Studies on Exhaust Emissions of a Low Heat Rejection Engine using Fish Oil - Diesel Blends

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Abstract: ***As part of research on alternate fuels, to avoid losing precious agricultural land to plant-based renewable fuel oils, fish oil from discarded parts of Fish has been used.To keep the combustion chamber hot enough to burn the viscous Fish Oil, low heat rejection engine has been fabricated and used. Experiments were conducted on a conventional Single Cylinder Diesel Engine too. The results clearly establish that Fish Oil can indeed be a good Bio-Diesel, without any major engine modifications, and a 20% Fish Oil-Diesel Blend on LHR Engine improves its performance by a good 16%, with better emission characteristics.***

Keywords: Fish Oil, Fish Oil Blends, LHR Engine, Exhaust Emissions

1. Introduction

Fossil fuel induced global warming is a growing concern since a few decades and several commitments and policies are being put in place by all the countries across the world to regulate the levels of greenhouse gases emitted to the atmosphere. Biofuel, based on Vegetable oils, has offered itself as an alternative to diesel usage since long, and had a big advantage of being a renewable source of energy. This led to a lot of precious agricultural land being diverted to production of the fuel based plants, impacting directly on agricultural output. Research focus moved onto non-plant based fuels renewable in nature, such as algae and fish oil. A lot of research has been done on the use of blends of fish oil biodiesel in compression ignition engines, and encouraging results are reported. Although the thermal efficiency is found to decrease a little, considerable improvements have been shown on the emissions front.

Largely, the properties of vegetable oils fall within a common narrow range and are close to those of diesel fuel. Vegetable oils have about 10-20% lesser heating value than diesel because of the presence of oxygen in their molecular structures. The relatively high kinetic viscosity, compared to pure diesel, leads to pumping and atomization problems. They have high viscosity, and have poor volatility characteristics. Due to these characteristics, the required heat in the combustion chambers cannot get maintained to burn the high density alternate fuels. This in turn opened up research opportunities on low heat rejection (LHR) diesel engines. Almost two thirds of the heat energy generated by the fuel is lost out to the coolant and to the exhaust, thereby leaving only about a third of the useful power output for utilization. Out of the total amount of heat rejected by the engine to the coolant the major contributors were found to be the piston and the liner. The target for the researchers on LHR engine was to regain and reduce some of the heat loss to the coolant, thereby improving the thermal efficiency of the engine.

Large number of studies were performed by various researchers on LHR engines, related to engine performance, build and durability. The aim was to improve efficiency, increase energy availability in the exhaust conduit and reduce heat transfer. Several concepts of LHR engines emerged, using different techniques such as ceramic coated components, air gap as an insulator in the Piston and liner components, etc. Out of the total amount of heat rejected by the engine to the coolant the major contributors were found to be the piston and the liner.

The current paper brings out the various studies conducted multiple emission parameters, using Fish Oil Blends with Diesel, experimented on both Conventional Engine (CE) and Low Heat Rejection Engine (LHRE).

2. Literature Survey

The concept of utilizing crushed oil from fish after being processed, dawned the era of experimenting with fish oil as an alternate for plant-based biodiesel. Fish based biodiesel is under experimentation in select parts of the globe particularly Canada and Alaska regions. As per the reports of 'New Agriculturist' [1], published a decade ago, 21 million gallons of fish oil are produced annually at Alaska shore based fish processing plants alone and yet two-thirds if it is currently being discarded. Fish waste degrades rapidly if not processed immediately and in turn loses its value which otherwise could have at least been used for animal feed.

T Hari prasad et al [2] studied the combustion performance and emission analysis of a diesel engine fueled with methyl esters of fish oil and found that the brake thermal efficiency slightly reduced while the hydrocarbon carbon monoxide and smoke emissions in the exhaust gases reduced. The NOX emissions where observed to be higher when fueled with methyl esters compared to diesel.

However the studies conducted by Sergeyi Ushakova [3] et al observed that fish oil showed very good ignition and combustion properties compared to conventional fuel. While carbon monoxide and total hydrocarbon and smoke emissions reduced, NOx and carbon dioxide remained almost unaffected. This study also advocated that by using fish oil as a fuel 80% reduction in particulate matter mass emissions can be achieved..

Another study conducted by Reddy Rana Pratap et al [4] on DI compression ignition engine operated on marine fish oil as biodiesel, indicated that the maximum thermal efficiency for 20% blend was at 32.28% which is higher than that of a diesel at rated load. The experimental results showed that the engine performance was close to the values obtained from diesel fuel and the amount of exhaust emissions were lower than those of diesel fuel.

Shrikanth H V[5] et al conducted studies on the performance and emission characteristics of conventional diesel, using fish oil as biodiesel, and diesel-biodiesel-ethanol blends on a single cylinder diesel engine. The conclusions of this investigation are as follows: The maximum brake thermal efficiency was higher than diesel fuel by 13.32% and 10.11% higher than fish oil biodiesel with the blend DE15B10. The BSFC of the biodiesel and all the other fuel blends was higher than that of the diesel fuel. The exhaust gas temperatures of the blends were lower than that of diesel fuel throughout the range of the load on the engine. The CO emissions reduced by 50% than the conventional diesel with the blend of DE15B10 at maximum load of engine. The HC emissions increased with the increase of ethanol percentage in diesel-biodiesel-ethanol blends, but lower than those of the diesel at higher loads on the engine. The NOx emissions of the biodiesel and all the other fuel blends were low at lower loads and high at higher loads compared with the diesel fuel. Smoke emissions is found to increase in B100 and fossil diesel, and as the percent of ethanol increases in the blends the smoke emissions decreased.

The thermal conductivity of air is in the order of point 0.026 W/m-K, and hence is a bad conductor of heat. This caught the attention of many researchers to use Air-gap ad a good insulation in the Piston and other components of the combustion chamber to form an LHR Engine.

Parker [6] experimented the concept of an air gap insulated piston by using bolting and welding techniques. Crowns welded to the pistons indicated that the air gap insulation was more effective and robust in providing reasonably good sealing to the air gap necessary to maintain the insulation, when compared to the bolted design. Prolonged running hours of the engine was possible with the air gap piston which continuously indicated reduced heat flow to the crown by an average of >30 %. Design improvisations are still on to achieve a 50% reduction in the heat flow.

K Kumar Sekharan et al [7] constructed a composite Piston made of a Crown piece fitted to the base of the piston with the gasket in between, and conducted steady state 2D thermal analysis to obtain thermal stress distribution. Pure mechanical stress analysis also was performed on the piston. These experiments proved that the Crown temperature increased by around 60% with the air gap insulated Ultra high strength Steel piston compared to standard aluminum single piece piston, while the heat loss through the Crown also reduced by about 25%.

Similar research work was also done by Y B Safdari [8], where the air gap insulated piston design uses composite gasket in between the crown piece and the piston body. Variations to these experiments were also conducted using a composite crown and air gap with aluminum base, an Aluminum composite Piston without air gap, and an Aluminum composite Piston with air gap, etc. All these combinations were subjected to a two dimensional thermal analysis using finite element method, and found that the heat loss reduction ranged from 17% to 60% while the crown temperatures increased in the range of 16 to 75%.

Ramamohan et al [9] used a completely different technique to seal the air gap insulated piston with the crown. Instead of using bolts or welding technique this design considered screwing the Crown as a cap to the Piston body with the desired air gap covering most of the under crown area. It was found that the exhaust gas temperature increased and brake specific fuel consumption decreased up to 80% of the full load conditions.

Several researchers attempted using varying materials of different thermal Properties to be used as the Crown of the piston, in order to achieve the aim of an LHR to reduce the heat loss to coolant, especially from the piston to the body of the piston. Much of the research went into to identifying the right material for the Crown of the Piston with the low thermal conductivity yet having the necessary strength to absorb the thermal shocks.

3. Methodology

The experiments have been carried out on a single cylinder 4-stroke constant speed Diesel Engine, (a Conventional engine with conventional piston and liner). The test engine has an aluminum alloy piston with a bore of 80 mm, and a stroke of 110 mm. The rated output of the engine is 3.7 kW at a rated speed of 1500 rpm. The naturally aspirated engine is provided with a water cooling system with thermostats to measure inlet and out temperature. The same engine was fitted with an air-gap piston (fabricated by fitting an SS-316 insert as the Piston crown, in such a way that a 4 mm air gap is uniformly maintained between the insert and the piston body), to act as a Low Heat Rejection engine.

Current research work has been attempted using Fish Oil blends of 20, 40, 60, 80, and 100% by volume, using conventional engine and LHR Engine. Table-1 below is the chemical analysis of Methyl Esterified Fish Oil (MEFO) and its comparison to Pure Diesel Vs the Refined Fish Oil sourced initially.

Table 1: Chemical Properties of Diesel and MEFO

Properties	Diesel	MEFO	Refined Fish Oil
Specific gravity	0.85	0.88	0.924
Kinematic viscosity- 40°C (cst)	3.07	4.97	21.4
Flash point (°C)	56	152	>300
Calorific value (KJ/kg)	44800	40839	36180
Density (kg/m3)	850	880	923.60

The Calorific Value for each Fish Oil Blend (FOB) was mathematically computed, corresponding to the volumetric proportion of each blend used. Each of the five blends was tested at different load conditions. The results are compared with pure diesel operation tested on the same engine. Various exhaust emission parameters like Unburnt Hydro Carbons, Carbon Monoxide, Smoke and Nitrous Oxides have been measured for varying power outputs.

Detailed analysis was done by operating the same set of fuel blends under the following conditions.

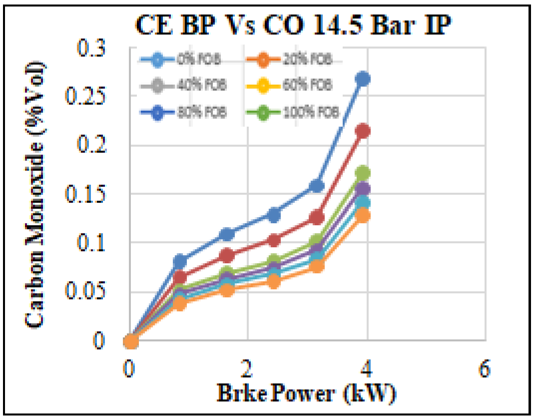
i) On a Conventional diesel Engine (CE).
ii) On a Low Heat Rejection (LHR) Diesel Engine,
iii) By varying the Injection Pressures from 190 psi to 230 psi on CE
iv) By varying the Injection Pressures from 190 psi to 230 psi on LHRE
v) By varying the Compression Ratios from 14 to 20 on CE

4. Results and Discussion

The performance evaluation of fish oil on the two engine variants - Conventional Engines (CE) and LHR Engines (LHRE) - covering various pollution parameters, at different operating conditions such as the OEM recommended injection pressure and Compression ratio, varying injection pressures, and varying Compression ratios - was conducted.

Carbon Monoxide:

The carbon monoxide emission vs Brake Power for diesel and biodiesel blends are presented in Figure-1. Carbon Monoxide emissions are a product of incomplete combustion due to the insufficient amount of air in the air-fuel mixture or insufficient time in the cycle for the completion of combustion.



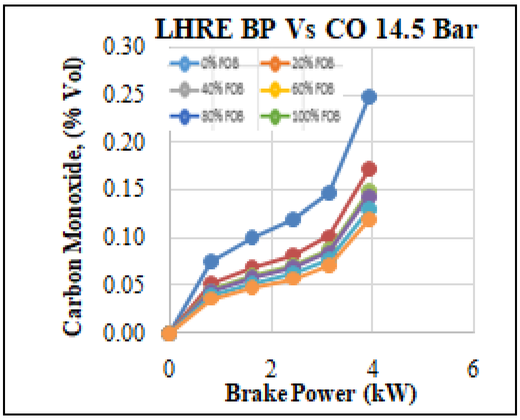


Figure 1: BP Vs CO Emissions with CE and LHRE at 14.5 Bar IP

The maximum CO produced at increasing bends of Fish Oil for Diesel, 20FOB, 40FOB, 60FOB, 80FB and 100FOB respectively are 0.27%, 0.22%, 0.17%, 0.16%, 0.14%, 0.13% in CE and 0.25%, 0.17%, 0.15%, 0.14%, 0,13% and 0,12% in LHRE respectively, as depicted in Figure-2.

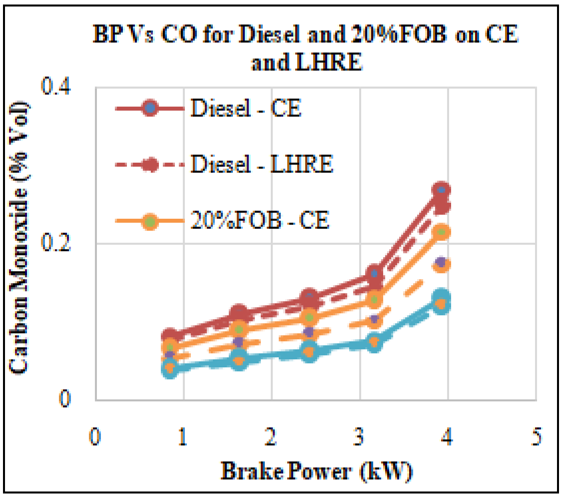


Figure 2: BP Vs CO Emissions for Diesel & MEFO with CE & LHRE

It is an indication that as FOB percentage increases in the fuel, complete combustion of biodiesel occurs due to the presence of better oxygenated fuel. The decrease in carbon monoxide emission for biodiesel and its blends is due to more oxygen molecule present in the fuel as compared to that of diesel.

Figure-3 shows the CO emissions vs Brake Power for different FOBs at different Injection Pressures, both for CE and LHRE variants. It is observed that the CO emissions decrease with increase in the Injection Pressures for all the blends of fuel. The CO emissions for diesel, 20FOB, 100FOB with CE and with LHRE variants ranges from 0.28 to 0.18 % by Volume at 13 Bar, from 0.27 to 0.12 % Vol at 14.5 Bar and 0.25 to 0.11% by Vol at 16 Bar respectively, at full Brake Power.

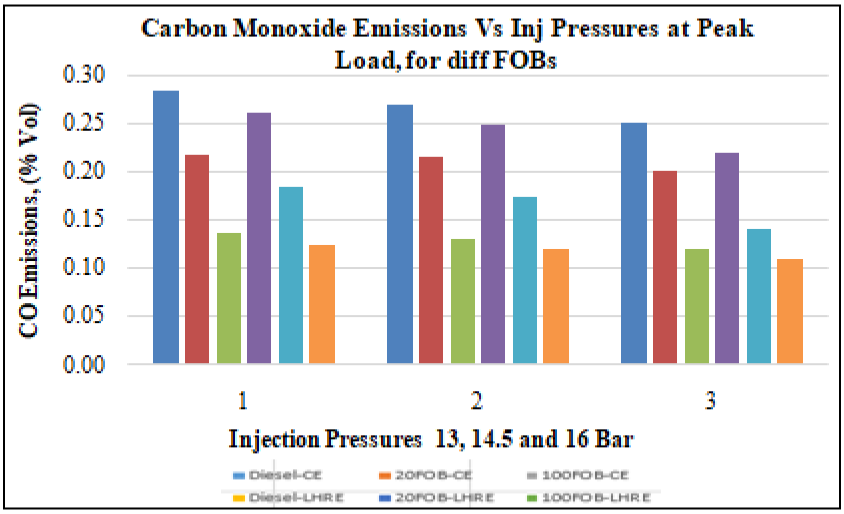


Figure 3: CO Emissions with CE and LHRE at different Injection Pressures

Figure-4 shows the CO emissions for all compression ratios tested at rated speed of 1500 rpm. Compression ratio (CR) 18 has the lowest CO among all Compression Ratios as shown in the fig. CO emissions decreased with increase of Compression ratio (CR) up to 18.

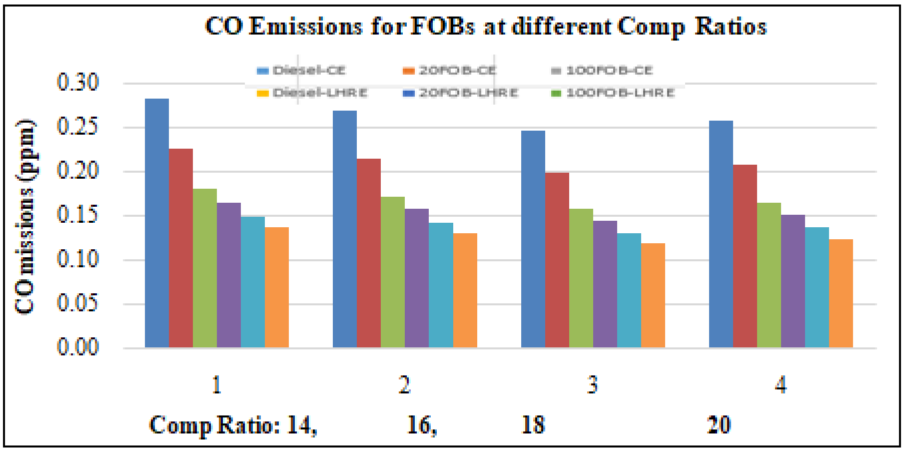


Figure 4: CO Emissions at different CRs for Diesel & FOBs with CE & LHRE

Unburnt Hydrocarbons:

Hydrocarbons unburned on or areas around the cylinder walls that are at a relatively low temperature, form UnBurnt Hydrocarbons (UBHC), as the flame does not propagate well into these areas. This is predominantly due to uneven temperature distribution across the cylinder, and also due to ignition delay period.

The un-burnt hydrocarbon emissions (UBHC) vs Brake Power for different biodiesel blends on CE and LHRE variants are shown in Figure-5. It can be observed that the UBHC decreases as the blends move form Diesel to complete Fish Oil, in both engine variants, CE and LHRE.

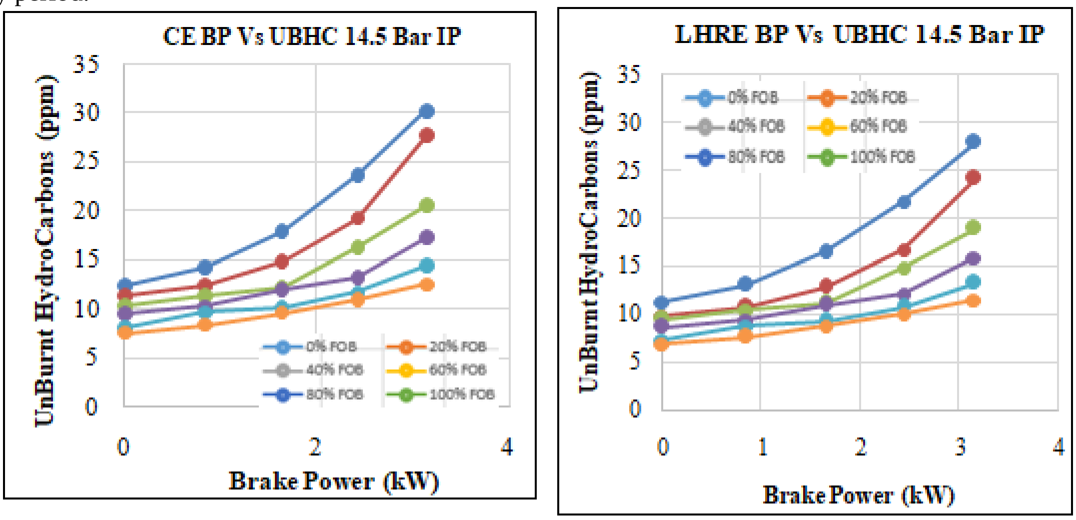


Figure 5: BP Vs UBHC with CE and LHRE at 14.5 Bar IP

This can be attributed to the fact that there is relatively higher availability of oxygen in the fish oil blends, leading to better combustion and hence better temperature to completely burn the fuel.

Figure-6 compares UBHC Vs Brake Power, for Diesel, 20%FOB and 100% Fish Oil, on CE as well as LHRE.

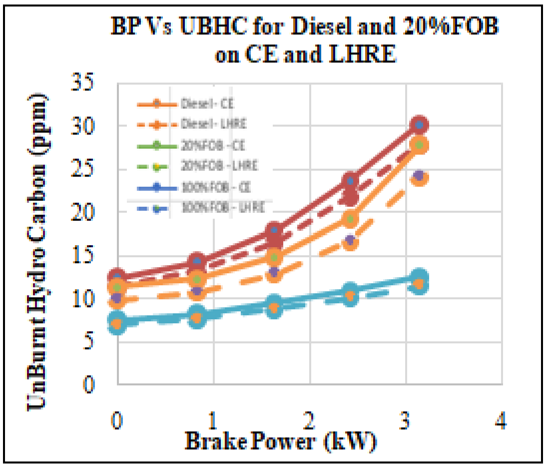


Figure 6: BP Vs UBHC for Diesel & MEFO with CE & LHRE

It can also be observed that the UBHC magnitudes are relatively lesser in LHRE variant of the engine, against because LHRE offers heat retention within the cylinder, leading to further temperatures. It can be seen that the UBHC for a Diesel with CE is 30 ppm while for LHRE it is 28 ppm, indicating an improvement of 7% when LHRE is used. However, with Fish Oil blended into Diesel, it can be seen that the UBHC for a 20%FOB with CE is 28 ppm while for LHRE it is 24 ppm, indicating an improvement of almost 15% when LHRE is used.

Figure-7 shows the UBHC emissions vs Brake Power for different FOBs at different Injection Pressures, both for CE and LHRE variants. It is observed that the UBHC emissions increase with increase in the Injection Pressures for all the blends of fuel.

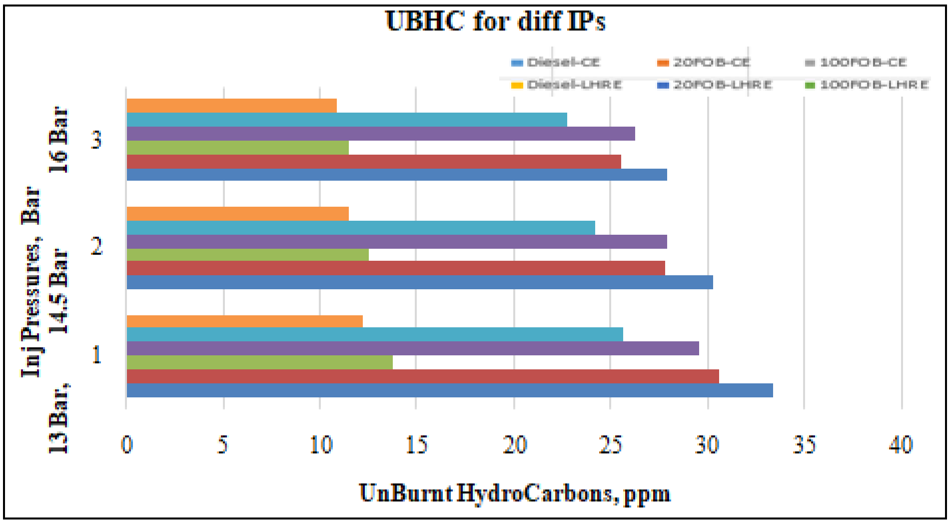


Figure 7: UBHC Emissions with CE and LHRE at different Injection Press

The UBHC emissions for diesel, 20FOB, 100FOB with CE and with LHRE variants ranges from 33 to 12 ppm at 13 Bar, from 30 to 12 ppm at 14.5 Bar and 28 to 11 ppm at 16 Bar respectively, at full Brake Power.

Figure-8 shows the Unburnt Hydrocarbon (UBHC) for all compression ratios with engine Brake Power at rated speed of 1500 rpm. Compression ratio (CR) 18 is observed to have the lowest UBHC amongst all Compression Ratios as shown in the fig. UBHC continuously decreased with increase of Compression ratio (CR) up to 18.

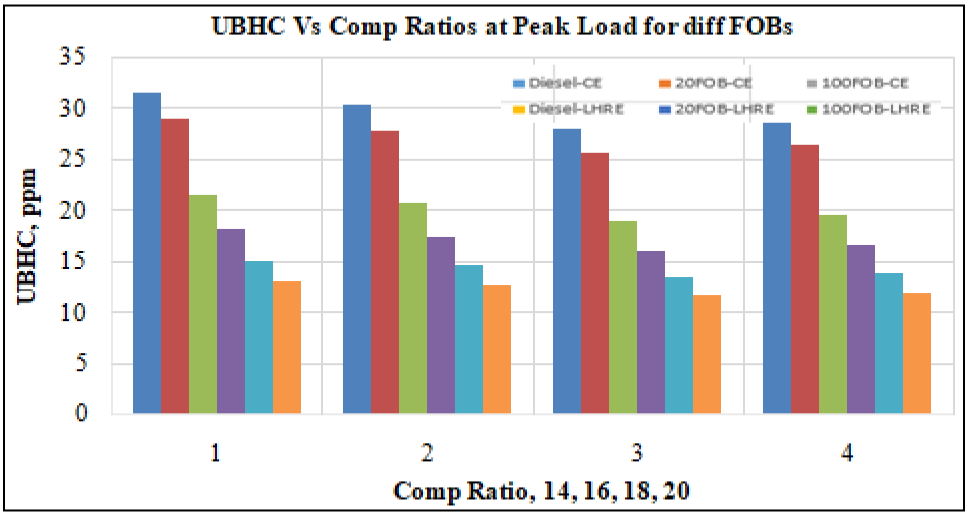


Figure 8: Peak Load UBHC Emissions at different Compression Ratio

Nitrous Oxides:
The nitrous oxide emissions vs Brake Power for biodiesel blends are presented in Figure-9. The formation of nitrogen oxides is mainly effected by the cylinder gas temperature and the actual availability of oxygen during combustion process.

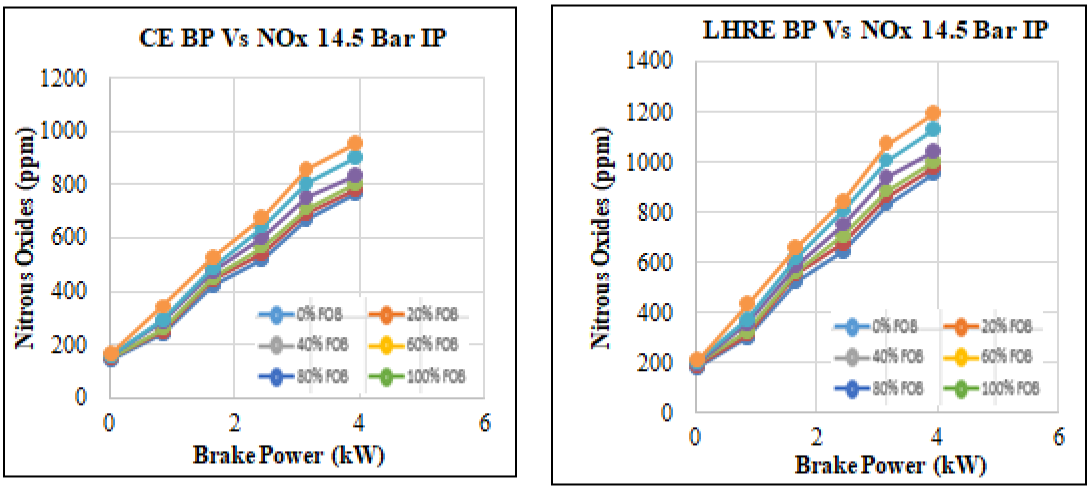


Figure 9: BP Vs NOx with CE and LHRE at 14.5 Bar IP

It is seen that there is significant increase in NOx emissions as Fish Oil Blend percentage increases, due to more number of oxygen atoms present in Methyl Esterified Fish oil blends.

Figure-10 compares NOx Vs Brake Power, for Diesel, 20%FOB and 100% Fish Oil, on CE as well as LHRE.

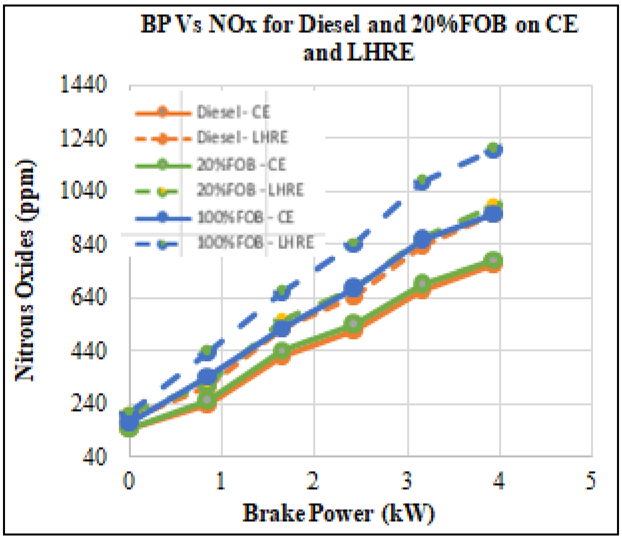


Figure 10: BP Vs NOx for Diesel & MEFO with CE & LHRE

In line with the above theory, the Nitrous Oxides (NOx) in CE for 20FOB is 785 ppm and for 100FOB is 957 ppm whereas for the diesel it is 767 ppm at full Brake Power conditions. The same in LHRE variant for 20FOB is 982 ppm and for 100FOB is 1196 ppm whereas for the diesel it is 959 ppm.

Smoke:

The smoke emissions vs Brake Power for CE and LHRE variants are presented in Figure-11. The exhaust of the diesel engines contains solid carbon particles generated in the rich fuel zones within the cylinder during combustion. These are observed as exhaust smoke and cause an undesirable odorous pollution, and are measured in Hartridge Smoke Units (HSU). As can be observed in the figure below, the smoke emissions increase with the Brake Power for all fuel blends as a common trend.

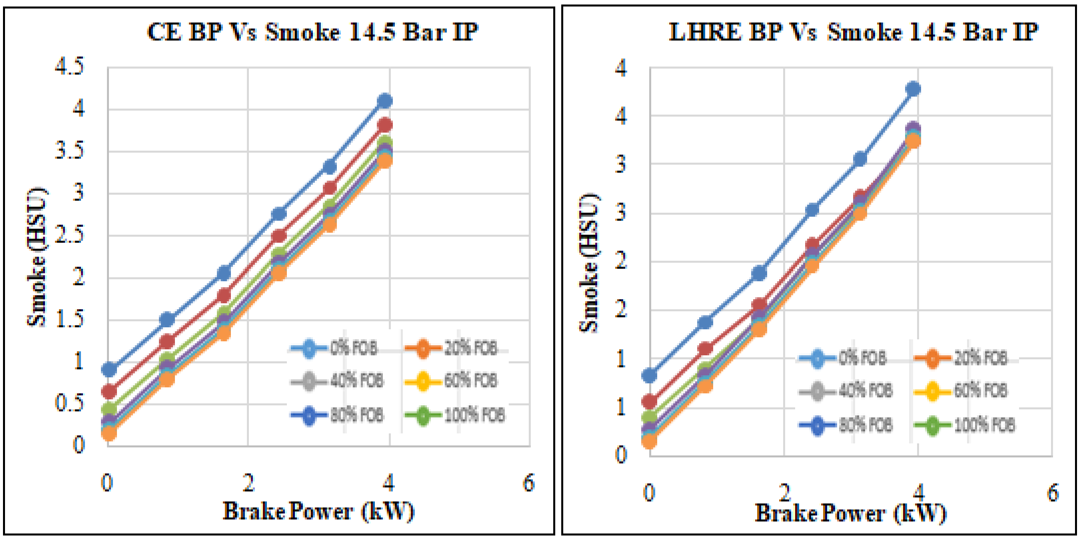


Figure 11: BP Vs Smoke with CE and LHRE at 14.5 Bar IP

The smoke density in a CE for diesel is 4.1 HSU at full Brake Power, whereas for 20FOB and 100FOB it is 3.8 HSU and 3.4 HSU respectively, at full Brake Power. The reduction in smoke for biodiesel blends is due to more oxygen atoms present in the biodiesel, resulting in better combustion of biodiesel.

The smoke density in a LHRE for diesel is 3.8 HSU at full Brake Power, whereas for 20FOB and 100FOB it is 3.3 HSU and 3.2 HSU respectively, at full Brake Power.

Figure-12 compares NOx Vs Brake Power, for Diesel, 20%FOB and 100% Fish Oil, on CE as well as LHRE.

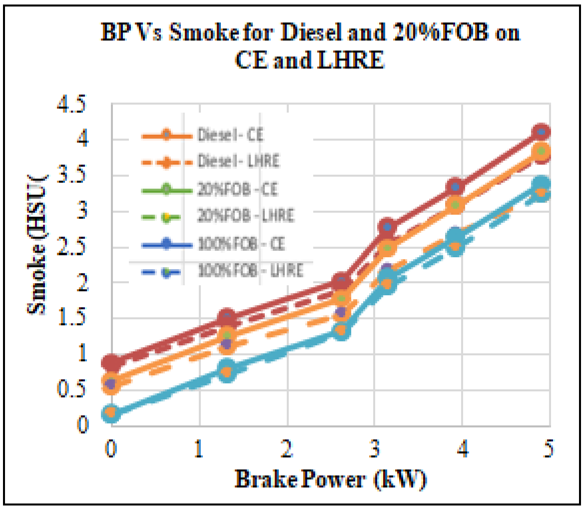


Figure 12: BP Vs Smoke for Diesel & MEFO with CE & LHRE

Fish Oil blends indicate lesser Smoke emissions compared to Diesel, in both CE and LHRE.

5. Conclusion

- Carbon Monoxide Emissions with Methyl Esterified Fish Oil on a LHRE is more than 50% lesser compared to pure Diesel operations. This is due to availability of higher O2 content in FOBs compared to Diesel, allowing complete combustion with FOBs.
- Unburnt Hydro Carbon Emissions with Methyl Esterified Fish Oil on an LHRE is about 60% lesser compared to pure Diesel operations. This is due to availability of higher O2 content in FOBs compared to Diesel, in addition to LHRE providing better combustion chamber heat retention to facilitate complete combustion with FOBs.
- Nitrous Oxide (NOx) Emissions of pure Methyl Esterified Fish Oil on a CE as well as LHRE are about 25% higher compared to pure diesel. This is due to the contribution of higher amounts of Oxygen in the FOBs leading to higher Nitrous oxides getting liberated.
- Carbon Monoxide Emissions with Pure Diesel and FOBs decrease significantly, proportional to the Injection Pressures on a CE as well as an LHRE. For instance, CO emissions reduced by 12% in CE as well as LHRE, when compared at 13 Bar and 16 Bar. This is due to the higher vaporization possible for better combustion, with increase in Injection Pressures.
- Unburnt Hydro Carbon Emissions with Pure Diesel and FOBs decrease significantly, proportional to the Injection Pressures on a CE as well as an LHRE. For

instance, UBHC emissions reduced by 16% in CE and about 11% in LHRE, when compared at 13 Bar and 16 Bar. This is due to the higher vaporization possible for better combustion, with increase in Injection Pressures. It can be noted that the impact of Injection Pressure rise is not as significant in LHRE, as LHRE already provides some of the conditions suitable for complete combustion such as higher chamber temperatures.

- The CO Emissions of Pure Diesel and FOBs decrease proportional to the Compression Ratios on a CE as well as an LHRE, at an average rate of 9% for every change in CR by 2 units. However, the maximum drop in emissions is found to be with a CR of 18:1, at 12%. This can be attributed to a possible behavior of mass flow of fuel in CRs higher than 18:1, where, the residence time is not enough to completely burn and convert fuel into heat energy.
- The UBHC Emissions of Pure Diesel and FOBs decrease proportional to the Compression Ratios on a CE as well as an LHRE, with the maximum drop in emissions being with a CR of 18:1, at 11%.

6. Future Scope

- Further investigations can be done to ascertain the behavior of Fish Oil Blends with varying ignition timing btdc.
- The experimentation can be conducted on multi-cylinder diesel engine, to asses the practical usage of the Fish Oil Blends in future.

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