Performance study of single cylinder engine dual fuel (diesel + LPG)

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Abstract
Diesel engines efficient and economical large, but at is large in size and non friendly environmental. LPG is available at a lower price than other fuels and environmentally friendly. One of the important research topics that have been updated is the use of LPG in diesel engines. The LPG has a high heat value, and its gaseous state makes mixing with air simple and has perfect redound of combustion to increase the power output also the LPG helps to fully consume the fuel and thus reduces emission and helps to harvest the total energy found in the fuel. It was designed a new Electronic Control Unit (ECU) and used of the LPG injection timing and duration while opening the air intake valve into the combustion chamber and a magnetic sensor is installed on top of a single cylinder diesel engine with air-cooled. The test engine was run in four fuel mode the start was used is D-100, after that the fuel was used LPG-25, LPG-50 and LPG-100. The test was under loads 0%, 25%, 50%, 75% and 100% at different speeds 1000, 1500 and 2000 rpm. At the engine speeds 1000, 1500, 2000 rpm compared with D-100 fuel, the thermal efficiency was better at using LPG-50 fuel were increased about by (0.99%, 0.92%, 1.29%) and bsfc were decreased as (9.81%, 9.4% and 9.68%) respectively. A decrease in emissions, NOx, HC, CO and CO2 was observed in all operating modes with LPG and the best emission reduction situation is LPG -50.

Index Terms— Diesel Fuel, Dual Fuel, Diesel Engine, LPG Fuel

1. Introduction
Diesel engines are large in size, high in efficiency, more economical and able to generate high power compared to other engines. Because of this they are commonly used in many other fields as agriculture, industry, transportation and electricity generate... etc. The environmental concerns increasing and the oil resources reducing led researchers making fuel consumption better, improve engine performance, and reduce fuel costs, especially in the country of Iraq, which is blessed with oil wealth and which has LPG and is available at a lower price than other fuels. One of the important research topics that have been updated is the use of liquefied 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 octane high [1]. Gas fuel won't dilute lubrication oil on the engine. Lubrication oil replacement time may be longer [2]. 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 [3]. The Increase 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 causes[4], as well as its impact on the life of the engine [5], 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 LPGLPG 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 [6] and Ehsan et al. [7], LPG was successfully used, but the dual fuel operation in the diesel engine was relatively less investigated. Jian, et al. [8] 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 [9] 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 the best efficiency and optimal combination of the proportions induced to inject fuel energy was calculated in each case. Salman et al. [10] investigated the reduction in the emission of exhaust gas from a dual-fuel diesel engine. Modified a single-cylinder, direct-injection diesel engine 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 [11][12], about 40 to 65 percent 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 [11][12]. Saleh[1] has shown that both environmental and economic benefits of dual fuel service with LPG. Karim [13] stressed the understanding essential the mechanisms of dual-fuel combustion engines at 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 [5][14].

From the previous studies reviewed, 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 is 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 figure (1) manufactured by LOMBARDINI LGA 226 Company is used in the present work. A control panel equipped with a laboratory device (T85D) 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. In the figure (2) shows the design and construction of an experimental apparatus engine modification to conduct the study. The tested it consists a unit of CI engine, LPG system. The engine tests 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 signal 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 shows in table (1).

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 setup
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 sensor.
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 setup

Table 1: Specification of the test engine

| Brand               | LOMBARDINI, ITALY |
|---------------------|--------------------|
| Type                | 15LD315            |
| Injector type       | Direct injection   |
| Engine type         | Single cylinder direct injection 4-stroke |
| Cooling type        | Air-cooled         |
| Cylinders           | N                  |
| Displacement        | cm³                |
| Stroke              | mm                 |
| Compression ratio   | 20.3:1             |
| Max. Power          | 5.0 Kw/6.8 HP      |
| Dry weigh           | Kg                 |
| Max. Torque         | NM                 |
| Rated speed         | RPM                |
| Dimension (LxWxH)   | mm                 |
| Method of starting  | Hand cranking      |

These diesel and LPG fuels were used as fuels in this experiment. The LPG content was consisted of gases three mixtures of Ethane (0.05 C2H6), Propane (0.5 C3H8) and Butane (0.45 C4H10). Test fuel properties are shown in table (2).

Table 2: Shows the properties of commonly used fuels.

| S. No. | Properties                  | Diesel          | LPG            |
|--------|-----------------------------|-----------------|----------------|
| 1      | Normal state                | Liquid          | Gaseous        |
| 1      | Formula                     | C9.12H16.85     | C3.34H8.68     |
| 2      | Density (kg/m³) @ 15 °C     | 870             | 550            |
| 3      | Boiling Point, °C           | 160-320         | -34            |
| 4      | Flashpoint, °C              | >52             | -140           |
| 5      | Auto Ignition Temperature, °C | 242-257        | 525            |
2.1 Diesel and LPG injection system
The amount of diesel fuel entering the combustion chamber is controlled by special nozzles that have
been worked on according to the percentages (100%, 75%, 50% and 0%) diesel as shown in the figure (3). These nozzles are used in each experiment according to the operation used in this study.

|   | Calorific Value, KJ/kg |
|---|------------------------|
| 1 | 43500                  |
| 2 | 49000                  |

Fig.3 Types of diesel injectors used

The LPG injector used is shown in Figure (3.15) and its specifications below:
- Dimension: 30x55x50
- Working Pressure: 1 ± 0.1 Bar (LPG), 1.5
- Working Temperature: -20 °C and + 120 °C
- Voltage: 12 V

Fig.4 LPG Injector

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 figure (4) and connected to a 12-volt DC source.

3. Results and Discussion
At 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):

\[ x = \frac{m_{\text{LPG}}}{m_{\text{LPG}} + m_{\text{Diesel}}} \times 100\% \]  

(1)

This formula was used to find out the consumption of LPG fuel. The term \( m_{\text{Diesel}} \) Represents diesel fuel consumption as determined by a flow meter appropriate for used pure diesel fuel, while \( m_{\text{LPG}} \) is the gaseous fuel consumption measured being is the fuel flow meter.

The brake specific fuel consumption (bsfc) is a unit at Kg/(kW h) by using Equation (2).

\[ \text{bsfc} = \frac{m_{\text{f Diesel}} + m_{\text{f LPG}}}{bp} \]  

(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)

\[ \eta_{\text{bth}} = \frac{bp}{(m \cdot f \cdot \text{LHV})_{\text{Diesel}} + (m \cdot f \cdot \text{LHV})_{\text{LPG}}} \times 100\% \]  

(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 (\( \eta_{\text{bth}} \))

The effect of experimental fuels on the thermal efficiency depends on the engine speed and engine load as shown in Figure (5) A, B and C. The following is noted. The thermal efficiency of the engine in dual fuel has improved compared to diesel fuel. The figure (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 (0.99%, 0.92% and 1.29%) respectively compared with pure diesel mode situation at the same engine speed. Thermal efficiency results are at concordance with other studies [1][15][16][17].
3.2 Brake Specific Fuel Consumption (bsfc)

The brake specific fuel consumption of experiment fuel is given as a function of engine loads at the figure (6) A, 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 showed reduced behavior 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 [1][4][18][19].

Fig.5 Variation of Brake Thermal efficiency depending on engine loads

Fig.6 Variation of bsfc depending on engine loads

3.3 NITROGEN OXIDE EMISSIONS (NOx)
The emission of NOx from LPG of dual fuel engine is lower than that compared to the pure diesel. Figure (7) shows the variation of NOx. High NOx 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 showed the highest increase in pure diesel D-100

The figure 7 (A and B and C) shows the differences in nitrogen oxides in different loads (0%, 25%, 50%, 75% and 100%). Where it increases when the load increases in NOx at LPG-25 and LPG-50. As explained below in detail:

1- The figure (7, A) shows the difference in NOx at 1000 rpm the nitrogen oxides were decreased by 3.8% and 3.19% at mode LPG-25 and LPG-50 respectively compared with the D-100.
2- The figure (7, B) shows the difference in NOx at 1500 rpm the nitrogen oxides were decreased by 7.57%, 18.18% at mode LPG-25 and LPG-50 respectively compared with the D-100.
3- The figure (7, C) shows the difference in NOx at 2000 rpm the nitrogen oxides were decreased by 4.82%, 10.38 % at mode LPG-25 and LPG-50 respectively compared with the D-100.

These findings are consistent with other studies [20] [21][22]

![Fig.7 NOx emission variation depending on engine load](image)

**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 engine and loads between (1000-2000) rpm and (0% - 100%) respectively are given in figure (8). HC emissions using different LPG ratios have 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 figure (8, A) 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 with the D-100.
2- The figure (8, B) 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 with the D-100.
3- The figure (8, C) 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 with the D-100.

Similar results were obtained by other studies [2] [23][24][25].

![Graph showing HC emission variation depending on engine load](image)

**Fig.8 HC emission variation depending on engine load**

### 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 the figure (9) where we note the following:

1- The figure (9, A) shows the difference in CO at 1000 rpm from the figure shown below was the CO at mode LPG-25 and LPG-50 decrease by 21.875% and 42.96%, respectively compared with the D-100.
2- The figure (9, B) shows the difference in CO at 1500 rpm from the figure shown below was the CO at mode LPG-25 and LPG-50 decrease by 16% and 23.21%, respectively compared with the D-100.
3- The figure (9, C) shows the difference in CO at 2000 rpm from the figure shown below was the CO at mode LPG-25 and LPG-50 decrease by 9.8% and 14.84%, respectively compared with the D-100.

### Fig.9 CO emission variation depending on engine load

#### 3.6 CARBON DIOXIDE EMISSIONS (CO2)

The emission of CO2 from LPG of dual fuel engine is lower than that compared to the pure diesel. The figure (10) shows the variations of CO2 emissions. At the loads on the engine and engine speed were increased the percentage of CO2 at diesel fuel And it reduces the increase in the percentage of LPG, as follows:

1- The figure (10, A) shows the variance in CO2 at 1000 rpm, from the calculations and from the figure shown below, decrease by 16% and 22.37% at mode LPG-25 and LPG-50 respectively compared with the D-100.
2- The figure (10, B) shows the variance in CO2 at 1500 rpm, from the calculations and from the figure shown below, decrease by 9.41% and 24.7% at mode LPG-25 and LPG-50 respectively compared with the D-100.
3- The figure (10, C) shows the variance in CO2 at 2000 rpm, from the calculations and from the figure shown below, decrease by 9.5% and 16.5% at mode LPG-25 and LPG-50 respectively compared with the D-100.
In general, CO2 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 burned insufficiently. The non-combustible part of the fuel produced HC emissions. The reasons why CO and HC emissions are produced are very 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 deceases HC and CO emissions. Those findings indicate with other studies [1][23][4][26].

4. Conclusions

The result of injecting LPG directly into the cylinder on output was experimentally investigated in this report. The LPG has a high heat value and its gaseous state make the combination with air simple. LPG has perfect combustion redundancies to increase the power efficiency, and good antiknock 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 was 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 below:
1-The thermal efficiency best was reached using LPG-50 fuel. It was increased about by 0.99% and 0.92% compared than D-100 fuel at the engine speeds 1000, 1500 and 2000 rpm, respectively.

2-The bsfc was depends on heating value which increased with the ratio of LPG fuel. The bsfc best was decreased using LPG-50 fuel by 9.81% and 9.4% at 1000, 1500 and 2000 rpm, respectively when comparing to 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- NOx 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- CO2 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 |
| NOx | Nitrogen oxide |
| CO2 | CARBON DIOXIDE EMISSIONS |
| CO | CARBON MONOXIDE EMISSIONS |
| O2 | Oxygen |
| bsfc | Brake specific fuel consumption |
| bp | Brake power |

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