

Performance And Emission Evaluation of a Diesel Engine Using Biodiesel Derived from Gmelina Seeds

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Abstract- This study produced and evaluated biodiesel from Gmelina arborea seeds to assess its impact on diesel engine performance and emissions. Oil was extracted via Soxhlet method and converted into biodiesel through transesterification using potassium hydroxide (KOH) catalyst. A B5 blend (95% diesel, 3% coco methyl ester, 2% Gmelina biodiesel) was tested on a CHANGGONG R190N single-cylinder engine with a Prony brake dynamometer at 1500–3000 rpm. Results showed that the B5 blend maintained comparable brake power and torque to conventional diesel. Emission analysis revealed reduced carbon monoxide and hydrocarbons, while nitrogen oxides slightly increased. The study concludes that Gmelina biodiesel is a viable renewable fuel, supporting cleaner combustion and contributing to energy sustainability. (Biodiesel, Gmelina arborea, Engine Performance, Prony Brake Dynamometer)

I. INTRODUCTION

Diesel engines are widely used because they're efficient and durable, but they also release harmful emissions like CO, HC, NOx, and particulate matter. With the world facing climate change and energy security issues, biodiesel has become a promising alternative fuel. It's renewable, biodegradable, and can be produced from non-edible oils, avoiding competition with food crops.

In the Philippines, coconut oil is the main biodiesel source, but relying on it alone is costly and unsustainable. That's why exploring other feedstocks like Gmelina arborea seeds is important. These seeds contain up to 53% oil, making them a strong candidate for biodiesel production. This study investigates whether biodiesel from Gmelina seeds can perform well in a diesel engine while reducing harmful emissions.

II. LITERATURE REVIEW

Biodiesel is recognized as a renewable, carbon-neutral fuel suitable for compression ignition (CI) engines with minimal modifications [1]. Its oxygenated composition promotes complete combustion, reducing harmful emissions compared to petroleum diesel [2].

Biodiesel Production Process: The most common method of biodiesel production is transesterification, where triglycerides react with methanol in the presence of a catalyst such as potassium hydroxide (KOH), producing fatty acid methyl esters (FAME) and glycerol [3], [4]. Non-edible feedstocks like Jatropha, Pongamia, and Mahua have been widely studied, offering sustainable options that avoid food competition [5], [6]. Recent studies confirmed that Gmelina arborea biodiesel meets ASTM standards, with favorable flash point and oxidation stability [7].

Engine Performance Testing: Engine performance evaluation is essential to determine biodiesel's viability. Brake power and torque are key indicators of efficiency, and the Prony brake dynamometer is widely used for small diesel engines due to its simplicity and reliability [8]. Studies show biodiesel blends generally maintain comparable brake power to diesel while reducing CO and HC emissions [9]. However, NOx emissions often rise slightly due to higher combustion temperatures [10].

Comparative Engine Results: Agarwal demonstrated that biodiesel blends reduce CO and HC emissions significantly while maintaining acceptable brake power [9]. Lapuerta et al. confirmed that biodiesel-fueled engines showed improved combustion quality, though NOx emissions were consistently higher [10]. Chauhan's experiments using biodiesel blends with a Prony brake dynamometer reported similar findings

— stable torque output, reduced CO/HC, and modest NOx increases [11].

In the Philippines, reliance on coconut oil for biodiesel has raised supply and cost concerns. The Department of Energy mandated progressive blending (B3–B5), highlighting the need for alternative feedstocks [12]. Gmelina arborea, with seeds containing up to 53% oil, offers a promising locally available option for biodiesel production [13].

III. METHODOLOGY

This study focused on the production, blending, and evaluation of biodiesel derived from Gmelina arborea seeds to determine its suitability as an alternative fuel for diesel engines. The process began with the preparation of raw materials, where Gmelina seeds were collected, dried, pulverized, and subjected to Soxhlet extraction to obtain the oil.

The extracted oil was then converted into biodiesel through the transesterification process using methanol and potassium hydroxide (KOH) catalyst. After purification, the biodiesel was blended with commercial diesel containing 3% coco methyl ester (B3) to form a B5 blend composed of 95% diesel, 3% CME, and 2% Gmelina biodiesel.

Laboratory analyses were conducted to verify the quality of the produced biodiesel, including Fatty Acid Methyl Ester (FAME) content and water content testing, ensuring compliance with biodiesel standards. These tests confirmed that the fuel properties were within acceptable ranges for engine application.

The performance evaluation was carried out using a CHANGGONG R190N single-cylinder diesel engine coupled with a Prony brake dynamometer. The engine was operated at varying speeds of 1500, 2000, 2500, and 3000 rpm to measure brake power and torque. This setup allowed for a comparative analysis between the baseline B3 fuel and the B5 blend with Gmelina biodiesel.

Emission testing was conducted using a gas analyzer to measure carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx). These parameters

were selected as indicators of combustion efficiency and environmental impact. The emission results were recorded under the same operating conditions as the performance tests to ensure consistency.

At the concluding phase, the data on engine performance and emissions will be gathered and compared between the two fuel blends. The mean values will be computed to represent the results for each operating condition. Through this process, the methodology will provide a systematic approach for evaluating the feasibility of Gmelina arborea biodiesel as a renewable fuel alternative.

IV. RESULTS

Table I. Laboratory Analysis Result of Biodiesel Derived from Gmelina Seeds

Test / Analysis	Test Method	Results
FAME Content %m/m	PNS / DOE TM 01	55.76
Water, % v/v	PNS ASTM E203	0.474

The Gmelina biodiesel analysis confirmed successful transesterification with a FAME content of 55.76 %m/m and showed effective purification with a water content of 0.474 % v/v, indicating good fuel quality for preliminary testing [14]. These findings demonstrate that the biodiesel was properly formed and sufficiently purified, establishing a strong basis for its use in performance and emission evaluation [15].

Table II. Results of Soxhlet Extraction using N-hexane as Solvent

No. of Batches	30
Total No. of Hours	120 hrs (4 hrs. Per batch)
Pulverized Gmelina Seed (g)	1950 g (65 g per batch)
Total Gmelina Oil in	355.567 g

grams	
Actual Extracted Gmelina Oil (mL)	406.809 mL
Expected Oil Extracted (mL)	2232 mL
Average Oil Yield (%)	18.23%

Table II presents the results of Soxhlet extraction of Gmelina seed oil using n-hexane as solvent. A total of 30 batches were processed over 120 hours, yielding 406.809 mL of extracted oil from 1950 g of pulverized seeds, with an average oil yield of 18.23%. These results indicate moderate extraction efficiency under the given conditions, providing a baseline for further optimization of the process.

Table III. Results of Transesterification using Methanol and Potassium Hydroxide

CATEGORY	VARIABLE	QUANTITY
Oil	W1	355.567 mL
Biodiesel	W1	324.9882 mL

Table III presents the results of the transesterification process using methanol and potassium hydroxide as catalysts. From 355.567 mL of Gmelina oil, the reaction produced 324.9882 mL of biodiesel, confirming efficient conversion of oil into methyl esters under the applied conditions.

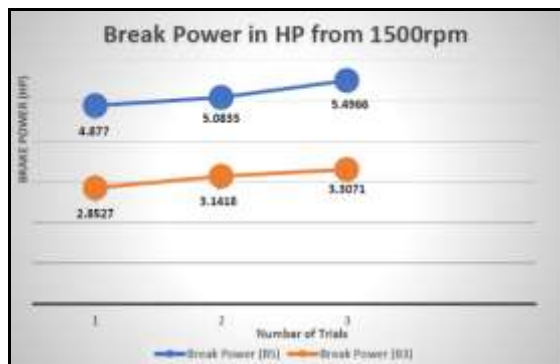


Fig. 1. Brake Power in Horsepower (HP) from 1500 rpm

Figure 1. The graph illustrates the brake power in horsepower (HP) measured at 1500 rpm across three

trials. Results show a consistent increase in brake power for both fuel samples (BS and BJ), indicating stable and improving engine performance during testing.

Table IV. Brake Power Efficiency at 1500 rpm

Trial	With Gmelina Biodiesel (B5)	Commercial Diesel (B3)
1	81.28%	47.55%
2	84.73%	64.21%
3	91.61%	55.12%
Average	85.87%	51.68%

Table IV shows the brake power efficiency at 1500 rpm for both Gmelina biodiesel (B5) and commercial diesel (B3) across three trials. The results reveal that Gmelina biodiesel consistently achieved higher efficiency values, averaging 85.87% compared to 51.68% for commercial diesel, indicating better engine performance with the biodiesel blend.

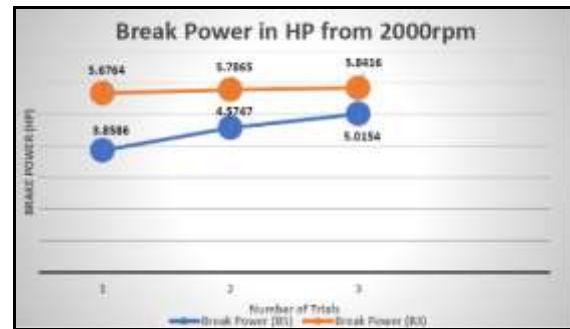


Fig. 2. Brake Power in Horsepower (HP) from 2000 rpm

Figure 2 illustrates the brake power in horsepower (HP) measured at 2000 rpm across three trials. Both fuel samples show a gradual increase in brake power, with the biodiesel blend (BIS) consistently producing higher values than the standard sample (BS), indicating improved engine performance at this speed.

Table V. Brake Power Efficiency at 2000 rpm Trial

Trial	With Gmelina Biodiesel (B5)	Commercial Diesel (B3)
1	64.31%	94.61%
2	76.25%	96.44%
3	83.59%	97.36%
Average	74.72%	96.14%

Table V presents the brake power efficiency at 2000 rpm for Gmelina biodiesel (B5) and commercial diesel (B3) across three trials. The results show that commercial diesel achieved higher efficiency, averaging 96.14 %, while Gmelina biodiesel recorded 74.72 %, indicating that although biodiesel performance was lower, it still demonstrated stable and consistent operation suitable for comparative evaluation.

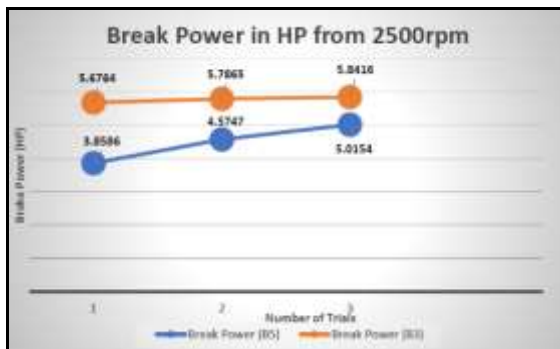


Fig. 3. Brake Power in Horsepower (HP) from 2500 rpm

Figure 3. illustrates the brake power in horsepower (HP) measured at 2500 rpm across three trials. The results show that both fuel samples exhibited increasing brake power with each trial, with commercial diesel (B3) consistently producing higher values than Gmelina biodiesel (B5), indicating stronger engine output at this speed.

Table VI. Brake Power Efficiency at 2500 rpm

Trial	With Gmelina Biodiesel (B5)	Commercial Diesel (B3)
1	79.76%	88.42%
2	82.68%	90.72%
3	87.27%	96.45%
Average	81.92%	91.86%

Table VI presents the brake power efficiency at 2500 rpm for Gmelina biodiesel (B5) and commercial diesel (B3) across three trials. The results show that commercial diesel achieved higher efficiency values, averaging 91.86 %, while Gmelina biodiesel recorded 81.92 %, indicating that although biodiesel performance was slightly lower, it maintained consistent efficiency suitable for comparative engine evaluation.

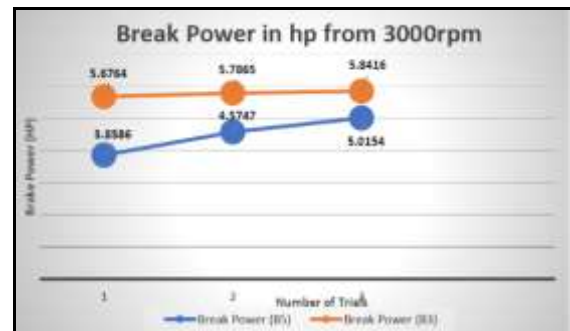


Fig. 4. Brake Power in Horsepower (HP) from 3000rpm

Figure 4. illustrates the brake power in horsepower (HP) measured at 3000 rpm across three trials. The results show that commercial diesel (B3) consistently produced higher brake power values (5.6764–5.8416 HP) compared to Gmelina biodiesel (B5) (3.8596–5.0154 HP), indicating stronger engine output with diesel while biodiesel maintained steady performance across trials.

Table VII. Brake Power Efficiency at 3000 rpm

Trial	With Gmelina Biodiesel (B5)	Commercial Diesel (B3)
1	99.22%	84.07%
2	96.47%	97.84%
3	97.84%	99.22%
Average	97.84%	93.71%

Table VII presents the brake power efficiency at 3000 rpm for Gmelina biodiesel (B5) and commercial diesel (B3) across three trials. The results show that Gmelina biodiesel achieved slightly higher average efficiency (97.84%) compared to commercial diesel (93.71%), indicating that the biodiesel blend performed effectively and maintained consistent engine efficiency at higher speeds.

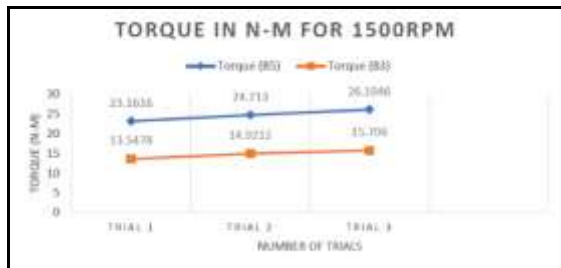


Fig. 5. Torque in Newton-meter (N·m) at 1500 rpm

Figure 5 shows the torque in Newton-meter (N·m) measured at 1500 rpm across three trials. The results indicate that Gmelina biodiesel (B5) produced higher torque values (23.16–26.10 N·m) compared to commercial diesel (B3) (13.55–15.71 N·m), demonstrating stronger engine performance and improved torque output with the biodiesel blend.



Fig. 6. Torque in Newton-meter (N·m) at 2000 rpm

Figure 6 illustrates the torque in Newton-meter (N·m) measured at 2000 rpm across three trials. The results show that commercial diesel (B3) produced higher torque values (20.22–20.81 N·m) compared to Gmelina biodiesel (B5) (13.74–18.44 N·m), indicating stronger torque output with diesel, while biodiesel demonstrated a steady increase in performance across trials.



Fig. 7. Torque in Newton-meter (N·m) at 2500 rpm

Figure 7 illustrates the torque in Newton-meter (N·m) measured at 2500 rpm across three trials. The results show that Gmelina biodiesel (B5) produced higher torque values (15.12–15.49 N·m) compared to commercial diesel (B3) (12.05–12.91 N·m), indicating that the biodiesel blend delivered slightly stronger and more consistent torque performance at this speed.



Fig. 8. Torque in Newton-meter (N·m) at 3000 rpm

Figure 8 illustrates the torque in Newton-meter (N·m) measured at 3000 rpm across three trials. The results show that Gmelina biodiesel (B5) maintained slightly higher torque values (13.94–14.14 N·m) compared to commercial diesel (B3) (11.98–13.94 N·m), indicating that the biodiesel blend provided consistent torque output and stable engine performance at higher speeds.



Fig. 9. Average Brake Power for B5 and B3 Blends

Figure 9 illustrates the average brake power for Gmelina biodiesel (B5) and commercial diesel (B3) blends across various engine speeds (1500–3000 rpm). The graph shows that brake power generally increases with speed for both fuels. At lower rpm, B5 exhibits higher power output, while B3 demonstrates superior performance at mid-range speeds, with both blends showing comparable results at 3000 rpm.

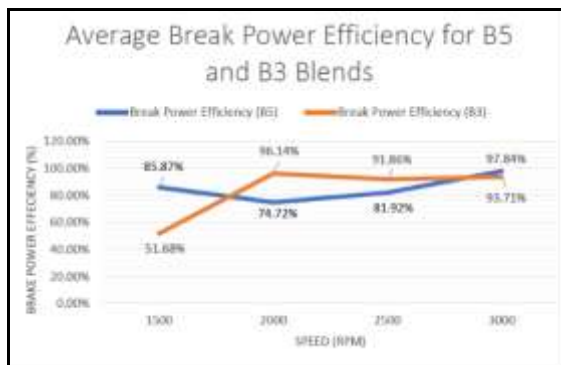


Fig. 10. Average Brake Power Efficiency for B5 and B3 Blends Figure

Figure 10 illustrates the average brake power efficiency for Gmelina biodiesel (B5) and commercial diesel (B3) blends across different engine speeds (1500–3000 rpm). The graph shows that efficiency generally increases with rpm for both fuels. B3 demonstrates higher efficiency at lower

speeds, while B5 shows significant improvement at higher rpm, reaching nearly comparable performance at 3000 rpm.



Fig. 11. Average Torque for B5 and B3 Blends

Figure 11 illustrates the average torque for Gmelina biodiesel (B5) and commercial diesel (B3) blends across different engine speeds (1500–3000 rpm). The graph shows that B5 produced higher torque at lower speeds (24.66 N·m at 1500 rpm), while B3 achieved greater torque at mid-range speeds (20.55 N·m at 2000 rpm). Both blends exhibited a gradual decline in torque as rpm increased, indicating reduced load capacity at higher speeds.

Table VIII. Average Brake Power, Efficiency, and Torque for B5 Blend

Speed (rpm)	Break Power (hp)	Break Power Efficiency (%)	Torque (N·m)
1500	5.1524	85.87%	24.6597
2000	4.4829	74.72%	15.9676
2500	4.9151	81.92%	14.0056
3000	5.8706	97.84%	13.9402

Table VIII presents the average brake power, efficiency, and torque for the Gmelina biodiesel (B5) blend at different engine speeds ranging from 1500 rpm to 3000 rpm. The data show that brake power and efficiency generally increase with speed, reaching their highest values at 3000 rpm (5.8706 hp and 97.84 %). Meanwhile, torque decreases as rpm

risers, indicating reduced load capacity at higher speeds.

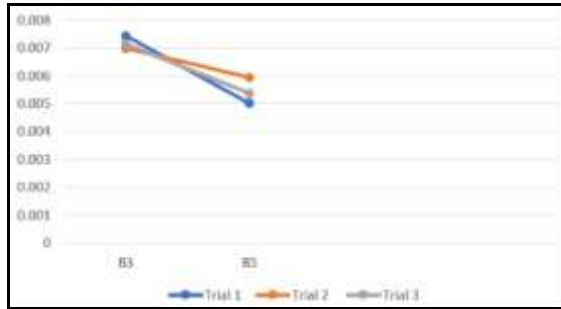


Fig. 12. Hydrocarbon (HC) Emission Results of Diesel Engine with Biodiesel Blends

Figure 12 shows the hydrocarbon (HC) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The graph indicates that HC emissions decreased when switching from B3 to B5, with all trials showing lower emission values for the higher biodiesel blend. This suggests that increasing the biodiesel ratio contributes to cleaner combustion and reduced hydrocarbon output.

Table IX. Hydrocarbon (HC) Emission Results of Diesel Engine with Biodiesel Blends

Blends	Trial 1 (%)	Trial 2 (%)	Trial 3 (%)	Average HC
B3	0.00743	0.00699	0.00714	0.007187 %
B5	0.00501	0.00594	0.00537	0.00544 %

Table IX presents the hydrocarbon (HC) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The data show that B5 consistently produced lower HC emission percentages (average = 0.00544 %) compared to B3 (average = 0.00719 %), indicating that the higher biodiesel blend contributes to reduced hydrocarbon emissions and cleaner combustion performance.

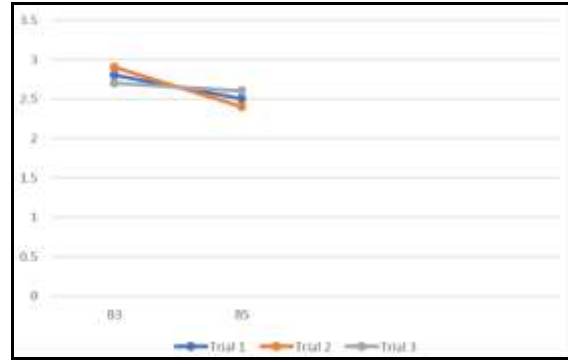


Fig. 13. Carbon Monoxide (CO) Emission Results of Diesel Engine with Biodiesel Blends

Figure 13 presents the carbon monoxide (CO) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The graph shows a slight decrease in CO emissions when switching from B3 to B5, indicating that higher biodiesel content contributes to cleaner combustion and reduced carbon monoxide output.

Table X. Carbon Monoxide (CO) Emission Results of Diesel Engine with Biodiesel Blends

Blends	Trial 1 (%)	Trial 2 (%)	Trial 3 (%)	Average CO
B3	2.8	2.9	2.7	2.8 %
B5	2.5	2.4	2.6	2.6 %

Table X presents the carbon monoxide (CO) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The data show that B5 consistently produced lower CO emission percentages (average = 2.6 %) compared to B3 (average = 2.8 %), indicating that the higher biodiesel blend contributes to reduced carbon monoxide emissions and improved combustion efficiency.

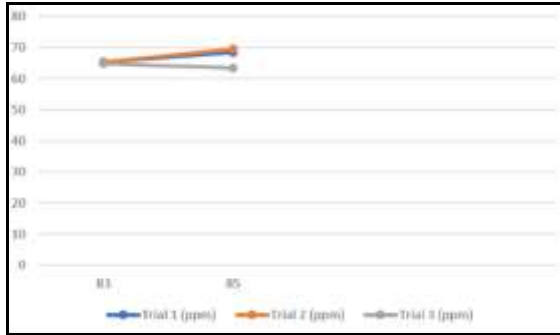


Fig. 14. Nitrogen Oxides (NO_x) Emission Results of Diesel Engine with Biodiesel Blends

Figure 14 shows the nitrogen oxides (NO_x) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The graph indicates that NO_x emissions are relatively similar for both blends, ranging around 65–70 ppm, with a slight increase observed for the B5 blend. This suggests that higher biodiesel content may lead to a minor rise in NO_x emissions due to enhanced combustion temperature and oxygen availability.

Table XI. Nitrogen Oxides (NO_x) Emission Results of Diesel Engine with Biodiesel Blends

Blends	Trial 1 (ppm)	Trial 2 (ppm)	Trial 3 (ppm)	Average NO _x
B3	65.3	64.8	63.4	64.5
B5	68.4	69.5	67.3	68.4

Table XI presents the nitrogen oxides (NO_x) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The data show that B5 produced slightly higher NO_x emissions (average = 68.4 ppm) compared to B3 (average = 64.5 ppm). This indicates that increasing biodiesel content may lead to a minor rise in NO_x emissions, likely due to improved combustion and higher oxygen concentration in the fuel.

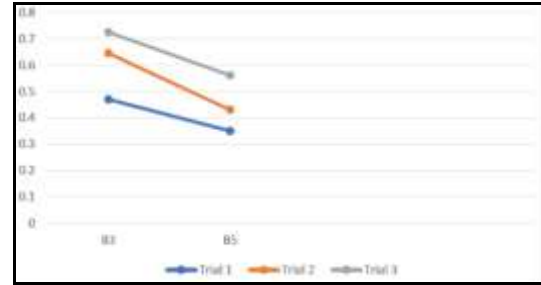


Fig. 15. Particulate Matter (PM) Emission Results of Diesel Engine with Biodiesel Blends

Figure 15 illustrates the particulate matter (PM) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The graph shows a consistent decrease in PM emissions when switching from B3 to B5, indicating that higher biodiesel content leads to cleaner combustion and reduced particulate output.

Table XII. Particulate Matter (PM) Emission Results of Diesel Engine with Biodiesel Blends

Blends	Trial 1 (ppm)	Trial 2 (ppm)	Trial 3 (ppm)	Average NO _x
B3	0.47	0.645	0.725	0.613
B5	0.35	0.43	0.561	0.447

Table XII presents the particulate matter (PM) emission results of a diesel engine using biodiesel blends B3 and B5 across three trials. The data show that B5 consistently produced lower PM emission values (average = 0.447 ppm) compared to B3 (average = 0.613 ppm), indicating that higher biodiesel content contributes to reduced particulate emissions and cleaner exhaust output.

V. CONCLUSION

The design and evaluation of biodiesel derived from *Gmelina arborea* seeds were successfully carried out through oil extraction, transesterification, blending, and engine testing. The B5 blend maintained stable brake power and torque comparable to conventional diesel. Emission results showed reduced carbon monoxide and hydrocarbons, with a slight increase in nitrogen oxides.

Overall, the study concludes that Gmelina biodiesel is a feasible renewable fuel alternative, supporting cleaner combustion and contributing to energy sustainability.

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