

Research Article

Impact of Injection Pressure on Performance Parameters of High Grade Semi Adiabatic Diesel Engine with Cotton Seed Biodiesel

D. Srikanth[†], M.V.S. Murali Krishna^{*†} and P. Usha Sri[†]

[†]Department of Mechanical Engineering, Sagar Group of Educational Institutions, Chevella, Hyderabad- 501503, Telangana State, I, India

^{*}Department of Mechanical Engineering, Chaitanya Bharathi Institute of Technology, Hyderabad- 500 075, Telangana India

[†]Department of Mechanical Engineering, College of Engineering, Osmania University, Hyderabad- 500007, Telangana State, India

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Abstract

As a renewable, sustainable and alternative fuel for compression ignition engines, biodiesel instead of diesel has been increasingly fueled to study its effects on engine performances and emissions in the recent 10 years. But these studies have been rarely reviewed to favor understanding and popularization for biodiesel so far in conventional diesel engines. Biodiesels derived from vegetable oils present a very promising alternative for diesel fuel, since they have numerous advantages compared to fossil fuels. They are renewable, biodegradable, provide energy security and foreign exchange savings besides addressing environmental concerns and socio-economic issues. However drawbacks associated with biodiesel of high viscosity and low volatility which cause combustion problems in CI engines, call for engine with hot combustion chamber. They have significant characteristics of higher operating temperature, maximum heat release, and ability to handle low calorific value fuel. Investigations were carried out to evaluate the performance with low heat rejection combustion chamber with cotton seed biodiesel with varied injection pressure. It consisted of an air gap insulated piston, an air gap insulated liner and ceramic coated cylinder head cotton seed biodiesel with varied injector opening pressure. Comparative studies were made for engine with LHR combustion chamber and CE at manufacturer's recommended injection timing (27° bTDC) with biodiesel operation. Engine with LHR combustion chamber with biodiesel showed improved performance at 27° bTDC over CE.

Keywords: Vegetable oil, Biodiesel; LHR combustion chamber; Fuel performance

1. Introduction

Fossil fuels are limited resources; hence, search for renewable fuels is becoming more and more prominent for ensuring energy security and environmental protection. It has been found that the vegetable oils are promising substitute for diesel fuel, because of their properties are comparable to those of diesel fuel. They are renewable and can be easily produced. When Rudolph Diesel, first invented the diesel engine, about a century ago, he demonstrated the principle by employing peanut oil. He hinted that vegetable oil would be the future fuel in diesel engine [Acharya *et al*, 2009.]. 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. It caused the problems of piston ring sticking, injector and combustion chamber deposits, fuel system deposits, reduced power, reduced fuel economy and increased exhaust emissions [[Acharya *et*

al, 2009; Venkanna *et al*, 2009; Misra *et al*, 2010; Soo-Young *et al*, 2011; Avinash Kumar Agarwal *et al*, 2013] The problems of crude vegetable oils can be solved to some extent, if these oils are chemically modified (esterified) to biodiesel. Studies were made with biodiesel on CE [[Rakopoulos, *et al*, 2008; McCarthy *et al*, 2011; Anirudh Gautam *et al*, 2013; Krishna *et al*, 2014; Durga Prasada Rao *et al*, 2014]. They reported from their investigations that biodiesel operation showed comparable thermal efficiency, decreased particulate emissions and increased nitrogen oxide (NO_x) levels, when compared with mineral diesel operation.

Increased injector opening pressure may also result in efficient combustion in compression ignition engine [Celikten, 2003; Avinash Agarwal *et al*, 2013]. It has a significance effect on performance and formation of pollutants inside the direct injection diesel engine combustion. Experiments were conducted on engine with biodiesel with increased injector opening pressure. They reported that performance of the engine was improved, particulate emissions were reduced and NO_x levels were increased marginally with an increase of injector opening pressure.

*Corresponding author: M.V.S. Murali Krishna

Table.1 Properties of test fuels

Property	Units	Diesel (DF)	Biodiesel(BD)	ASTM Standard
Carbon Chain	--	C ₈ -C ₂₈	C ₁₆ -C ₂₄	---
Cetane Number	-	51	56	ASTM D 613
Specific Gravity at 15°C	-	0.8275	0.8673	ASTM D 4809
Bulk Modulus at 15°C	MPa	1408.3	1564	ASTM D 6793
Kinematic Viscosity @ 40°C	cSt	2.5	5.44	ASTM D 445
Air Fuel Ratio (Stoichiometric)	--	14.86	13.8	--
Flash Point (Pensky Marten's Closed Cup)	°C	120	144	ASTM D93
Cold Filter Plugging Point	°C	Winter 6° C Summer 18°C	3° C	ASTM D 6371
Pour Point	°C	Winter 3°C Summer 15°C	0°C	ASTM D 97
Sulfur	(mg/kg, max)	50	42	ASTM D5453
Low Calorific Value	MJ/kg	42.0	39.9	ASTM D 7314
Oxygen Content	%	0.3	11	--

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 with provision of thermal resistance in the path of heat flow to the coolant. Three approaches that are being pursued to decrease heat rejection are (1) Coating with low thermal conductivity materials on crown of the piston, inner portion of the liner and cylinder head (low grade LHR combustion chamber); (2) air gap insulation where air gap is provided in the piston and other components with low-thermal conductivity materials like superni (an alloy of nickel), cast iron and mild steel (medium grade LHR combustion chamber); and (3) high grade LHR engine contains air gap insulation and ceramic coated components.

Experiments were conducted on engine with high grade LHR combustion chamber with biodiesel. It consisted of an air gap (3 mm) insulation in piston as well as in liner and ceramic coated cylinder head. The engine was fuelled with biodiesel with varied injector opening pressure and injection timing [Krishna Murthy, 2010; Ratna Reddy *et al*, 2012; Janardhan *et al*, 2012; Venkateswara Rao *et al*, 2013; Murali Krishna *et al*, 2013; Subba Rao *et al*, 2013]. They reported from their investigations, that engine with LHR combustion chamber at an optimum injection timing of 28° bTDC with biodiesel increased brake thermal efficiency by 10–12%, at full load operation–decreased particulate emissions by 45–50% and increased NO_x levels, by 45–50% when compared with mineral diesel operation on CE at 27° bTDC.

The present paper attempted to determine the performance of the engine with high grade LHR combustion chamber. It contained an air gap (3.2 mm) insulated piston, an air gap (3.2 mm) insulated liner and ceramic coated cylinder head with cotton seed biodiesel with varied injector opening pressure. Results were compared with CE with biodiesel and also with diesel at similar operating conditions.

2. Material and method

Cottonseeds have approximately 18% (w/w) oil content. India's cottonseed production is estimated to be around 35% of its cotton output (approximately 4.5millionmetric tons). Approximately 0.30 million metric ton cottonseed oil is produced in India and it is an attractive biodiesel feedstock.

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 crude cotton seed oil with methanol in the presence of a catalyst (KOH). A two-stage process was used for the esterification of the crude cotton seed oil [Avinash Kumar Agarwal *et al*, 2013]. 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. Molar ratio of cotton seed oil to methanol was 9:1 and 0.75% catalyst (w/w). 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 (biodiesel) 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 properties of the Test Fuels used in the experiment were presented in Table-1. [Avinash Kumar Agarwal *et al*, 2013].

2.3 Engine with LHR combustion chamber

Fig.1 shows assembly details of insulated piston, insulated liner and ceramic coated cylinder head. Engine with LHR combustion chamber contained a two-part piston ; the top crown made of superni was screwed to aluminium body of the piston, providing an air gap (3.2 mm) in between the crown and the body of the piston by placing a superni gasket in between the body and crown of the piston. A superni insert was screwed to the top portion of the liner in such a manner that an air gap of 3.2 mm was maintained between the insert and the liner body.

Table.2 Specifications of 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
Engine Displacement	553 cc
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 at full load	5.31 bar
Manufacturer’s recommended injection timing and injector opening pressure	27°bTDC × 190 bar
Number of holes of injector and size	Three × 0.25 mm
Type of combustion chamber	Direct injection type

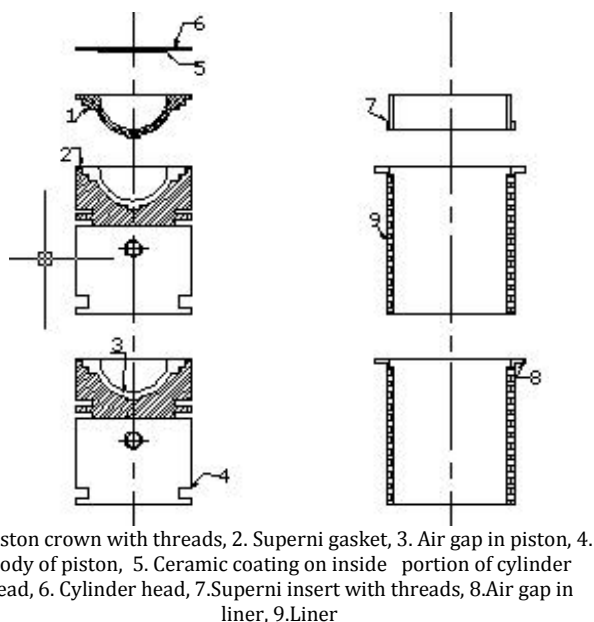


Fig.1 Assembly details of air gap insulated piston, air gap insulated liner and ceramic coated cylinder head

At 500°C the thermal conductivity of superni and air are 20.92 and 0.057 W/m-K. Partially stabilized zirconium (PSZ) of thickness 500 microns was coated by means of plasma coating technique. The combination of low thermal conductivity materials of air, superni and PSZ provide sufficient insulation for heat flow to the coolant, thus resulting in LHR combustion chamber.

2.4 Experimental set-up

The schematic diagram of the experimental setup used for the investigations on the engine with LHR combustion chamber with cotton seed biodiesel is shown in Fig.2. Specifications of Test engine are given in Table 2.

The engine was coupled with an electric dynamometer (Kirloskar), which was loaded by a loading rheostat. The fuel rate was measured by Burette. The accuracy of brake thermal efficiency obtained is ±2%. Air-consumption of the engine was obtained with an aid of air box, orifice flow meter and

U-tube water manometer assembly. 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%.

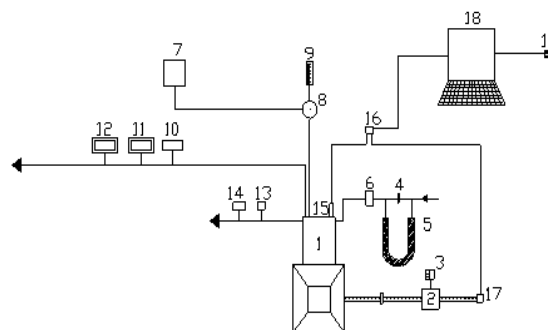


Fig.2 Schematic diagram of experimental set-up

1.Four Stroke Kirloskar Diesel Engine, 2.Kirloskar Electrical 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 opacity meter, 12. Netel Chromatograph NO_x Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter, 15.AVL Austria Piezo-electric pressure transducer, 16.Console, 17.AVL Austria TDC encoder, 18.Personal Computer and 19. Printer

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. Injector opening pressure was changed from 190 bar to 270 bar 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%.

3. Results and discussion

3.1 Performance Parameters

Fig.3 presents bar charts showing the variation of peak brake thermal efficiency with both versions of the engine at recommended injection timing and pressure with biodiesel operation. It showed that CE with biodiesel at 27° bTDC showed comparable performance. The presence of oxygen in fuel composition might have improved performance with biodiesel operation, when compared with diesel operation on CE at 27° bTDC. CE with biodiesel operation at 27° bTDC decreased peak BTE by 3%, when compared with diesel operation on CE. Low calorific value and high viscosity of biodiesel might have showed comparable performance with biodiesel operation in comparison with neat diesel.

From Fig.3, it is observed that at 27° bTDC, engine with LHR combustion chamber with biodiesel showed the comparable performance when compared with diesel operation on CE. High cylinder temperatures helped in improved evaporation and faster combustion of the fuel injected into the combustion chamber.

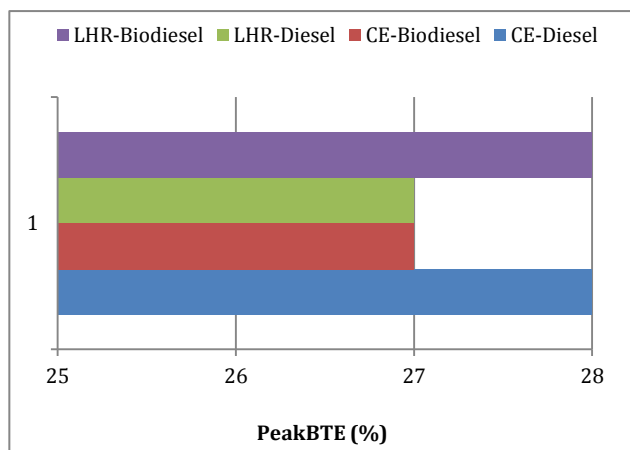


Fig.3 Bar charts showing the variation of peak brake thermal efficiency (BTE) with test fuels with both versions of the engine at recommended injector opening pressure of 190 bar

Reduction of ignition delay of the biodiesel in the hot environment of the engine with LHR combustion chamber might have improved heat release rates.

Engine with LHR combustion chamber with biodiesel operation increased peak BTE by 14% in comparison with same configuration of the engine with diesel operation. This showed that engine with LHR combustion chamber was more suitable for biodiesel.

Fig.4 presents bar charts showing the variation of brake specific energy consumption (BSEC) at full load with test fuels. BSEC was comparable with biodiesel with CE at 27° bTDC when compared with CE with diesel operation at 27° bTDC. Improved combustion with higher cetane number and presence of oxygen in fuel composition with higher heat release rate with

biodiesel may lead to produce comparable BSEC at full load. Engine with LHR combustion chamber with biodiesel decreased BSEC at full load operation by 6% at 27° bTDC when compared diesel operation with engine with LHR combustion chamber at 27° bTDC. This once again confirmed that engine with LHR combustion chamber was more suitable for biodiesel operation than neat diesel operation. Engine with LHR combustion chamber with biodiesel decreased BSEC at full load operation by 3% at 27° bTDC in comparison with CE at 27° bTDC. Improved evaporation rate and higher heat release rate of fuel with LHR combustion chamber might have improved the performance with LHR engine.

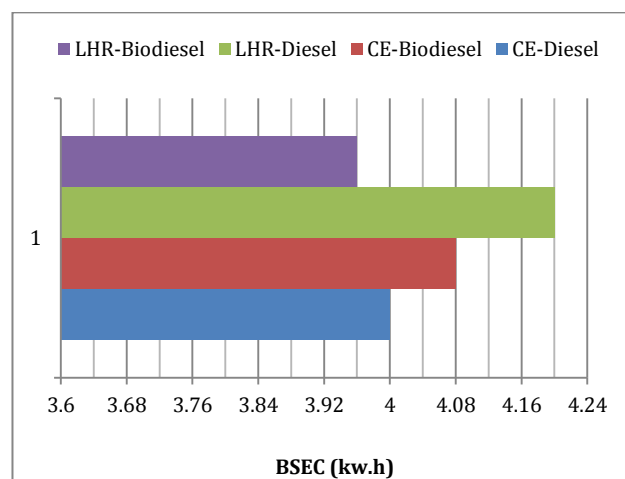


Fig.4.Bar charts showing the variation of brake specific energy consumption (BSEC) at full load operation with test fuels with both versions of the engine at recommended injection timing at an injector opening pressure of 190 bar

Fig.5 presents bar charts showing variation of exhaust gas temperature (EGT) at full load with test fuels. CE with biodiesel operation increased EGT at full load operation by 6% at 27° bTDC in comparison with CE with neat diesel operation at 27 ° bTDC. Though calorific value (or heat of combustion) of biodiesel is lower than that of diesel, density of biodiesel is higher, therefore greater amount of heat was released in the combustion chamber leading to produce higher EGT at full load operation with biodiesel operation than neat diesel operation. This was also because of higher duration of combustion of biodiesel causing retarded heat release rate. From Fig.5, it is noticed that engine with LHR combustion chamber with biodiesel operation increased EGT at full load operation by 5% at 27° bTDC when compared with diesel operation on same configuration of the engine at 27° bTDC. High duration of combustion due to high viscosity of biodiesel in comparison with diesel might have increased EGT at full load. Engine with LHR combustion chamber with biodiesel increased EGT at full load operation by 17% at 27° bTDC in comparison with CE at 27° bTDC.

Table.3 Comparative data on Peak Brake Thermal Efficiency, Brake Specific Energy Consumption and Exhaust Gas Temperature at full load

IT/ Combustion Chamber Version	Test fuel	Peak Brake Thermal Efficiency (%)		Brake Specific Energy consumption at full load operation (kW.h)		Exhaust Gas Temperature (°C) at full load operation	
		Injector opening pressure (bar)		Injector opening pressure (bar)		Injector opening pressure (bar)	
		190	270	190	270	190	270
27(CE)	DF	28	30	4.0	3.84	425	395
	BD	27	29	4.08	4.0	450	425
27(LHR)	DF	27	29	4.2	4.12	500	450
	BD	28	30	3.96	3.88	525	475

This indicated that heat rejection was restricted through the piston, liner and cylinder head, thus maintaining the hot combustion chamber as result of which EGT at full load operation increased with reduction of ignition delay.

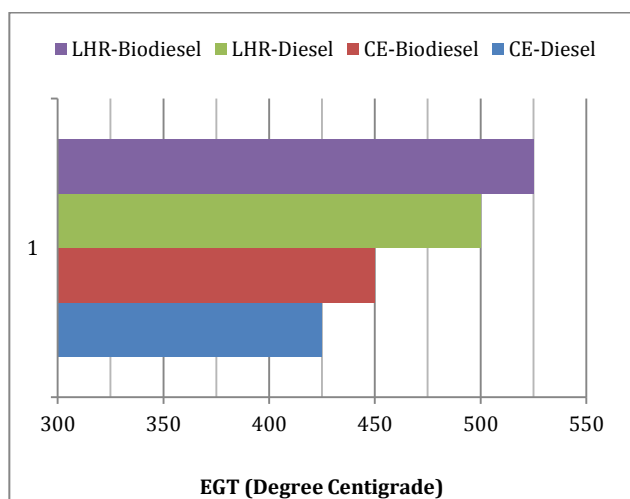


Fig.5 Bar charts showing the variation of exhaust gas temperature (EGT) at full load operation with test fuels with both versions of the engine at recommended injection timings at an injector opening pressure of 190 bar

Table.3 shows performance parameters of peak BTE, BSEC at full load and EGT at full load, From Table 3, Peak BTE improved marginally with an increase of injector opening pressure in both versions of the combustion chamber with test fuels.

As injector opening pressure increased, droplet diameter decreased influencing the atomization quality, and more dispersion of fuel particle, resulting in enhanced mixing with air, leads to improved oxygen-fuel mixing rate, as extensively reported in the literature [10–11]. EGT at full load reduced marginally with an increase of injector opening pressure in both versions of the combustion chamber as seen from Table.3. Improved combustion with improved oxygen-fuel ratios might have reduced EGT at full load with test fuels.

Fig.6 presents bar charts showing the variation of coolant load with test fuels. CE with biodiesel increased coolant load by 3% at 27° bTDC when compared with neat diesel operation on CE at 27° bTDC as observed

from Fig.6. Increase of un-burnt fuel concentration at the combustion chamber walls may lead to increase of gas temperatures with biodiesel produced higher coolant load than diesel operation. The reduction of coolant load in engine with LHR combustion chamber might be due to the reduction of gas temperatures with improved combustion. Hence, the improvement in the performance of CE was due to heat addition at higher temperatures and rejection at lower temperatures, while the improvement in the efficiency of the engine with LHR combustion chamber was because of recovery from coolant load with test fuels.

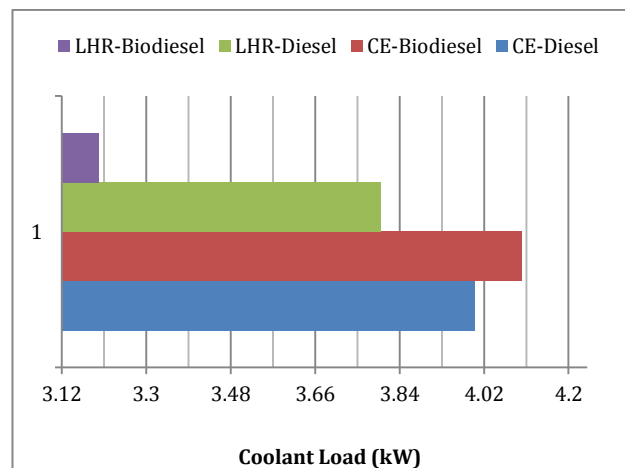


Fig.6 Bar charts showing the variation of coolant load at full load operation with test fuels with both versions of the engine at recommended injection timing at an injector opening pressure of 190 bar

Engine with LHR combustion chamber with biodiesel operation decreased coolant load operation by 16% at 27° bTDC when compared diesel operation with same configuration of the engine at 27° bTDC. More conversion of heat into useful work with biodiesel than diesel might have reduced coolant load with biodiesel. Fig.6 indicates that engine with LHR combustion chamber with biodiesel decreased coolant load at full load operation by 7% at 27° bTDC in comparison with CE at 27° bTDC. Provision of thermal insulation and improved combustion with engine with LHR combustion chamber might have reduced coolant load with LHR engine in comparison with CE with biodiesel operation.

Table.4 Comparative data on Coolant Load & Volumetric Efficiency at full load operation

IT/ Combustion Chamber Version	Test fuel	Coolant Load (kW)		Volumetric Efficiency (%)	
		Injector opening pressure (bar)		Injector opening pressure (bar)	
		190	270	190	270
27(CE)	DF	4.0	4.4	85	87
	BD	4.1	4.5	83	85
27(LHR)	DF	3.8	3.4	78	80
	BD	3.2	2.8	77	79

Fig.7 shows bar charts showing variation of volumetric efficiency at full load with test fuels. It indicates that CE with biodiesel operation decreased volumetric efficiency at full load by 2% at 27° bTDC, when compared with diesel operation on CE at 27° bTDC. Increase of EGT might have reduced volumetric efficiency at full load, as volumetric efficiency depends on combustion wall temperature, which in turn depends on EGT. From Fig.7, it is noticed that volumetric efficiency at full load operation on engine with LHR combustion chamber at 27° bTDC with biodiesel was marginally lower than diesel operation on same configuration of the engine at 27° bTDC. Increase of EGT was responsible factor for it.

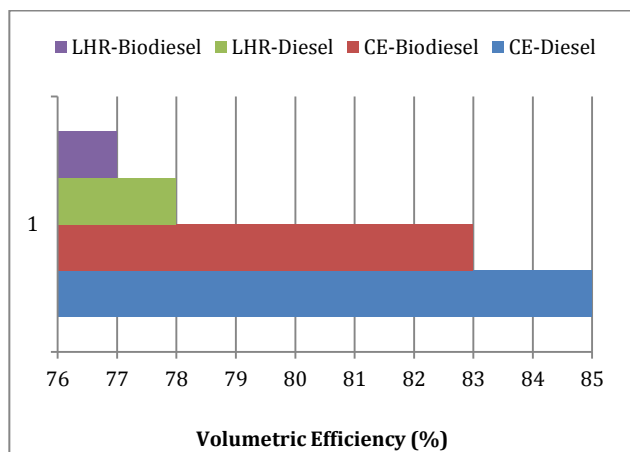


Fig.7 Bar charts showing the variation of volumetric efficiency at full load operation with test fuels with both versions of the engine at recommended injection timing and at an injector opening pressure of 190 bar.

Fig.7 indicates that engine with LHR combustion chamber with biodiesel decreased volumetric efficiency at full load operation by 7% at 27° bTDC in comparison with CE at 27° bTDC. The reduction of volumetric efficiency with engine with LHR combustion chamber was because of increase of temperatures of insulated components of LHR combustion chamber, which heat the incoming charge to high temperatures and consequently the mass of air inducted in each cycle was lower. Similar observations were noticed by earlier researchers [Murali Krishna, 2004; Murali Krishna et al, 2014].

Table.4 shows coolant load and volumetric efficiency at full load. Table.4 shows coolant load and

volumetric efficiency at full load. From Table.4, it is observed that that coolant load at full load operation marginally increased in CE, while decreasing it in engine with LHR combustion chamber with increased injector opening pressure with test fuels. This was due to the fact that increased injector opening pressure increased nominal fuel spray velocity resulting in improved fuel-air mixing with which gas temperatures increased in CE. The reduction of coolant load in engine with LHR combustion chamber was due to improved fuel spray characteristics and increase of oxygen-fuel ratios causing decrease of gas temperatures and hence the coolant load.

This was because of increase of EGT in CE, while decreasing of the same in engine with LHR combustion chamber. Volumetric efficiency at full load operation was marginally increased with an increase of injector opening pressure in both versions of the combustion chamber with test fuels. Improved oxygen-fuel ratios might have reduced EGT with test fuels. However, these variations were very small.

Summary

1. Engine with LHR combustion chamber is efficient for alternative fuel like biodiesel rather than neat diesel.
2. Engine with LHR combustion chamber with biodiesel improved its performance over CE at recommended injection timing.
3. The performance of the engine improved with increase of injector opening pressure with both versions of the combustion chamber with biodiesel.

Novelty

Engine parameters (injection pressure) and different configurations of the engine (conventional engine and engine with LHR combustion chamber) were used simultaneously to improve performance of the engine. Change of injection timing was accomplished by inserting copper shims between pump frame and engine body.

Highlights

- Fuel injection pressure affects engine performance and combustion parameters.
- Change of combustion chamber design improved the performance of the engine and combustion characteristics.

Future Scope of Work

Effect of preheating and injection timing of the fuel can be studied on the performance, exhaust emissions and combustion characteristic of the engine.

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References

- Acharya, S.K., Swain, R.K., & 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*, 33(1), pp 80-88.
- Venkanna, B.K., Venkataramana Reddy, C.K., Swati, B., & 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*, 2(3), pp 131-137.
- 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.
- Soo-Young, No. (2011). Inedible vegetable oils and their derivatives for alternative diesel fuels in CI engines: A review. *Renew Sustain Energy Rev*, 15, pp 131-149.
- Avinash Kumar Agarwal, & Atul Dhar. (2013). Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine, *Renewable Energy*, vol. 52, pp 283-291.
- Rakopoulos, C.D., Rakopoulos, D.C., Hountalas, D.T. (2008). Performance and emissions of bus engine using blends of diesel fuel with biodiesel of sunflower or cottonseed oils derived from Greek feedstock, *Fuel*, vol. 87: pp 147-157, 2008.
- McCarthy, P.M., Rasul, M.G., & Moazzem, S. (2011). Analysis and comparison of performance and emissions of an internal combustion engine fuelled with petroleum diesel and different biodiesels, *Fuel*, 90, pp 2147-2157.
- Anirudh Gautam, & Avinash Kumar Agarwal. (2013). Experimental investigations of comparative performance, emission and combustion characteristics of a cottonseed biodiesel fueled four-stroke locomotive diesel engine, *Int J Engine Res*, 14, pp 354-370.
- Krishna, Maddali, & Chowdary, R., (2014). Comparative studies on performance evaluation of waste fried vegetable oil in crude form and biodiesel form in conventional diesel engine, *SAE Paper 2014-01-1947*.
- Durga Prasada Rao, N., Murali Krishna, M.V.S., Anjeneya Prasad, B., & Murthy, P.V.K. (2014). Effect of injector opening pressure and injection timing on exhaust emissions and combustion characteristics of rice bran oil in crude form and biodiesel form in direct injection diesel engine. *IOSR Journal of Engineering*, 4,2, pp 9-19.
- Celikten, I. (2003). An experimental investigation of the effect of the injection pressure on engine performance and exhaust emission in indirect injection diesel engines, *Appl Therm Eng*, vol. 23, pp 2051-60.
- Avinash Kumar Agarwal, Dhananjay Kumar Srivastava, Atul Dhar, et al., (2013). Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine, *Fuel* vol. 111, pp 374-83.
- Krishna Murthy, P.V., (2010). Studies on biodiesel with low heat rejection diesel engine. PhD Thesis, J. N. T. University, Hyderabad.
- Ratna Reddy, T., Murali Krishna, M.V.S., Kesava Reddy, Ch., & Murthy, P.V.K. (2012). Performance evaluation of a low heat rejection diesel engine with mohr oil based biodiesel, *British Journal of Applied Science & Technology*, 2(2), pp 179-198.
- Janardhan, N., Ushasri, P., Murali Krishna, M.V.S., & Murthy, P.V.K. (2012). Performance of biodiesel in low heat rejection diesel engine with catalytic converter. *International Journal of Engineering and Advanced Technology*, 2(2), 97-109.
- Venkateswara Rao, N., Murali Krishna, M.V.S., & Murthy, P.V.K. (2013). Effect of injector opening pressure and injection timing on exhaust emissions and combustion characteristics of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel, *Int J Recent Technol Eng*, 2(4), pp 70-79.
- Venkateswara Rao, N., Murali Krishna, M.V.S., & Murthy, P.V.K. (2013). Effect of injector opening pressure and injection timing on performance parameters of high grade low heat rejection diesel engine with tobacco seed oil based biodiesel, *Int J Current Eng & Tech*, 3(4), 1401-1411.
- Murali Krishna, M.V.S., Durga Prasada Rao, N., & Anjeneya Prasad, B. (2013). Comparative studies on exhaust emissions and combustion characteristic of direct injection diesel engine with different combustion chamber with rice bran oil based biodiesel, *Int J Eng Innovative Technol*, 3(6), pp 163-173.
- Subba Rao, B., Ramjee, E., Murthy, P.V.K., & Murali Krishna, M.V.S. (2013). Studies on exhaust emissions and combustion characteristics of tobacco seed oil in crude form and biodiesel from a high grade low heat rejection diesel engine, *International Journal of Industrial Engineering and Technology*, 3(1), pp 27-36.
- Murali Krishna, M.V.S. (2004). Performance evaluation of low heat rejection diesel engine with alternative fuels, PhD Thesis, J. N. T. University, Hyderabad, India.
- Murali Krishna, M.V.S., Janardhan, N., Kesava Reddy, Ch., & Krishna Murthy, P.V.K. (2014). Experimental investigations on DI diesel engine with different combustion chambers, *British Journal of Applied Science & Technology*, 6(3), pp 239-260.