International Journal of Engineering Innovation & Research
Volume 1, Issue 5, ISSN : 2277 – 5668

Comparative Studies on Exhaust Emissions from a Low Heat Rejection Diesel Engine with Carbureted Methanol and Jatropha Oil

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***Abstract* – Investigations were carried out to control the exhaust emissions from different versions of low heat rejection (LHR) diesel engine- LHR-1 engine, LHR-2 engine and LHR-3 with carbureted methanol and crude jatropha oil (CJO). Exhaust emissions of smoke, oxides of nitrogen (NOx) and aldehydes from different configurations of the LHR engines were determined at peak load operation of the engine with test fuels with varied injection pressure and compared with pure diesel operation on conventional engine (CE). LHR-1 engine contained a ceramic coated cylinder head engine, LHR-2 engine- Air gap insulated piston with 3-mm air gap with superni (an alloy of nickel) crown and air gap insulated liner with superni insert, and LHR-3 engine-ceramic coated cylinder head, air gap insulated piston and air gap insulated liner. Smoke and NOx were measured at peak load operation by AVL Smoke meter and Netel Chromatograph NOx analyzer respectively. Aldehydes which include formaldehyde and acetaldehyde at peak load operation were measured by dinitrophenyle (DNPH) method. LHR-3 version of the engine decreased exhaust emissions considerably with carbureted methanol. Smoke emissions decreased by 58%, while NOx emissions decreased by 12% with LHR-3 engine in comparison with CE with pure diesel operation. The emissions decreased further with increase of injection pressure in different versions of the engine.**

***Keywords* – Crude Jatropha Oil, Methanol, LHR engine, Fuel Performance, Exhaust emissions**

I. Introduction

The exhaust emissions from diesel engine are smoke and NOx emissions. If the engine runs with alcohol, aldehydes are also to be checked. Inhaling of the emissions of smoke and NOx causes [1-3] severe health problems like severe headache, vomiting sensation, dizziness, respiratory problems etc,. Aldehydes are carcinogenic in nature, which are harmful to human beings. The measure of the aldehydes is not sufficiently reported in the literature. Aldehydes are eye and respiratory track irritants. Hence controlling of these pollutants is an immediate task.

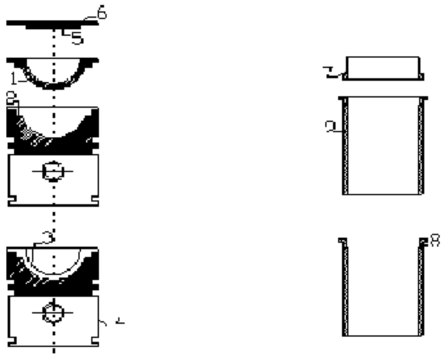
The search for fuels that are preferably renewable, clean burning and with low emission is gaining momentum. Vegetable oils have a high cetane number and a calorific value that is quite close to that of diesel. Several researchers [4-9] experimented the use of vegetable oils as fuel on conventional engines (CE) and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. Not only that, the common problems of crude vegetable oils in diesel engines are formation of carbon deposits, oil ring sticking, thickening and gelling of lubricating oil as a result of contamination by the vegetable oils. The presence of the fatty acid components greatly affects the viscosity of the oil. The increase in viscosity and crystal formation of fatty acids below cloud point hinders the operation of the injector. These fatty acids increase smoke emissions and also lead to incomplete combustion due to improper air-fuel mixing. These problems can be solved, if neat vegetable oils are chemically modified to bio-diesel. Crude vegetable oils were converted [10] into bio-diesel by means of esterification process. Experiments were [11-14] conducted on CE with biodiesel and it was reported that biodiesels improved the efficiency of the engine marginally and decreased the pollution levels of smoke and increased NOx levels.

On the other hand, alcohols which are renewable and volatile but they have low cetane number. Hence engine modification is necessary if they are to be used as fuels in diesel engines. Hence the drawbacks of vegetable oils such as high viscosity and poor volatility and low cetane number of alcohols call for low heat rejection diesel engine. Hence the concept of the LHR engine is to minimize the heat loss to the coolant; by providing thermal resistance in the path of heat flow to the coolant thereby gains thermal efficiency. Several methods adopted for achieving LHR to the coolant are i) using ceramic coatings on piston, liner and cylinder head and ii) creating air gap in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc. Investigations were carried [15-17] with pure diesel operation on LHR engine by coating with low thermal conductivity materials like ceramics on engine components like cylinder head, cylinder liner, valves and piston crown, and it was reported that ceramic coated engines improved specific fuel consumption (SFC) and decreased pollution levels. Experiments were also carried out [18-22] on ceramic coated LHR engines with biodiesel and reported that insulated engines improved SFC and decreased smoke levels and increased NOx levels. Creating an air gap in the piston involved the complications of joining two different metals. Air gap was created [23] in the piston by screwing the crown made of low thermal conductivity material, nimonic (an alloy of nickel) to the body of the piston, by keeping a gasket, made of nimonic, in between these two parts. But investigations were restricted to pure diesel operation. It was reported from these investigations that SFC was improved and pollution levels of smoke decreased at advanced injection timing. Studies were made [24] on LHR engine which consisted of an air gap insulated piston with superni crown, an air gap insulated liner with superni insert and ceramic coated cylinder head with crude jatropha oil and crude pongamia oil based biodiesel with varied injection timing and injection pressure and reported that biodiesel improved performance with LHR engine. There are many techniques available to induct methanol into the engine, out of which carburetion technique is simple Experiments were conducted [25-27] on CE with methanol, inducted through variable jet carburetor installed in the inlet manifold of the engine and diesel was injected in conventional manner and concluded that dual fuel operation improved thermal efficiency marginally and decreased smoke and NOx emissions. Investigations were carried [28-32] out on LHR engine contained an air gap (3-mm) insulated piston with superni (an alloy of nickel) crown and an air gap insulated liner with superni insert and methanol was carbureted through variable jet carburetor and it was reported from their investigations, BTE increased with dual fuel operation, when compared with pure diesel operation on CE. However, in their investigations, studies on exhaust emissions on different versions of LHR engines were not made. Vegetable oils have cetane number comparable with diesel fuel, but they have high viscosity and low volatility. Alcohols have low cetane fuels, though they have got high volatility. In order to take advantage from high cetane number and high volatility, both vegetable oils and alcohols are to be used in LHR engine.

The present paper attempted to control the exhaust emissions with different versions of LHR engines with crude jatropha oil and carbureted methanol with varied injection pressure and compared with pure diesel operation on CE at recommended injection timing and injection pressure.

II. Methodology

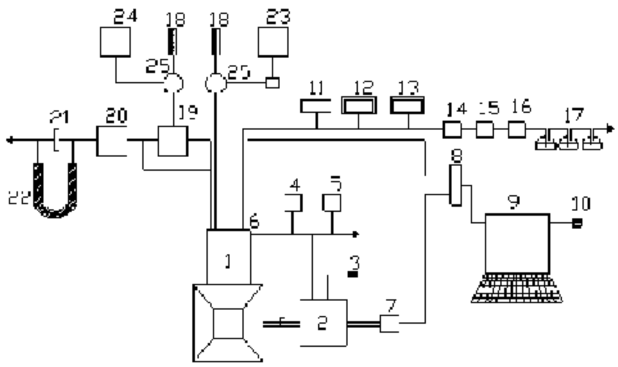
Figure.1 gave the details of insulated piston, insulated liner and ceramic coated cylinder head employed in the experimentation. LHR-3 diesel engine contained a two-part piston; the top crown made of low thermal conductivity material, superni-90 screwed to aluminum body of the piston, providing a 3mm-air gap in between the crown and the body of the piston. The optimum thickness of air gap in the air gap piston was found [23] to be 3-mm, for improved performance of the engine with diesel as fuel. A superni-90 insert was screwed to the top portion of the liner in such a manner that an air gap of 3mm is maintained between the insert and the liner body. At 500°C the thermal conductivity of superni-90 and air are 20.92 and 0.057 W/m-K respectively. Partially stabilized zirconium (PSZ) of thickness 500 microns was coated on inside potion of cylinder head.



1. Superni Crown with threads, 2. Gasket, 3. Air gap, 4. Body, 5. Ceramic coating 6. Cylinder head, 7 Insert with threads, 8. Air gap, 9. Liner Insulated piston Insulated liner Ceramic coated cylinder head

Figure.1 Assembly details of insulated piston, insulated liner and ceramic coated cylinder head

Experimental setup used for the investigations of different versions of the LHR diesel engine with crude jatropha oil (CJO) and carbureted methanol as fuels was shown in Figure.2.



1. Engine, 2.Electical Dynamo meter, 3.Load Box, 4. Outlet jacket water temperature indicator, 5.Outlet-jacket water flow meter Orifice meter, 6. Piezo-electric pressure transducer, 7. TDC encoder 8.Console, 9. Pentium Personal Computer, 10. Printer, 11.Exhaust gas temperature indicator,12.AVL Smoke meter, 13. Netel Chromatograph NOx Analyzer, 14. Filter, 15.Rotometer, 16.Heater, 17. Round bottom flask containing DNPH solution, 18.Burette, 19. Variable jet carburetor, 20. Air box, 21.Orifice meter, 22. U-tube water manometer, 23.Vegetable oil tank, 24.Alcohol tank, 25. Three-way valve.

Fig.2. Experimental Set-up

CE had an aluminum alloy piston with a bore of 80 mm and a stroke of 110mm. The rated output of the engine was 3.68 kW at a speed of 1500 rpm. The compression ratio was 16:1 and manufacturer's recommended injection timing and injection pressures were 27°bTDC and 190 bar respectively.

The fuel injector had three holes of size 0.25mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air.

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The engine was connected to an electric dynamometer for measuring its brake power. Methanol was inducted through the variable carburetor jet, located at the inlet manifold of the engine at different percentages of diesel flow rate by mass basis and crude vegetable oil was injected in conventional manner. Two separate fuel tanks and burette arrangements were made for measuring vegetable oil and alcohol consumptions. Air-consumption of the engine was measured by air-box method. The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water is maintained at 60°C by adjusting the water flow rate. The engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Injection pressure was changed from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injection pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature (EGT) was measured with thermocouples made of iron and iron-Constantan. Exhaust emissions of smoke and NO_x were recorded by AVL smoke meter and Netel Chromatograph NOx analyzer respectively at the peak load operation of the engine. With alcohol-vegetable mixture operation, the major pollutant emitted from the engine is aldehydes. DNPH method [10] was employed for measuring aldehydes in the experimentation. The exhaust of the engine was bubbled through 2,4 dinitrophenyl hydrazine (2,4 DNPH) solution. The hydrazones formed were extracted into chloroform and were analyzed by employing high performance liquid chromatography (HPLC) to find the percentage concentration of formaldehyde and acetaldehyde in the exhaust of the engine. The properties of the test fuels were shown in Table.1. The accuracy of the instrumentation used in experimentation is 0.1%.

Table.1. Properties of the Test fuels

Property	Diesel	Methanol	CJO
Specific gravity at 25° C.	0.84	0.79	0.92
Latent heat of evaporation (kJ/kg)	600	1110	500
Self ignition temperature (°C)	220	574	200
Cetane number	40-60	3	45
Lower calorific value (kJ/kg)	42000	19740	36500
Stoichiometric air fuel ratio	15.5:1	6.45:1	8.8:1

III. Results and Discussion

Figure 3 indicates that brake thermal efficiency (BTE) increased up to 80% of peak load and beyond that load it decreased with test fuels. This was due to increase of fuel conversion efficiency up to 80% of peak load operation and beyond that load friction power increased. BTE increased at all loads with 35% methanol induction and with the increase of methanol induction beyond 35%, it decreased at all loads in CE when compared with CE with diesel operation (standard diesel). The reason for improving the efficiency with the 35% methanol induction was because of improved homogeneity of the mixture with the presence of methanol, decreased dissociated losses, specific heat losses and cooling losses due to lower combustion temperatures. This was also due to high heat of evaporation of methanol, which caused the reduction the gas temperatures resulting in a lower ratio of specific heats leading to more efficient conversion of heat into work. Induction of methanol resulted in more moles of working gas, which caused high pressures in the cylinder. The observed increased in the ignition delay period would allow more time for fuel to vaporize before ignition started. This means higher burning rates resulted more heat release rate at constant volume, which is a more efficient conversion process of heat into work.

When methanol induction was more than 35%, thermal efficiency deteriorated at all loads with CE in comparison with pure diesel operation on same version of the engine. This was due to absorption of temperature from combustion reactions as methanol has got high latent heat of evaporation.

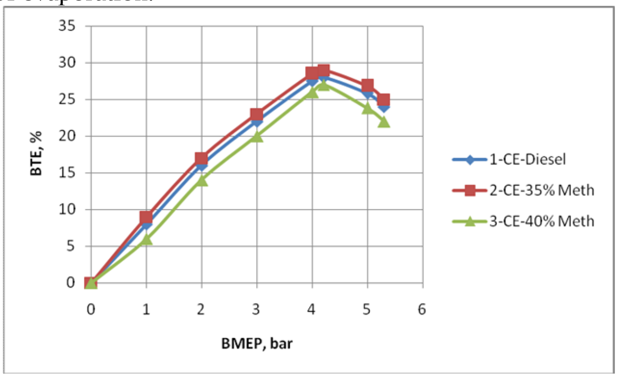

Fig.3. Variation of BTE with BMEP with different percentages of methanol induction in CE at an injection pressure of 190 bar.

From Figure 4, it is observed that LHR-1 engine (engine with ceramic coated cylinder head) showed an improvement in the performance with induction of 40% methanol at all loads when compared to the standard diesel engine. This was due to recovery of heat from the hot insulated components of LHR-1 engine due to high latent heat of evaporation of the methanol, which lead to increase in thermal efficiency. The maximum induction of methanol is 40% in LHR engine, which showed improvement in the performance at all loads when compared to standard diesel engine. However when the methanol induction was increased more than 40% in LHR engine, BTE deteriorated at all loads when compared with standard diesel. The maximum heat recovery from insulated components of LHR-1 engine was only with 40% induction of methanol and once it was more than 40%, it could not absorb the heat and hence the performance was deteriorated with more than 40% induction of methanol

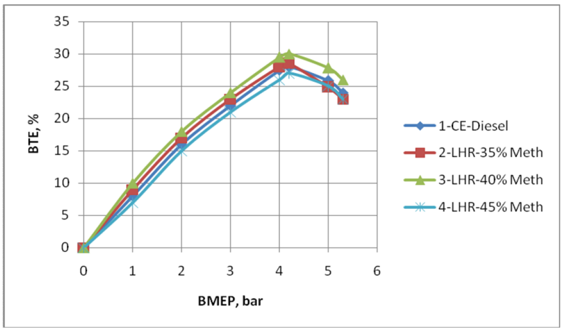

Fig.4. Variation of BTE with BMEP with different percentages of methanol induction in LHR-1 engine at an injection pressure of 190 bar.

From Figure 5, it is evident that LHR-2 engine (with air gap insulated piston and air gap insulated liner) showed an improvement in the performance at all loads with the maximum induction of 50% methanol when compared to the standard diesel engine. Since the degree of insulation was higher with LHR-2 engine compared with LHR-1 engine, it could absorb more amount of methanol which leads to improvement in the efficiency of the engine. However when the methanol induction increased more than 50% in LHR engine, BTE deteriorated at all loads when compared with standard diesel. The maximum induction of methanol was only 50% with LHR-2 engine and with this amount it could absorb more amount of heat from insulated components and converted the heat into actual work.

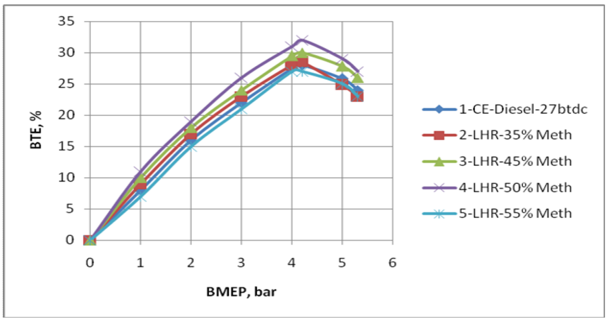

Fig.5. Variation of BTE with BMEP with different percentages of methanol induction in LHR-2 engine at an injection pressure of 190 bar.

From Figure 6, it is noticed that LHR engine (air gap insulated piston, air gap insulated liner and ceramic coated cylinder head) showed an improvement at all loads in the performance with the maximum induction of 60% methanol when compared to the standard diesel engine. Since the degree of insulation was higher with LHR-3 engine compared with LHR-2 engine, it could absorb more amount of methanol which leads to improvement in the efficiency of the engine. However when the methanol induction increased more than 60% in LHR engine, BTE deteriorated at all loads when compared with standard diesel.

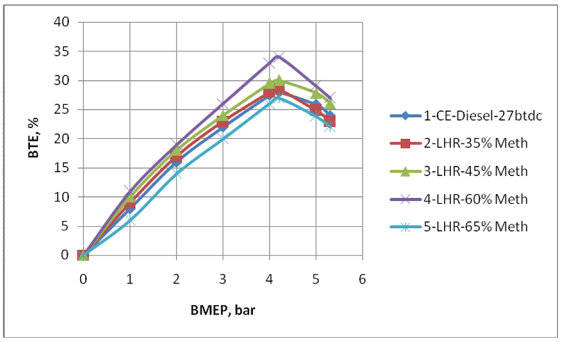

Fig.6. Variation of BTE with BMEP with different percentages of methanol induction in LHR-3 engine at an injection pressure of 190 bar.

From Figure 7, it is observed that for the same load, the smoke density decreased with induction of alcohol. Drastic levels of smoke were observed with CE with pure vegetable oil operation. The combustion of injected fuel in case of pure vegetable oil operation was predominantly one of oxidation of products of destructive decomposition. In this case, there were greater chances of fuel cracking and forming carbon particles. On the other hand, the combustion of alcohol was predominantly a process of hydroxylation and the chances of fuel cracking were negligible. Methanol does not contain carbon-carbon bonds and therefore cannot form any un-oxidized carbon particles or precursor to soot particles. One of the promising factor for reducing smoke levels with the alcohols was they contained oxygen in their composition which helped to reduce soot density. Soot emissions increased linearly with the increase of ratio (C/H) of carbon C to hydrogen atoms (H) provided the equivalence ratio was not altered. This was because higher C/H lead to more concentration of carbon dioxide, which would be further, reduced to carbon. Consequently, induction of alcohol reduced the quantity of carbon particles in the exhaust gases as the magnitudes of C/H for diesel fuel, vegetable oil and methanol are 0.45, 0.83 and 0.25 respectively. Lower smoke levels were observed in both versions of the engine in dual fuel mode when compared with pure diesel operation on CE. LHR-3 engine with 60% methanol induction showed lower smoke levels when compared with other versions of the engine. This was due to higher percentage of methanol induction in LHR versions of the engine. Smoke levels decreased with the increase of methanol induction in both versions of the engine. Smoke levels are related to the density of the fuel. Alcohols have low dense fuel in comparison with diesel fuel, lower smoke levels were recorded with carbureted methanol.

From Table-2, it could be seen that smoke emissions decreased marginally with increase of injection pressure in different versions of the engine. This was due to improved spray characteristics of the vegetable oil with which combustion improved. With higher injection pressure, fuel jet is sprayed onto combustion chamber rather than walls of combustion chamber.

Table.2; Data of Smoke emissions in Hartridge smoke unit (HSU)

Engine version	Test Fuel	Smoke Emissions (HSU) Injection Pressure (bar)		
		190	230	270
CE	Pure diesel	40	30	34
CE	CJO	70	65	60
CE	35% Meth	30	36	34
LHR-1	40% Meth.	32	30	28
LHR 2	50% Meth	26	24	22
LHR-3	60% Meth.	20	18	16

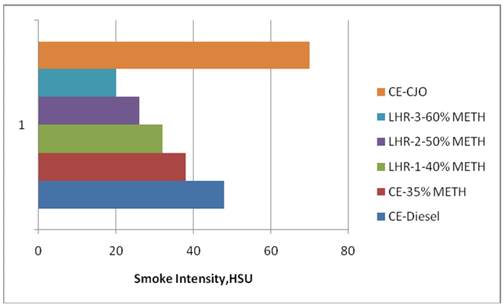

Fig.7. Bar charts showing the variation of smoke levels in different versions of the engine with maximum induction of methanol at an injection pressure of 190 bar.

From Figure 8, it is noticed that NOx emissions decreased in CE with pure vegetable oil operation. This was due to lower heat release rate because of high duration of combustion causing lower gas temperatures with the vegetable oil operation on CE, which reduced NOx levels., as temperature and availability of oxygen are the factors for formation of NOx levels. The low value of C/H ratio (0.25) in methanol had indirect effect in reducing oxygen availability in the gases and increased water vapor content, which leads to the reduction of NOx. However, LHR engines with different percentages of methanol induction showed higher NOx levels compared with CE with 35% methanol induction, due to increase of gas temperatures in LHR engine as hot combustion chamber is maintained by LHR engine. NOx levels further decreased with the increase of methanol induction in both versions of the engine. Methanol has high latent heat of evaporation, and it absorbs heat from combustion reactions leading to reduce the temperature and hence NOx levels.

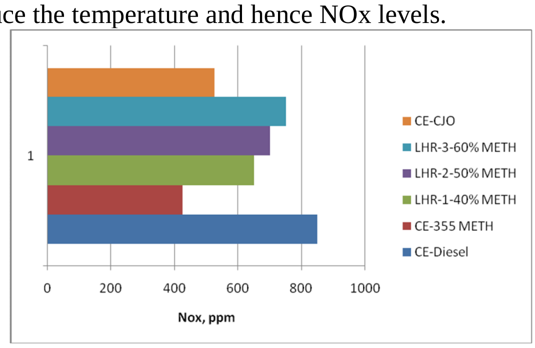

Fig.8. Bar charts showing the variation of NOx levels in different versions of the engine with maximum induction of methanol at an injection pressure of 190 bar.

From Table.3, it is observed that NOx emissions decreased with increase of injection pressure in different versions of the engine. This was due to improvement of air fuel ratios with which gas temperatures decreased leading to produce low NOx levels.

Table.3; Data of NOx emissions in ppm

Engine version	Test Fuel	NOx Emissions (ppm) Injection Pressure (bar)		
		190	230	270
CE	Pure diesel	850	800	750
CE	CJO	525	475	425
CE	35% Meth	425	390	350
LHR 1	40% Meth.	650	610	570
LHR-2	50% Meth	700	660	620
LHR-3	60% Meth	750	710	670

These aldehydes are responsible for pungent smell of the engine and affect the human beings when inhaled in the large quantities. Though Government legislation has not been pronounced regarding the control of aldehyde emissions, when more and more alcohol engines are coming to existence severe measures the controlling of aldehydes emitted out through the exhaust of the alcohol run engines will have to be taken as serious view.

It could be seen from Figure .9, that formaldehyde emissions were low with pure diesel operation in CE engine. However, they increased with CE with pure vegetable oil operation. This was due to increase of intermediate compounds as combustion was not proper with vegetable oil operation. Formaldehyde emissions increased drastically with methanol induction in different versions of the engine. 35% methanol induction with CE gave higher percentage of formaldehyde concentration. As degree of insulation increased in LHR version of the engine, the formaldehyde concentration decreased with maximum induction of methanol. This was due to hot environment of LHR engine completed combustion reactions and reduced the emissions of intermediate compounds, aldehydes. Hence it was concluded that LHR engines were more suitable for alcohol engines in comparison with CE.

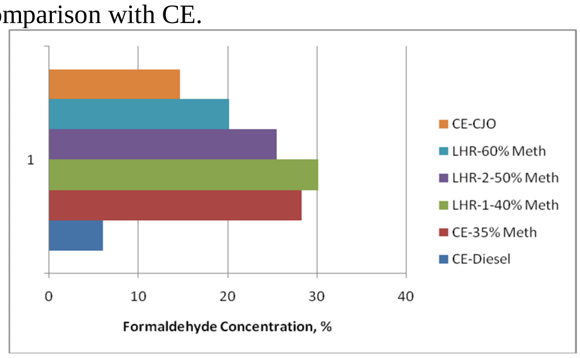

Fig.9. Bar charts showing the variation of formaldehyde concentration in different versions of the engine with maximum induction of methanol at an injection pressure of 190 bar.

International Journal of Engineering Innovation & Research
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From Table.4, it is noticed that formaldehyde concentration decreased with increase of injection pressure in different versions of the engine. This was due to improved injection properties spraying fuel on to the combustion chamber rather than on combustion chamber walls. However, the decrease in formaldehyde concentration was marginally small in different versions of the engine, with increase of injection pressure.

Table.4. Data of Formaldehyde emissions in % concentration

Engine version	Test Fuel	Formaldehyde Concentration (%) Injection Pressure (bar) 190	230	270
CE	Pure diesel	9	8	7
CE	CJO	14.7	13.2	12.2
CE	35% Meth	20.3	26.2	24.2
LHR-1	40% Meth.	30.2	27.2	24.1
LHR-2	50% Meth	25.5	21.1	17.4
LHR-3	60% Meth.	20.2	16.7	12.8

It is evident from Figure 10, that acetaldehyde emissions were low with pure diesel operation in CE engine. These emissions increased with pure vegetable oil operation on CE. This was due to higher duration of combustion leading to form intermediate compounds. Acetaldehyde emissions decreased with increase of degree of insulation in LHR engines. This was due to hot environment provided by LHR versions of the engine, which lead to improved combustion and chances of forming intermediate compounds were not there.

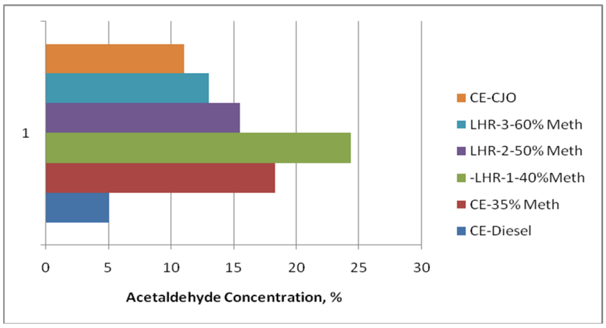

Fig.10. Bar charts showing the variation of acetaldehyde concentration in different versions of the engine with maximum induction of methanol at an injection pressure of 190 bar

From Table.5, it could be noticed that that acetaldehyde concentration decreased marginally with increase of injection pressure in different versions of the engine. This was due to improved fuel atomization properties. However, the magnitude of acetaldehyde concentration is lower in different versions of the engine when compared with formaldehyde concentration with different percentages of alcohol induction. This was due to nature of the fuel. Methanol increased formaldehyde concentration while ethanol increased acetaldehyde concentration. Similar trends were observed by other researcher[1] also.

Table.5; Data of Acetaldehyde emissions in % concentration

Engine version	Test Fuel	Acetaldehyde Concentration (%) Injection Pressure (bar) 190	230	270
CE	Pure diesel	5	4	3
CE	CJO	11	10	9
CE	35% Meth	18.3	17.1	16.2
LHR 1	40% Meth.	24.3	22.2	20.1
LHR-2	50% Meth	15.5	13.4	11.3
LHR-3	60% Meth.	13	11	9

IV. CONCLUSIONS

Maximum induction of ethanol was 35% on mass basis with best possible efficiency at all loads in CE while it is 40% in the LHR-1 engine, 50% in LHR-2 engine and 60% in LHR-3 engine. Smoke levels decreased by 58%, while NOx emissions decreased by 12% with LHR-3 engine with maximum induction of methanol, when compared with pure diesel operation on CE. LHR-3 engine was also suitable in reducing aldehyde emission when compared with CE with methanol induction. Marginal decrease of emissions was observed with increase of injection pressure in different versions of the engine with maximum induction of methanol.

ACKNOWLEDGMENTS

Authors thank authorities of Chaitanya Bharathi Institute of Technology, Hyderabad for providing facilities for carrying out research work. Financial assistance provided by All India Council for Technical Education (AICTE), New Delhi, is greatly acknowledged.

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