Performance and emission characteristics of Diesel+LPG dual fuel engine with exhaust gas recirculation

Pali Rosha*, R.S Bharj*, Kanwar J.S Gill

Abstract— **In the present work, an experimental investigation has been conducted to evaluate the effect of EGR on performance and emission characteristics of Diesel+LPG dual fuel engine. In this work, a single cylinder with rated power output of 3.7 kW, air cooled, constant speed, DI diesel engine was modified to use LPG in dual fuel mode equipped with EGR strategy was used, where LPG fumigated into the intake air. The results indicate that the Diesel+LPG fuelled engine produce less NO_X, CO_2 and Smoke emissions as compared to conventional diesel fuel alone, while in spite of this higher CO and HC emissions especially at part loads. Experimental results showed that by EGR technique, at part loads upto 60% with 16% EGR ratio HC and CO emissions reduced by 46.9% and 27.4 % respectively without any penalty on other emissions; however NO_X concentration could be considerably reduced to about 8.5 % as compared to LPG operation without EGR. Consequently, it was founded that the EGR strategy was a very effective method to reduce HC and NO_X emissions.**

Index Terms— **LPG, Diesel, Dual fuel engine, Engine performance, Emission characteristics**

1. Introduction

In recent years, one of the principal routes to use various gaseous fuels, such as producer gas, LPG, CNG, hydrogen and less frequently biogases have been explored as alternative fuels for use in transportation, power generation and other applications due to more serious energy and environmental awareness [1-3]. In addition, dual fuel combustion has received renewed interest due to selected performance and emission benefits and its adaptability for alternative fuels as compared to conventional diesel combustion [2]. Among the proposed alternative fuels, much attention has been focused on LNG, LPG and bio-derived gas in view of their friendly environmental nature [4]. On the other hand, LPG is an attractive alternative fuels worldwide and getting more positive response from researchers because, not only as a substitute for petroleum but also as a means of reducing NO_X, smoke and particulate matter [5].

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Many studies have been working on LPG, as a promising fuel for diesel engine for many years. During this many test have been performed on LPG as alternative fuel, as Karim. [6] investigated by mixing LPG with intake air and diesel as a primary fuel, reported that engine performance and emissions suffer at part loads because of very lean mixtures at such loads, which is slow to burn. Same author, concluded in next year [7], ignition delay of pilot fuel increased with lower concentration of LPG, results some of the homogeneously dispersed LPG remains un-burnt, resulting high CO and un-burnt HC emissions because of dilute LPG air mixture. In 1998 [8], they examined that extension of the delay is due to the chemical factors, which strongly depend on its concentration in the cylinder charge and the type of gaseous fuel used. Moreover, they suggested [6] method for re-burned some of the unburned fuel by increasing the intake charge temperature, hot EGR could promote better combustion for improving engine performance and reducing the emissions at part loads. It changes the rate of pressure rise inside the combustion chamber or the rate of combustion, which is related to another dangerous pollutant, i.e. combustion noise. Abdel-Rahman.[9] was shown three major negligible effects on combustion and emissions by introducing CO_2 into the inlet charge of a diesel engine such as, the dilution (reduction O_2 fraction in the inlet charge), the chemical (form free radicals by dissociation of CO_2), and the thermal (due to high specific heat capacity of CO_2) effects. K S salariya, V P sethi. [10] observed that CO, HC, and SO_2 exhaust emissions were reduced by 80%, 71%, and 21%, respectively with 20% LPG mixing. However, poorer NO_x emission was increased by 19%. Although brake specific fuel consumption decreased by 20% as compared to diesel at the same brake power output. Vijayabalan P. and Nagarajan G. [11] found that poor ignition of Diesel+LPG in dual fuel mode at low loads, which results poor BTE and high HC and CO emissions because of increased thus ignition delay period of pilot fuel due to low gas concentration at lower loads. Therefore, the study on Diesel+LPG engines with EGR has drawn considerable attention because less work is available on this technique as already suggested by [6].

In the present work, an attempt has been made to experimentally investigate the effect of EGR on performance and emissions of Diesel+LPG dual fuel engine.

2. Experimental details

The fuels selected for evaluation of engine performance and emission characteristics were LPG as an alternative fuel and

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diesel as a primary fuel. LPG is the abbreviation of Liquefied Petroleum Gas. This includes mixture of Propane (C_3H_8) and Butane (C_4H_{10}), as the standard of LPG is not universally observed. We used LPG (IS: 4576) contained 55% C_4H_{10} and 45% C_3H_8. Some important fuel properties of these selected fuels are given in Table 1.

Table.1 Shows the properties of commonly used fuels.

Properties	Diesel (IS:1460)	LPG(IS:4576)
Formula	C_8 to C_{20}	55% Butane, 45% Propane
Density kg/m^3	833	600 at 15°C
Boiling point °C	163	-22°C
Cetane number	40-55	<3
Auto ignition Temp °C	242-257	365
Calorific value (kJ/kg)	41800	49742

Table.2 Specifications of engine used

General details	**Single cylinder, four stroke, air cooled, compression ignition , constant speed, direct injection**
Bore	80 mm
Stroke	110 mm
Compression ratio	16.5:1
Rated output	3.7 Kw
Rated speed	1500 rpm

The engine employed for the this work was 3.7 kW air cooled, single cylinder, constant speed, diesel engine which was further modified to dual fuel engine by fumigated LPG just before the intake manifold of intake air. The technical specifications of the engine are given in Table 2.

The hot EGR system was developed and fitted in the engine. A metal pipe was installed between the exhaust and intake pipe, to route the exhaust and intake flow, where the hot gases were inducted into the succeeding cycles.

Different experimental studies were carried out to evaluate the performance and emission characteristics of Diesel+LPG dual fuel engine with EGR at different loads (0%, 20%, 40%, 60%, 80% and 100%) of full load at constant speed.

3. Result and Discussion

3.1 Fuel consumption

Fuel Consumption is directly related to the load, as the load increases fuel consumption also increases in order to maintain constant speed. Fig. 1 shows the variations of Fuel consumption.

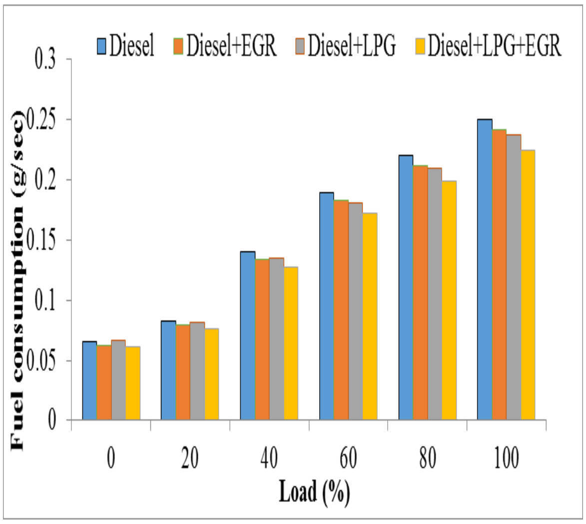

Fig.1. Variations of fuel consumption

3.2 BRAKE SPECIFIC FUEL CONSUMPTION

The BSFC is governed by the quality of combustion of fuel. Even the fuel of higher calorific value gives lesser or equivalent work output compared to fuel of comparatively lower calorific value [13]. It is due to higher hydrocarbons emissions or partial burning of fuel during combustion. Fig. 2 shows the variations of BSFC. The reason for improved BSFC on Diesel+LPG dual fuel operation for the same output as delivered by the use of 100% diesel was reduction in fuel consumption with the use of different Diesel+LPG dual fuel operation. The engine operation is more economical on the pure diesel mode of operation at lower loads [13] . However, at higher loads dual fuel mode of operation is more economical. At 20% load, BSFC is 1206.39 on the pure diesel operation and it is 1110.34 Diesel+LPG on the dual fuel operation, where at 100% load, BSFC is 469.18 on the pure diesel operation and it is 347.66 Diesel+LPG on the dual fuel operation.

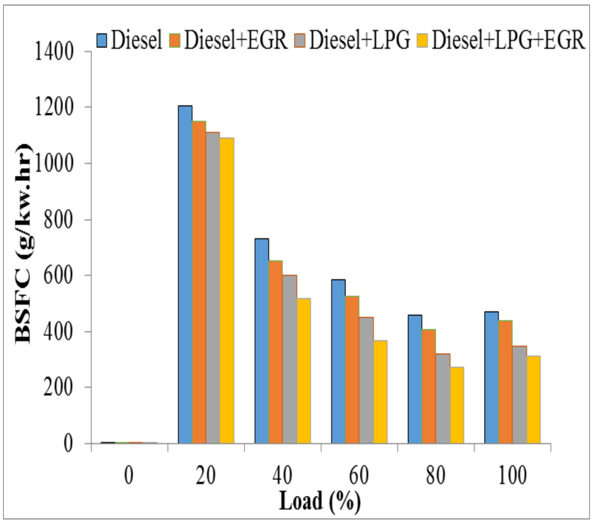

Fig.2. Variations of BSFC

3.2 BRAKE THERMAL EFFICIENCY

BTE may vary per device and which in turn may vary per application. Fig. 3 shows the variations of BTE. As the load increases, engine produces higher brake power. At lower loads, diesel operation is better than the Diesel+LPG. For

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instance, at 20% load in Diesel+LPG the efficiency is 11.0 % lower than diesel. However at higher loads, the Diesel+LPG are superior to the diesel because at 100% load in Diesel+LPG efficiency is 28.9 % higher than diesel. It has been observed at part loads efficiency is increased in case of EGR-operated engine due to re-burning of hydrocarbons that enter into the combustion chamber. The re-circulated exhaust gas contains less amount of CO_2 and fairly high amount of O_2 and unburned hydrocarbons in exhaust gas burns because of sufficient O_2 available in combustion chamber and reasonably high intake temperatures [14].

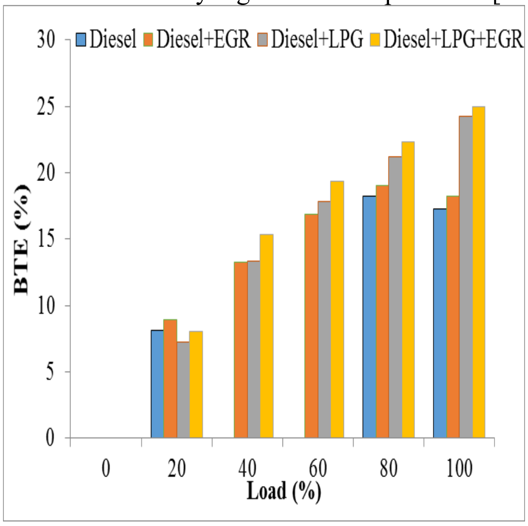

Fig.3. Variations of BTE

3.4 NITROGEN OXIDE EMISSIONS (NO_X)

Fig. 4 shows the variations of NO_X. The high NO_X emissions were observed on higher loads because of the temperature that drop rapidly during expansion and exhaust strokes [9]. But the reverse reaction or dissociation of NO is not rapid enough to establish equilibrium. Therefore higher amount of NO_X appears in the exhaust at higher loads and reached to 599 for diesel, 485 diesel with EGR, 300 for Diesel+LPG, 241 with EGR. The highest value of NO_X emissions was observed on 100% Diesel, after this the reduction starts with the application of EGR and LPG. Results shows that in Diesel+LPG, there is 49.9% reduction in NO_X emissions as compare to diesel because in Diesel+LPG, LPG produces a cooling effect in the combustion chamber which in turn decreased the NO_X emissions because of absorption of latent heat of vaporization during phase change of LPG from vapor to gaseous form and low peak combustion temperature with the use of LPG [12]. The lower reduction at part load is due to the low CO_2 and H_2O concentrations in the exhaust gas, being essentially proportional to the fuel/air ratio and this concentration is high at higher loads [15].

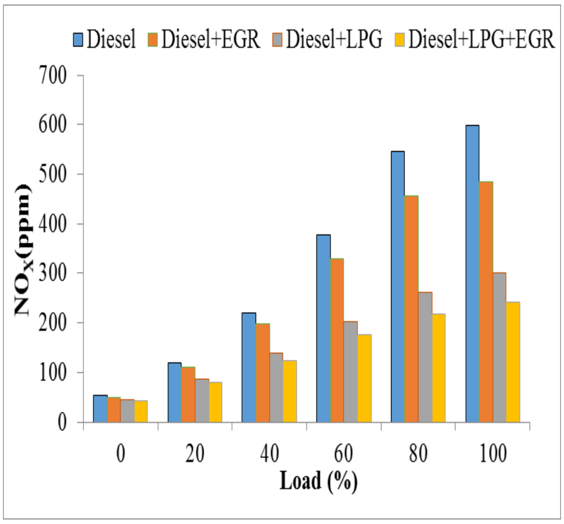

Fig.4.Variations of NO_X emissions

3.5 HYDROCARBON EMISSIONS (HC)

Fig. 5 shows the variations of HC. The production of HC emissions is higher in Diesel+LPG than diesel, especially up to 40% load because at part loads the cylinder charge temperature is lower and due to the high auto-ignition temperature of LPG (about 465°C) it does not auto-ignite, hence LPG remain unburned go to the exhaust, which attributed to the increase in HC emissions at part loads [16]. However the HC emissions decrease gradually as load increases and reaches to 120 at 60% load, 100 at 80% load and 88 at 100% load. The reduced HC emissions have been observed with EGR assistance. At 100% load in EGR assisted gave 60.2 % lower HC emission than without EGR.

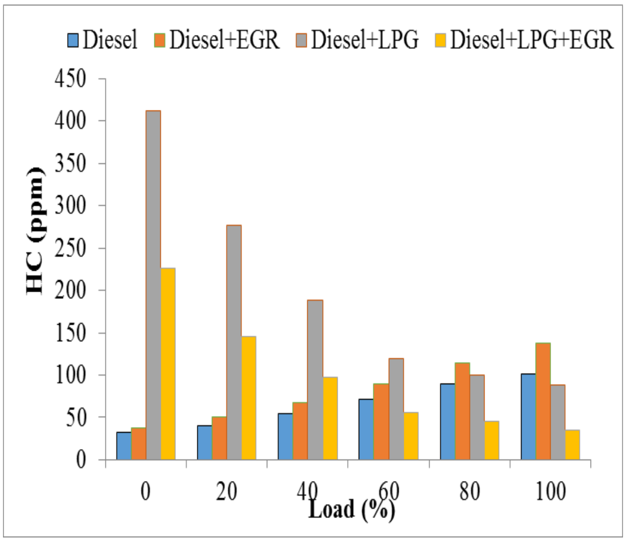

Fig.5. Variations of HC emissions

3.6 CARBON MONOXIDE EMISSIONS (CO)

Fig. 6 shows the variations of CO emissions. The CO emissions ranges vary from 0.15 at no load to 0.11 at full load for diesel, 0.17 to 0.14 diesel with EGR, 0.22 to 0.09 Diesel+LPG, 0.16 to 0.07 Diesel+LPG with EGR. As the quantity of fuel supplied increased with loads level, the fuel produced more heat in the combustion chamber resulting in greater conversion of CO to CO_2 [7]. Beyond the rated load, the percentage of CO in the exhaust started increasing due to

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deterioration of combustion process. In Diesel+LPG, CO emissions are higher; especially at part loads because of lower charge temperature due to very lean mixtures that leads to incomplete combustion of LPG-air mixture and very little oxidation of CO takes place consequently lesser conversion of CO–CO_2 emissions. CO emissions gradually decrease with increasing the engine load because of increasing LPG-air charge mixture and the combustion from each ignition centers within the charge becomes relatively faster that deal to an increase of the temperature and oxidation reactions and as a consequence lower CO emissions [10]. However CO emissions level did not increased beyond the safe limit. At 100% load in Diesel+LPG dual fuel operation CO emissions were approximately 18.18% less as compare to diesel operation. These emissions are reduced in EGR assisted because EGR raises the intake air temperature it could lead to a reduction in CO level.

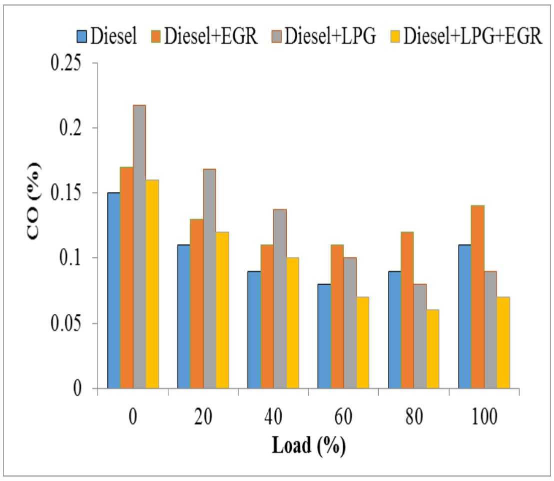

Fig.6. Variations of CO emissions

3.7 **CARBON DIOXIDE EMISSIONS (CO_2)**

Fig. 7 shows the variations of CO_2 emissions. As the loads on the engine were increased the percentage of CO_2 also increased gradually and ranges varies from 2.4 by volume at no load to 5.5 at full load for diesel, 2.1 to 4.5 diesel with EGR, 1.8 to 4.2 Diesel+LPG , 1.4 to 3.1 Diesel+LPG with EGR. Higher percentage of CO_2 in the exhaust indicated higher oxidation of fuel at the constant engine speed and release more heat for power conversion [17]. It also indicated better combustion as more fuel was converted from CO to CO_2. This trend because the engine attained optimum operation at the rated load conditions and as such the highest percentage of CO_2 was observed at rated load value. With the use of Diesel+LPG dual fuel operation CO_2 decreased on all the load percentages because due to lower carbon to hydrogen ratio of LPG.

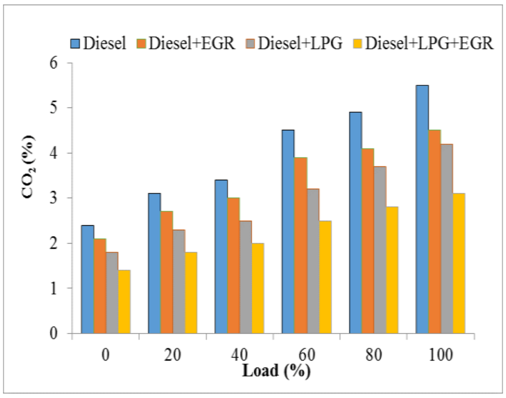

Fig.7. Variations of CO_2 emissions

4 CONCLUSIONS

The following conclusions can be drawn:

1. Diesel engine can be made to run on dual fuel (Diesel+LPG) successfully and a dual fuel engine is suitable for all the applications which a diesel engine can fulfill.
2. Diesel engine when run on dual fuel show better results at high loads (60% to 100%) as compared to conventional diesel.
3. NOx emissions are reduced by 49% with Diesel+LPG, which is increased upto 55 % by addition of EGR. HC emissions are reduced by 60% with EGR assisted with dual fuel as compared to pure Diesel. Reduction in smoke emissions upto 40% load is 12.6% in dual fuel mode which is increased by 16.3% with EGR assisted dual fuel mode.
4. At full load, (Diesel+LPG+EGR) the fuel consumption decreased by 8.75%, and BSFC and BTE improve by 29% and 28.9% respectively.
5. Dual fuel engine with EGR is more economical as compared to duel fuel mode at all load.

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