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# **Experimental Investigations on Exhaust Emissions of Medium Grade Semi Adiabatic Diesel Engine with Rice Bran Biodiesel with Varied Engine Parameters**

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**ABSTRACT:** In the scenario of depletion of fossil fuels, the search for alternative fuels has become inevitable. Vegetable oils and alcohols are important substitutes for diesel fuels. However, drawbacks associated with crude vegetable oils (high viscosity and low volatility) and alcohol (low energy content and cetane number) call for biodiesels. However, these biodiesels are moderately viscous and require hot combustion chamber, provided by low heat rejection (LHR) diesel engine. Investigations were carried out to study exhaust emissions of a medium grade LHR diesel engine consisted of air gap insulated piston and air gap insulated liner with different operating conditions [normal temperature and pre-heated temperature] of rice bran biodiesel with varied injection timing and injector opening pressure. Comparative studies on exhaust emissions were made with diesel working on similar conditions. Particulate emissions decreased, while nitrogen oxide (NO<sub>x</sub>) levels increased with LHR-2 engine with biodiesel operation. Exhaust emissions improved with increase of injector opening pressure, advanced injection timing and preheating of biodiesel.

**KEYWORDS:** Alternative fuels, biodiesel, exhaust emissions, vegetable oils,

## **I. INTRODUCTION**

It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel. They are renewable and can be easily produced. Rudolph Diesel, the inventor of the diesel engine that bears his name, experimented with fuels ranging from powdered coal to peanut oil [1]. Several researchers experimented the use of vegetable oils as fuel on diesel engine and reported that the performance was poor, citing the problems of high viscosity, low volatility and their polyunsaturated character. [2–7]. The drawbacks associated with crude vegetable oil for use in diesel engine of high viscosity and low volatility were reduced to some extent, if crude vegetable oils are chemically converted into biodiesel. These biodiesels have numerous advantages compared to fossil fuels as they are renewable, bio-degradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were conducted with biodiesel in conventional diesel engine. [8–11]. They reported that marginal improvement of performance and reduction of particulate emissions and increase of nitrogen oxide levels with biodiesel operation in comparison with diesel operation on conventional engine. Experiments were conducted on preheated vegetable oils [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel]. [12–15]. They reported that preheated vegetable oils decreased pollution levels of particulate emissions and NO<sub>x</sub> emissions. By controlling the injector opening pressure and the injection rate, the spray cone angle is found to depend on injector opening pressure [16]. Few investigators reported that injector opening

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pressure has a significance effect on the performance and formation of pollutants inside the direct injection diesel engine combustion.[17–19].They reported that particulate emissions decreased with increase of injector opening pressure. However drawbacks associated with biodiesel of high viscosity and low volatility which cause combustion problems, call for engine with hot combustion chamber with its significant characteristics of higher operating temperature, maximum heat release, and ability to handle the low calorific value fuel. The concept of the engine with LHR combustion chamber is reduce heat loss to the coolant, by providing thermal resistance in the path of heat flow to the coolant. Any saving in this part of the energy distribution would either increase the energy lost through exhaust gases or increase the power output. Considerable efforts are under way to reduce heat loss to the coolant by various researchers. However, the results are a little confusing as to whether the insulation would improve or deteriorate thermal efficiency.., These LHR engines have significant characteristics of higher operating temperature, maximum heat release, and ability to handle low calorific value fuel. Three approaches that are being pursued to decrease heat rejection are (1) Coating (low grade LHR combustion chamber or low grade semi adiabatic engine or LHR–1 engine) with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head, (2) air gap insulation (medium grade LHR combustion chamber or LHR–2 or medium grade semi adiabatic engine) where air gap is provided in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel and (3).High grade LHR combustion chamber or LHR–3 engine or high grade semi adiabatic engine is the combination of low grade and medium grade LHR combustion chambers. The technique of providing an air gap in the piston involved the complications of joining two different metals. Investigations were carried out on LHR-2 combustion chamber- with air gap insulated piston with pure diesel. [20]. However, the bolted design employed by them could not provide complete sealing of air in the air gap. Investigations were carried out with LHR-2 combustion chamber with air gap insulated piston with nimonic crown threaded with the body of the piston fuelled with neat diesel with varied injection timing and reported brake specific fuel consumption improved by 5%. [21]

Experiments were conducted on conventional engine with medium grade LHR combustion chamber, consisting of air gap (3 mm) insulated piston with superni crown, fitted to the body of the piston by threading by keeping a gasket made of superni material, air gap insulated liner with superni insert with biodiesel with varied injector opening pressure and injection timing [22–25]. The optimum injection timing was observed to be 29° bTDC with high grade semi adiabatic diesel engine with biodiesel operation. They reported from their investigations, that thermal efficiency increased by 6–8%, volumetric efficiency decreased by 4–6%, particulate emissions decreased by 40–45% ,NO<sub>x</sub> levels increased by 35–40%, peak pressure increased by 25-30% and maximum rate of pressure increased by 6–8% with engine with LHR combustion chamber with biodiesel at optimum injection timing when compared with neat diesel operation at 29° bTDC.

Little literature was available on comparative studies on exhaust emissions with rice bran biodiesel with high grade LHR engine with rice bran biodiesel. Hence an attempt was made here to determine exhaust emissions with rice bran oil biodiesel with LHR–2engine consisting of air gap insulated piston and air gap insulated liner at different operating conditions with varied injection timing and injector opening pressure and compared with CE with biodiesel.

## II. MATERIALS AND METHODS

### 2.1 Preparation of biodiesel

The chemical conversion of esterification reduced viscosity four fold. Crude cotton seed oil contains up to 70 % (wt.) free fatty acids. The methyl ester was produced by chemically reacting the crude rice bran oil with an methanol in the presence of a catalyst (KOH). A two-stage process was used for the esterification of the crude rice bran oil [10]. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in cotton seed oil by esterification with methanol (99% pure) and acid catalyst (sulfuric acid-98% pure) in one hour time of reaction at 55°C. In the second stage (alkali-catalyzed), the triglyceride portion of the cotton seed oil reacts with methanol and base catalyst (sodium hydroxide-99% pure), in one hour time of reaction at 65 °C, to form methyl ester and glycerol. To remove un-reacted methoxide present in raw methyl ester, it is purified by the process of water washing with air-bubbling. The methyl ester (or biodiesel) produced from crude rice bran was known as rice bran oil biodiesel (BD). The properties of the Test fuels used in the experiment were presented in Table-1.

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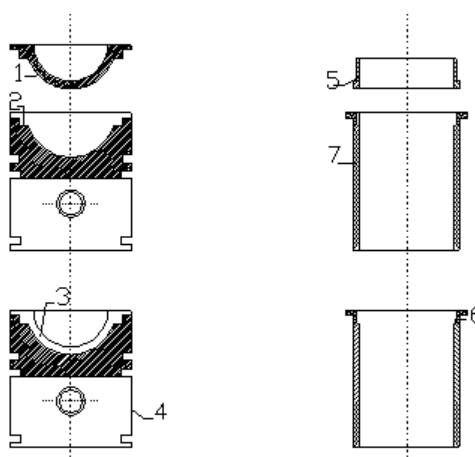
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## 2.2 Engine with LHR-2 combustion chamber

Engine with LHR-2 combustion chamber contained a two-part piston (Fig.1) the top crown made of low thermal conductivity material, superni was 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 to be 3 mm for improved performance of the engine with superni inserts with diesel as fuel [22]. A superni insert was screwed to the top portion of the liner in such a manner that an air gap of 3mm was maintained between the insert and the liner body. At 500°C the thermal conductivity of superni and air are 20.92 and 0.057 W/m-K. The combination of low thermal conductivity materials of air and superni provide sufficient insulation for heat flow thus resulting LHR combustion chamber. The physic-chemical properties of the biodiesel in comparison to ASTM standards are presented in Table-1.

Table.1. Properties of Test Fuels

Fuel	Specific Gravity at 40° C (cSt)	Cetane Number	Kinematic Viscosity at 40° C (cSt)	Lower Calorific value (kJ/kg)
Diesel	0.84	52	2.25	42000
Biodiesel	0.86	55	3.5	38500
ASTM Standard	ASTM D 4809	ASTM D 4809	ASTM D 445	ASTM D 7314



1 Superni crown with threads, 2. Superni gasket, 3. Air gap, 4. Body of piston, 5. Superni insert, 6. Air gap in liner, 7. Body of liner

Fig.1 Assembly details of air gap insulated piston and air gap insulated liner

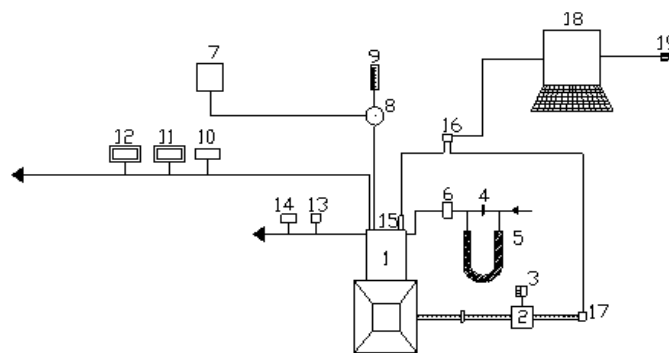
Schematic diagram of experimental setup used for the investigations on compression ignition diesel engine with rice bran biodiesel is shown in Fig.2. The test fuels used in the experimentation were neat diesel and biodiesel. The experimental engine was four-stroke, water cooled, single cylinder, 3.68 kW at the speed of 1500 rpm. The manufacturer's recommended injection timing and pressure were 27°bTDC and 190 bar. The bore of the engine was 80 mm, while stroke was 110 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 an air-box method (Air box was provided with an orifice flow meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which outlet temperature of water was maintained at 80°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. Copper shims of suitable size were provided in between the pump body and the engine frame, to vary the injection timing and its effect on the performance of the engine was studied, along with the change of injector opening pressure from 190 bar to 270 bar (in steps of 40

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bar) using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Exhaust gas temperature was measured with thermocouples made of iron and iron-constantan. Exhaust emissions of smoke and NO<sub>x</sub> were recorded by AVL (A company trade name) smoke meter and Netel Chromatograph (A company trade name) NO<sub>x</sub> analyzer respectively at full load operation of the engine. Various test fuels used in experimentation were neat diesel and biodiesel. Different operating conditions of the biodiesel were normal temperature and preheated temperature (75° C). Different injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27–34° bTDC.



1.Engine, 2.Electical Dynamometer, 3.Load Box, 4.Orifice flow 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<sub>x</sub> Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter, 15.Piezo-electric pressure transducer, 16.Console, 17.TDC encoder, 18.Pentium Personal Computer and 19. Printer.

Fig.2. Experimental Set-up

### III. RESULTS AND DICUSSION

The optimum injection timing with CE with diesel was 31°bTDC, while it was 29°bTDC with LHR–2 engine. [26]. Similarly with biodiesel operation, The optimum injection timing with CE with biodiesel was 31°bTDC, [27]. Fig.3 shows variation of brake thermal efficiency with brake mean effective pressure (BMEP) with biodiesel at various injection timings.

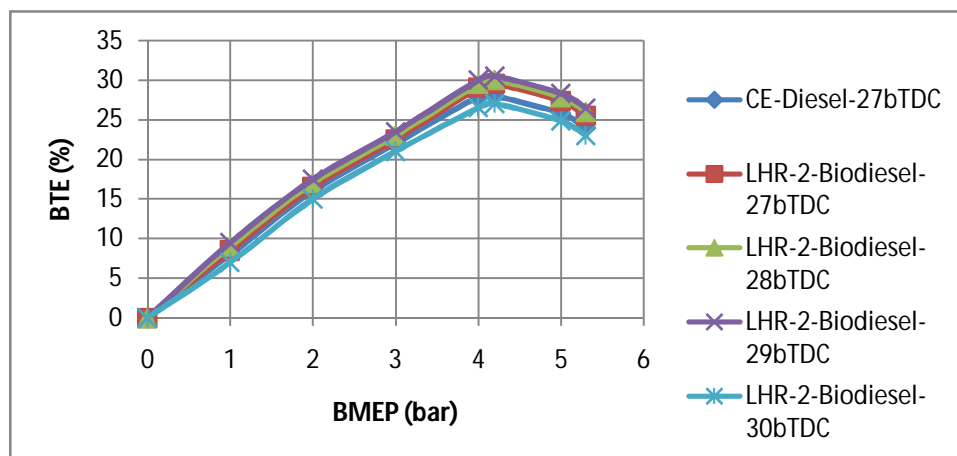


Fig.3 Variation of brake thermal efficiency with brake mean effective pressure (BMEP) with biodiesel at various injection timings.

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BTE increased up to 80% of the full load and beyond that load, it decreased with biodiesel operation on LHR-2 engine. Increase of fuel conversion efficiency, mechanical efficiency up to 80% of the full load might have improved performance of the engine; Reduction of fuel conversion efficiency, air fuel ratio and volumetric efficiency might have deteriorated the performance of the engine beyond 80% of the full load with biodiesel operation. At recommended injection timing, the performance of the LHR-2 engine was comparable with biodiesel operation. Presence of oxygen might have improved combustion reactions and increased the thermal efficiency of the engine. When the injection timing was advanced, the performance of the LHR-2 engine increased due to increase of atomization and resident time of fuel with air. Initiation of combustion at early period increased the performance of the LHR-2 engine with biodiesel operation. The optimum injection timing was found to be 29°bTDC with LHR-2 engine with biodiesel operation.

### 3.2 Exhaust Emissions

Particulate emissions and NO<sub>x</sub> are the emissions from diesel engine cause health hazards like inhaling of these pollutants cause severe headache, tuberculosis, lung cancer, nausea, respiratory problems, skin cancer, hemorrhage, etc. [28–30]. The contaminated air containing carbon dioxide released from automobiles reaches ocean in the form of acid rain, there by polluting water. Hence control of these emissions is an immediate task and important. Fig.8 presents bar charts showing the variation of particulate emissions at full load with test fuels of biodiesel and diesel at recommended injection timing and optimum injection timing with both versions of the engine. Fig.4 presents bar charts showing the variation of particulate emissions with both versions of the engine at recommended and optimum injection timing with test fuels at injection pressure of 190 bar.

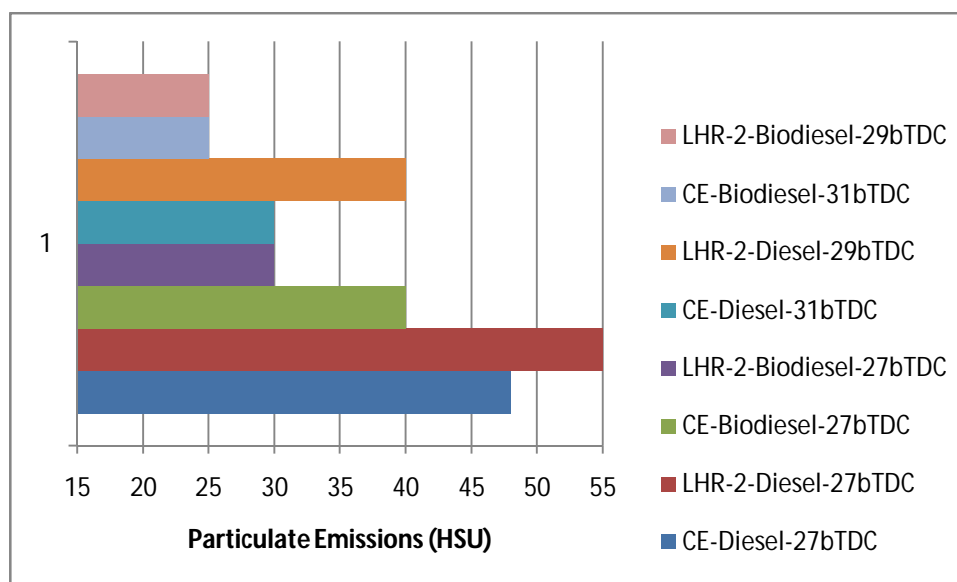


Fig. 4. Bar charts showing the variation of particulate emissions in Hartridge smoke unit (HSU) at full load.

Particulate emissions at full load decreased by 16% at recommended injection timing and 16% at optimum injection timing with biodiesel operation on CE in comparison with neat diesel (DF) operation. Presence of oxygen in fuel composition improved combustion, causing reduction of particulate emissions. LHR-2 engine reduced particulate emissions by 25% at recommended injection timing and 38% at optimum injection timing in comparison with CE with biodiesel operation, which showed that combustion improved with LHR-2 engine.

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Table.2 shows data of particulate emissions varied with injector opening pressure at different operating conditions of the biodiesel. Data from Table 2 shows a decrease in particulate emissions with different operating conditions of the biodiesel with both versions of the engine with increase of injector opening pressure. Improvement in spray characteristics might have reduced particulate emissions. Preheating of the biodiesel reduced particulate emissions, when compared with normal temperature of the biodiesel. This was due to i) the reduction of density of the biodiesel, as density was directly related to particulate emissions, ii) the reduction of the diffusion combustion proportion with the preheated biodiesel iii) the reduction of the viscosity of the biodiesel, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber. Temperature and availability of oxygen are two favorable conditions to form NO<sub>x</sub> levels.

Table.2 Data of exhaust emissions at full load operation

Injection Timing (°bTDC)	Test Fuel	Engine version	Particulate emissions (Hartridge Smoke Unit)						NO <sub>x</sub> Levels (ppm)					
			Injector Opening Pressure (Bar)						Injector Opening Pressure (Bar)					
			190		230		270		190		230		270	
			NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27	DF	CE	48	--	38	--	34	--	850	----	900	----	950	---
	Biodiesel	CE	40	35	35	30	30	25	950	900	1000	950	1050	1000
	DF	LHR-2	55	--	50	--	45	--	1250	--	1200	--	1150	--
	Biodiesel	LHR-2	30	25	25	20	20	15	1300	1250	1250	1200	1200	1150
29	DF	LHR-2	40	---	35	---	30	---	1100	---	1050	---	1000	---
	Biodiesel	LHR-2	25	20	20	15	20	15	1250	1200	1200	1150	1150	1100
31	DF	CE	30	--	35	--	40	--	1100	--	1150	--	1200	--
	Biodiesel	CE	25	20	30	25	35	30	1150	1100	1200	1150	1250	1200

Fig.5 presents bar charts showing the variation of nitrogen oxide levels at full load with biodiesel and diesel (DF) at recommended injection timing and optimum injection timing with both versions of the engine. From Fig.5, it is noticed that NO<sub>x</sub> levels were drastically higher with biodiesel operation at all loads when compared with diesel operation with both versions of the engine. The rice bran oil biodiesel having long carbon chain (C<sub>20</sub>-C<sub>32</sub>) recorded more NO<sub>x</sub> than that of fossil diesel (DF) having both medium (C<sub>8</sub>-C<sub>14</sub>) as well as long chain (C<sub>16</sub>-C<sub>28</sub>). The increase in NO<sub>x</sub> emission might be an inherent characteristic of biodiesel due to the presence of 54.9% of mono-unsaturated fatty acids (MUFA) and 18% of poly-unsaturated fatty acids (PUFA). That means, the long chain unsaturated fatty acids (MUFA and FUPA) such as oleic C18:1 and linoleic C18:2 fatty acids are mainly responsible for higher levels of NO<sub>x</sub> emission. Another reason for higher NO<sub>x</sub> levels is the oxygen (10%) present in the methyl ester. The presence of oxygen in normal biodiesel leads to improvement in oxidation of the nitrogen available during combustion. This will raise the combustion bulk temperature responsible for thermal NO<sub>x</sub> formation.

The production of higher NO<sub>x</sub> with biodiesel fueling is also attributable to an inadvertent advance of fuel injection timing due to higher bulk modulus of compressibility, with the in-line fuel injection system.

Residence time and availability of oxygen had increased, when the injection timing was advanced with test fuels, which caused higher NO<sub>x</sub> levels. Higher heat release rate of biodiesel in LHR-2 engine might have increased nitrogen oxide levels in comparison with CE with biodiesel operation. NO<sub>x</sub> levels increased with test fuels with CE, while marginal reduction of NO<sub>x</sub> levels with LHR-2 engine was observed with advanced injection timing. Residence time and availability of oxygen had increased, when the injection timing was advanced with test fuels, which caused higher NO<sub>x</sub> levels in CE, while improved combustion with improved air fuel ratios were responsible for reduction of NO<sub>x</sub> levels in LHR-2 engine with biodiesel operation.



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From Fig.5, it is noticed that NO<sub>x</sub> levels increased by 12% at recommended injection timing and 5% at optimum injection timing with CE with biodiesel operation in comparison with neat diesel operation. LHR-2 engine increased NO<sub>x</sub> levels by 37% at recommended injection timing and 9% at optimum injection timing in comparison with CE with biodiesel operation. From the Table 2, it is noted that NO<sub>x</sub> levels increased with increase of injector opening pressure with different operating conditions of biodiesel. NO<sub>x</sub> slightly increased with test fuels as injector opening pressure increased. This was because of improved combustion causes higher peak brake thermal efficiency due to higher combustion chamber pressure and temperature, which leads to higher NO<sub>x</sub> formation. This is an evident proof of enhanced spray characteristics, thus improving fuel air mixture preparation and evaporation process.

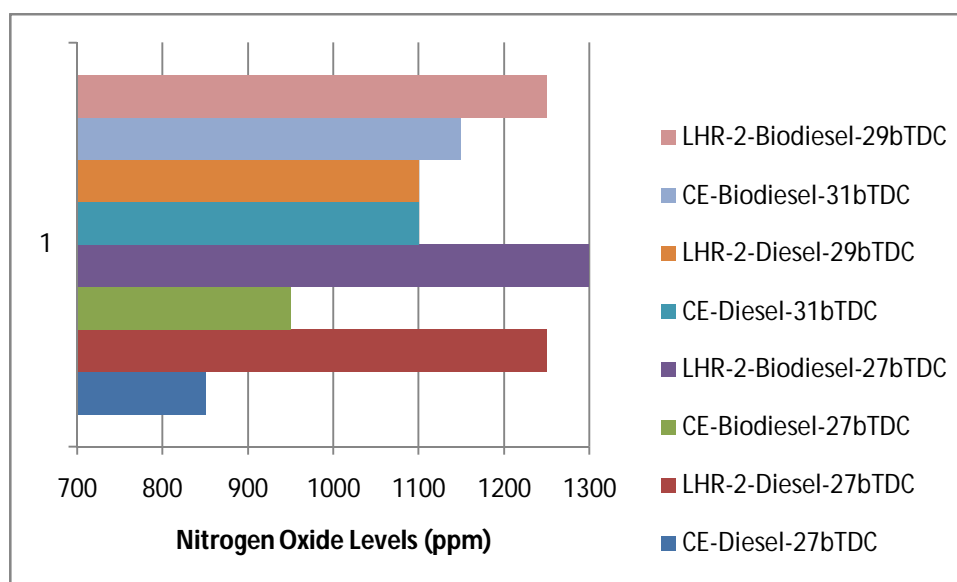


Fig.5 Bar charts showing the variation of nitrogen oxide levels (NO<sub>x</sub>) at full load operation with test fuels

NO<sub>x</sub> levels decreased with preheating of the biodiesel as noticed from the Table.2The fuel spray properties may be altered due to differences in viscosity and surface tension. The spray properties affected may include droplet size, droplet momentum, degree of mixing, penetration, and evaporation. The change in any of these properties may lead to different relative duration of premixed and diffusive combustion regimes. Since the two burning processes (premixed and diffused) have different emission formation characteristics, the change in spray properties due to preheating of the biodiesel are lead to reduction in NO<sub>x</sub> formation. As fuel temperature increased, there was an improvement in the ignition quality, which will cause shortening of ignition delay.

#### IV. CONCLUSIONS

1. Particulate emissions at full load decreased by 16% at recommended injection timing and 16% at optimum injection timing with biodiesel operation on CE in comparison with same version of the engine with diesel operation. LHR-2 engine reduced particulate emissions at full load by 46% at recommended injection timing and 38% at optimum injection timing with biodiesel operation in comparison with same version of the engine with neat diesel operation.
2. NO<sub>x</sub> levels increased by 12% at recommended injection timing and 5% at optimum injection timing with CE with biodiesel operation in comparison same version of the engine with neat diesel operation.

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LHR-2 engine increased nitrogen oxide at full load by 4% at recommended injection timing and 14% at optimum injection timing with biodiesel operation in comparison with same version of the engine with neat diesel operation.

3. With increase of injector opening pressure, particulate emissions decreased, while NO<sub>x</sub> levels increased in CE, while in LHR-2 engine, particulate emissions and NO<sub>x</sub> levels decreased. With preheating, decrease of particulate emissions and NO<sub>x</sub> levels were observed with biodiesel with both versions of the engine.

## 4.1.Future Scope of Studies

In order to reduce nitrogen oxide levels from LHR engine with biodiesel, selective catalytic reduction technique can be employed. [31]

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