Performance study on the C.I engine using LHR and LTC in combination with biodiesel blends

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ABSTRACT

Currently, the research of a single-cylinder 4-stroke direct injection diesel engine, which was naturally aspired, was used, and two modification methods were used. The first is the low-heat rejection method (LHR), and the second is the low-temperature combustion method (LTC). LHR was introduced into the engine by ceramic coating with alumina, which is applied to engine components such as the piston, cylinder lining, and valves and has a thickness of 300 microns without affecting the dimensions of the engine parts. In the next method, low - temperature combustion (LTC) method is done with EGR technique. And the exhaust gas recirculation setting (EGR) is included in the same setup as that of first method. Since, 15% of an exhaust gas is used in the EGR process. The diesel is blended with 20% of mahua biodiesel and 5% of ethanol as a fuel. After that, the engine performance is tested with conventional fuel when compared with biodiesel as a combined LHR and LTC methods. Finally, the engine output is increased by up to 3.48% as a result of the combination of LHR and LTC. As a result, emission levels could be dramatically decreased, and other results obtained could include a decrease in infrared radiation, resulting in a decrease in specific fuel consumption (SFC), and a substantial improvement in engine efficiency characteristics.

Key words: Low heat rejection; Low-temperature combustion; Mahua biodiesel; Alumina; Ethanol.

INTRODUCTION

The diesel engine, also known as the compression ignition engine or CI engine, is an internal combustion engine in which the ignition of the fuel injected into the combustion chamber is initiated by the high temperature achieved by a gas when it is heavily compressed by adiabatic compression. This contrasts with spark-ignition engines like a petrol engine, which uses a spark plug to ignite a mixture of air-fuel. Because of its compression and low combustion ratio, the diesel engine has a better thermal efficiency than all internal or external combustion engines, allowing excess air to dissipate heat (Heywood JB, 2002). Diesel engines are produced in the versions of two and four strokes. Nowadays, the two-stroke engines are banned in cars, but used in marine applications, because the pollutants from the two-stroke engines are very high compared to the four-stroke engines (Muthukumaran et al., 2018). In two-stroke engines, the power stroke is obtained by each crank revolution, so that we get the power output twice as much as the four-stroke. Due to higher combustion temperatures, NO_x, particulate matter and smoke emissions are high in diesel engines. The combustion of diesel engines depends primarily on the compression pressure and the automatic ignition temperature of the fuel. In all fields such as agriculture, industry, power generation and automobiles, the diesel engine plays a vital role. By taking human health into account, researchers are testing new techniques for reducing NOx, smoke and hydrocarbon emissions from the engine (Rakopoulos et al., 2006). By making certain changes, such as exhaust gas recirculation, increasing the injection pressure and retarding or advancing the injection timing, emissions and fuel economy are reduced. Although diesel engines have high thermal efficiency, high torque capacity and produce fewer HC and CO emissions than gasoline engines, they emit NOx and smoke (Kulkarni et al., 2011 & Vamsi Krishna et al. 2018), which pose a major threat to the clean environment and human health. The automotive industry has grown rapidly. Especially in IC engine invention and implementation. Thus, the use of IC engines has grown considerably throughout the world. In this experiment four different conditions (Diesel, B20, B20 (LHR), and B20E5 (LHR+15%LTC)) of diesel engine is investigated and compared with conventional engine.

LITERATURE REVIEW

Kannan and Anand, 2011 have investigated the diesel engine efficiency, combustion and emission characteristics run by diesel-biodiesel-ethanol blends or diestrol fuels. Based on the calorific value, miscibility and stability of blends are tested at temperatures of 40^{o}C to 10^{o}C, eleven combinations of fuel blends are selected. The engine operated at a constant speed of 1500 rpm with selected fuels. Finally, the authors concluded from the experimental results that high brake thermal efficiency 29.9% is obtained in diestrol (B30D60E10) fuel. Heat release of diesel is 7.5% higher than diestrol fuel under full load conditions. In biodiesel ignition delay 1.9^{o}CA higher than diesel. By using B30D60E10 diestrol fuel, NO and smoke emissions decreased compared to diesel. They have proven that B30D60E10 is the best alternative diesel fuel without modification compared to other biodiesel combination blends.

Xue et al., 2011 studies have reviewed the number of highly cited science index journals on biodiesel engine performance, combustion and emission characteristics. The review of journals focused on the biodiesel engine effects of brake power, efficiency and emissions. Authors concluded that the use of biodiesel rather than diesel reduces CO, HC and PM emissions from studies. Fuel consumption and NOx emissions, however, increase without any modification of the diesel engine. If engine modification and some additives are added to biodiesel to optimize performance and completely alternate diesel fuel.

Muthukumaran et al., 2018 prepared mahua biodiesel using a catalytic cracking process and investigated diesel engine performance, combustion and emission characteristics fuelled by cracked mahua biodiesel blend with diesel. Mahua biodiesel has been produced by using cheap heterogeneous catalysts (coal ash) because of the reduction in biofuel costs. Authors have identified that cracked mahua biofuels are better analysed with FTIR, GC spectrum. Coal ash compositions such as silicon, oxygen, aluminium and iron levels are analysed using SEM and

EDC for the cracking process. Mahua biodiesel blend with diesel such as B25, B50, B75 and B100 at different load conditions.

Finally, the authors conclude that B25 brake thermal efficiency is close to pure diesel and B100 NO_x emissions are 3.2% lower than diesel at 20% load conditions. With increases in the percentage of biodiesel blends for all load conditions, HC and CO emissions were increased. The maximum heat release was obtained in B25 compared to other blends.

Masjuki et al., 1996 studied viscosity reduction of palm oil methyl esters (POME) by using a 100oC preheating temperature in diesel engines. They examined pre- heated biodiesel fuel in diesel engine performance, combustion and emission characteristics. From the results, the authors concluded that the brake power output of biofuel is closer to diesel fuel operations. Preheated air intake temperatures of 60^{o}C have reduced HC emissions reasonably well. Engine air intake temperatures have been used to stabilize fuel to improve efficiency and emissions compared to diesel fuel.

Kulkarni et al., 2011 have investigated the performance of diesel engines using a low-heat rejection method fuelled by mahua oil methyl ester (MOME) before and after exhaust gas recirculation (EGR) ratios of 0 % to 20 %. In this study, the following engine parameters are kept constant, including speed 1500 rpm, injection time 23^{o} BTDC, compression ratio 17.5 and injection pressure 204 bar for diesel and 240 bar for MOME. The ceramic coating used to implement low heat rejection in the engine by using YSZ (yttria-stabilized zirconia) in engine parts with a thickness of 200 μm, such as piston, cylinder head, and valves. EGR ratios were varied using controlling valves. Authors have been observed that LHR engine increases the brake thermal efficiency and reduces the emissions like HC, CO and increases the NO_x compared to conventional engine fuelled by MOME. When the EGR rate increases BTE also increased and slightly increases the emissions including HC, CO and decreasing the NO_x. Finally, concluded that at 10% EGR has reduced NO_x and improves the engine overall Performance.

Vamsi Krishna et al., 2018 investigated performance, emissions and cylinder pressure by using the semi-adiabatic diesel engine(SADE) and combined with the EGR rate 10 percent diesel fuel and A15B85 blend by vol. (Additive Diethyl Ether 15% + Biodiesel 85% rubber seed) and compared with the ordinary diesel engine(ODE). SADE has been produced by using a ceramic coated cylinder head with a thickness of 400 µm thermal barrier 8 YSZ and an intermediate layer made by using NiCrAl bond coat with a thickness of 100 µm without change dimensions. In this experimental work, the authors maintained a constant engine speed at 1800 rpm, a compression ratio of 18.1 and an injection pressure of 190 bar with varying load conditions of 0 to 100 % and a varied start of injections from 30 to 35^o BTDC. Results showed that SADE's 7% improvement in BTE reduces fuel consumption by 5.5%compared to ordinary diesel engines. And engine emissions like NO_x, particulate matter (PM) decreased by 19.5 % and 48.5 %, with 33^{o}BTDC at full fuel blend load. Finally, the authors concluded that the A15B85 blend by volume has proven to be 100% renewable fuel for the diesel engine and 10 % EGR is optimal to reduce NO_x emissions with combined thermal engine barriers.

Geos et al., 2017 investigated the enhancement of diesel engine combustion by injecting ethanol during suction stroke intake. Engine fuel as diesel, rubber seed oil (RSO) and rubber seed oil methyl ester (RSOME). In this study authors interest to use alcohol in the compression ignition engine as an alternative biofuel due to oxygen and it is prepared by using biomass. In this research optimized injection timing and duration used dual fuel operation of ethanol injection. The authors compared the results of engine performance with various fuel mixtures with different ethanol energy ratios of 0% to 45%. The results of the experiment illustration that the brake thermal efficiency rises with the rise in the ethanol energy ratios of all fuels due to premix combustion rates. However, it increases NO_x emissions due to higher oxygen content under full load conditions. Smoke levels also decreased at maximum brake thermal efficiency for all tested ethanol injection fuels. HC, CO emission levels increase due to ethanol injection of all fuels. Combustion duration and ignition delay are higher in RSO compared to diesel due to ethanol injection. Finally, the authors concluded that the improvement of thermal efficiency and reduced smoke levels in the diesel engine with ethanol injection powered by diesel, rubber seed oil, and its ester at all loads.

Ramalingam et al., 2018 have reviewed the number of research articles on biodiesel-fuelled diesel engines to reduce the disadvantages of fossil fuels. Authors from their studies focus on biodiesel as an alternative fuel to the replacement of fossil fuel for diesel engines. They examined the methods and technologies used to improve efficiencies and reduce emissions of biodiesel fuelled by diesel engines. Finally, they concluded that, due to the low heating value of biofuels, biodiesel reduced the brake thermal efficiency compared to diesel. However, it reduces the engine exhaust emissions like CO, UHC, and smoke owing to the oxygen content of biofuels and increases NO_x emissions. This type of disadvantage has been rectified by increasing the engine compression ratio and some minor modifications needed to increase efficiency. B20 is the best combination of biodiesel used for alternative diesel fuel in the compression ignition engine with the catalytic converter and increases the compression ratios with minor modifications in the engine.

Govinda Rao et al., 2018 conducted a study of diesel engine performance and emission characteristics of diesel fuel, waste plastic oil and its mixtures by varying injection parameters and compression ratios. In this study authors has used different ratios of diesel, ethanol-blended with plastic oil for test fuels. From experimental results, blend P90D5E5 has maximum thermal efficiency and reduced fuel consumption, carbon monoxide and smoke levels compared to pure diesel and pure plastic oil. And it has a high heat release rate and cylinder pressure. Finally, the authors conclude that increasing the compression ratio, injection pressure and retarding injection leads to increased engine efficiency and NO_x, but decreases emissions of CO, HC, smoke and also specific fuel consumption.

Modi et al., 2017 have investigated the performance of the twin-cylinder diesel engine by using ceramic coated engine parts with different EGR ratios fuelled by diesel and neem biodiesel blends. Authors focused on reducing engine heat rejection and improving energy conservation and efficiency following the second law of thermodynamics. Ceramic coated on the engine piston and top surface of the cylinder head with partially stabilized zirconia (PSZ) thermal barrier material. The effect of the thermal barrier in the engine increases thermal efficiency and reduces exhaust emissions such as HC, CO, and smoke, but increases NO_x. And after implementing the EGR in the engine, it reduces NO_x and increases thermal efficiency by lowering a combustion temperature and the amount of oxygen content in the engine cylinder. Entire experimental work engine operated at a constant speed of 2000 rpm. From the results, the EGR 5 percent with the LHR engine reduces both NO_x and smoke density by 26% and 15%. EGR 10% with the LHR engine reduces both NO_x and smoke by 34% and 30%.

Senthil et al., 2015 examined and compared the performance and emission characteristics of single-cylinder diesel engines fuelled by Nerium oil diesel and methyl ester before and after the coating of ceramic materials. Engine parts such as the surface of the top of the cylinder head, piston and valves are coated with partially stabilized zirconia (PSZ) by using plasma spray coating. The results of the experiment showed that the specific fuel consumption was reduced in all load conditions in the coated engine. Finally, the author identifies the thermal efficiency of the coated engine brake around 3.8 percent higher than the uncoated engine. And coated engine emissions improved than the uncoated engine, except NO_x.

Banapurmath and Tewari, 2009 investigated the improvement in a diesel engine efficiency with a low heat rejection (LHR), and exhaust gas recirculation (EGR) fuelled by diesel, honge and neem oil methyl ester. In this experiment, the alternative fuel for diesel engines with varying injection times of 19, 23 and 27^o BTDC with and without EGR ratios of 5 % to 20% were examined. The results improved the specific fuel consumption and brake thermal efficiency of the LHR biodiesel engine. However, 10% of EGR with the LHR engine is better performance and reduced emissions such as HC, CO, and NO_x.

EXPERIMENTAL SETUP AND METHODOLOGY

Engine Setup

An experiment was carried out with four strokes, water-cooled, single-cylinder diesel engine. Engine specification is given in table 1. The tested engine coupled with an electrical dynamometer with the capacity of 10 kW. The engine operated by load conditions like 0%, 25%, 50%, 75% and 100%. Throughout experiments were conducted at a constant speed and compression ratio of 1500 rpm and 17.5. In this experiment used engine fuel is diesel and 20% of mahua biodiesel blend with diesel (Kulkarni et al., 2011 & Michael A Penny and Timothy J Jacobs, 2016). The experimental engine was run with and without modifications by using two techniques. One of the techniques is LHR and another is LTC, both technique setup is discussed below (Kulkarni et al., 2011). Engine speed is measured by using tachometer and temperatures of the engine like inlet air, exhaust gas, inlet and outlet of water has measured by using thermocouples. Exhaust gas smoke level is measured by using the smoke meter. Engine emissions like CO, HC, and NO_x are measured by connecting exhaust gas analyser.

Table 1 Specification of tested engine.

Description	
Make	Kirloskar
General details	Single cylinder, direct injection,
Stroke	110 mm
Bore	87.5 mm
Compression ratio	17.5
Rated speed and power	1500 rpm at 5.2 kW
Injection Pressure	210 bar
Injection duration	24^{o}BTDC

Production of Mahua Oil Biodiesel

In the present experimental engine used fuel is mahua oil. This mahua is a non-edible, fast-growth crop plant compared to other plants (Govinda Rao et al., 2018). Mahua oil having high viscosity, low heat value, etc. Production of biodiesel with mahua oil has done with two stages of processes are the esterification and transesterification. Esterification is done with acid catalyst H2SO4 and methanol as shown figure 1(Geos et al., 2017). After that transesterification is done with catalyst KOH and methanol as shown in figure 2 (Modi et al., 2017).

The following table. 2 shows the properties of the fuel. And also in this experiment tested fuel is B20 and ethanol 5% blend is used.

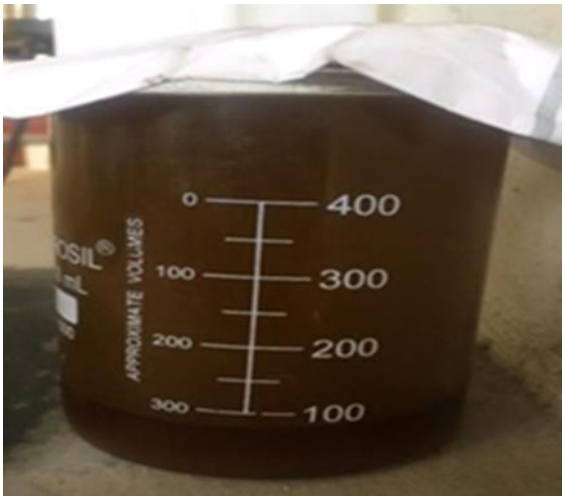

Figure 1 Esterification.

Figure 2 Transesterification.

Table 2 Properties of Mahua biodiesel.

Property	Unit	Mahua Oil	MOME	Diesel	D80/B20	D75/B20/E5
Density	**Kg/m³**	960	880	850	860	869
Kinematic Viscosity	**cSt**	24.58	3.98	3.52	3.62	3.49
Flashpoint	**ºC**	232	208	49	80	77
Calorific Value	**MJ/kg**	36	37	42	38	40
Cetane Number	**-**	45	47	53	51.2	51

Setup of LHR

LHR has done the ceramic coating of engine parts including top surfaces of the piston, cylinder head and valves with a thickness of 300 microns by using the plasma spray method. This modification of the engine is done with alumina (Al_2O_3) as a low heat rejection material. It is one of the famous thermal barrier material (Ramalingam et al., 2018). Because of ceramic coating, the bond coat was done with NiAlCr with a thickness of 200 microns for making a strong joint of ceramic materials in the engine parts. Figure 3 shows the before and after coating

of piston crown. The following table. 3 shows the properties of Alumina.

Table 3 Properties of Ceramic Material.

Parameters	Units	
Chemical formula		Al_2O_3(Aluminium Oxide)
thermal conductivity	W/mK	20 to 30
Hardness	Gpa	15 to 19
density	g/cm^3	3.75 to 3.95
Melting point	°C	2,072
Boiling point	°C	2,977

Figure 3 Before and after coating of the piston crown.

Setup of LTC

Figure 4 EGR setup.

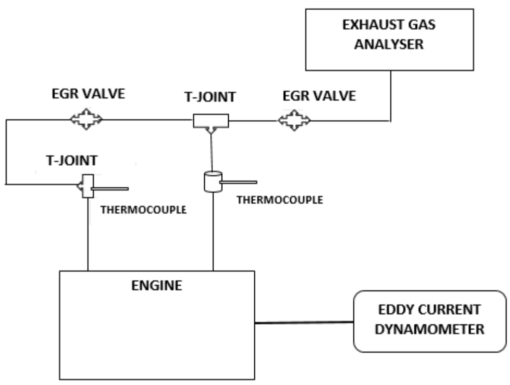

Figure 5 EGR block diagram.

The engine is designed to run on the exhaust gas by inserting it into the intake manifold pipe by means of an EGR valve. During the recirculation of the exhaust gas, (Kulkarni et al., 2011) the EGR control valves are used to regulate the amount of exhaust allowed back into the combustion chamber. Figures 4 and 5 show the EGR setup and block diagram.

Combination of LHR and EGR Setup

One of the primary technique is Low Heat Rejection (LHR) concept (or the so-called “Adiabatic" engine) applied in the experiment. In this case, improved efficiency can be achieved, but the disadvantage of the method is the increase in NOx emission by using optimal fuel B20 from first phase of this study. Another technique is Exhaust Gas Recirculation (EGR) modes mitigate NOx emission effectively by recirculating some exhaust gases like 0% to 20%. But this case compared LHR engine CO and HC were increased due to low oxygen concentration. For the above emission problems can be minimized by using LHR concepts combined with EGR are discussed in this experiment. Also 5% Ethanol and using simultaneously 15%EGR were used to decrease the NOx. Only 5% Ethanol is used reason is ethanol’s inability to get blended with diesel. The inlet temperature (IT) of the engine is regulated by E5 (5% ethanol). So, in this paper, the best performance of diesel engine fuelled biodiesel is given by adjusting the combination of using LHR and EGR with IT.

Analysis of uncertainty

Table 4 provides the levels of accuracy of the measured values and the uncertainties of the observed parameters. To minimize measurement errors, six measurements have been observed and only the average outcomes for analysis are presented (Banapurmath and Tewari, 2009).

Table 4 The measured value of accuracy and uncertainties of parameters.

S.No	Parameters	Uncertainty
1	Speed (rpm)	±1
2	Load	±0.1
3	Temperature (^oC)	±1
4	Fuel Consumption (g)	±0.1
5	Hydrocarbon (HC)	±1.5%
6	Carbon monoxide(CO)	±2.3%
7	Nitrogen Oxide (NOx)	±2.5%
8	Smoke	±2%
9	Brake Thermal Efficiency (BTE)	±1.2%

RESULT AND DISCUSSIONS

Performance and emission of the diesel engine with and without modifications fuelled by diesel, biodiesel (B20) and blend with ethanol 5%. Modifications are LHR and LTC is combined used to study the engine performance with using biodiesel (B20) blended with 5% of ethanol to compare with standard and LHR engine. This section discussed the obtained results of the diesel engine's performance, combustion and emission characteristics compared to different conditions of the engine.

Impact on BTE

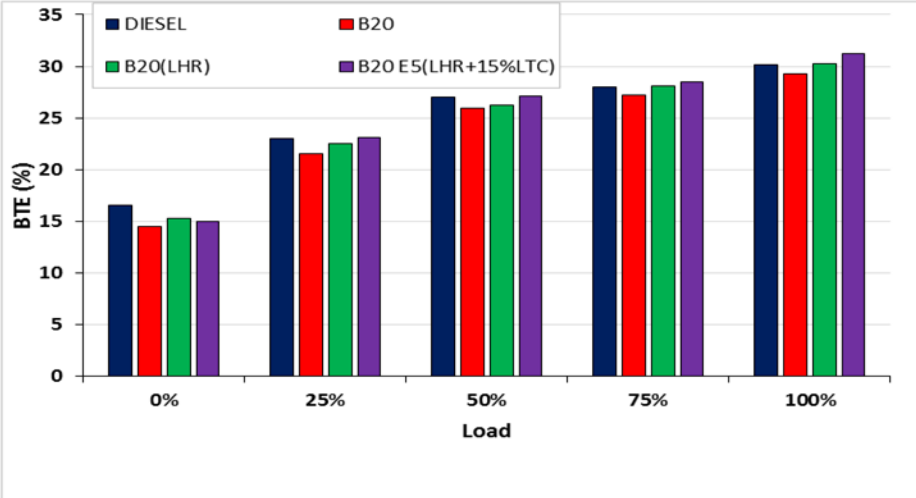

Figure 6 Brake Thermal Efficiency VS Load.

Figure 6 illustrated the difference of brake thermal efficiency with different load conditions for various conditions of diesel engines. It shows that load increases with a slight increase in efficiency of the engine. Mainly, at full load condition, high BTE obtained in B20E5 (LHR+15%LTC) nearly to diesel operation of a conventional engine. Due to two modifications (LHR, LTC) are implemented at the same time in the diesel engine with optimum fuel (B20E5). It has seen that, lower BTE in B20 due to less calorific value than diesel fuel (Kannan and Anand, 2011). LHR is used to reduce the heat loss and heat flux in the engine cylinder and improve engine efficiency (Xue et al., 2011). But increases the NOx emission due to high-temperature combustion (Rakopoulos et al 2006). The LTC and 5% ethanol in B20 are used to reduce the NOx emission by using the recirculation of exhaust gas of the engine. Compared to diesel fuel, BTE of B20 was 3.05% less and B20 (LHR), B20E5 (LHR+15%LTC) were 0.3%, 3.48 % improved. From figure B20E5 (LHR+15%LTC) was shows a better BTE than others.

Impact on BSEC

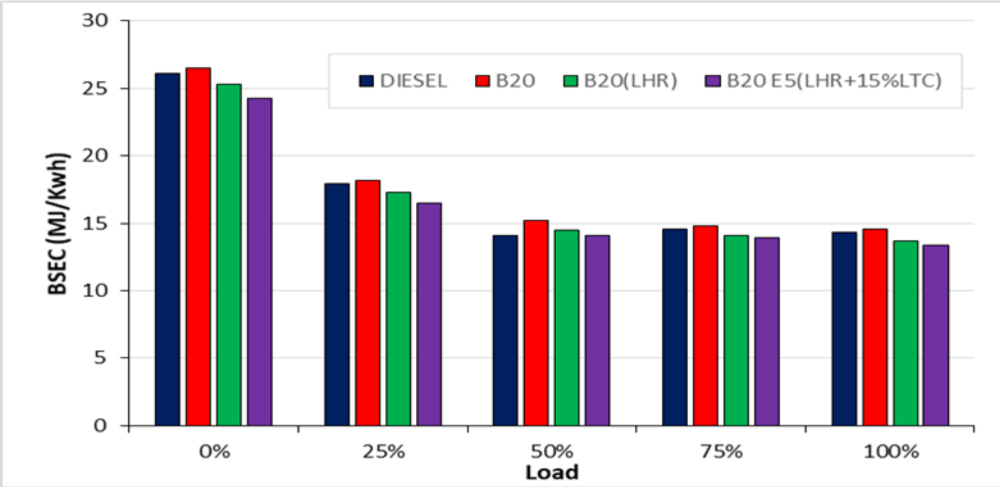

Figure 7 Brake Specific Energy Consumption VS Load.

Figure 7 displays the fluctuating of brake specific energy consumption (BSEC) from minimum to maximum various type of load conditions of a diesel engine fuelled diesel and biodiesel blend. It observed that BSEC decreased with an increase in load. Overall, BSEC was noticed that the maximum in B20 is 26.5 MJ/Kwh at 0% load and the minimum in B20E5 (LHR+15%LTC) is 13.4 MJ/Kwh at 100% load conditions (Vamsi Krishna et al., 2018). BSEC of the engine was more in B20 compared to others. Because biodiesel having lower calorific value, higher density, and viscosity than the diesel fuel. The energy content of biodiesel is lower than fossil fuel at the same power. Particularly, at 100% load condition shows less BSEC than other percentages of load in all conditions of the engine (Muthukumaran et al., 2018). Compared to diesel fuel, B20 was 2.09% high and B20 (LHR), B20E5 (LHR+15%LTC) were 4.19%, 6.29% is less was revealed in full load conditions (Ramadhas et al., 2004). It seems that B20E5 (LHR+15%LTC) gave satisfactory BSEC due to implemented the LHR and LTC methods at a time. Meanwhile, low BSEC was creates improved engine efficiency.

Impact on EGT

Figure 8 displays the variation of exhaust gas temperature (EGT) from minimum to maximum various type of load conditions of a diesel engine fuelled diesel and biodiesel blend. It observed that the highest EGT obtained in B20LHR and lowest EGT in diesel fuel at all load conditions.

Particularly LHR engine with biodiesel was found higher EGT compared to conventional diesel engines due to delay burning of biodiesel. The maximum EGT obtained were 328^oC, 364^oC, 319^oC and 296^oC For B20E5 (LHR+15%LTC), B20LHR, B20, and diesel respectively, at peak load. Among this reasonable EGT was found in B20E5 (LHR+15%LTC) due to both LHR and LTC was implemented in the engine and also 5% ethanol blended in biodiesel (Banapurmath, and Tewari, 2009). The biodiesel's properties like higher viscosity and lower cetane number, volatility were led to a more prevailing diffusion combustion phase than for diesel. The EGT was responsible for getting more BTE and meanwhile NO_x emission (Xue et al., 2011).

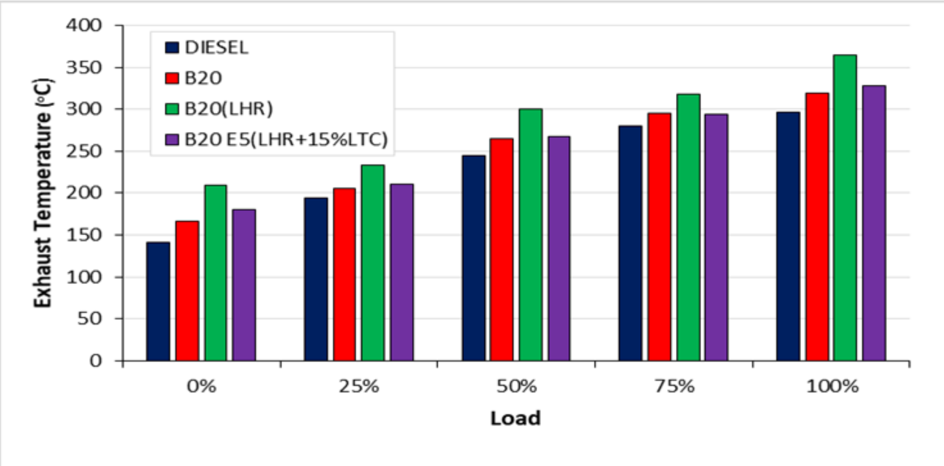

Figure 8 Exhaust Gas Temperature VS Load.

Impact on In-Cylinder Pressure

Figure 9 shows the in-cylinder pressure concerning the crank angle for different conditions of the engine at 100% load. It observed that peak pressure for diesel was 70.5 bar, for B20 was 67.52bar, for B20LHR was 69.8bar, and for B20E5 (LHR+15%LTC) was 70.1bar at 10oCA ATDC (Ramadhas et al., 2004). From these outcomes, diesel peak pressure was near to B20E5 (LHR+15%LTC) due to using two modifications at a time for biodiesel blend. The peak pressure was increased due to the raising of heat release, shorter combustion duration, and longer ignition

delay. Generally, mahua oil biodiesel having a low cetane number compared to diesel fuel

(Govinda Rao et al., 2018). The B20 was found to lower peak pressure compare to others due to low calorific value and high viscosity. But B20E5 (LHR+15%LTC) was shown reasonable peak pressure compared to diesel fuel.

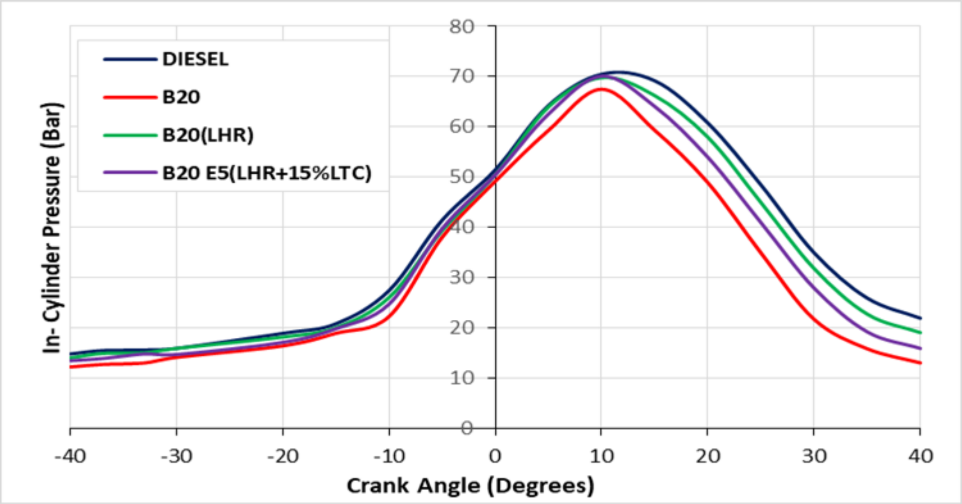

Figure 9 In-Cylinder Pressure Vs Crank Angles.

Impact on Heat Release

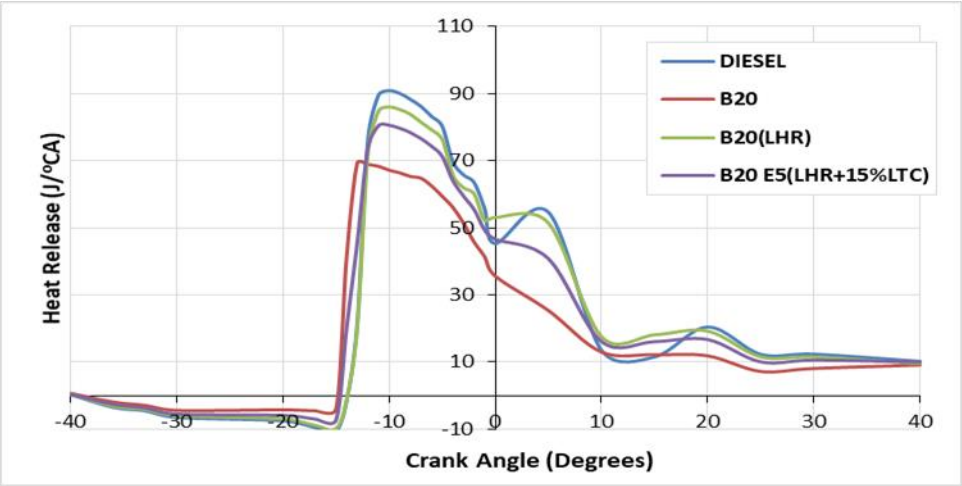

Figure 10 Heat Release VS Crank Angles.

Figure 10 shows Heat Release concerning the crank angle for different conditions of the diesel engine at 100% load. At the beginning of combustion, a negative heat release is revealed, which is owing to the delay in the vaporization of the gas collected during the delay in ignition (Senthil et al., 2015 & Michael A Penny and Timothy J Jacobs, 2016).

The heat release has become positive after the start of combustion. Overall, diesel fuel (90.9J/^{o}CA) has higher heat release than to other (B20, B20LHR and B20E5 (LHR+15%LTC)). The least heat release obtained in the B20 blend due to less calorific value and cetane number of biodiesel. Peak heat release of diesel, B20LHR, and B20E5 (LHR+15%LTC) were attained in the same crank angle (10^{o}CA BTDC) expect to B20 (69.36 J/^{o}CA at 13^{o}CA BTDC). B20LHR (86.04 J/^{o}CA) was the second-highest compared to the remaining conditions (Geo et al., 2017). Because implemented LHR engine to increase the performance of the diesel engine fuelled biodiesel. It seems that reasonable heat release was predicted in B20E5 (LHR+15%LTC) (80.6 J/^{o}CA) for applied two modifications and B20 blend in 5% of ethanol. It controls the heat release of the engine during the combustion to reduce the NO_x emissions. However, 15% of LTC applied to decrease NO_x emissions and increases efficiency. Compared to diesel fuel, 23.69%, 5.39%, and 11.32% were less heat release is achieved for B20, B20LHR, and B20E5 (LHR+15%LTC).

Impact on Ignition Delay

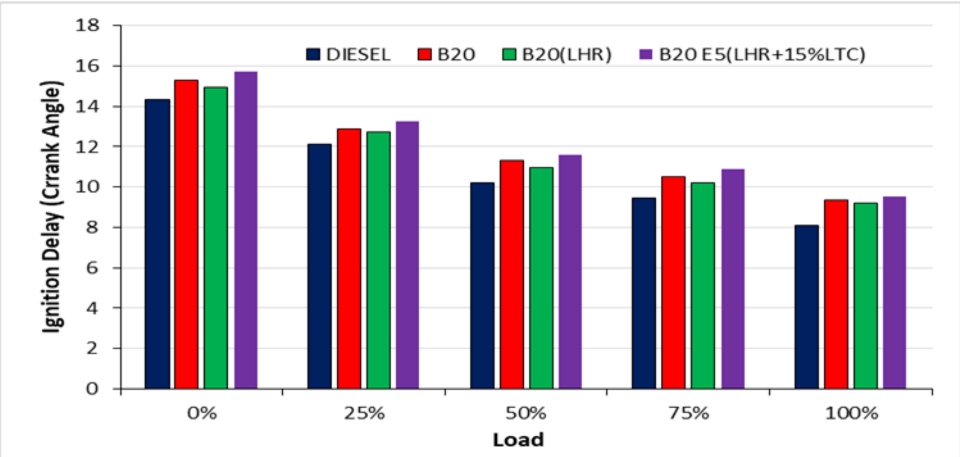

Figure 11 Ignition Delay VS Load.

Figure 11 shows the variation of ignition delay (ID) about different load conditions of a diesel engine fuelled diesel and biodiesel blend. From this graph, when the load increases and the ignition delay gradually reduces. It can be anticipated to compare four-engine conditions with different load conditions and comparable variation in the crank angle. The highest ignition delay was found to be 15.72^{o}CA at 0 % load in B20E5 (LHR+15 % LTC) and the minimum was 8.1^{o}CA at 100 % load in diesel fuel (Vinay kumar et al., 2012). Between 0% to 100%

load conditions, the graph from 25 % to 75 % load conditions and changes in ignition delay are nearly much nearer to it. Due to particular load conditions from 25% to 75 %, it is evident that the variation in engine load is more or less equal to the required values (Randazzo Mario, and Sodre Jose, 2011). While comparing the ignition delay (diesel, B20, B20 (LHR) and B20E5 (LHR+15 % LTC) the highest variation in diesel fuel was 43.55% from no load to full load. The rise in ignition delay with mahua oil biodiesel (B20) is due to the poor volatility and high viscosity, resulting in slow vaporization and blending.

HC Emission

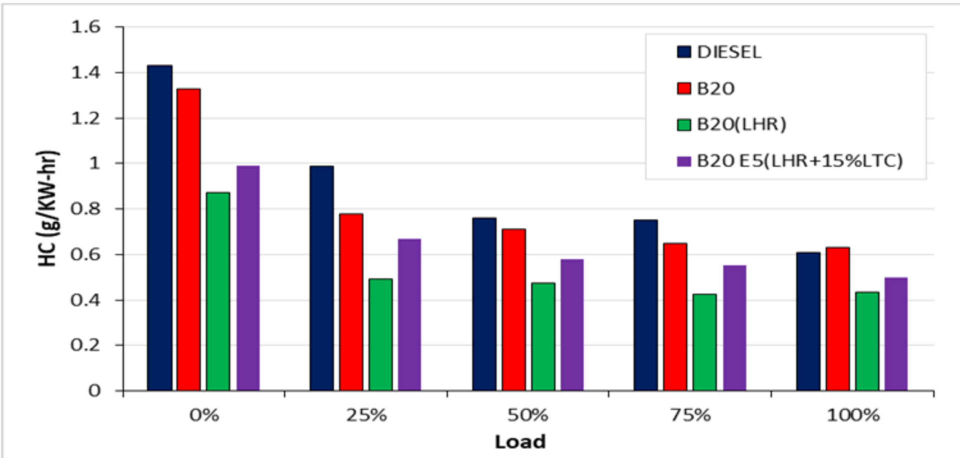

Figure 12 HC Emission VS Load.

HC emissions occur more due to the incomplete combustion of fuel. Commonly, it is a serious issue of diesel with lower load conditions (Govinda Rao et al., 2018). Figure 12 shows the variation of hydrocarbon (HC) emission with different load conditions for diesel, B20, B20 (LHR) and B20E5 (LHR+15 % LTC). Maximum HC emission levels were found in diesel compared to B20, B20 (LHR) and B20E5 (LHR+15 % LTC). While load rises were decreased with HC emissions. At full load, the HC concentration of B20 increased by 3.27 % and decreased by 29.28%, 18.36 % for B20 (LHR), B20E5 (LHR+15 % LTC) compared to diesel fuel. For mahua oil biodiesel has an oxygen content that increases the combustion temperature and reduces HC emissions (Michael A Penny and Timothy J Jacobs, 2016). It seems that lowest HC emission was shown in the B20 (LHR) in all load due to heat losses to coolant and outsides was reduced by ceramic coating in engine parts is lead to increases temperature of combustion (Senthil et al., 2015). However, in the B20E5 (LHR+15 % LTC) was noticed that a significant amount of HC emission produced at all load conditions. Because simultaneously using LHR and 15 % LTC is used to reduce HC emission. B20E5 (LHR+15 % LTC) is 16.27% higher than B20 (LHR) because of the use of 15%LTC and 5% ethanol in B20. Both LTC and ethanol will increase the level of HC emissions, but a sufficient amount will only be used in this study to decrease NO_x (C Srinidhi et al., 2019).

CO Emissions

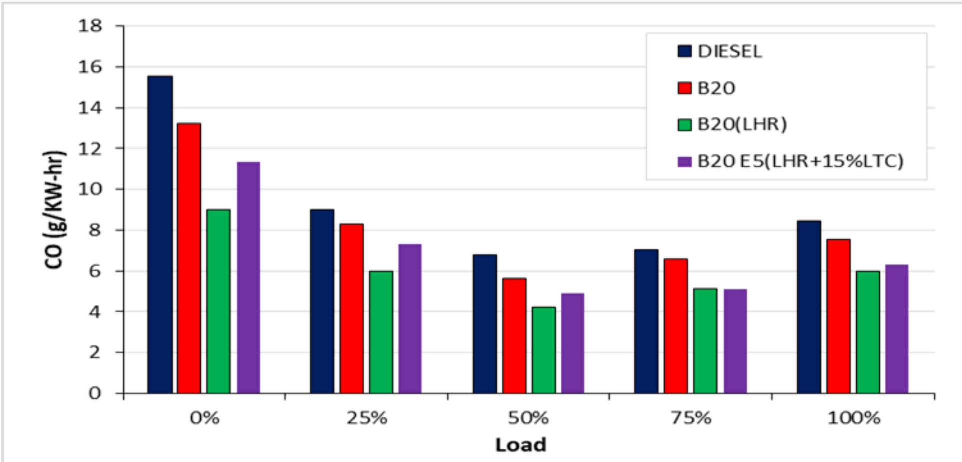

Figure 13 CO Emission VS Load.

CO emissions depend on the fuel properties and combustion characteristics of the diesel engine (Senthil et al., 2015). Figure 13 illustrates the variation of carbon monoxide (CO) emission with different load conditions for diesel, B20, B20 (LHR) and B20E5 (LHR+15 % LTC). Here also the same trend (Banapurmath and Tewari, 2009) of HC emissions due to both HC and CO emissions is generated due to incomplete combustion of fuel. Overall, the lowest CO emissions in all loads were noted in B20 (LHR) compared to diesel, B20, and B20E5 (LHR+15 percent LTC). Because the LHR engine raises the combustion temperature. While engine load rises are decreased with CO emissions (Ramadhas et al., 2004). Co-emissions for B20, B20 (LHR) and B20E5 (LHR+15%LTC) were decreased at 100 % load relative to diesel fuel by 10.99 %, 29.19 % and 25.39 % owing to oxygen content in biodiesel. Although in the B20 (LHR) and B20E5

(LHR+15 % LTC) values are very close in the 75% load. In B20E5 (LHR+15 % LTC) was achieved the CO emission level for acceptable in all load conditions due to implement the modification techniques like LHR and 15% of LTC (Kulkarni et al., 2011).

.NO_x Emission

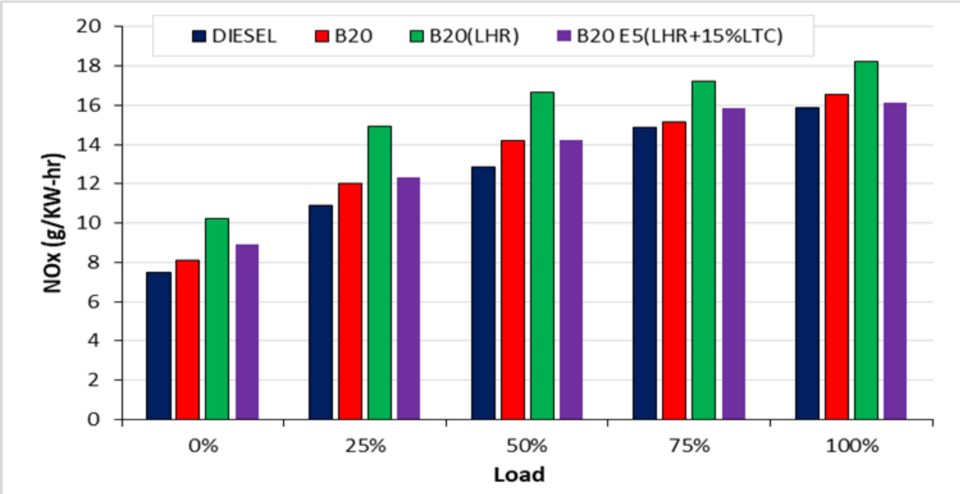

Figure 14 NO_x Emission VS Load.

Figure 14 illustrates the variation of NO_x emission with different load conditions for diesel, B20, B20 (LHR) and B20E5 (LHR+15 % LTC). From the graph, when engine load increases with NO_x emissions owing to the increase in combustion temperature, which indicates the temperature associated with the exhaust gas. It was revealed that, owing to the exhaust gas temperature of a coated engine fuelled mahua oil biodiesel, NO_x emission of B20 (LHR) was maximum at 100 % load which is 18.23g / KW-hr (Vamsi Krishna et al., 2018). In the diesel fuel, a minimum NO_x emission was achieved at a load of 0 % which is 7.51g / KW-hr compared to different load and fuel conditions. NO_x emissions for B20, B20 (LHR) and B20E5 (LHR+15%LTC) were increased at 100 % load relative to diesel fuel by 3.91 %, 14.95 % and 1.25 % owing to high combustion temperature. In particular, B20 (LHR) shows a higher percentage of NO_x emissions compared to others. Because B20 (LHR) has a high exhaust Temperature due to the heat retention of the ceramic layer in the engine. And also, it seems that the difference between diesel fuel and B20E5 (LHR+15 % LTC) at 100 % load condition was very small, which is 1.2% compared to others. Because the concept of LHR+LTC was introduced in the diesel engine and 5% of ethanol was also blended in B20 (Rakopoulos et al., 2006). It leads to a reduction in the exhaust gas temperature and is ascribed to a reduction in the NOx emission with biodiesel.

Smoke emission

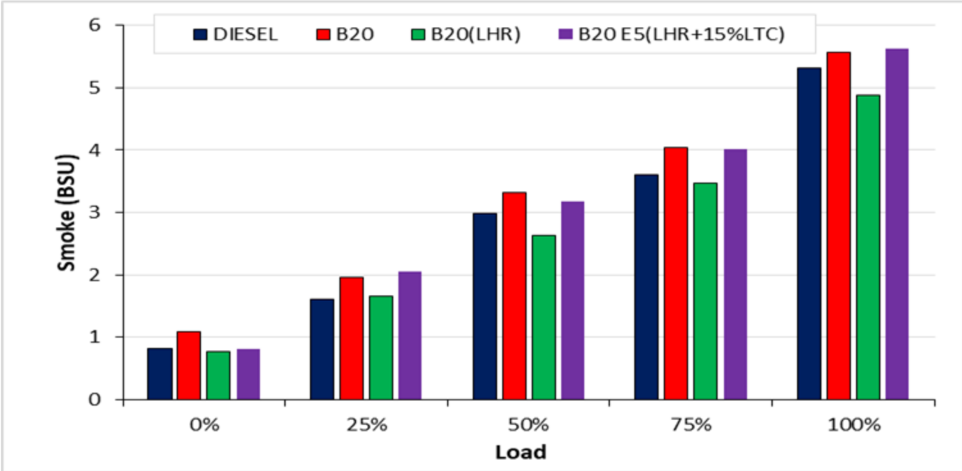

Figure 15 Smoke VS Load.

Smoke emissions were mainly dependent on air-fuel proportions and fuel characteristics (Govinda Rao et al., 2018). Figure 15 illustrates the variation of smoke emission with different load conditions for diesel, B20, B20 (LHR) and B20E5 (LHR+15 % LTC). It is evident that, in any load condition, B20 (LHR) shows less smoke (0.77 BSU) compared to others. Because the covered engine creates an elevated temperature of combustion that reduces the smoke in the engine (Srinidhi Campli, 2017). Due to elevated viscosity, low cetane number and calorific value in biodiesel, more smoke was observed in B20 (5.62 BSU). Smoke was generated attributable to a longer ignition delay in the biodiesel (Govinda Rao et al., 2018). At 100 % load, 4.84 % and 5.89 % more in B20 and B20E5 (LHR+15% LTC) compared to diesel (Randazzo Mario and Sodre Jose, 2011) Likewise, the smoke concentration in B20 (LHR) was 8.02% lower than in diesel fuel. Though, it was noted that B20E5 (LHR+15 % LTC) acquired a marginally higher variation in smoke for the implementation of LHR+LTC in the B20 engine mixed to 5 % ethanol.

CONCLUSIONS

Investigation of the present study was carried out by a single-cylinder diesel engine with a combined effect of LHR and EGR fuelled by diesel, mahua biodiesel (20%) and Ethanol (5%). And also compared with conventional diesel, biodiesel engine, and LHR engine. The following conclusions obtained through results and discussions.

- Compared to diesel fuel, B20E5 (LHR+15 % LTC) BTE is 3.48% increased. BSEC is 6.29% Decreased, EGT is 10.8% increased, HC is 18.36% decreased, CO is 25.39% decreased, NO_x is 1.2% increased and smoke is 5.89% increased.
- The increase in EGT and NOx emissions from LHR has decreased as a result of the implementation of the LTC.
- The findings showed an increase in BTE and also a decrease in the BSEC of the B20E5LHR+15%LTC, in particular when compared to diesel. The combustion peak pressure and heat release rate were similar to the unmodified diesel engine and higher than the uncoated B20 engine.
- LHR reduced smoke density and LTC increased smoke density. The net smoke density remained unchanged for the LHR+LTC engine fueled by B20 and was found to be lower than the diesel engine propelled by B20.
- Adding ethanol 5% in B20 was used to get complete combustion along with combined effect LHR and LTC methods implemented in the diesel engine.

Finally observed that modifications with both methods using at a time mean optimizing the fuel consumption and reducing the emission compared to other engines like B20, B20 (LHR).

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