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PERFORMANCE AND EMISSION ANALYSIS OF CME-BASED MIXED BIODIESEL BLENDS IN A COMPRESSION-IGNITION ENGINE

Carlos E. Zapanta, Almira H. Darilag and Gonzalo C. Salvador Jr
Faculty of Manufacturing and Energy Engineering Department, Integrated Research and Training Center,
Technological University of the Philippines, Manila, Philippines
E-Mail: carlos_zapanta@tup.edu.ph

ABSTRACT

The global shift toward sustainable energy has heightened interest in biodiesel as an alternative to conventional diesel. In the Philippines, biodiesel production is primarily dependent on coconut methyl ester (CME), but concerns over copra supply have driven the need to explore alternative feedstocks. This study investigates the performance and emission characteristics of mixed biodiesel blends in a compression-ignition engine using locally available feedstocks, including Jatropha, Moringa, and waste cooking oil. Biodiesel blends were prepared by mixing CME with lower percentages of these alternative biodiesels and were tested alongside commercial diesel (B2) and the standard B5 blend. Engine performance was evaluated in a single-cylinder, four-stroke diesel engine using a hydraulic dynamometer, measuring key parameters such as torque, brake power, specific fuel consumption, and brake thermal efficiency. Emission analysis was conducted using an exhaust gas analyzer to assess carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), nitrogen oxides (NO_x), and smoke density. Results indicate that biodiesel blends exhibited minor reductions in torque and power compared to conventional diesel, with MC5 (Moringa-CME blend) and WC5 (Waste Cooking Oil-CME blend) displaying the closest performance to commercial diesel. While biodiesel blends showed slightly higher fuel consumption, their emission characteristics demonstrated significant environmental benefits, particularly in CO and HC reduction. The study affirms the viability of mixed biodiesel blends as a sustainable alternative fuel in the Philippines, supporting the country's biofuel initiatives while addressing challenges related to feedstock supply and energy security.

Keywords: biodiesel, coconut methyl ester, jathropa oil, moringa oil, waste cooking oil, engine performance.

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1. INTRODUCTION

The rapid depletion of fossil fuels and the escalating levels of air pollution caused by the global dependence on diesel engines have intensified the search for sustainable and environmentally friendly energy alternatives. Fossil fuels, which account for approximately 80% of the world's energy consumption, are not only finite but also major contributors to greenhouse gas emissions and climate change [1]. The transportation sector is a significant source of air pollutants such as nitrogen oxides (NOx) and particulate matter (PM), which pose severe health and environmental risks. As the global population and energy demand continue to grow, the need for renewable and cleaner energy sources has become more urgent. Biodiesel, a biodegradable and non-toxic fuel derived from renewable resources, has emerged as a viable alternative to conventional diesel, offering the potential to reduce emissions and reliance on fossil fuels.

Biodiesel is produced through a chemical process called transesterification, which converts vegetable oils, animal fats, or recycled cooking oils into fatty acid methyl esters (FAMEs), the primary component of biodiesel [2]. This process not only yields biodiesel but also produces glycerin as a byproduct, which can be utilized in various industrial applications. Biodiesel is compatible with existing diesel engines without requiring significant modifications, making it an attractive option for immediate implementation [3]. Moreover, studies have shown that biodiesel combustion results in lower emissions of carbon monoxide (CO), hydrocarbons (HC), and particulate matter compared to conventional diesel [4]. These environmental benefits, coupled with its renewable nature, have positioned biodiesel as a key player in the transition to sustainable energy systems.

In the Philippines, biodiesel has gained significant attention as part of the country's efforts to reduce its carbon footprint and enhance energy security. The Philippine Biofuels Act of 2006 (Republic Act No. 9367) mandates the use of biodiesel blends in all commercial diesel fuels, starting with a 1% blend and later increasing to 2% (DOE, 2008). This blend is set to rise progressively, reaching 4 percent by October 2025 and 5 percent by October 2026. To meet each 1 percent increase in the CME blend, an estimated 900 million coconuts are required to produce the 100-120 million liters of CME necessary for compliance (DOE, 2024). However, the government's plan to increase the biodiesel blend faced challenges due to declining copra production, which affected the supply of CME. Although various programs have been introduced to boost CME supply, fuel oil companies remain concerned about the sustainability of meeting the B3 blend mandate. The coconut oil (CNO) export market continues to be more profitable, creating uncertainty in the availability of CME. This highlights the need to explore alternative feedstocks to ensure a stable and sustainable biodiesel supply.

To address the limitations of coconut oil as the sole feedstock, researchers have investigated other potential sources of biodiesel in the Philippines. Jatropha curcas, a drought-resistant plant, has been identified as a promising alternative due to its high oil content and ability to grow in marginal lands. Similarly, Moringa oleifera, known for its high oil yield and nutritional value, has been explored as a biodiesel feedstock [5]. Additionally, waste cooking oil (WCO), a by-product of the food industry, has gained attention as a low-cost and environmentally friendly feedstock for biodiesel production [6]. The utilization of WCO not only reduces waste but also provides an economical solution to feedstock shortages. These alternative feedstocks offer the potential to diversify the biodiesel industry in the Philippines and enhance its sustainability.

The transition to biodiesel as a mainstream fuel in the Philippines and globally requires addressing several challenges, including feedstock availability, production costs, and policy support. While biodiesel offers significant environmental and economic benefits, its large-scale adoption depends on the development of efficient production technologies, the establishment of reliable supply chains, and the implementation of supportive government policies [7]. Collaborative efforts between researchers, industry stakeholders, and policymakers are essential to overcome these challenges and unlock the full potential of biodiesel as a sustainable energy solution.

The present study focused on evaluating the performance of a compression-ignition engine using different biodiesel blends from various feedstocks without requiring engine modifications. Specifically, it aimed to compare the engine performance of these biodiesel blends and commercial diesel by assessing power output, efficiency, specific fuel consumption, and emissions.

2. MATERIALS AND METHODS

2.1 Composition of Fuel Samples

In this study, coconut methyl ester (CME) was blended with lower percentages of biodiesel derived from Jatropha, Moringa, and waste cooking oil. These feedstocks were selected due to their potential as alternative biodiesel sources and their availability in the Philippines [8], [9], [10]. To evaluate engine performance, five fuel samples were tested in a compression-ignition engine. One of the fuels was commercial diesel (B2), while the other four were five percent biodiesel blends mixed with unadditized diesel.

The primary objective of this study was to determine whether the three proposed biodiesel blends-Jatropha-CME blend (JC5), Moringa-CME blend (MC5), and Waste cooking oil-CME blend (WC5)- could perform at par with commercial diesel (B2) and the standard five-percent Coconut Methyl Ester blend (B5) in terms of power, torque, fuel consumption, and emissions.

The specific compositions of the biodiesel blends are summarized in Table-1 below:

Table-1. Composition of fuel samples.

Fuel Sample	Biodiesel Content (%)	Feedstock Composition	Diesel Content (%)
Diesel (B2)	2%	Commercial Diesel Blend	98%
B5	5%	Coconut Methyl Ester (CME)	95%
JC5	5%	2% CME + 3% Jatropha Methyl Ester	95%
MC5	5%	2% CME + 3% Moringa Methyl Ester	95%
WC5	5%	2% CME + 3% Waste Cooking Oil Methyl Ester	95%

By comparing these fuel samples, the study aimed to assess whether the proposed biodiesel blends (JC5, MC5, and WC5) could serve as viable alternatives to traditional diesel (B2) and the B5 blend while maintaining efficient engine performance and minimal emissions.

2.2 Engine Performance Test

Each fuel sample was tested in a single-cylinder, four-stroke compression-ignition engine coupled to a hydraulic dynamometer. The engine was operated at nine different speeds, ranging from 1400 rpm to 3000 rpm, to assess its performance across varying conditions. Key engine performance parameters, including torque, power, specific fuel consumption (SFC), and efficiencies, were continuously monitored and recorded using a real-time data acquisition system to ensure precise measurements. Additionally, exhaust emissions were analyzed using an emission analyzer designed for petrol and diesel engines. The emissions measured included carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), hydrocarbons (HC), and smoke density (K factor) to evaluate the environmental impact of each fuel blend.

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Table-2. Engine specification.

TD 212 Diesel Engine	
ITEM	**SPECIFICATION**
Dimension	Width: 400mm Height: 450mm Depth:350mm
Net Weight	35kg
Fuel type	Diesel
Absolute Max. Power	3.5 kW(4.8hp) at 3600rpm
Continuous Rated Power	3.1 kW at 3000 rpm
Bore	69mm
Stroke/ Crank Radius	62mm/31mm
Connecting Rod Length	104mm
Engine Capacity	232 cm^3 (0.232 L) or 232 cc
Compression Ratio	22:1
Oil Type	Multigrade SAE 5W-40
Oil Capacity	2.6 Liters

1. Dynamometer	5. VDAS
2. Diesel Engine	6. Table of data
3. Computer	7. Chart
4. Emission Analyzer	8. Emission data

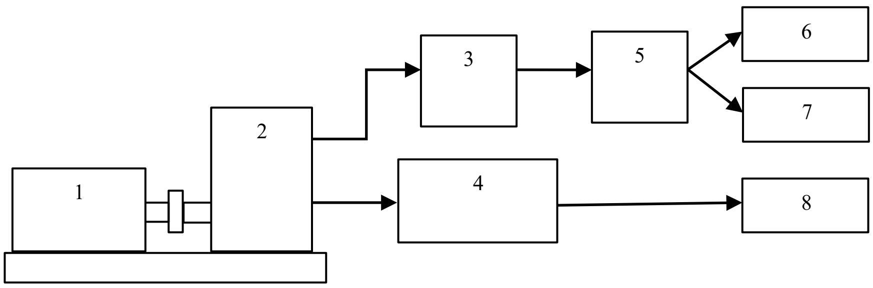

Figure-1. Engine testing experimental set-up.

3. RESULTS AND DISCUSSIONS

The performance and emission characteristics of the five biodiesel blends (B2, B5, JC5, MC5, and WC5) were compared across various engine speeds. The discussion is divided into engine performance parameters (torque, power output, fuel consumption, and efficiency) and exhaust emissions (CO, CO_2, HC, NO_x, and smoke density).

3.1 Engine Performance

3.1.1 Torque

Engine torque is a critical measure of an engine's ability to perform work at different speeds. Figure-2 shows that all fuel samples produced their highest torque at low engine speeds (1400-1800 rpm), with torque gradually decreasing as speed increased. This trend aligns with typical diesel engine behavior, where higher loads at lower speeds result in stronger combustion force.

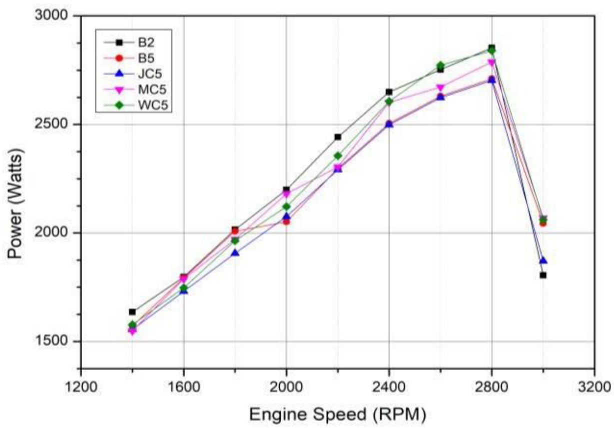

Figure-2. Torque vs engine speed.

The commercial diesel (B2) registered the highest average torque, as expected from a fully petroleum-based fuel. B5 exhibited a 3% reduction in torque, likely due to the slightly lower energy content of biodiesel. JC5 showed a 4% torque reduction, which could be attributed to the different viscosity and combustion characteristics of jatropha-based biodiesel. MC5 exhibited only a 1% decrease, indicating better combustion efficiency compared to JC5. WC5 performed almost identically to B2, highlighting its strong potential as a direct alternative fuel without significant performance loss.

These results suggest that biodiesel blends with waste cooking oil (WC5) and moringa (MC5) offer the closest torque performance to commercial diesel, while jatropha-based biodiesel (JC5) may require additional optimization to enhance its combustion efficiency.

3.1.2 Brake power output

Brake power is a direct measure of the usable power generated by the engine at different speeds. As shown in Figure-3, all fuel samples reached their peak brake power at 2800 rpm, followed by a gradual decline. This trend is typical of diesel engines, where optimal combustion efficiency occurs at mid-range speeds before frictional and thermal losses become more significant. B5 and JC5 exhibited 3% and 4% reductions in brake power, respectively. This aligns with previous studies showing that biodiesel fuels often result in slightly lower power output due to higher oxygen content, which promotes complete combustion but slightly lowers the overall energy density. MC5 experienced only a 1% drop, suggesting that moringa-based biodiesel may have better combustion characteristics compared to jatropha. WC5 again showed negligible differences from B2, reinforcing its viability as a direct substitute for commercial diesel.

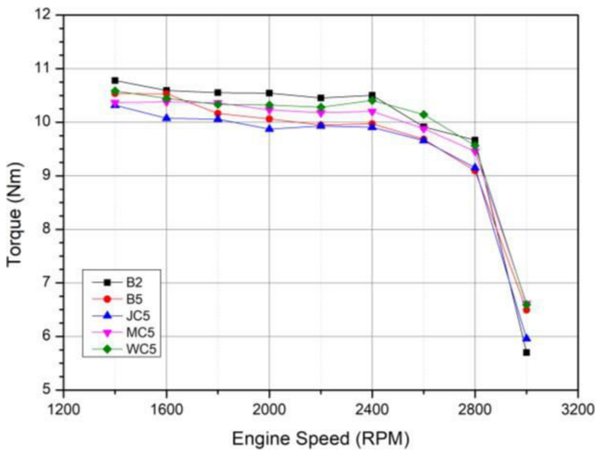

Figure-3. Brake power vs engine speed.

The slight reductions in brake power for some blends suggest that alternative feedstocks can still be viable, but optimization in blending ratios or additives may further enhance power output.

3.1.3 Specific fuel consumption (SFC)

Specific fuel consumption (SFC) is a key indicator of how efficiently fuel energy is converted into useful power. Figure-4 reveals that all biodiesel blends consumed slightly more fuel than B2, a trend consistent with biodiesel studies due to lower energy content per unit mass compared to fossil diesel. JC5 exhibited the highest increase in SFC (4%), suggesting that Jatropha biodiesel may have lower combustion efficiency, possibly due to higher viscosity affecting spray atomization. MC5 and B5 showed moderate increases (3% and 1%, respectively), implying that they maintain relatively good efficiency. WC5 had no significant change in SFC compared to B2, reinforcing its superior combustion properties among the tested blends.

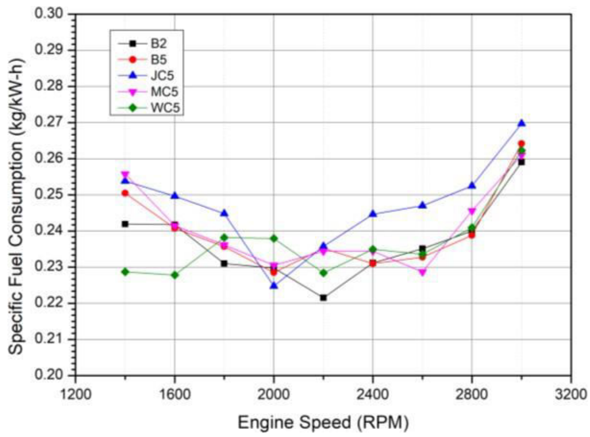

Figure-4. Specific fuel consumption vs engine speed.

The findings indicate that while biodiesel blends require slightly more fuel to achieve the same power output, the differences are minimal and can be mitigated through blending optimization and potential engine tuning.

3.1.4 Brake thermal efficiency (BTE)

Brake thermal efficiency (BTE) represents how effectively the fuel's energy is converted into useful work. Figure-5 shows that BTE remained fairly constant across all fuel samples, with minor variations. JC5 exhibited a 4% decrease in efficiency, likely due to higher viscosity and incomplete combustion. B5 and MC5 showed minor efficiency reductions (1%), indicating efficient energy conversion. WC5 closely matched B2, further confirming its excellent combustion properties.

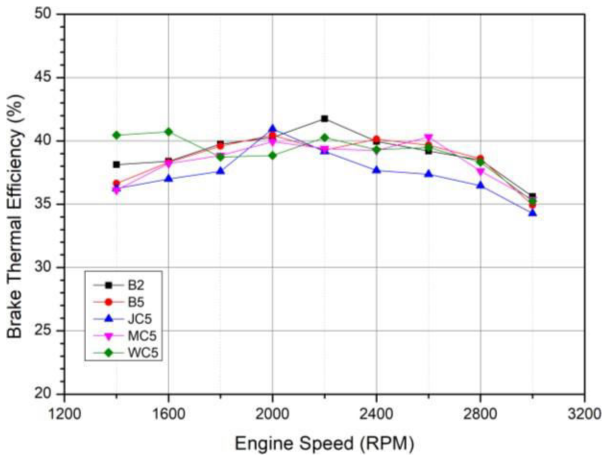

Figure-5. Brake thermal efficiency vs engine speed.

3.1.5 Volumetric efficiency

Volumetric efficiency refers to the engine's ability to intake air for combustion. Figure-6 demonstrates that WC5 performed nearly identically to B2, reinforcing its suitability as an alternative fuel. B5 showed a 4% efficiency reduction, which could be due to the slightly different vaporization characteristics of coconut methyl ester. JC5 and MC5 exhibited minor efficiency reductions (2%), suggesting slight air intake differences but no drastic impacts on combustion performance. These results suggest that biodiesel's impact on volumetric efficiency is minor and does not significantly hinder engine operation.

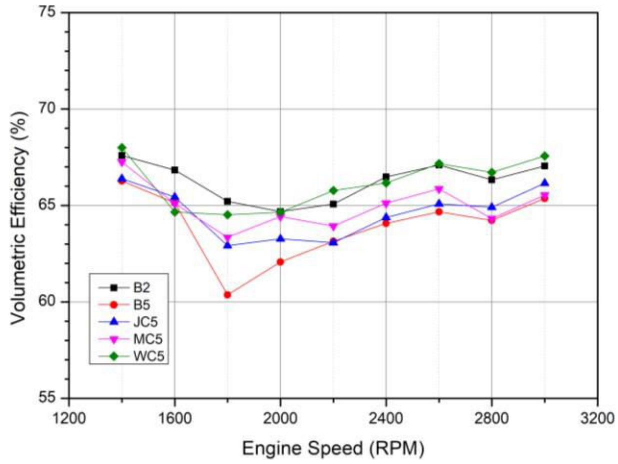

Figure-6. Volumetric efficiency vs engine speed.

3.2 Exhaust Emissions

3.2.1 Carbon monoxide (CO) emissions

Carbon monoxide (CO) emissions occur due to incomplete combustion. Figure-7 shows that MC5 exhibited a 38% CO reduction, highlighting moringa's ability to promote complete combustion. WC5, however, showed a 29% increase, suggesting potentially incomplete combustion in some cases, possibly due to differences in fuel-air mixing. B5 and JC5 performed similarly to B2, confirming consistent combustion behavior.

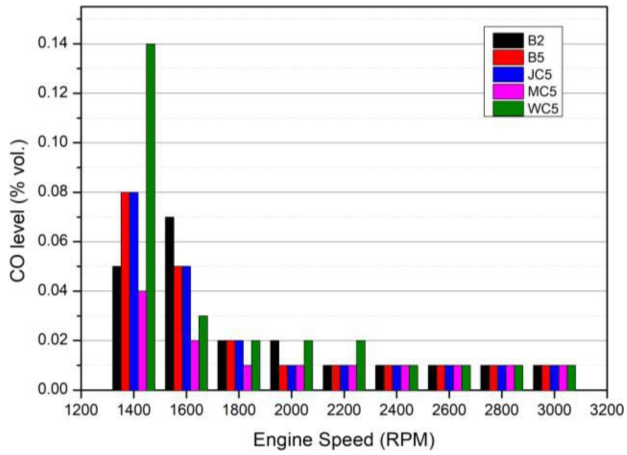

Figure-7. Carbon Monoxide (CO) level vs engine speed.

3.2.2 Carbon dioxide (CO_2) emissions

CO_2 emissions indicate combustion completeness. Figure-8 shows that B5, JC5, and MC5 led to CO_2 reductions of 5%, 3%, and 1%, respectively, suggesting more efficient fuel utilization. WC5 had a slight 2% increase, indicating higher carbon oxidation but still within acceptable limits.

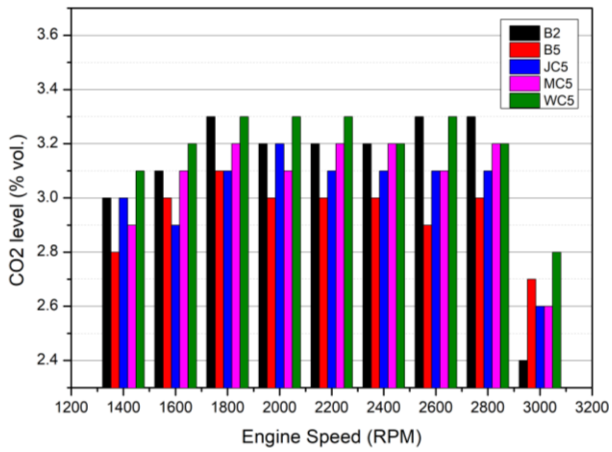

Figure-8. Carbon Dioxide (CO_2) level vs engine speed.

3.2.3 Hydrocarbon (HC) emissions

Hydrocarbon emissions result from unburned fuel. Figure-9 indicates that all samples exhibited low HC emissions, with MC5 and B2 registering the lowest HC levels (6 ppm), confirming good combustion efficiency. B5, JC5, and WC5 showed slightly higher HC emissions (8 ppm), which could be mitigated with optimized fuel injection strategies.

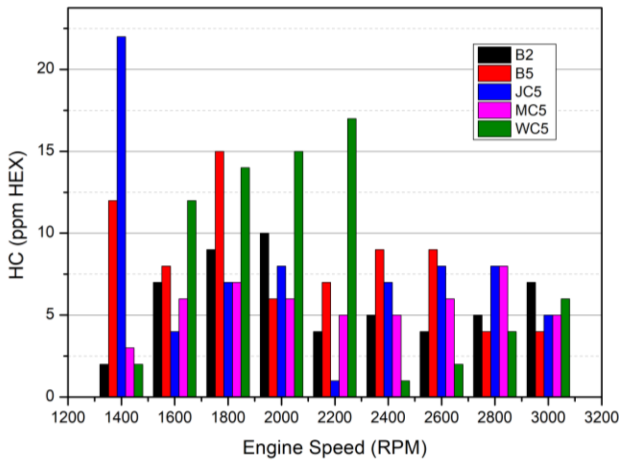

Figure-9. Hydrocarbon (HC) level vs engine speed.

3.2.4 Nitrogen oxide (NO_x) emissions

NO_x emissions are typically higher for biodiesel due to higher combustion temperatures. Figure-10 shows that B5 reduced NO_x by 3%, suggesting lower combustion temperatures. MC5 and WC5 showed slight NO_x increases (2% and 3%), which could be linked to higher oxygen content, enhancing combustion heat. JC5 closely matched B2 in NO_x emissions, indicating a balanced combustion process.

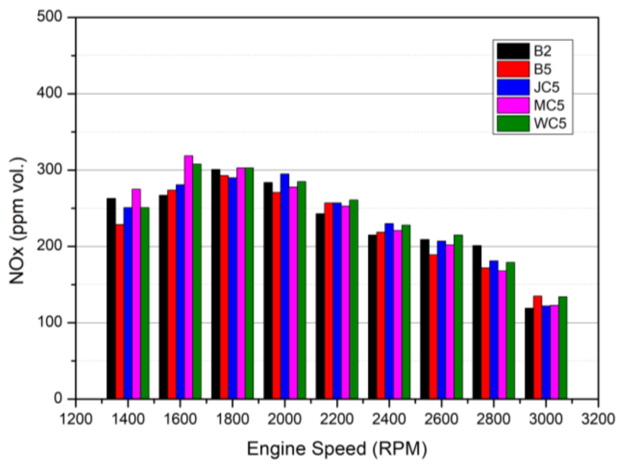

Figure-10. Nitrogen Oxide (NOx) level vs engine speed.

3.2.5 Smoke density

Figure-11 indicates that JC5 and B2 exhibited the lowest smoke density (0.40 K), while B5 recorded the highest (0.47 K) due to coconut biodiesel's higher viscosity. MC5 and WC5 had moderate values (0.42 K), suggesting controlled particulate emissions.

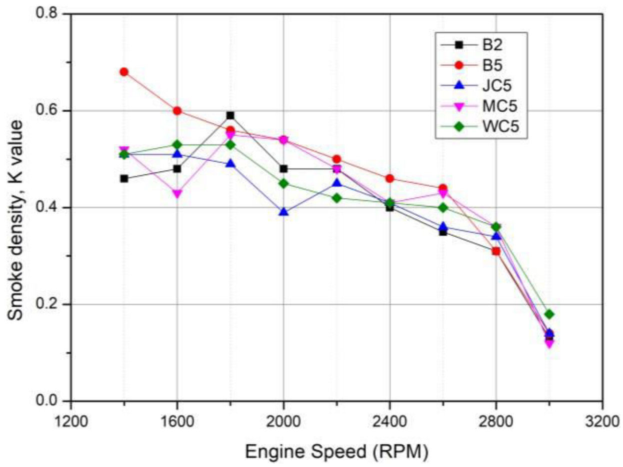

Figure-11. K value vs engine speed.

4. CONCLUSIONS AND RECOMMENDATIONS

This study aimed to determine whether the three proposed biodiesel blends-Jatropha-CME blend (JC5), Moringa-CME blend (MC5), and Waste Cooking Oil-CME blend (WC5)-could perform at par with commercial diesel (B2) and the standard five-percent Coconut Methyl Ester blend (B5) in terms of power, torque, fuel consumption, and emissions. The findings indicate that while the biodiesel blends exhibited slight reductions in performance, they remained within acceptable limits compared to commercial diesel. Specifically, the 5% biodiesel blends (B5) showed minor decreases in torque, power, and efficiency, with JC5 and MC5 demonstrating performance characteristics closest to B2. However, all biodiesel blends had higher specific fuel consumption than commercial diesel due to their lower energy content.

In terms of emissions, CME5, JC5, and MC5 produced lower levels of harmful pollutants compared to commercial diesel, reinforcing their environmental benefits. JC5 exhibited the lowest smoke density, with a 2% reduction compared to other biodiesel blends. WC5, while maintaining performance levels comparable to B2, showed a slight increase in emissions. Overall, the results confirm that biodiesel blends derived from Jatropha, Moringa, and waste cooking oil can serve as viable diesel fuel extenders while contributing to reduced emissions and enhanced sustainability.

To further validate these findings, on-road testing is recommended to assess the real-world performance and durability of these biodiesel blends in long-term engine operation. Additionally, further optimization of blend ratios, fuel formulations, and combustion strategies should be explored to enhance efficiency and minimize fuel consumption. Collaboration between researchers, policymakers, and industry stakeholders will be essential to advancing the adoption of mixed biodiesel fuels, ensuring their long-term feasibility and contribution to sustainable energy solutions.

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