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Performance and Emission Characteristics of CI Engine Fuelled with LPG and Pure Diesel

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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 efficiency 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.

Keywords: LPG, diesels, emissions, mixture, combustion

1. Introduction

This work deals with the control of emission from CI engines. CI engines emit various kinds of pollutants 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. First way to control the emission after the combustion at the exit point, using various equipments such as catalytic converter, thermal converter etc., and 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.
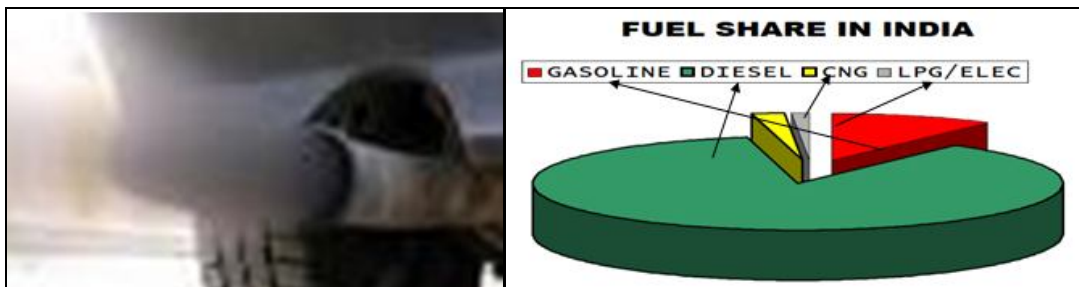

Figure 1: Poor combustion causing pollution
Figure 2

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. Comparison 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

Table 1: The above table provide us data about various properties of diesel and LPG

2. Literature Review

2.1. Combustion Phenomena In CI Engine
Combustion is defined as a relatively rapid exothermic chemical reaction of hydrogen and carbon in the fuel with the oxygen in the air liberating energy in the form of heat. The process of combustion in CI engine is fundamentally different from that in spark ignition engine. In the CI engine air alone is compressed through a large compression ratio (12:1 to 22:1) raising its temperature and pressure. In this highly compressed and heated air in the combustion chamber (well above ignition point of fuel) one or more jet of fuel are injected in the atomized state at high pressure of 110 to 200 bars by means of a fuel pump. Each minute droplet as it enters the hot air (temperature 450 to 550 °C and pressure 30 to 40 bar) gets quickly enveloped by its own vapour and ignites. In diesel engines, ignition of fuel is caused by the heat of compression. To support combustion, air is required. Approximately 7 kg of air is required for the combustion of 0.5 kg of fuel oil. However, to ensure the complete combustion of fuel, an excess amount of air is always supplied to the cylinders. The ratio of the amount of air supplied to the quantity of fuel injected during each power stroke is called the air fuel ratio. Normally there is an excess of air over the minimum required for complete combustion.
- The fuel must enter the cylinder at the, proper time. For this the fuel injection valve must open and close in correct relation to the position of the piston.
- The fuel must enter the cylinder in a fine mist or fog.
- The fuel must mix thoroughly with the air that supports combustion.
- Sufficient air must be present to assure complete combustion.
- The temperature of compression must be sufficient to ignite the fuel.

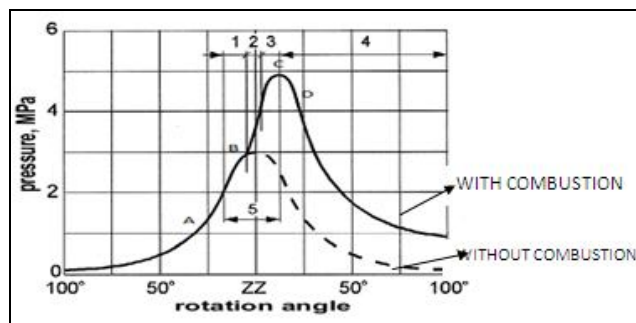Graph 2 gives the pressure inside the cylinder at different crank angles.

Figure 3: Crank Angle

2.2. Various Parameters Effecting Emissions:
- Fuel - air ratio
- Fuel Injected During Ignition Delay:
- Load:
- Cold –Start and Misfire:
- Intake Swirl:
- Nozzle Opening Pressure:
- Injection Timing:

- Intake Charge composition:

This work focuses on emission control by varying the intake mixture.

2.3. Controlling Methods Of Emissions:

Technologies to control air pollutant emissions from IC Engines can be categorized as process or post-combustion controls. Process controls include changes in the intake mix and improvements to the combustion chamber, fuel/air delivery, and engine components aimed at reducing air pollutant emissions. Post-combustion controls include catalytic converters and other technologies applied to react with combustion exhaust constituents including NO_x, CO, HCs, and particulate. This work focuses on changes in the intake mix. Various methods to vary the intake by supplementary injection have been tried in the past. These are listed below:

2.4. Effect Of Lpg Injection On Soot Formation:

All soot has a graphite structure with hexagonal basic carbon units forming small crystalline atom. Soot particles are nothing but the bunch of carbon particles which are formed in fuel rich regions due to the lack of oxygen and incomplete combustion. When fuel is injected into the cylinder, without proper atomization mixing with air or due to the high speed of engine some portion of cylinder remains oxygen deficient and hence incomplete combustion takes place which results in the formation of soot particles. When LPG is injected in the cylinder through inlet manifold with air in suction stroke, it makes homogeneous mixture with air but due to high auto ignition temperature doesn't ignite alone. When diesel fuel is supplied at the end of compression stroke burning of diesel and air mixture starts first and then LPG also ignites. Due to relatively homogeneous air-fuel mixture burning occurs in smooth manner. Thus noise from diesel engine is reduced. Due to homogeneous mixture inside the cylinder complete and proper burning of fuel (diesel+LPG) is achieved inside the cylinder. Thus injecting LPG with diesel will reduce exhaust, soot particles noise, HC and CO. It will also reduce fuel (diesel) consumption because LPG itself is a fuel and supplies some heat after combustion.
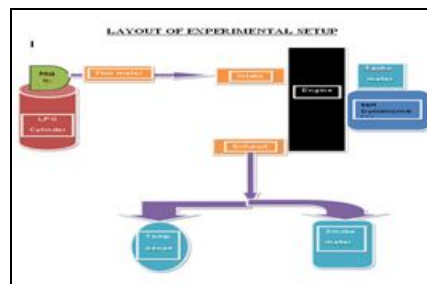
3. Experimental Set Up

Figure 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 14.2 Kg made up of steel to store LPG gas. The weight of the cylinder 15.6 kg. The pressure inside the cylinder is 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.

Figure 5: showing LPG cylinder with Regulator and hose pipe

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.
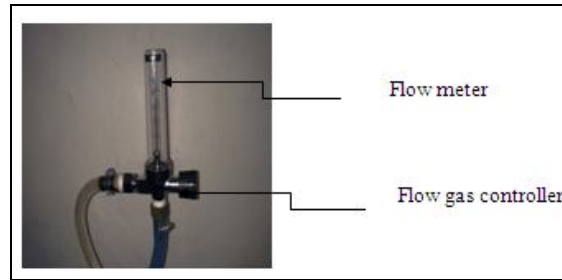
Figure 6: Gas flow meter

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.

Figure 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. 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.

Figure 8: Showing the smoke meter reading

3.2. Procedure For Experiment

Following are the steps to be followed in the experiment:

- Supply the diesel fuel from diesel tank.
- Start the engine.
- Supply the LPG from LPG cylinder.
- Vary the amount of LPG supplied with the help of LPG valve gas regulator.
- For each amount of LPG supplied vary load with the help of dynamometer.
- For each load measure the %HSU with the help of smoke meter.
- For each load measure the rpm with the help of digital tachometer.
- For each load also measure the fuel flow rate.
- Temperature of exhaust gas is also measured for each load.
- The above steps are repeated for more readings.

4. Results and Analysis

4.1. Fuel diesel without LPG addition

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (℃)	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

Table 2: experiment result when taken at a time interval of 10 seconds

4.2. 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 (℃)	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

Table 3: Experimental result when taken at 10 sec with added 0.5L/min LPG

LOAD (KG)	RPM	DIESEL FUEL CONSUMPTION (ml/s)	BRAKE POWER (KW)	BRAKE THERMAL EFFICIENCY (%)	EXHAUST GAS TEMP (℃)	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

Table 4: experiment result when taken for 10 second with added 0.90L/min LPG

4.3. 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

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

4.4. 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

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

4.5. Emission analysis: %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 to a decrease in % HSU.

4.6. 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.

4.7. 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 is 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 will increase, but at the same time when we supply LPG the amount of air supplied decreases due to this availability of nitrogen and oxygen decreases, which will reduce NO_x formation

4.8. 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

4.9. 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.

4.10. 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.
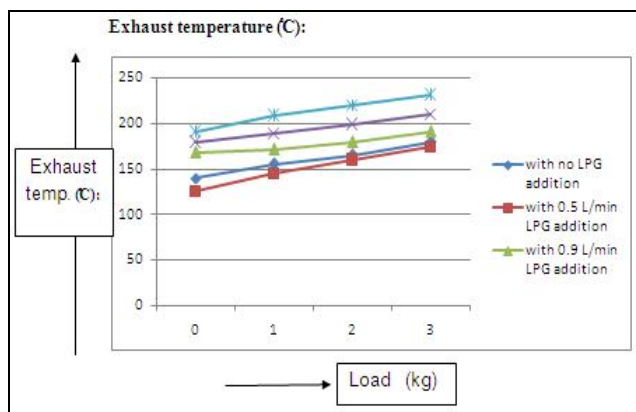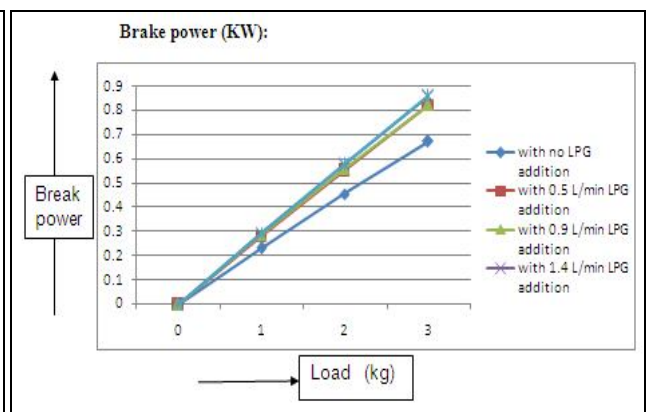
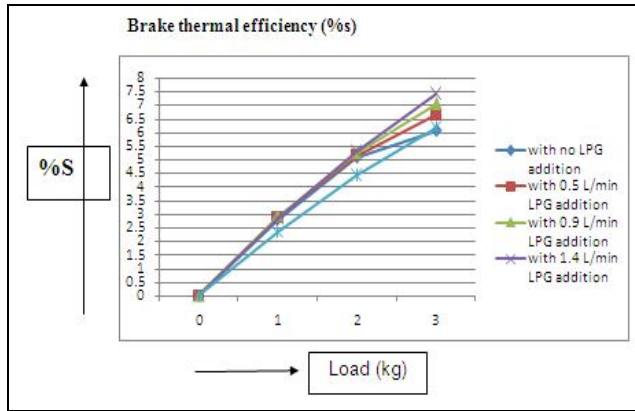## 5. Graphical Representations of Analysis
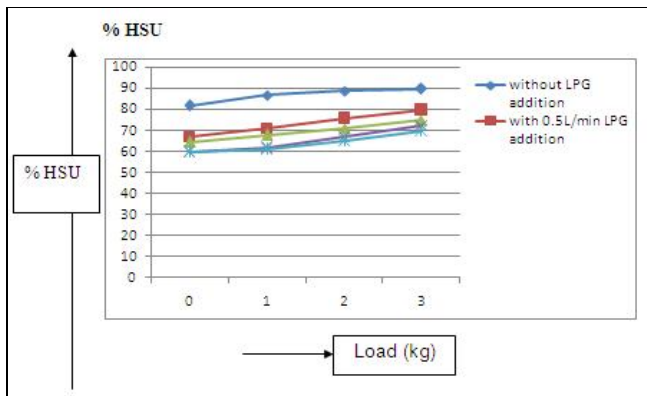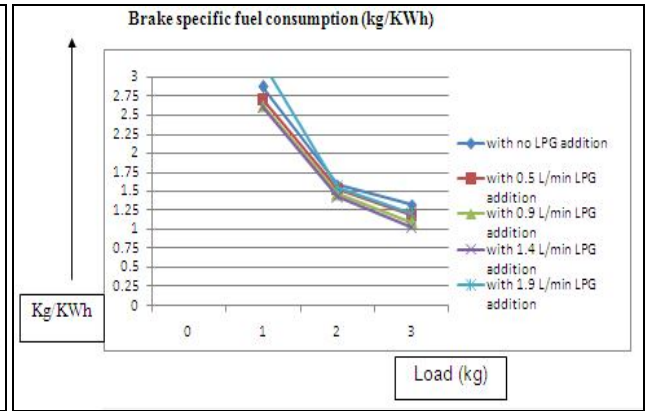

Graph 2
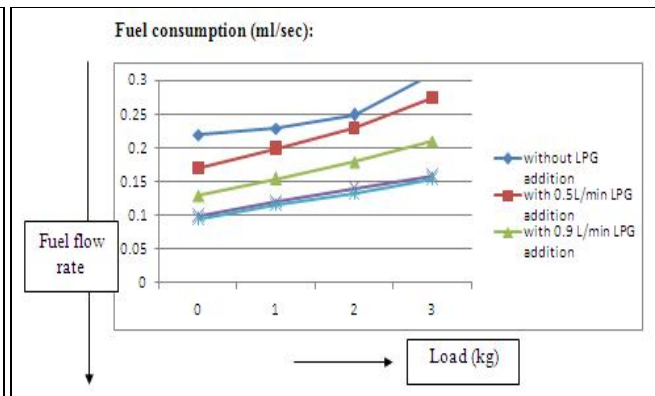
Graph 3

Graph 4

Graph 5

Graph 6

Graph 7

6. Calculation and Obervations

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

Then considering the following data:-

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

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.

- The emission level goes up with the increasing load.
- With LPG injection, however, there is a significant reduction (almost 30%) in smoke level at all loads.
- Fuel Consumption reduces progressively at all loads as LPG injection is stepped up. This substitution of the usual fuel diesel is cost effective.
- 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
- Observations show that LPG injection boosts the power output resulting in more effective utilisation of the engine.
- Thermal efficiency increases with LPG injection
- Specific fuel consumption shows an all-round drop in fuel consumption.

7. 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:

- 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.
- The temperature and %HSU also decreased.

- The running cost of an engine is also decreased from the single fuel.
- Brake specific fuel consumption is also reduced.
- Efficiency of engine is improved.
- The noise level is also reduced at higher load when LPG is added.

8. Suggestion for Future Development

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 added.
- Also using the glow plug at the time of injection.

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