ISSN 2394-739X
International Journal for Research in Science Engineering and Technology

CONTROL OF EXHAUST EMISSIONS OF LOW GRADE LOW HEAT REJECTION DIESEL ENGINE WITH COTTONSEED OIL BLENDED WITH BUTANOL

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ABSTRACT: In the context of depletion of fossil fuels, search for alternative fuels has become necessary. Alcohols and vegetable oils are important substitutes for diesel fuel as they are renewable in nature. Neat vegetable oils produce high particulate emissions in diesel engine as they contain fatty acids. Neat alcohol causes combustion problems as it has low cetane number and low energy content. Hence they call for low heat rejection (LHR) engine, which can give high heat release rate and burn low calorific value fuel. They are many methods to induct alcohol in diesel engine out of which blending of alcohol with vegetable oil is simple technique. Butanol has higher calorific value than ethanol and methanol. Hence use of butanol is finding favor in diesel engine. Exhaust emissions from diesel engine once they inhaled cause heat hazards and also environmental impact. Hence control of these emissions is an important and urgent task. Investigations were carried out to determine exhaust emissions of particulate emissions and oxides of nitrogen (NOx) from a low grade low heat rejection (LHR) diesel engine or LHR–1 engine consisting of ceramic coated cylinder head with crude cottonseed oil blended with butanol with varied injector opening pressure. Conventional engine (CE) showed drastic increase of particulate emissions, while LHR engine showed reduction of particulate emissions with crude vegetable oil, in comparison with neat diesel operation on conventional engine (CE). CEshowed reduction of NOx levels while LHR engine showed drastic increase of NOx emissions with crude vegetable oil, in comparison with neat diesel operation on CE. However, exhaust emissions reduced drastically with crude vegetable oil blended with butanol with both versions of the engine.

Keywords: [Vegetable oil, Injector opening pressure, LHR engine, Classification, Fuel Performance.]

1. INTRODUCTION

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

Vegetable oils and alcohols are promising substitutes for diesel fuel as they are renewable in nature. Out of many techniques available, blending is simple technique, to induct alcohol into diesel engine [Wang et al, 2008; Lalit Kumar et al, 2012; Satish Kumar et al, 2013]. Alcohols have low cetane number and hence engine modification is necessary for use as fuel in diesel engine[Murali Krishna et al, 2014; Murali Krishna et al, 2015]. On the other hand, vegetable oils have comparable properties in comparison with diesel fuel. The idea of using vegetable oil as fuel has been around from the birth of diesel engine. Rudolph diesel, the inventor of the engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil.[Cummins, 1993].Several researchers 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 [Pugazhvadivu, et al, 2005; Deepak Agarwalet al, 2008; Baiju et al, 2009; HanbeyHazaret al, 2010].

By controlling the injector opening pressure and the injection rate, the spray cone angle is found to depend on injection pressure. Further increasing the injector opening pressure increases the nominal mean spray velocity resulting in better fuel-air mixing in the combustion chamber. Higher fuel injection pressures increase the degree of atomization. The fineness of atomization reduces the ignition lag, due to higher surface volume ratio. Smaller droplet size will have a low depth of penetration, due to less momentum of the droplet and less velocity relative to air, from where it has to find oxygen after evaporation. Because of this, air utilization will be reduced due to fuel spray being shorter. Also with smaller droplets, aggregate area of inflammation will increase after ignition, resulting high-pressure rise during second stage of combustion. Thus lower injection pressure giving larger droplet size may give lower pressure rise during the second stage of combustion and probably smoother running. However, poor performance at lower injector opening pressures indicates slow mixing probably because of insufficient spray penetration with consequent slow mixing during diffusion burning. Hence an optimum mean diameter of the droplet should be attempted as a compromise. The variation of injection opening pressure is done with nozzle-testing device. The performance of the engine improved along with reduction of particulate emissions by an increase of injector opening pressure [Jindal et al, 2010; Venkannaet al, 2010; Avinash Kumar et al, 2013].

The concept of LHR engine is to reduce heat loss to coolant by providing thermal insulation in the path of heat flow to the coolant. LHR engines are classified depending on degree of insulation such as low grade or LHR–1, medium grade or LHR–2 and high grade insulated engines or LHR–3 engine. Several methods adopted for achieving low grade LHR engines are using ceramic coatings on piston, liner and cylinder head, while air gap insulation is provided in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc and high grade LHR engine is the combination of low grade and medium grade engines.

Experiments were conducted on low grade LHR engines with diesel and reported that diesel operation with LHR–1 engine improved performance and reduced smoke levels. [Parlaket al, 2005; Ekremet al, 2006;Cinivizet al, 2008]. However, they increased nitrogen oxide levels (NO_x) levels.

Investigations were carried out with low grade LHR engines with vegetable oil and reported that vegetable oil operation with LHR-1 engine improved performance and reduced smoke levels, however, they increased NO_x levels. [Murali Krishna et al, 2012; Kesava Reddy et al, 2012; Ratna Reddy et al, 2012; Murali Krishna et al, 2012].

However, little reports are available on exhaust emissions with LHR–1 engine with vegetable oil blended with butanol. Hence this paper reported the exhaust emissions with LHR–1 engine which contained ceramic coated cylinder head with varied injector opening pressure and compared with neat diesel operation on conventional engine (CE).

Test Fuel	Kinematic viscosity at 25^{o}C (centi-Stoke)	Density at 25^o C	Cetane number	Calorific value (kJ/kg)
Diesel	2.5	0.84	55	42000
Cottonseed oil (CSO)	4.0	0.90	45	41200

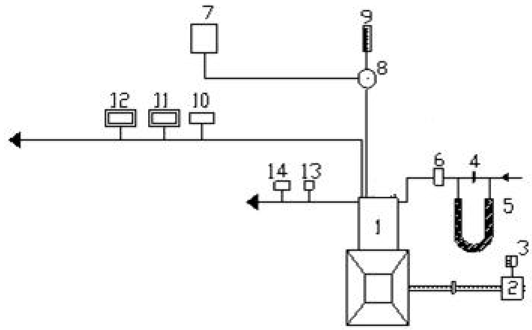
2. MATERIALS AND METHOD

Cottonseed oil is extracted from cottonseed. **Cottonseed oil** has a 2:1 ratio of polyunsaturated to saturated fatty acids. Its fatty acid profile generally consists of 70% unsaturated fatty acids including 18% monounsaturated (oleic) and 52% polyunsaturated (linoleic) and 26% saturated (primarily palmitic and stearic).**Cottonseed oil** is described by scientists as being "naturally hydrogenated" because of the levels of oleic, palmitic, and stearic acids which it contains. These make it a stable frying oil without the need for additional processing or the formation of trans fatty acids. Because **Cottonseed oil** is America's original vegetable oil, it has been the standard to which other oils are compared. [Srikanth et al, 2013]LHR diesel engine contained a cylinder head with ceramic coating of thickness 500 microns,by spray coating. The photographic view of ceramic coated cylinder head is shown in Fig.1

Figure 1- Photographic view of ceramic coated cylinder head

Butanol is manufactured from municipal waste. butanol is produced commercially from fossil fuels. The most common process starts with propene (propylene), which is put through a hydroformylationreaction to form butyraldehyde, which is then reduced with hydrogen to 1-butanol and/or 2-butanol. Butanol can also be produced by fermentation of biomass by bacteria. Butanol is not mixable with cottonseed oil. Hence a binder is required. Here soap solution (2%) was used a binder. These solutions were mixed by using mechanical stirrer. Experimental setup used for the investigations of LHR diesel engine with crude cottonseed oil (CSO) blended with butanol operation is shown in Fig.2. CE had an aluminum alloy piston with a bore of 80mm 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. The manufacturer's recommended injection timing and injection pressures were 27^{o}bTDC and 190 bar respectively.

Pollutant	Measuring Principle	Range	Least Count	Repeatability
Smoke Opacity	Light extinction	1–100%	1% of Full Scale (FS)	0.1% for 30 minutes
NO_x	Chemiluminiscence	1–5000 ppm	0.1% of FS	á0.5% F.S



1.Engine, 2.Electical Dynamo meter, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater, 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NO_x Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter,

Figure 2-Shematic diagram of experimental set-up

The fuel injector had 3-holes of size 0.25-mm. The combustion chamber consisted of a direct injection type with no special arrangement for swirling motion of air. The engine was connected to an electric dynamometer for measuring its brake power. Burette method was used for finding fuel consumption of the engine. 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 was maintained at 60^{o}C by adjusting the water flow rate. Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Injection pressure was varied from 190 bar to 270 bar (in steps of 40 bar) using nozzle testing device. The maximum injection pressure was restricted to 270bar due to practical difficulties involved. Exhaust gas temperature (EGT) was measured with thermocouples made of iron and iron-constantan. Particulate emissions were measured with AVL Smoke meter and while NO_x emissions were determined with Netel Chromatograph NO_x analyzer. The operating principle and least count of these analyzers were shown in Table.2

Test Fuel	**Nitrogen Oxide Levels (ppm) at full load operation**					
	Conventional Engine (CE)			**LHR–1 Engine**		
	Injector opening pressure (Bar)			**Injector opening pressure (Bar)**		
	190	230	270	190	230	270
	NT	NT	NT	NT	NT	NT
Diesel	850	900	950	1200	1150	1100
CSO	700	750	800	1250	1200	1150
20% Emulsified CSO	500	550	600	700	650	600
30% Emulsified CSO	--	--	--	600	550	500

Table 2- Specifications of the Smoke Opacimeter (AVL, India, 437). And exhaust gas emission analyzer (Netel hromatograph NO_x Analyzer (4000 VM))

3. RESULTS AND DISCUSSION

3.1. Performance Parameters

Investigations were carried out with conventional engine and LHR–1 engine with ceramic coated cylinder head with emulsified fuel of butanol and cotton seed oil. As mentioned earlier in previous article, emulsified solution was prepared with 20% of butanol by volume with 78% of cottonseed oil in the presence of 2% soap solution, which was stirred by a mechanical stirrer, so that phase separation should not occur among the solvents. The emulsified solution was tested with conventional diesel engine such that it should give maximum performance and at same time the engine was to be operated with the constant speed of 1500 rpm. The purpose of adding butanol to the vegetable oil was to reduce the viscosity of the vegetable oil, while the purpose of adding soap solution was that it acted as binder and emulsifier.

Investigations were carried out with the objective of determining the factors that would allow maximum use of butanol in diesel engine with best possible efficiency at all loads. These experiments found the basis to bring out the importance of the hot combustion chamber achieved with the LHR–1 engine. The conventional engine with neat diesel operation at the recommended injection timing and pressure was referred as the standard diesel engine.Performance of the convectional engine and LHR–1 engine with emulsified solution of butanol and cottonseed oil was evaluated at the recommended injection timing and injector opening pressure of 190 bar.

Fig.3shows the variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with different percentages of emulsified butanol in the conventional engine at the recommended injection timing and pressure. This figure also provided the data with the pure diesel operation for the comparison purpose. BTE increased at all loads with 20% emulsified butanol and with the increase of emulsified butanol beyond 20%, it decreased at all loads in the conventional engine when compared to the standard diesel engine. The reason for improving the efficiency with the 20% emulsified butanol was because of improved homogeneity of the mixture with the presence of butanol, decreased dissociated losses, specific heat losses and cooling losses due to lower combustion temperatures. This was also due to high heat of evaporation of butanol, which caused the reduction the gas temperatures resulting in a lower ratio of specific heats leading to more efficient conversion of heat into work. Blending of butanol resulted in increase of moles of working gas, which caused high pressures in the cylinder.

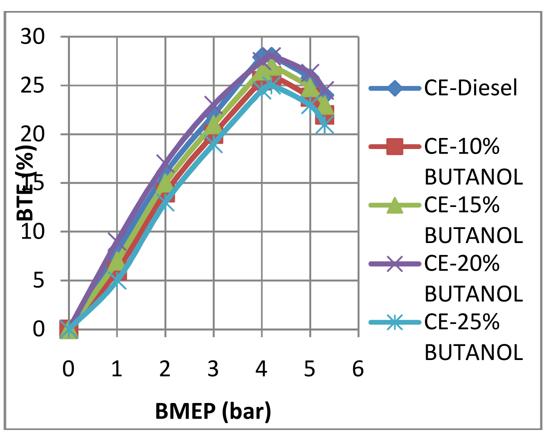


Figure 3-Variation of brake thermal efficiency (BTE) with brake mean effective pressure (BMEP) with different percentages of emulsified butanol in the conventional engine at the recommended injection timing and pressure

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 was a more efficient conversion process of heat into work.

When emulsified butanol was more than 20%, performance deteriorated with increase of ignition delay and reduction of combustion temperatures.

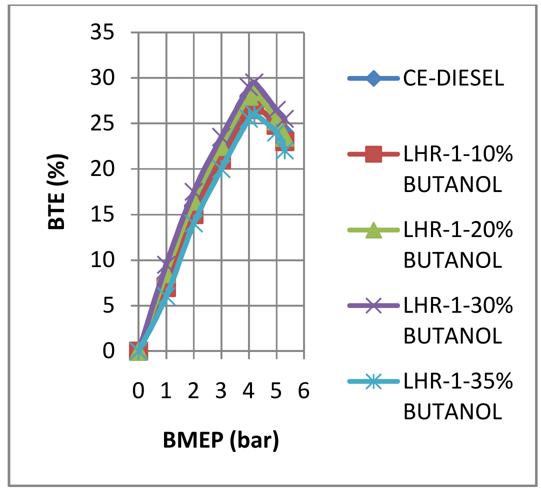


Figure 4- Variation of BTE with BMEP with different percentages of emulsified butanol in LHR-1 engine at the recommended injection timing and pressure

This was due to recovery of heat from the hot insulated components of engine with ceramic coated cylinder head (LHR–1)due to high latent heat of evaporation of the butanol, which lead to increase in thermal efficiency. The maximum blend of butanol was 30% in the LHR-1 engine which showed improvement in the performance at all loads when compared to standard diesel engine.

However when emulsified butanol was increased more than 30% in the engine with ceramic coated cylinder head (LHR–1), brake thermal efficiency deteriorated at all loads when compared to the standard diesel engine Fig.5presents bar charts showing the variation of particulate emissions at full load with test fuels with different versions of the engine at recommended injection timing and pressure. From Fig, it is noticed that CE increased drastically particulate emissions with vegetable oil operation. Presence of fatty acids in vegetable oil might have increased particulate emissions. Density is related to particulate emissions. Since vegetable oil has high density, particulate emissions are high with vegetable oil. Particulate emissions are proportional to the ratio of C/H. (C=Number of carbon atoms and H=Number of hydrogen atoms). Since C/H ratio is high for vegetable oil, particulate emissions are high with vegetable oil operation.

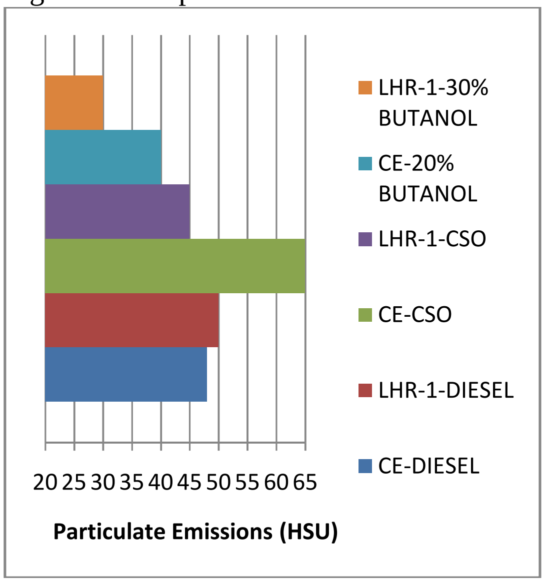


Figure 5 - Bar charts showing the variation of particulate emissions in Hartridge Smoke Unit (HSU) with test fuels with different versions of the engine at recommended injection timing and pressure

LHR engine with vegetable oil marginally reduced particulate emissions as combustion improved with LHR engine. Emulsified vegetable oil drastically reduced particulate emissions with both versions of the engine. Combustion of butanol is predominantly hydroxylation. As butanol contains oxygen, combustion improved with emulsified solution of vegetable oil blended with butanol.

3.1 Exhaust Emissions

Table.3shows variation of particulate emissions at full load operation with conventional engine and LHR–1 engine with test fuels at different injector opening pressure, at recommended injection timing. Particulate emissions at full load decreased with an increase of

Test Fuel	Particulate Emissions (HSU)					
	Conventional Engine (CE)			LHR–1 Engine		
	Injector opening pressure (Bar)			Injector opening pressure (Bar)		
	190 NT	230 NT	270 NT	190 NT	230 NT	270 NT
Diesel	48	29	30	50	45	40
CSO	65	60	55	45	40	35
20% Emulsified CSO	40	35	30	35	30	25
30% Emulsified CSO	--	--	--	30	25	20

Table 3- Data of Particulate Emissions at full load in Hartridge Smoke Unit (HSU)

injector opening pressure with both versions of the engine. Increase of fuel spray characteristics might have improved combustion and hence reduced particulate emissions.

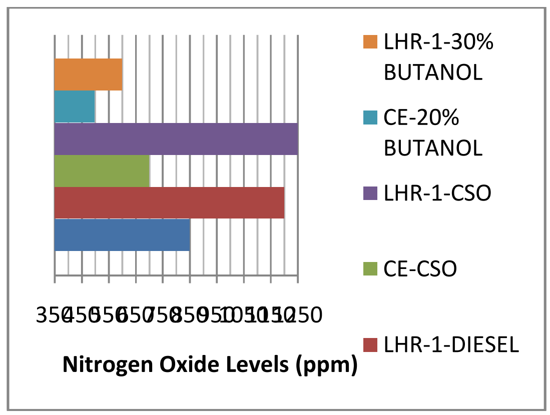


Figure 6 - presents bar charts showing the variation of nitrogen oxide levels at full load with test fuels with different versions of the engine at recommended injection timing and pressure.

CE reduced NO_x levels at full load with vegetable oil operation. Heat release rate was less with vegetable oil operation on CE. However, LHR engine drastically increased NO_x levels at full load with vegetable oil operation. LHR engine produced high heat release rate with the hot environment provided in the LHR engine causing increase of NO_x levels. Emulsified vegetable oil drastically reduced NO_x levels at full load as butanol absorbed combustion temperatures due to its high latent heat.

Table.4shows variation of nitrogen oxide levels with conventional engine and LHR–1 engine with test fuels at different injector opening pressure, at recommended injection timing. CE increased NO_x levels while LHR engine reduced NO_x levels with an increase of injector opening pressure. Increase of gas with CE while reduction of the same with LHR engine causing variation of NO_x levels with both versions of he engine..

CONCLUSIONS

The maximum blend ratio of butanol with cottonseed oil with conventional engine was observed to be 20%, while it was 30% for the LHR-1 engine.Both versions of the engine showed reduction of pollution levels of particulate emission and nitrogen oxide levels in comparison with conventional engine with diesel operation.

When compared with conventional engine with maximum blend ratio of butanol (20% butanol), LHR-1 engine with its maximum blend ratio (30% of butanol)

Decreased particulate emissions by 25%

Increased nitrogen oxide levels by 20%

Nitrogen oxide levels increased marginally with conventional engine, while they decreased with LHR engine with an increase of injector opening pressure.However, these exhaust emissions decreased with an increase of injector opening pressure with both versions of the engine.

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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