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# Effect of injection pressure on exhaust emissions of diesel engine fuelled with LPG

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**ABSTRACT**

In the context of exhaustion of fossil fuels day by day due to heavy demand with the use of agriculture sector and transport sector, escalation of fuel prices in International Oil Market causing huge economic burden on developing countries like India and rise of pollution levels with fossil fuel, the conservation of fossil fuels has become pertinent. Gaseous fuels have many merits over liquid fuels, as the pollutants emitted by gaseous fuels are low due to clean combustion, high calorific value in comparison with liquid fuels. Vegetable oils are good substitutes for diesel, as they are renewable, comparable calorific value and cetane (meausre of combustion quality) number when compared with neat diesel operation. However, the disadvantages associated with vegetable oils such as high viscosity and low volatility cause combustion problems in diesel engines. They can be rectified to some extent by converting them into biodiesel. They are many methods to induct gaseous fuels such as port injection, carburetion technique, injection of gaseous fuel at the near end of compression stroke etc,. Investigations were carried out with LPG as primary fuel inducted by port injection and diesel was injected into the engine in conventional manner. Particulate matter (PM), oxides of nitrogen ($NO_x$), carbon mono oxide (CO) levels and un-burnt hydro carbons (UBHC) are the exhaust emissions from a diesel engine. They cause health hazards, once they are inhaled in. They also cause environmental effects like Green-house effect and Global Warming. Hence control of these emissions is an immediate effect and an urgent step. The pollutants of PM, $NO_x$,CO and UBHC were determined at full load operation of the engine with varied injection pressure and compared with diesel operation on conventional engine. The maximum induction of LPG was 35% of total mass of diesel as full load operation. Particulate emissions were determined by AVL Smoke meter, while other emissions were measured by Netel Chromatograph multi-gas analyzer at full load operation. These pollutants were drastically reduced with induction of LPG and further reduced with an increase of injection pressure.

***Key words**: Diesel, biodiesel, CE, Exhaust emissions.*

## Introduction

The civilization of a particular country has come to be measured on the basis of the number of automotive vehicles being used by the public of the country. The tremendous rate at which population explosion is taking place imposes expansion of the cities to larger areas and common man is forced, these days to travel long distances even for their routine works. This in turn is causing an increase in vehicle population at an alarm rate thus bringing in pressure in Government to spend huge foreign currency for importing crude petroleum to meet the fuel needs of the automotive vehicles. The large amount of pollutants emitting out from the exhaust of the automotive vehicles run on fossil fuels is also increasing as this is proportional to number of vehicles. In view of heavy consumption of diesel fuel involved in not only transport sector but also in agricultural sector and also fast depletion of fossil fuels, the conservation of fossil fuels has become pertinent, which has been the concern of the engine manufacturers, users and researchers involved in combustion.

Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil (Cummins, 1993)

The exhaust emissions of diesel engine cause severe health hazards such as respiratory diseases, loss of hemoglobin, severe headache, vomiting sensation, when they are inhaled in. They are also carcinogenic in nature (Fulekar, 2004; Sharma, 2012; Khopkar, 2012). Various undesirable emissions are exhausted by the internal combustion (IC) engines which affect the environment and cause various problems such as ozone depletion, acid precipitation, global warming (Khopkar, 2012). Scientific results shows that the contribution to global anthropogenic emissions from transportation amount to 21% of CO2, 37% of Nox, 19% of volatile organic compounds (VOCs), 18% of CO and 14% of black carbon, the main source of carbonyls and VOCs result directly from incomplete combustion of fossil fuel such as vehicle exhausts and biomass burning (Peter Anyon, 2003). Therefore it is very important for the researchers to arrive at the clean burning fuel to contribute in reducing the environment problems and growth of global warming. In recent years in order to reduce the environmental damage of motor vehicles and meet the stringent emission regulations, clean alternative fuels such as liquefied petroleum gas (LPG), natural gas (NG) and Hydrogen (H) have been applied in the motor vehicles (Ceviz, 2005).

Liquefied Petroleum Gas (LPG or LP gas) also referred to as simply propane or butane or a mixture of propane (C3H8) and butane (C4H10), is a flammable mixture of hydrocarbon gases used as a fuel in heating appliances, cooking equipment and vehicles. LPG is prepared by refining petroleum or wet natural gas, and is almost entirely derived from fossil fuel sources, being manufactured during the refining of petroleum (crude oil), or extracted from petroleum or natural gas streams as they emerge from the ground. LPG also contains propylene and butylenes in small concentration. A powerful odorant, ethanethiol also known as ethyl mercapton (CH3CH2SH) is also added in a container, containing LPG so that leaks can be easily detected.

LPG is widely used as an alternative fuel in automobile due to its efficient combustion characteristics and low emissions. It's higher heating value, auto ignition temperature and wider flammability limits makes LPG a better CI engine fuel than diesel. LPG is a gas at atmospheric pressure and normal temperatures, but it can be liquefied when moderate pressure (0.7 to 0.8 MPa) is applied or when the temperature is sufficiently reduced Hakan Bayraktar *et al*, 2005; Hakan Ozcan *et al.*, 2006; Gong *et al.*, 2007; Hakan Ozcan *et al.*, 2008; Mustafa *et al.*, 2009). This property makes LPG an ideal energy source for a wide range of applications, as it can be easily condensed, packaged, stored and utilised. When the pressure is released, the liquid makes up about 270 times its volume as gas, so large amounts of energy can be stored and transported compactly.

LPG has been suggested as a convenient clean burning less pollutant fuel, therefore it is also known as Green Fuel. Since LPG burns cleaner with less carbon build up, oil contamination, engine wear is reduced and life of some components such as piston rings and bearing are much higher than with gasoline (Ali *et al.*, 2009; Arslan *et al*, 2010; Selahaddin *et al.*, 2011; Shankar *et al.*, 2011).

It has been reported that the use of LPG yields 40% less HC, 35% less $NO_x$, 50% less CO and 50% less ozone forming potential as compared to gasoline. LPG is also free of particulates, the main pollutant of diesel and GDI engines (Gumus *et al.*, 2011)

Various researchers carried out a number of experimental investigations and the results of the above investigations are promising. Power output from LPG was found to be decreasing but from the above investigation it can be concluded that by power output can be increased by advancing the injection timing, employing a electronically controlled LPG injection, by the variation in stroke length and by increasing the compression ratio. But advancing the injection timing and increasing the compression ratio has an adverse effect on $NO_x$. Brake thermal efficiency was found to be increased with LPG fueled CI engine. In all the cases emission characteristics were found to be improved as HC, CO and CO2 showed a reduction in concentration with LPG. (Gumus *et al.,* 2011; Thirumalmamidi *et al.,* 2011; Cha-lee Myung *et al*, 2012; Dheeraj Kalra *et al.,* 2014; BarisErkus *et al.,* 2012). Thus it can be concluded that LPG represents a good alternative fuel for gasoline and must be taken into consideration for transport purposes.

Very little reports were available with the use of LPG with varied injection pressure with CI engine. The authors have made an attempt in this direction. Investigations were carried out with CI engine with varied injection pressure with LPG as main fuel inducted into the engine through port injection. The exhaust emissions of Particulate matter (PM), Oxides of nitrogen(NOx) , carbon mono oxide (CO) emissions and un-burnt hydro carbons (UBHC) were determined with LPG as fuel with varied injection pressure and data was compared with neat diesel fuel operation on conventional engine.

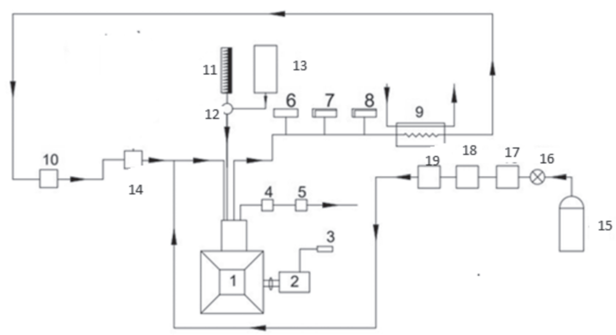
## Materials and Methods

### Experimental Set-up

**Table 1.** Gives the details of the engine.

| Details of the Engine | |
|---|---|
| Description | Specification |
| Make | Mahindra and Mahindra |
| Number of cylinders | 01 |
| Number of Strokes | 04 |
| Ratio of bore to stroke | 93 mm/92 mm |
| Power | 6.6 kW (9 HP) at the rated speed of 3000rpm |
| Compression Ratio | 18:1 |
| Type of cooling Arrangement | Water cooling |
| Recommended Injection Pressure | 190 bar |
| Recommended Injection Timing | 27 degrees before top dead centre |
| Maximum Torque | 30 Nm at 1800 rpm. |

Fig. 1 shows that the test engine (1) and the details of the common rail direct injection (CRDi) engine are given in Table 1. It was located at Applied Thermo Dynamics Laboratory of MED, CBIT, Hyderabad. The engine was connected to power measuring device (2). The engine had computerized test bed. There was facility of loading the engine by means of variable rheostat. (3). Outlet jacket water temperature was indicated with temperature sensor (4). The flow of the coolant was measured with flow meter (5). The temperature of the exhaust gas was indicated with exhaust gas temperature sensor (6). The particulate levels were determined with AVL Smoke meter (7) at full load operation. The pollutants of CO, $NO_x$ and UBHC were determined by Netel Chromatograph multi gas analyzer (8) at full load operation. The range and accuracy of the analyzers in multi gas analyzer are shown in Tabl.2. EGR (9) system was employed in the system to reduce $NO_x$ emissions. Air flow was measured with air flow sensor (10).burette (11) and three way valve (12) were used to induct biodiesel into the engine in conventional injection system. Bypass system was provided for EGR system. Air box arrangement (13) along with water manometer was employed to measure air flow rate from atmosphere. Directional valves (14) were provided for bypass system. Acetylene gaswas stored in a gas cylinder (15). Pressure regulator (16) was incorporated in the system. The pressure of the gas was noted in gas pressure sensor (17). The mass flow rate of the gas was noted by means of a rotometer (18). The flame arrestor (19) was employed in the gas circuit to ensure safety. Cam posi-




1. Engine, 2. Power measuring device, 3. Variable rheostat 4. Outlet jacket water temperature sensor, 5. Water flow meter, 6. Exhaust gas temperature sensor 7 AVL Smoke meter, 8. Netel Chromatograph multi-gas analyzer 9. EGR Heat exchanger, 10. Air flow rate sensor, 11. Fuel flow rate device, 12. Three-way butterfly valve, 13. CSO +DEE tank 14. Air Accumulator 15. Acetylene Gas cylinder, 16. Pressure regulator, 17. Gas pressure sensor, 18. Flow rate measuring device and 19. Flame Arrestor .

**Fig. 1.** Schematic Diagram of Experimental Set-up

**Table 2.** Range and accuracy of Analyzers

| S.No | Name of the Analyzer | Principle adopted | Range | Accuracy |
|---|---|---|---|---|
| 1 | AVL Smoke Analyzer | Opacity | 0-100 HSU (Hartridge Smoke Unit) | ±1 HSU |
| 2 | Netel Chromatograph CO analyzer | Infrared absorption spectrograph | 0-10% | ± 0.1% |
| 3 | Netel Chromatograph UBHC analyzer | NDIR | 0-1000 ppm | ±5 ppm |
| 4 | Netel Chromatograph$NO_x$ analyzer | Chemiluminiscence | 0-5000pm | ±5 ppm |

tion senor was used to measure injection timing. Crank position sensor was used to determine the speed of the engine. Fuel temperature was determined with fuel temperature sensor. Gas was injected through gas injector.

The engine was provided with gravity lubrication system. LPG was inducted through port injectionat the near end of compression stroke of the engine. There was facility to increase injection pressure by means of sensor.

The test fuels of the investigations were i) neat diesel and ii) LPG and diesel. The configurations or the versions of the engine were normal or base engine and insulated engine. Pollutants of PM, $NO_x$, CO and UBHC emissions were determined at full load of the engine, at different injection pressures with test fuels.

Fig. 2 shows the photographic view of experimental set-up.

**Fig. 2.** Photographic view of experimental set-up

## Results and Discussion

Fig. 3 shows the variation of brake thermal efficiency (BTE) with brake power (BP) with conventional engine (CE) with various percentages of LPG along with diesel operation. BTE increased with an increase of BP upto 80% of the full load and beyond that load, it decreased with different percentages of induction of LPG. This is due to increase of fuel conversion efficiency and mechanical efficiency up to 80% of the full load causing increase of BTE. However, beyond 80% of the full load, decrease of fuel conversion efficiency and oxygen-fuel ratio made reduction of BTE. At all load, BTE increased with increase of induction of LPG up to 35%. This is due to improved oxidation reaction of propane and butane and O2 in the combustion chamber. However, beyond 35% induction of LPG, BTE decreased at all load when compared with neat diesel operation on CE. This is due to reduction of ignition delay with LPG causing to produce peak pressure at an early stage. Hence the optimum induction of LPG was limited up to 35% of total consumption of LPG by mass basis along with diesel operation.

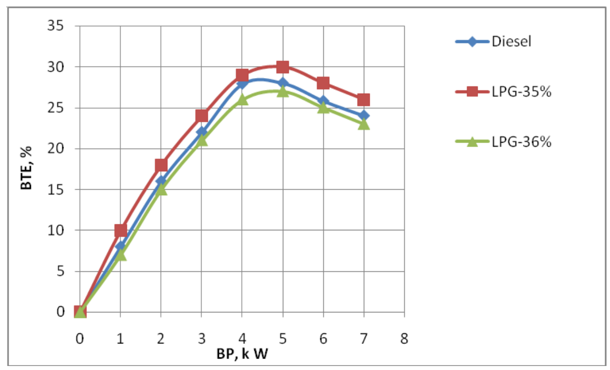



**Fig. 3.** Variation of BTE with BP in CE with LPG and diesel

Fig. 4 presents the bar chart showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) at full load with CE at maximum induction of LPG with varied injection pressure.

Particulate emissions at full load decreased with increased injection pressure with different operating conditions of the engine. This is due to improved spray characteristics and atomization of the fuel spray which is penetrating through oxygen zone. Particulate emissions at full load decreased with in-

**Table 3.** Range and accuracy of Analyzers

| S.No | Name of the Analyzer | Principle adopted | Range | Accuracy |
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| 4 | Netel Chromatograph $NO_x$ analyzer | Chemiluminiscence | 0-5000pm | ±5 ppm |

crease of induction of LPG at different injection pressures. Improved oxidation reaction of butane and propane present in the LPG and oxygen present in the combustion chamber causedimproved combustion reaction and thus reducing particulate emissions at full load.

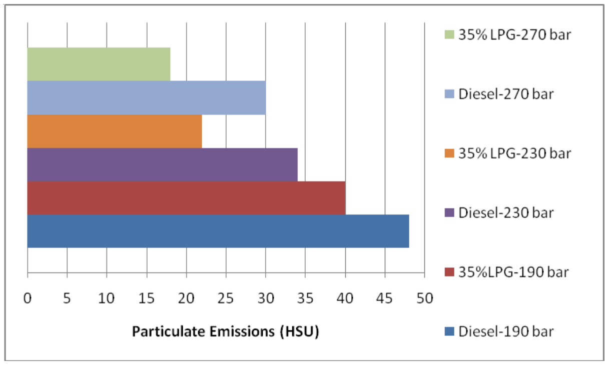


**Fig. 4.** Variation of particulate emissions at full load with injection pressure.

Fig. 5 presents the bar chart showing the variation of $NO_x$ levels at full load with CE at maximum induction of LPG with varied injection pressure.$NO_x$ levels increased with increased injection pressure with test fuels. Increase of combustion temperatures increased $NO_x$ levels with test fuels. $NO_x$ levels decreased with induction of LPG. This is due to presence of oxygen in the combustion chamber improved combustion, due to enrichment of oxygen with oxidation reaction of butane and propane present in LPG with oxygen present in the combustion chamber.

Fig. 6 presents the bar chart showing the variation of carbon monoxide (CO) emissions at full load with CE at maximum induction of LPG with varied injection pressure. CO emissions decreased with an increase of injection pressure with test fuels at different operating conditions of the engine. This is due to improved spray characteristics of the fuel. When the injection pressure increased, the depth of penetration of the fuel increased in oxygen zone leading to improve oxidation reaction of the fuel with oxygen with not only in the environment but also available with biodiesel causing improved combustion and reduced CO emissions. CO emissions reduced with induction of LPG. This is due to improved oxidation reaction of butane and propane in LPG with oxygen available in the combustion chamber.

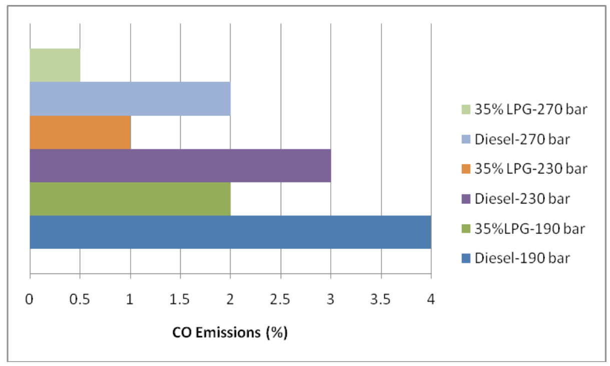


**Fig. 6.** Variation of CO emissions at full load with injection pressure.

Fig. 7 presents the bar chart showing the variation of un-burnt hydro carbon (UBHC) emissions at full load with CE at maximum induction of LPG with varied injection pressure.

The UBHC emissions at full load followed similar trends with CO emissions. CO is formed due to incomplete combustion of the fuel, while UBHC emissions are formed due to accumulation of the fuel in the crevice volume. UBHC emissions decreased with increased injection pressure at different operating conditions of the engine with test fuels. This is due to improved oxidation reaction of the fuel with

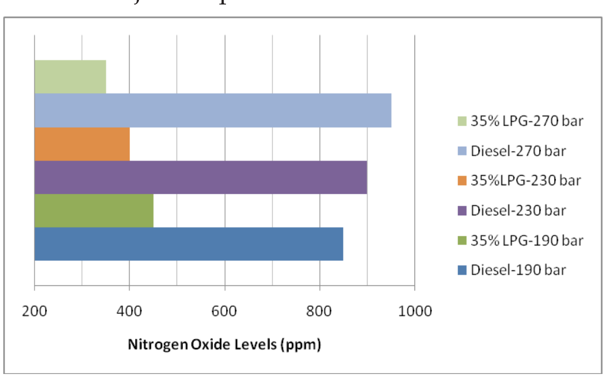


**Fig. 5.** Variation of Nitrogen Oxide emissions at full load with injection pressure.

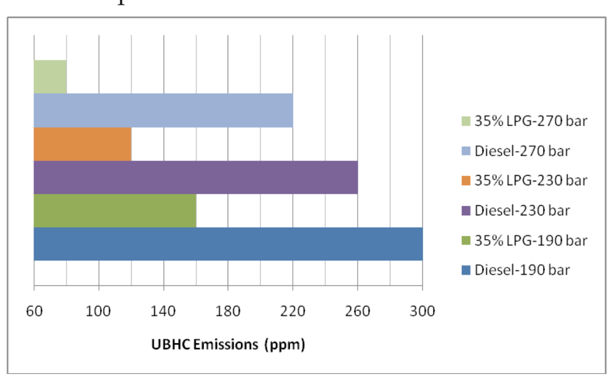


**Fig. 7.** Variation of UBHC emissions at full load with injection pressure.

increased fuel spray characteristic of the fuel along with atomization characteristics of the fuel. When the fuel injection pressure increased, number of fuel particles will increase along with reduction of mass, having good exposure of the fuel with oxygen particles due to improved surface to volume ratio. UBHC emissions at full load decreased with induction of biogas. Presence of oxygen in the combustion chamber and reacts with propane and butane present in LPG improved oxidation reaction of and thus reduced accumulation of the fuel in the crevice volume leading to reduce UBHC emissions at full load with induction of LPG.

## Conclusion

The maximum induction of LPG in conventional engine was 35% of total mass of diesel at full load operation. Particulate emissions, nitrogen oxide levels, carbon monoxide levels and un-burnt hydro carbons drastically decreased drastically with dual fuel operation in comparison with neat diesel operation on conventional engine. Increased injection pressure from 190 bar to 270 bar marginally decreased pollutants with test fuels.

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## References

Ali M., Pourkhesalian, Amir H., Shamekhi and Farhad Salimi, 2009. Performance and emission comparison and investigation of alternative fuels in SI engines. *SAE International*. 2009.

Arslan, O., Kose, I.R. and Ceylan, N. 2010. Experimental analysis of consumption and exhaust emissions of gasoline and LPG in car engines under cold climatic conditions. *Energy Sources.* 33 : 10-20..

Baris Erkus, Ali Surmen, M. and Ihsan Karamangil, 2012. A comparative study of carburation and injection fuel supply methods in an LPG-fuelled SI engine. *Fuel.* 107 : 511–517.

Ceviz, M.A. and Yuksel, F. 2005. Cyclic variations on LPG and gasoline-fuelled lean burn SI engine. *Renewable Energ*y. 31 : 1950-1960.

Cha-lee Myung, Kwanhee Choi, Juwon Kim, Yunsung Lim, Jongtae Lee and Simsoo Park. 2012. Comparative study of regulated and unregulated toxic emissions characteristics from a spark ignition direct injection light-duty vehicle fueled with gasoline and liquid phase LPG, *Energy.* 44 : 189-196.

Cummins, C. Lyle, Jr. 1993. *Diesel's Engine, Vol. 1: From Conception to 1918.* Wilsonville, OR, USA: Carnot Press.

Dheeraj Kalra, Veeresh Babu A. and Vijay Kumar, M. 2014. Effects of LPG on performance and emissions characteristics of SI engine, an overview. *International Journal of Engineering Development and Research.* 3(2): 2014.

Gong Li, Liguang Li, Zhimin Liu, Zhilong Li and Dongping Qiu, 2007. Real time NO emissions measurement during cold start in LPG SI engine. *Energy Conversion and Management.* 48 : 2508–2516..

Gumus, M. 2011. Effects of volumetric efficiency on the performance and emissions characteristics of a dual fueled (gasoline and LPG) spark ignition engine, *Fuel Processing Technology.* 92 : 1862-1867.

Hakan Bayraktar and Orhan Durgun, 2005. Investigating the effects of LPG on spark ignition engine combustion and performance. *Energy Conversion and Management.* 46: 2317–2333.

Hakan Ozcan and Soylemez, M.S. 2006. Thermal balance of a LPG fuelled, four stroke SI engine with water addition. *Energy Conversion and Management.* 47 : 570-581.

Hakan Ozcan, Jehad A. and Yamin, A. 2008. Performance and emission characteristics of LPG powered four-stroke SI engine under variable stroke length and compression ratio. *Energy Conversion and Management.* 49 : 1193–1201.

Khopkar, S.M. 2012. *Environmental Pollution Analysis.* [New Age International (P) Ltd, Publishers, New Delhi]: 180-190.

Fulekar, M.H. 2004. Chemical pollution – a threat to human life. *Indian J Environmental Protection.* 1: 353-359.

Mustafa, K.F. and Gitano-Briggs, H.W. 2009. Liquefied petroleum gas (LPG) as an alternative fuel in spark ignition engine: performance and emission characteristics, *Proceedings on International Conference on Energy and Environmen*t. Malacca.

Peter Anyon, 2003. LPG - the clean transport alternative: presenting the environmental case, Australian Liquefied Petroleum Gas Association Limited.

Selahaddin, Orhan Akansu, and Mehmet Bayrak. 2011. Experimental study on a spark ignition engine fueled by CH4/H2 (70/30) and LPG. *Hydrogen Energy.* 36: 9260-9266.

Shankar, K. S. and Mohanan, P. 2011. MPFI gasoline engine combustion, performance and emission characteristics with LPG injection. *Energy and Environment.* 2(4): 761-770.

Sharma, B.K. *Engineering Chemistry,* [Pragathi Prakashan (P) Ltd, Meerut]: 50-160

Thirumalmamidi and Suryawnshi, J.G. 2011. Investigations on SI engine using liquefied petroleum gas (LPG) as an alternative fuel. *Fuel.* 2(1) : 362-367.