 DOI: 10.35382/TVUJS.16.6.2026.225

THE INFLUENCE OF PLANT-BASED BIODIESEL FUELS (COCONUT OIL, SOYBEAN OIL, AND RAPESEED OIL) ON THE I4 D229-4 DIESEL ENGINE

Tran Van Dinh[1*], Nguyen Hoai Tan[1], Bui Van Huu[1]

Abstract – *This study employs plant-based biodiesel fuels, including coconut oil methyl ester, soybean oil methyl ester, and rapeseed oil methyl ester. The objective is to evaluate the performance and emission characteristics of the MWM D229-4 inline four-cylinder diesel engine. The simulation maintains the engine's original physical configuration and is conducted over an engine speed range of 1,200 to 2,400 rpm. At the rated speed of 1,800 rpm, the simulation results indicate that engine performance decreases by approximately 4.4214.01%, while brake specific fuel consumption increases by at least 13.28–23.61% for the three biodiesel fuels. From an emission perspective, biodiesel proves to be a promising alternative fuel by significantly reducing pollutant emissions. Specifically, at 1,800 rpm, NO_x emissions decrease by 5.45–39.15% when biodiesel fuels are used. In addition, SME demonstrates a remarkable advantage in reducing soot emissions by up to 77%. At the same time, CO_2 and SO_2 emissions are significantly reduced. These results indicate that biodiesel fuels derived from different feedstocks exert different effects on engine performance and emissions. Overall, biodiesel is a potential alternative fuel with a high possibility of direct application in existing diesel engines without any structural modifications.*

Keywords: biodiesel, CME, engine emissions, engine performance, RME, SME.

I. INTRODUCTION

As society develops, industrial and agricultural activities, commerce, and human utilities have expanded, especially in transportation and freight logistics. Traditional and widely used energy sources in the past have been fossil fuels. However, with the continuously increasing consumption rate, these resources are gradually being depleted. In addition, the use of non-renewable fuels leads to the emission of various harmful exhaust gases into the environment, resulting in environmental pollution, climate change, and negative impacts on human health. Therefore, it is necessary to improve or identify new energy sources to replace fossil fuels, ensuring energy activities while minimizing their adverse effects. To address this situation, a series of solutions has been implemented, such as the use of electricity, gaseous fuels, and fuel cells. Among these, biodiesel fuel is also a promising new direction.

Biodiesel is a renewable fuel derived from plant sources (coconut oil, peanut oil, sunflower seed oil, etc.), animal fats, or waste oils. A study on blending diesel fuel with coconut oil (coconut oil methyl ester) in a diesel engine showed that the diesel engine can operate stably with any coconut oil methyl ester (CME) blending ratio; however, engine power slightly decreases as the CME blending ratio increases [1]. In addition, with the objective of using soybean-based biodiesel (soybean oil methyl ester) to evaluate engine performance and emissions, the results showed that the Bosch smoke number decreased by 41.3% with B20, 53.2% with B40, and 62.6% with B100 compared to operation with pure diesel fuel. Furthermore, particulate matter (PM) emissions were also reduced by 47.2%

[1]College of Engineering, Can Tho University, Vietnam
*Corresponding author: tvdinh@ctu.edu.vn
Received date: 1 April 2026; Revised date: 19 May 2026; Accepted date: 18 June 2026

with B20, 60% with B40, and 68% with B100 [2]. Another study evaluated the reliability of biodiesel produced from rapeseed oil (rapeseed oil methyl ester) in biodiesel blends (B30, B50, and B100) with respect to the measurement of gaseous pollutant emissions such as CO, HC, NO_x, CO_2, and PM [3].

Overall, biodiesel is an ideal alternative solution that significantly contributes to the reduction of pollutant emissions from engines. On a global scale, soybean oil accounts for 23% and rapeseed oil for 14% of the feedstocks used for biodiesel production. In addition, coconut oil is also a potential feedstock, as coconut meat contains 50 – 65% oil [4]. Therefore, the objective of this study focuses on evaluating the effects and comparing the performance of three plant-based biodiesel fuels – coconut oil methyl ester, soybean oil methyl ester, and rapeseed oil methyl ester – on a diesel engine.

II. RESEARCH METHODOLOGY

The Diesel-RK software (Release: 4.3.0.189, May 2023) was used to simulate the working process of the D229-4 diesel engine. The simulation process was conducted by maintaining the original structural configuration of the diesel engine, with only the fuel type being changed, including CME, soybean oil methyl ester (SME), and rapeseed oil methyl ester (RME). The simulations were performed at engine speeds of 1,200, 1,400, 1,600, 1,800, 2,000, 2,200, and 2,400 rpm. The air-fuel equivalence ratio in the cylinder was set to 1.75, while the ignition timing was fixed at 100 BTDC (before top dead center). Ambient conditions were defined at a pressure of 1 bar and a temperature of 2880K. Since this study was conducted solely based on simulation using Diesel-RK software without experimental validation, several assumptions were introduced to simplify the computational model. In this study, the physicochemical properties of the fuels were assumed to be homogeneous and unaffected by variations in ambient temperature and humidity. The engine was considered to operate under optimal conditions, without taking into account the effects of aging or mechanical wear of engine components during operation. In addition, the operating conditions and engine performance characteristics were assumed to remain identical across all investigated fuel cases to ensure consistency in the comparative analysis. Furthermore, the complex interactions between fuel properties and the actual operating behavior of the engine were not considered within the scope of this study.

The main objective was to evaluate engine performance and the emission components. The simulation results serve as a basis for the application of new alternative fuels for the engine without requiring changes to the engine's technical characteristics, representing a solution to ensure energy security and to mitigate the negative impacts of fossil fuels in general, and conventional diesel fuel in particular, on the environment and human health.

A. Engine technical specifications

The MWM D229-4 diesel engine, with the technical specifications listed in Table 1, is commonly used in agricultural and industrial equipment such as tractors, pumps, and generators.

Table 1: Technical specifications of the D229-4 diesel engine

No.	Technical	Value
1	Manufacturer	MWM
2	Engine model	D229-4
3	Engine type	I4
4	Cylinder bore (mm)	102
5	Piston stroke (mm)	120
6	Compression ratio	17:1
7	Displacement (dm^3)	3.922
8	Firing order	1-3-4-2
9	Aspiration type	Naturally aspirated
10	Cooling system	Liquid cooling
11	Fuel injection type	Direct injection
12	Rated power/speed (kW/(rpm))	44 / 1,800
13	Fuel injection advance angle (crank angle degree)	10
14	Number of nozzle holes per injector	4
15	Number of injectors per cylinder	1
16	Number of compression rings	2
17	Number of oil control rings	1
18	Number of intake – exhaust valves	2 – 2

Source: Al-Dawody et al. [2]

B. Fuel properties

The fuels used in this study are biodiesel derived from coconut oil, soybean oil, and rapeseed oil. In this context, B0 represents conventional mineral diesel fuel, while B100 denotes fuel with 100% biodiesel content. The composition and properties of each fuel were collected from the integrated database of the Diesel-RK software as well as from reliable scientific publications.

III. RESULTS AND DISCUSSION

A. Evaluation of the combustion process in the engine cylinder

The simulation results in Figure 1 illustrate the variation of in-cylinder pressure as a function of crank angle (CA) for B0 (diesel), CME, SME, and RME fuels. For all tested fuels, the combustion process shows a typical pressure rise, reaching its peak when the piston approaches top dead center, at approximately 3750 CA. This reflects the main heat release phase occurring near the end of the compression stroke.

In terms of peak values, B0 produces the highest cylinder pressure, followed by CME and SME, while RME shows the lowest value. This indicates that conventional diesel provides a more intense combustion process compared to biodiesel fuels. Moreover, across the engine speed range from 1,200 to 2,400 rpm, the maximum in-cylinder pressure tends to decrease when biodiesel fuels are used instead of diesel (Figure 2). This can be explained by the higher viscosity and density of biodiesel, which lead to poorer fuel atomization and less efficient air-fuel mixing. As a result, the combustion process is slightly weaker, reducing the amount of energy released and thus lowering the peak cylinder pressure [6].

When considering the variation of the average in-cylinder temperature with respect to crank angle, Figure 3 shows that the temperature curves exhibit trends similar to those of the pressure curves. The temperature profiles of biodiesel fuels are relatively lower than those of neat diesel fuel. In addition, B0 maintains a higher peak in-cylinder temperature compared to biodiesel fuels. This indicates that biodiesel fuels have a certain influence on the thermal efficiency and power output of the engine (Figure 4) [7].

Regarding the engine Heat Release Rate (HRR) in Figure 5, the maximum HRR occurs when the piston has just passed top dead center (approximately 365–3700 CA). The highest HRR is observed with diesel fuel, while the lowest corresponds to RME. In addition, the HRR peak of biodiesel fuels appears relatively earlier than that of diesel fuel, but with a lower magnitude.

Furthermore, biodiesel fuels maintain a longer HRR duration over the crank angle range after top dead center. This phenomenon can be explained by the higher viscosity and poorer volatility of biodiesel, which cause the combustion process to release energy more gradually throughout the expansion stroke [8, 9].

B. Performance evaluation

The simulation results on performance indicate that biodiesel fuels exhibit reductions in power and torque compared to neat diesel fuel at the same engine speed, particularly at low and medium speeds. The power reduction is approximately 6–20% when using CME biodiesel, 6–14% for SME, and 15–24% for RME compared with diesel at the same operating speed (Figure 6). On the other hand, the torque of CME biodiesel decreases significantly at 1,200 rpm, while SME and RME biodiesel show torque reductions of about 10–35% compared to neat diesel across various engine speed ranges (Figure 7). The performance differences between fossil diesel fuel and biodiesel fuels can be explained by differences in work-producing capability and fuel properties. For biodiesel fuels, the amount of energy released during combustion is lower due to their lower heating value compared to conventional fossil diesel fuel, which leads to reductions in engine power and torque [10].

At the same time, the results for brake specific fuel consumption indicate that biodiesel exhibits higher values than fossil diesel fuel under all operating conditions (Figure 8). In particular, at 1,200 rpm, the brake specific fuel consumption

Table 2: Biodiesel fuel properties for the study

Parameter		Unit	B0	B100 (CME)	B100 (SME)	B100 (RME)
Composition (by mass)	Carbon (C)	%	87	75	77.31	77
	Hydrogen (H)	%	12.6	12	11.88	12.1
	Oxygen (O)	%	0.40	13	10.81	10.9
Sulfur content		%	0.002	0.001	0.005	0.0015
Lower heating value		MJ/kg	42.5	38.50	36.22	39.45
Cetane number		-	48	60	51.3	54.4
Fuel density at 323^0K		kg/m^3	830	841	878	885
Surface tension coefficient at		N/m	0.028	0.031	0.0433	0.0315
Kinematic viscosity at 323^0K		Pa.s	0.0030	0.0048	0.0046	0.0069
Latent heat of vaporization		kJ/kg	250	320	325	325
Molar mass		g/mol	190	245	292.2	296
Diffusion coefficient under atmospheric conditions		s				3.1×10^{-10}
Saturated vapor pressure at low temperature (481^0K)		bar	0.0477	-	-	0.001
Saturated vapor pressure at low temperature (465^0K)		bar	-	0.001	0.001	-
Saturated vapor pressure at critical temperature		bar	1.616	1.576	1.576	1.877
Critical temperature		^{0}K	710	786	786	802

Source: Al-Dawody et al. [2] and Lugo-Méndez et al. [5]

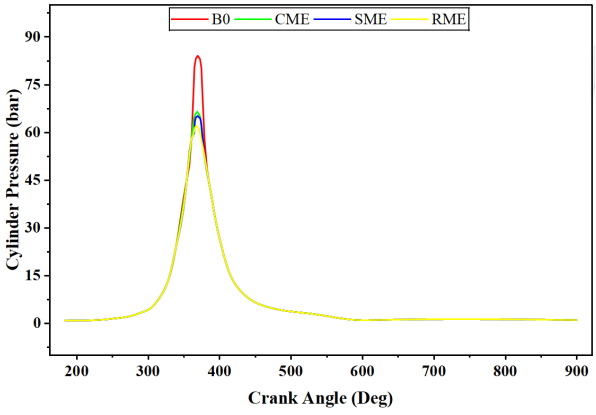

Fig. 1: In-cylinder pressure versus crank angle

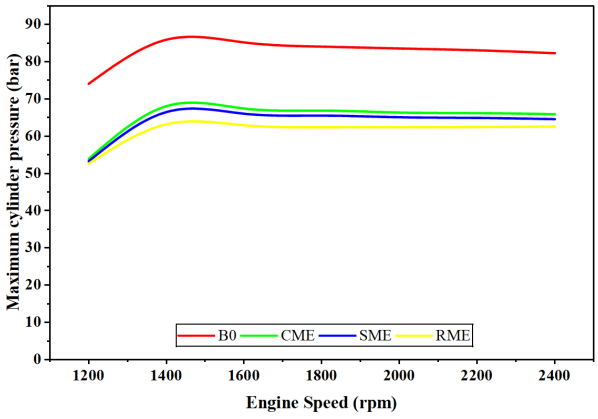

Fig. 2: Maximum in-cylinder pressure at different engine speeds

(BSFC) of CME biodiesel reaches approximately 395 g/kWh, representing an increase of about 76% compared to diesel fuel (approximately 224 g/kWh). In addition, SME and RME biodiesel also show higher BSFC values than B0, in the range of 20–60% depending on engine speed. Therefore, to maintain the same power output, a greater amount of biodiesel is required compared to mineral diesel fuel [11].

C. Emission evaluation

Figure 9 shows the variation of NO_x concentration (ppm) with respect to crank angle. In the pre-combustion phase (approximately 350–3650 CA), the NO_x concentration remains unchanged for all fuels. The NO_x formation of biodiesel fuels is lower than that of diesel fuel. As combustion occurs, the NO_x concentration increases sharply due to the peak temperature and pressure in the combustion chamber; it is observed that B0 exhibits the highest NO_x level, followed by CME and RME, while SME shows the lowest value. The simulation data evaluating NO_x emissions indicate that the use of biodiesel fuels derived from coconut oil, soybean oil, and rapeseed oil

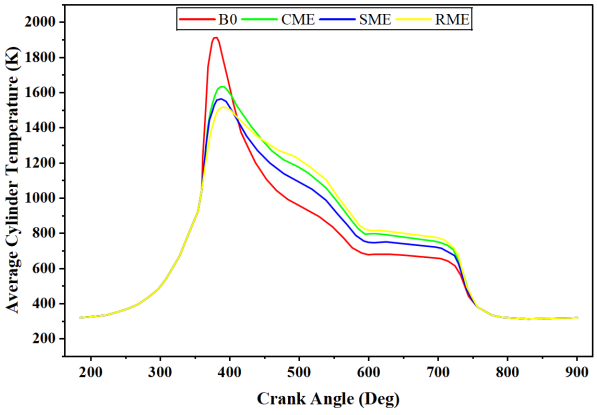

Fig. 3: In-cylinder temperature versus crank angle

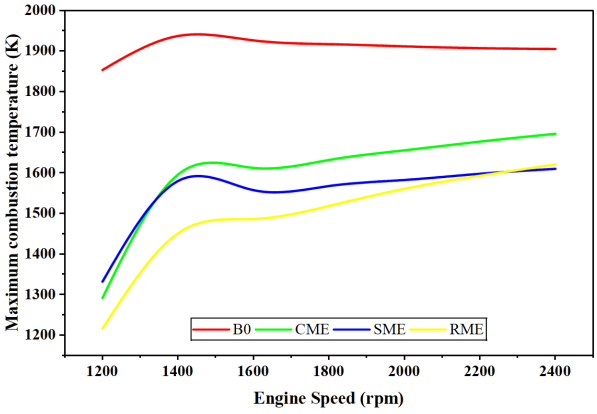

Fig. 4: Maximum in-cylinder temperature at different engine speeds

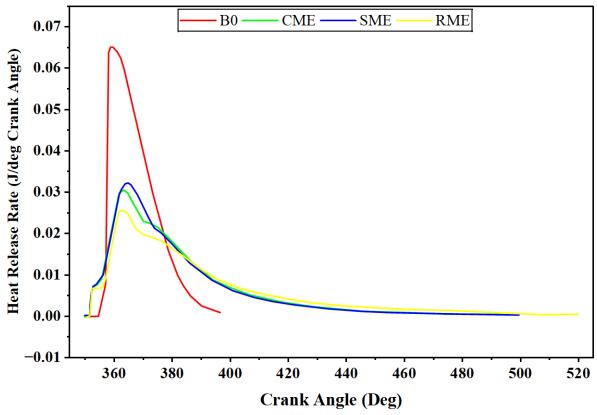

Fig. 5: In-cylinder heat release rate versus crank angle

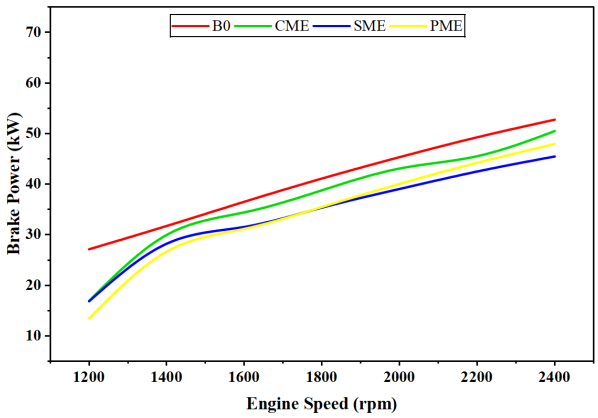

Fig. 6: Engine power at different engine speeds

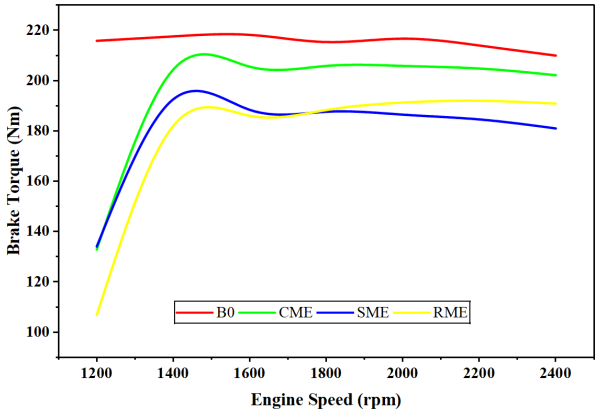

Fig. 7: Engine torque at different engine speeds

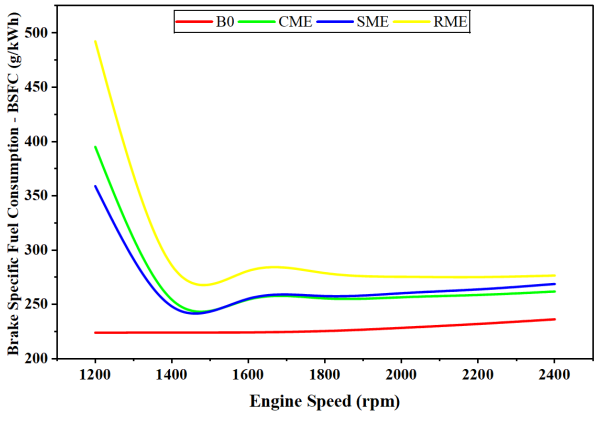

Fig. 8: Brake specific fuel consumption at different engine speeds

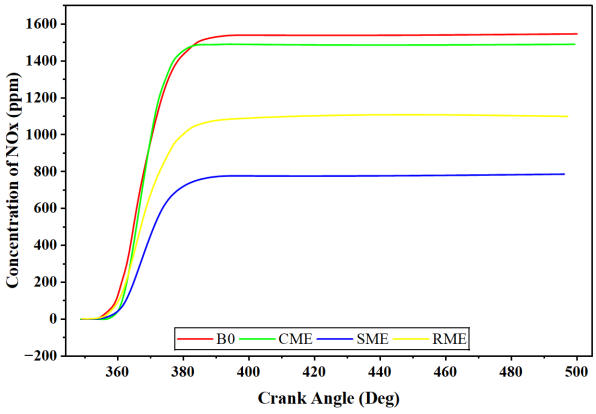

Fig. 9: NO_x emission evolution versus crank angle

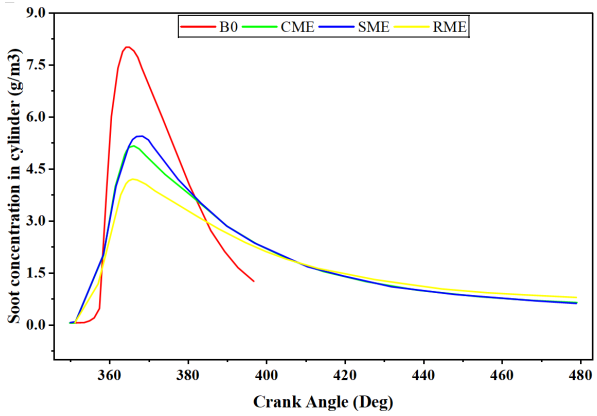

Fig. 11: PM emission evolution versus crank angle

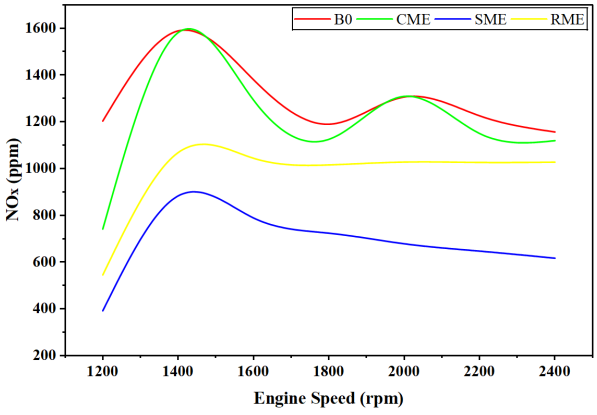

Fig. 10: NO_x emissions at different engine speeds

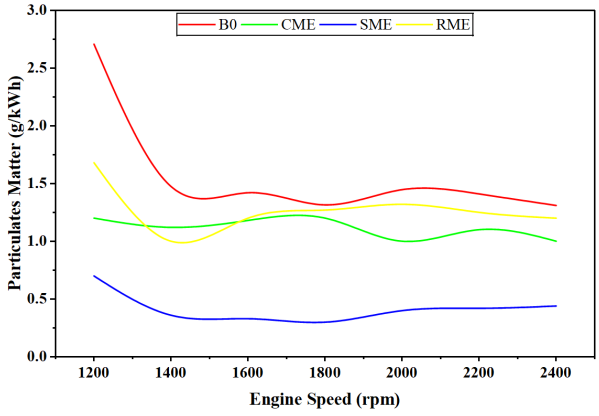

Fig. 12: PM emissions at different engine speeds

results in lower NO_x emissions than fossil diesel fuel over most engine speed ranges (Figure 10). Compared with conventional diesel fuel (1,202.7 ppm), at an engine speed of 1,200 rpm, the biodiesel fuels CME, SME, and RME record NO_x reductions of 38.4% (741.1 ppm), 67.4% (391.71 ppm), and 54.7% (544.75 ppm), respectively.

Figure 11 illustrates the variation of soot concentration (g/m3) with respect to crank angle for the four investigated fuels. Similar to the NO_x formation process, the PM concentration reaches its peak corresponding to the combustion phase and the thermal decomposition of the fuel (approximately 360 – 3700 CA). Notably, B0 exhibits the highest soot peak, while SME shows the lowest, with CME and RME at intermediate levels. This reflects the capability of biodiesel fuels to limit soot formation and effectively reduce PM emissions. In addition, PM emissions also show a reduction when biodiesel fuels are used to replace diesel fuel (Figure 12). For CME biodiesel, the PM emission reduction is approximately 55.7% at 1,200 rpm (compared with B0 at 2.706 g/kWh). Meanwhile, at 1,800 rpm, SME biodiesel exhibits the most effective reduction, reaching up to 77.2% (with the corresponding B0 value of 1.315 g/kWh). For RME, the most effective PM reduction is observed at 1,200 rpm, reaching 37.9%. The lower NO_x and PM emissions of

SME fuel compared with the other two tested fuels in this study may be attributed to its favorable physicochemical properties. The balanced composition of hydrogen, carbon, and oxygen in the fuel, together with its moderate viscosity (Table 2), contributed to improving the fuel injection, air-fuel mixing, and combustion processes inside the engine cylinder, thereby reducing incomplete combustion phenomena. In addition, the moderate in-cylinder combustion temperature obtained when using SME also contributed to suppressing the formation of NO_x and PM emissions. The reductions in NO_x and PM indicate that biodiesel fuels can effectively reduce these emissions due to their higher inherent oxygen content, which enhances combustion efficiency and significantly suppresses PM formation compared with conventional diesel fuel [12].

The simulation results for CO_2 emissions show a slight decreasing trend for biodiesel fuels compared to B0 (Figure 13). Overall, the CO_2 emissions produced by biodiesel fuels in this study decrease for CME and RME, whereas for SME, as engine speed increases, CO_2 emissions tend to increase slightly. More specifically, at an engine speed of 1,800 rpm, the CO_2 emissions of CME, SME, and RME biodiesel fuels are all lower than those of diesel fuel (878.95 g/kWh), with recorded reductions of 11.1% (781.7 g/kWh), 1.76% (863.48 g/kWh), and 2.77% (854.56 g/kWh), respectively.

Figure 14 presents the SO_2 emission levels of the investigated fuels at different engine speeds. The SO_2 emissions from biodiesel fuels are generally lower than those from diesel fuel. Specifically, biodiesel produced from rapeseed oil achieves an emission reduction of approximately 43.8% at 1,200 rpm (compared with B0 at 0.0089 g/kWh at 1,200 rpm). In addition, the use of soybean oil biodiesel results in a reduction of about 67.4% at 1,400 rpm (compared with B0 at 0.0089 g/kWh at 1,400 rpm). At 1,800 rpm, the highest reduction, up to 88.8%, is achieved when using coconut oil–based biodiesel (compared with B0 at 0.0090 g/kWh at 1,800 rpm). This can be explained by the much lower inherent

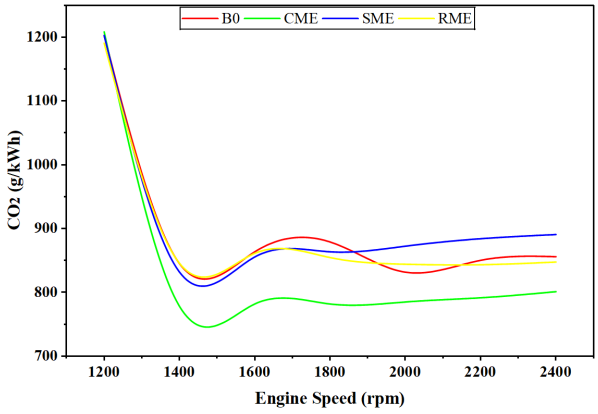

Fig. 13: CO_2 emissions at different engine speeds

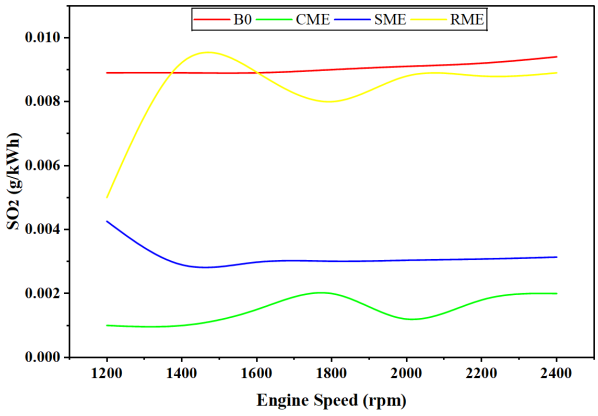

Fig. 14: SO_2 emissions at different engine speeds

sulfur content of biodiesel fuels compared to diesel fuel, leading to a significant reduction in SO_2 emissions [13].

Table 3 summarizes the performance and emission characteristics at the rated speed of 1,800 rpm for diesel fuel and CME, SME, and RME biodiesel fuels. The minus sign (–) denotes a reduction relative to B0, while the plus sign (+) indicates an increase relative to B0.

IV. CONCLUSION

The study evaluated the effects of biodiesel fuels derived from coconut oil, soybean oil, and rapeseed oil on the performance and emissions

Table 3: Comparison of engine performance and emissions at the rated speed of 1,800 rpm

Parameters	B0	CME	Δ% CME	SME	Δ% SME	RME	Δ% RME
Power (kW)	41.12	38.79	**–5.67**	35.36	**–14.01**	35.49	**–13.70**
Torque (Nm)	215.33	205.82	**–4.42**	187.61	**–12.87**	188.32	**–12.55**
BSFC (g/kWh)	225.61	255.57	**+13.28**	257.68	**+14.20**	278.87	**+23.59**
NO_x (ppm)	1189.2	1124.4	**–5.45**	723.57	**–39.15**	1015.2	**–14.64**
PM (g/kWh)	1.315	1.20	**–8.75**	0.30	**–77.19**	1.27	**–3.42**
CO_2 (g/kWh)	878.95	781.70	**–11.07**	863.48	**–1.76**	845.56	**–2.78**
SO_2 (g/kWh)	0.0090	0.0020	**–77.78**	0.0030	**–66.56**	0.0080	**–11.11**

of the MWM I4 D229-4 diesel engine over an engine speed range from 1,200 to 2,400 rpm. The simulation maintained the original operating condition and structural configuration of the engine, with only the fuel type being changed. The results showed that using the above-mentioned biodiesel fuels reduced engine power and torque compared to operation with conventional diesel fuel. Meanwhile, brake specific fuel consumption tended to increase in order to maintain the same performance level. However, this performance reduction remained within an acceptable range, given that the main advantage of this approach is the reuse of the existing engine, thereby reducing the investment cost for engine refurbishment.

Notably, the emission characteristics were improved compared to those obtained with conventional fuel. The benefits of biodiesel were significant, as the emissions of NO_x, PM, CO_2, and SO_2 were all markedly reduced. The advantages of biodiesel over conventional diesel fuel were most evident when using coconut oil–based fuel. Based on the simulation results, CME was identified as the optimal option, as it maintained engine performance while effectively reducing harmful emissions. In contrast, SME achieved very good emission reduction results but at the expense of a greater reduction in engine performance. In summary, biodiesel fuel can be practically applied even to existing diesel engines without requiring changes to the engine's physical structure; however, appropriate adjustments are necessary to achieve optimal performance.

The simulation results may be affected by the physicochemical properties of the fuels and the assumptions incorporated into the engine combustion model. Moreover, the absence of experimental validation, particularly for carbon monoxide and unburned hydrocarbon emissions, may introduce uncertainties regarding the predictive accuracy of the simulation. Accordingly, subsequent studies should incorporate alternative simulation platforms or conduct experimental measurements to achieve a more thorough and reliable assessment of these emission traits.

Based on the findings of this study, future research needs to prioritize experimental investigations into the application of biodiesel in internal combustion engines to expand the available dataset and enhance the reliability of the analysis. In addition, rather than retaining the engine's original operating configuration, further studies could explore potential modifications to engine operating parameters, fuel injection strategies, valve timing, and exhaust gas recirculation systems. Such adjustments may help mitigate the observed reduction in engine power while preserving the beneficial effects on exhaust emissions.

Despite these limitations, numerical simulation remains an efficient and cost-effective approach for the preliminary evaluation and comparative analysis of fuel characteristics in internal combustion engines without requiring modifications to the existing engine configuration.

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