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Investigation of Performance and Emissions Characteristic of Single Cylinder CI Engine Using High Blend Biodiesel

Mohamad Azmeer Iskandar Nordin[1], Md Norrizam Mohmad Ja'at[1*], Shaiful Fadzil Zainal Abidin[1]

[1] *Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: norrizam@uthm.edu.my
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Keywords

Biodiese blends, Compression ignition (CI) engine, Brake Specific fuel consumption (BSFC), NOx emissions mitigation

Abstract

This research examines the performance and emissions characteristics of a single-cylinder CI engine using high-blend biodiesel fuels (B10, B20, B30, and B40) under controlled conditions. The study was conducted using a Yanmar L70N6 diesel engine mounted on a Verladyne T10 dynamometer, with emissions measured via a Bosch BEA 060 gas analyzer. Results showed that B20 provided the best balance between fuel efficiency and power output, with a BSFC of 234 g/kWh at 50% load and an average power output of 4.359 kW at 3000 rpm. Higher blends, such as B30 and B40, significantly reduced CO and HC emissions, with CO emissions decreasing from 0.042% for B10 to 0.028% for B40 at 2500 rpm and HC emissions dropping from 22 ppm to 17 ppm. However, NOx emissions increased with higher biodiesel content, peaking at 12 ppm for B30 at 3000 rpm. Despite these trade-offs, biodiesel blends demonstrated stable combustion and adaptability across different loads and speeds. The findings highlight the potential of biodiesel as a sustainable fuel, underscoring the need for NOx mitigation strategies to enhance its viability as a cleaner alternative to fossil fuels while supporting global efforts to reduce environmental impact and reliance on non-renewable energy sources.

1. Introduction

The growing global need for sustainable energy sources underscores the importance of studying the performance and emissions characteristics of single-cylinder compression ignition (CI) engines using biodiesel as an alternative fuel. Biodiesel, a renewable and biodegradable fuel derived from vegetable oils, animal fats, and recycled cooking oil, offers significant environmental benefits, including reduced emissions of carbon monoxide (CO), hydrocarbons (HC), particulate matter (PM), and sulfur oxides (SOX). However, its higher oxygen content can result in increased nitrogen oxide (NOX) emissions, which necessitates a detailed investigation of its impact on engine performance and emissions under various operating conditions [1][2].

This research aims to evaluate the performance metrics, including power output and thermal efficiency, and the emissions profile of high-blend biodiesel fuels, focusing on blends exceeding 10% biodiesel content. The study employs a single-cylinder Yanmar L70 320cc diesel engine mounted on a Verladyne T10 engine dynamometer, with emissions analyzed using a BOSCH BEA 060 emission analyzer. The experiments involve testing biodiesel blends B10, B20, B30, and B40 across a range of operating conditions, including engine loads between 10% and 50% and speeds of 2500 rpm and 3000 rpm [3][4].

By addressing the challenges of compatibility with engine materials and variability in biodiesel quality, this study aims to provide comprehensive insights into optimizing biodiesel utilization. The findings contribute to the development of strategies to reduce harmful emissions while maintaining or improving engine performance. This research aligns with the global effort to advance sustainable automotive technologies, reduce reliance on fossil fuels, and mitigate the environmental impact of diesel engines [5][6].

Biodiesel has emerged as a promising renewable fuel, particularly for compression ignition (CI) engines, due to its environmental benefits and potential to mitigate reliance on fossil fuels. Research has shown that biodiesel, derived from plant oils and animal fats, has superior combustion characteristics and produces fewer emissions compared to conventional diesel [7]. Its oxygen content improves combustion efficiency, leading to reduced emissions of carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM), although it slightly increases nitrogen oxide (NOx) emissions due to elevated combustion temperatures [8]. The growing global demand for alternative fuels has prompted the exploration of biodiesel from non-edible feedstocks like jatropha and cottonseed, which are better suited for developing countries [9][10]. Furthermore, biodiesel's rapid biodegradability and balanced carbon cycle, where CO2 absorbed by plants offsets emissions during combustion, make it a sustainable choice [11].

The use of biodiesel blends impacts engine performance, combustion, and emissions characteristics. Biodiesel's lower calorific value results in a slight reduction in engine power and thermal efficiency compared to conventional diesel [12]. However, advancements such as using alumina nanoparticles and oxygenated additives like diethyl ether and butanol have been shown to improve brake thermal efficiency and mitigate some of these drawbacks [13]. Studies have demonstrated that biodiesel blends significantly reduce emissions, with B5 blends achieving a 32% reduction in HC and notable reductions in CO and CO2 emissions due to improved combustion [14]. Despite these advantages, the high viscosity and lower energy density of biodiesel necessitate strategies like transesterification and blending to optimize fuel properties for CI engine performance [15].

Emission characteristics of biodiesel blends vary depending on feedstock, blending ratio, and engine conditions. Biodiesel's oxygen content promotes more complete combustion, leading to a 20–50% reduction in PM emissions compared to diesel [16]. However, higher combustion temperatures associated with biodiesel result in increased NOx emissions, which can be reduced through technologies like selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) [17]. Laboratory tests often fail to reflect real-world NOx emissions, as highlighted by discrepancies in emissions data under different driving conditions [18]. On the other hand, biodiesel's low sulfur content minimizes sulfur oxide (SOx) emissions, reducing respiratory risks and environmental harm compared to petroleum diesel [19].

Despite its benefits, biodiesel adoption faces challenges, such as increased fuel consumption and slight reductions in power due to its lower energy content [20]. Research has emphasized the role of biodiesel additives and feedstock optimization in addressing these issues. For instance, studies have shown that palm oil biodiesel increases fuel consumption by 10% compared to diesel, but its superior cold flow properties enhance performance in colder climates [21]. As global fossil fuel reserves diminish and emissions regulations tighten, biodiesel remains a viable alternative to conventional diesel, offering significant environmental advantages while reducing dependence on non-renewable resources [22].

2. Methodology

Figure 1 shows the research flowchart that shows the step used in this research.

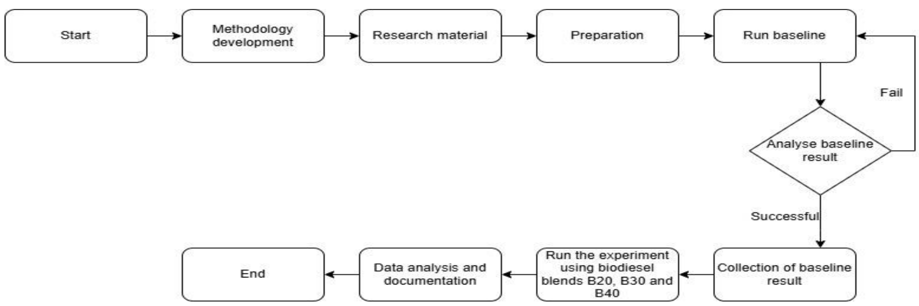


Fig. 1: Research Flowchart

Baseline engine testing would be conducted on a single-cylinder Yanmar L70 320cc diesel engine on engine dynamometer Verladyne T10, as shown in Figure 2. The engine specifications are shown in Table 1.

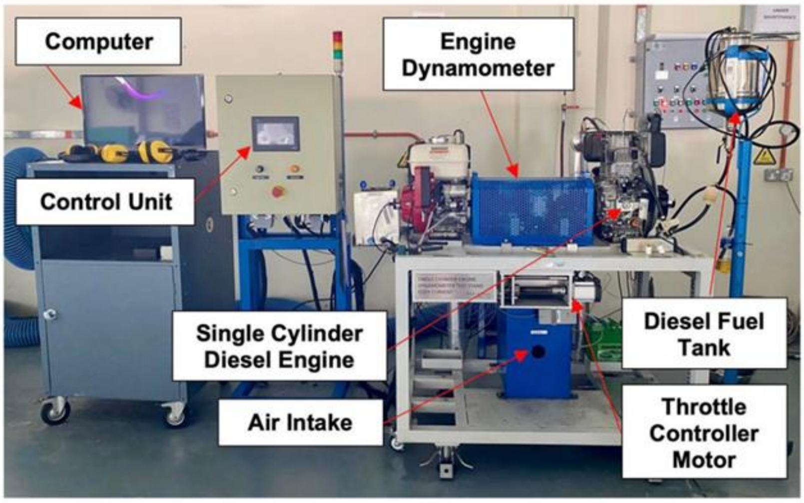


Fig. 2: Single-cylinder engine dynamometer

Table 1: Specification of engine YANMAR L70N6.

Engine Model- YANMAR L70N6	
Engine type	Air-cooled 4-stroke Diesel engine, Direct injection, vertical -cylinder
Bore x Stroke	78 x 67mm
Cubic-capacity	0.32cc
Displacement	320 cm^3
Max power	$4.9kW$ $(6.7HP)$ $/3600rpm$
Cont. rated power	$4.4kW$ $(6.0HP)$ $/3600rpm$
Injection Timing (FIC-air)	13.0 ±1.0 bTDC Deg
Starting system	Electric start
Fuel cons. At cont. rated power	$2.4L/hr$ – 3600rpm
Engine oil capacity	3.3 Litre
Dimensions (L × W× H)	378 × 426 × 453 mm

The tests were conducted on a single-cylinder, four-stroke, air-cooled direct-injection diesel engine (YANMAR L70N6). Before recording data, the engine was operated for at least 15 minutes to reach a steady state, ensuring stable torque, speed, and temperature for at least one minute. The engine was tested at initial speeds of 2500 RPM and 3000 RPM under varying loads of 10%, 20%, 30%, 40%, and 50% to evaluate performance differences as shown in Figure 3.

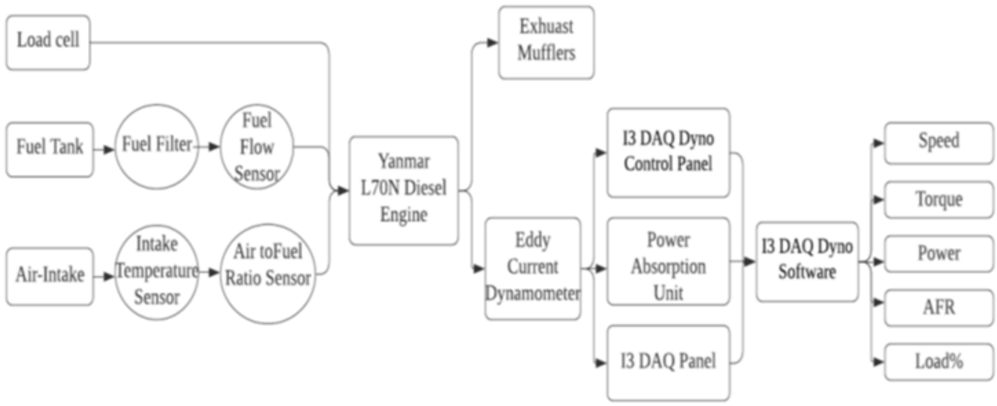


Fig. 3: Schematic diagram of the experiment setup

B20, B30, and B40 biodiesel blends were prepared by mixing B100 palm oil and B10 biodiesel in specific ratios, calculated using blending formulas. The required amounts of each fuel were measured, mixed thoroughly for 10 minutes, and stored in labeled bottles. The blend ratios using B10 as the base are shown in Table 2 below.

Table 2: Fuel Blend Quantity and Ratio using B10 as Diesel Base.

Blend Target	V_{B10} (liters)	V_{B100} (liters)	Total Blend Volume (liters)
B20	2.00	0.25	2.25
B30	2.00	0.57	2.57
B40	2.00	1.00	3.00

The blending process involved using B100 and B10 fuels to produce B20, B30, and B40 biodiesel blends. The blending calculations are detailed below:

$$V_{blend} = V_{B10} + V_{B100} \quad \text{(Eq2.1)}$$

The biodiesel content in the blend must satisfy:

$$B_{target} = \frac{(V_{B10} \cdot V_{B100}) + (V_{B100} \cdot B_{B100})}{V_{blend}} \quad \text{(Eq2.2)}$$

Rearranging for V_{B100}:

$$V_{B100} = \frac{V_{B10} \cdot (V_{B10} - B_{B100})}{B_{target} - B_{B100}} \quad \text{(Eq2.3)}$$

Where:

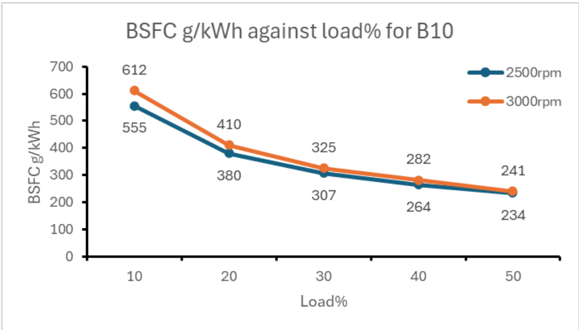
- V_{B10} = 2 liters
- B_{B10} = 0.10
- B_{B100} = 1.00
- B_{target} is the desired biodiesel percentage (0.20 for B20, 0.30 for B30, 0.4 for B40)

3. Result and Discussion.

The performances and emissions for engine YANMAR L70N6 when using B10, B20, B30, and B40 biodiesel blends were collected, respectively. Further discuss the experimental data and find out their differences in vehicle performance and emissions depending on the fuel used. The study focused on key powertrain parameters, including Brake Specific Fuel Efficiency (BSFC), Power Output and emission analysis.

3.1 Brake Specific Fuel Consumption (BSFC)

The Brake Specific Fuel Consumption (BSFC) for (a) B10, (b) B20, (c) B30, and (d) B40 is affected by engine load, speed, and biodiesel blend. BSFC decreases with increasing load as the engine operates more efficiently, using less fuel per unit of power. At 3000 rpm, BSFC is slightly higher than at 2500 rpm due to greater friction and heat losses at higher speeds, reducing efficiency. Among biodiesel blends, B10 has the lowest BSFC, showing the best fuel efficiency, while higher blends like B20, B30, and B40 show higher BSFC due to lower energy content. At low loads, BSFC is higher for all blends because the engine operates less efficiently, but it decreases significantly at higher loads as efficiency improves.



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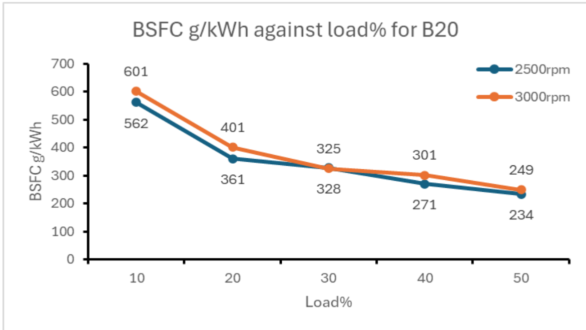

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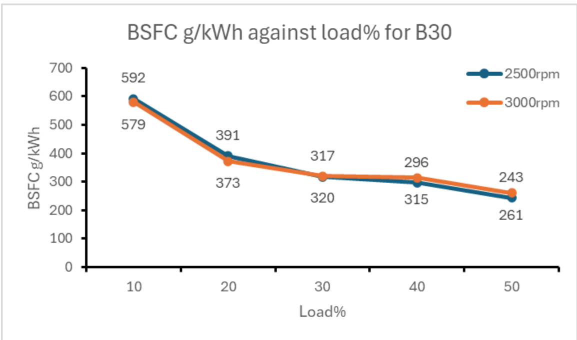

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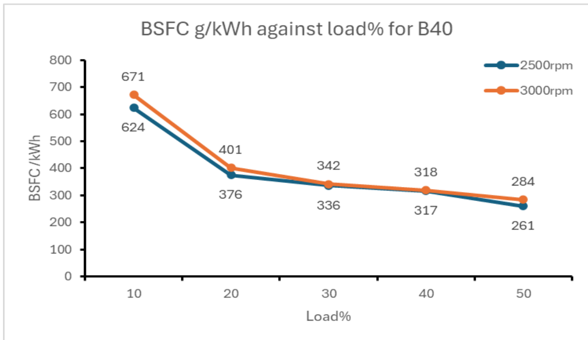
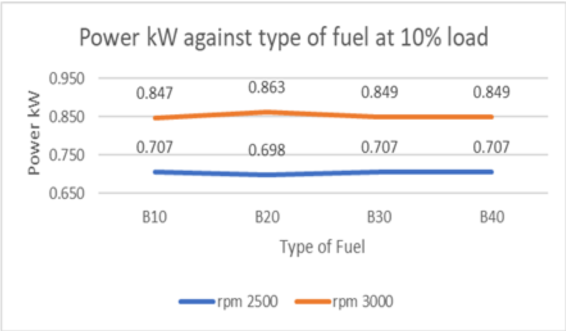


(d)

Fig. 4: Brake specific fuel consumption for (a) B10, (b) B20, (c) B30, and (d) B40

3.2 Power Output.

The analysis of power output against type of fuel at (a) 10%, (b) 20%, (c) 30%, (d) 40%, and (e) 50% load shows clear trends based on engine load and speed. At low loads (10–20%), all blends produced similar power outputs with minimal differences, as the engine's energy demand is low and the effects of biodiesel's higher viscosity and lower calorific value are less significant. As the load increased to 30% and above, differences in power output became more noticeable. B20 performed best at mid-loads due to its balanced oxygen content and energy density, which improved combustion efficiency. At higher loads (40–50%), the power outputs of all blends converged due to better combustion conditions, higher cylinder temperatures, and improved fuel atomization. B40's performance at these loads can be attributed to its higher viscosity and lubricating properties, which enhance combustion stability. This shows that the engine adapts well to different biodiesel characteristics as load increases.



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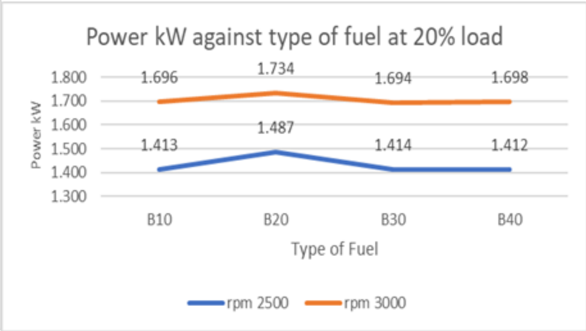

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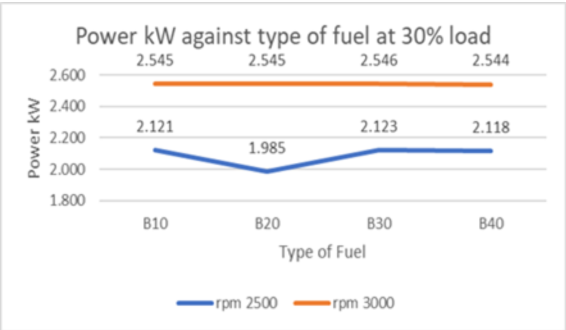

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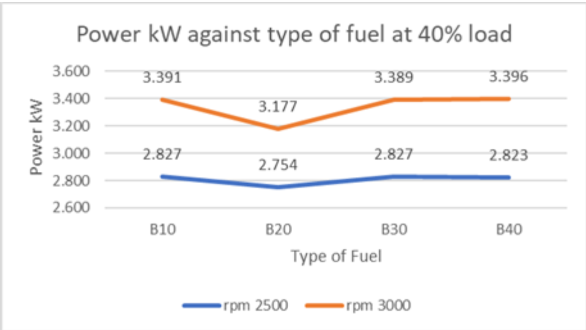

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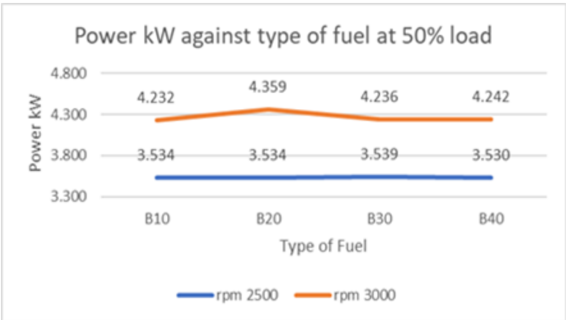

(e)

Fig. 5: Power output against type of fuel at (a) 10%, (b) 20%, (c) 30%, (d) 40%, and (e) 50% load

3.3 Emission Analysis.

Figure 6 shows the carbon monoxide (CO) emissions for B10, B20, B30, and B40 biodiesel blends. CO emissions result from incomplete combustion, where insufficient oxygen prevents the fuel from burning fully. The data shows that CO emissions decrease as the biodiesel percentage increases, at both 2500 RPM and 3000 RPM. For example, CO emissions drop from 0.042% for B10 to 0.028% for B40 at 2500 RPM and from 0.044% for B10 to 0.028% for B40 at 3000 RPM. This decrease occurs because biodiesel's high oxygen content promotes more complete combustion.

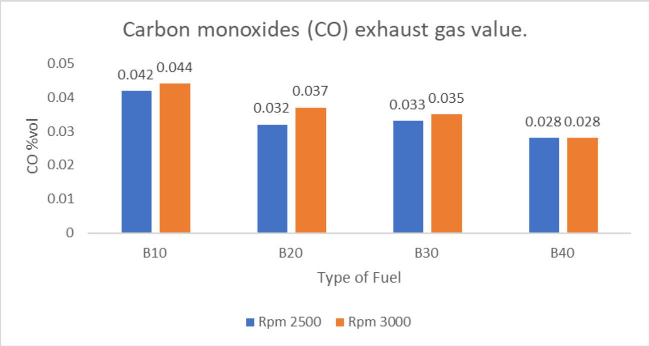

Fig. 6: Carbon monoxides exhaust gas value for B10, B20, B30 and B40

Figure 7 shows the carbon dioxide (CO_2) emissions for B10, B20, B30, and B40 biodiesel blends. CO_2 emissions, a key greenhouse gas, reflect combustion efficiency. The study shows that CO_2 levels remain mostly consistent across biodiesel blends, with only minor changes. For example, CO_2 peaks at 1.33% for B20 at 3000 RPM but stabilizes for other blends, while it decreases slightly from 0.88% for B10 to 0.84% for B40 at 2500 RPM. These small variations likely result from differences in fuel composition or engine conditions. Overall, the steady CO_2 emissions indicate that biodiesel maintains combustion efficiency similar to conventional diesel while offering potential climate benefits.

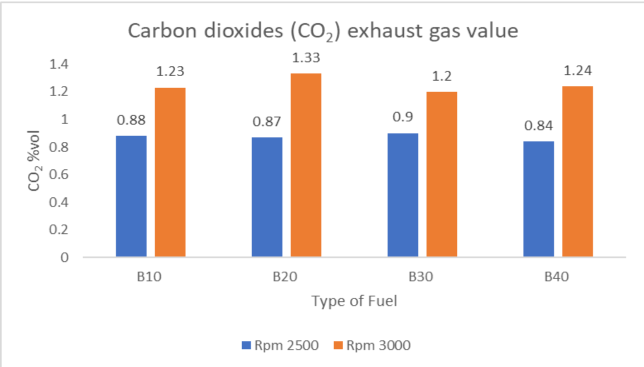

Fig. 7: Carbon dioxides exhaust gas value for B10, B20, B30 and B40

Figure 8 shows hydrocarbon (HC) emissions for B10, B20, B30, and B40 biodiesel blends. HC emissions, caused by unburned fuel from incomplete combustion, decrease as the biodiesel percentage increases. At 2500 RPM, HC emissions drop from 22 ppmvol for B10 to 17 ppmvol for B40, and at 3000 RPM, they decrease from 23 ppmvol to 17 ppmvol for the same blends. This reduction is due to biodiesel's higher cetane number and oxygen content, which improve ignition and combustion. The consistent decrease in HC emissions highlights biodiesel's ability to reduce unburned hydrocarbons and contribute to cleaner exhaust.

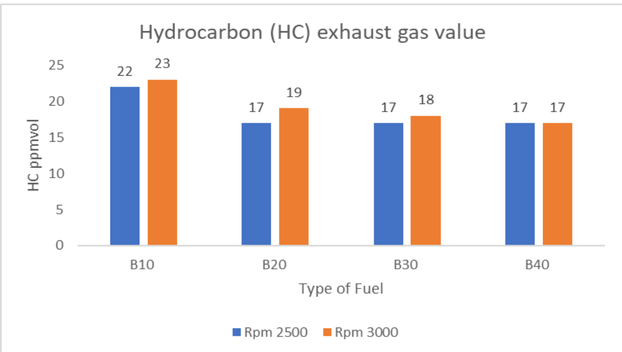

Fig. 8: Hydrocarbon exhaust gas value for B10, B20, B30 and B40

Figure 9 shows nitrogen oxide (NO_x) emissions for B10, B20, B30, and B40 biodiesel blends. NO_x emissions, produced at high combustion temperatures, contribute to environmental issues like acid rain and smog. The data shows fluctuating NO_x levels across blends, with a peak of 12 ppmvol for B30 at 3000 RPM and the lowest levels of 7 ppmvol for B20 and B40 at 2500 RPM. These variations are likely due to the higher flame temperatures during biodiesel combustion, influenced by engine operating conditions. While biodiesel can reduce NO_x under certain conditions, its effectiveness may require engine adjustments or exhaust treatment systems to achieve consistent reductions.

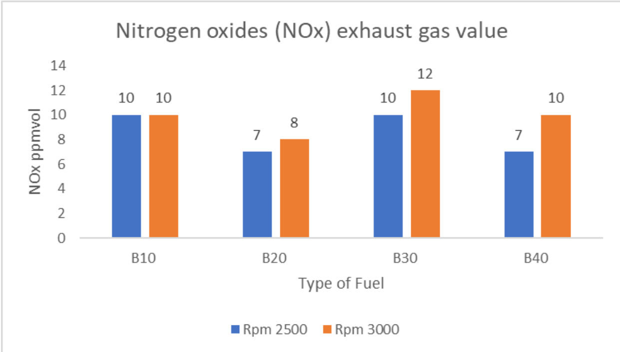

Fig. 9: Nitrogen oxides exhaust gas value for B10, B20, B30 and B40

4. Conclusion

The performance and emissions characteristics of a single-cylinder YANMAR L70N6 CI engine using high-blend biodiesel fuels (B10, B20, B30, and B40) were analyzed to meet the study's objectives. The findings revealed that biodiesel blends can sustain comparable power output to conventional diesel, with B20 offering the best balance of efficiency and emissions reduction, particularly under medium to high engine loads. CO, CO_2, and HC emissions were significantly reduced due to biodiesel's oxygen-rich composition, while NOx emissions increased with higher blends, highlighting the need for emission control strategies like SCR or EGR systems.

These results confirm biodiesel as a viable and sustainable alternative to fossil fuels, aligning with the objective of introducing cleaner fuels for diesel engines. Future research should expand on higher biodiesel blends, explore second-generation feedstocks, and validate results through real-world testing to optimize biodiesel for practical applications and support global sustainability efforts.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the paper's publication.

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