INVESTIGATIONS ON PERFORMANCE PARAMETERS OF CERAMIC COATED DIESEL ENGINE WITH TOBACCO SEED OIL BIODIESEL

N. Venkateswara Rao[1], M.V.S. Murali Krishna[2] and P.V.K. Murthy[2]
[1]Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad-500 075, Andhra Pradesh, India,
[2]Mechanical Engineering Department, Chaitanya Bharathi Institute of Technology, Gandipet, Hyderabad-500 075, Andhra Pradesh, India,
[3]Jayapraksan Group of Educational Institutions, Mahabubnagar, Andhra Pradesh, India,

ABSTRACT

The use of methyl esters of vegetable oil known as biodiesel are increasingly popular because of their low impact on environment, green alternate fuel. Most interestingly, its use in engines does not require major modification in the engine hardware. Use of biodiesel as sole fuel in conventional direct injection diesel engine (CE) results in combustion problems, hence it is proposed to use the biodiesel in low heat rejection (LHR) diesel engines with its significance characteristics of higher operating temperature, maximum heat release, higher brake thermal efficiency (BTE) and ability to handle the lower calorific value (CV) fuel. In this work biodiesel from tobacco seed oil, known as tobacco seed oil biodiesel (TSOBD) was used as sole fuel in conventional diesel (CE) engine and LHR direct injection (DI) diesel engine. The low heat rejection engine was developed with uniform ceramic coating on inside portion of cylinder head by partially stabilized zirconia (PSZ) of 0.5 mm thickness. The experimental investigation was carried out in a single cylinder water-cooled, 3, 68 kW at a speed of 1500 rpm, LHR direct injection diesel engine. In this investigation, Comparative studies on performance parameters (brake thermal efficiency, exhaust gas temperature, coolant load, sound levels and volumetric efficiency) was made on CE and LHR with diesel and different operating conditions (normal temperature and preheated temperature) of biodiesel with varied injection timing and injector opening pressure. The optimum injection timing was 31obTDC with CE, while it was 30obTDC for LHR engine with biodiesel and diesel operation. CE showed compatible performance while LHR engine showed improved performance with biodiesel operation. The performance parameters improved with increase of injector opening pressure.

KEYWORDS: *Alternate Fuels, Vegetable Oils, Biodiesel, LHR engine, Performance parameters.*

I. INTRODUCTION

The world is presently confronted with the twin crises of fossil fuel depletion and environmental degradation. The fuels of bio origin can provide a feasible solution of this worldwide petroleum crisis (1-2). It has been found that the vegetable oils are promising substitute, because of their properties are similar to those of diesel fuel and 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. Several researchers [3-6] 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. Viscosity can be reduced with preheating. Experiments were conducted [7-10] on preheated vegetable [temperature at which viscosity of the vegetable oils were matched to that of diesel fuel] oils and it was reported that preheated vegetable oils improved the performance marginally, decreased exhaust emissions of smoke and NOx

emissions. The problems of crude vegetable oils can be solved, if these oils are chemically modified to bio-diesel. Bio-diesels derived from vegetable oils present a very promising alternative to diesel fuel since biodiesels have numerous advantages compared to fossil fuels as they are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. Experiments were carried out [11-15] with bio-diesel on direct injection diesel engine and it was reported that performance was compatible with pure diesel operation on conventional engine. However biodiesel operation increased NOx levels.

Few investigators [16-19] reported that injector opening pressure has a significance effect [20] on the performance and formation of pollutants inside the direct injection diesel engine combustion. The other important engine variable to improve the performance of the engine is injection timing. Investigations were carried out [21-24] on single cylinder water cooled vertical diesel engine with brake power 3.68 kW at a speed of 1500 rpm with varied injection timing from 27-34ºbTDC. It was reported from their investigations that performance of the engine improved with advanced injection timing. However, it increased NOx emissions and decreased smoke levels. Sound levels determine the phenomena of combustion in engine whether the performance was improving or deteriorating. Studies were made [22-24] on sound levels with convention engine with vegetable oils and it was reported from the studies, that performance deteriorated with vegetable oil operation on conventional engine leading to produce high sound levels. The drawbacks associated with biodiesel for use in diesel engine call for low heat rejection (LHR) diesel engine.

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, medium grade and high grade insulated engines. Several methods adopted for achieving low grade LHR engines are using ceramic coatings on piston, liner and cylinder head. Medium grade LHR engines provide an air gap in the piston and other components with low-thermal conductivity materials like superni, cast iron and mild steel etc. High grade engines contain ceramic coatings on engine components and air gap insulated components.

LHR engines with ceramic coating of thickness in the range of 500 microns on the engine components with pure diesel operation [25-27] provided adequate insulation and improved brake specific fuel consumption (BSFC) in the range of 5-7%. The investigations on low grade LHR engine consisting of ceramic coating on cylinder head were extended to crude vegetable oil [28-29] and biodiesel [30]. It was revealed from their investigations that ceramic coated LHR engines marginally improved brake thermal efficiency, decreased smoke levels by 30% and increased NOx levels by 40%. Little literature was available on comparative studies of conventional diesel engine and ceramic coated LHR engine with different operating conditions of the biodiesel with varied injection timing and injector opening pressure. Hence it was attempted here to determine performance parameters with tobacco seed oil based biodiesel with CE and LHR with varied injector opening pressure and injection timing. The data of standard diesel fuel was taken from the reference [31]. Section-2 contains Materials and Methods, Section-3 contains Results and Discussions, Section-4 consists of Conclusions, Section-5 contains Future scope of work, and Section-6 contains Acknowledgements followed by References followed.

II. MATERIALS AND METHODS

The inner side portion of cylinder head was coated with partially stabilized zirconium (PSZ) of thickness of 500 microns in order to convert conventional diesel engine to low heat rejection (LHR) diesel engine. The chemical conversion of esterification reduced viscosity four fold. Tobacco seed oil contains up to 72.9 % (wt.) free fatty acids [31].The methyl ester was produced by chemically reacting the tobacco seed oil with an alcohol (methyl), in the presence of a catalyst (KOH). A two-stage process was used for the esterification [32-33] of the waste fried vegetable oil. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in tobacco 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 tobacco 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 tobacco seed oil was known as tobacco seed oil biodiesel (TSOBD). The physic-chemical properties of the crude tobacco seed oil and biodiesel in comparison to ASTM biodiesel standards are presented in Table-1 This section contains fabrication of ceramic coated LHR engine, preparation of biodiesel, properties of biodiesel, description of the schematic diagram of experimental set up and specifications of experimental engine along with specifications of sound analyzer. The inner side portion of cylinder head was coated with partially stabilized zirconium (PSZ) of thickness of 500 microns in order to convert conventional diesel engine to low heat rejection (LHR) diesel engine. The chemical conversion of esterification reduced viscosity four fold. Tobacco seed oil contains up to 72.9 % (wt.) free fatty acids [32].The methyl ester was produced by chemically reacting the tobacco seed oil with an alcohol (methyl), in the presence of a catalyst (KOH). A two-stage process was used for the esterification [33-34] of the waste fried vegetable oil. The first stage (acid-catalyzed) of the process is to reduce the free fatty acids (FFA) content in tobacco 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 tobacco 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 tobacco seed oil was known as tobacco seed oil biodiesel (TSOBD). The physic-chemical properties of the crude tobacco seed oil and biodiesel in comparison to ASTM biodiesel standards are presented in Table1.

Table.1. Properties of Test Fuels

Property	Units	Diesel	Biodiesel	ASTM D 6751-02
Carbon chain	--	C_8-C_{28}	C_{16}-C_{24}	C_{12}-C_{22}
Cetane Number		55	55	48-70
Density	gm/cc	0.84	0.87	0.87-0.89
Bulk modulus @ 20Mpa	Mpa	1475	1850	NA
Kinematic viscosity @ 40ºC	cSt	2.25	4.2	1.9-6.0
Sulfur	%	0.25	0.0	0.05
Oxygen	%	0.3	11	11
Air fuel ratio (stochiometric)	--	14.86	13.8	13.8
Lower calorific value	kJ/kg	42 000	37500	37 518
Flash point (Open cup)	ºC	66	174	130
Molecular weight	--	226	261	292
Preheated temperature	ºC	--	60	--
Colour	--	Light yellow	Yellowish orange	---

The test fuels used in the experimentation were pure diesel and tobacco seed oil based biodiesel. The schematic diagram of the experimental setup with test fuels is shown in Figure 1. The specifications of the experimental engine are shown in Table-2. 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 meter and U-tube water manometer). The naturally aspirated engine was provided with water-cooling system in which inlet temperature of water was maintained at 80ºC 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 (to vary the length of plunger of pump barrel) 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 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.

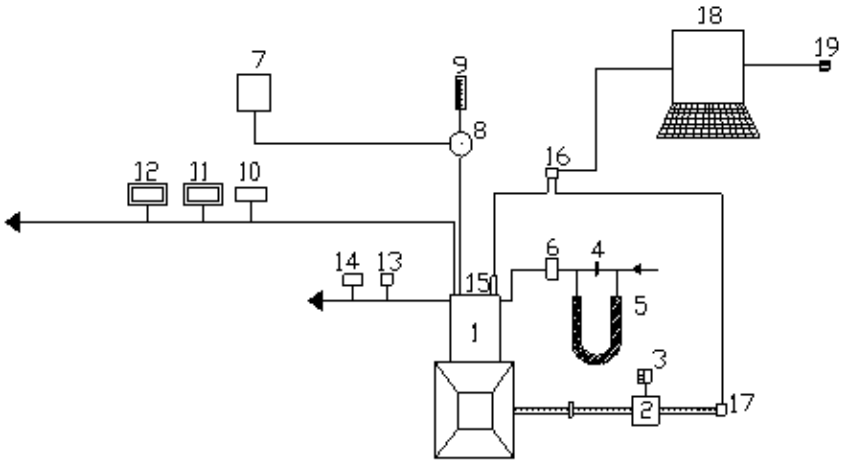
Table.2. Specifications of the Test Engine

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	27ºbTDC × 190 bar
Dynamometer	Electrical dynamometer
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type
Fuel injection nozzle	Make: MICO-BOSCH No- 0431-202-120/HB
Fuel injection pump	Make: BOSCH: NO- 8085587/1

Different operating conditions of the biodiesel were normal temperature and preheated temperature. Different injector opening pressures attempted in this experimentation were 190 bar, 230 bar and 270 bar. Various injection timings attempted in the investigations were 27-34ºbTDC.
The specifications of the sound analyzer were given in Table-3.

Table 3. Specifications of Sound Analyzer

Name of the analyzer	Measuring Range	Precision	Resolution
Sound Analyzer	0-150 Decibels	1 decibel	1 decibel



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 NOx 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.

Figure 1. Experimental Set-up

III. RESULTS AND DISCUSSION

The performance of diesel fuel in conventional engine and LHR engine was taken from Reference [31]. The optimum injection timing with conventional engine with pure diesel operation was 31ºbTDC, while it was 30ºbTDC for LHR engine.
Comparative studies were made between CE and LHR engine with different operating conditions of the biodiesel with varied injection timing and injector opening pressure. The results were compared with standard diesel under the same conditions.

3.1. Performance Parameters

Curves from Figure 2 indicate that at recommended injection timing, engine with biodiesel showed the compatible performance for entire load range when compared with the pure diesel operation. This may be due to the difference of viscosity between the diesel and biodiesel and calorific value of the fuel. The reason might be due to (1) higher initial boiling point and different distillation characteristics, (2) higher density and viscosity leads to narrower spray cone angle and higher spray penetration tip, leading to inferior combustion compared to neat diesel [35]. However, higher density of biodiesel compensates the lower value of the heat of combustion of the biodiesel thus giving compatible performance with engine. Biodiesel contains oxygen molecule in its molecular composition. Theoretical air requirement of biodiesel was low [Table.1] and hence lower levels of oxygen were required for its combustion. Brake thermal efficiency increased with the advanced injection timing with conventional engine with the biodiesel at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment [31] in fuel spray giving higher brake thermal efficiency. Brake thermal efficiency increased at all loads when the injection timing was advanced to 31ºbTDC with the engine at the normal temperature of biodiesel. The increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with biodiesel with conventional engine could be attributed to its longer ignition delay and combustion duration [31].

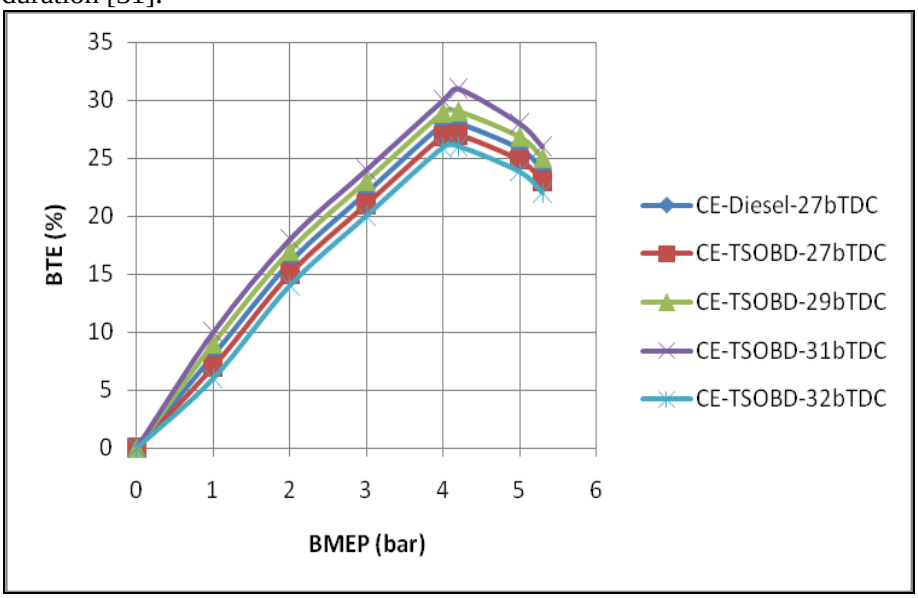


Figure 2. Variation of Brake Thermal Efficiency (BTE) With Brake Mean Effective Pressure (BMEP) in Conventional Engine (CE) at Different Injection Timings with Biodiesel (TSOBD) Operation.

Curves from Figure 2 indicate that at recommended injection timing, engine with biodiesel showed the compatible performance for entire load range when compared with the pure diesel operation. This may be due to the difference of viscosity between the diesel and biodiesel and calorific value of the fuel. The reason might be due to (1) higher initial boiling point and different distillation characteristics, (2) higher density and viscosity leads to narrower spray cone angle and higher spray penetration tip, leading to inferior combustion compared to neat diesel [35]. However, higher density of biodiesel compensates the lower value of the heat of combustion of the biodiesel thus giving

compatible performance with engine. Biodiesel contains oxygen molecule in its molecular composition. Theoretical air requirement of biodiesel was low [Table.1] and hence lower levels of oxygen were required for its combustion. Brake thermal efficiency increased with the advanced injection timing with conventional engine with the biodiesel at all loads. This was due to initiation of combustion at earlier period and efficient combustion with increase of air entrainment [31] in fuel spray giving higher brake thermal efficiency. Brake thermal efficiency increased at all loads when the injection timing was advanced to 31°bTDC with the engine at the normal temperature of biodiesel. The increase of brake thermal efficiency at optimum injection timing over the recommended injection timing with biodiesel with conventional engine could be attributed to its longer ignition delay and combustion duration [31].

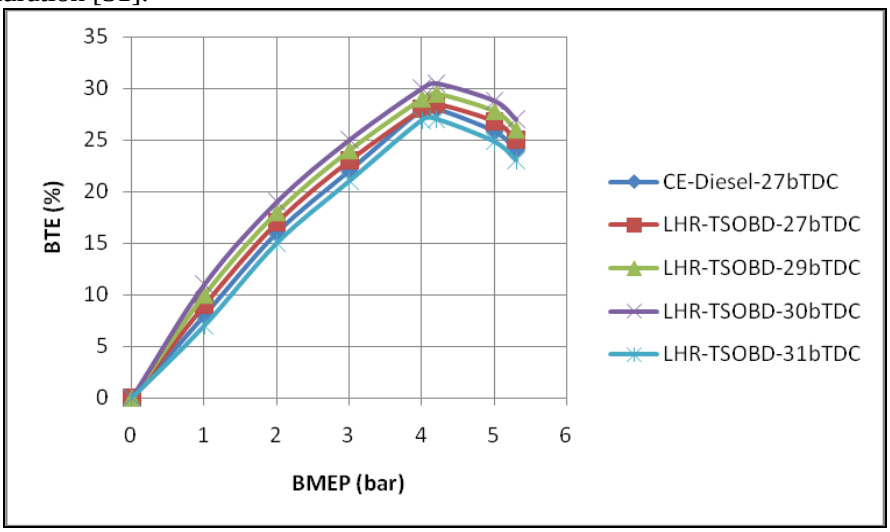


Figure 3. Variation of Brake Thermal Efficiency (BTE) with Brake Mean Effective Pressure (BMEP) in LHR Engine at Different Injection Timings With Biodiesel (TSOBD) Operation.

Part load variations were very small and minute for the performance parameters and exhaust emissions. The effect of varied injection timing on the performance was discussed with the help of bar charts while the effect of injector opening pressure and preheating of biodiesel was discussed with the help of Tables. Data of diesel was considered for comparison purpose from the literature [31].

From Figure.4, it was noticed that peak brake thermal efficiency (BTE) with LHR engine with pure diesel operation was lower in comparison with conventional engine at recommended (4%) and optimized injection timings (3%). LHR engine [31] with pure diesel operation deteriorated the performance in comparison with conventional engine. As the combustion chamber was insulated to greater extent, it was expected that high combustion temperatures would be prevalent in LHR engine. It tends to decrease the ignition delay thereby reducing pre-mixed combustion as a result of which, less time was available for proper mixing of air and fuel in the combustion chamber leading to incomplete combustion, with which peak BTE decreased. More over at this load, friction and increased diffusion combustion resulted from reduced ignition delay.

Peak BTE with LHR engine with biodiesel operation was higher in comparison with conventional engine at recommended and optimized injection timings.

This was due to higher degree of insulation provided in the piston, liner (with the provision of air gap with superni-90 inserts) and cylinder head reduced the heat rejection leading to improve the thermal efficiency. This was also because of improved evaporation rate of the biodiesel. High cylinder temperatures [31] helped in better evaporation and faster combustion of the fuel injected into the combustion chamber. Reduction of ignition delay of the vegetable oil in the hot environment of the LHR engine improved heat release rates and efficient energy utilization.

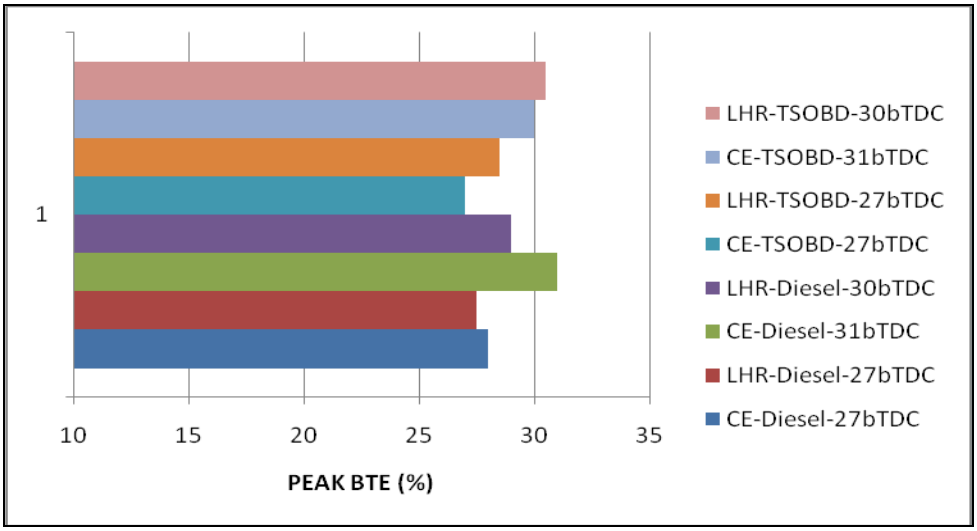


Figure. 4. Bar charts showing the variation of peak brake thermal efficiency (BTE) with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in Conventional engine and ceramic coated LHR engine.

Injector opening pressure was varied from 190 bar to 270 bar to improve the spray characteristics and atomization of the test fuels and injection timing is advanced from 27 to 34ºbTDC for CE and LHR engine. As it is observed from Table.4, peak brake thermal efficiency increased with increase in injector opening pressure at different operating conditions of the biodiesel.

For the same physical properties, as injector opening pressure increased droplet diameter decreased influencing the atomization quality, and more dispersion of fuel particle, resulting in turn in better vaporization, leads to improved air-fuel mixing rate, as extensively reported in the literature [16-18,35]. In addition, improved combustion leads to less fuel consumption.

Performance improved further with the preheated biodiesel when compared with normal biodiesel. This was due to reduction in viscosity of the fuel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil causing efficient combustion thus improving brake thermal efficiency. The cumulative heat release was more for preheated biodiesel [35] than that of biodiesel and this indicated that there was a significant increase of combustion in diffusion mode [35]. This increase in heat release [35] was mainly due to better mixing and evaporation of preheated biodiesel, which leads to complete burning.

Table4. Data of Peak Brake Thermal Efficiency (BTE) And Brake Specific Energy Consumption at Peak Load Operation

Injection Timing (º bTDC)	Test Fuel	Peak BTE (%)						Brake Specific Energy Consumption at peak load operation (kW/kW)					
		Injection Pressure (Bar)						Injection Pressure (Bar)					
		190		230		270		190		230		270	
		NT	PT	NT	PT	NT	PT	NT	PT	NT	PT	NT	PT
27(CE)	DF	28	--	29	---	30	--	4.0	--	3.96	--	3.92	--
	TSOBD	27	27.5	27.5	28	28	28.5	4.1	3.96	3.96	3.94	3.94	3.96
27(LHR)	DF	27.5	--	28	--	29	--	4.3	--	4.2	--	4.1	--
	TSOBD	**28.5**	**29**	**29**	**29.5**	**29.5**	**30**	**3.84**	**3.80**	**3.80**	**3.76**	**3.76**	**3.72**
30(LHR)	DF	29		29.5		30		3.80		3.76		3.72	
	TSOBD	**30.5**	**31**	**31**	**31.5**	**32**	**32.5**	**3.72**	**3.68**	**3.68**	**3.64**	**3.64**	**3.62**
31(CE)	DF	31		31.5		32		3.6	--	3.5	--	3.4	---
	TSOBD	**30**	**31**	**31**	**32**	**32**	**32.5**	**3.78**	**3.76**	**3.76**	**3.72**	**3.72**	**3.68**

DF- Diesel fuel, TSOBD Biodiesel, NT- Normal temperature, PT- Preheated temperature

Generally brake specific fuel consumption, is not used to compare the two different fuels, because their calorific value, density, chemical and physical parameters are different. Performance parameter, BSEC, is used to compare two different fuels by normalizing brake specific energy consumption, in terms of the amount of energy released with the given amount of fuel.

From Figure.5, it was evident that brake specific energy consumption with LHR engine with pure diesel operation was higher in comparison with conventional engine at recommended (10%) and

optimized injection timings (4%). This was due to reduction of ignition delay with pure diesel operation with LRH engine as hot combustion chamber was maintained by LHR engine.
BSEC was lower with LHR engine with biodiesel operation in comparison with conventional engine with biodiesel operation at recommended injection timing and optimum injection timing.
BSEC was higher with conventional engine due to due to higher viscosity, poor volatility and reduction in heating value of biodiesel lead to their poor atomization and combustion characteristics. The viscosity effect, in turn atomization was more predominant than the oxygen availability [35] in the blend leads to lower volatile characteristics and affects combustion process**.** BSEC was improved with LHR engine with lower substitution of energy in terms of mass flow rate.
BSEC decreased with advanced injection timing with test fuels. This was due to initiation of combustion and substitution of lower energy as seen From the Figure.6.
BSEC of biodiesel is almost the same as that of neat diesel fuel as shown in Figure.6. Even though viscosity of biodiesel is slightly higher than that of neat diesel, inherent oxygen of the fuel molecules improves the combustion characteristics. This is an indication of relatively more complete combustion [35].
From the Table.4 it is noticed that BSEC at peak load operation decreased with increase of injector opening pressure with different operating conditions of the test fuels. This was due to increase of air entrainment [35] in fuel spray giving lower BSEC.
BSEC decreased with the preheated biodiesel at peak load operation when compared with normal biodiesel. Preheating of the biodiesel reduced the viscosity, which improved the spray characteristics of the oil.

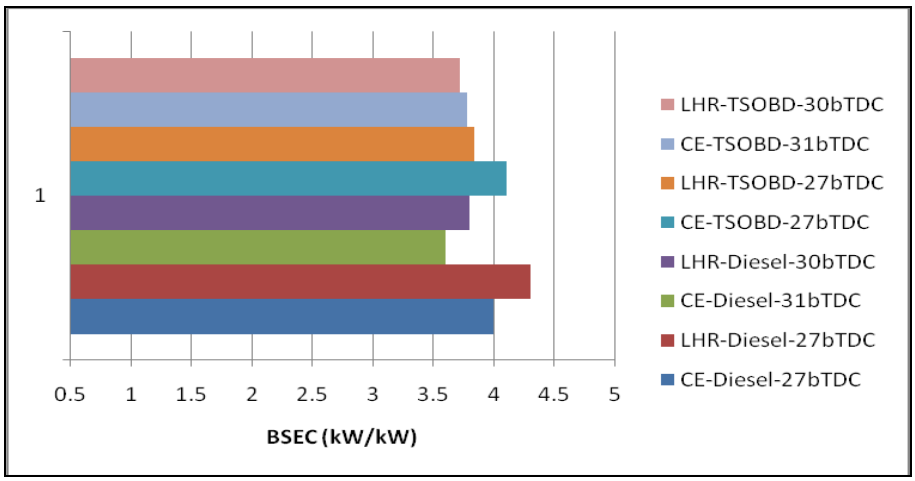


Figure. 5. Bar charts showing the variation of brake specific energy consumption (BSEC) at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar in CE and LHR engine.

From Figure.6, it was observed that exhaust gas temperature (EGT) with LHR engine with pure diesel operation was higher in comparison with conventional engine at recommended (12%) and optimized injection timings (15%).
This was due to reduction of ignition delay with pure diesel operation with LRH engine as hot combustion chamber was maintained by LHR engine. This indicated that heat rejection was restricted through the piston, liner and cylinder head, thus maintaining the hot combustion chamber as result of which the exhaust gas temperature increased.
EGT with LHR engine with biodiesel operation was marginally higher in comparison with conventional engine at recommended and optimized injection timings. This was due to reduction of ignition delay in the hot environment with the provision of the insulation in the LHR engine, which caused the gases expand in the cylinder giving higher work output and lower heat rejection.
EGT decreased with advanced injection timing with test fuels as seen from the Figure. This was because, when the injection timing was advanced, the work transfer from the piston to the gases in the cylinder at the end of the compression stroke was too large, leading to reduce in the value of EGT.

Though the calorific value (or heat of combustion) of fossil diesel is more than that of biodiesel; the density of the biodiesel was higher therefore greater amount of heat was released in the combustion chamber leading to higher exhaust gas temperature with conventional engine, which confirmed that performance was compatible with conventional engine with biodiesel operation in comparison with pure diesel operation. Similar findings were obtained by other studies [21].

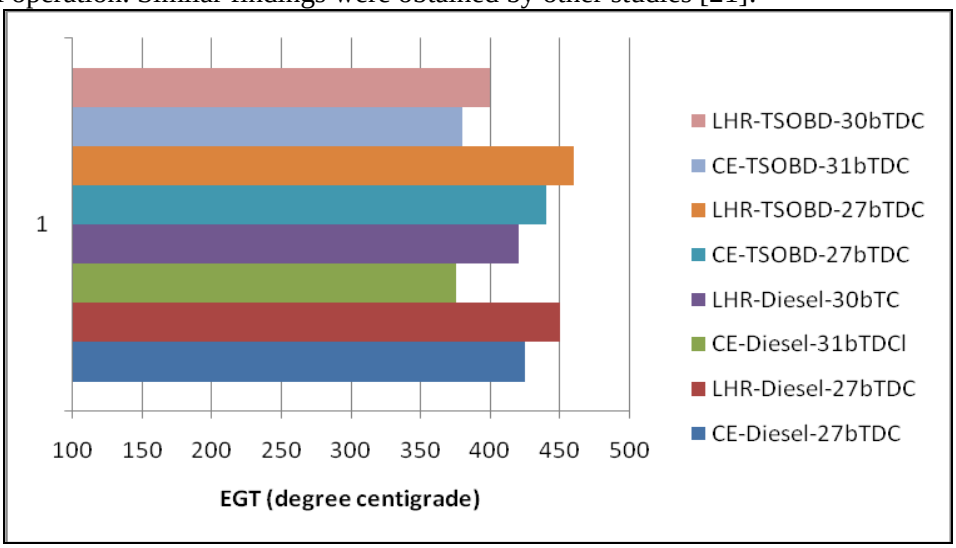


Figure. 6. Bar charts showing the variation of exhaust gas temperature (EGT) at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.

From the Table.5, it is noticed that the exhaust gas temperatures of preheated biodiesel were higher than that of normal biodiesel, which indicates the increase of diffused combustion [35] due to high rate of evaporation and improved mixing between methyl ester and air. Therefore, as the fuel temperature increased, the ignition delay decreased and the main combustion phase (that is, diffusion controlled combustion) increased [35] which in turn raised the temperature of exhaust gases. The value of exhaust gas temperature decreased with increase in injector opening pressure with test fuels as it is evident from the Table.5. This was due to improved spray characteristics of the fuel with increase of injector opening pressure.

Exhaust gas temperature was lower with diesel operation with conventional engine when compared with biodiesel operation, while EGT was lower with LHR engine with biodiesel operation in comparison with diesel operation. Hence conventional engine was more suitable for diesel operation, while LHR engine was suitable for biodiesel operation.

Table.5. Data of Exhaust Gas Temperature (EGT) and Coolant Load at Peak Load Operation

Injection Timing (º bTDC)	Test Fuel	EGT at peak load operation (degree centigrade)						Coolant load at peak load operation (kW)					
		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	425	--	410	---	395	--	4.0	---	4.2	--	4.4	---
	TSOBD	440	460	425	450	400	425	4.2	4.0	4.4	4.2	4.6	4.4
27(LHR)	DF	**450**	--	**430**	--	**410**	--	3.8	--	3.6	--	3.4	--
	TSOBD	**460**	**480**	**440**	**460**	**420**	**440**	3.6	3.4	3.4	3.2	3.2	3.0
30(LHR)	DF	420	--	400	--	380	--	3.6		3.8		4.0	
	TDOBD	400	420	386	405	360	380	3.4	3.2	3.2	3.0	3.0	2.8
31(CE)	DF	375	---	350	---	325	--	4.2	--	4.4	--	4.6	---
	TSOBD	380	410	370	390	350	370	4.4	4.2	4.6	4.4	4.8	4.6

DF- Diesel fuel, TSOBD Biodiesel, NT- Normal temperature, PT- Preheated temperature

Figure 7 indicates that coolant load with LHR engine with pure diesel operation was lower (5% and 14%) at recommended and optimized injection timings respectively in comparison with conventional engine. This was due insulation provided with LHR engine. Coolant load with LHR engine with biodiesel operation was lower at recommended and optimized injection timings respectively in

comparison with conventional engine. This was due insulation provided with LHR engine. In case of conventional engine, un-burnt fuel concentration reduced with effective utilization of energy, released from the combustion, coolant load with test fuels increased marginally at peak load operation, due to un-burnt fuel concentration reduced with effective utilization of energy, released from the combustion, with increase of gas temperatures, when the injection timing was advanced to the optimum value. However, the improvement in the performance of the conventional engine was due to heat addition at higher temperatures and rejection at lower temperatures, while the improvement in the efficiency of the LHR engine was due to recovery from coolant load at their respective optimum injection timings with test fuels. Murali Krishna [31] noticed the similar trend at optimum injection timing with his LHR engine.

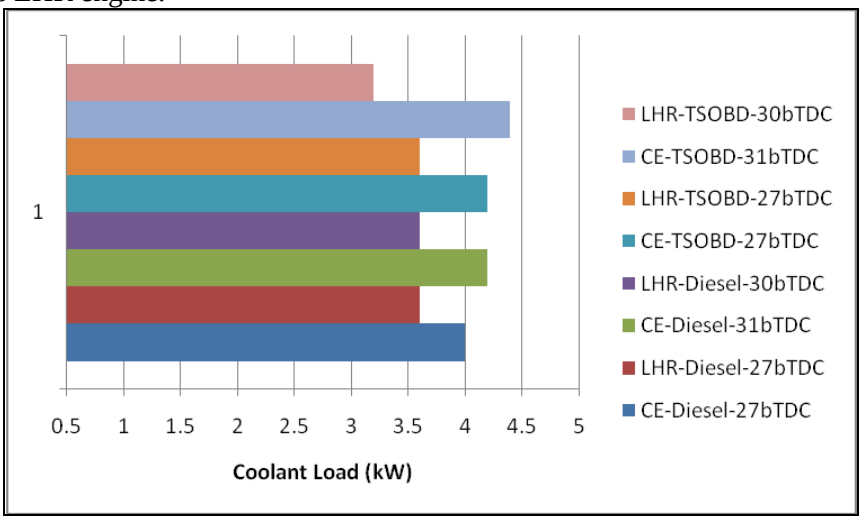


Figure. 7. Bar charts showing the variation of coolant load at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.

From Table.5, it is seen that coolant load increased marginally in the conventional engine while it decreased in the LHR engine with increasing of the injector opening pressure with test fuels. This was due to the fact with increase of injector opening pressure with conventional engine, increased nominal fuel spray velocity resulting in better fuel-air mixing with which gas temperatures increased. The reduction of coolant load in the LHR engine was not only due to the provision of the insulation but also it was due to better fuel spray characteristics and increase of air-fuel ratios causing decrease of gas temperatures and hence the coolant load.

Coolant load decreased marginally with preheating of biodiesel. This was due to improved air fuel ratios [31] with improved spray characteristics.

Figure 9 denotes that sound levels were higher (12% and 23%) with LHR engine with pure diesel operation at recommended and optimized injection timings respectively in comparison with conventional engine. This showed that performance deteriorated with LHR engine with pure diesel operation. This was due to reduction of ignition delay.

Sound levels were lower with LHR engine with biodiesel operation at recommended and optimized injection timings respectively in comparison with conventional engine. This showed that performance improved with LHR engine with biodiesel operation.

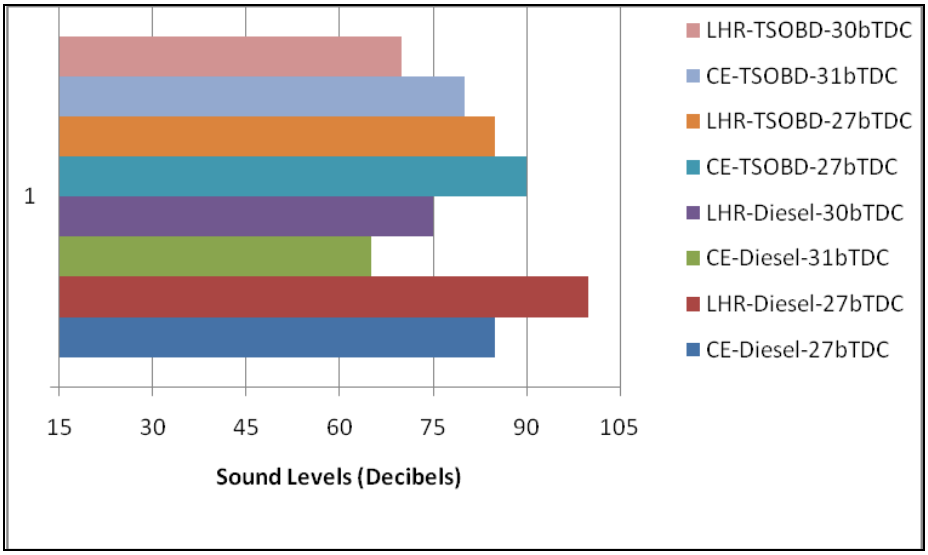


Figure. 9. Bar charts showing the variation of sound levels at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.

With advanced injection timings, air fuel ratios improved with early initiation of combustion hence sound levels got reduced with both versions of the engine with test fuels.

Table 6 denotes that the Sound levels decreased with increase of injector opening pressure with the test fuels. This was due to improved spray characteristic of the fuel, with which there was no impingement of the fuel on the walls of the combustion chamber leading to produce efficient combustion.

Sound intensities were lower at preheated condition of preheated biodiesel when compared with their normal condition. This was due to improved spray characteristics, decrease of density and viscosity of the fuel.

Table.6. Data of Sound Levels and Volumetric Efficiency with Test Fuels at Peak Load Operation.

Injection Timing (º bTDC)	Test Fuel	Sound Levels at peak load operation (Decibels)						Volumetric Efficiency (%) at peak load operation					
		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	85	--	80	--	95	--	85	--	86	--	87	--
	TSOBD	90	85	85	80	80	70	83	82	84	83	85	84
27(LHR)	DF	100	--	95	--	90	--	80		81		82	
	TSOBD	85	80	80	75	75	70	81	82	82	83	83	84
30 (LHR)	DF	75		70		65		81		82		83	
	TSOBD	70	65	65	60	60	55	82	82	83	84	84	85
31(CE)	DF	65	--	60	--	55	--	89	--	90	--	91	--
	TSOBD	80	75	75	70	70	65	87	88	87	89	88	87

DF- Diesel fuel, TSOBD Biodiesel, NT- Normal temperature, PT- Preheated temperature

Volumetric efficiency depends on density of the charge which intern depends on temperature of combustion chamber wall. Figure 8 denotes that volumetric efficiency were lower (8% and 11%) with LHR engine with pure diesel operation at recommended and optimized injection timings respectively in comparison with conventional engine.

Volumetric efficiency in the LHR engine decreased at peak load operation when compared to the conventional engine at recommended and optimized injection timing with test fuels. This was due increase of temperature of incoming charge in the hot environment created with the provision of insulation, causing reduction in the density and hence the quantity of air. However, this variation in volumetric efficiency is very small between these two versions of the engine, as volumetric efficiency mainly depends [20] on speed of the engine, valve area, valve lift, timing of the opening or closing of

valves and residual gas fraction rather than on load variation. Murali Krishna [35] also observed the similar trends in the value of volumetric efficiency.

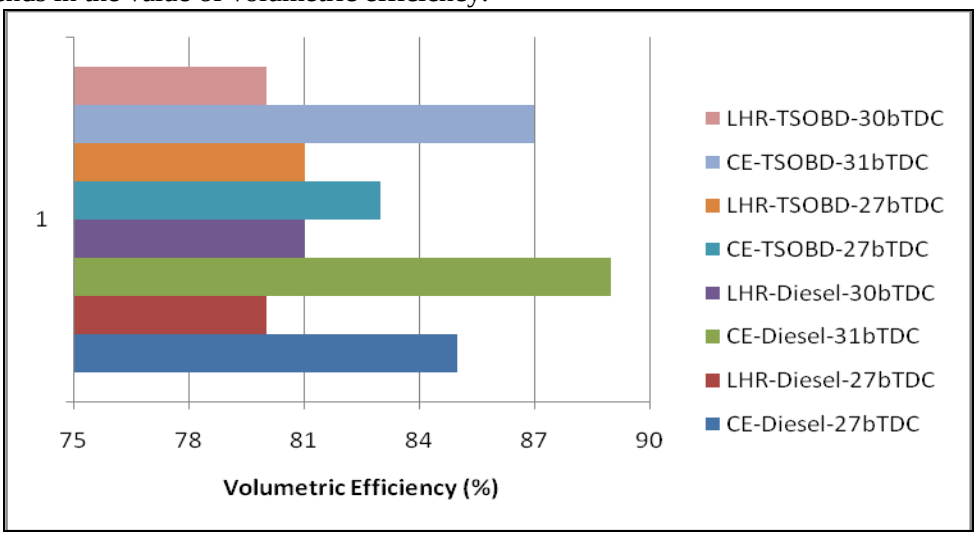


Figure. 8. Bar charts showing the variation of volumetric efficiency at peak load operation with test fuels at recommended and optimized injection timings at an injector opening pressure of 190 bar.

Volumetric efficiency was higher with pure diesel operation at recommended and optimized injection timing with conventional engine in comparison with biodiesel operation. This was due to increase of combustion chamber wall temperatures with biodiesel operation due to accumulation of un-burnt fuel concentration. This was also because of increase of combustion chamber wall temperature as exhaust gas temperatures increased with biodiesel operation in comparison with pure diesel operation.
Volumetric efficiency increased marginally with both versions of the engine with test fuels with advanced injection timing. This was due to decrease of combustion chamber wall temperatures with improved air fuel ratios [34].
From Table-6, it is evident that volumetric efficiency increased with increase of injector opening pressure with test fuels. This was due to improved fuel spray characteristics and evaporation at higher injection pressures leading to marginal increase of volumetric efficiency. This was also because of decrease of exhaust gas temperatures and hence combustion chamber wall temperatures. This was also due to the reduction of residual fraction of the fuel, with the increase of injector opening pressure.
Preheating of the biodiesel marginally decreased volumetric efficiency, when compared with the normal temperature of biodiesel, because of reduction of bulk modulus, density of the fuel and increase of exhaust gas temperatures.

IV. CONCLUSIONS

Peak BTE with LHR engine with biodiesel operation was higher in comparison with conventional engine at recommended (4%) and optimized injection timings (3%).
BSEC was lower with LHR engine with biodiesel operation in comparison with conventional engine with biodiesel operation at recommended injection timing (7%) and optimum injection timing (4%).
EGT with LHR engine with biodiesel operation was marginally higher in comparison with conventional engine at recommended (5%) and optimized injection timings (11%).
Coolant load with LHR engine with biodiesel operation was lower (19% and 27%) at recommended and optimized injection timings respectively in comparison with conventional engine. This was due insulation provided with LHR engine.
Sound levels were lower (11% and 12%) with LHR engine with biodiesel operation at recommended and optimized injection timings respectively in comparison with conventional engine.
Volumetric efficiencies were lower (5% and 8%) with LHR engine with biodiesel operation at recommended and optimized injection timings respectively in comparison with conventional engine.
Increase of injection pressure with both versions of the engine with test fuels.

Peak brake thermal efficiency increased. At peak load operation- brake specific energy consumption decreased, exhaust gas temperature decreased, volumetric efficiency increased, coolant load increased (CE), and sound levels decreased.

With preheating of biodiesel with both versions of the engine-Peak brake thermal efficiency increased, at peak load operation- brake specific energy consumption decreased, exhaust gas temperature increased(CE), volumetric efficiency decreased(CE), coolant load decreased, sound levels decreased.

LHR engine was more suitable for biodiesel operation than pure diesel operation.

V. FUTURE SCOPE OF WORK

The effect of injection timing and increase of injector opening pressure on exhaust emissions and combustion characteristics with LHR engine with tobacco seed oil based biodiesel operation are to be determined.

ACKNOWLEDGEMENTS

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

REFERENCES

[1]. Matthias Lamping, Thomas Körfer, Thorsten Schnorbus, Stefan Pischinger, Yunji Chen : Tomorrows Diesel Fuel Diversity – Challenges and Solutions", SAE 2008-01—1731

[2]. Agarwal, A.K (2006)" Bio-fuels (alcohols and biodiesel) applications as fuels for internal combustion engines", International Journal Energy Combustion Science, Vol.33, pp.233-271

[3]. Acharya, S.K., Swain, R.K. and Mohanti, M.K. (2009) "The use of rice bran oil as a fuel for a small horse- power diesel engine", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol.33 (1), pp.80-88.

[4]. Venkanna, B.K., Venkataramana Reddy,C., Swati B. and Wadawadagi. (2009) "Performance, emission and combustion characteristics of direct injection diesel engine running on rice bran oil / diesel fuel blend", International Journal of Chemical and Biological Engineering, Vol.2 (3), pp.131-137.

[5]. Devan, P.K. and Mahalakshmi, N.V. (2009)"Performance, emission and combustion characteristics of poon oil and its blends in a DI diesel engine", Fuel, Vol.88, pp.861-870.

[6]. Misra, R.D., Murthy, M.S. (2010) "Straight vegetable oils usage in a compression ignition engine—A review", Renewable and Sustainable Energy Reviews, Vol. 14, pp. 3005–3013.

[7]. Bari, S., Lim, T.H.,Yu, C.W.(2002 "Effect of preheating of crude palm oil on injection system performance and emission of a diesel engine", Renewable Energy, Vol.27 (3), pp. 339-351.

[8]. Senthil Kumar, M., Kerihuel, A., Bellettre, J. and Tazerout, M. (2005) "Experimental investigations on the use of preheated animal fat as fuel in a compression ignition engine". Renewable Energy, Vol.30, pp.2314- 2323.

[9]. Agarwal, D., Agarwal, A.K. (2007) "Performance and emissions characteristics of jatropha oil (preheated and blends) in a direct injection compression ignition engine". Int. J. Applied Thermal Engineering,

[10]. Vol.27, pp.2314-23.

[11]. Hanbey Hazar and Huseyin Aydin. (2010) "Performance and emission evaluation of a CI engine fueled with preheated raw rapeseed oil (RRO)-diesel blends", Applied Energy, Vol.87, pp.786-790.

[12]. Venkatramn. And Devaradjane, G. (2010) "Experimental investigation of performance and emission characteristics of diesel-pongamia oil, methyl esters diesel blends fueled DI engine at optimum engine operating parameters", International Journal of Green energy and env, Vol.1, pp.7-12.

[13]. Rambabu Kantipudi, Appa Rao, B.V., Hari Babu.N and Satyanarayana,.Ch. (2010) "Studies on DI diesel engine fueled with rice brawn methyl ester injection and ethanol carburetion", International Journal of Applied Engineering Research, Dindigul, Vol.1(1), pp.61-67.

[14]. Rasim, B. (2011) "Performance and emission study of waste anchovy fish biodiesel in a diesel engine", Fuel Processing Technology, Vol.92, pp.1187-1194.

[15]. Murugesan, A., Umarani, C., Subramanian, R., Nedunchezhian, N. (2009).Bio-diesel as an alternate fuel for diesel engines. Renewable and Sustainable Energy Reviews, 13(3), 653-662.

[16]. Jaichandar, S. and Annamalai, K. (2011) "The status of biodiesel as an alternative fuel for diesel engine-An Overview", Journal of Sustainable Energy & Environment, Vol.2, pp.71-75

[17]. Ridvan Arslan. (2011). "Emission characteristics of a diesel engine using waste cooking oil as a bio-diesel fuel", African Journal of Bio-Technology, pp.3790-3794.

[18]. Celikten, I. (2003) "An experimental investigation of the effect of the injection pressure on the engine performance and exhaust emission in indirect injection diesel engines", Applied Thermal Engineering, Vol.23, pp.2051–2060.

[19]. Cingur, Y., & Altiparmak, D. (2003) "Effect of cetane number and injection pressure on a DI diesel engine performance and emissions", Energy Conversion and Management, Vol.44, pp.389–397.

[20]. Hountalas, D.T., Kouremenos, D.A., Binder, K.B., Schwarz, V., & Mavropoulos, G.C. (2003) "Effect of injection pressure on the performance and exhaust emissions of a heavy duty DI diesel engine", SAE Technical Paper No. 2003-01-0340. Warrendale, PA.

[21]. Venkanna, B.K., & Venkataramana, R.C. (2010) "Influence of fuel injection rate on the performance, emission and combustion characteristics of DI diesel engine running on calophyllum nophyllum linn oil (honne oil)/diesel fuel blend", SAE Technical Paper No. 2010- 01-1961.

[22]. Heywood, J.B. (1988) "Fundamentals of Internal Combustion Engines", Tata McGraw Hill New York.

[23]. Chandrakasan Solaimuthu and Palani Swamy Govindaraju (2012) "Effect of injection timing on performance, combustion and emission characteristics of diesel engine using mahua oil methyl ester", Journal of Scientific and Industrial Research, Vol.71, pp.69-74.

[24]. Ratna Reddy, T., Murali Krishna, M.V.S., Kesava Reddy, Ch and Murthy, P.V.K. (2012) "Performance evaluation of Mohr oil based biodiesel in low grade low heat rejection dieselengine", International Journal of Innovative Research in Science, Engineering and Technology, Vol.1 (1), pp. 80- 94.

[25]. Murali Krishna, M.V.S., Durga Prasada Rao, N., Anjeneya Prasad, B. and Murthy, P.V.K (2013) "Improving of emissions and performance of rice brawn oil in medium grade low heat rejection diesel engine", International Journal of Renewable Energy Research, Vol.3 (1), pp.98-108.

[26]. Janardhan, N., Murali Krishna, M.V.S., Ushasri, P. and Murthy, P.V.K. (2013) "Comparative performance, emissions and combustion characteristics of jatropha oil in crude form and biodiesel form in a medium grade low heat rejection diesel engine", International Journal of Soft Computing and Engineering, International Journal of Innovative Technology and Exploring Engineering, Vol.2(5), pp.5-15.

[27]. Parlak, A., Yasar, H., ldogan O. (2005) "The effect of thermal barrier coating on a turbocharged Diesel engine performance and exergy potential of the exhaust gas", Energy Conversion and anagement, Vol.46 (3), pp.489–499.

[28]. Ekrem, B., Tahsin, E., Muhammet, C. (2006) "Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments", Journal of Energy Conversion and Management, Vol.47, pp.1298-1310.

[29]. Ciniviz, M., Hasimoglu, C., Sahin, F., Salman, M. S. (2008) "Impact of thermal barrier coating application on the performance and emissions of a turbocharged diesel engine", Proceedings of Institution of Mechanical Engineers Part D-Journal Of Automobile Eng, Vol.222 (D12), Pp.2447-2455.

[30]. Murali Krishna, M.V.S., Chowdary, R.P., Reddy, T.K.K and Murthy,P.V.K.. (2012) "Performance evaluation of waste fried vegetable oil in la low grade low heat rejection diesel engine", International Journal of Research in Mechanical Engineering and Technology, Vol.2 (2), pp.35-43.

[31]. Kesava Reddy, Ch., Murali Krishna, M.V.S., Murthy, P.V.K. and Ratna Reddy,T.(2012) "Performance evaluation of a low grade low heat rejection diesel engine with crude jatropha oil", International Scholarly Research Network (ISRN) Renewable Energy (USA), Article ID 489605, pp.1-10.

[32]. Ratna Reddy, T., Murali Krishna, M.V.S., Kesava Reddy, Ch. and Murthy, P.V.K. (2012) "Comparative performance of ceramic coated diesel engine with mohr oil in crude and biodiesel form", International Journal of Engineering and Advanced Technology, (CSIR, Vol.2 (3), pp.588-596.

[33]. Murali Krishna, M.V.S. (2004) Investigations on LHR diesel engine with alternative fuels. Ph.D Thesis, J.N.T. University, Hyderabad.

[34]. Velikovic, V.B., Lakicevic, S.H., Stamenkovic, O.S., Todorovic, Z.B. and Lazic., M.L. (2006) "Biodiesel production from tobacco seed oil (nicatiana tabacom.L) seed oil wit high content of free fatty Acids", Fuel, Vol.85, pp.17-18,

[35]. Tapasvi D, Wiesenborn D, Gustafson C (2005) "Process Model for Biodiesel Production from various Feedstock's", Trans. ASAE,, Vol.48 (6), pp.2215- 2221.

[36]. Jindal S, Bhagwati PN, Narendra SR (2010) "Comparative Evaluation of Combustion, "Performance and Emissions of Jatropha Methyl Ester and Karanja Methyl Ester in a Direct Injection Diesel Engine", Energy Fuels, Vol. 24, Pp.1565-1572.

[37]. Rao, P.V. (2011) "Effect of properties of Karanja methyl ester on combustion and NOx emissions of a diesel engine", Journal of Petroleum Technology and Alternative Fuels, Vol. 2(5), 63-75.

AUTHORS

N. Venkateswar Rao did his B.Tech and ME in CAD/CAM, working as assistant Professor in CBIT, Hyderabad. He put up more than 14 years teaching experience. Presently he is doing his PhD in alternative fuels. He attended several national and international conferences.

M. V. S. Murali Krishna did his B.Tech from Andhra University and M.Tech from Osmania University, Hyderabad and completed his PhD in Thermal Engineering from JNT University, Hyderabad. . Presently he is working as Professor in CBIT, Hyderabad. He published more than 120 papers in National and International Journals and attended several national and international seminars. He guided more than 200 under graduate students, 60 Post graduate students. Presently he is guiding 9 PhD Scholars. He is a life member of Combustion Institute (Indi), Fellow of Institute of Engineers (India) and Chartered Engineer (India) and member of several well known bodies. He had undertaken several projects.

P. V. Krishna Murthy did his AMIE (India) in Mechanical Engineering in 1983 and M.Tech (Production Engineering) for JNT University, Hyderabad and completed PhD in Thermal Engineering from JNT University, Hyderabad in 2010. Presently he is working as Director/Principal of Integrated campus of JPNES, Mahabubnagar, Andhra Pradesh. He published more than 90 papers in National and International Journals and attended several national and international seminars. He guided more than 100 under graduate students, 20 Post graduate students. Presently he is guiding 3 PhD Scholars. He is a life member of Combustion Institute (India), Fellow of Institute of Engineers (India) and Chartered Engineer (India)