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Effect of Low Thermal Conductivity Materials on Performance of Internal Combustion Engine- A Review And Experimentation

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Abstract: *The combustion chamber of diesel engine is maintained hot with the provision of low thermal conductivity materials, so as to burn high viscous vegetable oils, biodiesel and low cetane alcohols. Experiments were conducted on different combustion chambers of diesel engine like low insulated engine (LIE), medium insulated engine (MIE) and high insulated engine (HIE).with pongamia biodiesel. LIE contained ceramic coated cylinder head, while MIE consisted of an air gap insulated piston with superni (an alloy of nickel) crown and air gap insulated liner with superni insert. HIE had the combination of LIE and MIE. The provision of low thermal conductivity materials like air, partially stabilized zirconium (PSZ) and superni resulted in semi adiabatic diesel engine which prevented heat loss to the coolant thereby increased thermal efficiency and reduced particulate emissions. Comparative studies were made with different combustion chambers and also with conventional engine (CE) at recommended injection timing. The performance of the insulated engine improved with an an increase of degree of insulation.*

Keywords: *Alternative fuels; Low thermal conductivity materials, insulated combustion chamber; Fuel performance; Exhaust emissions; Combustion characteristics.*

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I. Introduction

In the scenario of fossil fuel depletion, the use of alternative fuels which are renewable in nature are becoming increasingly important to ensure energy security and environmental protection. Biodiesel provided an appropriate solution for the crisis in developing countries around the world. When Rudolph Diesel first invented a diesel engine, he experimented with peanut oil, and he predicted that vegetable oil would be the future fuel for diesel engines. [1]. Biodiesel from feed is an important alternative to diesel fuels because they have many advantages over fossil fuels because they are renewable and biodegradable and provide energy security in addition to addressing ecological and socioeconomic issues, besides foreign exchange savings. These biodiesel have a lower viscosity, density, molecular weight and ratio of carbon to hydrogen than crude oil. Experiments were carried out using a conventional engine (CE) for biodiesel operation. They reported that performance was comparable to diesel operation. However, it increased nitrogen oxide levels. [2-5].Various heat output from an engine are brake thermal efficiency, heat loss to the coolant, heat loss to exhaust gas and un-accounted heat losses. Any savings in heat loss to the coolant would improve thermal efficiency of the engine. Low thermal conductivity materials like ceramics, stainless steel, superni etc reduce heat loss to the coolant by providing thermal insulation in the path of heat flow to the coolant. Hence the concept of insulated engine is to reduce heat loss to the coolant with the provision of insulation. Insulated engines are classified as LIE, MIE and HIE. LIE consisted of coating of low thermal resistance materials over top of the piston, inside potion of cylinder head, cylinder liner etc, so as to prevent heat loss to the coolant. MIE contained air gap insulated piston with crown of low thermal conductivity material and air gap insulated liner with insert of low thermal conductivity material. Different techniques were employed to assemble body and crown of the piston like welding, stud design and threading. Out of which threading was proved to be successful. HIE contained a ceramic-coated cylinder head, an air-gap insulated piston and an air gap insulated liner. Experiments were conducted with biodiesel Operation with LIE [6-8]. They reported a 4% increase in thermal efficiency, 25% drop in particulate emissions and a 30% increase in nitrogen oxides (NOx) levels compared to CE operating with neat diesel. Investigations were carried out with biodiesel operation with MIE [9–12]. They reported a 6% increase in thermal efficiency, a 35% drop in particulate emissions and a 45% enhanced in NOx levels compared to neat diesel operations. Experiments were carried out using HIE for biodiesel operation [13–15]. They reported an 8% enhance in thermal efficiency, a 40% reduction in particulate emissions and a 55% increase in nitrogen oxides (NOx) levels compared to CEs operating with neat diesel. Studies were made with diesel operation on different versions of the insulated engine [16]. They report that performance increased with an increase of degree of insulation. However, there were few reports available on the performance studies of LIE, MIE and HIE with pongamia biodiesel

This paper attempts to make comparative studies on the performance of the LIE, (engine with ceramic coated cylinder head); MIE (engine with air gap insulated piston and air gap insulated liner); and HIE (the combination of LIE and MIE) and CE with pongamia (non-edible vegetable oil) biodiesel.

II. Materials And Methods

2.1 Pongamia Biodiesel: Pongam is synonymous with karanji oil; later more common in trade and business. Pongamia oil is extracted from the tree species and belongs to the species Pongamia Glabra. The yield report for each tree varies between 8 kg and 24 kg. The granules contain 27-39% of the oil. Esterification will reduce viscosity and improve volatility. Pongamia biodiesel esterification process is carried out in two steps [17]. The properties of the test fuels used in the investigation are shown in Table 1.

Table.1: Properties of the Test Fuels

Property	Units	Diesel(DF)	Biodiesel (BD)	ASTM Standard
Density	gm/cc	0.84	0.88	ASTM D 4809
Kinematic viscosity at 40^{o}C	cSt	3.18	5.01	ASTM D 445
Lower calorific value	MJ/kg	44.8	42.2	ASTM D 240
Cetane Number	---	55	60	ASTM D 613

2.2.INSULATED ENGINES: High insulated engine (HIE) contained two parts of the piston- body and the crown. The crown was made of low thermal conductivity material superni screwed to the piston body with the insertion of gasket made of superni material so as to maintain 3-mm air gap between the aluminum body and crown. Previous researchers found that the optimum thickness of the air gap is 3- mm [18]. Medium insulated engine (MIE) engine consists of an air-gap insulated piston and an air-gap insulating bushing, while low insulated engine (LIE) contains only a partially stabilized zirconium (PSZ) coating inside the cylinder head. The degree of insulation increased from the LIE to the HIE. Table.2 shows the composition of superni-90 material, while Table-3 shows the important properties of the superni and PSZ materials. Thermal conductivity of aluminium alloy used for manufacturing of piston was 180 W/m–K, against 21 W/m–K of superni material. Because of higher insulation provided for the insulated engine reduced heat loss to the coolant. The photographic views of insulated piston, insulated liner and insulated cylinder head are shown in Fig.1, Fig.2 and Fig.3 respectively.

Table-2: The composition of Superni material

Cobalt -- 2.0 %, Chromium---2.93 %, Aluminum-- 1.5 %, Titanium – 2.5 %, Carbon—0.07%, Iron – 1 % and Nickel – Balance**.**

Table-3: Properties of test materials

Property	**Superni**	**Partially Stabilized Zirconium**
Specific gravity	8.1	5.7
Thermal conductivity at 500^{0}	21 W/m-K	2.05 W/m-K
Young's modulus at 500^{0}C	120 GPa	200 GPa
Mean coefficient of Thermal expansion	14.1×10^{-6} K^{-1}	9.8×10^{-6} .K^{-1}

Fig.1 Photographic view of insulated piston

Fig.2. Photographic view of insulated liner

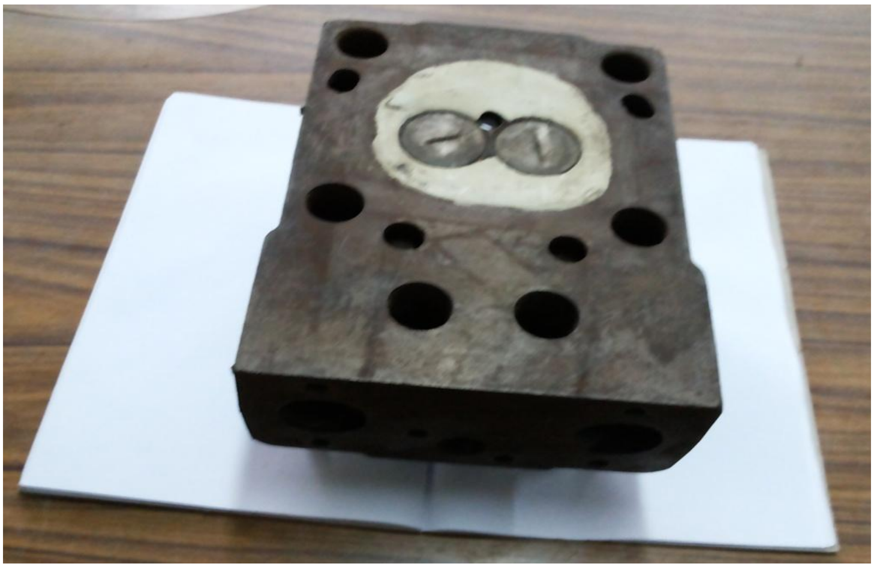

Fig.3 Photographic view of insulated cylinder head

2.3 Experimentation

Fig.4 shows a line diagram of an experimental setup for the study of different versions of insulated engines for Pongamia biodiesel. The experimental engine was a 1-cylinder 4-stroke water-cooled natural aspirated compression-ignition engine. At 1500 rpm, the engine has a brake power of 3.68 kW. The engine has a compression ratio of 16:1. The engine was connected to dynamometer used to measure its braking power

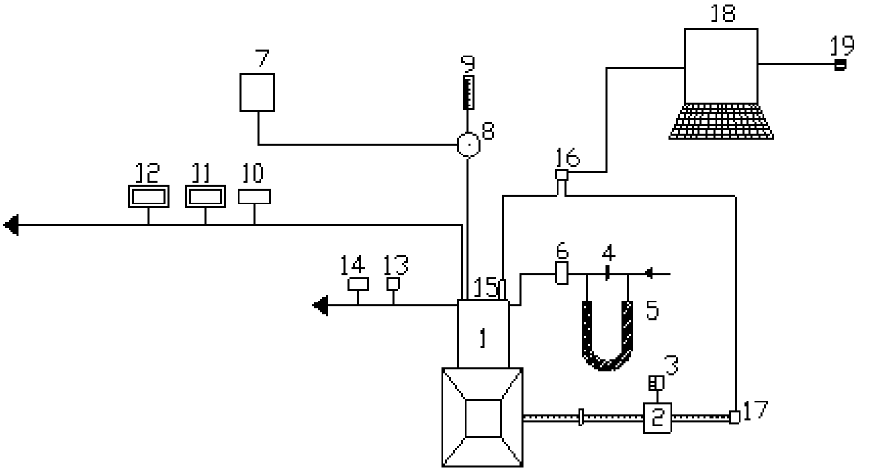

Fig.4 Schematic diagram of experimental set up

1.Four–Stroke Kirloskar Diesel Engine, 2.Kirloskar Electrical Dynamometer, 3.Load Box, 4.Orifice meter, 5.U-tube water manometer, 6.Air box, 7.Fuel tank, 8, Pre-heater 9.Burette, 10. Exhaust gas temperature indicator, 11.AVL Smoke meter, 12.Netel Chromatograph NO_x Analyzer, 13.Outlet jacket water temperature indicator, 14. Outlet-jacket water flow meter, 15.AVL Austria Piezo-electric pressure transducer, 16.Console, 17.AVL Austria TDC encoder, 18.Pentium Personal Computer and 19. Printer.

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III. Results And Discussion

3.1 Performance parameters

Fig.5 shows bar chart showing the variation of peak brake thermal efficiency for different versions of the engine with biodiesel operation at recommended injection timing. Conventional engine (CE) with biodiesel showed comparable performance with diesel operation.

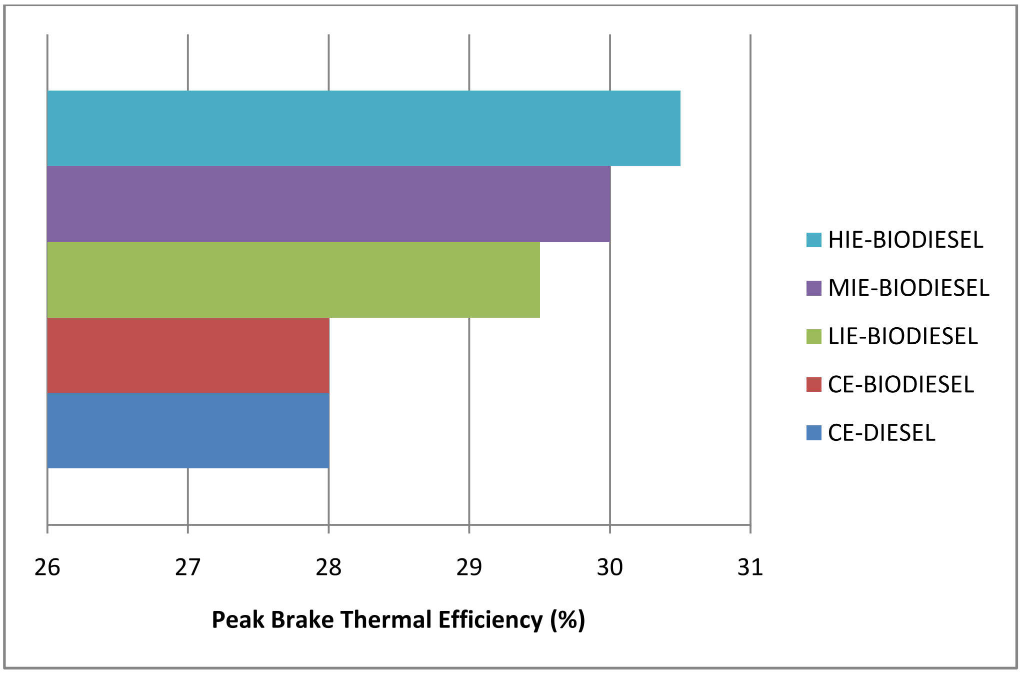

Fig.5 Bar chart showing the variation of peak brake thermal efficiency with different versions of the insulated engines.

The calorific value of biodiesel is low, but the density of biodiesel is high leading to give comparable heat release rate. The presence of oxygen in the biodiesel composition improved combustion. In case of insulated engines, high cylinder temperatures increased the rate of fuel evaporation causing increase of BTE. The provision of thermal insulation with low thermal conductivity material like air, PSZ and superni made the combustion chamber more hot, as most of heat loss was prevented to the coolant, thus improved the combustion .As shown in Fig, BTE increased with an increase of degree of insulation as more and more insulation was added and more and more thermal insulation was provided with provision of low thermal conductivity materials with increased degree of insulation leading to reduce coolant load and thereby increased BTE. Higher cylinder temperatures helped in improving the evaporation of fuel at a faster rate.

Fig.6 presents bar chart showing the variation of exhaust gas temperature (EGT) at full load with different versions of the insulated engines with biodiesel operation At recommend injection timing. The exhaust gas temperature (EGT) of CE with biodiesel increased by 6% compared to CE with diesel operation. Though calorific value of biodiesel is low, its density is high leading to release high heat release rate, besides high duration of combustion causing higher EGT than diesel operation, EGT increased with an increase of degree of insulation. This indicates that as the insulation increased with the provision of more thermal insulated materials, the heat rejection to the coolant was reduced, and hence more amount of heat loss to the exhaust gas increased. However, the heat loss to the exhaust gas is less when compared to heat gain in coolant heat loss.

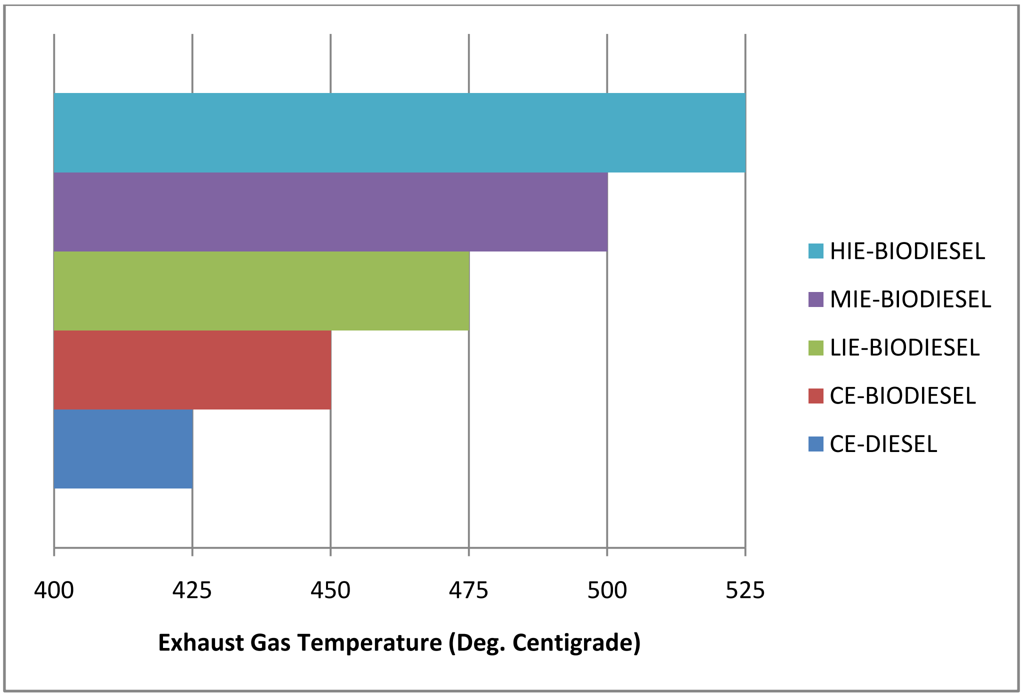

Fig.6 Bar chart showing the variation of exhaust gas temperature at full load with different versions of the insulated engines

Fig.7 presents bar chart showing the variation of coolant load at full load with different versions of the insulated engines with biodiesel operation At recommended injection timing, the biodiesel operating on CE exhibits a comparable coolant load at full load with diesel operation, because of improved combustion with the presence of oxygen in its fuel composition. The coolant load with biodiesel operation decreased with an increase of degree of insulation. With provision of more and more insulating materials like air, partially stabilized zirconium (ceramics) and superni increased thermal insulation thereby reducing heat flow to the coolant with which coolant load decreased and BTE increased with different configurations of the insulated engines with biodiesel operation

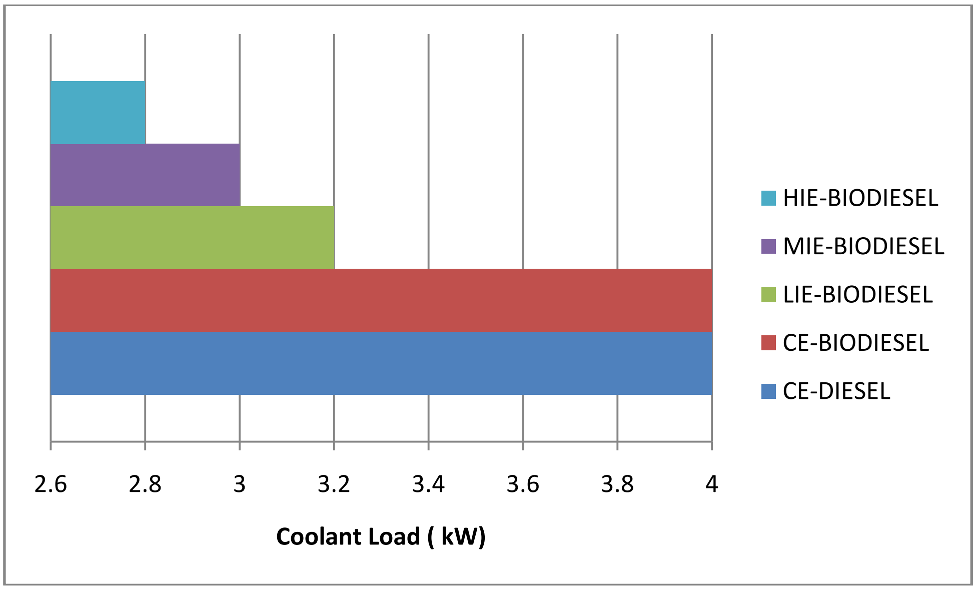

Fig.7 Bar chart showing the variation of coolant load at full load with different versions of the insulated engines

3.2 Exhaust emissions

Fig.8 presents bar chart showing the variation of particulate emissions at full load with different versions of the insulated engines with biodiesel operation.

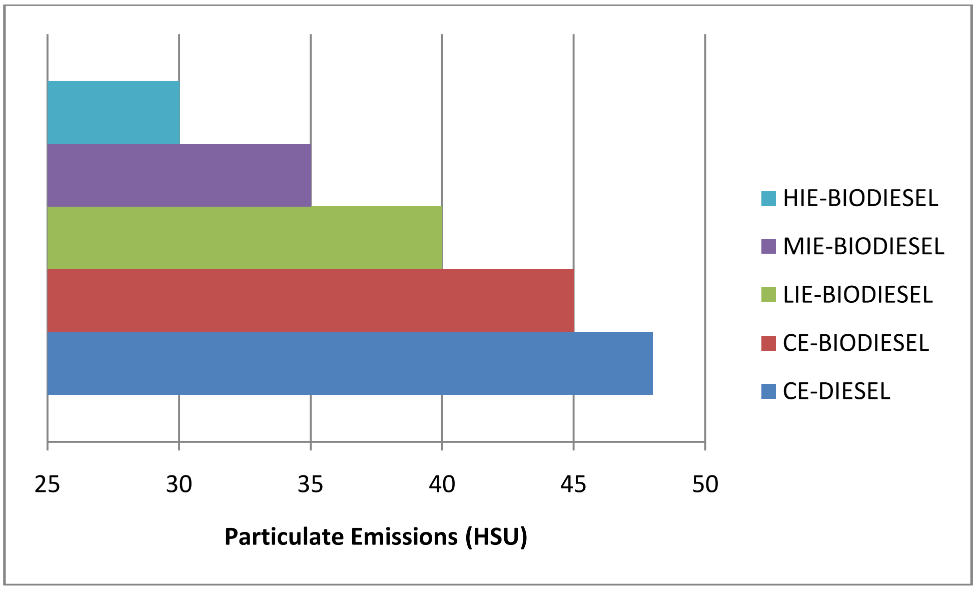

Fig.8 Bar chart showing the variation of particulate emissions at full load in Hartridge Smoke Unit (HSU) at full load with different versions of the insulated engines

CE with biodiesel decreased particulate emissions at full load when compared to CE with diesel operation due to presence of oxygen in its fuel composition and improved cetane number. It is observed that particulate emissions at full load operation decreased with an increase of degree of insulation. Improved combustion of biodiesel with the reduction of ignition delay with the hot environment provided by the different versions of the insulated engines due to their low thermal conductivity might have reduced particulate emissions. With biodiesel operation, insulated engines reduced particulate emissions when compared to CE. This showed that combustion improved with different versions of the insulated engines, when compared with CE. Fig.9 presents bar chart showing the variation of nitrogen oxide (NO_x) levels at full load with different versions of the insulated engines with biodiesel operation.

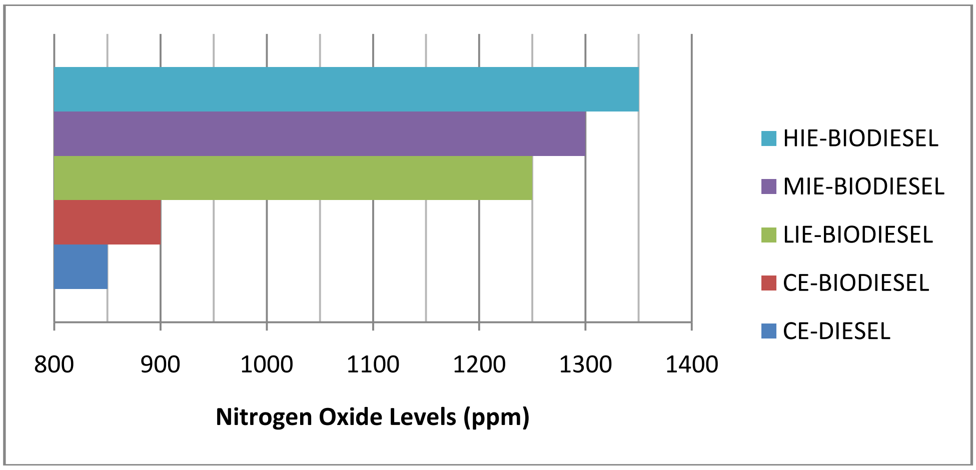

Fig.9 Bar chart showing the variation of nitrogen oxide levels at full load with different versions of the insulated engines

CE with biodiesel operation increased NOx levels compared to diesel operation on CE. Pongamia oil biodiesel with longer carbon chains (C_{20}-C_{32}) recorded more NO_x than fossil diesel with both medium (C_8-C_{14}) and long chain (C_{16}-C_{28}). Presence of oxygen in its fuel composition increased combustion temperatures causing higher NO_x levels with biodiesel operation. NO_x levels at full load operation increased with an increase of degree of insulation with biodiesel operation. The improved combustion in the hot environment provided with different insulated materials improved heat release rates and combustion temperatures causing higher NOx levels

3.3 Combustion Characteristics

Peak pressure was comparable with biodiesel operation on CE when compared with neat diesel operation on CE. Higher density of biodiesel produced high heat release rate and peak pressures through its calorific value is less. Peak pressures at full load operation increased with an increase of degree of insulation. Improved combustion in hot environment provided by different insulated combustion chambers construed with various insulating materials increased peak pressures at full load operation. Maximum rate of pressure rise (MRPR) at full load followed similar trends with peak pressures with biodiesel operation. . Time of occurrence of peak pressure (TOPP) at full load operation decreased with an increase of degree of insulation of different versions of the insulated engines. As more and more insulation was added, combustion improved with reduction of heat flow to the coolant because of which combustion improved with accumulation of heat in combustion chamber.

IV. Conclusions

1. The performance of the different versions of the engine in terms of peak brake thermal efficiency and coolant load improved with biodiesel operation with increased degree of insulation as more and more insulating materials were provided in the path of heat flow to the coolant.
2. The particulate emissions decreased, while nitrogen oxide levels increased with an increase of degree of insulation with biodiesel operation as combustion chamber was maintained hotter, with insulating materials.
3. Combustion characteristics at full load improved with an increase of degree of insulation with biodiesel with improved combustion.

V. Future Scope Of Studies

Different types of LHR engines gave higher NO_x emissions. Hence control of NOx levels is essential. Hence NO_x levels in engine with LHR combustion chamber can be controlled by means of the discriminating catalytic reduction (SCR) technique using lanthanum ion exchanged zeolite (catalyst–A) and urea infused lanthanum ion exchanged zeolite (catalyst–B) with different varieties of combustion chamber at full load operation of the engine [19].

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