

## **STUDIES ON INFLUENCE OF INJECTION PRESSURE ON EXHAUST EMISSIONS OF DIESEL ENGINE WITH MEDIUM GRADE INSULATED COMBUSTION CHAMBER WITH CRUDE JATROPHA OIL OPERATION**

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**Abstract**—In the context of depletion of fossil fuels, ever increase of pollution levels with fossil fuels, search for alternative fuels has become pertinent. Vegetable oils are important substitutes for diesel fuel as their properties are comparable to diesel fuel. Investigations were carried out to study exhaust emissions of diesel engine with air gap insulated low heat rejection (LHR–2) combustion chamber consisting of air gap insulated piston with 3 mm air gap, with superni (an alloy of nickel) crown and air gap insulated liner with superni insert with varied injector opening pressure. Exhaust emissions [particulate emissions and nitrogen oxide levels] were determined at various values of brake mean effective pressure (BMEP) of the LHR–2 combustion chamber and compared with neat diesel operation on conventional engine (CE) and vegetable oil operation at similar operating conditions. Engine with LHR–2 combustion chamber with vegetable oil operation showed reduction of particulate emissions at manufacturer’s recommended injection timing of 27° bTDC, and these emissions decreased marginally with increased injector opening pressure in comparison with CE with diesel and vegetable oil at 27°bTDC. However, LHR-2 engine drastically increased nitrogen oxide levels in comparison with conventional engine with vegetable oil.

**Index Terms**– Alternative fuels, Vegetable oil, Exhaust emissions, Particulate Emissions, Nitrogen oxide levels, Conventional engine, LHR engine, Injection pressure.

### **1.INTRODUCITON**

Non-edible vegetable oils can be seriously considered as alternative fuels for engines as their properties are comparable to diesel fuels and also edible oils are in great demand and are far too expensive as fuels. When Rudolph Diesel, first invented the diesel engine, about a century ago, he demonstrated the principle by employing peanut oil and hinted that vegetable oil would be the future fuel in the diesel engine [1]. 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 causing the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [1]–[8]. The presence of the fatty acid components greatly affects the viscosity of the oil, which in turn affect the wear of engine components, oil consumption, fuel economy, hot starting, cold starting, low temperature pumpability, noise and shear stability. The limitation of unsaturated fatty acids is necessary due to the fact heating higher unsaturated fatty acids results in polymerization of glycerides. This can leads to formation of deposits or to deterioration of lubricating oil. The different fatty acids present in the vegetable oil are palmitic, steric, linoleic, oleic, and fatty acids [1]. These fatty acids increase particulate emissions and also lead to incomplete combustion due to improper air–fuel mixing. Studies were made with single cylinder, four-stroke water cooled direct injection diesel engine, with 3.68 kW brake power at a speed of 1500 rpm with a compression ratio of 16:1 with vegetable oils with varied injector opening pressure and injection timing.[ 5]-[6]. The injection timing was varied by inserting copper shims in between pump body and engine frame, while change of injector opening pressure was achieved by using nozzle–testing device. At manufacturer’s recommended injection timing of 27° bTDC, particulate emissions increased by 56%, while nitrogen oxide (NO<sub>x</sub>) levels decreased by 18% with crude vegetable oil when compared with neat diesel operation on conventional engine. Particulate emissions decreased by 15–20%, while NO<sub>x</sub> levels increased by 15–20% with conventional engine with crude vegetable oil operation with an increase of injector opening pressure of 80 bar, when compared with neat diesel operation.

Experiments were conducted on preheated vegetable oil in order to equalize their viscosity to that of pure diesel may ease the problems of injection process [5]–[6]. Investigations were carried out on conventional four stroke diesel engine, 3.68 kW at a speed of 1500 rpm with preheated vegetable oil with varied injection timing and injection pressure. They reported that preheated vegetable oil at 27° bTDC, decreased particulate matter emissions by 8–9%, NO<sub>x</sub> emissions by 5–6%, when compared with normal vegetable oil. Increased injector opening pressure may also result in efficient combustion in compression ignition engine It has a significance effect on the performance and formation of pollutants inside the direct injection diesel engine combustion. Experiments were conducted on conventional four stroke diesel engine, with neat diesel operation with increased injector opening pressure. [9]–[13]. They reported that particulate emissions decreased while NO<sub>x</sub> levels increased with an increase of injection pressure.

Experiments were conducted on conventional four stroke diesel engine, 3.68 kW at a speed of 1500 rpm with vegetable oil operation with increased injector opening pressure. They reported that performance of the engine improved with increased injector opening pressure with vegetable oil operation.[5]–[6]. It decreased particulate emissions by 20–22% and increased NO<sub>x</sub> levels by 10–14% with an increase of injector opening pressure by 80 bar.

The drawbacks associated with biodiesel (high viscosity and low volatility) call for hot combustion chamber, provided by low heat rejection (LHR) combustion chamber. 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. Three approaches that are being pursued to decrease heat rejection are (1) Coating (low grade LHR combustion chamber) 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) 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).Combination of low grade and medium grade LHR combustion chambers results in high grade LHR combustion chamber.

Experiments were conducted on high 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 and ceramic coated cylinder head (partially stabilized zirconium of thickness 500 microns coated on inside portion of cylinder head) with vegetable oil with varied injector opening pressure and injection timing [14]-[17]. They reported from their investigations, that thermal efficiency increased by 3-41%, volumetric efficiency increased by 2-3%, particulate emissions decreased by 20-25% NOx levels decreased by 20-25%, peak pressure increased by 20-25% and maximum rate of pressure increased by 6-8% with engine with LHR combustion chamber with vegetable oil operation with an increase of injector opening pressure of 80 bar when compared with neat diesel operation on conventional engine at 27° BTDC.

Little reports were available on comparative studies of exhaust emissions of medium grade LHR engine with crude jatropha oil and diesel with varied injector opening pressure and at different operating conditions of the vegetable oil. The authors have made an attempt in this direction. Studies were made on exhaust emissions of medium grade LHR engine consisted of air gap insulated piston and air gap insulated liner with different operating conditions of the crude vegetable oil with varied injector opening pressure and compared with vegetable oil with conventional engine.

## 2. MATERIALS AND METHODS

### 2.1 Crude Vegetable Oil

India with just 2.4% of the global area supports more than 16% of world's human population and 17% of the cattle population.

According to economic survey (2000-2001), of the cultivable land area, about 175 million hectares are classified as waste and degraded or marginal land. If the non forest waste-lands could be used to cultivate plants which can survive on such soil and which can produce oilseeds, these could be effectively used to combat fuels shortage in the country and at the same time bring such degraded lands back to its productive capacity.

Jatropha (*Jatropha curcas*, Ratanjyot) is a suitable candidate for its purpose. Jatropha oil [18] known as moglaerand, beghierand, chandsaiyoti, or nepalam in India can be substituted for diesel. India imports jatropha oil of worth about 400 crores annually, which is used for making soap. Jatropha is a large shrub or small tree found throughout the tropical and subtropical regions of the world. The plant has several distinguishing and useful properties such as hardness, rapid growth easily propagation and wide ranging usefulness. It grows on any type of soil and is well adapted to cultivation. The plant has no major diseases or insect pests and is not browsed by cattle or sheep even during times of drought. The plant can survive for more than a year without water. Propagation is easily achieved by seed or stem cutting and its growth is rapid as is implied by its ability to form a thick live hedge nine months after planting. The plant starts yielding from the third year onwards and continues to yield for the next 25 years. The whole seeds can be crushed to yield about 25% oil. Double crushing can increase the yield to 28.5% and solvent extraction to 30%. The yield from established plantations in Brazil is around 1.5 to 2.3 tons per hectare. The seed and oil possess toxins and hence non-edible. The oil cake is also toxic and can be used only as manure and is very useful for this application with high nitrogen content and a favorable N: P: K ratio of 2.7:1.2:1.

The properties of vegetable oil are shown in Table.1

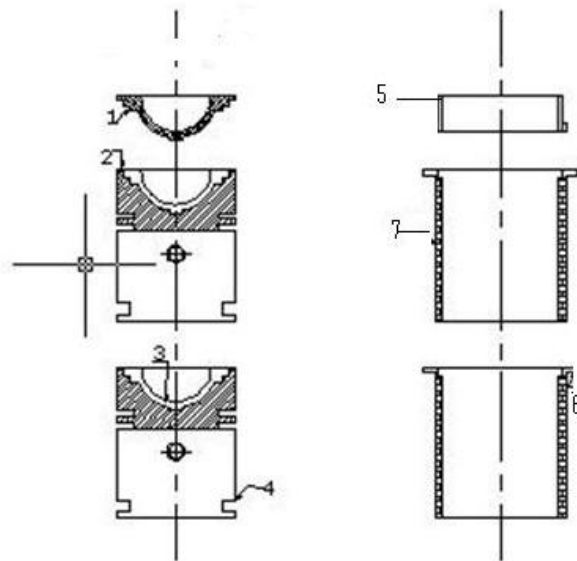
TABLE.1  
PROPERTIES OF TEST FUELS

Test Fuel	Viscosity at 25°C (centi-poise)	Specific gravity at 25° C	Cetane number	Lower Calorific value (kJ/kg)
Diesel	12.5	0.84	55	42000
Jatropha oil (crude)	125	0.90	45	36000

ASTM Standard	ASTM D 445	ASTM D 4809	ASTM D 613	ASTM D 7314
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### 2.2 Engine With LHR Combustion Chamber

Engine with high grade LHR 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 [19]. 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.

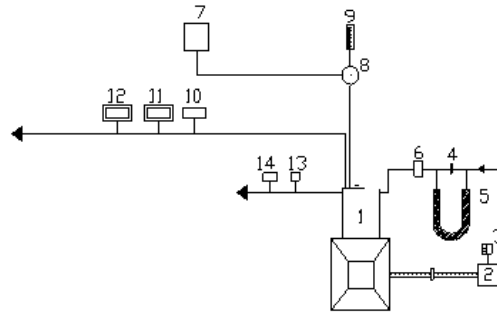


1. Superni piston crown with threads, 2. Superni gasket, 3. Air gap in piston, 4. Body of piston, 5. Superni insert with threads, 6. Air gap in liner, 7. Liner

Fig.1 Assembly details of air gap insulated piston, air gap insulated liner and ceramic coated cylinder head

### 2.3 Experimental Set-Up

The schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with cotton seed oil based biodiesel is shown in Fig.2. Specifications of the test engine were given in Table 2. The engine tests were carried out with a single-cylinder, four-stroke, naturally aspirated, compression ignition engine with brake power 3.68 kW at a speed of 1500 rpm. The compression ratio of engine was 16:1. Manufacturer's recommended injection timing and injector opening pressure were 27° bTDC and 190 bar. The engine was connected to an electric dynamometer for measuring its brake power. Dynamometer was loaded by a loading rheostat. The accuracy of engine load was ±0.2 kW. The speed of the engine was measured with digital tachometer with accuracy ±1%. The fuel consumption was registered with the aid of fuel measuring device (Burette and stop watch). The accuracy of brake thermal efficiency obtained is ±2%. Vegetable oil was injected into the engine through conventional injection system. Provision was made for preheating of vegetable oil to the required levels (90°C) so that its viscosity was equalized to that of diesel fuel at room temperature.



1.Engine, 2.Electical Dynamo meter, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Three way valve, 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 and 14. Outlet-jacket water flow meter.

Fig.2. Schematic diagram of experimental set-up

Air-consumption of the engine was obtained with an aid of air box, orifice flow meter and U-tube water manometer assembly. Air-box with diaphragm was used to damp out the pulsations produced by the engine, for ensuring a steady flow of air through the intake manifold. 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. The water flow rate was measured by means of analogue water flow meter, with accuracy of measurement of ±1%.

TABLE.2.  
 SPECIFICATIONS OF THE TEST ENGINE

Description	Specification
Engine make and model	Kirloskar ( India) AV1
Maximum power output at a speed of 1500 rpm	3.68 kW
Number of cylinders ×cylinder position× stroke	One × Vertical position × four-stroke
Bore × stroke	80 mm × 110 mm
Method of cooling	Water cooled
Rated speed ( constant)	1500 rpm
Fuel injection system	In-line and direct injection
Compression ratio	16:1
BMEP @ 1500 rpm	5.31 bar
Manufacturer's recommended injection timing and pressure	27°bTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm

Engine oil was provided with a pressure feed system. No temperature control was incorporated, for measuring the lube oil temperature. Change of injector opening pressure from 190 bar to 270 bar (in steps of 40 bar) was made using nozzle testing device. The maximum injector opening pressure was restricted to 270 bar due to practical difficulties involved. Coolant water jacket inlet temperature, outlet water jacket temperature and exhaust gas temperature were measured by employing iron and iron-constantan thermocouples connected to analogue temperature indicators. The accuracies of analogue temperature indicators are ±1%. Particulate emissions were measured by AVL Smokemeter, while nitrogen oxide (NO<sub>x</sub>) levels were determined by Netel Chromatograph NO<sub>x</sub> Analyzer at various values of brake mean effective pressure (BMEP) of the engine. The measuring principle and repeatability of these analyzers was given in Table.3. Analyzers were allowed to adjust their zero point before each measurement. To ensure that accuracy of measured values was high, the gas analyzers were calibrated before each measurement using reference gases.

TABLE.3  
 SPECIFICATIONS OF THE  
 SMOKE OPACIMETER (AVL, INDIA, 437). AND NO<sub>x</sub> ANALYZER (NETEL INDIA, (4000 VM))

Pollutant	Measuring Principle	Range	Least Count	Repeatability
Particulate Emissions	Light extinction	1–100%	0.1% of Full Scale (FS)	0.1% for 30 minutes
NO <sub>x</sub>	Chemiluminiscence	1–5000 ppm	0.5% of FS	≤0.5% F.S

### 3.RESULTS AND DISCUSSION

Various exhaust emissions measured were particulate emissions and nitrogen oxide levels at various values of brake mean effective pressure of the engine

Fig.3 shows variation of particulate emissions with brake mean effective pressure in conventional engine and LHR-2 engine at at 27° b TDC and injector opening pressure of 190 bar.,with crude jatropha oil operation. Similar characteristics with neat diesel operation on conventional engine at recommended injection timing was also shown for comparison purpose.

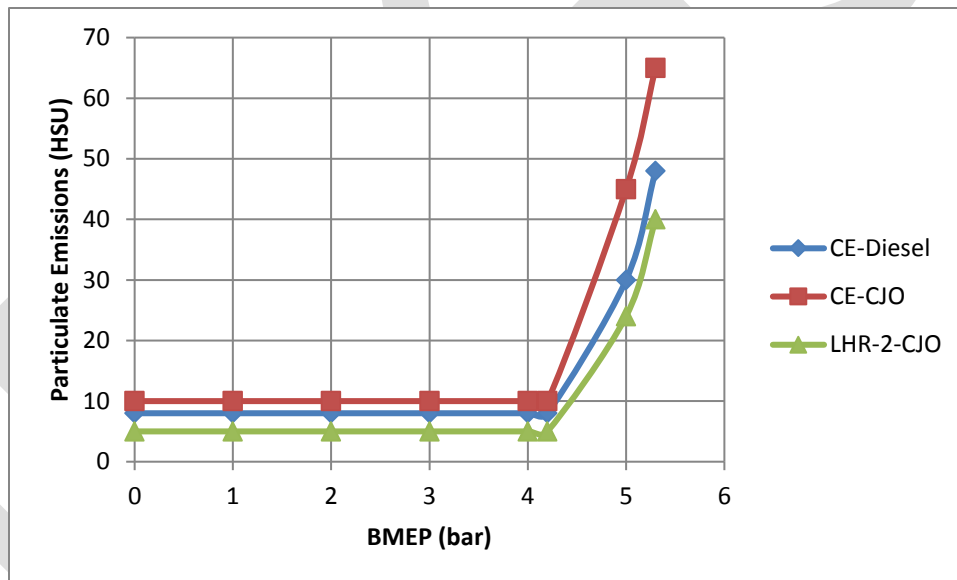


Fig.3 Variation of particulate emissions with brake mean effective pressure (BMEP) in conventional engine (CE) and LHR-2engine with crude jatropha oil (CJO) operation at 27° b TDC and injector opening pressure of 190 bar.

Particulate emissions were more or less constant during part load and suddenly at 80% of the full load, they increased with both versions of the combustion chamber. This was due to excess air fuel ratios at part load and decrease of the same at full load. Conventional engine with crude vegetable oil showed the deterioration in the performance at all loads when compared with the neat diesel operation on conventional engine at recommended injection timing. From this Fig, it is observed that drastic increase of particulate emissions at all loads with vegetable oil operation was observed compared with neat diesel operation. This was due to the higher value of ratio of C/H (0.7 for vegetable oil while it is 0.45 for diesel) in fuel composition. (C= Number of carbon atoms and H= Number of hydrogen atoms in fuel composition (C<sub>18</sub>H<sub>27</sub>O<sub>6</sub>). Higher the value of this ratio means, number of carbon atoms is higher, leading to produce higher levels of carbon dioxide and carbon monoxide and hence higher particulate emissions. The increase of particulate emissions was also due to reduction of oxygen-fuel ratios and volumetric efficiency with vegetable oil operation. Different fatty acids present in the crude vegetable oil are palmic, steric,

**lingoceric, oleic, linoleic and fatty acids [5]. These fatty acids increase particulate emissions and also lead to incomplete combustion due to improper air-fuel mixing.**

This was also because of higher viscosity of vegetable oil. Particulate emissions are related to the density of the fuel. Since crude vegetable oil has higher density compared to diesel fuel, particulate emissions were higher with vegetable oil. Particulate emissions at all loads decreased at the optimum injection timing with vegetable oil operation with both versions of the combustion chamber. This was due to early initiation of combustion with increased contact of fuel with air leading to improve atomization.

Fig.4. presents bar charts showing the variation of particulate emissions at full load operation with test fuels at recommended at an injector opening pressure of 190 bar. Conventional engine increased particulate emissions at full load by 35% at 27° bTDC when compared with neat diesel operation. This was due to fuel composition, higher density and deteriorated of combustion of vegetable oil with conventional engine. LHR-2 engine with vegetable oil reduced particulate emissions by 42% at 27° bTDC in comparison with diesel operation on same configuration of the engine. This showed that combustion improved with hot environment and higher heat release rate with LHR-2 engine with vegetable oil operation in comparison with diesel operation.

LHR-2 engine with vegetable oil operation reduced particulate emissions at full load by 46% at recommended injection timing in comparison with conventional engine with vegetable oil operation. This was due to reduction of ignition delay with higher duration of combustion of vegetable oil with which improved combustion leading to reduce particulate emissions. Reduction of ignition delay of higher cetane value of diesel fuel leads to fuel cracking and hence higher particulate emissions with LHR-2 engine with diesel as fuel. Thus once again, it is confirmed that LHR-2 engine was more suitable for vegetable oil operation.

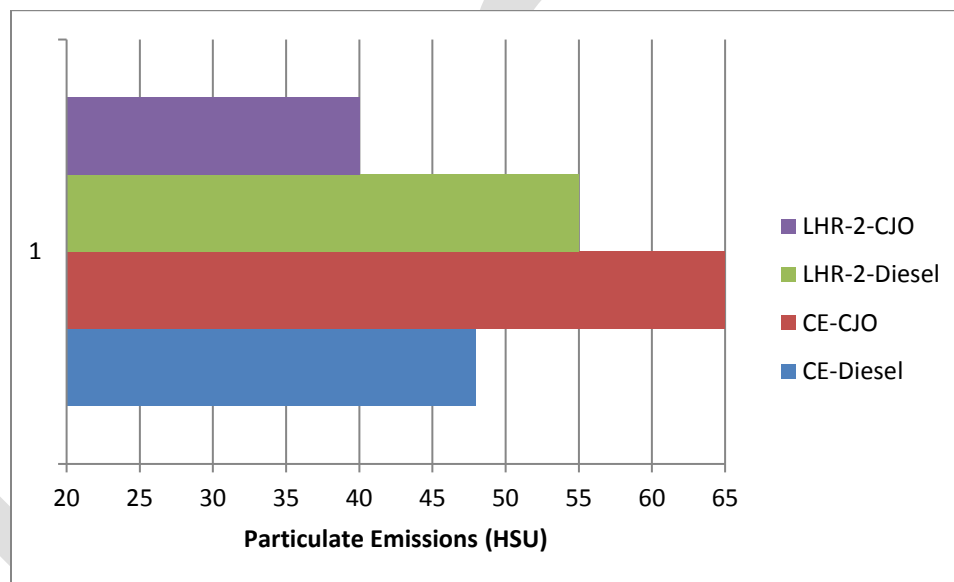


Fig. 4. Bar charts showing the variation of particulate emissions at full load operation with conventional engine and LHR-2 engine with neat diesel and crude jatropha oil operation.

LHR-2 engine with vegetable oil operation reduced particulate emissions at full load by 27% at recommended injection timing when compared with neat diesel operation on conventional engine. This showed that combustion improved with LHR-2 engine with vegetable oil operation. Particulate emissions at full load were observed to be higher with conventional engine with vegetable oil at recommended injection timing.

Nitrogen oxide (NO<sub>x</sub>) levels are the precursor pollutants which can combine to form photochemical smog. These irritate the eyes and throat, reduces the ability of blood to carry oxygen to the brain and can cause headaches, and pass deep into the lungs causing respiratory problems for the human beings. Long-term exposure has been linked with leukemia. Therefore, the major challenge for the existing and future diesel engines is meeting the very tough emission targets at affordable cost, while improving fuel economy.

Temperature and availability of oxygen are two favorable conditions to form NO<sub>x</sub> levels. Fig. 5. shows the variation of nitrogen oxide levels with brake mean effective pressure with both versions of the combustion chamber at recommended and injection timing with vegetable oil operation at an injector opening pressure of 190 bar. NO<sub>x</sub> levels increased with increase of brake mean effective pressure with vegetable oil operation at recommended and optimized injection timing due to higher peak pressures, temperatures as larger regions of gas burned at close-to-stoichiometric ratios particularly at full load operation. Conventional engine registered lower at all loads with vegetable oil operation when compared with diesel operation. This was due to deterioration of combustion due its high viscosity, low volatility and low calorific value of the fuel of the vegetable oil at recommended injection timing leading to produce low temperatures and hence lower NO<sub>x</sub> levels.

Drastically increase of NO<sub>x</sub> emissions were observed at all loads with engine with LHR-2 combustion chamber with vegetable oil operation when compared with neat diesel operation on conventional engine. This was because of increase of peak pressures and temperatures due to reduction of ignition delay with hot environment provided by the engine with LHR-2 version of the combustion chamber.

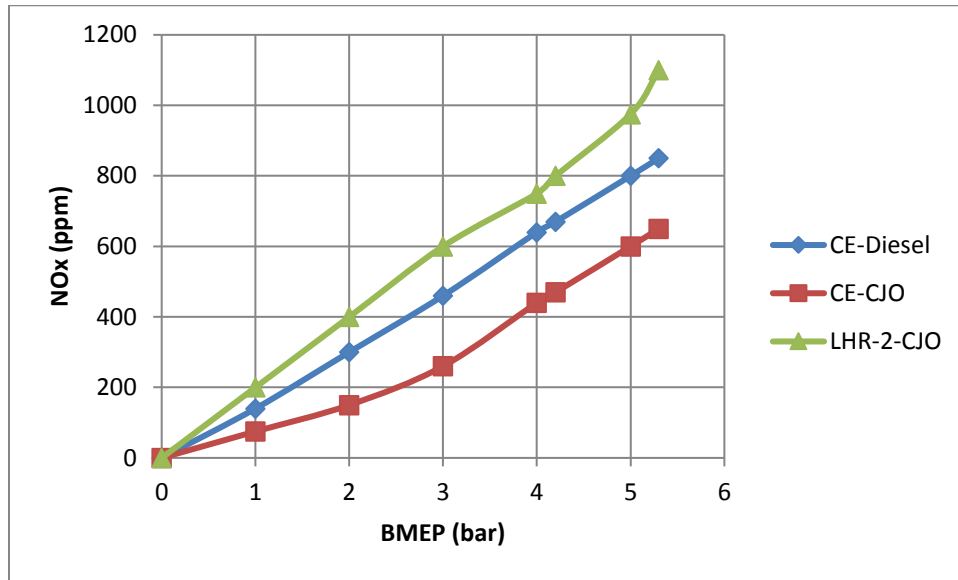


Fig.5. Variation of nitrogen oxide levels (NO<sub>x</sub>) with brake mean effective pressure (BMEP) with conventional engine and LHR-2 engine with crude vegetable oil operation at recommended injection timing at an injector opening pressure of 190 bar.

Fig.6. presents bar charts showing the variation of particulate emissions at full load operation with test fuels at recommended injection timing at an injector opening pressure of 190 bar.

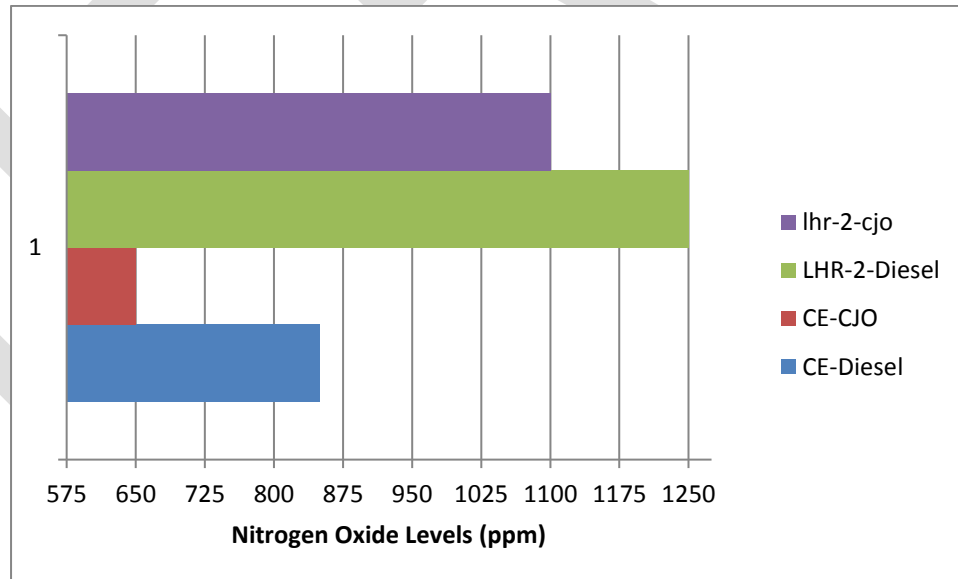


Fig.6. Bar charts showing the variation of nitrogen oxide levels (NO<sub>x</sub>) at full load operation with conventional engine and LHR-2 engine with neat diesel and crude jatropha oil operation.

Conventional engine decreased NO<sub>x</sub> levels at full load by 23% at 27°bTDC when compared with neat diesel operation. This was due to deteriorated in combustion of vegetable oil with conventional engine. LHR-2 engine with vegetable oil reduced particulate

emissions by 12% at 27° bTDC in comparison with diesel operation on same configuration of the engine. This was because of higher calorific value of diesel producing higher gas temperatures causing higher NO<sub>x</sub> levels with diesel operation.

LHR-2 engine with vegetable oil operation increased NO<sub>x</sub> emissions at full load by 77% at recommended injection timing in comparison with conventional engine with vegetable oil operation. This was due to higher heat release rate and gas temperatures with vegetable oil operation with LHR-2engine.

LHR-2 engine with vegetable oil operation increased NO<sub>x</sub> levels at full load by 35% at recommended injection timing when compared with neat diesel operation on conventional engine. This was due to higher heat release rate with LHR-2 engine with vegetable oil operation.

NO<sub>x</sub> emissions at full load were observed to be higher with LHR-2 engine with neat diesel at recommended injection timing. NO<sub>x</sub> emissions at full load were observed to be lower with conventional engine with vegetable oil at recommended injection timing.

Table.4. shows data of particulate emissions and nitrogen oxide levels at full load with conventional engine and engine with LHR-2 combustion chamber at recommended injection timing with varied injector opening pressure with different operating conditions of the vegetable oil.

The data from Table.4 shows a decrease in particulate emissions at full load with increase of injector opening pressure, with different operating conditions of the vegetable oil. This was due to improvement in the fuel spray characteristics at higher injector opening pressure and increase of air entrainment, causing lower particulate emissions. Even though viscosity of vegetable oil was higher than diesel, high injector opening pressure improves spray characteristics, hence leading to a shorter physical delay period. The improved spray also leads to better mixing of fuel and air resulting in turn in fast combustion. Similar trends were noticed by earlier researchers.[20].

From Table.4. it is noted that particulate emissions decreased with preheated vegetable oil, when compared with normal temperature of the vegetable oil. This was due to i) the reduction of density of the vegetable oil, as density was directly related to smoke emissions ii) the reduction of the diffusion combustion proportion with the preheated vegetable oil, iii) the reduction of the viscosity of the vegetable oil, with which the fuel spray does not impinge on the combustion chamber walls of lower temperatures rather than it directed into the combustion chamber.

From Table.4, it is noted that nitrogen oxide (NO<sub>x</sub>) levels increased with increase of injector opening pressure with different operating conditions of vegetable oil with conventional engine. The increase in peak brake thermal efficiency was proportional to increase in injector opening pressure. Normally, improved combustion causes higher peak brake thermal efficiency due to higher combustion chamber pressure and temperature and leads to higher NO<sub>x</sub> formation (Table.4). This is an evident proof of enhanced spray characteristics, thus improving fuel air mixture preparation and evaporation process.

However, NO<sub>x</sub> levels decreased with engine with LHR-2 combustion chamber with test fuels with increase of injector opening pressure. This was due to reduction of gas temperatures with improved combustion in engine with LHR-2 combustion chamber. Similar trends were noticed by earlier researchers. [14]-[17].

NO<sub>x</sub> levels decreased with preheating of the vegetable oil with both versions of the engine as noticed from Table.7.4. The 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 vegetable oil 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. A short ignition delay period lowers the peak combustion temperature which suppresses NO<sub>x</sub> formation. Lower levels of NO<sub>x</sub> was also attributed to retarded injection, improved evaporation, and well mixing of preheated vegetable oil due to their viscosity at preheated temperatures. Similar trends were noticed by earlier researchers [14]-[17]

TABLE.4

DATA OF PARTICULATE EMISSIONS AND NITROGEN OXIDE (NOX) LEVELS WITH TEST FUELS

AT FULL LOAD OPERATION.

Injection timing	Test fuel	Particulate Emissions at full load operation (HSU)	NO <sub>x</sub> Levels (ppm) at full load operation
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( $^{\circ}$ bTDC)		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(CE)	DF	48	--	38	--	34	--	850		900		950	
	CJO	65	60	63	58	58	54	650	600	700	650	750	700
27(LHR-2)	DF	55	---	50	---	45	---	1250	--	1200	--	1150	---
	CJO	40	35	35	30	30	25	1100	1050	1050	1000	1000	950

#### 4.CONCLUSION

1. Engine with LHR-2 combustion chamber consisted of air gap insulated piston with superni (an alloy of nickel) crown, and air gap insulated liner with vegetable oil opertoin showed reduction of particulate emissions and increase of nitrogen oxide levels at full load at  $27^{\circ}$  bTDC in comparison with conventional engine with vegetable oil operation and diesel operation at  $27^{\circ}$  bTDC.
2. Engine with LHR-2 combustion chamber with vegetable oil opertoin showed reduction of particulate emissions and nitrogen oxide levels at  $27^{\circ}$  bTDC in comparison with same configuration of the engine with diesel operation
3. Exhasut emissions improved marginally with an increase of injector opening pressure with vegetable oil operation with both versions of the combustion chamber.

#### 4.1 Research Findings and Suggestions

Comparative studies on exhaust emissions with direct injection diesel engine with LHR-3 combustion chamber and conventional combustion chamber were made at varied injection pressure with neat vegetable oil operation. LHR-2 engine increased drastically NOx emissions. Hence, NOx levels can be reduced with selective catalytic reduction technique. [21].

#### 4.2 Future Scope of Work

Hence further work on the effect of injection timing with engine with LHR-3 combustion chamber with vegetable oil operation is necessary. Studies on exhaust emissions with varied injection timing and injection pressure with vegetable oil operation on engine with LHR-2 combustion chamber can be taken up.

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