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Experimental Investigations on the Duel Fueled Diesel Engine

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Abstract: In the present study, a four stroke, five horse power diesel engine was tested with two different fuel blends. In the first case, diesel-kerosene blends and in the second case, air and Liquefied Petroleum Gas (LPG) mixture along with diesel was tested at constant engine speed of 1500 rpm. Different engine exhaust emissions were compared using pure diesel, diesel-kerosene blends and air-LPG mixtures. With diesel-kerosene blends minimum exhaust emissions were observed at 30% kerosene blend, when compared with pure diesel emissions. Slight increase in the NOx exhaust emission was observed. With air-LPG mixtures, minimum exhaust emissions were observed at 11% LPG mixing. However, increase in NOx exhaust emission was observed. Engine performance improved and Specific Fuel Consumption (SFC) was observed to be minimal at 30% kerosene blending and decreased as compared to pure diesel value at the same brake power output. SFC was also observed to be minimum at 11% LPG mix and decreased by about 20% as compared to pure diesel value at the same brake power output. The fuel operating cost also reduced at 30% kerosene blend and further reduced at 23% LPG mixing with air.

Key words: Exhaust emissions, air pollution, diesel engine, duel fuels, performance

INTRODUCTION

Exhaust gas emission in an internal combustion engine can be controlled by different methods i.e., by modifying the engine design, treating the exhaust gas and by fuel modifications. Guy (2003) conducted studies for the change in engine designs like changing inlet and outlet valve opening time for reducing emissions. Olenev (2002) studied the control of combustion process and exhaust gas emissions using secondary air along with fuel injection to achieved better mixing. Karpov (2007) tried to improve the exhaust emissions and engine performance using fuel properties and anti-smoke additives. Exhaust gas treatment methods using catalytic converters to oxidize and reduce exhaust emissions have been tried (Sond, 1997). Sharma (1994) used after burners with a spark plug in the exhaust muffler for the combustion of un-burnt hydrocarbons and exhaust gas recircnlation methods to reduce NO_x emissions. Mustafa *et al*. (2007) has also used biofuel from high-oleic soybeans in engines and additives like cynuric acid. Jian-Guang *et al*. (2004) investigated the combustion of ethanol and blends of ethanol with diesel fuel. It was observed that the effects of adding ethanol to diesel fuel were increased ignition delay, increased rates of pre-mixed combustion, increased thermal efficiency and reduced exhaust smoke. Czerwinski (1994) used rape seed oil, ethanol and diesel fuel blend and

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compare the heat release curves with diesel fuel. It was observed that the addition of ethanol caused longer ignition lag at all operating conditions. During the literature survey studies on the diesel exhaust smoke could ouly be found. How ever, very little information is available on the complete exhaust analysis of diesel engine using diesel and with alternate/dual fuels. Thus there is an urgent need to develop cheap and simple methods of reducing exhaust gas emission levels from the compression ignition engines. There fore in this study authors have used a low cost and simple method of reducing exhaust gas emissions of diesel engine without loosing any power out put. In the first case, diesel fuel and in the second case Air-Liquefied petroleum gas mixtures along with diesel was tried at engine rated speed of 1500 rpm. The main objectives of the study are, to analyze the diesel engine exhaust pollutants, to see the effect of using fuel blends on the emission levels from diesel engine exhaust, to study the engine performance using fuel blends and to conduct the cost benefit analysis as compared to the pure diesel.

MATERIALS AND METHODS

Selection Criteria of the Fuel Blends

The blending fuels used in the current work have been selected on the basis of some chemical and thermodynamic properties as shown in Table 1.

A stationary, five horse power direct injection diesel engine was used to conduct experiments. Its specifications are shown in Table 2. The exhaust gas emissions were measured using on-line Non-dispersive Infrared (NDIR) AVL exhaust gas analyzer.

Experimental Procedure

In the first case, engine was operated with diesel-kerosene blends having 10 to 50% kerosene on volume basis. In the second phase, Liquefied Petroleum Gas (LPG) was mixed with suction air having 11 to 23% LPG on volume basis along with pure diesel. The fuel injection system was adjusted to supply lesser diesel during the operation with air-LPG mixture for smooth operation. The experiments were conducted at six load levels. The last reading was at maximum full load.

A simple, low cost air-LPG mixing device shown in Fig. 1 was used to mix LPG with iulet air during suction stroke. Initially 5% kerosene mixing level was also tried but no significant change in exhaust emissions and engine performance could be observed.

Table 1: Properties of fuel used

Properties	Diesel	Kerosene	LPG
Calorific value (kj kg^{-1})	44500	45400	50000
Self ignition temperature (°C)	725	640	525
Boiling point range (°C)	260-320	180-240	-34
Ignition delay period (sec)	0.002	0.0015	-
Flame propagation rate (cm sec^{-1})	10.5	11.8	83.7
Flame temperature (°C)	1715	1782	1985
Surface tension (dynes)	32	30	-
Viscosity at 39°C (centistoke)	2.7	2.2	-
Specific at 32°C	0.83	0.72	0.43
Sulphur content by (wt., %)	0.8	0.12	0.0112

Table 2: Engine specifications

Make	Kirlosker model AV
Number of cylinders	1
Stroke×Bore (mm)	80×110
Cooling	Water cooled
Rated brake power (h.p)	5
Rated speed (rpm)	1520
Compression ratio	16.5:1
Injection timing (btdc)	32°

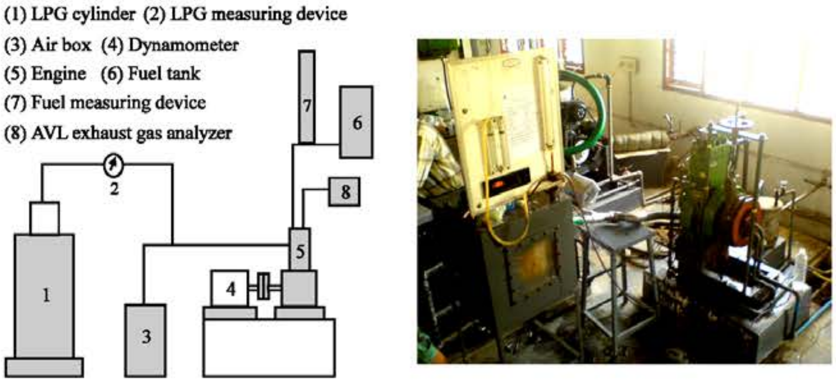

Fig. 1: Experimental set up (with Air-LPG mixing device)

RESULTS AND DISCUSSION

Engine performance in terms of load against SFC has been shown in Fig. 7. A comparative cost analysis of using different fuel blends has been discussed. A comparison of exhaust gas emissions with pure diesel, selected diesel-kerosene blends and selected air-LPG mixture has been discussed here.

Carbon Monoxide (CO) Emissions

As the load on the engine was increased the percentage of CO also decreased gradually and reached a minimum value of 3.6% for pure diesel, 3.4, 3.0, 2.4 and 5.0% at 10, 20, 30 and 40% kerosene blends, near rated load for all the fuel blends. Also observed value of CO was 0.4, 0.6 and 5.3% for 11, 15 and 23% air-LPG mixtures, respectively as shown in the Fig. 2. At smaller loads the quantity of fuel supplied was small, i.e., the mixture remained lean which produced lesser heat in the chamber resulting in lower flame temperature consequently lesser conversion of CO into CO_2. As the quantity of fuel supplied increased, the combustion of this fuel produced more heat in the combustion chamber resulting in greater conversion of CO into CO_2. Beyond the rated load value the percentage of CO in the exhaust started increasing due to deterioration of combustion process. Also with diesel-kerosene blends minimum CO emissions occurred at 30% kerosene mixing level. It was due to improved combustion because kerosene has lower self-ignition temperature and has higher volatility as compared to diesel that reduced ignition lag period according to Sen (1994). However, at 40% kerosene mixing level, the combustion process deteriorated due to too much of kerosene that caused much change in the combustion characteristics of the mixture.

The reason for decrease in CO emissions with air-LPG mixtures was that LPG has a great affinity for air, i.e., it is highly miscible with air that improved air-fuel contact ratio. When thoroughly mixed air-LPG mixture entered the combustion chamber and diesel sprayed, combustion started immediately due to decrease in the lag period as LPG was already in the gaseous phase. Moreover, it has eight times more flame propagation rate as compared to diesel. The early combustion of LPG molecules helped in producing higher temperature for diesel molecules.

Carbon Dioxide (CO_2) Emissions

As the load on the engine was increased the percentage of CO_2 also increased gradually and reached a value of 18% for pure diesel, 19, 19.5, 21 and 16% at 10, 20, 30 and 40% kerosene blends at rated load for all the fuel blends as shown in Fig. 3. The observed values of CO_2 emissions were 20.6, 22.5 and 16.4% at 11, 15 and 23% air-LPG mixtures, respectively. Higher percentage of CO_2 in

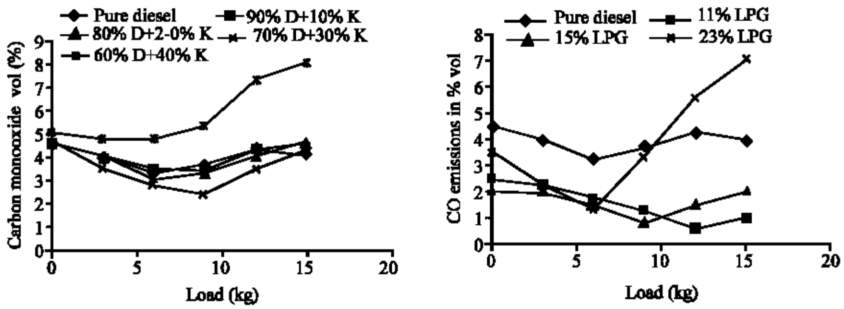

Fig. 2: Carbon monoxide emissions of different blends at various loads

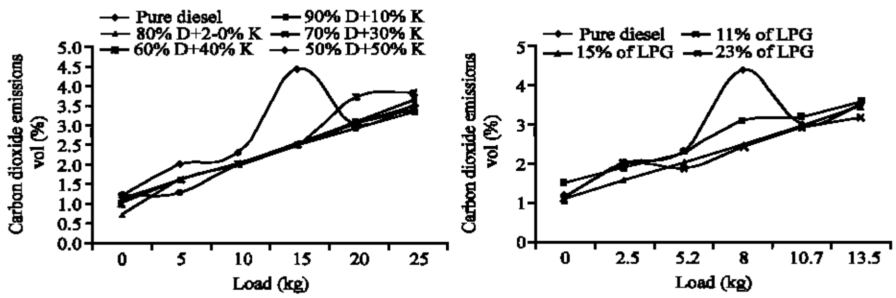

Fig. 3: Carbon dioxide emissions of different blends at various loads

the exhaust indicated higher oxidation of fuel at the constant engine speed and release of more heat for power conversion. It also indicated better combustion as more fuel was converted from CO to CO_2. This trend was 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. Results shown in Fig. 3 shows that CO_2 emissions initially increased as the load on the engine was increased. It reached a maximum value and then started decreasing, which showed deterioration at higher loads. At 40% kerosene level and at 23% LPG level reduction in CO_2 emissions also indicated poor combustion.

Unburnt Hydrocarbon (UHC) Emissions

As the load on the engine was increased, UHC decreased gradually and reached a value of 175 ppm for pure diesel, 173, 170, 160 and 250 ppm at 10, 20, 30 and 40% kerosene blends at rated load for all the fuel blends. The observed values of UHC were 46, 50 and 135 ppm for 11, 15 and 23% air-LPG mixtures respectively as shown in Fig. 4. At smaller loads oxidation reactions were slow due to lower temperature and lean mixture. UHC are formed in the core of the spray and the regions just outside the flame zone. They are also formed at the point where the fuel spray touches the wall and there by gets quenched, according to Sen (1994). As the load was increased, heat released by the fuel also increased which improved combustion and consequently UHC level started decreasing. The above rated value UHC emission again started increasing due to poor combustion.

With air-LPG mixture, UHC level was observed to be very small at rated load. It was due to further improvement in combustion process because of high air-fuel contact ratio, higher flame propagation rate and higher calorific value of LPG as compared to diesel.

Oxides of Nitrogen (NO_x) Emissions

As the load on the engine was increased, NO_x emissions also increased gradually and reached a value of 895 ppm for pure diesel, 887, 857, 524 and 955 ppm at 10, 20, 30 and 40% kerosene blend

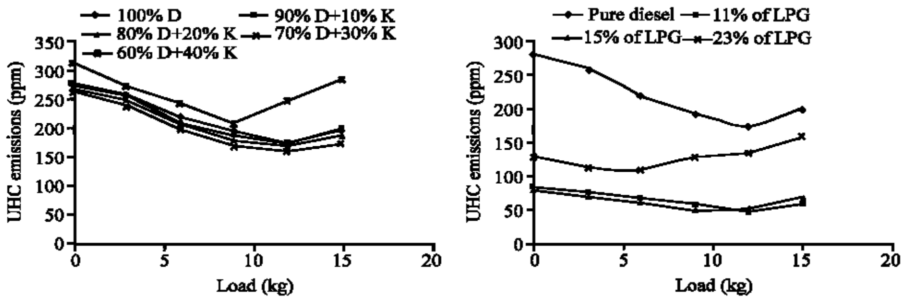

Fig. 4: UHC emissions of different blends at various loads

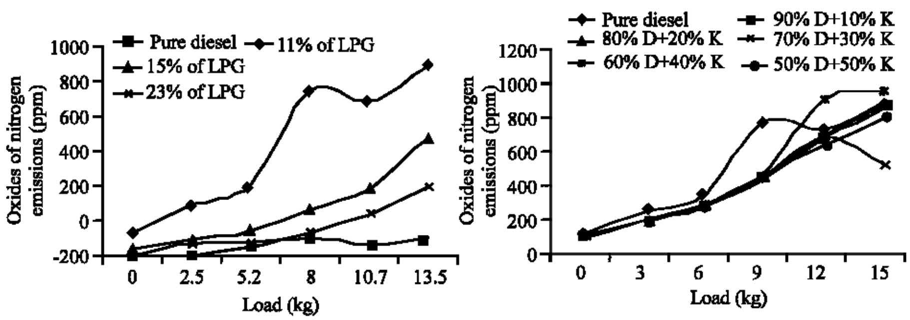

Fig. 5: Oxides of nitrogen emissions of different blends at various loads

at rated load for all the fuel blends. The observed values of NO_x were 88, 565 and 329 ppm for 11, 15 and 23% air-LPG mixtures, respectively as shown in Fig. 5. Increase in NO_x emission level with increase in load was observed because NO_x emissions are very much dependent on combustion chamber temperature. At the higher chamber temperature the reaction $N_2+O_2 \rightarrow 2NO$ takes place. Temperature drops rapidly during expansion and exhaust strokes, but the reverse reaction or disassociation of NO is not rapid enough to establish equilibrium and therefore higher amount of NO_x appears in the exhaust at higher loads, according to Sen (1994). Still higher NO_x emissions were observed with air-LPG mixtures. It was due to higher combustion chamber temperature as indicated from measured exhaust gas temperature values which were between 400 and 425°C as compared to 385°C with pure diesel.

The authors are trying to reduce the NO_x emission from the diesel engine exhaust using the Exhaust Gas Recirculation (EGR) method, as EGR is one of the most effective techniques currently available for reducing NO_x emission in internal combustion diesel engines. NO_x emissions are mainly affected by two factors: (i) the presence of oxygen in the charge and (ii) the reaction temperature, which promoted chemical activity during both the formation and destruction stages.

During the formation stage, the reaction temperature is close to the adiabatic flame temperature, which is a consequence of the oxygen concentration in the charge. The engine tests (Ladommatoes *et al*., 1998) have demonstrated that NO_x emission is greatly suppressed when the O_2 concentration in the combustion chamber is reduced. By using EGR, the intake mixture composition and thermodynamic state are changed and the resulting charge contains significant quantities of radicals and diluents, such as, CO_2, N_2 and H_2O. The primary effect of diluents in the intake mixture on the NO_x formation process is that it reduces the flame temperature by increasing the heat capacity of the cylinder charge per unit mass of fuel (Unchide *et al*., 1993).

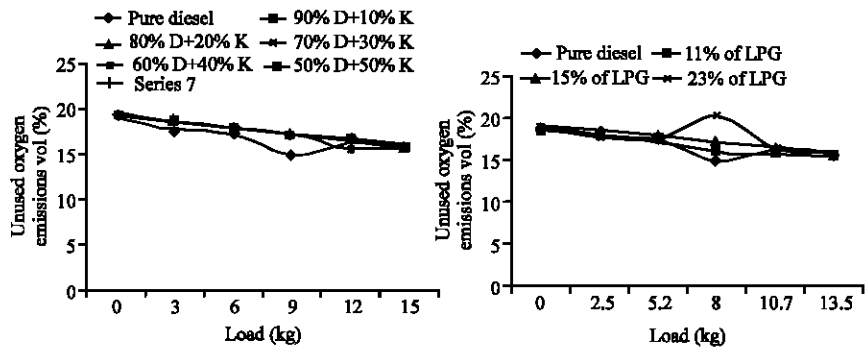

Fig. 6: Unused oxygen emissions of different blends at various loads

Un Used Oxygen Emissions

Unused oxygen in the engine exhaust is very important parameter as it shows the level of fuel mixing with air and presence of sufficient air in the combustion chamber. As the load on the engine was increased, unused oxygen emissions started decreasing and reached a value of 15.6% vol. for pure diesel, 15.66, 15.18, 15.93 and 15.49% at 10, 20, 30 and 40% kerosene blend at rated load for all the fuel blends. The observed values of unused oxygen were 15.23, 15.69 and 15.79% for 11, 15 and 23% air-LPG mixtures, respectively as shown in Fig. 6.

As the time available for fuel injection is very small (0.003 sec) there is a very little time available for fuel to uniformly mix with oxygen present in the combustion chanmbers. Unused oxygen appeared in the engine exhaust because of heterogeneous mixing of O_2 with diesel (Sen, 1994). At lesser loads fuel supplied to the combustion chamber was small and the mixture remained lean resulting in more unused O_2 in the exhaust. As the load was increased more oxygen was consumed due to higher fuel supplied resulting in decrease in unused O_2.

With air-LPG mixture, further reduction in unused oxygen was observed in exhaust due to further improvement in combustion, because mixing of air with LPG started during iulet manifold and better air fuel contact ratio was achieved resulting in almost nil amount of unused oxygen.

Engine Performance

Brake power (load) and Specific Fuel Consumption (SFC) were calculated for evaluating the engine performance using different fuel blends. Brake power increased with increasing in engine load up to maximum load value for all the fuel blends of kerosene and LPG. However, SFC decreased with increase in B.P. and reached a minimum value at the rated load indicating minimum fuel consumption per unit of power produced which is the best point of engine operation. There after, SFC increased indicating higher fuel consumption per unit of power produced (Fig. 7). It was observed that at rated load SFC decreased at the same B.P for different fuel blends of kerosene as well as with LPG and was found to be lower at 30% kerosene blend and 23% LPG mixing level as compared to SFC value when engine was an on pure diesel.

Cost Analysis

Comparative cost analysis has been made for the best optimum recommended fuel blends (diesel plus 30% kerosene blend and air plus 23% LPG) and the diesel. The use of 30% kerosene along with diesel can save about 12.3% of the fuel cost and mixing of 23% LPG in the air during the suction stroke along with diesel can save about 19.27% of the fuel cost. The air-LPG mixing device is a very simple low cost design, which can be fabricated even by a village artisan.

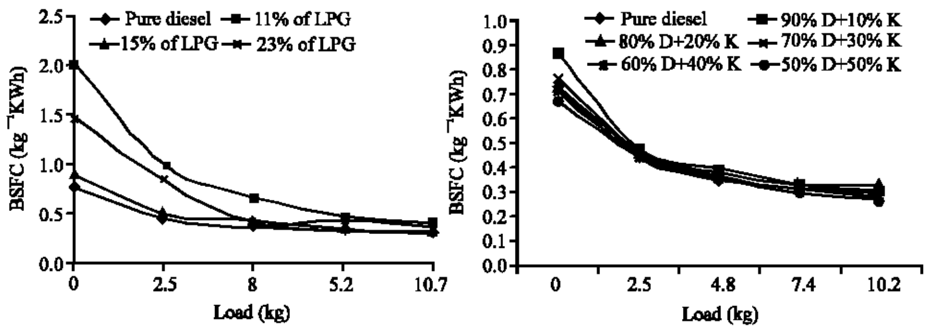

Fig. 7: Load against SFC relationship at various loads

Numerous stationary installations are being used for power productions, compression of gases and there are millions of stationary diesel engines in the agricultural fields in world being operated for irrigation purposes. The use of suggested fuel blends at these installations can save a lot of money in terms of fuel operating costs. In transport section of diesel engine vehicles, the problem of the portability of the LPG and provision of a compact storage facility in mobile applications remain a field of research that can have the potential for opening widely the market for the duel fuel engine and the increased exploitation of gaseous fuel resources.

Addition of LPG with air during suction stroke is an absolutely risk free operation. There are no chances of backfire because during the ignition of fuel, suction valve remain closed thus making it absolutely safe in operation.

CONCLUSIONS

- Using diesel-kerosene blends, exhaust emissions from diesel engine were lowest (as compared to pure diesel) at 30%kerosene blend in pure diesel
- Using air-LPG mixtures, exhaust emissions from diesel engine were lowest (as compared to pure diesel and 70% diesel plus 30% kerosene blend) at 11% LPG mixing level with air in suction stroke along with pure diesel
- Slight increase in the NO_x emission level was observed with both dual fuel blends when compared with pure diesel
- Specific fuel consumption lowered by 3.57% using 30% kerosene blend in pure diesel and by 19.8% using 11% LPG mixture in air
- Fuel operating cost reduced by 12.3% at 30% kerosene blend than pure diesel
- Fuel operating cost further reduced by 19.27% at 23% LPG mixing level with air in suction stroke along with pure diesel

RECOMMENDATIONS

- Using diesel-kerosene blends, 30% kerosene blending (by volume) is recommended for diesel engine operation
- Using air-LPG mixtures, 23% LPG mixing (by volume) with air in suction stroke is recommended along with pure diesel

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