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INJECTION PARAMETER OPTIMIZATION FOR EFFICIENT BIODIESEL BLENDS IN COMPRESSION IGNITION ENGINE

OPTIMIZACIÓN DE PARÁMETROS DE INYECCIÓN PARA MEZCLAS EFICIENTES DE BIODIÉSEL EN MOTORES DE ENCENDIDO POR COMPRESIÓN

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ABSTRACT

The increasing global energy demand, depletion of petroleum reserves, volatile petroleum prices, and growing environmental concerns have accelerated the search for sustainable and clean energy sources. Biodiesel (methyl ester) was produced from scum oil (MESO) and waste vegetable oil (MEWVO) through transesterification using sodium hydroxide and methanol as catalysts and reactants. The composition of the methyl esters in MESO and MEWVO was analyzed using Gas Chromatography-Mass Spectrometry (GC-MS). Various methyl ester blends were prepared by adding pure diesel to MESO and MEWVO, and the best blend was selected for use in compression ignition (CI) engines. The performance, emission, and combustion characteristics of MESO-B20 and MEWVO-B20 blends were studied. Results showed that retarded injection timing (19° before TDC) significantly reduced ignition delay by 15% and improved brake thermal efficiency (BTE) by 6.4% compared to standard injection timing. The increase in injection pressure to 220 bar enhanced fuel atomization, leading to a 10% reduction in brake specific fuel consumption (BSFC) plus 5% reduction in exhaust gas temperature (EGT).

These findings demonstrate that MESO-B20 and MEWVO-B20, with optimized injection parameters, are a viable alternative to conventional diesel in CI engines, showing improved combustion efficiency and emission reductions, particularly in CO and unburned hydrocarbons (HC), although there was increase in NOx emissions.. Further research is recommended to address NOx emissions and optimize biodiesel formulations for long-term engine performance.

RESUMEN

La creciente demanda mundial de energía, el agotamiento de las reservas de petróleo, la volatilidad de los precios del crudo y las crecientes preocupaciones ambientales han acelerado la búsqueda de fuentes de energía sostenibles y limpias. El biodiésel (éster metílico) se produjo a partir de aceite de escoria (MESO) y aceite vegetal usado (MEWVO) mediante transesterificación, utilizando hidróxido de sodio y metanol como catalizador y reactivo. La composición de los ésteres metílicos en MESO y MEWVO fue analizada mediante Cromatografía de Gases-Espectrometría de Masas (GC-MS). Se prepararon diversas mezclas de ésteres metílicos con diésel puro, seleccionándose la mejor mezcla para su uso en motores de encendido por compresión (CI).

Se estudiaron las características de desempeño, emisiones y combustión de las mezclas MESO-B20 y MEWVO-B20. Los resultados mostraron que el retraso del tiempo de inyección (19° antes del PMS) redujo significativamente el retardo de ignición en un 15% y mejoró la eficiencia térmica al freno (BTE) en un 6.4% en comparación con el tiempo de inyección estándar. El aumento de la presión de inyección a 220 bar mejoró la atomización del combustible, lo que condujo a una reducción del 10% en el consumo específico de combustible al freno (BSFC) y a una disminución del 5% en la temperatura de los gases de escape (EGT).

Estos hallazgos demuestran que MESO-B20 y MEWVO-B20, con parámetros de inyección optimizados, son una alternativa viable al diésel convencional en motores CI, mostrando mejoras en la eficiencia de combustión y reducciones de emisiones, particularmente en CO e hidrocarburos no quemados (HC), aunque se observó un incremento en las emisiones de NOx. Se recomienda continuar la investigación para abordar las emisiones de NOx y optimizar las formulaciones de biodiésel para el rendimiento a largo plazo del motor.

KEYWORDS / PALABRAS CLAVE

Methyl Ester Scum Oil | Methyl Ester Waste Vegetable Oil | Injection Timing | Injection Pressure.
Biodiésel | Biocombustibles | Aceite vegetal usado | Aceite residual | Motores de encendido por compresión | Sincronización de la inyección | Presión de inyección.

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1. INTRODUCTION

The world is grappling with crises like oil and plant depletion, and the increasing consumption of petroleum-based fuels. Alternative fuels, such as biodiesel, are being explored as sustainable, efficient, and eco-friendly alternatives. Biodiesel, a compression ignition engine fuel, is a promising alternative, although its benefits and applications require detailed studies. It can be used in non-dedicated vehicles and can be improved by modifying engine hardware.

Biodiesel, a liquid biofuel made from plant or animal materials and alcohol, reduces greenhouse gas emissions and is produced worldwide from vegetable oils, non-vegetable oils, and animal fat (Rahees K and Meera V, 2014). Biodiesel feedstock selection is influenced by food crop feedstock issues, with non-edible oil, scum oil, waste vegetable oil, and animal fats being potential alternatives (T.A. Priyanka and A.P Gawande, 2013). Biodiesel production costs more than diesel due to food crop oil use, but waste oils are cheaper and also suitable for production. Transesterification, a reversible reaction, produces biodiesel and glycerol, which can be anaerobically digested (C. Komintarachat and S. Chuepeng ,2010).

Scum oil is produced by municipal wastewater treatment plants (Sravan Kumar Yellapu et al., 2019) [4], dairy milk industries (et al., 2020) [5], and tannery plants (R., Balasubramanian et al., 2018). Fatty, lipid, and other water-insoluble substances are found in scum oil. These industries collect scum oils when washing equipment (Yatish, K.V et al., 2016). This insoluble water scum must be treated before disposal. Even though soap manufacturers use small or medium amounts of scum, dairy milk industries struggle to dispose of this massive amount (Kavitha V et al., 2019). Industries produce scum, which is problematic. Many dairy industries dump excess scum into waste treatment sites (Kelessidis & Stasinakis, 2012), which leads to pollution. Waste oil from these dairy industries could be used as biodiesel feedstock.

Vegetable oils include edible and non-edible oils, which are used for food processing and hair oil, paints, and soaps (El-Hamidi, and M., Zaher, F. A., 2018). Used cooking oil, a waste vegetable oil, can be economically and effectively used to reduce diesel use. India plans to mix 5% biodiesel into diesel by 2030, using 2700 crore liters of cooking oil. Different feedstocks and injection parameters can improve performance and emissions (Kulandaivel, D. et al., 2020). Increased combustion duration and reduced injection time improve engine performance while lowering nitrogen oxide emissions. However, recent trends are shifting away from advanced injection timing (Singh et al., 2004). Fuel injection pressure also plays a significant role in affecting CI engine performance (Jayashankara & Ganesan, 2010). Higher injection pressures enhance the combustion of a finely atomized fuel-air mixture and improve spray propagation within the combustion chamber. Hence, optimal fuel-air mixing and effective spray propagation lead to better combustion and reduced emissions, even under lower injection pressures (Shundoh et al., 1992).

A study on biodiesel blends in CI engines determined that a dairy scum oil-B20 blend reduces most emissions, except nitrogen oxide (M. S. Gad et al., 2018). Similar results were observed with waste vegetable oil blends, which also lower emissions but show elevated nitrogen oxide levels (K. A. Abed et al., 2018). Additionally, using a multi-vegetable oil blend combined with n-butanol has proved to enhance engine performance and decrease emissions without requiring engine modifications (Atmanli A. et al., 2014). Biodiesel, which has fuel properties similar to diesel, can be formulated with the right proportions of diesel (Harish H et al., 2014; Punith Kumar S. V. et al., 2015); however, it often results in increased nitrogen oxide emissions (Kantharaju T et al., 2015). Various biodiesel blends have demonstrated improved thermal efficiency and lower smoke emissions (Jayaprabakar Jayaraman et al., 2019). Furthermore, studies indicate that water injection can reduce nitrogen oxide emissions by up to 50% in CI engines using biodiesel, although this approach may increase hydrocarbon and carbon monoxide emissions and fuel consumption (Prabhu Appavu et al., 2018).

Research on biodiesel production in 4-stroke compression ignition (CI) engines has shown that adjusting injection timing, measured in crank angle (CA) degrees, can significantly influence engine performance and emissions. For example, a 2° CA retardation in injection times has led to reduce nitrogen oxide (NOx) emissions and fuel consumption (Erkan Öztürk et al., 2020). Likewise, a 3° CA retardation can improve brake thermal efficiency and reduce brake specific fuel consumption (S. Jindal, 2011) while also lowering NOx emissions. Studies have further indicated that a 19° CA retardation enhances brake thermal efficiency (N. R. Banapurmath et al., 2008), while a 14° CA retardation specifically reduces NOx emissions (Mani M et al., 2011). Moreover, slightly increasing the injection opening pressure can improve overall engine performance (G. Suresh et al., 2013). However, advancing injection timesg by 23% can lead to increased NOx emissions (A. K. Wamankar and S. Murugan, 2014), whereas a retarded injection time of 11.5% has resulted in decreasing NOx emissions (S. Prasanna Raj Yadav et al., 2015).

Research on biodiesel use in diesel engines has shown that retarded injection timing injecting fuel later in the cycle can reduce nitrogen oxide (NOx) emissions and improve brake thermal efficiency. Adjusting injection timing to specific crank angles, such as 19°, 23°, and 27° before top dead center (TDC), can optimize engine performance (M. Harun Kumar V et al., 2018). Retarded injection timing is particularly effective in reducing NOx emissions, which is a significant limitation for biodiesel use without engine hardware modifications (P. Vara Prasad et al., 2013). Additionally, increasing injection pressure has shown to optimize combustion, leading to lower emissions overall (S. Saravanan et al., 2014). Studies on various biodiesel blends have rendered mixed results, with some blends producing higher NOx emissions than conventional diesel but reducing other emissions (Roy, Murari Mohon, 2009). For lemongrass oil-diesel blends, advanced injection timing yields better results, with higher cylinder pressure and improved brake thermal efficiency (R. Sathiyamoorthi and G. Sankaranarayanan, 2015). However, increased injection opening pressure can marginally raise NOx emissions (S. Saravanan et al., 2014).

Injection pressure andtimes are injection parameters that play a crucial role in the performance of a diesel engine (G. R. Kannan and R. Anand., 2012). Different injection parameters, such as B20, can improve the performance of a diesel engine. The B20 blend of honge biodiesel showed better results among the different blends, with retarded injection timing and higher injection pressure resulting in better performance (N. R. Banapurmath et al., 2008). The B20 biodiesel blend shows better performance and lower emission values than pure diesel values (Krishnamurthy K N and Sridhara S N., 2018). Higher injection timing and injection pressure also result in increased brake thermal efficiency and decreased emissions (Shivashimpi M et al., 2019).

The primary objective of this research is to optimize injection parameters for MESO-B20 and MEWVO-B20 biodiesel blends in CI engines. The study analyzes the impact of injection timing and injection pressure on combustion efficiency, emissions, and engine performance. The hypothesis is that retarded injection timing combined with higher injection pressures will improve engine efficiency and reduce harmful emissions when using biodiesel blends, compared to conventional diesel. This study also evaluates the economic feasibility and environmental benefits of using waste oils (such as dairy scum oil and used vegetable oil) as biodiesel feedstocks. Specifically, the research aims to optimize biodiesel blends (MESO-B20 and MEWVO-B20) and determine the best injection timing and pressures for enhanced performance in CI engines, with the goal of reducing reliance on non-renewable fuel sources and improving fuel efficiency while minimizing harmful emissions. The results of this study could help bridge the gap between renewable fuel production and the practical application of biodiesel blends in diesel engines, contributing to a more sustainable future in the transportation sector.

Biodiesel samples were tested using gas chromatographic fatty acid analysis to confirm their conversion to biodiesel. These biodiesel blends were then evaluated for their suitability as fuel for compression ignition engines. The experiment consisted of four phases: setting parameters, optimizing biodiesel blends, determining optimal injection timing for the diesel engine, and optimizing injection pressure for the compression ignition engine. In the first phase, experimental parameters were established. The second phase focused on optimizing biodiesel blends. The third phase involved adjusting injection timings to enhance engine efficiency, combustion quality, and emissions reduction. Finally, in the fourth phase, the engine operated with the optimized biodiesel blends and injection timing at constant engine speed and compression ratio to identify the optimal injection pressure.

2. EXPERIMENTAL SETUP

The diesel engine setup is shown in Figure 1 and detailed in Table 1, which outlines the essential instruments for experimentation. Each component is computerized to assess engine characteristics such as pressure-volume and pressure-crank angle graphs, temperatures, airflow, fuel flow, and load. A compression ignition (CI) engine was used for evaluating performance parameters. Measurements for air flow rate and fuel flow rate are taken from an eddy current type dynamometer, a U-tube manometer, and a burette. Engine characteristics, including cylinder pressure, are recorded with the "Engine soft" software, and an ADC with a sixteen-port computer interface measures in-line cylinder pressure.

An AVL 437C smoke meter and AVL DIGAS 444 N gas analysers monitor exhaust gas opacity and primary emissions under steady-state conditions. To ensure accuracy, all experimental values represent an average of three trials conducted at a constant engine speed of 1500 rpm and a 17.5:1 compression ratio. Tests are performed at various injection timings and opening pressures, with additional experiments conducted using the optimized injection timing and pressure. Table 2 provides details on the accuracy and uncertainty of measured and calculated parameters, which are crucial for assessing the reliability of the experimental results.

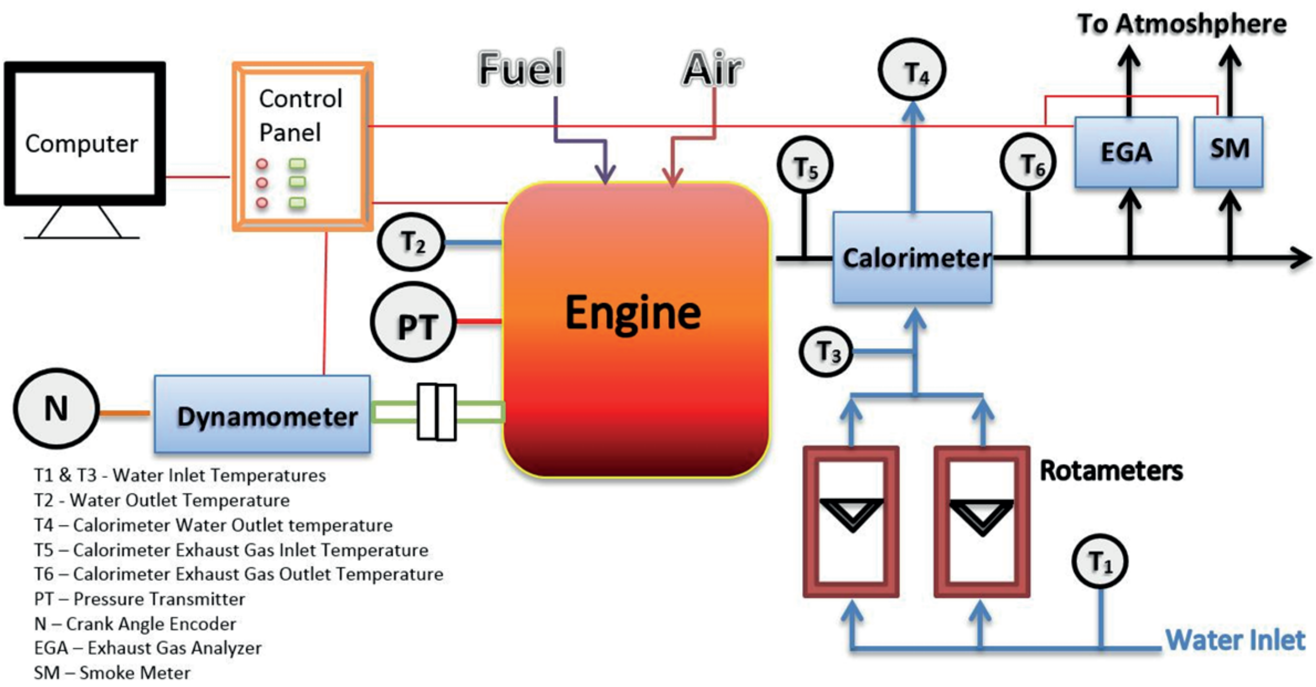

Figure 1. Diesel Engine Test setup

Table 1. Specifications of the engine test system

Parameter	Specification
Engine company, Model	Kirloskar, Model TV1
Cylinder	Single cylinder
Number of Strokes	4 strokes
Dynamometer	Eddy current type with water cool
Power	5.2 kW at 1500 rpm
Bore	87.5 mm
Stroke	110 mm
Displacement	661 cc
Compression Ratio	17.5:1

Table 2. Accuracy and uncertainty of measured and calculated parameters

Parameter	Accuracy	Uncertainty (%)
Smoke Opacity	± 1% of a full scale	± 0.5
CO	0.0001 % Vol	± 0.03
HC	± 1 ppmVol	± 1.3
NOx	± 1 ppm	± 0.05
Time	± 0.2 Seconds	± 1
Fuel Flow	± 0.2 CC	± 0.75
Load	± 0.1 kg	± 0.5
Temperature	± 1º C	± 0.2
Speed	± 30 rpm	± 1.9
Calculated parameters	--	Uncertainty (%)
BSFC	--	± 1.7
BTE	--	± 1.8
HRR	--	± 0.15

3. RESULTS

FUEL PROPERTIES

Basic fuel properties of diesel and biodiesel blends were tested and evaluated to determine the suitability of these biodiesel blends as alternative fuels for internal combustion (IC) engines. The fuel properties of MESO and MEWVO blends are similar to those of diesel, particularly B10 and B20 blends. Among these, MESO-B20 and MEWVO-B20 were identified as the best methyl ester blends given their favorable combustion characteristics. Table 3 compares key fuel properties between diesel and selected methyl ester blends.

Table 3. Fuel properties comparison between diesel and methyl ester blend

Fuel Properties	Diesel	MESO-B20	MEWVO-B20
Specific gravity	0.83	0.8452	0.8466
Viscosity during 40ºC (cSt)	2.9	2.992	3.072
Flash Points (ºC)	52	68.6	82.4
Calorific Value (kJ/kg)	42500	41561.2	41211.4
Cetane Number	49	52	51.4

FATTY ACID METHYL ESTER ANALYSIS

This study analyses the composition of biodiesel derived from scum oil and waste vegetable oil using Gas Chromatography and Mass Spectrometry (GC-MS) to identify key saturated and unsaturated compounds in MESO and MEWVO. The detailed compositions of MESO and MEWVO shownin Tables 4 and 5 highlight the specific compounds present in each biodiesel type, demonstrating their reliability and suitability as alternative fuels for compression ignition engines.

Table 4. Fatty acid methyl ester composition of MESO

Sl. No	Name	Chemical Formula	Remarks
1	Hexanoic acid, methyl ester	$C_7H_{14}O_2$	Saturated
2	Octanoic acid, methyl ester	$C_9H_{18}O_2$	Saturated
3	Decanoic acid, methyl ester	$C_{11}H_{22}O_2$	Saturated
4	Dodecanoic acid, methyl ester	$C_{13}H_{26}O_2$	Saturated
5	Tridecanoic acid, 12-methyl-, methyl ester	$C_{15}H_{30}O_2$	Saturated
6	Methyl tetradecanoate	$C_{15}H_{30}O_2$	Saturated
7	Methyl Z-11-tetradecenoate	$C_{15}H_{28}O_2$	Unsaturated
8	Tetradecanoic acid, 12-methyl-, methyl ester, (S)	$C_{16}H_{32}O_2$	Saturated
9	Pentadecanoic acid, methyl ester	$C_{16}H_{32}O_2$	Saturated
10	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	Saturated
11	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	Saturated
12	9-Hexadecenoic acid, methyl ester, (Z)	$C_{17}H_{34}O_2$	Unsaturated
13	Hexadecanoic acid, 14-methyl-, methyl ester	$C_{17}H_{36}O_2$	Saturated
14	Hexadecanoic acid, 14-methyl-, methyl ester	$C_{18}H_{36}O_2$	Saturated
15	cis-10-Heptadecenoic acid, methyl ester	$C_{18}H_{34}O_2$	Unsaturated
16	Methyl stearate	$C_{19}H_{38}O_2$	Saturated
17	9-Octadecenoic acid, methyl ester, (E)-	$C_{19}H_{36}O_2$	Unsaturated
18	9,12-Octadecadienoic acid, methyl ester	$C_{19}H_{34}O_2$	Unsaturated
19	Methyl 9-cis,11-trans- octadecadienoate	$C_{18}H_{31}O_2$	Unsaturated

Table 5. Fatty acid methyl ester composition of MEWVO

Sl. No	Name	Chemical Formula	Remarks
1	Dodecanoic acid, methyl ester	$C_{13}H_{26}O_2$	Saturated
2	Methyl tetradecanoate	$C_{15}H_{30}O_2$	Saturated
3	Hexadecanoic acid, methyl ester	$C_{17}H_{34}O_2$	Saturated
4	Heptadecanoic acid, methyl ester	$C_{18}H_{36}O_2$	Saturated
5	Methyl stearate	$C_{19}H_{38}O_2$	Unsaturated
6	9-Octadecenoic acid, methyl ester, (E)	$C_{19}H_{36}O_2$	Unsaturated
7	9,12-Octadecadienoic acid (Z, Z)-, methyl ester	$C_{19}H_{34}O_2$	Unsaturated
8	9,12,15-Octadecatrienoic acid, methyl ester,(Z,Z,Z)	$C_{19}H_{32}O_2$	Unsaturated
9	Methyl 18-methyl nonadecanoate	$C_{21}H_{42}O_2$	Saturated
10	cis-Methyl 11-eicosenoate	$C_{21}H_{40}O_2$	Unsaturated
11	Docosanoic acid, methyl ester	$C_{23}H_{46}O_2$	Saturated

The cetane number and calorific value of biodiesel are influenced by their fatty acid composition, with saturated and unsaturated fatty acids playing distinct roles in compression ignition engine performance and emissions (N. Sunil Naik & B. Balakrishna, 2017).

Generally, biodiesel with higher saturated fatty acid content is more stable, whereas high levels of unsaturated fatty acids make biodiesel more prone to oxidation, which can reduce engine performance (K. Shaine Tyson, 2004; M.P. Dorado et al., 2004). Studies recommend biodiesel with a greater proportion of saturated fatty acids over unsaturated acids for optimal engine performance and stability (A. Monyem et al., 2001).

In MESO, 78.48% of the fatty acids are saturated, with the remaining 21.52% unsaturated; in contrast, MEWVO contains 57.07% saturated and 42.03% unsaturated fatty acids. This higher proportion of saturated fatty acids in MESO corresponds to a higher cetane number, which improves combustion stability (Tamilselvan, Palsami et al., 2020). However, the elevated unsaturated fatty acid content in MEWVO can lead to faster oxidation and slightly lower cetane numbers, potentially affecting fuel longevity and performance (Patel, Alok et al., 2017). Additionally, calorific value tends to increase with longer fatty acid chain lengths but decreases as the degree of unsaturation rises (Folayan, Adewale Johnson et al., 2019).

EXPERIMENTAL OPTIMIZATION OF METHYL ESTER BLENDS

The straight biodiesel or methyl ester oil cannot be used as fuel for compression ignition engines due to the high viscosity and lower calorific value of the methyl ester oil. Straight biodiesel requires additives when used in diesel engines (Suthisripok, Tongchit, and Semsamran, Pattawee., 2018). Pure biodiesel cannot be stored for a long time due to oxidation problems, and these oxides clog the filters and fuel injector holes, along with the formation of carbon molecules in the combustion chamber (James Pullen and Khizer Saeed, 2012). Therefore, instead of using straight methyl ester as fuel in a compression ignition engine, blended biodiesel with the appropriate proportion of pure diesel could resolve the problems. Similarly, this research also followed the practice of blending biodiesel with an appropriate proportion of pure diesel for further study on a compression ignition engine. The biodiesel blend B10 – (10% methyl ester oil + 90% diesel), was prepared, along with other blends.

The prepared biodiesel blends were used as fuel to run the CI engine without any engine modifications. While running the engine, some standard parameters were considered, like an engine running at constant speed is 1500 rpm, CR 17.5:1, SIT is 23° before TDC, and standard injection pressure is 200 bar. The engine performance characteristics and results were collected for discussion from the "CIEngineSoft" software.

BRAKE THERMAL EFFICIENCY

Brake thermal efficiency measures how well fuel converts into engine heat. Figure 2 and 3 show compression ignition engine performance with biodiesel blends like MESO and MEWVO. As load increases, brake thermal efficiency increases due to reduced heat loss (Gvidonas Labeckas and Stasys Slavinskas., 2005). B10 and B20 biodiesel blends have more oxygen, leading to higher efficiency (R. Kumar et al., 2015). Pure diesel brake thermal efficiency is 34%, while MESO-B10 and MESO-B20 blends have 31.82% and 31.04% respectively. B10 biodiesel blend has the highest efficiency, followed by B20.

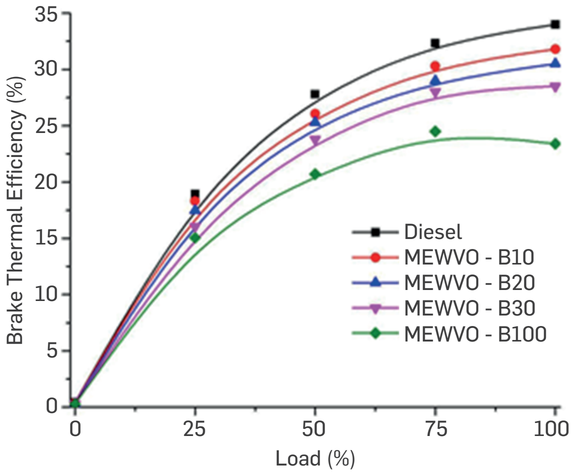

Figure 2. Brake thermal efficiency of MESO blends

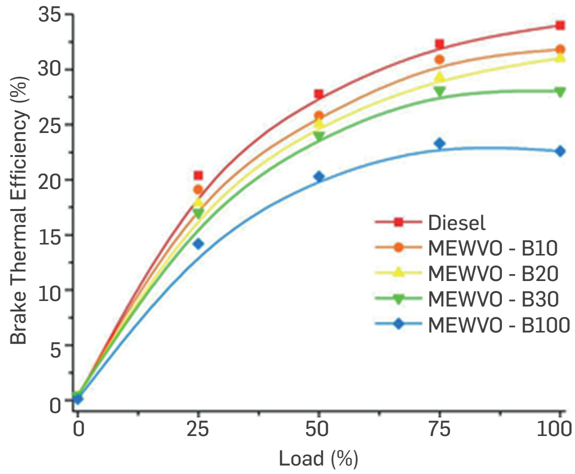

Figure 3. Brake thermal efficiency of MEWVO blends.

BRAKE SPECIFIC FUEL CONSUMPTION

Brake specific fuel consumption (BSFC) is a measure of fuel efficiency in compression ignition engines. In this study, biodiesel blends such as MESO and MEWVO were evaluated and compared with baseline data from pure diesel. Pure diesel achieved a BSFC of 0.25 kg/kW-h, while MESO-B10, MESO-B20, and MEWVO-B10 blends recorded values of 0.26 kg/kW-h and 0.27 kg/kW-h, respectively. The fuel consumption curves showed higher consumption at lower engine loads, which gradually decreased as load increased, as shown in Figures 4 and 5. Despite biodiesel's lower calorific value compared to diesel, resulting in higher fuel consumption at lower loads (M. A. Asokan et al., 2018), the lowest BSFC was achieved by the B10 biodiesel blends of MESO and MEWVO, followed by the B20 blends. The MESO-B20 and MEWVO-B20 blends show promising potential for further investigation as alternative fuels.

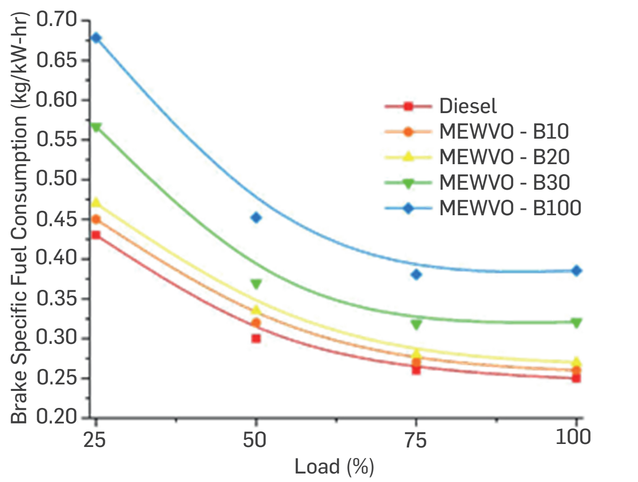

Figure 4. Brake specific fuel consumption of MESO blends

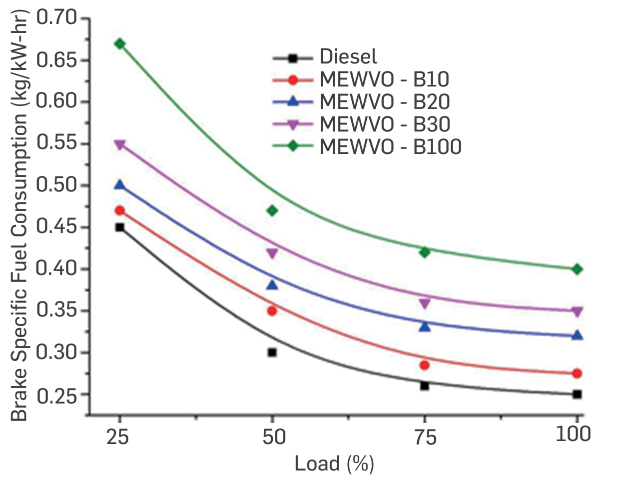

Figure 5. Brake specific fuel consumption of MEWVO blends

EFFECT OF INJECTION TIMINGS ON B20 METHYL ESTER BLENDS

The performance, emission, and combustion characteristics of MESO - B20 and MEWVO - B20 compression ignition engines were analyzed using ICEngineSoft software, considering different injection timings and standard injection pressure.

BRAKE THERMAL EFFICIENCY

Brake thermal efficiency (BTE) is a critical measure of engine performance, reflecting the conversion of chemical energy from the fuel into mechanical work. The BTE of MESO-B20 and MEWVO-B20 biodiesel blends in compression ignition engines was tested using pre-defined injection parameters. Conventional diesel has a BTE of 34%, while MESO-B20 and MEWVO-B20 show varying efficiencies depending on injection timing, as shown in Figure 6.

At the Start of Injection Time (SIT) of 23° before TDC, biodiesel blends show lower efficiency compared to conventional diesel. This is primarily due to the lower calorific values of biodiesels, which affect the overall energy release during combustion (Sathish Kumar P.S. and S. Mahalingam, 2014). However, BTE improves significantly as the injection timing is retarded, particularly at 19° before TDC, where the biodiesel blends show the best efficiency. This improvement is attributed to changes in combustion phasing, which facilitate better fuel-air mixing and lead to more efficient energy conversion (Zhou, Hua et al., 2019).

Additionally, MESO-B20 consistently outperforms MEWVO-B20 in terms of BTE across all injection timings. This is mainly due to MESO-B20's higher oxygen content and superior cetane number, which contribute to more complete combustion and higher engine efficiency.

The highest BTE for both biodiesel blends is achieved at 19° before TDC, as this injection timing provides an optimal balance between oxygen availability, fuel-air mixing, and combustion efficiency.

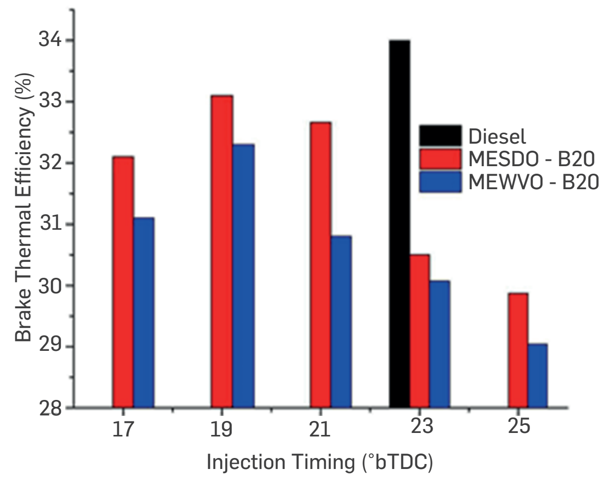

Figure 6. BTE of MESO – B20 and MEWVO – B20 at different injection timings

BRAKE SPECIFIC FUEL CONSUMPTION

The study analyzes the impact of injection timing on Brake Specific Fuel Consumption (BSFC), revealing that optimized fuel atomization leads to more complete combustion and, consequently, lower fuel consumption. As shown in Figure 7, the lowest BSFC for MESO-B20 and MEWVO-B20 was achieved at 19° before TDC, with values of 0.255 kg/kW-h and 0.28 kg/kW-h, respectively. These values represent a 2% and 12% increase in BSFC compared to conventional diesel, which highlights the differences in fuel efficiency between the biodiesel blends and traditional diesel.

Advanced injection timing (such as 19° before TDC) generally leads to better fuel atomization, promoting more efficient combustion, reducing the energy lost to incomplete combustion. However, it is worth noting that both MESO-B20 and MEWVO-B20 exhibited slightly higher BSFC compared to conventional diesel, particularly in the case of MEWVO-B20, where a 12% increase in BSFC was observed. This is consistent with findings by Kim et al. (2019), which indicated that both advanced and retarded injection timings require more fuel to achieve the same brake power.

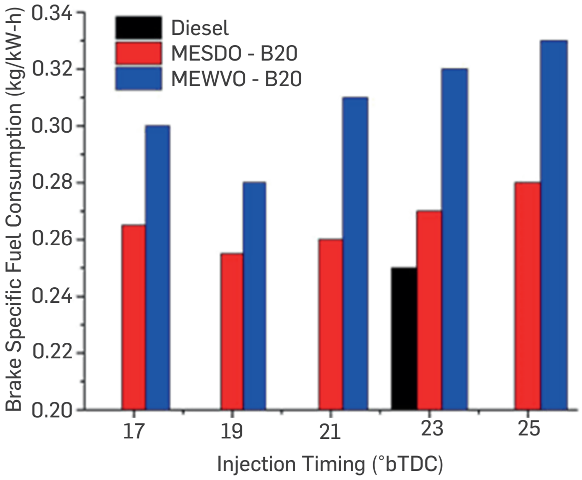

Figure 7. BSFC of MESO – B20 and MEWVO – B20 at different Injection Timings

EXHAUST GAS TEMPERATURE

The study analyzes the impact of injection timing on engine thermal efficiency and exhaust gas temperature (EGT), which refers to the temperature of the exhaust gases leaving the engine. Figure 8 shows that the heat released from the engine is higher at 19° before TDC, resulting in lower EGT and higher brake thermal efficiency (BTE). This is consistent with previous studies (Mani M, Nagarajan G, and Sampath S., 2011), which highlighted the positive impact of advanced injection timing on combustion efficiency.

At 19° before TDC, both MESO-B20 and MEWVO-B20 achieved lower EGT compared to conventional diesel. The improved thermal efficiency of the biodiesel blends leads to a more complete combustion process, thus lowering EGT. Specifically, MESO-B20 and MEWVO-B20 show a 7.7% and 9.1% lower EGT, respectively, compared to conventional diesel, mainly due to the higher BTE values associated with these biodiesels.

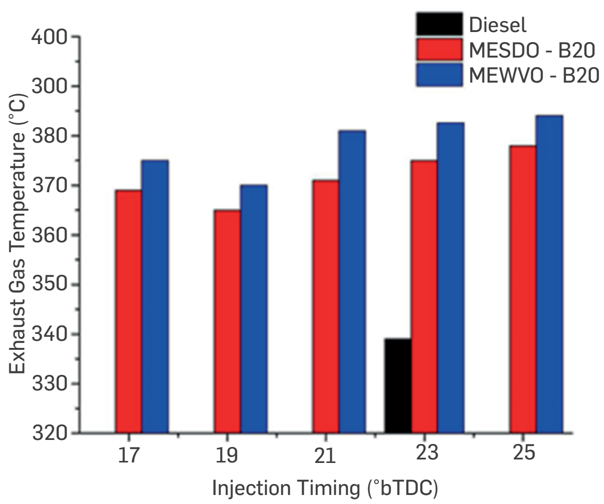

Figure 8. EGT of MESO – B20 and MEWVO – B20 at different Injection timings

CARBON MONOXIDE

This research analyzes the formation of carbon monoxide (CO) during combustion, as it is a harmful pollutant with significant health impacts (Thomas Abdallah, 2017). The results show that CO emissions decrease as injection timing is retarded, as illustrated in Figure 9. Higher emissions are observed with advanced injection timings due to incomplete combustion, leading to the formation of unburned carbon particles (Ahmed, Salman Abdu et al., 2019). In contrast, retarded injection timings generally lead to lower CO emissions. However, further retardation of injection timing can increase CO emissions due to insufficient time for complete combustion, as the fuel has less time to mix with air, causing inefficiencies (Ioannis Kalargaris et al., 2017).

As for biodiesel blends, MEWVO-B20 produced higher CO emissions at all injection timings compared to MESO-B20. This behavior can be attributed to the highrt oxygen content in MEWVO-B20, which may promote the formation of CO at specific timings due to its combustion characteristics. In contrast, MESO-B20 achieved 6.3% lower CO emissions than conventional dieselwhereas MEWVO-B20 resulted in 6.3% higher CO emissions than conventional diesel. These variations highlight the significant influence of fuel properties, particularly oxygen content on CO formation and combustion efficiency.

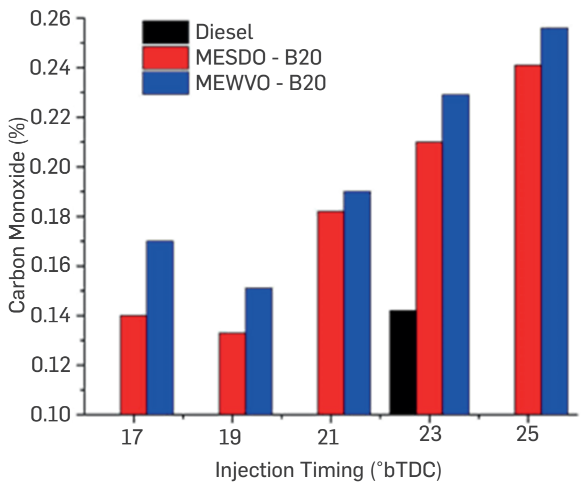

Figure 9. CO of MESO – B20 and MEWVO – B20 at different Injection timings

UNBURNT HYDROCARBON

The study suggests that adding methyl ester to diesel reduces unburned hydrocarbon emissions (UHC) due to enhanced combustion resulting from the oxygen molecules present in biodiesel (M. Vijay Kumar et al., 2018). Injection timing is also key in influencing UHC emissions. Advanced injection timings can result in a rich fuel-air mixture, leading to incomplete combustion and increased unburned hydrocarbon particles (Yesilyurt, M.K. et al., 2020). On the other hand, retarded injection timings can lead to the formation of formless unburned hydrocarbons due to improper combustion, while advanced injection timings may accumulate fuel before combustion, further affecting combustion efficiency.

As shown in Figure 10, MEWVO-B20 exhibits higher unburned hydrocarbon emissions than MESO-B20. This is likely due to the increased oxygen content in MEWVO-B20, which could promote incomplete combustion under certain conditions. However, both MESO-B20 and MEWVO-B20 achieve the lowest UHC emissions at 19° before TDC, which aligns with the optimized combustion conditions observed in other sections of the study.

Specifically, reductions in unburned hydrocarbon emissions from Start of Injection Timing (SIT) to retarded injection timing are 24.6% for MESO-B20 and 15.5% for MEWVO-B20, respectively. These reductions reflect the improved combustion efficiency achieved by the advanced injection timing (19° before TDC), which resulted in more complete combustion and reduced UHC emissions.

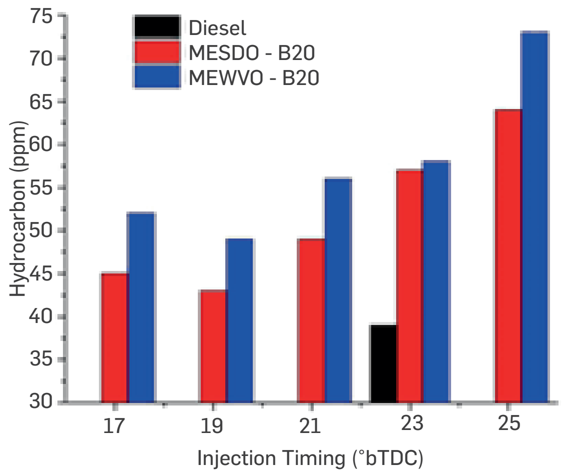

Figure 10. Unburnt hydrocarbon of MESO – B20 and MEWVO – B20 at different Injection timings

SMOKE OPACITY

Smoke formation in diesel engines is caused by incomplete combustion due to a rich or lean fuel-air mixture. Methyl esters can reduce smoke emissions by promoting combustion (Bhaskar Kathirvelu et al., 2017). Injection timings also affect smoke opacity, with retarded timing causing less smoke opacity and advanced timing increasing smoke formation. The lowest smoke opacity was found in MESO-B20 and MEWVO-B20 at 19° before TDC, with MESO-B20 achieving 3.7% more smoke opacity than conventional diesel, which is portrayed in Figure 11. The reduction in smoke opacity from SIT to retard injection timing was 4.8% for MESO-B20 and 5.1% for MEWVO-B20. The higher oxygen content in MESO-B20 also contributed to higher smoke opacity.

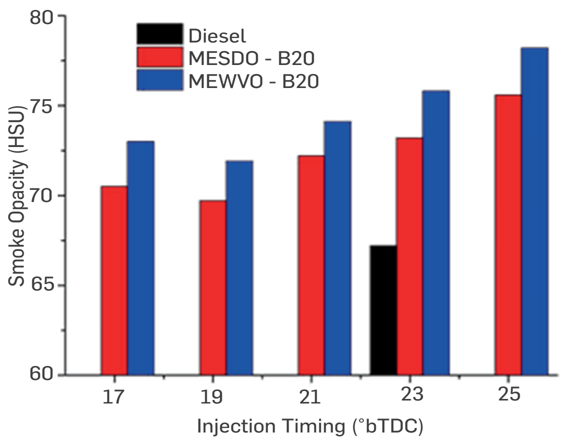

Figure 11. Smoke Opacity of MESO – B20 and MEWVO – B20 at different Injection timings

NITROGEN OXIDES

NOx formation in biodiesel depends on oxygen content, inner cylinder temperature, exhaust gas temperature, and air oxygen and nitrogen levels (Maroa Semakula and Prof Freddie Inambao., 2018). Injection timing affects NOx emissions. Retard injection timing reduces in-cylinder temperature, reducing NOx emissions (R. Sindhu et al., 2018). Advance injection timing increases in-cylinder temperature, causing more NOx emissions.

MESO-B20 and MEWVO-B20 achieve lower NOx emissions at 19° before TDC and standard injection pressure, with MESO-B20 and MEWVO-B20 achieving 18.9% and 30% lower emissions than diesel as shown in Figure 12. The decrease in NOx emission from SIT to retard injection timing is 16.5% for MESO-B20 and 27% for MEWVO-B20.

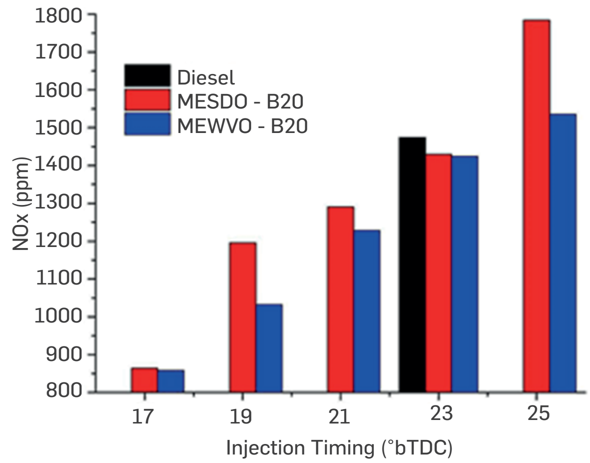

Figure 12. NOx of MESO – B20 and MEWVO – B20 at different Injection timings

CYLINDER PRESSURE

Cylinder pressure represents the pressure inside the cylinder during engine operation and indicates the combustion behavior of the fuel-air mixture. Peak pressure indicates power and emission generated in the CI engine. Retarded injection timing has the highest peak cylinder pressure due to higher premixed combustion. Advanced injection timing has lower peak cylinder pressure due to a rich mixture of fuel-air (S. Rostami et al., 2014).

MESO-B20 and MEWVO-B20 achieve higher peak cylinder pressure due to more oxygen content as shown in Figure 13. They achieved 2.7% and 4.2% lower peak cylinder pressure than conventional diesel.

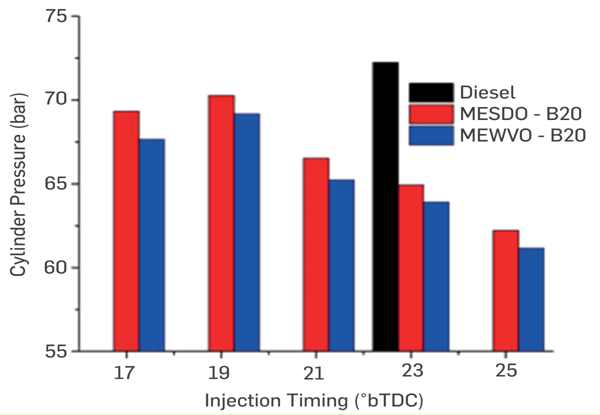

Figure 13. Cylinder pressure of MESO – B20 and MEWVO – B20 at different Injection timings

HEAT RELEASE RATE

Heat Release Rate (HRR) is a key parameter in a combustion engine, as it directly influences the amount of heat released during combustion of the fuel-air mixture. It is influenced by several factors, including the fuel's calorific value, viscosity, and fuel injection timing. The peak HRR is an important indicator of both engine power and emissions generated during combustion, as higher HRR typically correlates with higher power output and more efficient combustion. As shown in Figure 14, conventional diesel exhibits the highest peak HRR due to its higher calorific value. This is expected, as diesel's higher energy content results in more heat being released during combustion, leading to a higher peak HRR.

The injection timing is also material in determining the peak HRR. Retarded injection timings typically result in a higher peak HRR due to an increase in premixed combustion, where a larger proportion of the fuel is burned before the start of the combustion phase. Conversely, advanced injection timings tend to produce a lower peak HRR. This is because the rich fuel-air mixture associated with advanced injection timings results in a less efficient combustion process, leading to lower heat release (V. Dhana Raju et al., 2018). Both MESO-B20 and MEWVO-B20 biodiesel blends achieve higher peak HRR compared to conventional diesel. This can be attributed to their higher calorific value and increased oxygen content, which facilitate more complete combustion. The higher oxygen content in these biodiesels promotes better air-fuel mixing, translating into more efficient combustion and contributing to higher heat release rates.

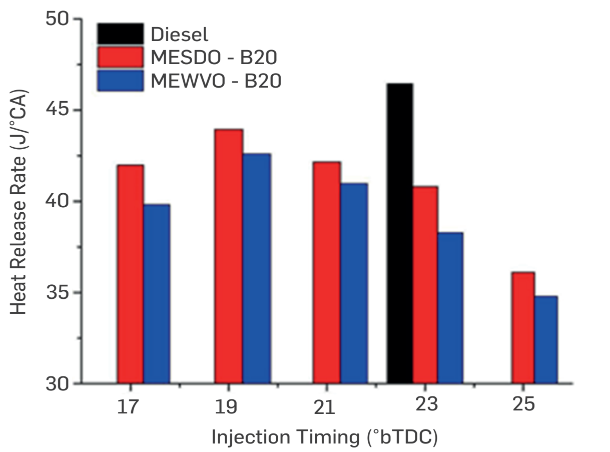

Figure 14. HRR of MESO – B20 and MEWVO – B20 at different Injection timings

IGNITION DELAY

Ignition delay is the time it takes for atomized fuel particles to ignite or combustion. It is measured using the heat release rate graph and decreases with load due to increased cylinder wall temperature and quicker premixed combustion. Diesel has an ignition delay of 8.2° CA, while MESO-B20 and MEWVO-B20 have varying delays at full load conditions. The analysis shows that ignition delay decreases as injection time sets towards retardation as shown in Figure 15. Retarded injection timing (19° before TDC) has the lowest ignition delay due to higher premixed combustion (Venkanna Krishnamurthy Belagur and Venkataramana Reddy Chitimini., 2012). Advanced injection timing (25° before TDC) has higher delays due to a rich mixture of fuel and air (Raheman, H and Padhee, D., 2014). MESO-B20 and MEWVO-B20 achieve 13.4% and 11% lower ignition delay than conventional diesel. The decrease in ignition delay from SIT to retard injection timing is 21.1% for MESO-B20 and 23.2% for MEWVO-B20.

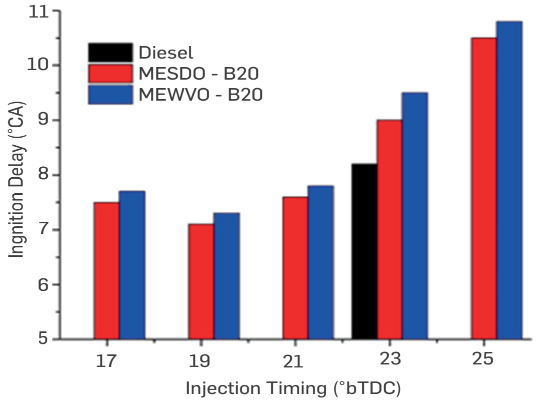

Figure 15. Ignition delay of MESO – B20 and MEWVO – B20 at different Injection timings

COMBUSTION DURATION

Combustion duration refers to the period between start and end of combustion. It includes premixed, rated controlled, and late combustion. Advanced injection timing has lower combustion duration due to higher ignition delay (Chenxi Sun et al., 2016). Figure 16 shows that, MESO-B20 and MEWVO-B20 achieve higher combustion duration due to lower ignition delay and higher calorific value and oxygen content (V. R., Sabu et al., 2020). They achieve 12% and 11.4% higher combustion duration than conventional diesel. The increase in combustion duration from SIT to retard injection timing is 8.1% for MESO-B20 and 7.9% for MEWVO-B20.

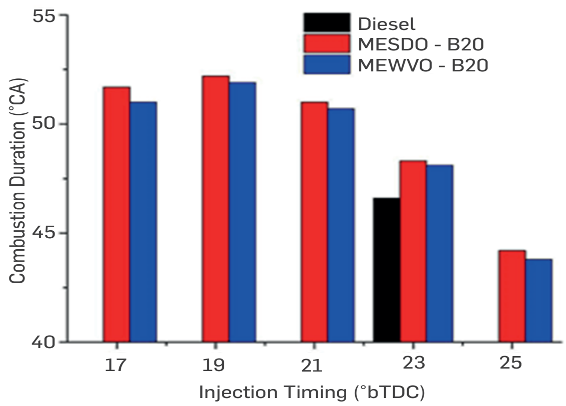

Figure 16. Combustion duration of MESO – B20 and MEWVO – B20 at different Injection timings

The study tested methyl ester blends (MESO – B20 and MEWVO – B20) in diesel engines at different injection timings and standard injection pressure. Results showed improvements in engine characteristics at retarded injection timing (19° before TDC) and standard injection pressure (200bar). The methyl esters B20 blends showed more positive engine characteristics at 19° before TDC and 200 bar compared to diesel at standard injection parameters. The retarded injection timing was considered optimal, resulting in better performance and emission characteristics.

EFFECT OF INJECTION PRESSURES ON B20 METHYL ESTER BLENDS

The optimal injection timing for MESO - B20 and MEWVO - B20 is 19° before TDC, based on performance, emission, and combustion characteristics compared to diesel values. The effect of injection pressure on these products was explored by varying injection pressures (180 bar, 200 bar, 220 bar, and 240 bar).

BRAKE THERMAL EFFICIENCY

Biodiesel's high viscosity reduces the flow rate into the combustion chamber, affecting fuel flow and atomization. Higher injection pressure influences fuel flow, leading to higher brake thermal efficiency. Higher oxygen content in MESO and MEWVO improves brake thermal efficiency (F.J. Salvador et al., 2011). MESO - B20 and MEWVO - B20 achieve 33.69% and 32.93% brake thermal efficiency at 220 bar, respectively as shown in Figure 17. These fuels achieve 1% and 3.1% less brake thermal efficiency than conventional diesel.

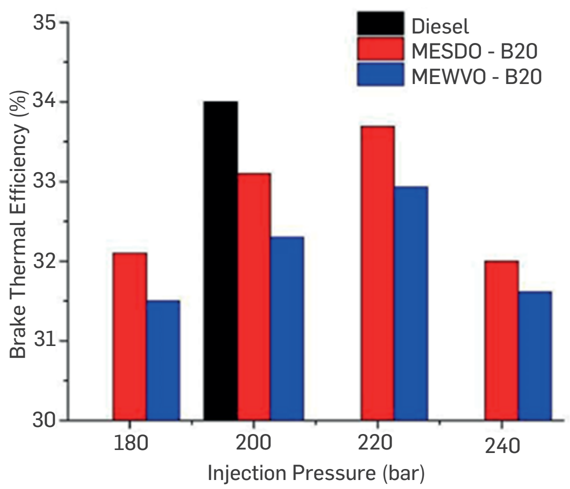

Figure 17. BTE of MESO – B20 and MEWVO – B20 at different Injection pressures

BRAKE SPECIFIC FUEL CONSUMPTION

The study examines the impact of injection pressures on BSFC with optimized injection timing (19° before TDC). The results show that higher injection pressure leads to better combustion and lower fuel consumption (F.J. Salvador et al., 2011). However, higher pressures result in incomplete combustion and more fuel consumption (Bakar, Rosli Abu et al., 2008). The study also compares the BSFC variation between MESO - B20 and MEWVO - B20, with MESO having more oxygen and calorific value. The lowest BSFC achieved by MESO - B20 and MEWVO - B20 is 0.255 kg/kW-h and 0.28 kg/kW-h, respectively as shown in Figure 18. The BSFC improved from standard to optimized parameters by 6.3% for MESO - B20 and 15.6% for MEWVO - B20.

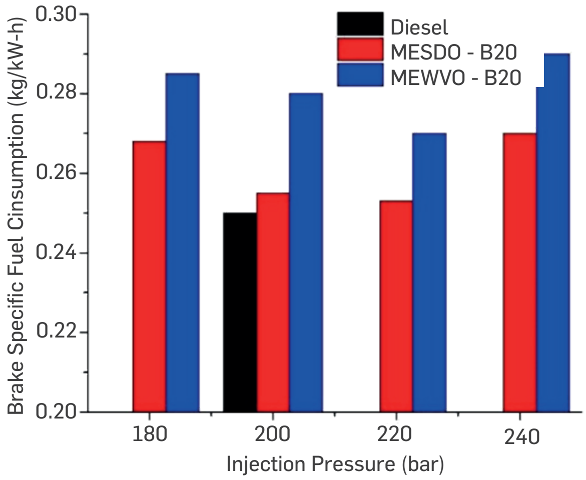

Figure 18. BSFC of MESO – B20 and MEWVO – B20 at different injection pressures

EXHAUST GAS TEMPERATURE

Exhaust gas temperature (EGT) is inversely related to brake thermal efficiency. The EGT decreases with increasing injection pressure (Mutyalu, K.B et al., 2018), with more heat released during optimized timing. MESO - B20 and MEWVO - B20 have lower EGT due to biodiesel BTE values. MESO - B20 and MEWVO - B20 achieve 6.2% and 7.7% higher EGT than conventional diesel as shown in Figure 19. The EGT reduction from standard to optimized parameters is 4% for MESO - B20 and 4.6% for MEWVO - B20.

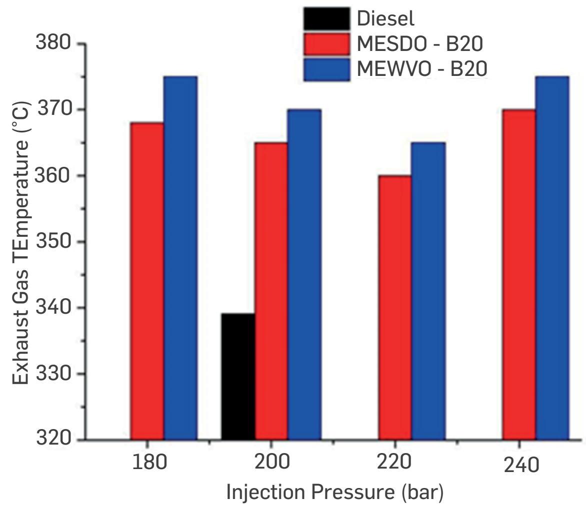

Figure 19. EGT of MESO – B20 and MEWVO – B20 at different injection pressures

CARBON MONOXIDE

The study examines the impact of CO emission formation at different injection pressures and timings. The results show that higher injection pressures lead to better combustion, reduced CO emissions, and uniform fuel droplet spraying (Kim, Ho Young et al., 2019). Higher pressures result in a rich mixture, while lower pressures result in a lean mixture (Özdalyan, B., and S. Özer. 2011). The study also reveals that MESO-B20 and MEWVO-B20 have lower CO emissions due to higher oxygen content as shown in Figure 20. The reduction in CO emissions from standard to optimized injection parameters is 39% for MESO-B20 and 35% for MEWVO-B20.

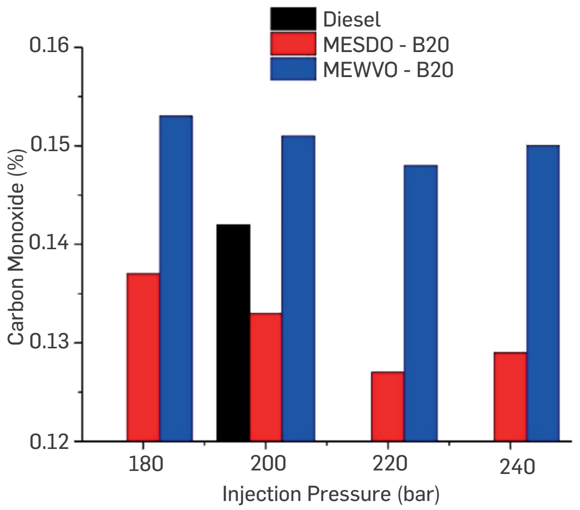

Figure 20. CO of MESO – B20 and MEWVO – B20 at different injection pressures

UNBURNT HYDROCARBONS

The study examines the impact of different injection pressures and optimized injection timing on unburnt hydrocarbon emission. The results show that higher injection pressures lead to better combustion, while lower pressures promote a lean mixture (S. Gowthaman, A.P. Sathiyagnanam et al., 2016). The unburnt hydrocarbon emission variation between MESO - B20 and MEWVO - B20 is less due to increased oxygen content as shown in Figure 21. The lowest emissions were found at 19° before TDC and 220 bar, with MESO - B20 emitting 2.6% more than conventional diesel and MEWVO - B20 10.3% more.

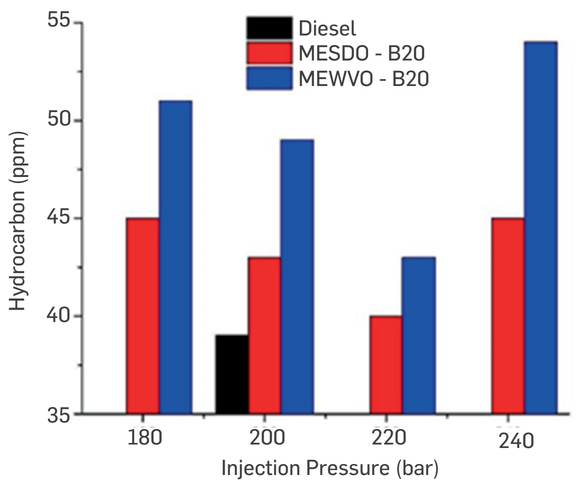

Figure 21. Unburnt hydrocarbon of MESO – B20 and MEWVO – B20 at different injection pressures

SMOKE OPACITY

The study examines the impact of smoke opacity on combustion at different injection pressures and optimized injection timing. The results show that higher injection pressures lead to better combustion, while lower pressures result in a lean mixture (Gangadhara Rao et al., 2018). The smoke opacity variation between MESO - B20 and MEWVO - B20 is less due to higher oxygen content. The lowest smoke opacity was found at 19° before TDC and 220 bar, with MESO - B20 having a 0.4% higher smoke opacity than conventional diesel as shown in Figure 22. The reduction in smoke opacity from standard to optimized parameters is 7.9% for MESO - B20 and 9.6% for MEWVO - B20.

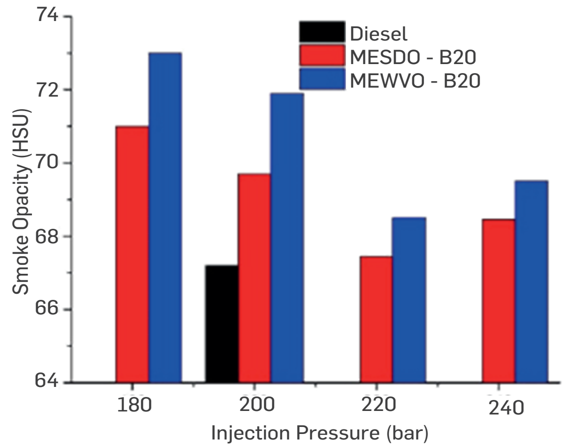

Figure 22. Smoke opacity of MESO – B20 and MEWVO – B20 at different injection pressures

NITROGEN OXIDES

The formation of NOx in fuel-air mixtures depends on in-cylinder temperature and EGT. The effect of injection pressure on NOx formation at optimized injection timings is analyzed. Increased injection pressure leads to higher in-cylinder temperature, oxidation of nitrogen molecules, and lower in-cylinder temperature (Sanjay Patil, Dr. M. M. Akarte et al., 2012). This process repeats with lower injection pressure. Results show that MESO - B20 and MEWVO - B20 have more NOx emission due to more oxygen molecules in the mixture. Figure 23 shows MESO - B20 and MEWVO - B20 achieved 8.4% and 22.3% lower NOx emission than conventional diesel.

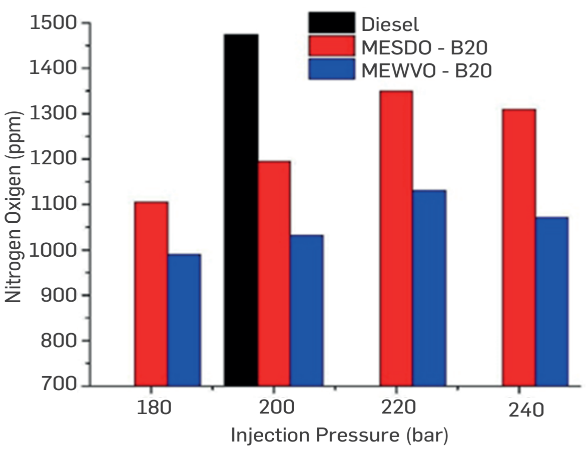

Figure 23. NOx of MESO – B20 and MEWVO – B20 at different injection pressures

CYLINDER PRESSURE

The peak cylinder pressures of MESO - B20 and MEWVO - B20 are analyzed, showing that as injection pressure increases, peak cylinder pressure increases. Lower injection pressures result in poor fuel impingement, while higher pressures promote better atomization and combustion (Gangadhara Rao et al., 2018). The highest peak cylinder pressure is achieved at 220 bar due to complete combustion of fuel-air mixture as shown in Figure 24. Higher injection pressures result in 1.1% and 1.4% lower peak cylinder pressure than conventional diesel. MESO - B20 and MEWVO - B20 achieve an increase in peak cylinder pressure from standard to optimized parameters, with MESO - B20 experiencing a 10% increase and MEWVO - B20 11.5% increase.

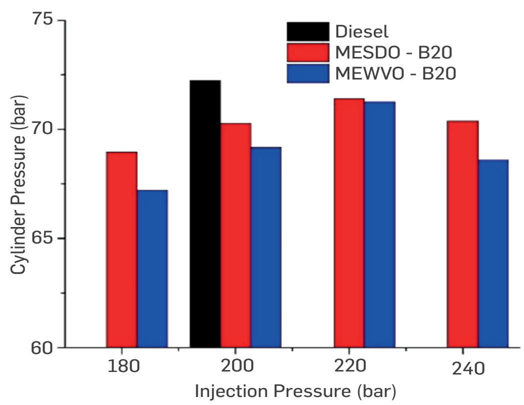

Figure 24. Cylinder pressure of MESO – B20 and MEWVO – B20 at different injection pressures

HEAT RELEASE RATE

The analysis of peak HRR in diesel shows that it increases with injection pressure, with higher pressures promoting better combustion. Improper atomization and impingement can lead to incomplete combustion and lower HRR (V. R., Sabu et al., 2020). MESO-B20 and MEWVO-B20 achieve higher peak HRR at all injection pressures due to more oxygen content and calorific value as shown in Figure 25. MESO-B20 and MEWVO-B20 achieve 1.3% and 4.8% lower peak HRR than conventional diesel. The increase in peak HRR from standard to optimized parameters is 12.4% for MESO-B20 and 15.5% for MEWVO-B20.

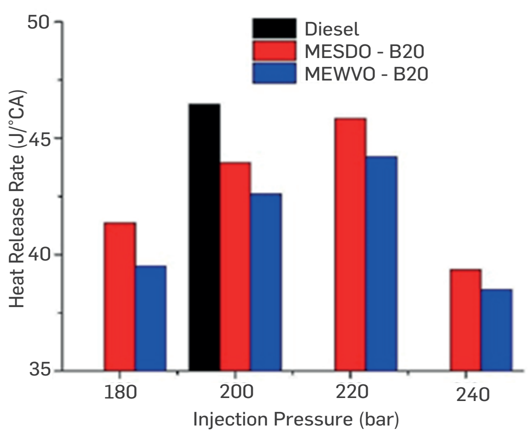

Figure 25. HRR of MESO – B20 and MEWVO – B20 at different injection pressures

IGNITION DELAY

The analysis of ignition delay in diesel shows that it decreases with an increase in injection pressure, reversing the trend of the curve. Lower injection pressures result in poor fuel impingement, leading to a late start of combustion. Higher injection pressures result in better atomization and combustion rate (Salmani, Mahir H et al., 2015) and (Srivastava, Anmesh Kumar et al., 2017). The lowest ignition delay is achieved at 220 bar due to complete combustion of fuel-air mixture as shown in Figure 26. MESO-B20 and MEWVO-B20 achieve lower ignition delays at all injection pressures due to more oxygen content and calorific value. They achieve 20.7% and 18.3% lower ignition delay than conventional diesel.

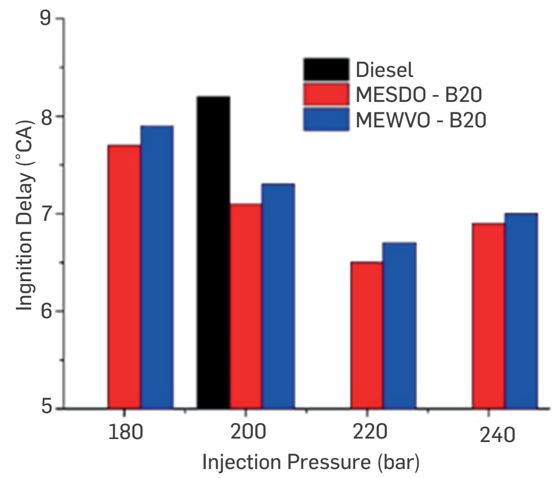

Figure 26. Ignition delay of MESO – B20 and MEWVO – B20 at different injection pressures

COMBUSTION DURATION

Figure 27 shows the combustion duration variation between MESO – B20 and MEWVO – B20 at full load. MESO – B20 has a higher duration due to lower ignition delay period and higher calorific value and oxygen content (Kim, Ho Young et al., 2019). It achieves 16.5% and 15.9% higher duration than conventional diesel. The increase in combustion duration from standard to optimized parameters is 12.4% for MESO - B20 and 12.3% for MEWVO - B20.

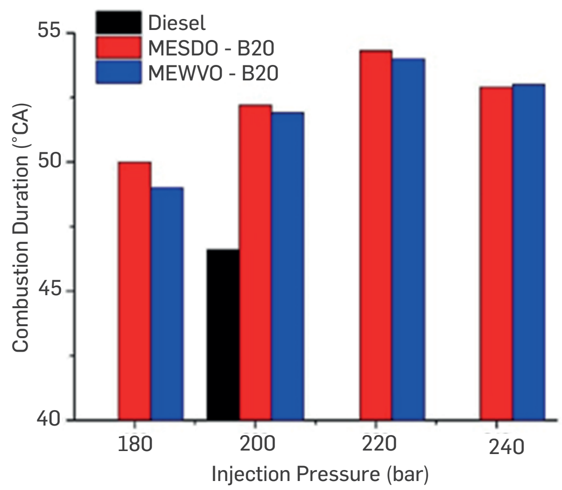

Figure 27. Combustion duration of MESO – B20 and MEWVO – B20 at different injection pressures

The study analyzed the effect of injection pressures on performance, emission, and combustion characteristics of MESO – B20 and MEWVO – B20 blends in an engine. Results showed that ignition delay decreases with increasing injection pressure, while improper atomization leads to improper combustion. Improved engine characteristics were observed at retarded injection timing (19° before TDC) and higher injection pressure (220bar) compared to standard injection parameters. The methyl ester B20 blend at 19° before TDC and 220 bar had more favorable engine characteristics than diesel at standard injection parameters. Conversely, the methyl esters B20 blend at 19° before TDC and 220 bar had less favorable engine characteristics than diesel at standard injection parameters.

4. DISCUSSIONS

This study investigates the optimization of injection parameters for MESO-B20 (methyl ester scum oil) and MEWVO-B20 (methyl ester waste vegetable oil) biodiesel blends in compression ignition (CI) engines, focusing on improving fuel efficiency, combustion performance, and emissions. The findings align with and extend current research on alternative fuels for CI engines, highlighting the potential of these biodiesel blends as viable substitutes for conventional diesel.

CRITICAL EVALUATION OF RESULTS:

UNEXPECTED TRENDS

An unexpected trend observed was the higher CO emissions from MEWVO-B20 compared to MESO-B20, despite the higher oxygen content in MEWVO-B20, which is generally associated with better combustion. This result may be explained by the higher viscosity of MEWVO-B20, which could have hindered fuel atomization during the injection process. Incomplete atomization can lead to poor mixing of the fuel and air, resulting in localized rich regions in the combustion chamber where combustion is incomplete, leading to higher CO emissions. This is a critical factor, as fuel atomization is essential for achieving homogeneous combustion and reducing emissions (Vijay Kumar et al., 2017).

Another unexpected finding was the increase in NOx emissions across both biodiesel blends. While biodiesels are typically expected to lower particulate matter and CO emissions, they often produce higher NOx emissions due to the increased oxygen content and combustion temperatures (Khujamberdiev et al., 2023). In our study, the increase in NOx emissions was consistent with this trend, as higher oxygen content promotes more complete combustion, which, while improving thermal efficiency, can lead to higher peak combustion temperatures and consequently higher NOx production.

COLD FLOW PROPERTIES AND LOW-TEMPERATURE PERFORMANCE:

While this study focused on the impact of injection timing and pressure, cold flow properties of the biodiesel blends—such as pour point, cloud point, and oxidation stability—are crucial factors for evaluating the suitability of these biodiesels in colder climates. MEWVO-B20 and MESO-B20 may exhibit poorer low-temperature properties compared to conventional diesel, which could be challenging for cold starts and fuel handling in regions with low ambient temperatures. Future research should focus on the low-temperature performance of these biodiesel blends and explore potential additives to improve cold flow characteristics.

REAL-WORLD IMPLICATIONS:

FEASIBILITY FOR COMMERCIAL DIESEL ENGINES:

The results indicate that the MESO-B20 and MEWVO-B20 biodiesel blends deliver promising performance in terms of thermal efficiency, combustion stability, and reduction in emissions such as CO and HC,compared to conventional diesel. However, the increase in NOx emissions remains being a significant challenge for large-scale adoption, particularly in regions where stringer standards are in place such as Euro VI.

For real-world applications, after-treatment technologies such as exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) would be necessary to mitigate NOx emissions without compromising engine performance. These technologies could help make biodiesel blends compliant with existing emission regulations whereas maintaining fuel efficiency and reducing CO emissions.

ECONOMIC FEASIBILITY:

The use of waste oils as feedstocks for biodiesel production offers considerable economic benefits. Waste oils, such as dairy scum oil and used cooking oil, are generally less expensive than edible oils, making biodiesel production from waste oils more cost-effective. Additionally, industries that generate waste oils can significantly reduce disposal costs by converting them into biodiesel, thus creating a sustainable revenue stream.

When compared with conventional diesel, the production costs for MESO-B20 and MEWVO-B20 blends may be competitive, particularly in regions where waste oil is abundant and feedstock costs are low. However, biodiesel production still needs to compete with petroleum diesel prices. Policy incentives and government subsidies for renewable fuels will be critical in enhancing the long-term viability of biodiesel as an alternative to diesel.

ENVIRONMENTAL BENEFITS:

The environmental impact of using waste oils for biodiesel production is significant, as it not only reduces greenhouse gas emissions compared to conventional diesel but also helps address the issue of waste oil disposal. By converting waste oils into biodiesel, pollution caused by improper disposal of these oils can be reduced, which often end up in landfills or wastewater treatment facilities. Additionally, biodiesel production from waste oils contributes to energy independence, as it reduces reliance on imported oil and supports the development of local, sustainable fuel sources. This is particularly important for emerging economies and regions with large agricultural sectors, where waste oil is abundant.

LONG-TERM ENGINE EFFECTS:

While this study examined the short-term performance, the long-term effects of using MESO-B20 and MEWVO-B20 blends in CI engines should be further investigated. Potential issues include engine wear, injector coking, fuel system corrosion, and lubricant degradation due to the higher oxygen content and viscosity of biodiesel. Future research should address these long-term effects and determine whether engine modifications or additives are needed to ensure the durability and reliability of engines operating with biodiesel blends.

CONCLUSIONS

This study evaluated the use of biodiesel blends derived from scum oil (MESO) and waste vegetable oil (MEWVO) as alternative fuels for compression ignition (CI) engines. The results indicate that MESO-B20 and MEWVO-B20 show strong potential as viable diesel substitutes, addressing some of the challenges typically associated with unsaturated methyl esters in biodiesel.

Key findings:

- Optimized Injection Parameters: Retarded injection timing improved fuel atomization and combustion by better utilizing the oxygen content in the blends. This resulted in higher combustion temperatures and pressures, thus optimizing engine performance.
- Performance and Emission Improvements: Both MESO-B20 and MEWVO-B20 achieved higher brake thermal efficiency (BTE), lower brake-specific fuel consumption (BSFC), reduced CO and NOx emissions, and improved peak heat release rates (HRR). Retarded injection timing, combined with higher injection pressures, further contributed to better combustion and engine efficiency.
- Emission Analysis: MESO-B20 produced 10% lower CO emissions and 2.6% higher HC emissions compared to conventional diesel. Although NOx emissions increased, this drawback can be mitigated with after-treatment solutions.

Overall, MESO-B20 and MEWVO-B20 prove to have significant potential for replacing conventional diesel in CI engines, as a sustainable and efficient alternative. However, further research isrequired to address NOx emissions and optimize fuel formulations for commercial applications.

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