engine loads

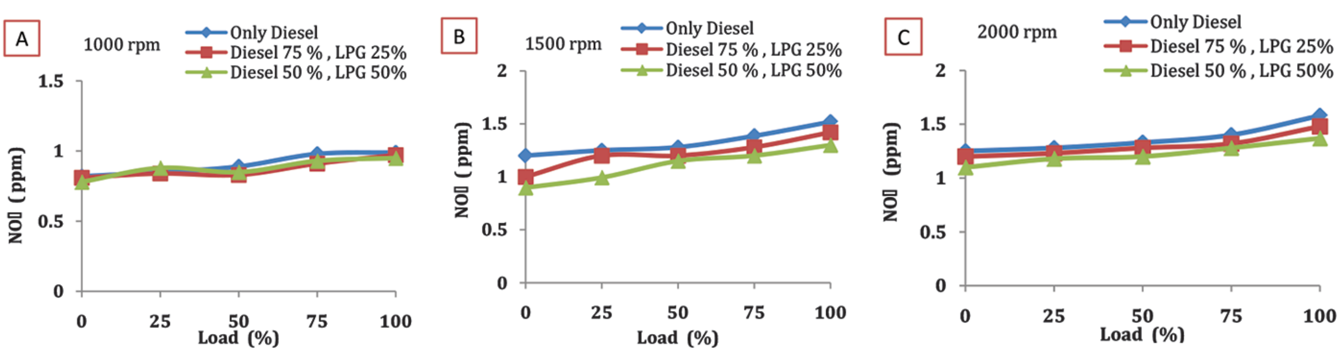


Fig.6 NOx emission variation depending on engine load

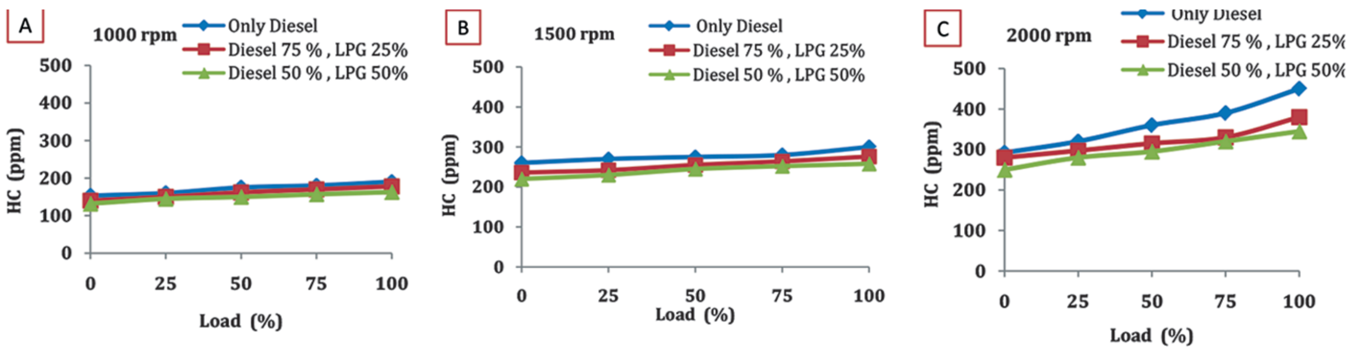


Fig.7 HC emission variation depending on engine load

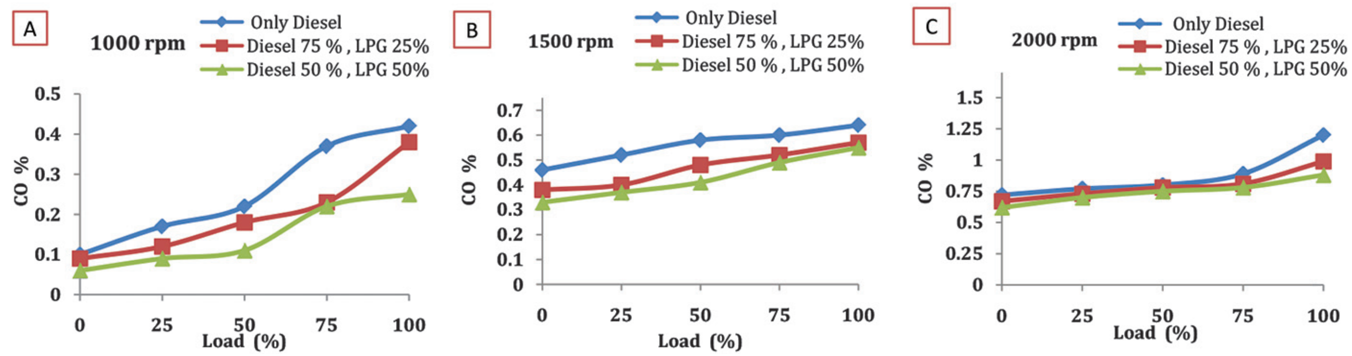


Fig.8 CO emission variation depending on engine load

decreased through improved combustion reactions with diesel pilot fuel and more effective combustion reactions with the help of LPG. As explained below in detail:

1. The Fig.7A shows the variance in HC at 1000 rpm from the figure shown below, that HC decrease by 6.75% and 12.93%, respectively at mode LPG-25 and LPG-50 compared to the D-100.
2. The Fig.7B shows the variance in HC at 1500 rpm from the figure shown below, that HC decrease by 8.3% and 13%, respectively at mode LPG-25 and LPG-50 compared to the D-100.
3 The Fig.7C shows the variance in HC at 2000 rpm from the figure shown below, that HC decrease by 11.94% and 18%, respectively at mode LPG-25 and LPG-50 compared to the D-100.

Similar results were obtained by other studies [4][25][26][27].

3.5 Carbon monoxide emissions (CO)

The emission of CO from LPG of dual-fuel engine is less as compared to the pure diesel and as shown in Fig.8 where we note the following:

1 The Fig.8A shows the difference in CO at 1000 rpm from the figure shown here was the CO at mode LPG-25 and LPG-50 decrease by 21.875% and 42.96%, respectively compared to the D-100.

2 The Fig.8B shows the difference in CO at 1500 rpm from the figure shown here was the CO at mode LPG-25 and LPG-50 decrease by 16% and 23.21%, respectively compared to the D-100.

3 The Fig.8C shows the difference in CO at 2000 rpm from the figure shown here was the CO at mode LPG-25 and LPG-50 decrease by 9.8% and 14.84%, respectively compared to the D-100.

3.6 Carbon dioxide emissions (CO_2)

The emission of CO_2 from LPG of dual fuel engine is lower than that compared to the pure diesel. The Fig.9 shows the variations of CO_2 emissions. At the loads on the engine and engine speed were increased the percentage of CO_2 at diesel fuel and it reduces the increase in the percentage of LPG, as follows:

1. The Fig.(9A shows the variance in CO_2 at 1000 rpm, from the calculations and from the figure shown here, decrease by 16% and 22.37% at mode LPG-25 and LPG-50 respectively compared with the D-100.
2. The Fig.9B shows the variance in CO_2 at 1500 rpm, from the calculations and from the figure shown here, decrease by 9.41% and 24.7% at mode LPG-25 and LPG-50 respectively compared with the D-100.
3. The Fig.9C shows the variance in CO_2 at 2000 rpm, from the calculations and from the figure shown here, decrease by 9.5% and 16.5% at mode LPG-25 and LPG-50 respectively compared to the D-10.

In general, CO_2 emissions were caused by the full combustion of a large amount of fuel at the cylinder and on the other hand, the CO emissions occurred in the remaining fuel from all combustion was burnt insufficiently. The non-combustible part of the fuel produced HC emissions. The reasons why CO and HC emissions are produced are very

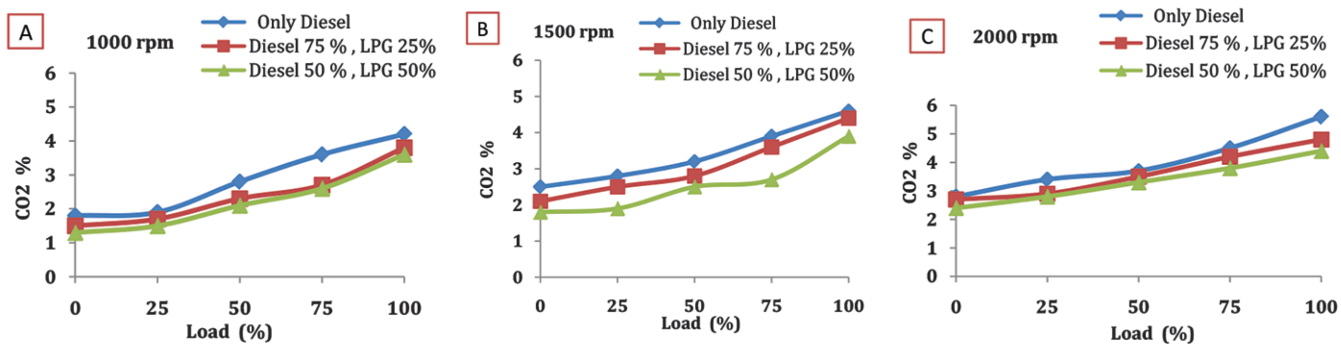


Fig.9 CO_2 emission variation depending on engine load

similar. The direct injection of LPG fuel in the cylinder by an injector under is pressure enabled the LPG to achieve a better atomization level compared to the pure diesel fuel. The improving the combustion reaction with the use the LPG fuel, thus produced a reduction in CO emissions. Better combustion and higher LPG calorific value enhance the flaming propagation and oxidation reactions which slightly reduce HC and CO emissions. In addition, the lower LPG C/H ratio decreases HC and CO emissions, and CO_2 emissions. Those findings indicate with other studies [3][25][6][28].

4. Conclusions

The result of injecting LPG directly into the cylinder on output was experimentally investigated in this paper. The LPG has a high heat value and its gaseous state makes the combination with air simple. LPG has perfect combustion redundancies to increase the power efficiency, and good anti-knock due to high octane. The experiment was carried out application of different compositions of fuel and engine loads at (1000, 1500 and 2000) rpm engine speed. D-100, LPG-25, LPG-50 and LPG-100 were used in the experiments. The test engine was at (0%, 25%, 50%, 75% and 100%) loads through of the loading unit. Depending on these parameters, thermal efficiency and fuel consumption and emissions were measured. The results are given below:

1. The best thermal efficiency was reached using LPG-50 fuel. It was improving about by (4%, 3.6%, and 4.9%) compared to D-100 fuel at the engine speeds 1000, 1500 and 2000 rpm, respectively.
2. The bsfc depends on heating value which increased with the ratio of LPG fuel. The best bsfc was decreased using LPG-50 fuel by 9.81% and 9.4% at 1000, 1500 and 2000 rpm, respectively when comparing with D-100 fuel.
3. No results were obtained in LPG-100 or D-0 mode because the engine did not continuously operate in this mode and it suffers from low thermal brake efficiency due to lack of ignition continues.
4. When the engine runs on the dual fuel show results better emissions than diesel. The best operating mode to reduce emissions is LPG-50 as it contributed to reducing emission ratios by proportions as shown below for each gas:

A. NO_x reduced (3.19% at 1000 rpm, 18.18% at 1500 rpm and 10.38 % at 2000 rpm)

B. HC reduced (12.93% at 1000 rpm, 13% at 1500 rpm and 18% at 2000 rpm)

C. CO reduced (42.96% at 1000 rpm, 23.21% at 1500 rpm and 14.84 % at 2000 rpm)

D. CO_2 reduced (22.37% at 1000 rpm, 24.7% at 1500 rpm and 16.5% at 2000 rpm)

Nomenclature

CNG	Compressed natural gas
LPG	Liquefied petroleum gas
D-100	Diesel fuel
D-0	Diesel 0%
LPG-25	LPG 25% + diesel 745%
LPG-50	LPG 50% + diesel 50%
LPG-100	LPG 100%
ECU	Electronic control unit
GDI	Gasoline direct injection
HC	Hydrocarbon
NO_x	Nitrogen oxide
CO2	Carbon dioxide emissions
CO	Carbon monoxide emissions
O2	Oxygen
bsfc	Brake specific fuel consumption
bp	Brake power

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