Evaluation of liquefied Petroleum Gas as a Fuel Input in a Mechanical Injection Diesel Internal Combustion Engine

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ABSTRACT

Recent studies have shown that the incorporation of LPG in the combustion mixture of diesel engines reduces pollutant emissions and increases power output. This study evaluated a 1998 diesel internal combustion engine, which was adapted to an LPG injection system as input fuel. Torque, power, opacity, particulate matter, and fuel consumption tests were carried out using the IM240 cycle, using different diesel and LPG mixtures. The results show that there is an increase in torque values 22.06 lb. ft and power of 13.47 HP at 300 rpm with a mixture of 53.43% diesel and 46.57% LPG. Opacity had an increase to 82% at the critical point, while there is a decrease in fuel consumption. In addition, as the LPG / Diesel ratio increases, the engine exhibits strong internal explosions as a result of delayed ignition, which could cause engine damage. Finally, the results are contrasted with those of other research studies.

Keywords: Exemplary Paper, Human Systems Integration, Systems Engineering, Systems Modeling Language

INTRODUCTION

Environmental pollution from internal combustion engines is a problem of global concern(Dhingra et al., 2019), (Forouzanfar et al., 2016), so the way to reduce pollution and pollutant emissions is constantly being investigated while maintaining or improving parameters such as torque and power. To achieve this goal an alternative that has been studied is the mixture of fuels using diesel cycle engines with LPG. Some works were develop and any one had a different results (Wang et al., 2016), (Chakraborty, Roy and Banerjee, 2016), (Rimkus, Melaika and Matijošius, 2017), (Romero, Acosta and Lopez, 2016), (Alberto et al., 2018).

For the project execution, a diesel fuel with sulphur content up to 500 ppm (INEN Standard 1489) (INEN, 2016) was used, which produced a higher percentage of opacity. LPG and diesel mixtures were tested in a 1998 TOYOTA HILUX diesel internal combustion engine with mechanical injection without electronic control, where torque, power, fuel consumption, opacity, and particulate matter were tested.

METHODOLOGY

A quantitative experimental approach was used to evaluate the vehicle's performance by performing torque, power, and particulate material tests. The tests were carried out at the Technology Transfer Center for Training and Research in Vehicle Emission Control in Ecuador (CCICEV). The tests were carried out under the NTE INEN 22 07 standards following an IM 240 driving cycle protocol that lasts 240 seconds and covers 3.2 km of distance.

LPG System Adaptation to the diesel engine.

The system used for LPG injection in the diesel engine was a KIT BIGAS/GLP EASY GAS LPG, with DGM 59645 GPL approval number, which incorporates a pressure reducer, a solenoid valve, ECU, wiring, stepper motor, switch, pipes, belts, and mixer.

Software.

The system has BIGAS Dual Fuel CPP software installed on a computer, where the engine data is entered and where the signals from the sensors installed in the vehicle also reach. This software makes it possible to monitor the vehicle behavior with the different diesel and LPG mixtures.

In-vehicle tests

The performed tests were Torque, Power, Opacity and Particulate Matter. Comparative tests were carried out between diesel and diesel + LPG mixtures in proportions of 19.77%, 33.29%, and 46.57% of LPG in the blend to analyze the vehicle behavior. The fuel energy formula, which is part of a system's energy balance was used to calculate mass percentages of diesel and LPG.

$$m_{D\,1} * P.C.I._{D} * \eta = m_{D\,2} * P.C.\,I._{D} * \eta + m_{GLP1} * P.C.I._{GLP} * \eta$$

Torque and Power. A chassis dynamometer LPS 3000 was used for torque and power tests and to simulate the IM240 driving cycle.

Fuel consumption. To measure fuel consumption, an external graduated fuel storage system was adapted during a driving cycle from which volumetric difference readings were taken before and after the tests.

Opacity. The opacity was measured with the MAHA MDO2 equipment. The probe was placed inside the exhaust pipe during the cycles determined above. This parameter was measured with unmixed diesel and the three mixtures mentioned above.

Particulate matter. The MAHA MPM-4 equipment designed to continuously measure particulate matter was used to measure particulates. Similar to the opacity, the probe was placed inside the exhaust pipe while performing the IM 240 driving cycle tests with the four diesel/LPG ratios.

The test is performed by raising the engine speed from idle to 2500 rpm at full load, with the throttle fully open. When the desired speed is reached, the accelerator pedal is released immediately.

RESULTS AND DISCUSSION

Mixture composition

The experiment was carried out with 4 different blends between diesel and LPG, all in the same IM 240 driving cycle. The main fuel is diesel, while LPG is added as a fuel supply. The tests performed were limited to a 46.57% contribution due to increased engine vibration. This value diverges from the work done in (Omar, Selim and Emam, 2017), (Aydin, Irgin and Çelik, 2018) where LPG represents 70% of the mixture. Table 1 shows the mixture composition values.

Table 1. Composition of the mixture

Test	**Diesel**	**Diesel+GLP1. (Mixture 1)**	**Diesel+GLP2 (Mixture 2)**	**Disel+GLP3. (Mixture 3)**
Diesel mass (%)	100	80.23	66.71	53.43
LGP mass %	0	19.77	33.29	46.57

The experiment had a range of mixtures greater than 50%, but when exceeding 46.57% by mass of LPG, an increase in engine vibration and subsequent engine failure was observed, that is why no further experimental data are presented.

Power

The Power results of the tests performed with the different Diesel + LPG mix compositions are shown in Table 2.

Table 2. Power results in HP

	Base	Mixture 1	Mixture 2	Mixture 3
rpm	100 %	80.23+19.77 %	66.71+33.29 %	53.43+46.57%
1000	6,17	5,77	8,70	8,57
1200	7,83	7,93	11,10	10,77
1400	9,73	9,73	13,47	13,30
1600	11,23	11,40	15,27	15,37
1800	12,53	12,63	17,07	17,40
2000	13,67	13,90	19,03	19,30
2200	15,93	16,07	22,70	22,73
2400	19,10	18,57	27,10	26,70
2600	23,03	22,47	31,70	32,50
2800	27,50	26,13	37,27	38,70
3000	30,23	30,00	41,40	43,70

According to the results obtained, the power output increases due to the addition of LPG fuel, which delivers additional energy to the diesel mixture that normally works with excess air. These results are congruent with the results obtained in (Kim et al., 2017), (F. Payri, J.M., 2011), (Tiwari and Sinha, 2014), (Boretti, 2017).

Torque

Lambda and Opacity in a static test

The opacity values depend on the lambda values obtained during engine operation. The lambda values that were obtained by means of the lambda CAN interface software and are shown in Table 4.

Table 4. Lambda results in %

	Base (%)	**Mixture 1**	**Mixture 2**	**Mixture 3**
	100 %	80.23+19.77 %	66.71+33.29 %	53.43+46.57 %
λ	2.5	2.4	2.1	1.6

The obtained lambda results show that the values decrease as the amount of LPG increases, i.e., the diesel engine tends to work with an increasingly richer mixture, with the amount of fuel getting closer to the 14.7: 1 ratio corresponding to petrol engines (F. Payri, J.M., 2011). This behavior is consistent because diesel engines normally work in a lean mixture, i.e., in lambda ranges greater than 1. In this case, the engine is calibrated at $\lambda = 2.5$ with diesel only and is reduced as LPG is added. Table 5 shows the opacity values obtained in the tests.

Table 5. Opacity results in %

	Base 100%	**Mixture 1 80.23+19.77 %**	**Mixture 2 66.71+33.29 %**	**Mixture 3 53.43+46.57 %**
Opacity (%)	24.66	26.33	27.66	28.33

Table 5 shows that the opacity values increase as the amount of LPG in the mixture increases, reaching an opacity of 28.33% when 46.57% LPG is added. This is because diesel fuel normally runs lean, i.e., with excess air to ensure complete combustion of the fuel. When it is premixed with LPG, the available air mass is reduced, producing incomplete combustion of the diesel in the flame front, the area where particulate matter is generated, which results in increased opacity. Similar opacity results are reported in (Boretti, 2017), (Ashok, Denis Ashok and Ramesh Kumar, 2015).

In general, exhaust gas analysis allows diagnosing the engine condition based on lambda, which in diesel engines is normally a value greater than 1 and ideally up to 1.65 for maximum efficiency (lower consumption). Lambda values between 2.5 and 1.5, were obtained in the tests, therefore an increase in opacity, a similar case experienced by (Gómez et al., 2020). The particulate matter values obtained are shown in Table 6.

Table 6. Particulate matter results

	Base (%)	Mixture 1	Mixture 2	Mixture 3
M.P	98.96	173.89	180.57	181.4

Figure 1 shows the results of the particulate matter test of one of the mixes; each peak represents a load applied to the engine until its speed rises to 2500 rpm. Each group of three peaks represents the three measurements taken with each fuel mixture tested.

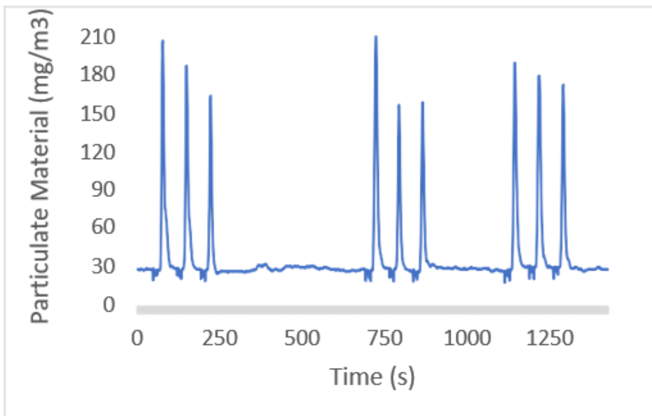

Figure 1. Diesel only particulate matter test

According to the results obtained, the opacity values increase as the amount of LPG in the mixture increases. On the other hand, and contrary to this work, (Ashok, Denis Ashok and Ramesh Kumar, 2015) reports a reduction of particulate matter in LPG-rich mixtures and a power loss with respect to the engine operation that only works with diesel. (Gómez et al., 2020).

CONCLUSIONS

This research shows that the use of LPG as input fuel in a diesel engine does not ensure the pollutant reduction emitted to the environment, but the result depends on conditions such as ignition time, type of electronic injection control, and fuel input characteristics used, as reported in other investigations ((Rimkus, Melaika and Matijošius, 2017),(Aydin, Irgin and Çelik, 2018) and (Ashok, Denis Ashok and Ramesh Kumar, 2015)) where emission reductions and total consumption are achieved when the ignition is controlled by the injection system, but also a decrease in engine power. Even in [1] it is indicated that an emission reduction and power increase can be achieved by effectively controlling these parameters compared to a commercial diesel engine. In this regard, the best results in terms of emissions and energy efficiency could be determined to identify the minimum equipment required by an engine to work with fuel input and in this way quantify the impact of mass deployment of these elements.

Another important difference with other studies is the mixture type and how to start the combustion of the mixture. In the current study, diesel is used as the main fuel and LPG is used as the input fuel, where as the percentage of LPG increases, so do engine vibrations. Unlike (Omar, Selim and Emam, 2017), where the base fuel is LPG and diesel is added to start the gas combustion, which makes it possible to control the optimum combustion point and reduce vibrations. This is because the mixture of LPG and air charges the combustion chamber, so that when the diesel is injected, a premature pressure peak occurs, generating the tapping of the internal elements, similar to the results observed in Cusiana by(Romero, Acosta and Lopez, 2016), where it is mentioned that the origin of LPG and its characteristics alter the combustion properties, to the point where it is necessary to install a system that interrupts the injection of LPG if the vibrations exceed a predetermined limit.

As the amount of LPG in the mixture increases, the mixture changes from lean (typical diesel) to a rich mixture, which is why the fuel fails to combust properly, increasing opacity and the possibility of emitting hydrocarbons as particulate matter. These results are consistent with those mentioned by (Rimkus, Melaika and Matijošius, 2017), where it indicates that the addition of LPG in the mixture increases the concentration of partially combusted products, such as carbon monoxide and hydrocarbons in the exhaust gases. Additionally, the results agree with (Romero, Acosta and Lopez, 2016), who mentions that CO emissions rise, attributing this effect to the lack of control in the injection of diesel in the mixture.

Finally, the results obtained in this research are aligned to the studies as (Romero, Acosta and Lopez, 2016) in terms of power and torque increase. Researchers in agree that LPG can be used as an additional fuel in proportions up to 40%, but it is recommended to carry out studies on durability, operation, and maintenance costs that should be considered in the long term.

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