Performance and Emission Study of LPG Diesel Dual Fuel Engine

Deo Raj Tiwari, Gopal P. Sinha

Abstract- This paper presents observations, results and their analysis with respect to the experiments conducted on fuel mix used in a set up on CI engine. LPG air mixes have been used in the air intake manifold at different concentration level while the diesel injection through injector at the end of compression stroke has remained undisturbed at the original level. The experiments were conducted at different loads. The objective of the study has been to minimize the pollutant emission. Observations were also taken for the impact on thermal effiencey and the power developed. Results have shown an all round favourable impact of LPG injection.Further; prospects of optimisation have been indicated on which the experiments have been initiated. The results, analyses and recommendation will be reported in our next paper.

Keywords: LPG, Performance, Emission, Combustion, Pollution

I. INTRODUCTION

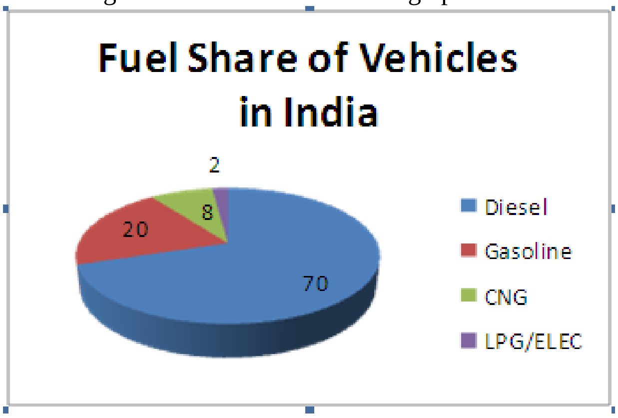
This work deals with the control of emission from CI engines. CI engines emit various kinds of pollutant such as NO_x, SOx, CO_2, CO, particulate matter, soot particles etc. Apart from engine parameters, the emission depends on combustion phenomenon and the chemistry of fuel used. By using bio diesel and gaseous fuel additives these emissions can be reduced significantly. This exhaust emission from CI engine is harmful for our respiratory system besides causing global warming.

There are two ways for controlling emissions. The first method is to control the emission after the combustion, at the exit point using various equipment such as catalytic converter, thermal converter etc. The second method is to control the emissions during combustion. This can be done either by the changing the fuel injection timing or by injecting some additive from outside which may react inside combustion chamber and produces clean exhaust. This can be done by injecting LPG, hydrogen, or steam in combustion chamber.

LPG is injected in combustion chamber during suction stroke through intake manifold with air. It forms a homogeneous combustible mixture. LPG however, doesn't burn due to high auto ignition temperature. But when supplied with another fuel having low auto ignition temperature e.g. diesel then it is easily burned. Due to homogeneous combustion, unburned hydrocarbon, soot particles are reduced lowering pollutants in exhaust.

Manuscript received February 2014.
Deo Raj Tiwari, Department of Mechanical & Automobile Engineering, Sharda University, Greater Noida, India.
Gopal P. Sinha, Department of Mechanical & Automobile Engineering, Sharda University, Greater Noida, India.

Fig.1- Poor combustion causing pollution



Graph 1

From graph 1, we can see that diesel oil, the common fuel used in CI engine is the major fossil fuel used for transport requirement. This has been the motivation for the work.

1.1 THE MECHANISM OF POWER GENERATION IN CI ENGINE

CI engine are a type of IC engines which are mainly classified as

- Spark ignition(SI) engine
- Compression ignition (CI) engine

1.2 BASIC WORKING CYCLES FOR I.C. ENGINE

Combustion in reciprocating piston I. C. Engine is commonly assumed to taken place either a constant volume or at a constant pressure. The Otto cycle, a constant volume heat addition thermodynamic process, closely models combustion in spark ignition (SI) I. C. Engine. The diesel cycle is a constant pressure process, slower speed cycle depicting combustion in Compression ignition, or diesel cycle engine, which is given in fig.2

Air standard diesel cycle
1-2: Adiabatic compression
2-3: Const. pressure heat addition
3-4: Adiabatic expansion
4-1: Const. volume heat rejection

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

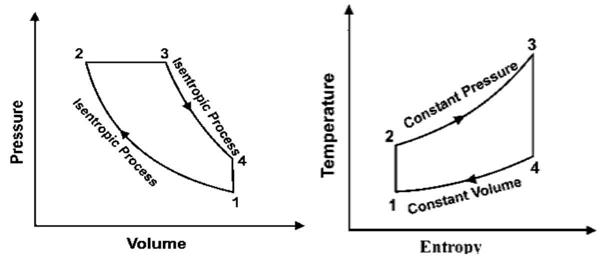


Fig.2–DieselCycle

1.3COMPARISON BETWEEN DIESEL AND LPG

Properties	Diesel	LPG
Normal State	Liquid	Gaseous
Formulae	C_3H_8	$C_{12}H_{26}$
Calorific value (kJ/kg)	44800	50350
Specific gravity	0.8	0.587(liquid)
Auto ignition temperature (°C)	225	540
Flash point (°C)	62	-104
Cetane no.	5-10	40-60
Stoichiometric A/F ratio (mass)	14.5	15.7
Peak flame temperature (°C)	2054	1990

Tab.1-The above table provide us data about various properties of diesel and LPG.

II. LITERATURE REVIEW

A number of experimentalists have tried to improve the emission performance through various strategies. Vijaybalan and Nagarajan[1] have tried to minimize pollutant emission by using a glow plug inside the combustion chamber. Simultaneously, they have also injected LPG in the air manifold. Diesel was injected through injector in usual manner. It achieved reduction in smoke and NO_X. However, it's suffered from induction in brake thermal efficiency, high hydrocarbon and CO emission at lower loads without glow plug. A 3% improvement in brake thermal efficiency was attained using glow plug.

Rao, et.al[2] have studied the performance of diesel engine with diesel and LPG. They have used the LPG carburettor on the intake side of the engine. The performance has been evaluated at the constant speed of 1500 rpm, under varying load for different proportion of LPG energy. They observe better engine performance on pure diesel up to engine load of about 35%. At higher engine load, they have found superior performance in respect of power and emission both. Their recommendation is to operate the engine on pure diesel up to 35%of load beyond which the dual fuel can be used.

Punia, et.al [3] have investigated the engine performance and exhaust emission in an LPG diesel dual fuel engine. They have also studied the impact of exhaust gas recirculation, intake air throttling and rate of injection. Diesel fuel was used as the pilot fuel while LPG was used as the main fuel. LPG was inducted in intake manifold. It was found that the intake air throttling at low loads can improve both engine efficiency and high Carbon emission. The effect is more pronounced on 20% load. Lower rate of injection gives poor brake thermal efficiency due to improper mixture formation. Advancing the injection timing improves the combustion process with no decrease in combustion duration. The reduction in CO and un burnt hydrocarbon was also observed.

In a recent study by Elnajjar, et.al [4] have compared the impact of various pilot fuel to gaseous fuel ratio on engine performance like speed, injection timing, load and compression ratio experimentally. They have used three different fuels: pure diesel fuel, dual fuel of diesel-LPG and diesel- natural gas. The study reported the location (crank angle) corresponding to maximum cylinder pressure and maximum pressure rise rate. They have also reported that as the engine speed, injection time and compression ratios were kept constant then the noise would become the same two regardless of the increase amount of gaseous fuel. This observation is important for dual fuel engine as it would give the same noise with increased power output.

Our study has given us further insight into the effective use of LPG for superior performance of CI engine along with conventional diesel fuel.

III. EXPERIMENTAL SET UP DESCRIPTION

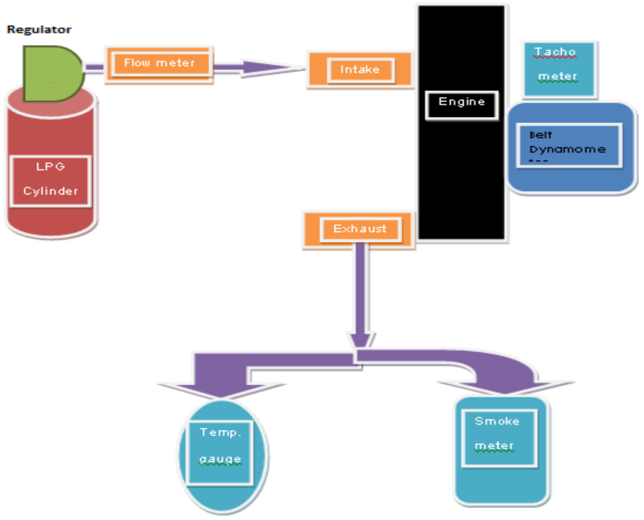


Fig.4 Layout of experimental set up

3.1 DESCRIPTION OF EXPERIMENTAL SETUP

3.1.1 LPG Cylinder, gas hose pipe and gas regulator

It is a simple cylinder of capacity 5 litres made up of steel to store LPG gas. The weight of the cylinder is 4.5 kg and water capacity is 5.6 litres. The pressure inside the cylinder is a little above the atmospheric pressure. Gas hose pipe of PVC is used to supply LPG from cylinder to intake manifold of engine through regulator. LPG valve gas regulator is used to control the supply of LPG from cylinder to inlet manifold. It is made of copper and capacity of supplying gas at the rate of $0.5m^3$/hr at atmospheric pressure when it is fully open.

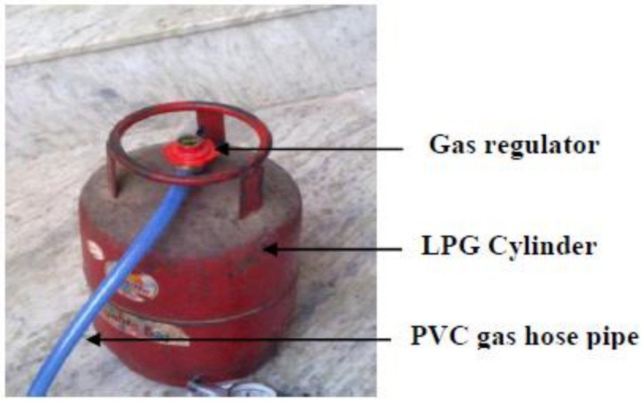


Fig-5.showing LPG cylinder with hose pipe

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

3.1.2 Gas flow meter

A gas flow meter is used for measuring the amount of LPG going into the combustion cylinder. It is the most important component of the experiment as this flow meter helps us to find how much LPG is going at what interval of time; its unit is L/min. When the gas is flown in this gas meter then the iron ball which is inside the glass shell goes up, and give the exact reading of how much LPG is going into the engine.

Fig-6. Gas flow meter

3.1.3 Engine Description

Engine used for experiment is a single cylinder diesel engine. The rated power of engine is 5 HP that is 3.73 kW, rated speed of engine is 1500 rpm. Load is varied with the help of friction dynamometer which is of belt type.

Fig.-7. Engine with dynamometer arrangement

3.1.4 Hydraulic friction dynamometer

This is used for varying the load on the engine. In this the quantity of water is varied with the help of a rotator type valve. The load variation is indicated on a needle indicator. The load given by needle indicator is in kg which is converted into N by multiplying it with gravity constant.

3.1.5 Fuel measurement device

It is simply a burette on which marking is done to measure the fuel in ml. Fuel consumption is measured by measuring fuel consumed with help of the burette in a specified time measured by a stop watch.

3.1.6 Digital tachometer

Digital tachometer is used for measuring RPM of the engine at different load and also at different amount of LPG introduction. Further if we know the RPM then we can easily calculate the break power and break thermal efficiency.

3.1.7 Smoke meter

Diesel exhaust smoke meter, also referred to as opacity meter or smoke density meter, detect and measure the amount of light blocked in a sample of smoke emitted by engines the smoke meter display the smoke density a measure of the efficiency of combustion. This makes the meter excellent diagnostic tools to ensure proper maintenance of diesel engines for improved fuel economy and protection of the environment.

An optical unit mounted inside a measuring head and a separate electronic control unit works on the basis of extinction detection. The collimated beam from light source is absorbed and scattered by the particulate exhaust emission. A photodiode determines the light intensity of the attenuated beam and the corresponding opacity value is transmitted to a remote display. Partial flow continuous gas sampling combined with a heated and temperature controlled smoke chamber compensate for change in pressure and test conditions to give us the most accurate reading possible. Diesel smoke particularly consists of aerosol, suspended in the exhaust steam in diesel engine. The %opacity is the light source which is prevented to reach the light detector, which is expressed in %HSU (Hartridge Smoke Unit). Also the smoke density is the function of the number of smoke particle per unit gas volume, the size distribution of smoke particle, and the light absorbed and scattering property in any substances.

Fig -8.Showing the smoke meter reading

3.2 PROCEDURE FOR EXPERIMENT

Following are the steps to be followed in the experiment:

1. Supply the diesel fuel from diesel tank.
2. Start the engine.
3. Supply the LPG from LPG cylinder.
4. Vary the amount of LPG supplied with the help of LPG valve gas regulator.
5. For each amount of LPG supplied vary load with the help of dynamometer.
6. For each load measure the %HSU with the help of smoke meter.
7. For each load measure the rpm with the help of digital tachometer.
8. For each load also measure the fuel flow rate.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

9. Temperature of exhaust gas is also measured for each load.
10. The above steps are repeated for more readings.

All the above procedure are repeated for different load and fuel composition but the important point to be noted is that the all this test are being performed over a particular period of time, which is measured by the stop watch.

IV. RESULTS AND ANALYSIS

EXPERIMENTAL RESULTS

Fuel diesel without LPG addition

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (□C)	SMOKE DENSITY (%HSU)
0	1440	0.220	0	0	140	82
1	1404	0.230	0.2307	2.79	155	87
2	1382	0.250	0.4543	5.07	165	89
3	1365	0.310	0.6730	6.05	180	90

Tab .2- experiment result when taken at a time interval of 10 seconds

Fuel diesel with LPG addition @0.50L/min

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (°C)	SMOKE DENSITY (%HSU)
0	1720	0.170	0	0	125	67
1	1703	0.200	0.2790	2.881	145	71
2	1685	0.230	0.5532	5.152	160	76
3	1662	0.275	0.8190	6.638	174	80

Tab.3-Experimental result when taken at 10 sec with added 0.5L/min LPG

Fuel diesel with LPG addition @0.90L/min

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (□C)	SMOKE DENSITY (%HSU)
0	1742	0.130	0	0	168	64.6
1	1732	0.155	0.2846	2.92	172	68
2	1701	0.180	0.5591	5.25	180	71
3	1672	0.210	0.8244	7.04	191	75

Tab.4- experiment result when taken for 10 second with added 0.90L/min LPG

Fuel diesel with LPG addition @1.4L/min

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (̊C)	SMOKE DENSITY (%HSU)
0	1784	0.100	0	0	180	60
1	1771	0.120	0.2912	2.86	189	62
2	1750	0.140	0.5752	5.30	199	67
3	1739	0.160	0.8575	7.41	210	72.1

Tab. 5-Table showing the experiment result when taken for 10 sec when added 1.4 L/min LPG

Fuel diesel with LPG addition @1.9L/min

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (̊C)	SMOKE DENSITY (%HSU)
0	1795	0.095	0	0	191	59.9
1	1775	0.115	0.2917	2.33	209	61.3
2	1762	0.132	0.5795	4.22	220	65.2
3	1744	0.155	0.8599	6.18	232	69.9

Tab.6- Table showing experiment result when taken for 10 sec when added 1.9L/min LPG

4.1 Emission analysis

4.1.1 %HSU (smoke density/%capacity)

Load (kg)	%HSU				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	82	67	64.6	60	59.9
1	87	71	68	62	61.3
2	89	76	71	67	65.2
3	90	80	75	72.1	69.9

Table 7

From this table we can see that soot is increasing as we increase in load when only diesel fuel is supplied, this happens because at higher loads the fuel supply to engine increases for the same amount of air sucked by air intake port and due to which there is lack of oxygen at some places inside the combustion chamber due to heterogeneous mixing.

When LPG is supplied with diesel then decrease in % HSU is observed at % of LPG. Also at lower loads decrease in %HSU observed. The reason behind this is the fact that at lower loads delay period of diesel increases and at the same time due to low temperature and pressure inside the combustion chamber proper ignition and burning of LPG does not occur. But at higher loads delay period of diesel decreases and also pressure and temperature inside the combustion chamber become high, due to this proper ignition and combustion of LPG occur resulting a decrease in % HSU.

4.1.2 Fuel consumption

Load(kg)	Fuel diesel flow rate (ml/sec)				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	0.220	0.170	0.130	0.100	0.095
1	0.230	0.200	0.155	0.120	0.115
2	0.250	0.230	0.180	0.140	0.132
3	0.310	0.275	0.210	0.160	0.155

Table - 8

From this table we can see that with increase in load, fuel consumption increases but when we supply LPG with diesel then fuel consumption at every load decreases because LPG in itself is a fuel.

4.1.3 Exhaust temperature

Load (kg)	Exhaust temperature (°C)				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	140	125	168	180	191
1	155	145	172	189	209
2	165	160	180	199	220
3	180	174	191	210	232

Table-9

From above table it is clear that temperature increases with increase in load and also with increase in amount of LPG supplied. It is due to fact that when LPG is supplied it burns in later stage due to high auto ignition temperature.

The temperature of combustion is closely related to the formation of NO_x in exhaust. With increase in combustion temperature NO_x formation increased, but at the same time when we supply LPG, the amount of air supplied decreases.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

This reduces the availability of nitrogen and oxygen, reducing NO_x formation

4.1.4 Brake power (KW)

Load (kg)	Brake power(KW)				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	0	0	0	0	0
1	0.2307	0.2790	0.2846	0.2912	0.2917
2	0.4543	0.5532	0.5591	0.5752	0.5792
3	0.6730	0.8190	0.8244	0.8575	0.8599

Table -10

4.1.5 Efficiency

Load (Kg)	Brake thermal efficiency (% increase)				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	0	0	0	0	0
1	2.79	2.88	2.92	2.86	2.33
2	5.07	5.15	5.25	5.30	4.22
3	6.07	6.63	7.04	7.41	6.18

Table- 11

From above table it is clear that with increase in load brake thermal efficiency of engine increases and when LPG is supplied with diesel then at every load brake thermal efficiency is increased. It is due to the fact that LPG helps in making homogeneous mixture inside the combustion chamber and proper combustion is occur. As a result more heat is obtained from combustion and efficiency is improved.

Brake specific fuel consumption

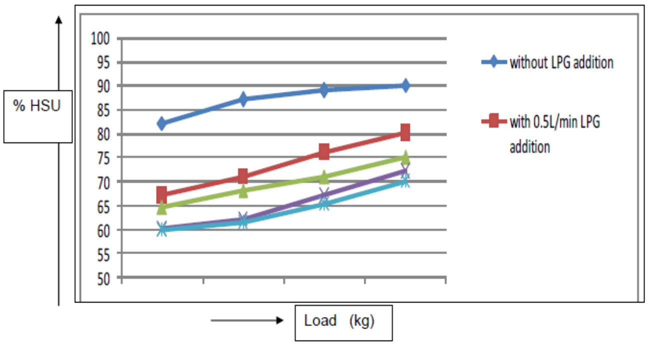
Load (Kg)	Brake specific fuel (diesel) consumption (kg/kWh)				
	Without LPG addition	With 0.5L/min LPG addition	With 0.9L/min LPG addition	With 1.4L/min LPG addition	With 1.9L/min LPG addition
0	0	0	0	0	0
1	2.87	2.70	2.62	2.61	3.18
2	1.58	1.52	1.46	1.42	1.55
3	1.32	1.18	1.09	1.02	1.20

Table 12

From this table we can see that with increase in load brake specific fuel consumption decreases but when we supply LPG with diesel then brake specific fuel consumption at every load further decreases because LPG in itself is a fuel and supply some heat after combustion.

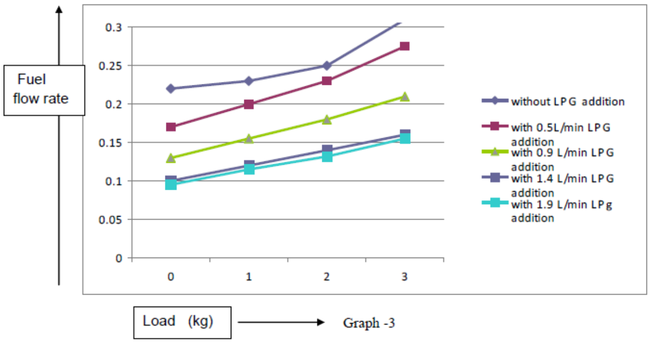
4.2 Graphical Representations Of Analysis

4.2.1 % HSU



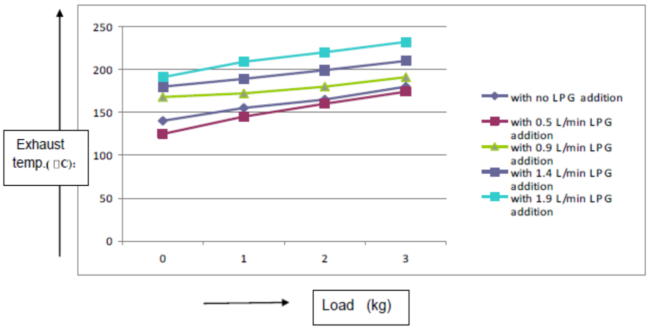
Graph 2

4.2.2 Fuel consumption (ml/sec)



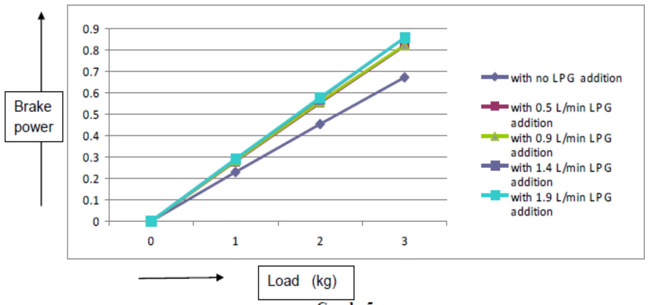
Graph -3

4.2.3Exhaust temperature (□C)



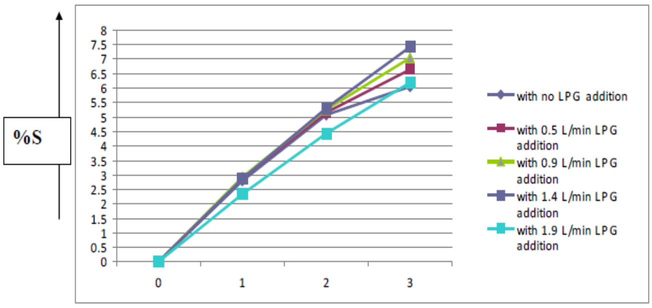
Graph -4

4.2.4Brake power (KW)



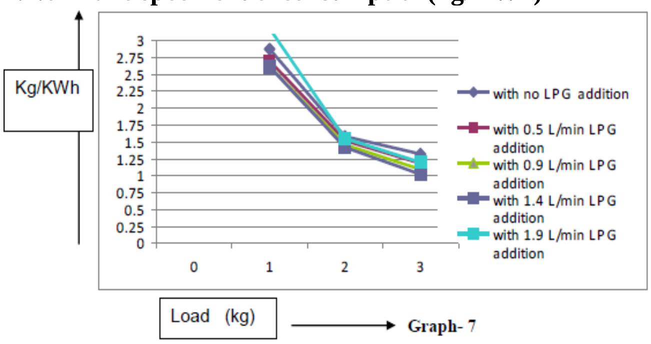
Graph- 5

4.2.5 Brake thermal efficiency (%)



Graph- 6

4.2.6 Brake specific fuel consumption(kg/KWh)



Graph- 7

V. CALCULATION FOR FEASIBILITY

Assuming that a engine is running through 10000km/year, at the maximum load.

Then considering the following data:-

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.

Total km = 10000/year
Average speed = 50km/hr
Total running time of engine = 200 hr/year
Also,
Without LPG addition = Discharge of diesel is 232.2 L/year
With adding 0.5L/min LPG = Discharge of diesel = 198 L/year and for LPG = 36 kg/year,
With adding 0.9 L/min LPG = Discharge of diesel = 151.2 L/year and for LPG = 60 kg/year,
With adding 1.4 L/min LPG = Discharge of diesel = 115.2 L/year and for LPG = 84 kg/year,
With adding 1.9 L/min LPG = Discharge of diesel=111.6 L/year and for LPG= 119.50kg/year.
Also taking the present value of diesel and LPG as:
Diesel = Rs 54/ Litre and for LPG = Rs 400/ 14.2 kg cylinder.

Amount of fuel	Without LPG	LPG @ 0.5L/min	LPG @ 0.9 L/min	LPG @ 1.4 L/min	LPG @ 1.9 L/min
Cost (Rs)	12052	11706	9854	8586	9393

Table -13 showing the calculation of running cost of duel fuel engine

VI. OBERVATION AND INFERENCE

Twenty experiments were conducted for four different loads (0, 1, 2, 3kg) and five levels of LPG injection in the air-intake manifold. The impact on emission, power developed and brake thermal efficiency was recorded and their trends have been analysed. The observations are shown in table 2 to 12. The corresponding graph plots marking the trends are given in graph.2 to 7.
The Following inferences can be drawn from the experimental observations.

(A)Impact on pollutant emission

(i)The emission level goes up with the increasing load.
(ii) With LPG injection, however, there is a significant reduction (almost 30%) in smoke level at all loads.

(B)Impact on fuel consumption

Fuel Consumption reduces progressively at all loads as LPG injection is stepped up. This substitution of the usual fuel diesel is cost effective (refer to Table13)

(C) Impact on exhaust temperature and NOx in exhaust

For the minimum exhaust temperature, LPG injection has to be less than 0.5 l/min for this engine. Thus reduction in temperature of exhaust is likely to decrease the formation of NO_x- an undesirable constituent of emission.

(D)Impact on power developed measured at brake wheel

Observations show that LPG injection boosts the power output resulting in more effective utilisation of the engine.

(E)Impact on Brake Thermal Efficiency (%):

Thermal efficiency increases with LPG injection

(F) Impact on specific fuel/consumptions (Kg/KWh)

Specific fuel consumption shows an all-round drop in fuel consumption.

VII. CONCLUSION

In this experimental work effect of LPG addition on emission and performance characteristics of a diesel engine has been analysed. LPG injection has favourable impact on emission, fuel consumption, power developed and above all the thermal efficiency However; LPG injection into the air intake manifold has to be restricted to the optimum value. The economic analysis shows a cost optimization, for maintaining minimum exhaust temperature. The present study has indicated that the optimum with respect to temperature is below 0.9 l/min, for the engine used for the experiments.
Thus major findings of this work are:
(i) The first and most important change is on soot. When LPG is added through inlet manifold soot level is reduced at higher loads, although at lower loads there is almost no change soot level is observed.
(ii) The temperature and %HSU also decreased.
(iii) The running cost of an engine is also decreased from the single fuel.
(iv) Brake specific fuel consumption is also reduced.
(v) Efficiency of engine is improved.
(vi) The noise level is also reduced at higher load when LPG is added.

VIII.SUGGESTION FOR FUTURE WORK

An electronic injector can be used to inject the LPG in a properly measured quantity and directly into the cylinder in spite of through intake manifold in suction stroke.

- Various digital flow measuring instruments can be used to measure the accurate amount of LPG and the experiments may be conduct with different proportions of LPG anddiesel fuel.
- Glow plug may be provided in the combustion chamber to study its impact on pollution.

REFERENCES

1. P. Vijayabalan and G. Nagarajan, “Performance, Emission and Combustion of LPG diesel dual fuel engine using glow plug”, Jordan Journal of Mechanical and Industrial Engineering, Vol. 3, No. 2, June 2009.
2. G.A. Rao, A.V.S. Raju, K. Govinda Rajulu and C.V. Mohan Rao, “Performance Evaluation of a Dual Fuel Engine (LPG+Diesel)”, Indian Journal of Science and Technology, Vol. 3, No. 3, March 2010.
3. M.P. Poonia, A. Bhardwaj, A.S. Jethoo and U. Pandel, “Experimental Investigations on Engine Performance and Exhaust Emissions in an LPG Diesel Dual Fuel Engine”, International Journal of Environmental Science and Development, Vol: 2, No. 6, December 2011
4. Emad elnajjar, Mohamed Y.E. Selim and Farag Omar, “Comparison Study Of Dual Fuel Engine Performance And Overall Generated Noise Under Different Dual Fuel Types And Engine Parameters”, International Journal of Basic and Applied Sciences IJBAS-IJENS Vol: 11 No. 03, June 2011.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication Pvt. Ltd.