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Research Article

# Influences of iso-amyl nitrate oxygenated additive on mahua methyl ester/diesel blends thermal stability and crdi engine performance characteristics

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## ABSTRACT

Mahua oil is a remarkable fuel since it has a similar calorific value to diesel and has similar viscosity, flash point, and boiling points to diesel. However, since mahua oil has a lower cetane number than diesel when utilized as a blend, it displays a longer ignition delay and a greater peak heat release rate, resulting in higher NOx emission. To decrease the negative impact of mahua oil on NOx emission, an effort is made to introduce the ignition improver in different proportions (i.e., 5-20% by vol). Due to its higher latent heat, IAN shows some adverse effects on performance and emission outcomes. An investigation is conducted on a CRDI engine using mahua methyl ester blended with diesel by adding oxygenated additives to the engine characteristics. The emissions like HC, CO, and smoke were reduced by 16.32, 23.56, and 23.12%. The improved combustion process increases NOx and CO2 emissions by 13.62 and 19.89%. Also, an increase in HRR and CP values was noticed at full load operation. Additionally, it is observed that the engine's performance is enhanced using 15% Iso-amyl nitrate (IAN), indicating that the IAN blend is a useful ignition improver for mahua oil and diesel blends.

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## INTRODUCTION

Petroleum supplies, which account for most of the world's energy resources, significantly influence global politics and the global economy. Global energy consumption is rapidly increasing as a consequence of widespread fuel use. Alternatives to conventional fuels, including biodiesel, have been developed due to growing environmental concerns and the depletion of fossil fuel supplies worldwide. The development of diesel engines and the discovery of biodiesel occurred around the same period. The diesel engine was created by Rudolf Diesel (1858–1913), who also experimented with using peanut oil in his engine [1]. Due to their high viscosity, vegetable oils have several drawbacks

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when used in diesel engines, including trumpet formation, glazing, and injector choking. Additionally, this promotes the development of engine deposits and poor atomization [2]. Vegetable oils may have their viscosity reduced via processes like pyrolysis and transesterification. The phrase "biodiesel" was first used in a study published in 1988 and was then often used after that. Transesterification is the process of producing fatty acids or long-chain fatty acid alkyl esters [3]. Due to its low calorific value, glycerine in the oil is one of the significant contributors to carbon deposits in diesel engines. Glycerine should thus be taken out of glyceride oils. Without changing the engine, diesel fuel and biodiesel may be mixed [4,5]. It can be seen that most engine manufacturers include biodiesel on their warranty cards.

It is simple to mix biodiesel with conventional fuel such that it may be utilised effectively either in a mixed form with diesel fuel or straight up as biodiesel [6]. Codes are used to indicate the volumetric % of mixed biodiesel. The literature analysis revealed that the proportion of methyl ester in a gasoline mix determines how much fuel is used. Additionally, the smoke and carbon monoxide were decreased (apart from NOx) since the heating value of the fuel was lower than that of regular diesel fuel [7–13]. To evaluate the emission and performance characteristics of a diesel engine, Tuccar et al. [14] and Ozener et al. [15] employed biofuels and their blends (soybean and Pongamia pinnata) as the fuel. They discovered that using biodiesel and biodiesel blends resulted in a slight reduction in braking power levels. Additionally, it was discovered that NOx emissions were rising while hydrocarbon and carbon monoxide emissions were down. The combustion study showed that using a blend of regular diesel and biodiesel reduced the pre-mixed peak and ignition delay. Mahua oil-based biodiesel was blended and utilized to power a Ricardo E6 engine to study the engine's performance characteristics (Ghadge and Raheman) [16]. Mahua biodiesel was determined to have characteristics that fall within the ASTM D 6751 standard limitations. The CRDI technology allows the diesel engine to be operated at injection pressures up to 200 MPa, which produces a quieter and more refined engine that is better for the environment [17]. By properly atomizing the fuel injected with the proper Pinj, complete combustion of the fuels may limit the release of contaminants [18]. Due to rapid evaporation and the use of the most available air, combustion efficiency may be increased with this approach [19]. Kumar et al. [20] experimented using a diesel engine running on biodiesel (B100) at various Pinj (160–180 kgf/cm$^2$). The findings made it evident that the BTE of the biodiesel rose significantly when the Pinj was raised at peak load. To investigate the effects of conventional diesel engines on combustion and atomization properties, Lee et al. [21]. It was shown that the improved physical characteristics of biodiesel caused the Weber number to fall, reducing the injection velocity of fuels blended with biodiesel. Additionally, it was shown that when the mix ratio rises, so does the average droplet size. The spray tip's penetration was discovered to be somewhat longer when the Pinj was elevated. Kuti et al. [22] experimented using a CRDi diesel engine and palm biodiesel to examine the combustion characteristics and spray production. Because biodiesels have a high cetane number, there is less ignition delay, and more fuel ignites quickly. Bakar et al. [23] investigated how fuel Pinj affected the engine's performance. According to the findings, the engine's peak performance was recorded at 220 bars of Pinj. The combustion period is shortened, and the fuel's penetration length is lengthened as Pinj rises [24]. The waste cooking oil was more suited than other non-edible biodiesel variations because of its simple accessibility, high BTE (break brake thermal efficiency), reduced BSFC, and better emission characteristics, cetane number, and viscosity.

Subramanian et al. [25] investigated the influence of oxygenated additives blended with camphor oil in different proportions on DI diesel engines and reported that 10% of eugenol reduced harmful pollutants like smoke and NOx emissions. Devarajan et al. [26] investigated the influence of cyclohexanol (CH) in different proportions blended with biodiesel (neem oil) to assess the engine characteristics. They reported that using the additives, even though ID is reduced but a decrease in the CP is also observed. Also, CH30% harmful pollutants like HC, CO, and smoke were reduced drastically by 16.34%, 21.8%, and 24.23%, respectively. Mack et al. [27] investigated the influence of DEE and DTBP in different proportions blended with low viscous alcohol to assess the engine characteristics. They reported using the additives even though peak CP is achieved before TDC, HRR duration is significantly less. Devaraj et al. [28] investigated the influence of DEE (5% and 10% by vol) to enhance combustion characteristics by blending with plastic oil on the CRDI diesel engine. They reported that with 10% DEE maximum BTE and minimum BSFC are observed compared to pure diesel. However, due to DEE's inclusion, higher HC and CO emissions are observed compared to plastic oil. Ramalingam et al. [29] experimentally investigated the influence of amona methyl ester (AME) blended with 1,4-dioxane on the engine characteristics. They reported that by using additives, better ignition temperature is achieved, resulting in a decrease in ID period leading to the enhancement of CN. Musthafa [30] investigated the influence of DTBP blended with palm oil on the modified diesel engine and reported that the maximum BTE is achieved, and the BSFC is decreased drastically. Also, the engine pollutants such as HC, CO, and smoke are decreased considerably. Nanthagopal et al. [31] investigated the influence of Calophyllum Inophyllum oil blended with different proportions of DEE on DI diesel engines. They reported that as the proportion of DEE is increased, BTE is decreased; however, engine pollutants are reduced drastically. Musthafa [32] investigated the influence of DTBP blended with palm oil (20%) on the modified diesel engine and reported that the maximum BTE is achieved, and the

BSFC is decreased drastically. Also, the engine pollutants such as HC, CO, and smoke are decreased considerably [33,34].

The operating settings were optimized to enhance the engine's performance and emission results. Even though the results significantly improved, the MME biodiesel blends could not demonstrate a sufficient improvement to approach close to diesel fuel. Thus, proving the apparent cause for the MME biodiesel blends inability to function at its peak level even if it had all the necessary qualities, much like diesel fuel. The decreased cetane value of gasoline might be the major cause of this. According to a literature review, using gasoline with a higher cetane rating may enhance the fuel's performance and emission results while also enhancing its quality. 2-ethylhexyl nitrate (EHN) and iso-amyl nitrate (IAN) are therefore selected as prospective ignition improvers from the literature after a comprehensive analysis. As both additions had the potential to provide positive effects, they were blended with mahua methyl ester blend in various ratios to compare them and determine which ingredient was most effective and best suited for biofuel.

## EXPERIMENTAL SETUP

A Kirloskar single-cylinder water-cooled, the compression-ignition diesel engine was used for all the trials in this investigation [Figure 1]. The engine's rated output is 5.2 kW at a steady 2000 rpm. To regulate the loading levels, it is directly connected to a water-cooled eddy current dynamometer. Table 1 contains information on the engine's precise specifications. An electronic fuel injection system has been retrofitted onto this engine. The current diesel engine is modified by attaching all necessary sensors and actuators, including the rail pressure sensor, coolant temperature sensor, cam position sensor, and mass air flow sensor. A rail pressure sensor, a high-pressure injector, a high-pressure pump, and a pressure regulating valve are fitted to the engine to install the common rail injection system [35,36]. The electronic fuel injection system's sensor outputs are all coupled to an open ECU system. The FIP, FIT and CR are all under the direction of this electronic control unit. The solenoid high-pressure injector has a pressure range of 500 to 1000 bar for fuel injection. A Kistler piezoelectric pressure sensor was used to detect the changes in pressure within the cylinder at each position of the crank. For all data collecting requirements, apex innovations' "Enginesoft" software is used. HC, CO, NOx, and CO2 exhaust gas emissions are monitored using an AVL exhaust gas analyser (Model No. 444N), and smoke opacity was evaluated using an AVL smoke metre (Model No: 437C). Table 2 contains the specifications for both emission measurement instruments. Figure 1 depicts the experimental setup's schematic arrangement [37,38]. Before beginning the studies, it was guaranteed that the test engine was correctly set up to assess the performance, combustion, and emission results. Table 3 displays uncertainty levels and a complete uncertainty analysis.

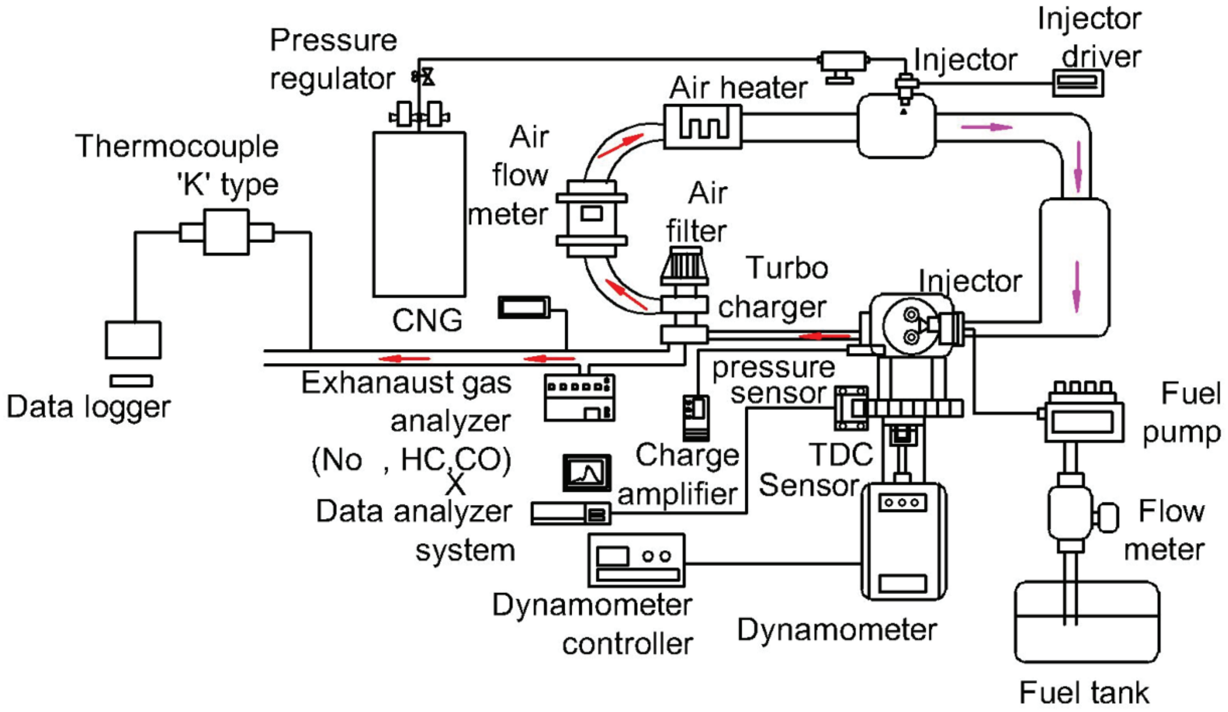


**Figure 1.** Block diagram of the test rig.

**Table 1.** Specification details of the engine [39-40]

| Make | Kirloskar |
|---|---|
| Software used | Engine soft |
| Stroke & Bore | 110 & 87.5 mm |
| Dynamometer | Eddy current |
| Piston bowl geometry | Mexican hat |
| ECU | i7r |
| Gas analyser | AVL |
| FIP range | 40 -100 MPa |
| Power | 5.2 kW |
| Max. volume | 18 cm3 |
| Max. pressure | 120 MPa |
| Fuel injection range | 0.5 – 100 mg per inj |

**Table 2.** Technical specifications of exhaust gas analyser

| Emissions | Range | Resolution |
|---|---|---|
| O2 | 0-25% | 0.01% |
| HC | 0-30000 ppm | 1 ppm |
| CO | 0-15% | 0.01% |
| CO2 | 0-20% | 0.01% |
| NOx | 0-5000 ppm | 1 ppm |
| Smoke opacity | 0-100% | 0.1% |

**Table 3. Uncertainty analysis of instruments used in experiments [41-42]**

| Parameters | Accuracy |
|---|---|
| HC | ± 0.3 |
| CO | ± 0.2 |
| NOx | ± 0.2 |
| EL (N) | ± 0.12 |
| Speed (rpm) | ± 1 |
| Smoke | ± 0.2 |
| BTE | ± 1.1 |

**Table 5.** MME biodiesel blended with IAN ignition improver

| Fuel Blend | Composition of fuel (by volume) |
|---|---|
| IAN5 | 95% MME biodiesel and 5% IAN |
| IAN10 | 90% MME biodiesel and 10% IAN |
| IAN15 | 85% MME biodiesel and 15% IAN |
| IAN20 | 80% MME biodiesel and 20% IAN |

### Types of Fuel Used

This section aims to analyse the different mahua methyl ester (MME) blends to identify the one that creates the fewest emissions while maintaining or improving performance. Initially, the MME blend is mixed with diesel fuel at 25, 50, and 75% before being tested alongside 100% MME blend (Table 4) and diesel fuel for performance outcomes like BTE and BSFC and emissions like BSHC, BSCO, BSNOx, and smoke. All test fuels were evaluated in the modified single-cylinder diesel engine under the manufacturer-specified standard operating conditions. The engine was first to run on diesel fuel, and the measurements were taken. The gasoline is then totally emptied from the tank and fuel channel. The mixes were then gradually changed, and all readings were recorded using the same procedure. Readings were obtained at various loading levels, ranging from 0% load to 100% load, in 25% load value increments.

### Influence of Ignition Improvers

The operating settings were optimized to enhance the engine's performance and emission results. Even though the results significantly improved, the MME biodiesel blends could not demonstrate a sufficient improvement to approach close to diesel fuel. Thus, proving the apparent cause for the MME biodiesel blends inability to function at its peak level even if it had all the necessary qualities, much like diesel fuel. The decreased cetane value of gasoline might be the major cause of this. According to a literature review, using gasoline with a higher cetane rating may enhance the fuel's performance and emission results while also enhancing its quality. Iso-amyl nitrate (IAN) is therefore selected as prospective ignition improvers from

**Table 4.** Properties of diesel, MME100 and IAN blends

| Properties | Fuel blends | | | | | |
|---|---|---|---|---|---|---|
| | Density at $20^0$C (kg/m$^3$) | Viscosity at $40^0$C (cSt) | Cetane number | Calorific value (MJ/kg) | Water content (ppm) | Flash point ($^0$C) |
| D100 | 824 | 3.6 | 52 | 43.20 | 12 | 65 |
| MME100 | 885 | 1.30 | 19 | 41.90 | 162 | 44 |
| IAN | 702 | - | - | 109 | | 6 |
| ASTM standards | D1298 | D445 | D976 | D240 | D92 | D93 |

the literature after a comprehensive analysis. As both additions had the potential to provide positive effects, they were blended with mahua methyl ester blend in various ratios to compare them and determine which ingredient was most effective and best suited for biofuel.

### Impact of Iso-Amyl Nitrate (IAN)

Iso-amyl nitrate (IAN) is the oxygenated additives which possess improved cetane improvers are mixed in 4 different quantities, as shown in Table 5, to enhance the performance and emission results of the MME biodiesel blends. The findings for only the four mixes are contrasted in this part to determine the ideal ratio and mixture.

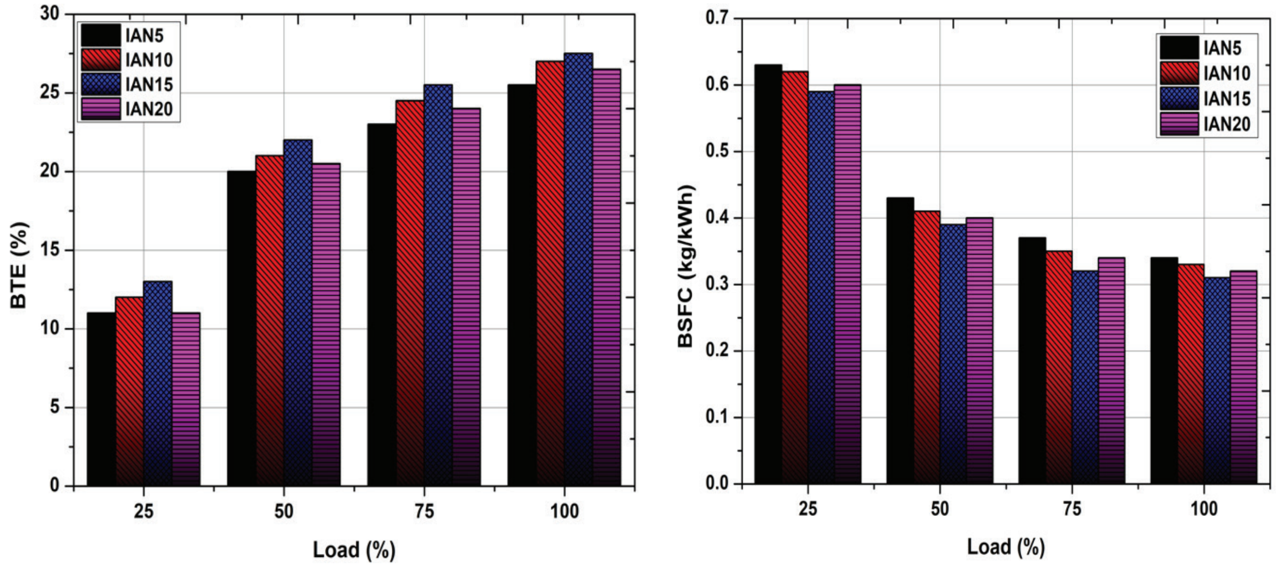
## RESULTS AND DISCUSSION

### Influence of Ignition Promoters on Engine Performance Characteristics

Figure 2 (a) shows the progressive fluctuation of BTE under various loading settings, and additive ratios of iso-amyl nitrate (IAN) applied to MME biodiesel blend. Different proportions of IAN oxygenated addition show a modest drop in BTE during a full load operation. In addition, noted a decrease in combustion efficiency brought on by the high latent heat of IAN vaporization and the consequent drop in in-cylinder temperature. Compared to MME biodiesel blend at full load, BTE decreased by 3.84%, 2.12%, and 0.46% in case of IAN5, IAN10, IAN20 blends and slightly increased by 1.84% for IAN15. Due to IAN's increased latent heat of vaporization and the cooling impact it produces, the net calorific value of the blends is decreased, which causes a decrease in BTE. Figure 2 (b) shows the variance in BSFC under various loading settings and iso-amyl nitrate (IAN) additive addition with different MME biodiesel blends. The fuel consumption at full load rose with the inclusion of IAN and MME biodiesel blend. At full load operation, the BSFC increased by 6.34%, 4.12%, 0.2%, and 1.86% in case of IAN5, IAN10, IAN15, and IAN20 blends. Due to its cooling effect, which was boosted with the increase in IAN proportions, the increased heat of IAN vaporization lowers the in-cylinder temperature. Additionally, the net calorific value of the complete MME biodiesel blend is decreased due to IAN's lower calorific value. These factors result in a decrease in BTE, which raises fuel consumption.

### Influence of Ignition Promoters on Engine Emission Characteristics

Figure 3(a) depicts the variance in BSHC under various loading settings and iso-amyl nitrate (IAN) additive addition in different proportions with MME biodiesel blend. In comparison to the optimized MME biodiesel blend value, IAN blended MME biofuel exhibits an increase in BSHC value. Compared to the optimum MME blend, IAN10, IAN15 and IAN20 increase BSHC by 2.32%, 6.12%, and 12.32% respectively. However, IAN5 decreased the BSHC emission by 1.84%. IAN may interact with air molecules during injection, build up between the piston rings, and prevent combustion. Additionally, according to Rakopoulos et al. (2012), slower IAN evaporation causes a leaner flameout zone and enhances the flame-quenching effect, which increases BSHC emission. The fluctuation of BSCO under various loading circumstances and iso-amyl nitrate (IAN) additive amounts applied to MME biodiesel blend is shown in Figure 3(b). It is evident that when the

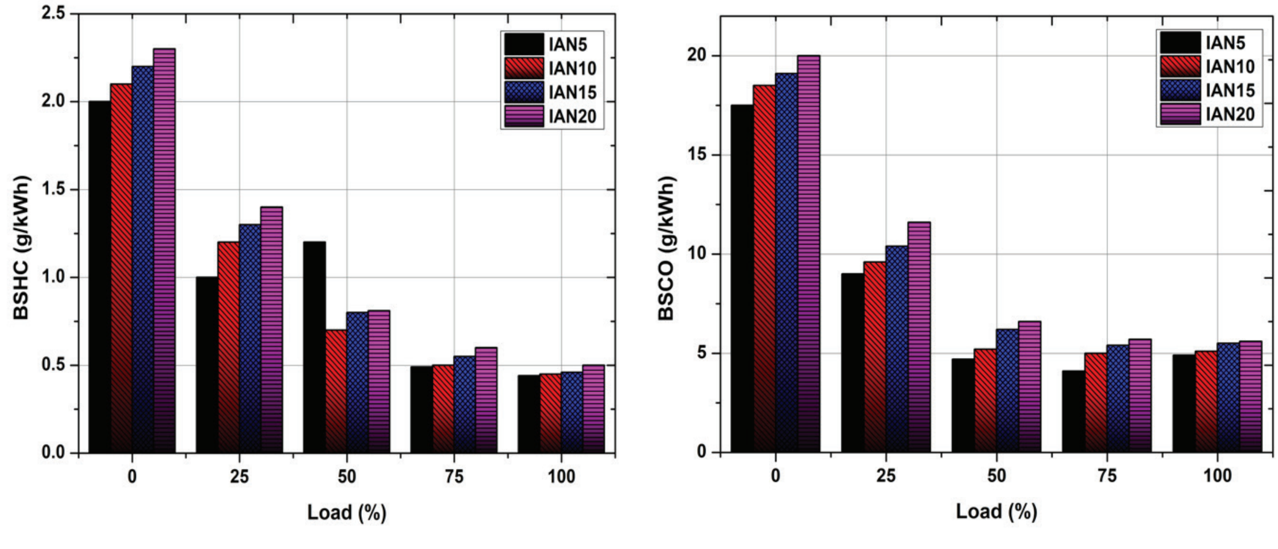


a) b)

**Figure 2.** Influence of oxygenated additives on BTE and BSFC varying the engine load.

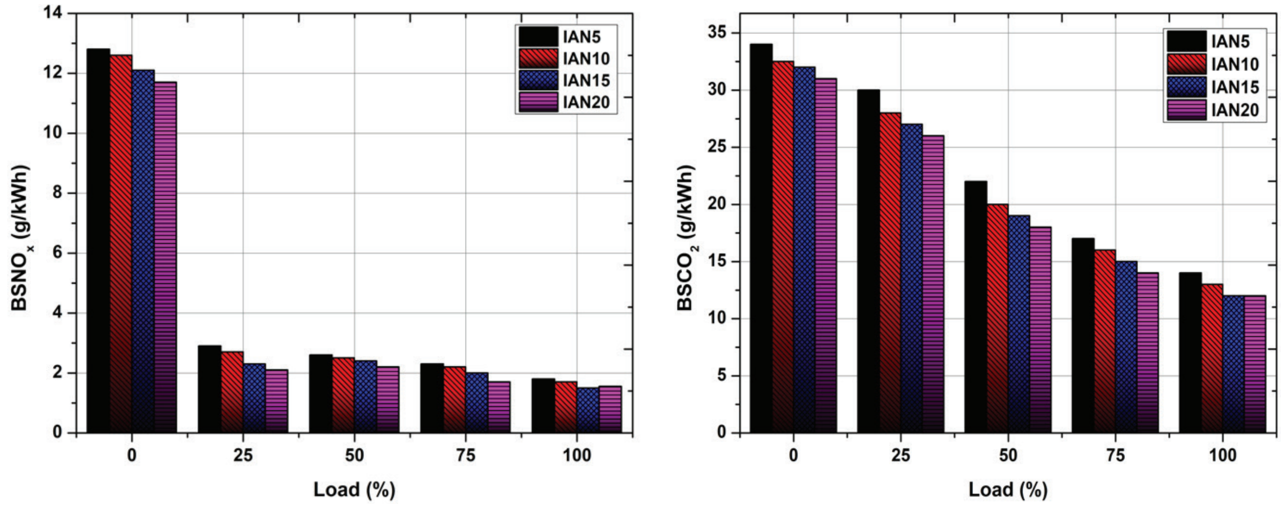
IAN fraction in the MME biodiesel blend increases, the BSCO emission also increases. Due to the in-cylinder temperature rise at increasing loads, BSCO emission decreases as load values increase. However, at a similar load, a rise in IAN proportions also causes an increase in BSCO emission. Compared to optimized MME biodiesel blend at full load, IAN5 reduced BSCO by 1.52%, however, IAN10, IAN15, and IAN20 increased BSCO by 2.12%, 12.63%, and 14.16% respectively. This is because the cooling effect caused by the higher heat of vaporization impedes the combustion process and raises the BSCO emission value [20].

Figure 4(a) depicts the fluctuation in BSNOx under various loading settings and iso-amyl nitrate (IAN) additive addition ratios to MME biodiesel blend. Due to its larger cetane and oxygen content, the inclusion of IAN was anticipated to have a good impact on the combustion process and boost BSNOx emission, however, the data indicate otherwise. Compared to MME biodiesel blend, IAN5, IAN10, IAN15, and IAN20 reduced BSNOx emission by 4.84%, 7.24%, 15.84%, and 17.24%, respectively, during a full load operation. IAN absorbs more heat from the combustion chamber during its vaporization, which lowers the temperature within the cylinder. Due to the direct relationship between temperature and BSNOx production, this drops in in-cylinder temperature decreases BSNOx emission. The change of BSCO2 under various loading



a) b)

**Figure 3.** Influence of oxygenated additives on BSHC and BSCO varying the engine load.



a) b)

**Figure 4.** Influence of oxygenated additives on BSNOx and BSCO2 varying the engine load.

settings and iso-amyl nitrate (IAN) additive quantities applied to MME biodiesel blends is shown in Figure 4(b). The addition of greater concentration of IAN results in a reduction in BSCO2 emissions. Compared to MME biodiesel blend, IAN5, IAN10, IAN15, and IAN20 reduced BSCO2 emissions by 3.12%, 6.23%, 10.21%, and 14.26%, respectively, during a full load operation. An incomplete oxidation process and excessive cooling may cause this decline. Additionally, the blends' carbon content decreases as the IAN percentage rises, likewise linked to a decrease in BSCO2 emission.

Figure 5 illustrates the fluctuation in smoke emission under various loading circumstances and iso-amyl nitrate (IAN) additive addition with different MME biodiesel blends. The opacity of the smoke in the exhaust increased as DEE increased. Smoke was decreased by 2.12% at IAN5, but at IAN10, IAN15 and IAN20 blends, smoke emission rose by 2.32%, 5.12%, and 10.21% in comparison to MME biodiesel blend at full load. A more uniform combination of IAN in the fuel blend may be achieved with oxygenating blends because of their increased instability owing to their lesser consistency, which can also enhance the dispersion combustion phase and minimize smoke emission. However, the causes for the increased smoke emission in the exhaust stream may be attributed to a decrease in combustion temperature, inappropriate mixture formation due to the reduction in IAN evaporation rate, and inadequate time for complete oxidation.

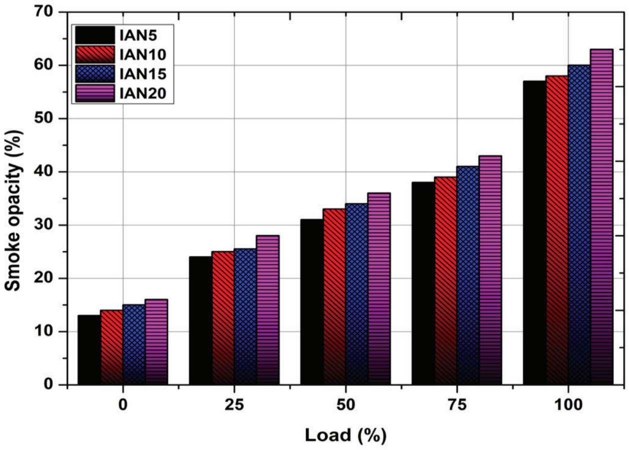
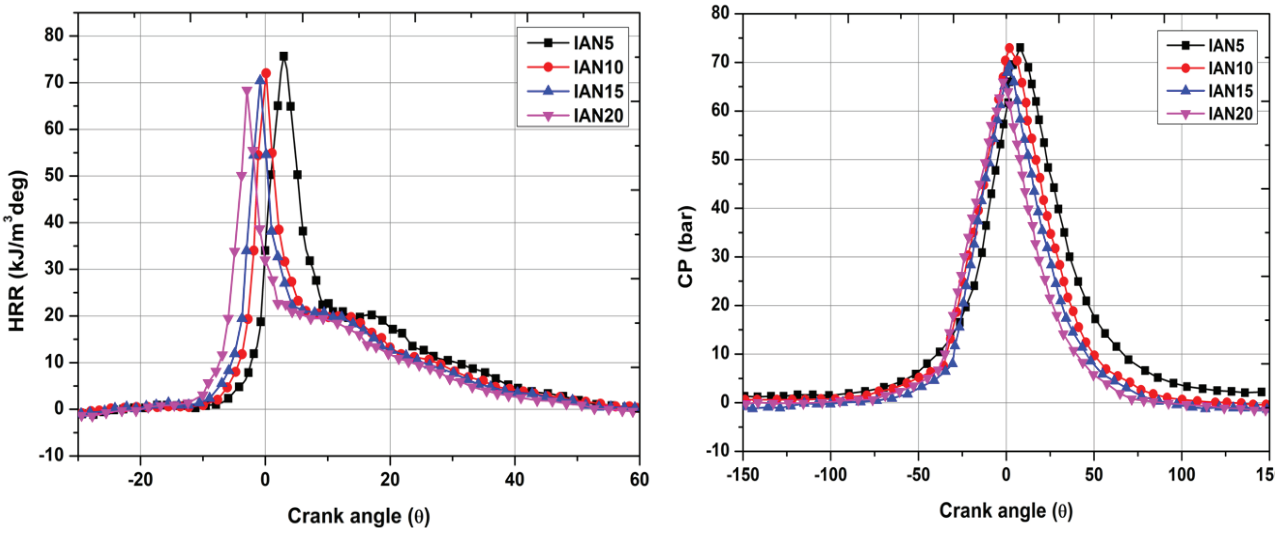


**Figure 5.** Influence of oxygenated additives on smoke opacity by varying the engine load.

### Influence of Ignition Promoters on Engine Combustion Characteristics

Figure 6(a) shows the fluctuation in HRR for various amounts of iso-amyl nitrate (IAN) additive applied to MME biodiesel blend under full load circumstances. As IAN additive has a greater cetane value than MME biodiesel blend, adding IAN shortens the time until ignition. Because of the inefficient combustion, increased heat of vaporization, and consequent cooling of in-cylinder temperature, the peak HRR value decreases as the concentration of IAN percentage rises. At full load operation, the highest HRRs for IAN5, IAN10, IAN15, and IAN20 blends were determined to be 76.23, 73.52, 71.86, and 69.12 kJ/m3.deg, respectively. Figure 6(b) shows how the cylinder pressure changes when various amounts of iso-amyl nitrate (IAN) additive are mixed with MME biodiesel blends at full load. The fuel used during the premixed combustion phase and the combustion pace are the key factors that affect the increase in peak pressure point within the combustion



a) b)

**Figure 6.** Influence of oxygenated additives on HRR and CP against the crank angle.

chamber. The graph shows that adding IAN blend to MME biodiesel blend decreased the ignition delay time owing to the IAN additive's enhanced cetane value. With a rise in IAN additive percentage, the peak cylinder pressure falls. At full load, the IAN5, IAN10, IAN15, and IAN20 blends generated maximum pressure of 74.12, 74.06, 71.26, and 68.12 bar, respectively.

## CONCLUSION

On the performance, combustion, and emission results in a CRDI engine, the comparison between the impact of the combustion enhancer additives (IAN) combined with MME biodiesel blend with different proportions is analysed. The data shown above make it quite evident that using the IAN additive produced superior outcomes. The main disadvantage of IAN is that it has a more significant latent heat of vaporization. This slows the additive's fast evaporation, resulting in decreased performance and higher emission results. The lower cetane number of the biofuel might be the major reason for the inferior outcomes compared to diesel fuel. As a measure to overcome this, cetane improver/ignition enhancer additives like IAN are added.

- IAN due to its higher latent heat, shows some negative effects in the performance and emission outcomes.
- 15% of IAN addition provides much better results as follows; the BTE value increased by 11.36% with a decrease in 8.26% in BSFC.
- The emissions like HC, CO and smoke reduced by 16.32, 23.56, and 23.12%. The improved combustion process, increases NOx and CO2 emissions by 13.62 and 19.89%. Also, an increase in HRR and CP values were noticed at full load operation.

## AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

## DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

## CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## ETHICS

There are no ethical issues with the publication of this manuscript.

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