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Analysis of the Effect of Biodiesel Mixtures on Pressure, Temperature, and Heat Release Rate in Diesel Engines

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Abstract
This study analyzes the effect of biodiesel blends on the combustion characteristics of diesel engines, including in-cylinder pressure, in-cylinder temperature, and Rate of Heat Release (ROHR) at 75% and 100% loads. The fuels used were pure diesel (DB100) and biodiesel blends with compositions F10B10, F20B10, F20B20, and F30B10. The results showed that peak in-cylinder pressure increased with the use of biodiesel. At 75% load, the maximum pressure for DB100 was 69 bar, while F30B10 reached 72 bar. At 100% load, the maximum pressure for DB100 was 70 bar, while F30B10 increased to 74 bar. In addition, the in-cylinder temperature also increased with the biodiesel blend. At 75% load, the peak temperature for DB100 was recorded at 1480 K, while F20B20 reached 1550 K. At 100% load, the temperature increased to 1600 K for DB100 and 1700 K for F10B10. ROHR analysis showed that biodiesel increased energy release compared to pure diesel. At 75% load, DB100 had a peak ROHR of 52,000 kW, while F30B10 reached 57,000 kW. At 100% load, DB100 recorded a ROHR of 48,000 kW, while F30B10 increased to 58,000 kW. The results of this study indicate that biodiesel blends can improve combustion efficiency, which is characterized by increased pressure, temperature, and heat release. However, this increase can also cause an increase in NO_x emissions, so an emission mitigation strategy is needed to balance energy efficiency and environmental impacts.

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1. Introduction

Biodiesel as an alternative fuel has become an interesting research topic in recent decades. The energy crisis and environmental impacts of using fossil fuels have driven various efforts to find more environmentally friendly and sustainable fuels. Biodiesel, which is derived from vegetable oil or animal fat, has been shown to have potential as an alternative fuel because its combustion properties are close to conventional diesel. Several previous studies have shown that biodiesel has a higher oxygen content, which can improve combustion efficiency and reduce particulate matter (PM) emissions, but also has the potential to increase NO_x emissions (Bahagia, Nizar, Yasin, Rosdi, & Faisal, 2025; Gani et al., 2025; Ghoto et al., 2024). Research on the effect of biodiesel on engine performance has been widely conducted, primarily related to in-cylinder pressure, combustion temperature, and heat release rate. For example, research showed that biodiesel can increase combustion pressure compared to pure diesel due to the high oxygen content that accelerates combustion (Ghazali, Rosdi, Erdiwansyah, & Mamat, 2025; Najafi, 2018; S. M. M. Rosdi, Erdiwansyah, Ghazali, & Mamat, 2025). Meanwhile, research found that higher in-cylinder temperatures in biodiesel can increase engine thermal efficiency but can also increase exhaust emissions such as NO_x (Irhamni, Kurnianingtyas, Muhtadin, Bahagia, & Yusop, 2025; Savaş, Şener, Uslu, & Der, 2025; Subbiah et al., 2024).

On the other hand, research showed that biodiesel with a 20% blend (B20) can increase the Rate of Heat Release (ROHR) without causing excessive detonation (Fitriyana, Rusiyanto, & Maawa, 2025; Niculescu, Clenci, & Iorga-Siman, 2019; S. M. Rosdi, Maghfirah, Erdiwansyah, Syafrizal, & Muhibbuddin, 2025). This increase occurs because biodiesel has a higher cetane number compared to pure diesel, which causes a faster ignition time. However, another study revealed that higher biodiesel blends, such as B30 or more, can significantly increase maximum pressure and cause additional load on engine components (Agarwal, Yadav, Mudgal, & Khan, 2025; Alenezi et al., 2021; Muhibbuddin, Hamidi, & Fitriyana, 2025). In addition, research showed that using biodiesel can provide varying results depending on engine load. At low to medium loads, biodiesel tends to provide more stable combustion with higher pressure and temperature (Alenezi, Erdiwansyah, Mamat, Norkhizan, & Najafi, 2020; Erdiwansyah et al., 2019; Saxena, Kumar, & Saxena, 2017). However, increased pressure and temperature in the cylinder at high loads become more significant, impacting long-term engine durability. Therefore, selecting the optimal biodiesel blend is crucial to balance increasing engine performance and reliability.

Considering previous studies, this study aims to analyze in more detail how biodiesel blends affect the combustion characteristics of diesel engines, especially in terms of in-cylinder pressure, in-cylinder temperature, and heat release rate at 75% and 100% loads. The results obtained are expected to provide insight into the potential use of biodiesel as an alternative fuel and the challenges that must be overcome in its implementation. This study was conducted using various biodiesel blends, namely DB100 (pure diesel), F10B10, F20B10, F20B20, and F30B10, to evaluate changes in pressure, temperature, and heat release in the combustion chamber of a diesel engine. This analysis is essential to understand how biodiesel can improve combustion efficiency while anticipating potential impacts on emissions and engine life. The results of this study can also be the basis for the development of renewable energy policies and recommendations for the automotive industry in optimizing the use of biodiesel in modern diesel engines.

2. Methodology

Fig. 1 shows a schematic diagram of the dynamometer-based engine testing system used to measure the performance and emissions of the Yanmar TF120M engine. The system consists of several main components, including a diesel engine as a power source, an eddy current dynamometer as a load and torque measuring device, and a load cell to measure the reaction force from the dynamometer. In addition, the system is also equipped with a speed sensor to measure engine rotation and several thermocouples placed at various points, such as the air intake, engine, and exhaust pipe, to observe temperature changes during the test. The fuel used is measured using a fuel weight scale, while the intake airflow is monitored using an airflow meter.

The test also involves monitoring exhaust emissions, where gases such as O_2, CO_2, CO, and NO_x are measured to evaluate the engine's combustion efficiency and environmental impact. The results of engine combustion are analyzed through an exhaust gas analyzer connected to the exhaust system. The dynamometer controller functions to regulate and record operational parameters such as speed, torque, and engine load. The electrical load generated by the engine during testing is absorbed by the load resistor bank so that load simulations can be carried out with various operational scenarios. Overall, this system allows for accurate engine performance and emissions measurement, which is useful in alternative fuel research and optimisation of diesel engines.

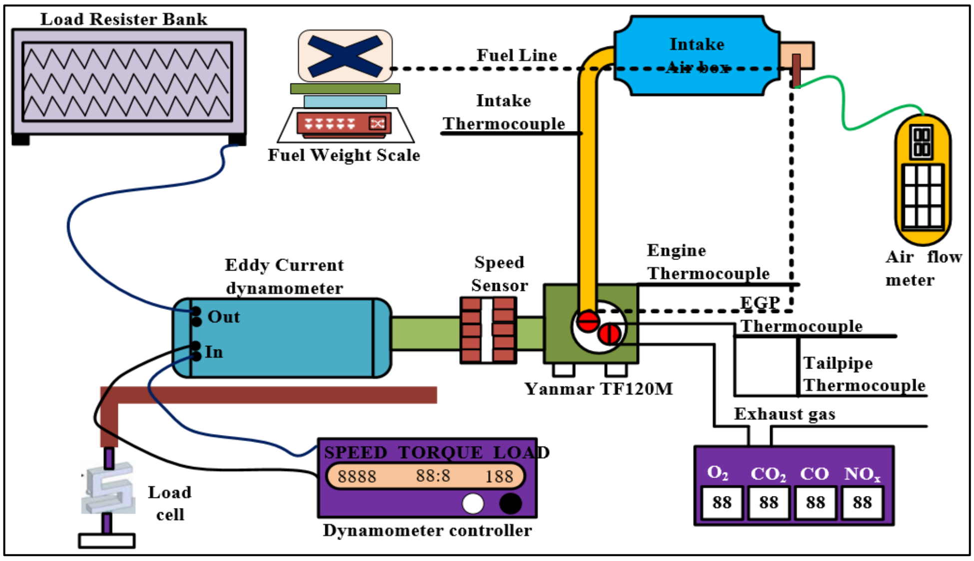

Fig. 1. Schematic diagram

3. Result & Discussion

Fig. 2 shows the relationship diagram between in-cylinder pressure and crank angle at 75% load for various fuel blends. This graph provides insight into the combustion characteristics of the tested fuels, including DB100 (pure diesel) and blends of biodiesel and other biofuels. The results shown in this graph indicate that the peak in-cylinder pressure varies with the type of fuel used. The maximum in-cylinder pressure for DB100 (pure diesel) was recorded at around 69 bar, while for the other fuel blends, the peak pressure was higher, with the highest value reaching 72 bar for the F30B10 blend. This increase in peak pressure indicates that the biodiesel and biofuel blends have better combustion characteristics in terms of increasing combustion pressure. In addition, the inset in the figure zooms in on the peak pressure for a more detailed analysis of the differences between the fuels. The blended fuel produces peak pressure earlier than the pure diesel, indicating that alternative fuels can accelerate combustion and improve thermal efficiency. This phenomenon can be attributed to biodiesel's high oxygen content, which increases the combustion reaction rate. However, a pressure increase that is too high can also have an impact on engine performance and possibly increase mechanical loads on engine components. Therefore, selecting the optimal fuel mixture must consider the balance between higher combustion pressure and engine operational safety.

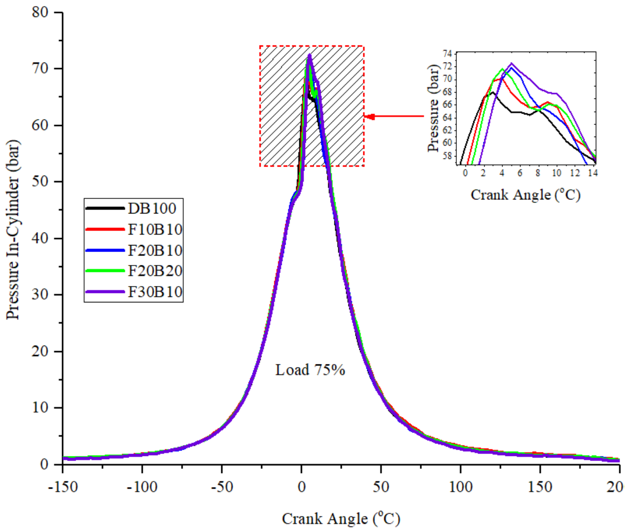

Fig. 2: In-Cylinder Pressure vs. Crank Angle Diagram at 75% Load

Fig. 3 shows the relationship between in-cylinder pressure and crank angle at full load (100%) for various fuel blends. The graph reveals that the peak in-cylinder pressure varies depending on the type of fuel used. From the study results, the maximum pressure produced by pure diesel fuel (DB100) was recorded at around 69 bar, while blended fuels such as F30B10 produced the highest pressure reaching 74 bar. This increase in pressure indicates that the biodiesel and biofuel blends have faster and more efficient combustion than pure diesel. This can be attributed to the additional oxygen content in biodiesel, which accelerates the combustion reaction rate and increases the overall combustion pressure. The inset in the figure zooms in on the peak pressure section, showing that blended fuels reach maximum pressure earlier than pure diesel. This indicates that alternative fuels can improve combustion efficiency and optimize energy release during the engine work cycle. However, higher pressures also need to be studied further because they can increase the mechanical load on engine components and potentially affect engine life. Therefore, although fuel blends such as F30B10 show improved performance, further analysis is needed to ensure that higher pressures do not cause harmful effects on long-term engine reliability.

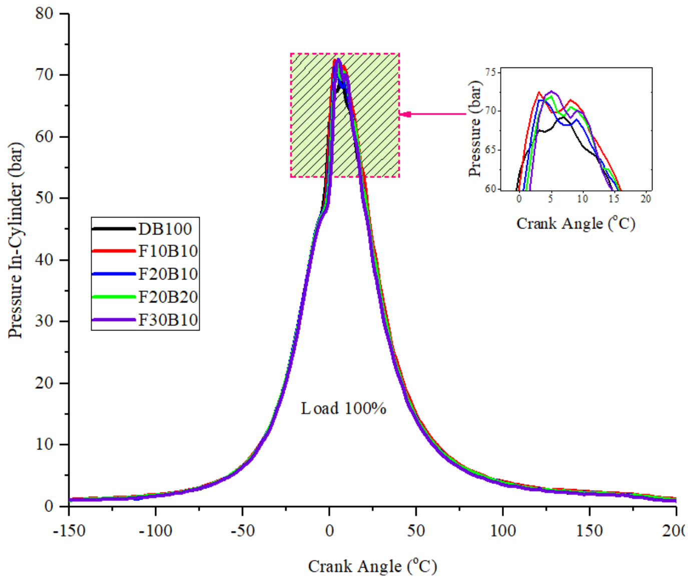

Fig. 3: In-Cylinder Pressure vs. Crank Angle Diagram at 100% Load

Fig. 4 shows the relationship between in-cylinder temperature and crank angle at 75% load for various fuel blends. The graph illustrates how the in-cylinder temperature changes during the combustion process, with the horizontal axis showing the crank angle and the vertical axis showing the in-cylinder temperature in Kelvin (K). Based on the results of the study, the highest peak temperature occurred in the F20B20 blend fuel, which reached around 1550 K, while pure diesel fuel (DB100) produced a lower peak temperature, around 1480 K. This increase in temperature is due to the high oxygen content in the biodiesel blend, which increases combustion efficiency and accelerates the combustion reaction rate. The inset of the graph zooms in on the temperature peak section to compare the fuel variations in more detail. The blend fuel produces a higher temperature than pure diesel, indicating increased combustion efficiency. However, this increase in temperature can also increase NO_x emissions, which must be considered in the environmental impact analysis. In addition, higher temperatures can cause increased thermal loads on engine components, potentially shortening engine life if not balanced with adequate cooling systems. Therefore, although fuel blends such as F20B20 show better combustion performance, further optimization is needed to balance combustion efficiency, exhaust emissions, and engine reliability.

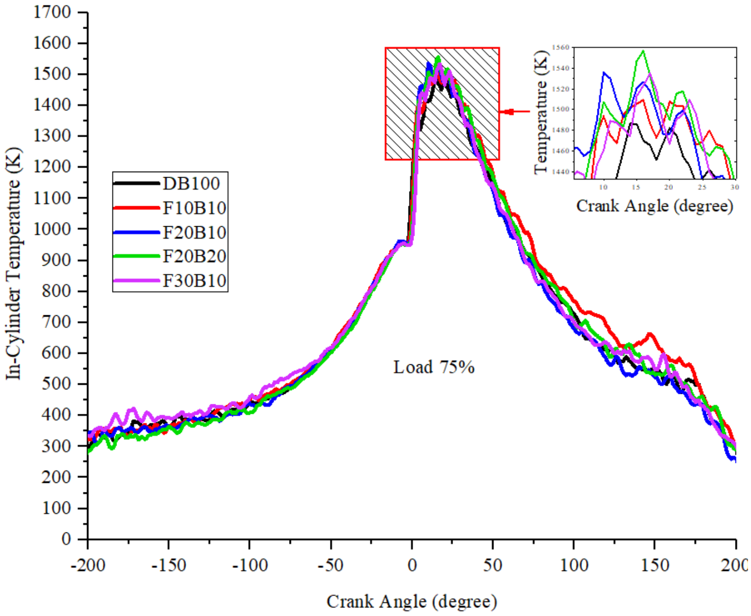

Fig. 4: In-Cylinder Temperature vs. Crank Angle Diagram at 75% Load

Fig. 5 shows the relationship between in-cylinder temperature and crank angle at full load (100%) for various fuel blends. The graph reveals that the peak in-cylinder temperature varies depending on the type of fuel used. From the results, pure diesel fuel (DB100) produces a peak temperature of around 1600 K, while fuel blends such as F10B10 reach the highest temperature of around 1700 K. This increase in temperature indicates that biodiesel and biofuel blends have more efficient combustion compared to pure diesel. This is most likely due to the higher oxygen content in biodiesel, which increases the engine's combustion rate and thermal efficiency. The inset in the figure zooms in on the peak temperature section to compare the differences between the fuels in more detail. Biodiesel blends, especially F10B10 and F20B10, produce higher peak temperatures than pure diesel, indicating an increase in the energy conversion efficiency of the fuel. However, this increase in temperature can also lead to an increase in the formation of NO_x (Nitrogen Oxide), a harmful exhaust gas for the environment. In addition, higher temperatures can increase the thermal load on engine components, which needs to be considered in terms of engine durability and reliability. Therefore, although biodiesel provides increased combustion efficiency, further optimization is required to control exhaust emissions and maintain engine life.

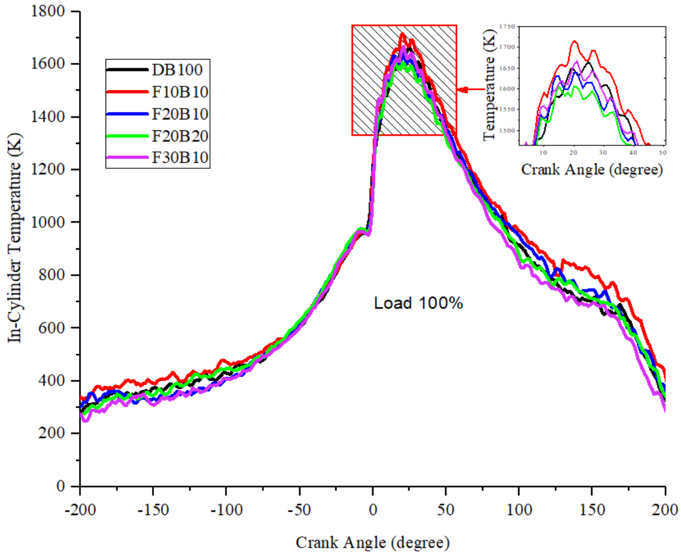

Fig. 5: In-Cylinder Temperature vs. Crank Angle Diagram at 100% Load

Fig. 6 shows the relationship between the Rate of Heat Release (ROHR) and crank angle at 75% load for various fuel blends. This graph illustrates how heat energy is released during the combustion cycle in the engine. From the study's results, pure diesel fuel (DB100) produces a peak ROHR of around 52,000 kW, while a blend of biodiesel with biofuels such as F30B10 produces the highest ROHR of around 57,000 kW. This increase indicates that specific fuel blends can improve combustion efficiency, possibly due to the higher oxygen content in the blended fuel, accelerating the combustion rate and increasing energy release in a shorter time. The inset of the graph zooms in on the ROHR peak area to compare the effects of various fuel blends. Blended fuels such as F30B10 and F20B10 produce higher heat release and occur slightly earlier than DB100. This indicates that alternative fuels can accelerate combustion and improve engine thermal efficiency. However, the exceptionally high increase in heat release can also impact increasing the temperature in the cylinder and potentially increase NO_x emissions. Therefore, although blended fuels show potential for performance improvement, further optimization is needed to balance energy efficiency, exhaust emissions, and long-term engine reliability.

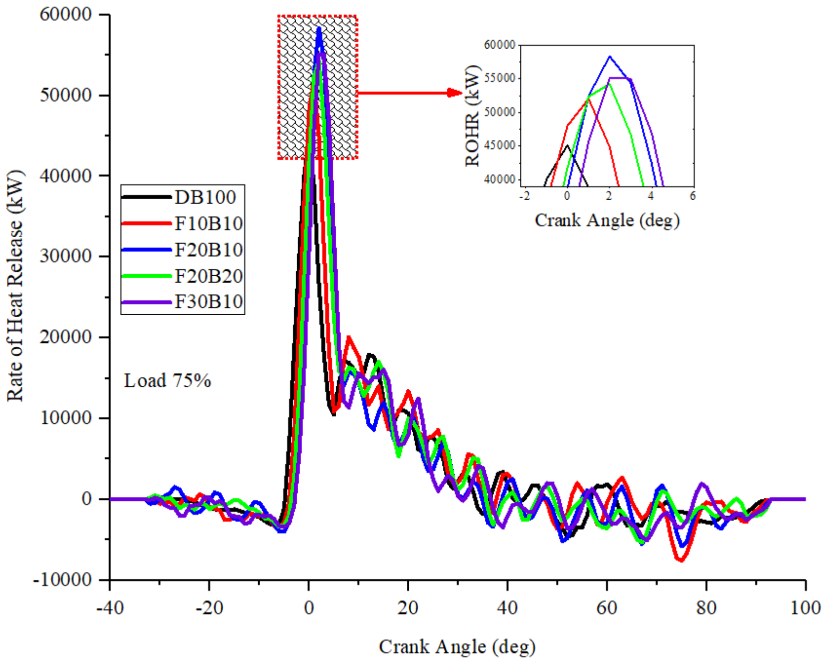

Fig. 6: Rate of Heat Release vs. Crank Angle Diagram at 75% Load

Fig. 7 shows the relationship between the Rate of Heat Release (ROHR) and crank angle at 100% load for various fuel blends. This graph provides an overview of how heat energy is released during the combustion process in the engine cylinder with multiple fuel types. From the research results, pure diesel fuel (DB100) produces a peak ROHR of around 48,000 kW, while the F30B10 fuel blend recorded the highest value of around 58,000 kW. This increase in heat release indicates that using biodiesel in the fuel blend can improve combustion efficiency, mainly because of the additional oxygen content in biodiesel, accelerating the combustion reaction process. The inset in the graph enlarges the ROHR peak area, showing that blended fuels such as F30B10 and F20B10 produce higher heat release than pure diesel and occur earlier. This phenomenon indicates that biodiesel can improve thermal efficiency and accelerate fuel combustion in the engine. However, although higher heat release can improve performance, this increase can also cause an increase in temperature in the cylinder, which has the potential to accelerate the formation of NO_x in the exhaust gas. Therefore, although biodiesel offers increased energy efficiency advantages, it is necessary to implement emission mitigation strategies and optimize engine cooling systems to maintain a balance between performance and environmental impact.

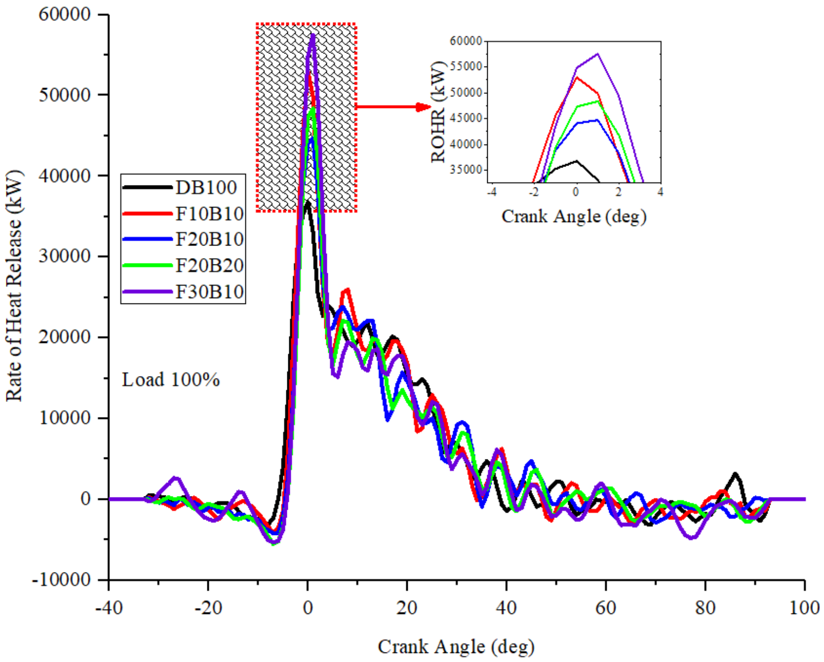

Fig. 7: Rate of Heat Release vs. Crank Angle Diagram at 100% Load

Figs. 2 and **3** show the pressure in the cylinder against the crank angle for two different load conditions, namely 75% load (**Fig. 2**) and 100% load (**Fig. 3**). From the analysis results, the peak pressure at 100% load is higher than at 75% load. At a 75% load, the peak pressure for DB100 fuel is around 69 bar, while for the F30B10 fuel mixture, it is 72 bar. While at 100% load, the peak pressure increases, with DB100 around 70 bar and F30B10 reaching 74 bar. This increase in pressure is caused by the higher load, which requires more fuel supply, resulting in more potent combustion and more tremendous pressure in the cylinder. In addition, the inset in both figures shows that the blended fuel produces higher peak pressure and occurs earlier than pure diesel. This indicates that biodiesel or biofuel has better combustion efficiency, which is characterized by increased pressure and a shift in combustion time. However, at 100% load, the pressure difference between the fuels was more significant compared to 75% load, indicating that the effect of oxygen content in biodiesel is more pronounced when the engine operates at higher loads.

Figs. 4 and **5** compare the in-cylinder temperature versus crank angle at 75% and 100% loads. In general, the in-cylinder temperature increases with increasing engine load. At 75% load, the peak temperature produced by DB100 is around 1480 K, while the F20B20 fuel mixture reaches 1550 K. Meanwhile, at 100% load, the peak temperature increases further, with DB100 around 1600 K and F10B10 reaching 1700 K. This increase in temperature is due to the increased amount of fuel burned due to the high load, resulting in more heat energy in the combustion chamber. From the insets in both figures, blended fuels such as F10B10 and F20B20 produce higher temperatures than DB100 at both load conditions. However, the difference between the fuels becomes more apparent at 100% load, where biodiesel shows a more significant increase in temperature. This higher temperature can positively impact combustion efficiency, but it can also increase the formation of NO_x, a harmful exhaust gas. Therefore, although biodiesel offers improved performance, emission mitigation measures must be implemented to control the environmental impact.

Figs. 6 and **7** show the Rate of Heat Release (ROHR) against crank angle for 75% and 100% loads. In both graphs, biodiesel produces a higher ROHR than pure diesel, with a more significant increase at 100% load. At 75% load (**Fig. 6**), the peak ROHR for DB100 is around 52,000 kW, while for F30B10 it reaches 57,000 kW. At 100% load (**Fig. 7**), DB100 reaches around 48,000 kW, while F30B10 increases to 58,000 kW. This indicates that biodiesel can improve combustion efficiency, especially at high loads, where the combustion reaction occurs faster and energy release is more outstanding. In addition, the insets in both figures show that the peak heat release occurs earlier for the blended fuel than pure diesel, indicating that biodiesel has a faster ignition time and more efficient combustion. However, at 100% load, the variation between fuel types is more pronounced, with biodiesel having a higher ROHR value than at 75% load. This indicates that at high loads, the effect of oxygen content in biodiesel is more substantial in accelerating combustion. However, increasing heat release too high can cause an increase in temperature in the cylinder and potentially increase pressure and the formation of NO_x emissions, which needs to be considered in the optimal use of mixed fuels.

4. Conclusion

Based on the study's results on the effect of biodiesel fuel mixtures on the combustion characteristics of diesel engines, it can be concluded that using biodiesel provides increased combustion efficiency compared to pure diesel (DB100). The analysis of in-cylinder pressure found that at 75% load, the peak pressure for DB100 was 69 bar, while the F30B10 mixture reached 72 bar. At 100% load, the peak pressure increased to 70 bar for DB100 and 74 bar for F30B10. This shows that the fuel mixture with biodiesel can increase combustion pressure, leading to increased engine thermal efficiency. In addition, the analysis of in-cylinder temperatures showed that biodiesel produced higher temperatures than pure diesel. At 75% load, the peak temperature for DB100 was recorded at 1480 K, while F20B20 reached 1550 K. At 100% load, the peak temperature increased to 1600 K for DB100 and 1700 K for F10B10. This increase in temperature indicates that blended fuels can increase the combustion rate and energy release but also potentially increase the formation of NO_x emissions.

The analysis of the Rate of Heat Release (ROHR) found that biodiesel produces higher energy release than pure diesel. At 75% load, DB100 has a peak ROHR of 52,000 kW, while F30B10 reaches 57,000 kW. At 100% load, DB100 recorded a ROHR of 48,000 kW, while F30B10 increased to 58,000 kW. This difference indicates that biodiesel accelerates the combustion rate and increases energy release efficiency, especially at high loads. Using biodiesel in a diesel engine fuel blend improves combustion performance, such as higher pressure, temperature, and heat release than pure diesel. However, this increase can also impact increasing in-cylinder temperatures and NO_x emissions, so further optimization strategies are needed to balance energy efficiency and environmental impacts.

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