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The combustion characteristics of compression ignition engine fuelled partially by LPG-Diesel blends (Simulation study)

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ABSTRACT

This paper proposes a numerical investigation of the behavior of the dual diesel-Liquefied Petroleum Gas (LPG) engine. Numerical analysis is performed with the aid of the simulation program Diesel-RK. Three volumetric LPG blends: 5 % LPG, 8 % LPG, and 10%LPG are inducted with air intake for a single cylinder,4-stroke, constant speed diesel engine with a fixed compression ratio of 15.5/1. No dramatic change in combustion pressure is seen for 5%,8%, and 10% LPG compared to the case of 0% LPG (diesel only). Diesel's maximum energy production is 32.53 (1/deg.) at 365 degrees BTDC, and this is lowered to 30.28 (1/deg.) at the same crank angle when using 10% LPG. Maximum temperature and pressure rise a little bit by 0.14 % and 0.41 % for 10 % LPG. Increasing the LPG injection rate reduces volumetric efficiency and mechanical efficiency slightly. The results found a slight increase in NOx and a considerable reduction is captured in Bosch smoke number (BSN) when LPG is used with diesel. The obtained is validated with the findings of other researchers.

1. Introduction

Improvements in diesel engine fuel efficiency have led to its widespread use in recent years as a primary propulsion source across industries. Due to their high power output and low cost, diesel fuel engines have become popular in many domains [1]. Despite their fuel economy, diesel engines have certain disadvantages, including higher NOx and particulate emissions. [2] So, alternative fuels could be used instead of traditional diesel to cut down on pollution [3].

Liquefied petroleum gas (LPG) is a viable alternative fuel for diesel engines. because it has the potential to drastically reduce pollution emissions (particularly nitrogen oxides (NOX) and smoke) without compromising engine performance.[4]. Gaseous LPG, often known as "autogas," is a byproduct of refining petroleum and consists mostly of propane, propylene, butane, and other light hydrocarbons [5-7]. It can only be used in the CI engine in dual fuel mode, and a substantial study has been conducted in this way. It results in improved performance as well as lower particle and smoke emissions [8]. Since diesel fuel and LPG are both suitable for this engine, we call it a "dual fuel" engine. LPG and air are either mixed directly in the intake manifold or injected into the engine's cylinders [9]. Dual fuel operation increased specific fuel consumption

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Nomenclature

Ao, A2, A3	Constants	HC	Hydrocarbons
		LNG	Liquefied Natural Gas
BSFC	Brake Specific fuel consumption	LPG	Liquefied petroleum gas
BSN	Bosh smoke number	NOx	Nitrogen Oxides
CA	Crank Angle degrees	P	cylinder pressure (pa)
CI	Compression ignition engine	PI	Prediction interval
CO	Carbon monoxide	Ps	saturation vapor pressure of fuel
CO2	Carbon Dioxide	Vc	the volume of a cylinder
DF	Diesel Fuel	X	percentage of heat release
DI	Direct Injection	Xo	the proportion of fuel vapor generated during the delay interval
EFM	Elementary fuel mass		

relative to diesel operation. Also, when comparing pure diesel operation to dual-fuel operation, we find that the latter reduces

emissions of nitric oxide and soot, though it also increases emissions of carbon monoxide [10]. Because the engine may use either liquid or a combination of liquid and gaseous fuel, it can be used in a range of situations, making the dual-fuel idea very desirable [3]. A high octane number prevents LPG from igniting during the compression stroke (high self-ignition temperature).but it ignites fast when blended with a fuel that has a lower octane rating (such as diesel) [11]. When more LPG is put into the engine, the power and performance both get better, and the emissions go down. LPG can only be used in diesel engines as a dual fuel because it has a low cetane number and is hard to use in large amounts [12]. The gaseous LPG fuel phase may be injected into diesel engines through the intake manifold[13]. Because the pumping pressure is more than 0.5 MPa, At higher pressure, diesel moves from the gas phase into the liquid phase. LPG has a low boiling point, so when it's pumped into the cylinder, it evaporates and helps spread out the fuel spray [14-15]. There have been several studies conducted on LPG–Diesel dual-fuel engines, Vezir Ayhan et al[16]. Emissions and performance indicators of a normally aspirated four-stroke diesel engine with a single cylinder were measured while the engine was exposed to LPG injection during the air input phase. After figuring out the best LPG mix for dual operation, designers made an electrical device to inject the fuel. 5 %, 10%, 15 %, and 25 % LPG injection rates were established by mass. The results showed that the best SFC and brake thermal efficiency occurred at 15% LPG and engine speeds between 1400 and 1800 rpm. Optimal exhaust gas emission levels and engine performance were achieved with a 5% LPG injection rate D.H. Qi[17]. The combustion of LPG and diesel is being investigated. By increasing the LPG energy, the peak cylinder pressure, the pressure rise rate, and the heat release rate are all decreased under modest engine loads. At 25% LPG energy content and maximum engine loads, these characteristics are at their maximum. The study indicated that when the amount of LPG was increased, the ignition delay time and combustion duration also rose while the engine was operating under light load. However, they first rise and then fall with increased engine loads. Each engine load corresponds to an output of LPG energy. Dual-fuel operation is only detrimental at mild loads while being more efficient than diesel. Le and The Nguyen[18] experimented with a modified one-cylinder diesel engine fuelled by diesel and LPG to assess its combustion and environmental effects. Due to the knocking limit being reached at low engine speeds, the maximum LPG replacement happens under full load.

Dual-fuel engines, however, save the most money when driven quickly. Specifically, LPG is at 54% at 2000 rpm but lowers to 40% at higher speeds. Qi et al[19] The performance and pollution of a diesel engine with a single cylinder and DI were studied experimentally to determine the effect of LPG-diesel mixed fuel combustion. An increase in LPG mass fraction reduces peak pressure in the cylinder and delays ignition. Emissions of nitrogen oxide (NOx), hydrocarbons (HC), and carbon monoxide (CO) all decrease at high engine loads This research looked examined the effects of different loads on a constant speed, single-cylinder, four-stroke diesel engine's performance, combustion characteristics, and emissions. while increasing at low loads when LPG mass fraction is low. Rao. et al.[20] Mechanical

and brake thermal efficiency decreases as LPG percentage increases below 20% of engine load, but increases above this load (80%). Reduced volumetric efficiency, however, with an increasing LPG percentage in both engine load states. When looking at emissions, it was found that increasing the content of LPG led to higher concentrations of both HC and CO. Conversely, There has been a reduction in smoke density and nitrogen oxide (NOX) emission. Elnagjjar et al[21] Using a variety of LPG compositions (propane/butane volume ratios of 100:0, 70:30, 55:45, 25:75, and 0:100), the efficiency of a normally aspirated, directly injected diesel engine is evaluated and compared. The results show that, while LPG composition has little effect on engine performance, it has a significant impact on the number of exhaust emissions. Proportions of 50/50 propane and butane are more efficient than either gas alone. Ronald and somasundaram[22] By replacing some of the diesel with LPG, the thermal and mechanical efficiency of a diesel engine may be increased by around 5 % while specific fuel consumption is reduced by about 33 % and carbon monoxide emissions are reduced by about 13 %. However, when using a fuel mixture of 60% LPG and 40% diesel, both NOx and CO2 emissions were reduced by 35% and 67%, respectively. Vijayabalan and Nagarajan[23] It was found that the diesel engine's characteristics were improved by installing a glow-plug within the combustion chamber under low load, with increases in braking thermal efficiency of 3% and decreases in HC emissions of 69%, CO emissions of 50%, and smoke emissions of 9%. Rimkus et al.[24] The use of LPG and its impact on the performance and environmental impact of a turbocharged, four-stroke, compression-ignition engine is under study. Blending LPG with diesel decreased engine efficiency, according to the study authors, since it decreased the quantity of diesel supplied to the cylinder and delayed the diesel injection moment. The addition of LPG increased both CO and HC levels in the exhaust emissions while reducing NOx and carbon monoxide levels. Giang and son[25] Change the amount of LPG in diesel fuel in a Toyota 3CTE diesel engine and see how it affects performance and pollution. When they used a dual fuel configuration, they saw that the engine's normal torque and output went down, but not by a huge margin compared to when it was running on 100% diesel and producing 98.5% and 85% of its maximum torque and power, respectively. In all modes of operation, NOx and smoke emissions are reduced, while CO and HC emissions are greatly increased. Anye [26] We used a one-dimensional model developed in AVL BOOST to conduct a numerical analysis of the performance characteristics and associated pollutants of dual-fuel (diesel-LPG) under various operating regimes and fuel (diesel-LPG) mass ratios. At maximum LPG content (70% diesel, 30% LPG) and engine speed (2435 rpm), the maximum cylinder pressure for a pure diesel engine is raised by 21.07%. Furthermore, power increased linearly when the LPG mass ratio was increased from 10% to 30%. With a higher LPG mass ratio, NOx emissions are reduced. Hadi and Qadir[27] Researchers tested using varying percentages of Iraqi LPG (from 10% to 25%) with varying percentages of Iraqi gas-oil fuel while keeping the thermal load constant to determine the possibility of reducing pollutant emissions. Combining LPG and gas–oil as well as air mass flow uncommon, the Rota-meter regulates the mass flow rate to reach a set temperature. Incomplete combustion was indicated by a 3% rise in CO, soot, and UHC levels with an increase in the equivalency ratio and a 2.5% decrease in CO2 and NOx levels owing to the lower oxygen ratio in the mixture. Helin xiao et al.[28] Analysis and modeling of spray and combustion parameters of LPG, diesel, and 30% and 50% LPG/diesel blends were conducted. For numerically computing the spray properties, we use the KIVA–3V approach and apply it to a high-pressure constant-volume container and high-speed photography. Compared to diesel, LPG results in a smaller spray angle and a shorter spray combustion duration. Spray loses efficiency as air pressure increases. The numerical results were in agreement with the observational data within very small margins. But the low sensitivity of the imaging equipment when used at high speeds led to results that did not match what was expected at the late injection point.Albert Boretti[29]. The performance of a diesel–LPG engine with two main injectors in each cylinder was analyzed numerically. Analytical results are presented for a high-speed direct-injection turbocharged diesel engine with a displacement of 1600 cc running throughout a wide speed and load range on both diesel and LPG. Direct injection of LPG into the engine is made possible by adding a new injector to each cylinder. The purpose of this research is to determine how much pilot/per diesel fuel energy is needed to power a diesel engine in a way similar to combustion with LPG primary injection.

The purpose of this study is to examine the characteristics of a diesel engine running on a dual-fuel LPG-diesel setup with the help of simulation software Diesel-RK.

2. The Materials and Methods

In this study, liquefied petroleum gas (LPG) was used as a replacement for diesel in an effort to lower diesel engine emissions. Gaseous liquid petroleum gas (LPG) was utilized as the primary fuel, with diesel serving as the secondary fuel while operating in dual fuel mode. The current study compared three different LPG flow rates (5%, 8%, and 10%). The characteristics of diesel and LPG fuel are compared in Table 1.

3. Properties and composition of Iraqi LPG

When considering the many clean gaseous fuels on the market, including LPG, LNG, and DME (Dimethyl-ether), LPG stands out as one of the most promising alternatives. [30]. LPG is made from hydrocarbons created during crude oil refining and heavier natural gas components[31]. Propane (C_3H_8) is the most common component of LPG, however variable quantities of butane (C_4H_{10}) are used depending on the geographical region, season, and production technique. Beyond propane and butane, LPG may also include trace quantities of other hydrocarbons[5]. Table 1 presents the properties of Iraqi LPG and diesel[24]. Because of its wide supply infrastructure and higher heating value, LPG is a viable alternative fuel. Since it has a higher octane value, LPG has benefits in terms of operating characteristics at high compression ratios[32]. At the low-pressure range of (0.7–0.8) MPa, it may liquefy at room temperature. Due to its lower density and better stoichiometric (fuel/air) ratio, LPG may reduce specific fuel consumption compared to petro-diesel. Since LPG has a greater calorific value than petro-diesel, an LPG-fueled engine using the same equivalency ratio as a petro-diesel-fueled engine might provide more effective power[33,34]. By comparison, the emissions of greenhouse gases and other pollutants that are controlled by law are reduced when LPG is used. Furthermore, LPG's greater ignition temperature than diesel slows the fuel's auto-ignition, preventing knocking[35]. The diesel engine shown in Table 2 is the subject of mathematical analysis.

Table1 diesel fuel and Liquefied petroleum gas properties [24]

Properties	**Iraqi diesel**	**5%Iraqi LPG**	**8%Iraqi LPG**	**10%Iraqi LPG**
Formula	$C_{13.775}H_{24.7}$	$C_{13.24}H_{24.2}$	$C_{12.92}H_{23.97}$	$C_{12.7}H_{23.77}$
Molecular mass	190	183.147	179.036	176.295
Density (kg/m3)	830	788.606	763.77	747.056
Lower heating value(MJ/kg)	45.83	45.855	45.866	45.874
Stoichiometric A/F ratio(kg/kg)	14.406	14.463	14.493	14.519

Table 2 Specifications for engine [36]

Engine Make	**Kirloskar diesel engine**
Engine type	4 stroke, single-cylinder
Bore × Stroke	80 mm× 110 mm
Compression ratio	15.5
Rated output	3.7KW
Injection pressure	160 bar
Injection timing	20 CA BTDC

4. LPG/diesel dual-fuel.

Similarly to a spark-ignited engine, the air-LPG intake mixture is forced into the cylinder and compressed to increase the temperature and pressure. A little quantity of pilot diesel fuel is injected at the end of the compression stroke to ignite the mixture. This ignition source is a pilot injection. The LPG gas-air combination ignites in many places around the injected diesel spray, creating several flame fronts. The result is a rapid and easy start to the combustion process. [37].

5. Numerical modeling

The diesel engine (detailed in Table 2) was analyzed using the modeling program Diesel RK to determine its performance characteristics when fueled by diesel and LPG mixes. In the works cited, details about the different equations used in the simulation are given[36,38].

5.1 Spray Evaluation Model

When an elementary fuel mass (EFM) is being moved from the injector to the spray tip in a very short time interval, its speed may be described by equation (1). Figure 1 illustrates the spray's path over time:

$$[\frac{V}{V_O}]^{\frac{3}{2}} = 1 - \frac{l}{l_m} \quad (1)$$

Where:
V: is the EFM's current speed.
V_O : The initial EFM speed at the injector nozzle
l : current distance between EFM and the nozzle injector.
l_m : The distance between the beginning of an EFM pulse and its end in front of a spray

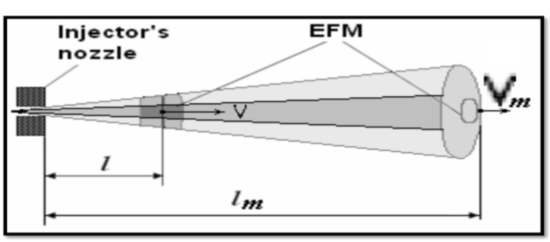

Figure 1. The spray development over time[39]

Following is a solution to equation (1)

$$3l_m[1 - [\frac{l}{l_m}]^{0.333}] - V_O\,\tau_k = 0 \quad (2)$$

Where, τ_k is the time required for the EFM to travel l distance from the nozzle injector, When The EFM is turned off at the spray nozzle $l = l_m$ and $\tau_k = \tau_m$.

Where, τ_m: There is travel time for the EFM to the quantity at the front of the spray before it ends. Equation (2) can also be rewritten as follows:

$$l_m = V_0 \frac{\tau_m}{3} \quad (3)$$

Equations (1) and (2) may be used to determine the speed and length of EFM at any given time.

$$V = V_0\{1 - \frac{\tau_k}{\tau_m}\}^2 \quad (4)$$

$$l = l_m[1 - \left[1 - \frac{\tau_k}{\tau_m}\right]^3] \quad (5)$$

5.2 Model for releasing heat

The combustion process is separated into four phases, each with its own chemical and physical characteristics that limit the rate of burning. The stages are shown here.

1. Ignition delay interval phase:

$$\tau = e^{\left(\frac{Ea}{8.312T} - \frac{70}{CN+25}\right)} * \sqrt{\frac{T}{P}} * 3.8 * 10^{-6} * (n * 1 - 1.6 * 10^{-4}) \quad (6)$$

2. Combustion of a combination of air and fuel vapor produced by premixed combustion phase :

$$\frac{dx}{dt} = \varphi_1\left\{\frac{d\sigma_u}{d\tau}\right\} + \left\{A_0 * (0.1\sigma_{ud} + x_0)(\sigma_{ud} - x_0)\left(\frac{m_f}{V_i}\right)\right\} * \varphi_o \quad (7)$$

3. A phase of diffuse combustion (A direct injection of fuel is then burnt):

$$\frac{dx}{d\tau} = \varphi_2 * \left\{(\emptyset - x)(\sigma_u - x) * \left\{\frac{m_f}{V_c}\right\} * A_2\right\} + \varphi_1 * \left\{\frac{d\sigma_u}{d\tau}\right\} \quad (8)$$

4. A phase of late combustion (fuel combustion after injection is complete):

$$\frac{dx}{d\tau} = K_T * A_3 * (\epsilon_b\emptyset - x)(1 - x) * \varphi_3 \quad (9)$$

$\varphi_o = \varphi_1 = \varphi_2 = \varphi_3$ is a function representing the end of fuel vapor combustion in different regions:

$$\varphi = 1 - \left[\frac{A_1}{\epsilon_b * \emptyset} - x\right]\frac{dx}{dt}\{\sum_{i=1}^{m_w}[300 * r_{wi} * e^{\left(\frac{-16000}{r_{wi}+2500}\right)}] + r_v\} \quad (10)$$

Where, ϵ_b: reveals the efficiency of air use, r_v: The data show how different environmental zones and fronts vary in their evaporation rates, $\emptyset$: reflects the equivalence ratio,r_{wi}: represents the relative rate of evaporation in different zones of the wall surface flow

5.3 Modeling NOx Formation

In a mixture of nitrogen dioxide (NO2) and nitric oxide (NO), (NOx) emissions are produced. Due to the fact that combustion in a dual-fuel engine is governed by temperature, the Zeldovich mechanism is a generally accepted approach for NOx generation. The following equations describe the main processes that govern the generation of NO from molecular nitrogen during burning :

$$O_2 \leftrightarrow 2\,O \quad (11)$$

$$O + N_2 \leftrightarrow NO + N \quad (12)$$

$$O_2 + N \leftrightarrow NO + O \quad (13)$$

As seen in Equation 13, the concentration of atomic oxygen influences the reaction rate. The NO volume concentration is calculated using the following formula[40].

$$\frac{d[NO]}{d\theta} = \frac{2.33*10^7*P\left[1-\left(\frac{[NO]}{[NO]_e}\right)\right]*[N_2]_e[O]_e*e^{\frac{-38020}{T_z}}}{RT_z\left[1+\frac{[NO]}{[O_2]_e}*\left(\frac{2365}{T_z}\right)e^{\frac{3365}{T_z}}\right]}\left[\frac{1}{rps}\right] \quad (14)$$

5.4 Concentration modeling of soot

The term "soot" refers to a specific kind of very small black carbon particles. that forms when a vapor carrier is present. In most cases, it is the result of an incomplete hydrocarbon combustion process. The combustion process causes it to develop, oxidize, and increase. In Ref[41].A thorough study on modeling soot is given.

When the engine is running normally, the amount of soot in the exhaust can be described as:

$$[C] = \int_{\theta_B}^{480} \frac{d[C]}{d\tau}\,\frac{d\theta}{6n}\left[\frac{0.1}{P}\right]^{\gamma} \quad (15)$$

Equation (16) is used to define particulate matter (PM) as a function of (BSN): [43]

$$[PM] = \left[ln\frac{10}{10-Bosch}\right]^{1.206} * 565 \quad (16)$$

6. The Validity of the Model

Data generated by the program is double-checked against the findings of other researchers. All the same parameters and operation states are entered into the program's databases. Figure 2 shows the spray development per time for diesel fuel. Similar tendencies and good agreement with a variation of 5% are found. Figure 3 demonstrates the history of diesel heat release rate for the present work and the work of Qusay et al [43]. It is safe to say that Diesel RK software is an effective simulation tool for studying IC engine combustion characteristics.

7. Results and Discussion

The exhaust gas emissions were first measured with the diesel engine running on pure diesel fuel (D-100) before adding varying amounts of LPG to the fuel (5% LPG, 8% LPG, and 10% LPG) at 100% load (full load) at a steady engine speed of 1500 rpm

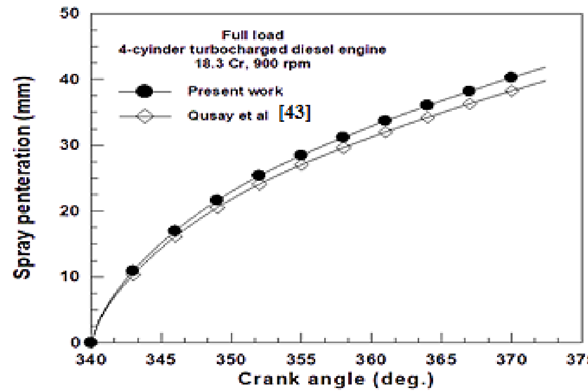

Figure 2. Validation of diesel full-load spray tip penetration

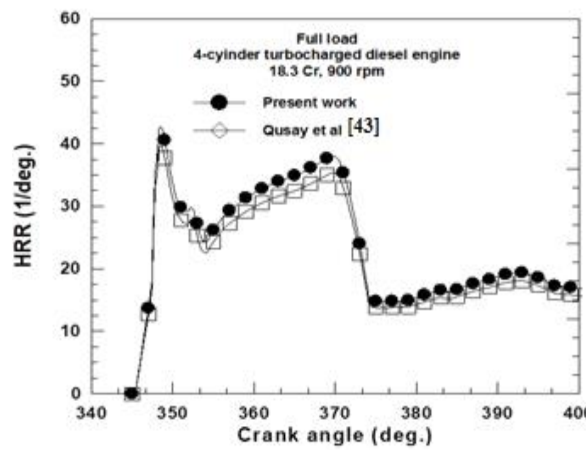

Figure 3. Validation of f diesel full-load heat-release rates

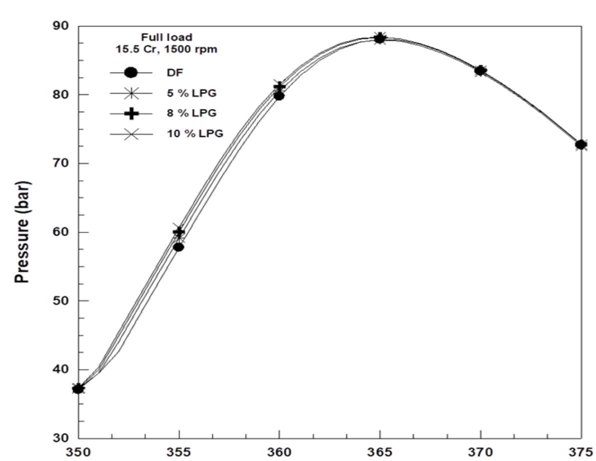

Figure 4. Variation of cylinder pressure with crank angle.

7.1 A Combustion Analysis

Figure 4 This presents the change in cylinder pressures as a ratio of LPG injection rates. It is clear from the illustration that an increase in LPG use led to a pressure rise. Injecting LPG into a mixture result in greater pressure since more energy is being delivered into the system. Diesel fuel has a maximum operating pressure of 88.07 bar, with LPG the maximum pressure of 88, 88.38, and 88.43 for 5%, 8%, and 10% LPG, respectively. [43].

The release rate of heat is seen in Figure 5. When LPG is mixed with diesel, the delay between ignition and combustion is cut down, so combustion can start sooner, and less heat is given off [45]. Diesel's highest energy output is 32.53 (1/deg.) at 365 degrees BTDC, however, at 365 degrees BTDC, it is just 31.14, 30.76, and 30.28 (1/deg.). For LPG concentrations of 5%, 8%, and 10%, BTDC is used.

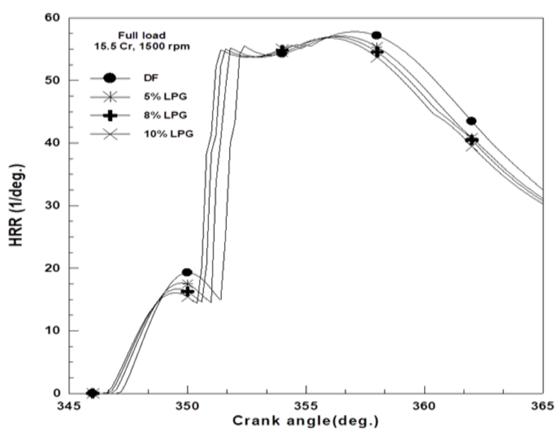

Figure 5. Rate of heat release history for diesel and LPG mixtures

Maximum temperature and pressure as a result of LPG addition are shown in Figure 6. Maximum pressure increased by 0.088%, 0.35%, and 0.41% at 5%, 8%, and 10% LPG concentrations, respectively, due to increased flame speed in the homogeneous mixture of air and LPG. The maximum temperatures reached their highest point at 10% LPG.

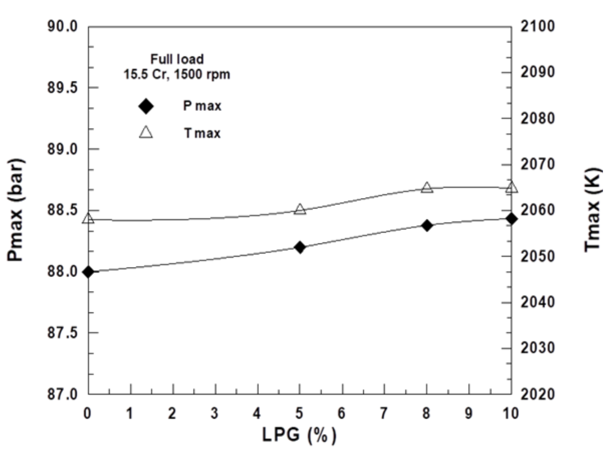

Figure 6. effect of varying LPG on the maximum (pressure and temp.)

Figure 7 presents the impact of LPG concentration on ignition delay and combustion duration. Upon adding LPG the ignition delay is decreased by about 4.3%,6.9%, and 8.7% for 5% LPG,8% LPG, and 10% LPG, respectively, which reduces the tendency of knocking as well as regulates combustion pressure and hence, improves combustion. This is also confirmed with the other side of this Figure where inducting LPG reduces the combustion duration clearly, by 8.9%, 10%, and 9.4% for 5% LPG,8% LPG, and 10% LPG, respectively.

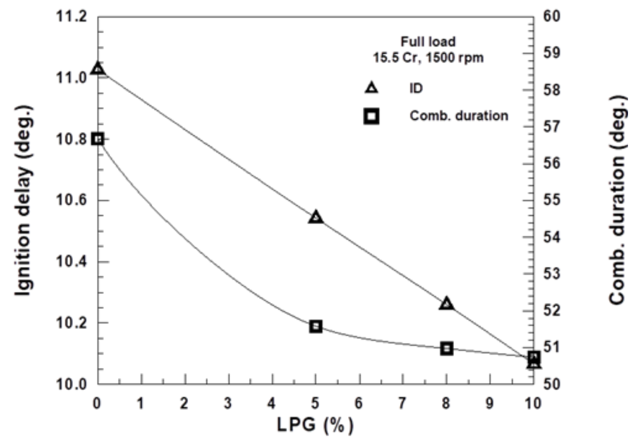

Figure 7. Illustrates the variation in ignition delay and combustion duration

7.2 The performance analysis.

To properly understand the influence of LPG on engine performance, we measured the brake-specific fuel consumption (BSFC) and brake thermal efficiency (BTE) at full load and a constant engine speed of 1500 rpm. The effect of LPG on BTE and BSFC is shown in Figure 8. It stands to reason that when LPG is used with diesel, more fuel will be used overall, resulting in higher brake-specific fuel consumption (BSFC) of about 0.14%, 0.26%, and 0.4% at 5%,8%,10% of LPG, respectively and lower brake thermal efficiency according to the direct relationship between them occurred at 10% LPG. The current result is also found in the results of

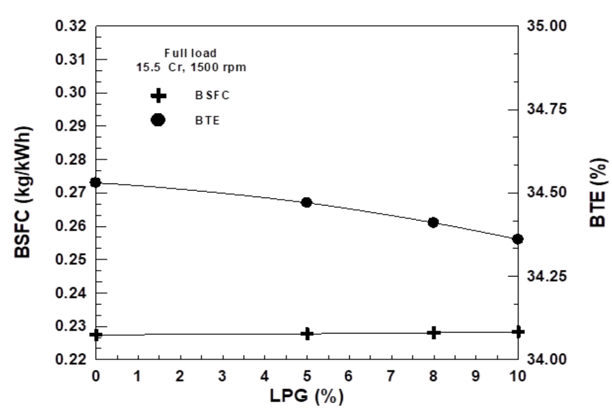

Figure 8. The Effect of LPG on BSFC and BTE

Figure 9 shows that the mechanical efficiency and volumetric efficiency of the engine are significantly affected by the LPG content. The engine's volumetric efficiency, which was 92.59% while running on diesel fuel but dropped to 92.53% when using LPG, and the mechanical efficiency of the engine dropped as the LPG concentration rose. This percentage drops from 83.18 when there is no LPG present to 82.9 when there is 10% LPG present. Reasons for this might include an unfavorable combustion environment and/or incomplete combustion.

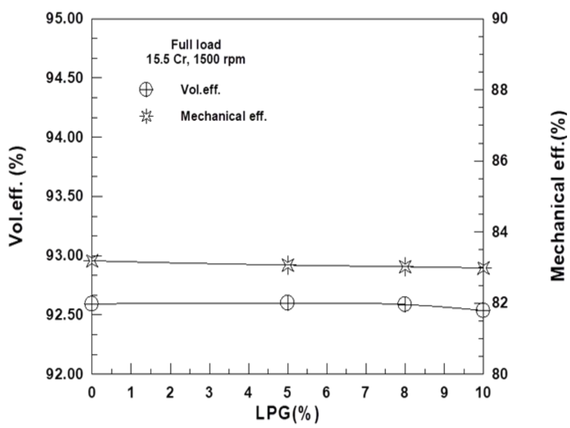

Figure 9: Variation in Mechanical and Volumetric Efficiency

7.3 The emission analysis

Since most emissions occur at full load, this is the case we concentrate on to determine which blends have the most value. In Figure 10, we see the NOx concentration and BSN verse LPG percentage. A slight increase was noticed in NOx, only at higher LPG concentrations; at 10% LPG, the NOx increase is roughly 0.83 %. Considerable reduction in the BSN was observed in the case of using LPG along with diesel because LPG has a lower C/H ratio hence it emits less smoke compared to neat diesel. As the engine ran with 5%, 8%, and 10% LPG the BSN is reduced by 3%, 6.74%, and 9.83% respectively compared to the case of 0% LPG (diesel alone).

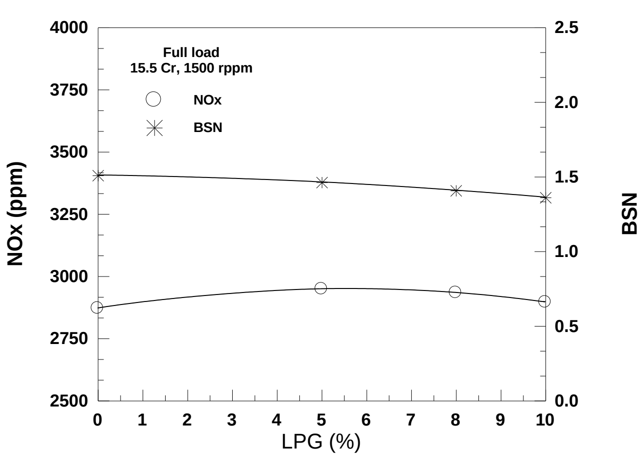

Figure 10. depicts the variation in smoke and NOx emissions

8. Conclusions

Following are the results of the simulation analysis:

1. No considerable increase in cylinder pressure when LPG is added, for example, the maximum increase is 0.4% while using 10% LPG.

2. Compared to pure diesel, the rate of heat release at a crank angle of 365 degrees has dropped a little. Diesel fuel is around 32.53 (1/deg) and 10% LPG is approximately 30.28 (1/deg).

3. Ignition delay was reduced by 8.7%, 7%, and 4.3% when used 10% LPG, 8% LPG, and 5% LPG respectively.

4. Insignificant changes in BTE and BSFC are noticed while adding LPG to diesel.

5. The mechanical efficiency and volumetric efficiency of the engine both decrease a bit with increasing the percentage of LPG.

6. It is possible to notice a slight increase in NOx when LPG is used along with diesel

7. Measurable decrease in BSN by 3%, 6.74%, and 9.83% for 5%, 8%, and 10% LPG respectively compared to the case of 0% LPG (diesel alone)

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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