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Combustion Analysis of Biodiesel Blends on Pressure, Temperature, and Heat Release at Engine Loads

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Abstract

This study analyzed the combustion performance of various biodiesel blends on in-cylinder pressure, in-cylinder temperature, and Rate of Heat Release (ROHR) in a diesel engine with 25% and 50% loads. The tested fuel blends included pure diesel (DB100), and biodiesel blends with 10%, 20%, and 30% biodiesel content (F10B10, F20B10, F20B20, and F30B10). The results showed that in-cylinder pressure increased with increasing load, where the peak pressure on DB100 reached 63 bar at 25% load and increased to 65 bar at 50% load. Meanwhile, the F30B10 blend experienced a slight decrease in pressure, with a peak value of 61 bar at 50% load, indicating slower combustion characteristics. Regarding in-cylinder temperature, DB100 has the highest peak temperature of 1250 K at 25% load and 1380 K at 50%. Biodiesel blends with higher proportions, such as F30B10, have lower temperatures, namely 1180 K at 25% load and 1250 K at 50% load. ROHR analysis shows that at 50% load, the F20B20 blend has the highest ROHR, reaching 45,000 kW, compared to 42,000 kW for DB100. These results indicate that biodiesel can maintain good combustion performance despite experiencing a slight decrease in pressure and peak temperature. Thus, biodiesel blends can be an alternative fuel that has the potential to reduce dependence on conventional diesel without sacrificing engine performance significantly.

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1. Introduction

Biodiesel as an alternative fuel has become a significant concern in diesel engine research because of its more environmentally friendly nature than fossil fuels. Biodiesel has a higher oxygen content, which can improve combustion efficiency and reduce exhaust emissions such as carbon monoxide (CO) and hydrocarbons (HC). Several studies have shown that blending biodiesel with pure diesel can improve combustion characteristics, although it can cause slight changes in engine performance. For example, a survey found that biodiesel has a lower cetane number than conventional diesel, which can affect the ignition timing of the fuel in the combustion chamber (Almardhiyah, Mahidin, Fauzi, Abnisa, & Khairil, 2025; Ghazali, Rosdi, Erdiwansyah, & Mamat, 2025; S. M. Rosdi, Maghfirah, Erdiwansyah, Syafrizal,

& Muhibbuddin, 2025; Yesilyurt, Eryilmaz, & Arslan, 2018). Several studies have evaluated the impact of biodiesel on in-cylinder pressure in diesel engines. It was reported that in-cylinder pressure decreased slightly with the increasing proportion of biodiesel in the blend due to its slower combustion properties than pure diesel (Abdalla, 2018; Fitriyana, Rusiyanto, & Maawa, 2025; Muhibbuddin, Hamidi, & Fitriyana, 2025; S. M. M. Rosdi, Erdiwansyah, Ghazali, & Mamat, 2025). This is in line with the findings, which showed that peak pressure decreased by about 2-5 bar when the biodiesel content in the blend increased to 30% (Alenezi et al., 2021; Gani, Mahidin, Erdiwansyah, Sardjono, & Mokhtar, 2025; Mufti, Irhamni, & Darnas, 2025; ul Haq et al., 2024). In this study, the results obtained showed that the maximum in-cylinder pressure for DB100 was 65 bar, while the biodiesel blend with 30% biodiesel content (F30B10) experienced a pressure decrease of up to 61 bar, indicating a similar effect.

In addition to in-cylinder pressure, the temperature in the combustion chamber is also an essential factor in the analysis of alternative fuel combustion. A study showed that the peak in-cylinder temperature tends to be lower when biodiesel is used due to slower heat release than pure diesel (Alenezi, Erdiwansyah, Mamat, Norkhizan, & Najafi, 2020; Kanthasamy, Selvan, & Shanmugam, 2020; Nizar, Yana, Bahagia, & Yusop, 2025; S. M. Rosdi, Ghazali, & Yusop, 2025). This study found that the peak temperature for DB100 was 1380 K at 50% load, while the F30B10 blend had a lower temperature of 1250 K, indicating that increasing the biodiesel content in the blend affects the energy release process in combustion. The rate of heat release (ROHR) is also a significant parameter in assessing the combustion performance of biodiesel. It was found that biodiesel tends to have a slightly lower ROHR than diesel but can produce more gradual and even combustion (Erdiwansyah et al., 2019; Muhibbuddin, Muchlis, Syarif, & Jalaludin, 2025; Rayapureddy, Matijošius, Rimkus, Caban, & Słowik, 2022; Sardjono, Khoerunnisa, Rosdi, & Muchlis, 2025). In this study, the results showed that at 50% load, DB100 had a peak ROHR of 42,000 kW, while the F20B20 blend reached a peak value of 45,000 kW, indicating that specific biodiesel blends can have higher heat release than pure diesel.

In addition, several other studies have observed the impact of biodiesel blends on diesel engines' thermal efficiency and emissions. It was reported that although biodiesel has a higher oxygen content that can improve combustion, the higher heat transfer rate can cause a decrease in thermal efficiency (Maulana, Rosdi, & Sudrajad, 2025; Muchlis, Efriyo, Rosdi, & Syarif, 2025; Muchlis, Efriyo, Rosdi, Syarif, & Leman, 2025; S. M. Rosdi, Yasin, Khayum, & Maulana, 2025; Shirneshan, Kanberoglu, & Gonca, 2025). However, a study showed that biodiesel can reduce particulate and NOx emissions, making it a cleaner fuel alternative (Iqbal, Rosdi, Muhtadin, Erdiwansyah, & Faisal, 2025; Jalaludin, Kamarulzaman, Sudrajad, Rosdi, & Erdiwansyah, 2025; Mirhashemi & Sadrnia, 2020; Muhtadin, Rosdi, Faisal, Erdiwansyah, & Mahyudin, 2025). Thus, despite a slight change in combustion pressure and temperature, biodiesel still has the potential to be an alternative fuel that can be used without significant modifications to diesel engines. Based on various previous studies and the analysis results in this study, it can be concluded that using biodiesel blends impacts in-cylinder pressure, in-cylinder temperature, and heat release rate in diesel engines. Although there is a slight decrease in pressure and temperature, biodiesel can still provide quite good performance in diesel engines. Therefore, this study aims to provide a deeper understanding of the effect of biodiesel on the combustion characteristics of diesel engines at various load levels to support the development of more sustainable and environmentally friendly fuels.

2. Methodology

Fig. 1 shows a schematic diagram of this study's diesel engine test system. The system consists of a Yanmar TF120M diesel engine and an eddy current dynamometer to control the load and measure engine performance. The load is applied through a load resistor bank, while the dynamometer controller is used to display operational parameters such as engine rotational speed (RPM), torque (Nm), and load (N). The system is also equipped with various sensors and measuring instruments, such as a speed sensor to detect engine speed, a load cell to measure the applied load, and several thermocouples to monitor temperatures at various critical points, including intake air temperature, engine temperature, and exhaust gas temperature. In addition, the system also includes emission measuring instruments, consisting of sensors for O_2, CO_2, CO, and NO_x in the exhaust gas, which aim to analyze the impact of biodiesel fuel use on engine exhaust emissions. A fuel weight scale measures fuel consumption, while an airflow meter records the air flow rate entering the engine. With the combination of various sensors and measuring instruments, this system allows a comprehensive evaluation of diesel engine performance in terms of pressure and temperature in the cylinder, combustion efficiency, fuel consumption, and exhaust emission characteristics. This makes this test system a comprehensive tool for analyzing the impact of alternative fuels on diesel engine performance and efficiency.

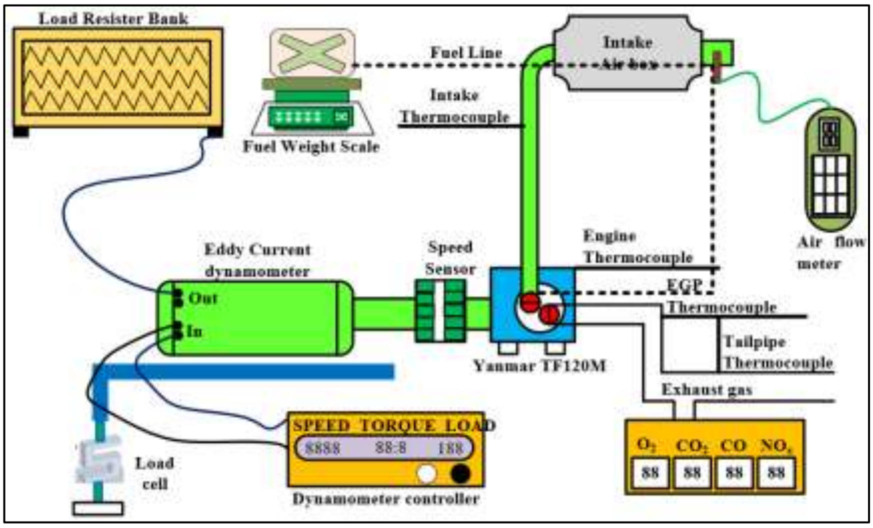

Fig. 1: Diagram Schematic for Engine

3. Result & Discussion

Fig. 2 compares in-cylinder pressure for various fuel mixtures at 25% load. The graph shows that the highest peak pressure is achieved by DB100 fuel (black line) with a value of around 63 bar at a crankshaft angle of around 0°. Meanwhile, other fuel mixtures (F10B10, F20B10, F30B10) show a slight decrease in peak pressure, ranging from 60–62 bar. This difference indicates that increasing the content of FAME fuel mixtures in diesel fuel reduces in-cylinder pressure slightly. In the inset section that enlarges the area around the peak point, it can be seen that DB100 has a higher pressure value than other mixtures in the range of 5° to 15° after TDC (Top Dead Center). However, this pressure difference is not too significant, indicating that the fuel mixture can still maintain combustion characteristics that are relatively similar to pure diesel. Thus, using biodiesel mixtures in higher ratios can be a feasible alternative without drastically reducing in-cylinder pressure performance.

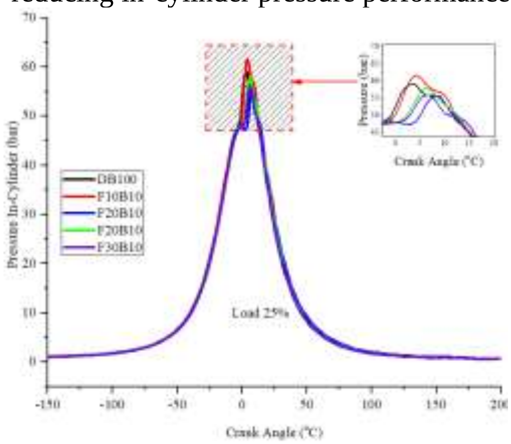

Fig. 2: Comparison of In-Cylinder Pressure for Various Fuel Mixtures at 25% Load

Fig. 3 compares in-cylinder pressure for various fuel mixtures at 50% load. The main graph shows that the highest peak pressure occurs in DB100 fuel (black line) with a value of around 65 bar at a crankshaft angle of around 0°. Meanwhile, other fuel mixtures such as F10B10, F20B10, F20B20, and F30B10 show a slight decrease in peak pressure with values ranging from 61–64 bar. This pressure difference is more visible than at 25% load, indicating that the higher the load, the greater the influence of fuel composition on in-cylinder pressure. In the inset graph that zooms in on the area around the peak point, it can be seen that DB100 fuel still has a higher pressure than other mixtures in the range of 5° to 15° after TDC. The F20B20 mixture (green line) shows a slightly higher peak pressure than the F30B10 mixture (purple line), indicating that increasing the biodiesel content in the mixture can slightly reduce in-cylinder pressure. This is likely due to the combustion properties of biodiesel, which has a lower cetane number than pure diesel, which can affect the energy release characteristics during combustion. Despite the slight pressure drop, the biodiesel blend still showed acceptable combustion characteristics at 50% load.

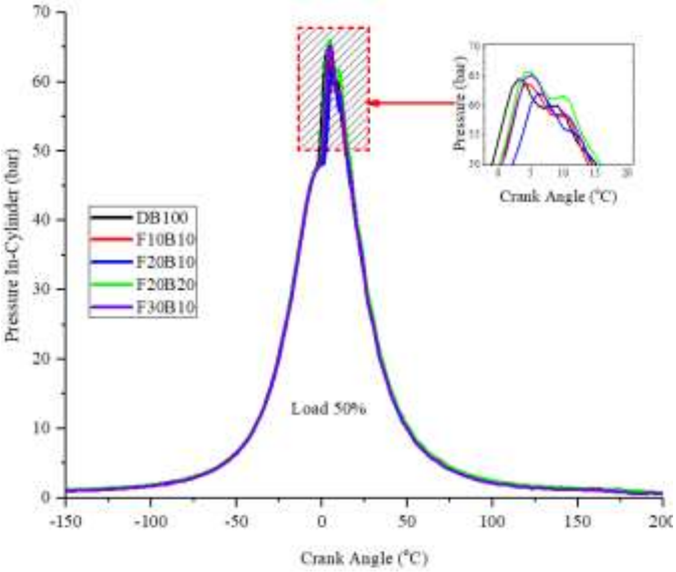

Fig. 3: Comparison of In-Cylinder Pressure for Various Fuel Mixtures at 50% Load

Fig. 4 compares in-cylinder temperatures for various fuel blends at 25% load. The main graph shows that the highest peak temperature occurs in DB100 fuel (black line) with a value of around 1250 K at a crankshaft angle of around 5° after TDC. Other fuel blends, such as F10B10, F20B10, F20B20, and F30B10, have slightly lower peak temperatures, with values ranging from 1180–1240 K. This decrease in temperature is related to the increase in biodiesel content in the fuel blend, which affects the combustion properties and energy release. In the inset graph, DB100 fuel has a higher temperature than other biodiesel blends in the range of 5° to 20° after TDC. The F30B10 blend (purple line) shows the lowest temperature, around 1180 K, indicating that higher biodiesel content causes slower combustion and lower energy release. This is likely due to the higher oxygen content in biodiesel, which slows down the combustion rate compared to pure diesel. Despite the slight decrease in temperature, the temperature distribution in the cylinder is still relatively uniform, indicating that biodiesel blends can still be used as alternative fuels without drastic changes in combustion characteristics.

Fig. 5 compares in-cylinder temperatures for various fuel blends at 50% load. The main graph shows that the highest peak temperature occurs in DB100 fuel (black line) with a value of around 1380 K at a crankshaft angle of around 10° after TDC. Other fuel blends, such as F10B10, F20B10, F20B20, and F30B10, show a slight decrease in peak temperature with a range of 1250–1350 K. This difference is more evident than at 25% load, indicating that the higher the load, the more significant the effect of fuel composition on combustion temperature. The inset graph shows that DB100 fuel has a higher temperature than other biodiesel blends in the range of 10° to 35° after TDC. The F30B10 blend (purple line) shows the lowest temperature, around 1250 K, which confirms that increasing the biodiesel content in the fuel blend can lower the combustion temperature. This decrease is related to the nature of biodiesel, which has a lower cetane number and higher oxygen content, resulting in a slower energy release. However, the temperature distribution is still relatively uniform, indicating that the biodiesel blend can still be used as an alternative fuel without drastic changes in engine performance at 50% load.

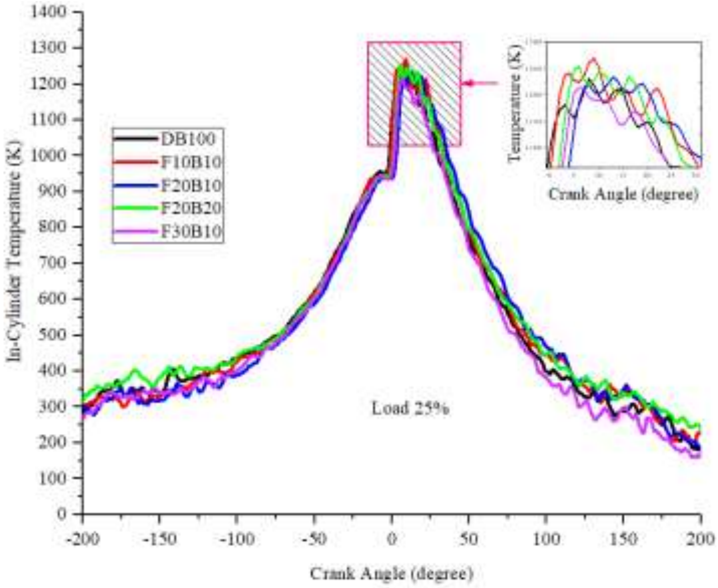

Fig. 4: In-Cylinder Temperature Comparison for Various Fuel Blends at 25% Load

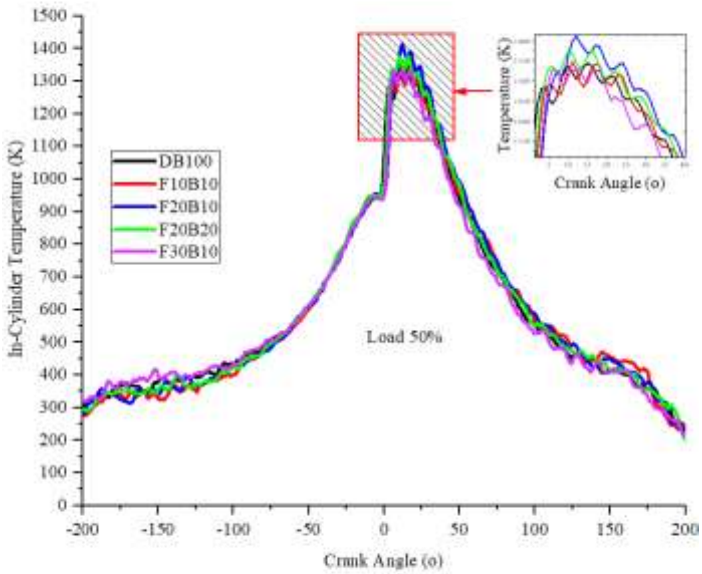

Fig. 5: In-Cylinder Temperature Comparison for Various Fuel Blends at 50% Load

Fig. 6 compares the Rate of Heat Release (ROHR) for various fuel blends at 25% load. The main graph shows that DB100 fuel (black line) has the highest ROHR peak with a value of around 34,000 kW at a crankshaft angle of around 2° after TDC. The F20B20 blend (green line) shows almost the same ROHR value, slightly higher than the other blends, with a peak reaching around 35,000 kW. Meanwhile, F30B10 (purple line) has a lower ROHR peak, around 30,000 kW, indicating that higher biodiesel content in the blend tends to decrease the heat release rate. The inset graph shows that the ROHR of DB100 and F20B20 are higher than the other blends in the range of 0° to 6° after TDC. The F10B10 blend (red line) has an earlier ROHR peak, about 1° after TDC, but with a lower peak value, about 28,000 kW. This indicates that fuels with higher biodiesel content have slower combustion due to their higher oxygen content and lower cetane number. Thus, although biodiesel can provide good combustion performance, increasing the proportion of biodiesel in the blend can change the heat release characteristics, which needs to be considered in engine optimization.

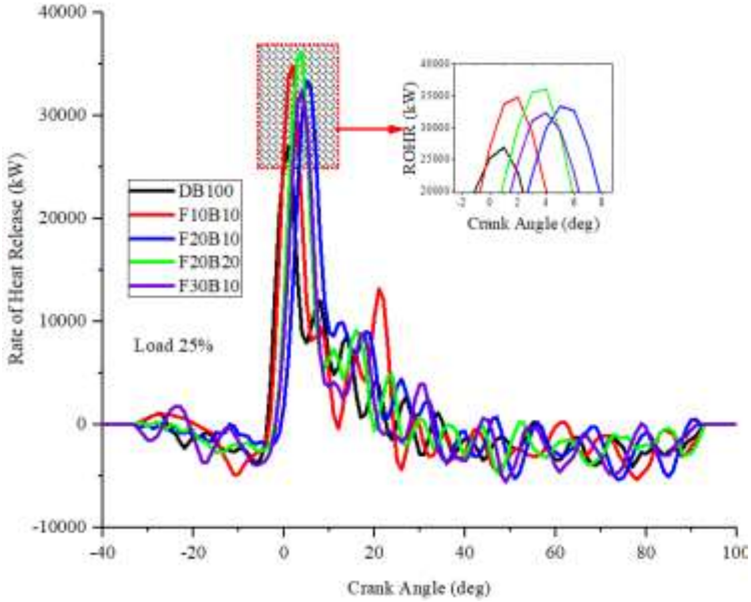

Fig. 6: Comparison of Heat Release Rates for Various Fuel Mixtures at 25% Load

Fig. 7 compares the Rate of Heat Release (ROHR) for various fuel blends at 50% load. The main graph shows that the highest ROHR peak occurs in the F20B20 blend (green line) with a value of around 45,000 kW at a crankshaft angle of around 2° after TDC. The DB100 fuel (black line) has a slightly lower ROHR of around 42,000 kW, while the F30B10 blend (purple line) shows an even lower value of around 38,000 kW. This trend indicates that increasing the biodiesel content in the blend tends to decrease the maximum heat release rate. However, it remains in a range high enough to support efficient combustion. The inset graph shows that the crank angle range of 0° to 5° after TDC is the leading region where the ROHR peaks. The F10B10 blend (red line) shows an earlier increase in ROHR than the other blends, with a peak of around 40,000 kW. This suggests that fuel blends with lower biodiesel content can produce faster and more focused heat release in a shorter time. Conversely, blends with higher biodiesel tend to make slower but more even heat release, which can help reduce the possibility of knocking and improve combustion efficiency under high load conditions.

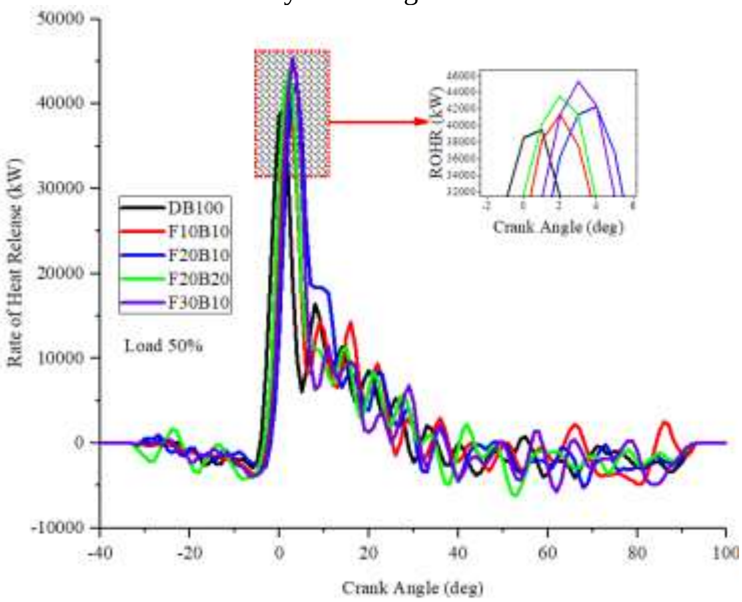

Fig. 7: Comparison of Heat Release Rates for Various Fuel Mixtures at 50% Load

Figs. 2 and **3** compare in-cylinder pressure for various fuel blends at 25% and 50% loads. From these two graphs, increasing the load from 25% to 50% causes an increase in the peak pressure in the cylinder. At 25% load, the highest peak pressure was recorded at around 63 bar for DB100 fuel, while at 50% load, the pressure increased to 65 bar. This indicates that more fuel is burned with increasing load, which results in higher pressure in the combustion chamber. In addition, the effect of fuel composition on peak pressure becomes more evident at 50% load. At 25% load, the pressure difference between the various fuel blends is relatively tiny, varying in the 60-63 bar range. However, at 50% load, the F30B10 blend shows a more significant pressure drop than DB100, with a peak value of around 61 bar. Higher biodiesel content can cause slower combustion and lower maximum pressure, especially at higher loads.
Figs. 4 and **5** compare the in-cylinder temperature distributions for various fuel blends at 25% and 50% loads. As the in-cylinder pressure shows, the peak temperature increases with increasing load. At 25% load, the highest peak temperature was recorded at around 1250 K for DB100, while at 50% load, it increased to 1380 K. This indicates that increasing the load causes more energy to be released during combustion, thereby increasing the in-cylinder temperature. At 50% load, the fuel with a higher biodiesel content has a slightly lower peak temperature than pure diesel. At 25% load, the F30B10 blend has a temperature of around 1180 K, while at 50% load, its peak temperature only reaches 1250 K, lower than DB100. This difference indicates that biodiesel, with its lower cetane number, causes slightly slower combustion, which may affect the heat distribution in the combustion chamber. However, the temperature distribution remains uniform, indicating that biodiesel still provides stable combustion characteristics at various loads.
Figs. 6 and **7** compare heat release rate (ROHR) for various fuel blends at 25% and 50% load. From these two graphs, the heat release rate increases significantly as the engine load increases. At 25% load, the highest peak ROHR values were recorded at around 34,000 kW for DB100 and 35,000 kW for F20B20. Meanwhile, at 50% load, the peak ROHR values increased to 45,000 kW for F20B20 and 42,000 kW for DB100. This increase is due to the more considerable amount of fuel burned at higher loads, resulting in quicker outstanding energy release. In addition, the ROHR distribution pattern shows that at 50% load, fuel with higher biodiesel content tends to release heat more slowly and evenly than pure diesel. For example, at 50% load, the F30B10 blend has a peak ROHR of about 38,000 kW, which is lower than that of DB100 or F20B20. This indicates that biodiesel, which has a higher oxygen content, tends to produce a more gradual combustion than pure diesel. However, despite the slight decrease in heat release rate, biodiesel can still produce efficient combustion with a more stable heat distribution pattern at high loads.

4. Conclusion

Based on the analysis results of in-cylinder pressure, in-cylinder temperature, and heat release rate for various fuel mixtures at 25% and 50% loads, it can be concluded that increasing the load causes an increase in pressure and temperature in the combustion chamber. At in-cylinder pressure, pure diesel fuel (DB100) has the highest peak pressure, which is 63 bar at 25% load and increases to 65 bar at 50% load. Biodiesel mixtures with higher proportions, such as F30B10, experience a slight decrease in pressure, with a maximum value of around 61 bar at 50% load. This shows that biodiesel has slightly slower combustion characteristics than pure diesel, especially at higher loads. In terms of in-cylinder temperature, increasing the load causes an increase in peak temperature. At 25% load, the highest peak temperature was recorded at 1250 K for DB100, while at 50% load, it increased to 1380 K. Higher biodiesel blends, such as F30B10, had lower peak temperatures, which were around 1180 K at 25% load and 1250 K at 50% load. This indicates that biodiesel tends to produce a more gradual combustion, which can help reduce the risk of knocking. In addition, the heat release rate (ROHR) showed that at 50% load, the highest peak ROHR was achieved by the F20B20 blend, with a value of 45,000 kW, compared to 42,000 kW for DB100. This suggests that specific biodiesel blends can produce energy release equivalent to or higher than pure diesel. Although biodiesel causes a slight decrease in peak pressure and temperature, this blended fuel still shows good performance and can be a viable alternative to replace conventional diesel.

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